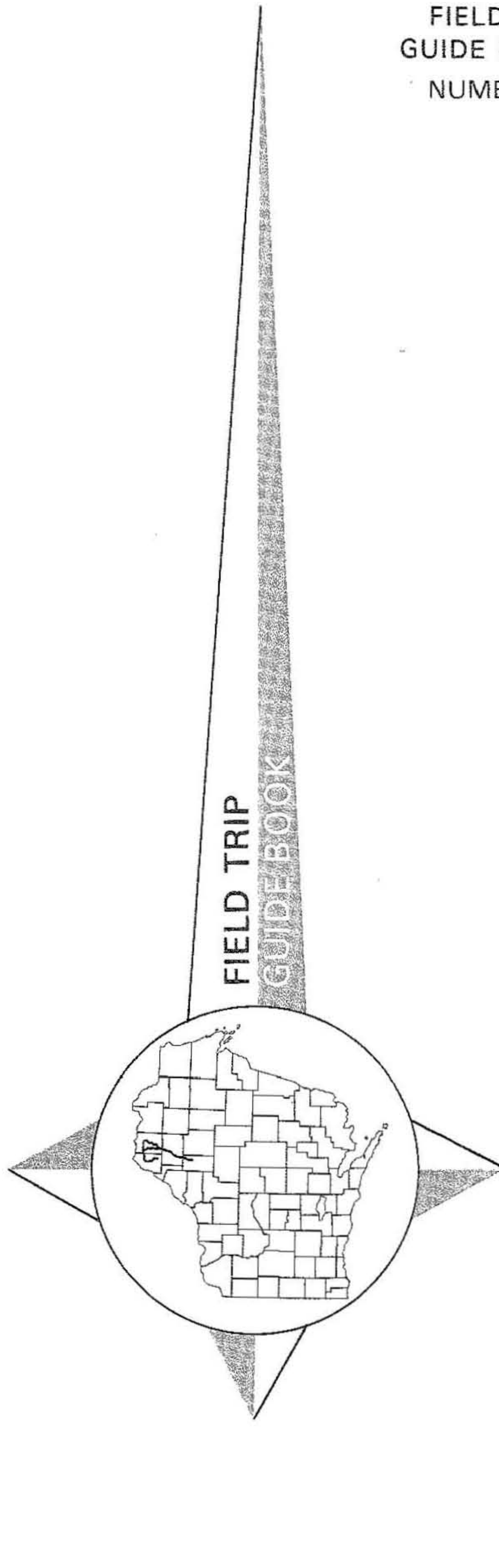
UNIVERSITY OF WISCONSIN-EXTENSION
GEOLOGICAL AND NATURAL HISTORY SURVEY
Meredith E. Ostrom, State Geologist and Director

FIELD TRIP
GUIDE BOOK
NUMBER 11
1984

PLEISTOCENE HISTORY OF WEST–CENTRAL WISCONSIN

with special paper

URANIUM–SERIES DATING OF CALCITE CEMENTED SANDS AND GRAVELS IN MINNESOTA AND WISCONSIN



Prepared for
THE 31ST ANNUAL MIDWEST FRIENDS
OF THE PLEISTOCENE FIELD CONFERENCE
RIVER FALLS, WISCONSIN
JUNE 1–3, 1984

Field Trip Guide Book
Number 11

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

PLEISTOCENE HISTORY

OF WEST-CENTRAL WISCONSIN

Discussion, Roadlog, and Geologic Stop Descriptions

Robert W. Baker

Special Paper
URANIUM-SERIES DATING OF
CALCITE CEMENTED SANDS AND GRAVELS
IN MINNESOTA AND WISCONSIN

Richard S. Lively

Prepared for

The 31st Annual
MIDWEST FRIENDS OF THE PLEISTOCENE
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Dedicated to

HERBERT EDGAR WRIGHT, JR.

one of the founding fathers of the
Midwest Friends of the Pleistocene,
for almost four decades of
outstanding contributions to
knowledge and understanding of
Pleistocene geology, and in appreciation
for service to the geologic community.

FORMER MEETINGS OF THE MIDWEST FRIENDS OF THE PLEISTOCENE

		Location	Leaders
1	1950	Eastern Wisconsin	Sheldon Judson
2	1951	Southeastern Minnesota	H. E. Wright and R. V. Ruhe
3	1952	Western Illinois and Eastern Iowa	P. R. Shaffer and H. W. Scholtes
U	1952	Southwestern Ohio	R. P. Goldthwait
U	1953	Northeastern Wisconsin	F. T. Thwaites
U	1954	Central Minnesota	H. E. Wright and A. F. Schneider
6	1955	Southwestern Iowa	R. V. Ruhe
U	1956	Northwestern Lower Michigan	J.H. Zumberge and others
8	1957	South-central Indiana	W. D. Thornbury and W. J. Wayne
9	1958	Eastern North Dakota	W. M. Laird and others
10	1959	Western Wisconsin	R. F. Black
11	1960	Eastern South Dakota	A. F. Agnew and others
12	1961	Eastern Alberta	C. P. Gravenor and others
13	1962	Eastern Ohio	R. P. Goldthwait
14	1963	Western Illinois	J. C. Frye and H. B. Willman
15	1964	Eastern Minnesota	H. E. Wright and E. J. Cushing
16	1965	Northeastern Iowa	R. V. Ruhe and others
17	1966	Eastern Nebraska	E. C. Reed and others
18	1967	South-central North Dakota	Lee Clayton and T. F. Freers
19	1969	Cyprus Hills, Saskatchewan and Alberta	W. O. Kupsch
20	1971	Kansas-Missouri Border	C. K. Bayne and others
21	1972	East-central Illinois	W. H. Johnson and others
22	1973	Lake Michigan Basin	E. B. Evenson and others
23	1975	Western Missouri	W. H. Allen and others
24	1976	Meade County, Kansas	C. K. Bayne and others
25	1978	Southwestern Indiana	R. V. Ruhe and C. G. Olsen
26	1979	Central Illinois	L. R. Follmer and others
27	1980	Yarmouth, Iowa	G. R. Hallberg and others
30*	1981	Northeastern Lower Michigan	W. A. Burgis and D. F. Eschman
29	1982	Driftless Area, Wisconsin	J. C. Knox and others
30	1983	Wabash Valley, Indiana	N. K. Bleuer and others
31	1984	West-central Wisconsin	R. W. Baker

U - Unnumbered
* - Misnumbered

ACKNOWLEDGEMENTS

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Sincerest appreciation is extended to the undergraduate students of the University of Wisconsin-River Falls who provided able and enthusiastic assistance in both the field and laboratory since the inception of this project: W. J. Autio, P. R. Beisbier, B. D. Bowen, T. J. Burns, S. R. Faffler, K. I. Hakenson, J. K. Harris, D. B. Johnson, M. J. Kopecky, S. G. Krug, S. McMurry, G. A. Moore, S. C. Mravik, T. G. Ritten, K. A. Shimko, R. A. Smith, C. M. Wamback, M. S. Watson, K. Wickgren, and C. J. Wilcox.

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Finally, this trip would be impossible without the cooperation of many landowners. Sincere gratitude is expressed to all of these individuals.

PLEISTOCENE HISTORY OF WEST-CENTRAL WISCONSIN

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INTRODUCTION

The purpose of this field conference is (1) to review the pre-late Wisconsinan glacial stratigraphy in west-central Wisconsin, (2) to examine the geologic and pedologic characteristics of these stratigraphic units, (3) to summarize results of the application of paleomagnetics as a Quaternary age-dating tool, and (4) to outline some new ideas on the Quaternary stratigraphy and chronology of western Wisconsin.

The trip will begin with a brief stop in the late Wisconsinan St. Croix moraine complex, and then will systemically work down section on subsequent stops. We will examine relict and buried Yarmouth and Sangamon paleosols and will reexamine an exposure at Woodville, Wisconsin, that has been studied by a number of well known Quaternary geologists during the past 80 years--namely R. T. Chamberlin, Frank Leverett, and R. F. Black. The second day of the trip will focus on the geologic and pedologic characteristics of proglacial as well as ice-contact sediments, and we will visit several exposures of considerable stratigraphic complexity.

In the descriptions of the stratigraphic sections contained in this guidebook, standard pedologic terminology and horizon nomenclature are used for soils and paleosols (U.S.D.A. Soil Conservation Service, 1975), and all textural data refer to matrix textures. Particle-size analyses were conducted using the hydrometer method (Black, 1965) and U.S.D.A. particle size classes (sand = 0.05 to 2 mm, silt = 0.002 to 0.5 mm, and clay 0.002 mm). Free-iron oxides were extracted using citrate dithionite-bicarbonate, and content was determined titrimetrically (Black, 1965).

Till fabrics were determined by measuring a minimum of fifty clast orientations per site using the technique of McDonald (1967, p. 145-146). All clast orientations were made from within the C horizon, generally at a depth of greater than 3 m below the surrounding land surface. The results were plotted as rose diagrams and as stereographic projections (Newsome, 1976). Fabric maxima were determined by visual inspection.

Matrix sand-fraction lithologies were determined by disaggregating samples in water, decanting off the suspended particles, and oven drying. Samples were then sieved and the fraction passing through a 2 mm sieve but retained on a 0.05 mm sieve, averaging about 60 g, was separated into lithologic categories using standard optical techniques (Kerr, 1959).

Limestone to dolostone ratios were then determined from the carbonate fraction using the staining technique of Scholle (1978), which involves boiling the sample in a solution of concentrated NaOH and safranine O.

Samples for clay mineralogical analyses were pretreated with H_2O_2-NaOAc adjusted to pH 5.0 and then treated with citrate dithionite-bicarbonate to remove organic matter and oxide coatings, respectively. The sand-sized fraction was separated by wet sieving. Silt and clay fractions were separated using dilute Na_2CO_3 adjusted to pH 9.5.

Oriented mounts of the clay fraction were prepared by placing approximately 250 mg of sample on a ceramic tile, saturating with Mg or K, washing free of salt, and glycerating. X-ray diffraction patterns of the air dry, 100°, 200°, and 550°C heated samples were obtained using a Diano XRD-8000 X-ray diffractometer equipped with a graphite crystal monochromator, an LSI-11 computer, and a printer. Samples were scanned at 2° 2θ per minute using CuKα radiation.

Thermal analysis of the clay fraction was accomplished with a Dupont 1090 Differential Scanning Calorimeter. Samples were heated from 40° to 625°C in a nitrogen atmosphere at a rate of 20°C per minute. Quantitative estimation of gibbsite and kaolinite were obtained by calibrating respective 280° and 520°C endothermic peak areas with those of Reynolds synthetic gibbsite RH-31F and poorly crystalline Georgia kaolinite on a weight-equivalent basis. Mica content was estimated from K analysis by X-ray fluorescence-spectroscopy, assuming that the mica in the sample had the same K content as the Wards standard muscovite used in calibration.

PREVIOUS WORK

R. T. Chamberlin (1910) was the first person to recognize pre-late Wisconsinan drift in western Wisconsin. In a number of deep ravines along the St. Croix River, he found two older till sheets beneath late Wisconsinan units. Recognizing that in many exposures the older till units were separated by a paleosol, Chamberlin deduced that they were considerably different in age. The older, a greyish-black calcareous clayey till from a northwestern (Keewatin) source, was thought to be Kansan in age and was correlated with similar Kansan till in Iowa. The younger, a red to reddish-brown sandy till from the Lake Superior area, was assigned to the Illinoian Stage.

The next study of the older drifts beyond the Woodfordian limit in western Wisconsin was conducted by Leverett (1932). Leverett, like Chamberlin (1910), recognized and mapped both "old grey" and "old red" till units. Observing that an erosional surface separated these two till sheets and that the degree of weathering in the old red till was comparable to that in Illinoian till in Illinois, Leverett echoed Chamberlin's (1910) conclusion that the old grey and old red till units were deposited during the Kansan and Illinoian glaciations, respectively. In addition, in railroad cuts near Woodville, Wisconsin, Leverett (p.16) observed a second grey till below the Kansan till. Because the grey tills were separated by a bed of peat and wood and because the lower unit contained a weathered zone, Leverett assigned the bottom till to the Nebraskan Stage.

The most recent studies of the older drifts in western Wisconsin were conducted by R. F. Black (1959; 1962; 1974; Black and Reed, 1965). After several years of field investigation, which included restudy of a number of the exposures described by Chamberlin (1910) and Leverett (1932), Black suggested that the upper two till sheets were deposited by the same ice advance and were thus of the same age (1959, p. 172; Black and Reed, 1965, p. 62-63). He interpreted the grey till as being a basal till derived locally from dolomitic bedrock sources and the overlying red till as being an ablation or superglacial till, which was derived from areas underlain by sandstones. Based on two finite radiocarbon dates, from spruce fragments found within the grey drift of about 30,000 B.P., Black assigned these drifts to the latter part of the early Wisconsinan (Altonian) Substage, which he named the Rockian. According to Black, the Rockian represented the earliest glacial event in the state of Wisconsin and, consequently, no pre-Wisconsinan glacial sediments are present anywhere in the state (1959; 1962; 1974; Black and Reed, 1965; Frye and others, 1965). Black apparently never observed Leverett's Nebraskan grey till during his investigations.

During the course of this field trip, we will examine evidence focusing on the above age-relationship controversy. In brief, it will be demonstrated that the interpretations of Chamberlin (1910) and Leverett (1932) were essentially correct. However, each of the previous studies failed to recognize at least two or more of the pre-late Wisconsinan stratigraphic units in west-central Wisconsin.

STRATIGRAPHY

The Pleistocene stratigraphic units of west-central Wisconsin are summarized in table 1. This trip will principally focus on the pre-late Wisconsinan stratigraphy. These deposits are formally seperated into two formations: the Pierce Formation of pre-Illinoian age and the River Falls Formation of Altonian (early Wisconsinan) or Illinoian age (table 1). The formations consist primarily of till, glaciolacustrine, and undifferentiated glaciofluvial sediments. The pre-Illinoian units were deposited by glaciers that moved into western Wisconsin from northwestern (Keewatin) sources, whereas the Altonian/Illinoian age till was deposited by Lake Superior Lobe ice that moved from the north-northeast. The differences in provenance of the tills produced differences in physical and mineralogic properties, which allow differentiation of the deposits. Specifically, the till deposits can be distinguished from one another on the basis of matrix texture, clast composition, clay mineralogy, sand-fraction lithologies, engineering properties, color, stratigraphic position, paleomagnetic properties, and degree of soil development. Each of the stratigraphic units will be described briefly here. However, more detailed descriptions and lithostratigraphic definitions are given by Baker and others (1983) and Michelson and others (in press).

Table 1.--Current Pleistocene stratigraphic nomenclature for west-central Wisconsin.

	TIME STRATIGRAPHY	ROCK STRATIGRAPHY	SOIL STRATIGRAPHY
PLEISTOCENE SERIES	Wisconsinan Stage	Wisconsinan loess; unnamed sediments, includes till and sand and gravel of St. Croix moraine and colluvium	Modern soil
	Farmdalian Substage or Sangamon Stage	Unnamed sediments, includes colluviated till and undifferentiated sediments	Farmdale Paleosol or Sangamon Paleosol
	Altonian Substage or Illinoian Stage	River Falls Formation; unnamed till members; unnamed glaciofluvial sediments	
	Yarmouth Stage		Yarmouth Paleosol
	Pre-Illinoian Stages undifferentiated	Pierce Formation; Kinnickinnic Member; Hersey Member; Woodville Member; Eau Galle Member	Unnamed

Pierce Formation

The Pierce Formation includes four members. The lower two members, the Eau Galle Member, a grey lacustrine clay, and the Woodville Member, a grey calcareous till, are presently only known to exist in the subsurface, through borehole investigations and well-log data. These are overlain by the Hersey Member, another grey calcareous till, and associated sand and gravel. The till of this unit is the "old grey" till of Chamberlin (1910) and Leverett (1932) and the "basal till" of R. F. Black (1959; Black and Reed, 1965). The Hersey Member is locally overlain by the Kinnickinnic Member, a unit of thinly-laminated silt and clay.

Eau Galle Member--The Eau Galle Member is an apparently massive, non-calcareous glaciolacustrine sediment. Its color varies from yellowish brown (10 YR 5/4) to grey (10 YR 5/1) and it is texturally a clay, averaging 7 percent sand, 36 percent silt, and 57 percent clay (fig. 1). The clay mineralogy of the Eau Galle Member averages 65 percent montmorillonite, 20 percent mica (illite), 10 percent kaolinite, and 5 percent chlorite. Because the Eau Galle Member has only been found in sub-surface investigations, its distribution in western Wisconsin and thickness are presently unknown. However, based on drillhole sampling at Woodville, Wisconsin, the thickness of the Eau Galle Member is known to exceed 8 m (26 ft).

Woodville Member--The Woodville Member is the "Nebraskan" till of Leverett (1932) and is massive, structureless, and strongly calcareous. Its color varies from grey (5 YR 5/1) to dark grey (10 YR 4/1). The Woodville Member is texturally a loam, averaging 45 percent sand, 31 percent silt, and 24 percent clay, (fig. 1). The clay mineralogy of the unweathered Woodville Member averages 63.5 percent montmorillonite, 21.5 percent kaolinite, 14 percent mica (illite), and no vermiculite. Like the Eau Galle Member, the Woodville Member has only been recognized in subsurface power-auger and hand-auger investigatations. As a consequence, its distribution and maximum thickness are unknown. However, at Woodville, Wisconsin, the Woodville Member is known to be 4.5 m (15 ft) thick.

Hersey Member--The till of the Hersey Member, henceforth referred to as the Hersey Member, is predominantly massive and structureless, and in the unweathered state, strongly calcareous. Its color varies vertically within the weathering profile from a yellowish brown (10 YR 5/4-6) in the oxidized zone to a dark grey (10 YR 4/1) in the unoxidized zone. The Hersey Member exhibits exceptionally thick soil development, with a solum up to 2.9 m in thickness and oxidation extending to a depth of 3.5 m. The unweathered Hersey Member is loam textured, averaging 42 percent sand, 33 percent silt, and 25 percent clay rather consistently throughout Pierce and St. Croix Counties (fig. 1). The weathered Hersey Member is typically clay loam with the particle-size distribution depending on the position of the solum. In the C horizon, sand fraction lithologies average 21.4 percent carbonates with an average limestone-to-dolostone grain ratio of 3.1, 24.9 percent total sedimentary grains, and 75.1 percent igneous and metamorphic grains (quartz, feldspar, and rock fragments). The clay mineralogy of the Hersey Member is quite distinctive. In all profiles, vermiculite drops to

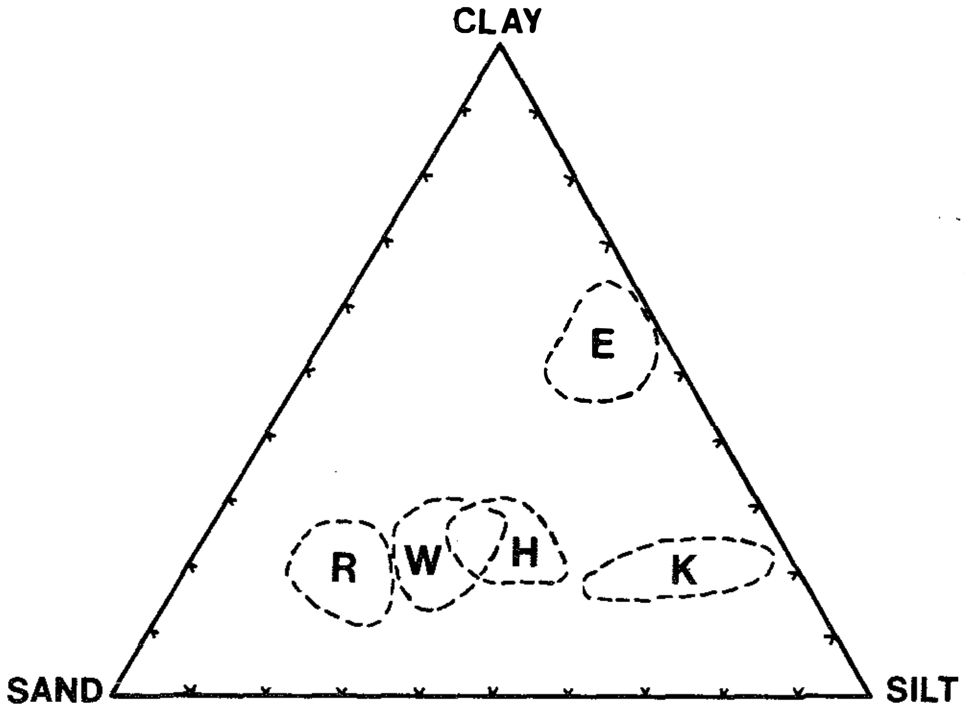


Figure 1.--Ternary diagram illustrating C-horizon textures of the pre-Wisconsinan units in west-central Wisconsin. Enclosed areas show distribution of (R) 23 samples of River Falls Formation, (W) 10 samples of Woodville Member, (H) 26 samples
kinnic Member, and (E) 7 samples of Eau Galle Member.

either 5 percent or 0 in the lower portion of the B horizon and is totally absent from the C horizon. Other clay minerals average 50 to 60 percent montmorillonite, 25-30 percent kaolinite, 15 percent mica (illite), 5 to 10 percent quartz and 0 to 5 percent chlorite. The thickness of the Hersey Member varies from less than 1 m over bedrock uplands to greater than 55 m in southern Pierce County, Wisconsin. In many areas, however, its exact thickness is unknown.

The distribution of the Hersey Member in west-central Wisconsin is illustrated in figure 2A. The dashed boundary in the northern portion of the study area (fig. 2A) is a consequence of the deep burial of the Hersey Member in that area by at least two distinct drift sheets and, hence, limited exposures.

Kinnickinnic Member--The Kinnickinnic Member is a thinly-laminated calcareous glaciolacustrine sediment. Its color varies vertically within the weathering profile from a very dark greyish brown (10 YR 3/2) in the oxidized zone to a dark grey (10 YR 4/1) in the unoxidized zone. The Kinnickinnic Member is silt loam textured, averaging 14 percent sand, 66 percent silt, and 20 percent clay (fig. 1). Because of its abundant silt and clay, the Kinnickinnic Member has a low permeability and consequently has undergone rather limited soil development; the solum has a thickness of generally less than 2 m and leaching rarely occurs to depths in excess of 2.8 m. The clay mineralogy of the Kinnickinnic Member averages 50 percent montmorillonite, 25 percent kaolinite, 15 percent mica (illite), and 10 to 15 percent vermiculite. Its distribution in the various valleys is not uniform because of episodes of cutting and filling that have occurred subsequent to its deposition. Because the lower contact of the Kinnickinnic Member is frequently not observable, its maximum thickness is unknown. However, based on measurements made in vertical exposures and from power augering, its thickness is known to be over 30 m.

The laminated sediments of the Kinnickinnic Member were deposited in an extensive interconnecting network of glacially dammed lakes. The glacial advance which deposited the Hersey Member, also blocked the drainage of the Kinnickinnic, Trimbelle, Rush, Chippewa, and Buffalo Rivers forming a series of proglacial lakes. As the glacial lobe retreated from its maximum position, these lakes lengthened to the southwest (fig. 2B). Based on the distribution of the Kinnickinnic Member in these valleys, the lake complex covered an area of over 5800 km^2. Estimates of sedimentation rates, by counting varve couplets at the thickest exposure, indicate that these lakes existed for a minimum of 5,000 years.

River Falls Formation

The River Falls Formation consists of reddish-brown sandy tills and associated fluvial deposits, typical of those derived from the Lake Superior basin. Recent analyses suggest that the formation may contain at least two till units, however, at the present it is premature to separate these into members. The River Falls Formation is bounded below by either the Pierce Formation or Precambrian or Paleozoic bedrock and above by the sandy loam-textured tills of the Copper Falls Formation. In northern Pierce and St. Croix Counties, Wisconsin, the River Falls Formation is the surface unit and overlies the Pierce Formation.

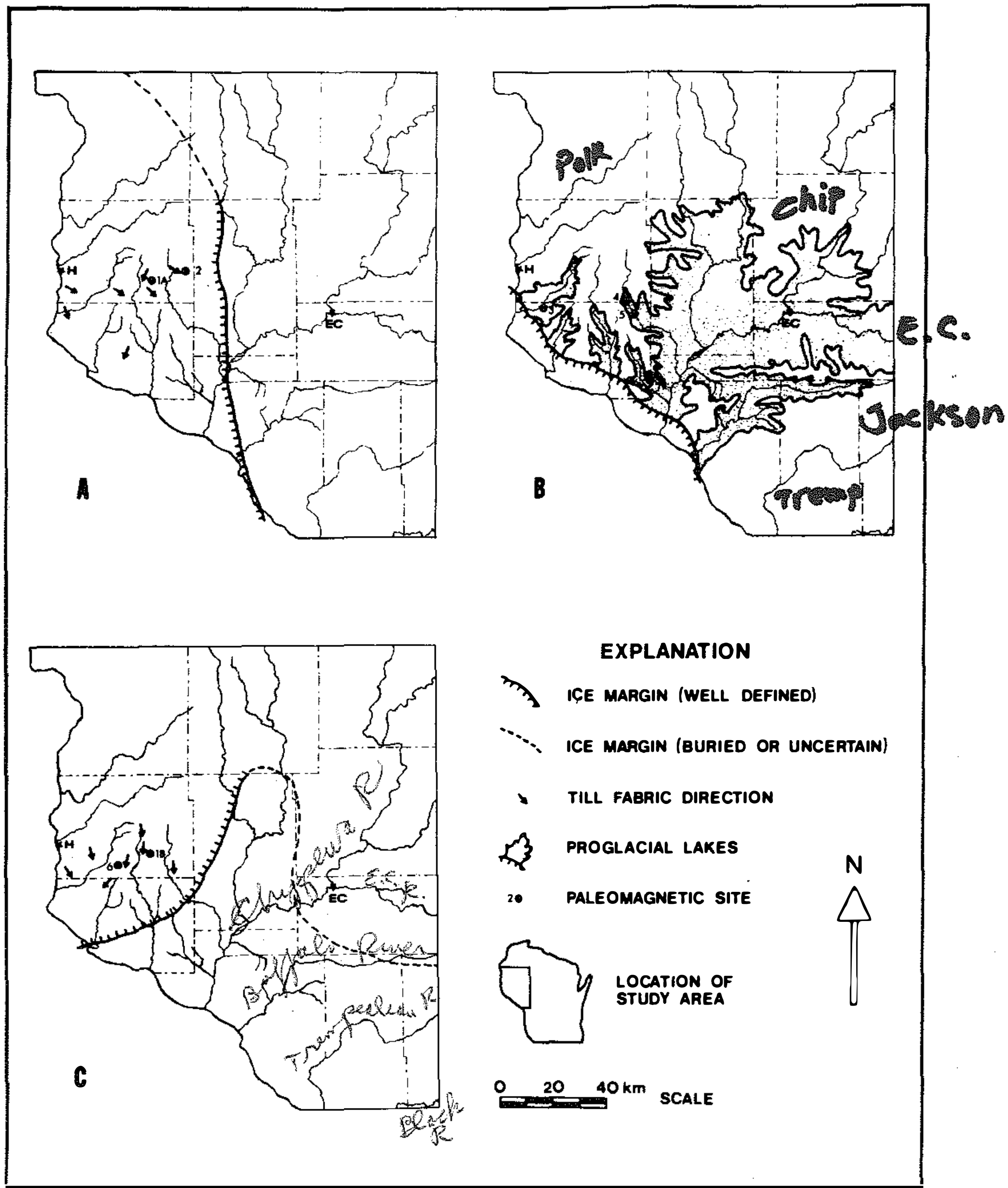


Figure 2.--Distribution of pre-Wisconsinan units in west-central Wisconsin: (A) distribution of the Hersey Member of the Pierce Formation; (B) distribution of the Kinnickinnic Member of the Pierce Formation, which includes some non-lacustrine areas (islands); (C) distribution of the River Falls Formation. H and EC represent locations of the towns of Hudson and Eau Claire, respectively.

The till of the River Falls Formation, henceforth referred to as the River Falls Formation, is the "old red" till of Chamberlin (1910) and Leverett (1932), the "superglacial drift" of R. F. Black (1959) and Black and Reed (1965), and the Baldwin till of Baker and Simpson (1981) and Baker and others (1982). The majority of the River Falls Formation is a massive, structureless basal till. However, locally in St. Croix County, the upper portion of the unit is weakly stratified, containing discontinuous lenses of fine sand, and is probably of superglacial origin. The color of the River Falls Formation varies vertically within the weathering profile from yellowish red (5 YR 4/6) in the argillic horizon to a reddish brown (5 YR 4/4) in the C horizon. The River Falls Formation is deeply weathered, with sola thicknesses of up to 2.8 m. The unweathered till is sandy-clay-loam textured, averaging 60 percent sand, 15 per cent silt, and 25 percent clay (fig. 1). The weathered River Falls Formation is also a sandy-clay loam; however, the particle-size distribution varies somewhat depending on the position in the solum. In the C horizon, sand-fraction lithologies average 1 percent carbonates, 5.7 per cent total sedimentary grains, and 94.3 percent igneous and metamorphic grains (quartz, feldspar, and rock fragments). The clay mineralogy of the River Falls Formation averages 30 to 40 percent montmorillonite, 20 to 25 percent kaolinite, 15 to 20 percent vermiculite, 5 to 10 percent mica (illite), and up to 5 percent quartz. The thickness of the River Falls Formation ranges from less than 1 m on bedrock uplands to more than 13 m in St. Croix County, Wisconsin.

The color, texture, and clay and sand-fraction mineralogy of the River Falls Formation are characteristic of tills derived from the Lake Superior basin (Chernicoff, 1980). This is supported by till-fabric data which suggest that the member was deposited by a glacier that advanced from the north-northeast (fig. 2C). The spread in till-fabric directions in figure 2C is apparently due to both local topographic control and radial ice flow near the glacier margin.

PALEOMAGNETIC STUDIES

This section summarizes our paleomagnetic investigations to date, indicating that the glacial units beyond the late-Wisconsinan limit in western Wisconsin are pre-Wisconsinan in age. For further discussion of these results, see Baker and others (1983).

For each of the surface units, a minimum of five oriented samples were collected at different stratigraphic levels within the C horizon at several different localities. Samples were collected by pushing cylindrical tubes, measuring 2.5 cm in diameter and 2.5 cm in length, vertically downward into benches levelled into the various glacial sediments. Melted parafin was used to seal the tubes and north arrows were scribed on the tops for orientation. Errors in orientation were within 5 degrees.

The natural remanent magnetization (NRM) of the samples was measured using a Schonstedt SSM-1A spinner magnetometer. Two samples from each site were then subjected to step-wise alternating field (AF) demagnetization utilizing a Schonstedt GSD-1 specimen demagnetizer. Results were plotted on vector end-point diagrams (Zijderveld, 1967), to determine the demagnetization level necessary to remove the masking effects of any secondary components. When the level of demagnetization necessary to remove secondary components was thusly established, all remaining samples were demagnetized to this level or to successively higher levels.

Vector end-point diagrams from representative samples are shown in figure 3. As seen in this figure, the first demagnetization step or steps remove a secondary component that is generally directed to the north and down and is interpreted to be present day in origin, perhaps due to weathering. With higher levels of demagnetization, the vector end-points define a linear decay toward the origin indicating that a single component of magnetization has been isolated (fig. 3). Thus, the samples were stably magnetized and responded well to AF demagnetization.

Selected samples were also given an isothermal remanent magnetization (IRM), in progressively increasing fields of up to 9 kOe, with a 10 cm water-cooled electromagnet. The IRM-acquisition curves (fig. 4) show that the samples become fully saturated in fields of less than 3 kOe, indicating that the carrier of remanence is most likely magnetite (Dunlop, 1972). The fact that magnetite appears to be the remanence carrier indicates that a depositional-remanent magnetization has been measured. That is, the sediments were deposited in a water slurry, either by debris-rich ice melting at the glacier bed or by the deposition of rock flour in pro-glacial lakes, so that the magnetite particles were able to rotate into alignment with the earth's magnetic field (Gravenor and others, 1973); Verosub, 1975, 1977).

Results of AF demagnetization for the various glacial units are summarized in table 2 and are shown in figure 5. Remanent directions for the Hersey Member of the Pierce Formation are shown in figure 5A. The samples from the Woodville site (paleomagnetic Site 1a) were collected from two different levels approximately 4 m apart vertically, while samples from the Hersey Site (paleomagnetic Site 2) were collected from three levels separated vertically by about 2.5 m. Notice that for the Woodville Site all samples are reversely magnetized (the remanent vectors point to the south and upward). The results from the Hersey Site, however, are quite scattered. For most of the samples from this site, a single component of magnetization could not be recovered during AF demagnetization. Specifically, the samples had IRM acquisition curves that showed no tendency to level off

Table 2.--Summary of paleomagnetic data from pre-Wisconsinan glacial units

Unit	Site(s)	NS	H	I	D	$\alpha95$	Polarity	Age
River Falls Fm	1B & 7	10	100	61.1	3.6	13.8	N	Illinoian
Kinnickinnic Mbr	3 & 4	11	100/200	65.2	354.9	4.8	N	Pre-Illinoian
Kinnickinnic Mbr	5b	5	300	-16.7	178.3	9.2	I	Pre-Illinoian
Kinnickinnic Mbr	5a	5	300	-48.0	177.1	14.0	R	Pre-Illinoian
Hersey Member	1a	8	300	-56.6	183.8	12.2	R	Pre-Illinoian
Hersey Member	2	13	100	81.6	45.6	39.7	?	Pre-Illinoian

Explanation: NS, number of samples; H, demagnetization level for minimum dispersion in Oersteds; I, mean inclination of site in degrees; D, mean declination in degrees; $\alpha95$, cone of 95 percent confidence (Fisher, 1953).

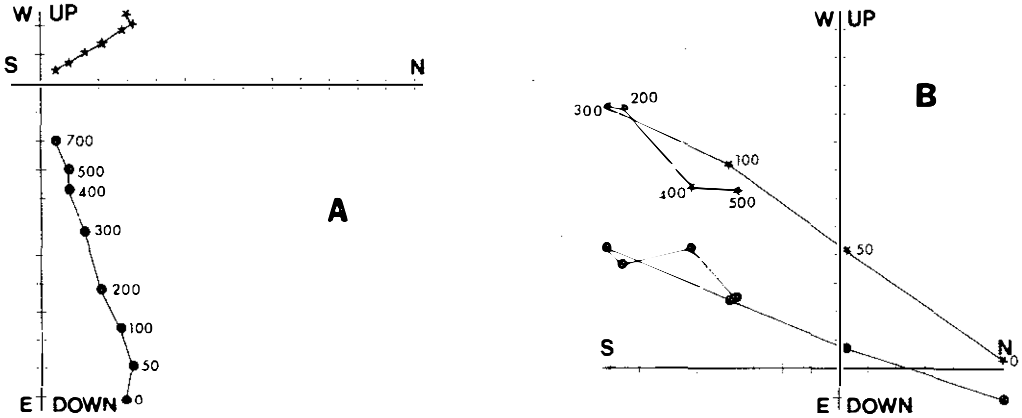


Figure 3.--Typical vector diagrams showing results of alternating field demagnetization for the Kinnickinnic Member (A) and the Hersey Member (B). Starred symbols are projections on the horizontal plane; dots are the projections on the north-south plane. Numbers adjacent to data points represent demagnetization levels in oersteds. Horizontal and vertical divisions are: (A) 2.0×10^{-6} emu/cm^3 and (B) 3.0×10^{-7} emu/cm^3 (1emu=12.57×10^{-4} tesla).

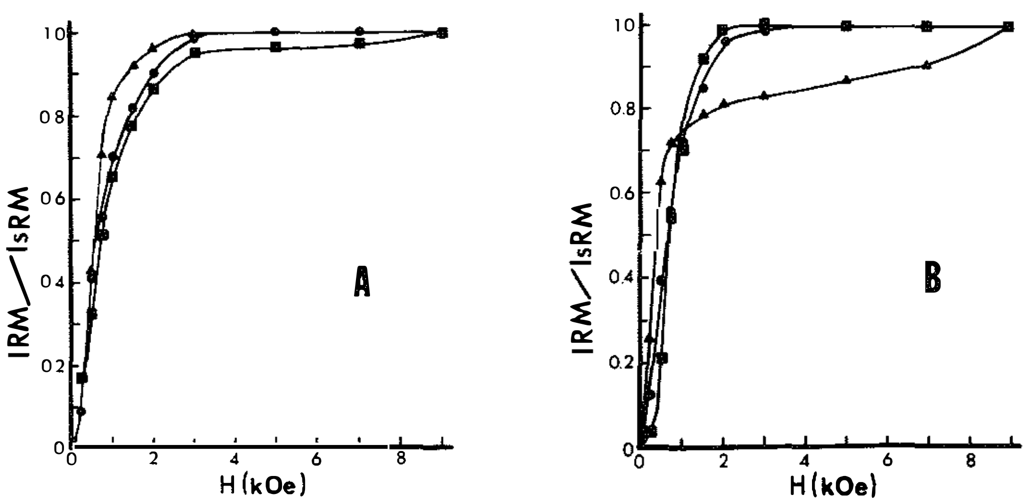


Figure 4.--Isothermal-remanence acquisition curves for representative samples from (A) the Kinnickinnic Member (lacustrine sediments) and (B) the tills of the Hersey Member (square and triangular symbols) and the River Falls Formation (dots). IRM is the isothermal remanent magnetization, IsRM is the isothermal saturation remanent magnetization, and H is the magnetic field intensity (1 Oe=76.6 ampere/meter).

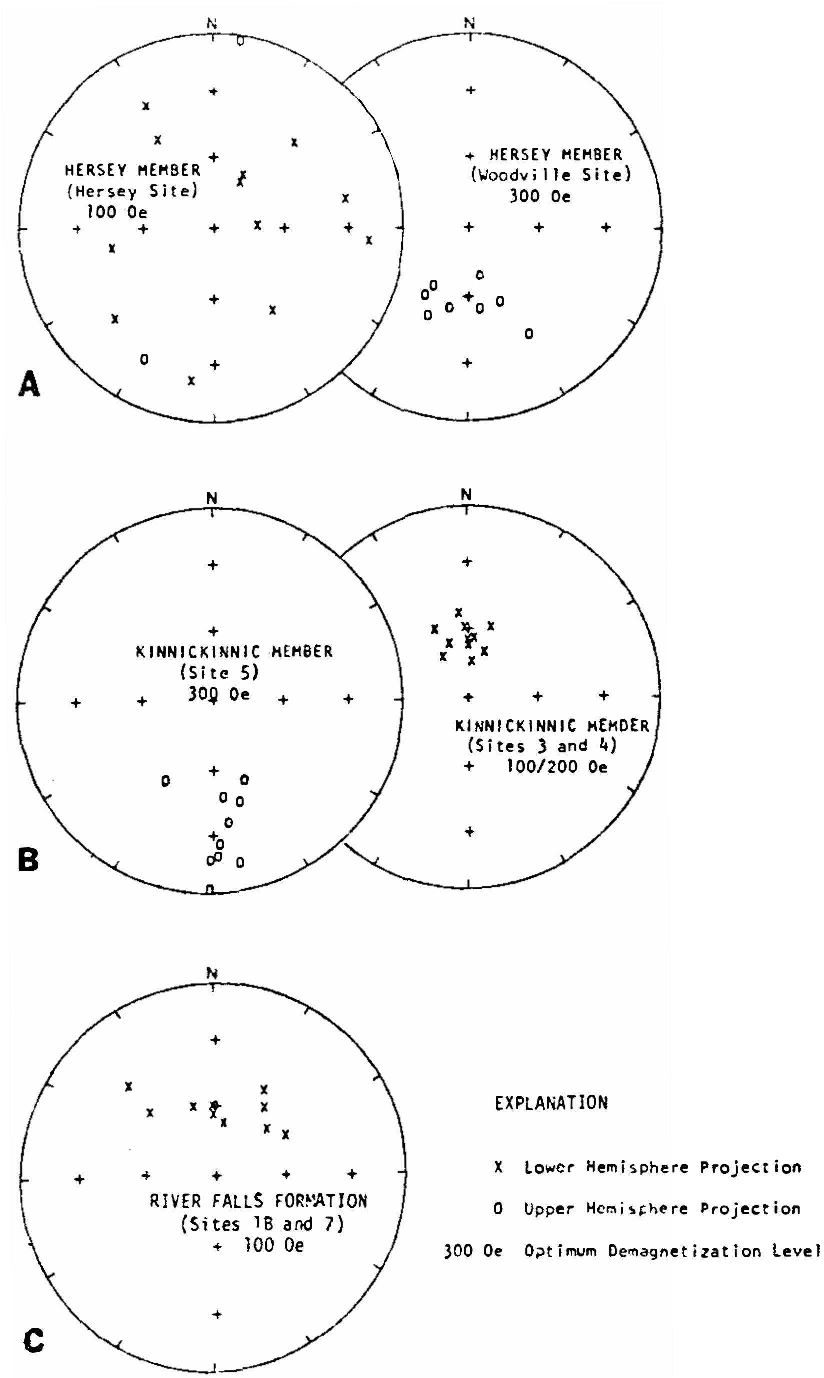


Figure 5.--Remanent directions for the pre-Wisconsinan units in west-central Wisconsin. Projection is equal area.

(saturate) in fields up to 9 kOe (see figure 4B, triangular symbols). This type of behavior can generally be attributed to the presence of a hydrous-iron oxide such as goethite (Strangway and others, 1968). Therefore, the scatter in the data from the Hersey Site is probably the result of a secondary magnetic component associated with weathering that was impossible to remove using AF demagnetization techniques. Alternatively, it is possible that the till at this locality was not deposited as a wet slurry, but perhaps instead was deposited as dry flows or by sublimation at the glacier surface or margin and, consequently, never acquired a depositional remanent magnetization.

The results of AF demagnetization for the Kinnickinnic Member are shown in figure 5B. From this figure it can be seen that the samples from Sites 3 and 4 (highest in the varved section) are normally magnetized (the remanent vectors point to the north and downward and that the mean direction is not significantly different from the axial geocentric dipole direction (declination = 0^{o}, inclination = 63.4^{o}) for the sample sites. Samples from Site 5 with inclinations of less than -30^{o}: (Site 5b, table 2) are stratigraphically higher, by approximately 1 meter, than those whose inclinations fall between -30^{o} and -60^{o} (Site 5b, Table 2). As seen in table 2, samples from Site 5b have a mean direction that is distinct from the "reversed" axial geocentric position (that is, these samples have an intermediate field direction). Samples lower in the section (Site 5a) have a mean direction that, although statistically distinct from the axial geocentric direction, is close enough to it that this may be considered a reversely magnetized site. All samples from Site 5 have intensities of order of 10^{-6} emu/cm^{3}, at least an order of magnitude less than those of the Kinnickinnic Member from Sites 3 and 4 (7×10^{-5} emu/cm^{3}). Therefore, it appears that these samples were magnetized during a reverse-to-normal transition of the earth's magnetic field.

The remanent directions for the till of the River Falls Formation are shown in figure 5C. The data in this figure are from samples collected at two different sites (figure 4C, paleomagnetic sites 1B and 7). It can be seen in table 2 that the samples are all normally magnetized and, like the Kinnickinnic Member from Sites 3 and 4, the mean direction is statistically similar to the axial geocentric-dipole direction for this area.

AGE RELATIONSHIPS

As mentioned previously, the grey and red till units (Hersey Member and River Falls Formation, respectively) were interpreted by Black (1959) and Black and Reed (1965) as having been deposited simultaneously by the same ice advance. The current studies do not support this interpretation. Clay and sand-fraction mineralogy, matrix texture, and till fabrics all suggest the tills have completely different provinances, with only minor contribution from local bedrock sources. This is also supported by the pebble lithology data from till-fabric measurements, which show that 85 to 90 percent of the pebble-sized clasts in the River Falls Formation are erratics from the Lake Superior basin. Furthermore, in northern Pierce and St. Croix Counties, Wisconsin, the Hersey Member is separated from the overlying River Falls Formation by a truncated paleosol. Also, relic soils in the Hersey Member have much thicker sola and oxidized zones and more strongly developed argillic horizons than those in the River Falls Formation. These points, when coupled with the contrasting stable-remanent magnetizations, clearly indicate that the Hersey Member and River Falls Formation were deposited by distinctly different glaciers which are widely separated in time.

The age of the Pierce Formation can be estimated from the paleomagnetic data. Specifically, there have been a number of departures of the geomagnetic field from its normal state since the end of the Matuyama reversed polarity epoch approximately 730,000 B.P. For example, the Laschamp (Bonhommet and Zahringer, 1969), the Blake (Smith and Foster, 1969; Denham, 1976), the Emperor (Champion and others, 1981; Wilson and Hey, 1981) or those from Lake Biwa, Japan (Kawai and others, 1972). Of these geomagnetic departures, only the Emperor possibly attained a full reversed polarity of sufficient duration to be considered a reversed event (Champion and others, 1981). Thus it appears that all of the geomagnetic departures, except the Emperor, are excursions where the earth's magnetic polarity never fully changed direction (reversed) (Verosub and Banerjee, 1977). In addition, only the Emperor appears to be unequivocably world-wide, having been documented from marine-linear magnetic anomalies (Wilson and Hey, 1981), terrestrial basalts from the Snake River Plain (Champion and others, 1981), and paleomagnetism of marine sediments from the Caribbean and Pacific (Ryan, 1972; Zubakov and Kochegura, 1976; Wollin and others, 1971). Consequently, based on paleomagnetic data, the Hersey Member of the Pierce Formation appears to have been deposited during either the Emperor reversed event dated at 460,000 B.P., with a duration estimated as ranging from 10,000 years (Champion and others, 1981) to 100,000 years (Zubakov and Kochegura, 1976), or during the Matuyama reversed polarity epoch prior to 730,000 B.P., and in either case it is pre-Illinoian in age. Likewise, due to their stratigraphic positions below the Hersey Member, the Eau Galle and Woodville Members of the Pierce Formation are also pre-Illinoian in age. Depositon of the Kinnickinnic Member appears to have spanned either the Emperor-Brunhes or the Matuyama-Brunhes boundary and was therefore deposited at either 460,000 or 730,000 B.P. Alternatively, it is possible that the reversed-to-normal transition within the Kinnickinnic Member might be related to one of the normal events within the Matuyama, such as the Jaramillo normal event (970,000 B.P.) or the Olduvai normal event (1,870,000 B.P.)

A pre-Illinoian age for the Pierce Formation is further supported by reginal correlation. Matrix texture, sand-fraction lithologies, particularly the limestone-to-dolostone ratio and absence of shale, clay mineralogy, and the degree of soil development in the Hersey Member are extremely similar to those of the pre-Illinoian Wolf Creek Formation of Iowa (Hallberg, 1980) and broadly similar to those of the pre-Illinoian till in the Bridgeport Terrace near the mouth of the Wisconsin River in southwestern Wisconsin (Knox and others, 1982) (table 3).

Table 3.--Comparison of Hersey Member with Wolf Creek Formation and pre-Illinoian till of Bridgeport terrace

	Matrix Texture (Ave)				Sand-Fraction Lithologies (Ave)		Clay Mineralogy (Ave)			
Unit	Sand %	Silt %	Clay %	Carbonates %	Total Sedimentary %	Igneous and Metamorphic %	Kaolinite and Chlorite %	Mica (Illite) %	Expandables Montmorillonite & Vermiculite	Relic Solum Thickness
PIERCE FORMATION Hersey Member	42	33	25	21.4	21.4	75.1	27.5	15	56.3	2.9
WOLF CREEK FORMATION	40	37	23	21.7	24.6	75.4	21.4	16.7	62.1	3.6
Pre-Illinoian till of Bridgeport terrace	50	30	20	N.D.	12.4	87.6	17	16	67	N.D.

N.D. = Not determined

Based on its normal remanent magnetization, the River Falls Formation appears to have been deposited during the Brunhes normal-polarity epoch. Consequently, it could be pre-Illinoian or younger. The texture and clay and clast mineralogy of the River Falls Formation tentatively suggest it correlates regionally with the Hawk Creek Till of western Minnesota (Matsch, 1971, 1972), the till of the Hampton moraine of eastern Minnesota (Ruhe and Gould, 1954), the gumbotil of western Wisconsin (Foss, 1965), and the Bakerville Till of east-central Wisconsin (Mode, 1976) which have been assigned early Wisconsinan or pre-Wisconsinan ages. However, because the solum thickness of the River Falls Formation averages almost three times greater than that of the similarly textured till of the Woodfordian aged St. Croix moraine complex (Ruhe and Gould, 1954; Schneider, 1961; Chernicoff, 1980) and because its solum and textural profile are comparable to Illinoian tills with similar physical properties in northwestern Illinois (Follmer and others, 1979), it is believed that this unit is Illinoian in age.

Finally, the finite radiocarbon dates from wood and peat from within the grey till of the Hersey Member (R. F. Black and Rubin, 1967; R. F. Black, 1974) should be discussed. Black and Rubin (1967) reported two finite dates of 29,000 ± 1,000 B.P. (W-747) and 30,650 ± 1,640 B.P. (Y-572), and two infinite dates of 38,000 B.P. (W-1598) and 45,000 B.P. (W-1758). In addition, this study has added an additional infinite date from the Hersey Member of 40,000 B.P. (I-11,563). R. F. Black interpreted the infinite dates as coming from older organic material that was incorporated when a bog was overridden (R. F. Black and Rubin, 1967, p. 107; R. F. Black, 1974, p. 202), and therefore based his Rockian chronology on the two finite dates of about 30,000 B.P. It is believed that the samples yielding finite dates were contaminated and that these dates are suspect for the following reasons: firstly, the remanent magnetization of the Hersey Member is reversed; secondly, it correlates regionally with the pre-Illinoian Wolf Creek Formation of Iowa; and thirdly, one of the samples yielding a finite date (Y-572) was collected by Samuel F. Weidman in the early 1900's and dated after over 50 years of storage (Black, verbal communication, May, 1982). Consequently, it is felt that the infinite dates are more realistic representations of the age of the Hersey Member.

GEOLOGIC ROADLOG - DAY 1

-- Mileage is cumulative, with increments between entries in parentheses

Miles	
0 (0.1)	Trip begins in front of west entrance to the Rodli Commons building, University of Wisconsin-River Falls, River Falls, Wis.
0.1 (0.4)	Proceed north from Rodli Commons to Cascade Ave. Turn left on Cascade Avenue.
0.5 (1.5)	Drive west on Cascade Ave. to Wis. Hwy 35. Turn right on Hwy. 35 and head north through town of River Falls.
2.0 (0.5)	Cross Kinnickinnic River. Much of the Kinnickinnic River valley in this area is underlain by lacustrine sediments of the Kinnickinnic Member. These sediments were deposited when Pre-Illinoian ice blocked the drainage of the Kinnickinnic River forming Glacial Lake River Falls.
2.5 (0.6)	Junction Wis. Hwy. 65, continue north on Hwy. 35.
3.1 (1.6)	Junction with County Hwy. U; go straight on Hwy. 35. The mesa and butte topography in this area is related to a dissected westerly dipping cuesta that is capped by the Platteville Formation, a resistant dolomitic limestone of Ordovician age.
4.6 (1.4)	Road cut on right exposes St. Peter Formation (Ordovician) at the base of a large mesa.
6.0 (1.6)	The knob and kettle topography in this area marks the beginning of the St. Croix moraine complex of late Wisconsinan age. In this area, the St. Croix moraine complex is composed primarily of sorted sand and gravel with occasional lenses of reddish brown, sandy-loam textured till.
7.6 (1.5)	Large knob of sand and gravel (kame) with a local relief of over 37 m (120 ft.), can be seen on right.
9.1	Junction with County Hwy. N; turn right on N and proceed east.
9.3 (0.3)	Road cuts expose ice-contact sand and gravel of the St. Croix moraine.
9.6 (0.3)	Junction with County Hwy. U; turn left on U and proceed north.
9.9 (1.6)	Overpass over I-94 and junction with U.S. Hwy. 12. Continue north on Hwy. U/U.S. 12.

11.5 (0.2)	Fork in road. Follow Hwy. U to left.
11.7 (0.2)	Railroad crossing.
11.9 (1.5)	End Hwy U; begin County Hwy. A. Continue straight on Hwy. A.
13.4 (1.1)	Passing entrance to Willow River State Park on left.
14.5 (0.4)	Dropping into Willow River valley, a southwesterly trending valley that cuts diagonally through the St. Croix moraine complex.
14.9 (0.5)	Cross Willow River and turn left on County Hwy. I.
15.4 (1.7)	Fork in road; bear right on Hwy. I.
17.1 (0.9)	Cross County Hwy. E and continue north on Hwy. I.
18.0 (3.0)	Notice the particularly well developed knob and kettle topography in this portion of the St. Croix moraine.
21.0 (2.4)	STOP 1. Exposure of St. Croix moraine. Road cut on east side of Hwy. I. Buses will turn around while we examine this exposure. Refer to stop description on p. 25.
	Proceed south on Hwy. I.
23.4 (0.8)	Turn left onto Boardman Road.
24.2 (1.2)	Road crosses southern end of Bass Lake, one of many water-table controlled lakes in this region of the St. Croix moraine that have experienced significant rises in water level in recent years. This particular lake has risen over 3 m (10 ft.) in past 10 years.
25.4 (0.4)	Junction County Hwy. E; turn left and drive east.
25.8 (0.2)	Junction County Hwy. A; bear right and continue east on Hwy. E.
26.0 (2.2)	Cross Willow River.

28.2 (1.9)	The drift thickness in this portion of the St. Croix moraine is sufficiently thin that a number of mesas can be seen protruding through the moraine to the right (south) of the highway.
30.1 (0.2)	Turn right on 120th Street.
30.3 (0.7)	Road cut through mesa on left exposes buff colored St. Peter Formation of Ordovician age.
31.0 (0.9)	Turn left on 110th Ave. and drive east.
31.9 (5.2)	For approximately the next mile, we will be descending the distal slope of the St. Croix moraine in a series of steps, onto the more subdued pre-Wisconsinan drift surface.
37.1 (1.0)	Junction with County Hwys. E and T; turn right.
38.1 (3.9)	Turn left on Hwy. E and continue east.
42.0 (0.8)	Junction U.S. Hwy. 63; continue straight on Hwy. E.
42.8 (0.1)	Turn right on 220th Street.
42.9 (0.2)	Turn right into gravel pit for STOP 2. South wall of pit exposes till of the River Falls Formation with a truncated Sangamon paleosolum. Refer to stop description on p. 29. Return to 220th Street.
43.1 (1.9)	Turn right on 220th Street and continue south.
45.0 (0.6)	Pavement ends; continue south on 220th Street.
45.6 (2.6)	Junction U.S. Hwy. 12; turn left on Hwy. 12 and proceed east.
48.2 (0.2)	Turn right on County Hwy. B.
48.4 (0.1)	Turn right on Elm Street
48.5 (0.1)	Turn left into Blackhawk Plant Foods, Inc. and park on the east side of lot. STOP 3, the Woodville railroad cut, is exposed on the north side of the tracks, approximately 275 m (300 yards) west of the parking area. Refer to stop description on p. 36. Return to Elm Street.

48.6 (0.4)	Turn left on County Hwy. B into Woodville.
49.0 (0.1)	Junction with County Hwy. BB; turn left and continue on Hwy. B.
49.1 (0.1	Turn left on Park Drive into Woodville City Park for lunch. Return to Hwy. B.
49.2 (0.5)	Turn right on Hwy. B.
49.7 (2.8)	Junction with U.S. Hwy. 12; turn right on Hwy. 12 and drive east.
52.5 (0.4)	Crossing Eau Galle River.
52.9 (1.5)	Park on right shoulder of highway. STOP 4, the pre-Illinoian Hersey Member with a well developed Yarmouth Paleosol is exposed in an abandoned quarry approximately 90 m (100 yards) to the left (north) of Hwy. 12. Refer to stop description on p. 42. Continue east on Hwy. 12.
54.4 (1.6)	Junction with Wis. Hwy. 128; turn right on Hwy. 128.
56.0 (3.1)	Turn left on I-94 and drive east.
59.1 (2.9)	Dunn County line.
62.0 (7.1)	Descending cuesta escarpment into pre-Illinoian Glacial Lake Eau Claire basin. This was the largest of the proglacial lakes in western Wisconsin, occupying the Eau Galle, Red Cedar, and Chippewa drainage basins.
69.1 (2.1)	Highway construction along this portion of I-94 in the summer of 1983, revealed many exposures of lacustrine sediments of the Kinnickinnic Member overlain by 0.3 to 3 m (1 to 10 ft.) of terrace sands of the Late-Wisconsinan Wissota terrace. The Wissota terrace was mapped in 1965 by G.W. Andrews was shown to originate in the Chippewa moraine.
71.2 (13.3)	Cross Red Cedar River.
84.5 (8.1)	Enter Eau Claire County.
92.6 (5.7)	Cross Chippewa River.

98.3 (0.6)	Take Exit 70 to U.S. Hwy. 53 south. Go south on Hwy. 53.
98.9 (0.2)	Turn right on County Hwy. 1A.
99.1 (1.9)	Fork in road, continue straight on Old Town Hall Road.
101.0 (0.7)	Junction with Wis. Hwy. 93; turn left on Hwy. 93 and drive south.
101.7 (0.3)	Turn right into entrance to Eau Claire County clay pit and proceed into excavation area.
102.0 (0.3)	STOP 5. Exposure of glaciolacustrine sediments of the Kinnickinnic Member in Eau County clay pit. Refer to stop description on p. 46. Return to Hwy. 93.
102.3 (0.7)	Turn left on Hwy. 93.
103.0 (2.1)	Turn right on Old Town Hall Road and proceed east.
105.1 (0.6)	Junction with U.S. Hwy. 53; turn left.
105.7 (6.0)	Turn on I-94 west bound.
111.7 (21.4)	Crossing Chippewa River.
133.1 (12.3)	Crossing Red Cedar River.
145.4 (21.4)	St. Croix County line.
166.8 (8.0)	Take Exit 10 to Hwy. 65. Drive south on Hwy. 65.
174.8 (0.5)	Junction with Wis. Hwy. 35; turn left on Hwy. 35.
175.3 (1.5)	Cross Kinnickinnic River.
176.8 (0.4)	Turn left on Cascade Ave.
177.2 (0.1)	Turn right and return to Rodli Commons.
177.3	End of trip for first day.

GEOLOGIC ROADLOG - DAY 2

-- Mileage is cumulative, with increments between entries in parentheses.

Miles	
0 (0.1	Trip begins in front of west entrance to the Rodli Commons building, UW-River Falls. Proceed north to Cascade Ave.
0.1 (0.4)	Turn left on Cascade Ave.
0.5) (0.1)	Junction with Wis. Hwys. 29 and 35; continue straight.
0.6 (0.1)	Turn left on Hwy. 29 and proceed south.
0.7 (1.8)	Cross South Fork of the Kinnickinnic River.
2.5 (1.2)	Junction with County Hwy. FF; continue south on Hwy. 29.
3.7 (2.2)	Junction with County Hwy. E; continue south on Hwy. 29. We are travelling through the Glacial Lake River Falls pro-glacial lake basin. Lacustrine sediments of the Kinnickinnic Member, capped by either loess or till of the River Falls Formation, underlie the fields on either side of the highway.
5.9 (1.0)	Junction with County Hwy. MM, turn on Hwy. MM. The ridge that parallels Hwy. MM, immediately to the left, is a portion of a dissected pre-Illinoian recessional moraine, known as the Trimbelle moraine.
6.9 (0.2)	Junction with County Hwy. QQ; continue straight on Hwy. MM.
7.1 (0.1)	Turn left into the R. C. Rohl farm lot.
7.2 (0.1)	STOP 6. Exposure in the pre-Illinoian Trimbelle moraine. Refer to stop description on p. 48. Return to Hwy. MM and turn right (east).
7.3 (0.8)	Turn right on Hwy QQ and drive south across the Trimbelle moraine.
8.1 (0.5)	Junction with Wis. Hwy. 29; turn left and drive north.
8.6 (1.3)	Turn right on Forestville Road.
9.9 (0.9)	Descending into a portion of the Glacial Lake River Falls proglacial lake basin.

10.8 (3.5) Junction with County Hwy. E; continue straight on Forestville Road.

14.3 (0.5) Junction with County Hwy. O; turn left on Hwy. O.

14.8 (0.6) Turn right on Pleasant View Road.

15.4 (0.5) Park on right shoulder of road and walk down service road on the right to gravel quarry for STOP 7, the till of the River Falls Formation with a relict Sangamon Paleosolum. Refer to stop description on p. 53. Continue east on Pleasant View Road.

15.9 (0.2) View straight ahead is of the Glacial Lake Beldenville proglacial lake basin.

16.1 (1.1) Pleasant View Road ends; turn right on Sleepy Hollow Drive and proceed into Glacial Lake Beldenville basin.

17.2 (0.6) Turn right on Wis. Hwy. 35.

17.8 (1.6) Cross Trimbelle River.

19.4 (1.2) Enter village of Beldenville.

20.6 (0.3) Turn left on County Hwy. J.

20.9 (3.7) Bear right at fork in road on County Hwy. N and proceed east.

24.6 (1.8) Junction with U.S. Hwy. 63; continue straight on Hwy. N.

26.4 (1.8) The subdued, rolling topography in this area is underlain by the Hersey Member and is typical of the pre-Illinoian landscapes in western Wisconsin.

28.2 (0.1) Village of El Paso; junction with County Hwy. G; turn left and continue on Hwy. N.

28.3 (0.1) "T" in road; turn left and continue on Hwy. N.

28.4 (0.1) Cross Rush River.

28.5 (0.3) Fork in road; bear right on Old School House Drive.

28.8 Pavement ends; continue straight on Old School House Drive.
(1.0)

29.8 Turn right on County Hwy. BB and drive north.
(2.0)

31.8 Turn right on Gravel Pit Drive and drive east.
(1.8)

33.6 Turn left on entrance road to gravel pit.
(0.2)

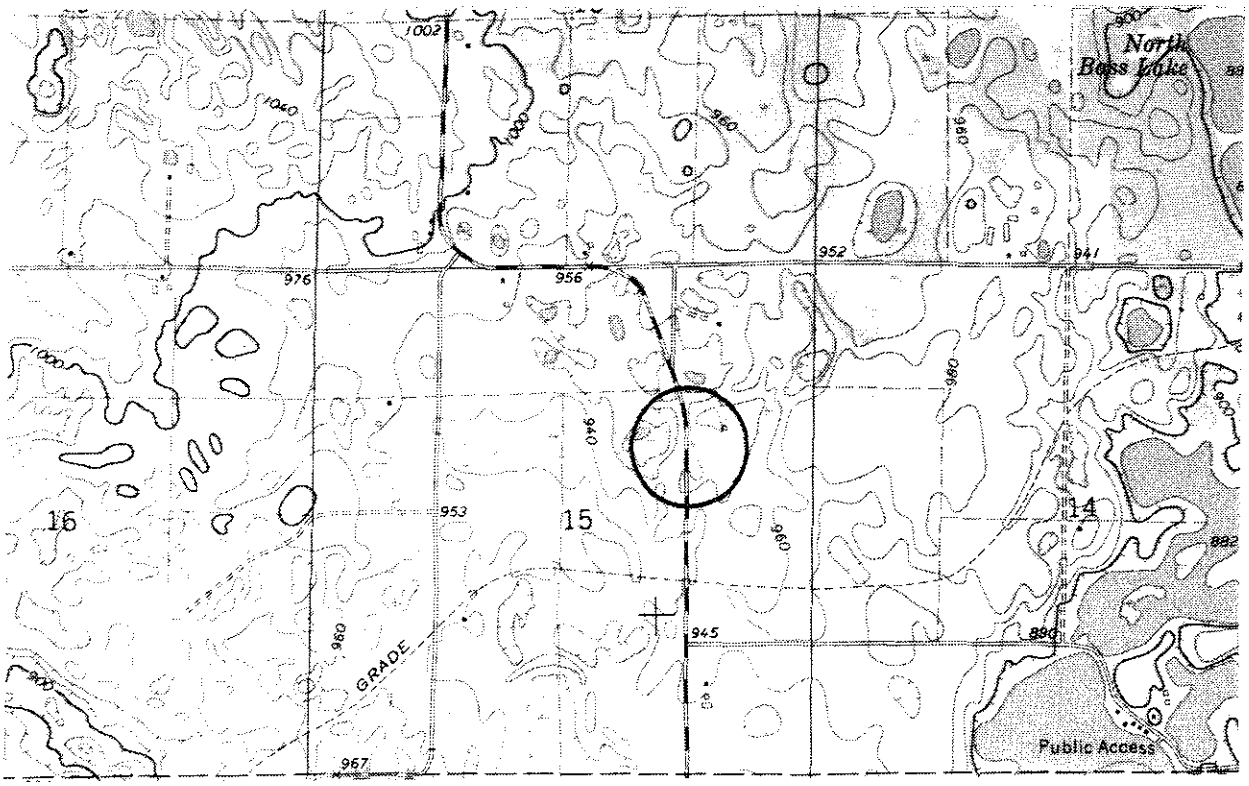
33.8 STOP 8. Gillman Township gravel quarry. Refer to stop description on p. 57.

End of 1984 Friends of the Pleistocene trip.

GEOLOGIC STOP DESCRIPTIONS

STOP 1

Title: Late-Wisconsinan St. Croix Moraine, County Hwy. I Road Cut.



Location: NE1/4 SW1/4 NE1/4 sec. 15, T. 30 N., R. 19 W. Somerset South 7½-minute topographic quadrangle. Road cut on east side of County Hwy. I.

Author: Robert W. Baker (1984)

The St. Croix moraine complex is a major glacial geomorphic landform in eastern Minnesota and western Wisconsin. It can be traced for over 500 km (300 mi.), as a belt of high relief lake studded terrain. The complex was deposited by the Superior Lobe during its late-Wisconsinan maximum, the St. Croix phase, approximately 20,000 B.P. (Wright, 1973). Because of its rugged knob and kettle nature and because it contains substantial amounts of stratified sands and gravels and lacustrine sediments, as well as till, it is believed that the St. Croix moraine was deposited as an extensive ice-cored moraine complex (Wright and Ruhe, 1965).

At this stop, the road cut on the east side of County Hwy. I exposes a rather typical section of St. Croix moraine sediments, while the view to the west, shows the classic knob and kettle topography common to the moraine complex. There are two major glacial sediments exposed in the road cut--till and ice-contact stratified drift. The pebble lithologies in each of these materials are diagnostic of northeastern provenance. Common clast lithologies include basalt, gabbro, red sandstone, felsite, and occasional Lake Superior agates.

The section description is given in table 4 and the particle-size description is shown in figure 6. The brown to reddish-brown colors and the sandy-loam texture of the till at this locality are characteristics common throughout the entire St. Croix moraine belt (Chernicoff, 1980). The clay mineralogy of the till in the C horizon at this location averages 35 percent montmorillionite, 25 percent vermiculite, 20 percent kaolinite, 15 percent mica (illite), 5 percent quartz, and trace amounts of chlorite and feldspar. These results are within the ranges in clay-mineral content for the St. Croix moraine reported by Chernicoff (1980).

Note that the solum thickness at this location is 0.92 m (3.0 ft) (table 4 and fig. 6). This value is very close to the maximum solum thickness of about 1 m, found elsewhere in the St. Croix moraine (Ruhe and Gould, 1954; Schneider, 1961; Chernicoff, 1980).

Table 4.--Section description for St. Croix moraine exposure County Hwy. I, St. Croix County, Wisconsin. Surface elevation approximately 280 m (920 ft)

DEPTH (m)	HORIZON	DESCRIPTION
Wisconsinan till (undifferentiated)		
0-0.05	A	Dark brown (10 YR 3/3) sandy loam; weak, fine granular structure; very friable; abrupt, smooth boundary.
0.05-0.18	E	Brown to dark brown (10 YR 4/3) sandy loam; weak fine subangular blocky structure; friable; clear wavy boundary.
0.18-0.30	Bt1	Brown to dark brown (7.5 YR 4/4) sandy loam to sandy clay loam; moderate fine and medium subangular blocky structure; friable; gradual, smooth boundary.
0.30-0.92	Bt2	Dark reddish brown (5 YR 3/4) sandy loam; moderate fine and medium subangular blocky structure; friable; many medium discontinuous clay skins; diffuse, wavy boundary.
0.92-2.54	C1	Reddish brown (5 YR 4/4) sandy loam; strong fine and medium subangular blocky structure (till related); friable.
Wisconsinan sand and gravel		
2.54+	2C2	Yellowish red (5 YR 4/6) sands, coarse sands, and gravels; structureless, single grained; noncalcareous.

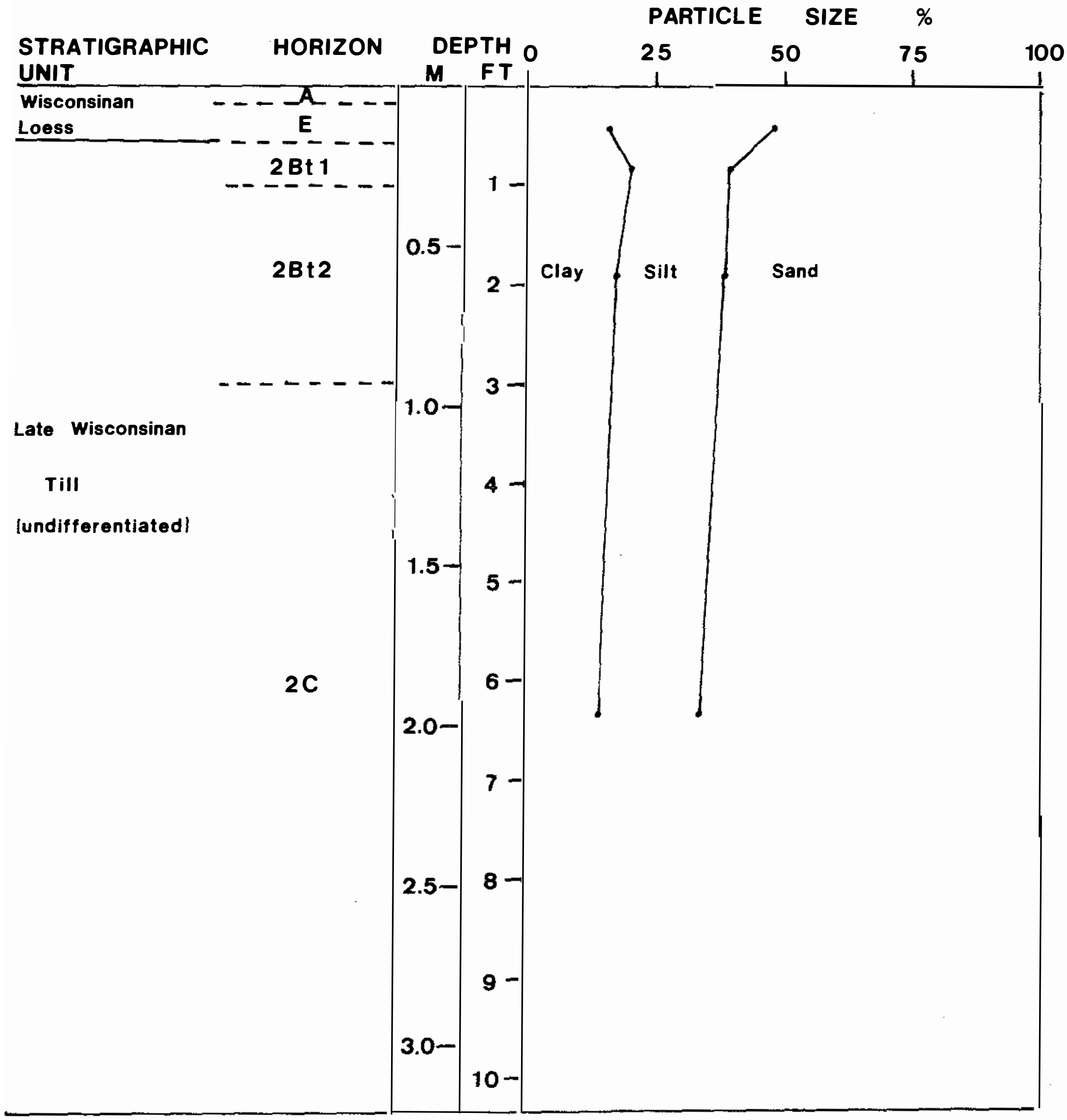
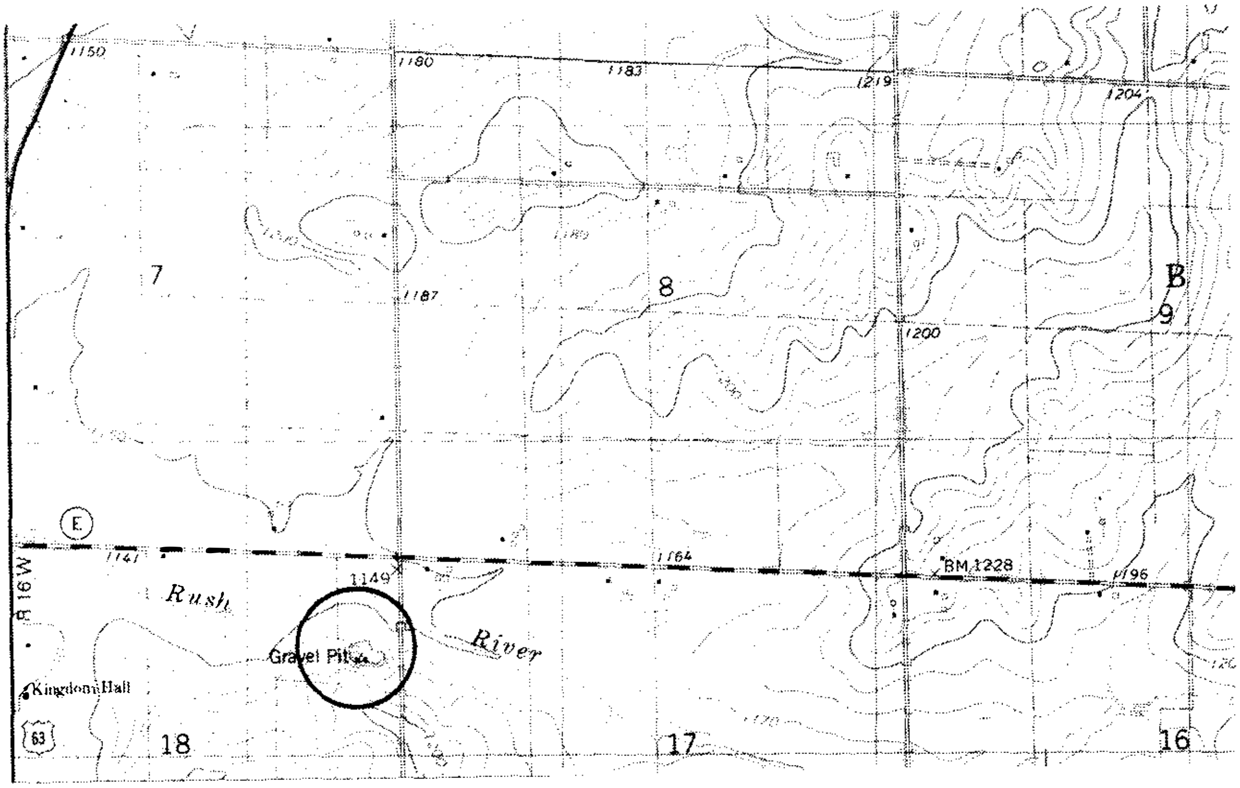


Figure 6.--Stratigraphy and particle-size data for the County Highway I roadcut in St. Croix moraine.

STOP 2

Title: River Falls Formation, County Hwy. E gravel pit.



Location: SE1/4 NE1/4 NE1/4 sec. 18, T. 29 N., R. 16 W. Emerald 7½-minute topographic quadrangle. Southeast wall of gravel quarry, 300 m south of County Hwy. E.

Author: Robert W. Baker (1984)

This stop is the type section for the River Falls Formation. The section exposes a complex assortment of loess, colluvium, erosional surfaces, till, and sand and gravel (fig. 7). Two sections were described (soil profile locations 1 and 2, fig. 7) at this stop with section descriptions given in tables 5 and 6 and stratigraphy and particle-size data presented in figures 8 and 9.

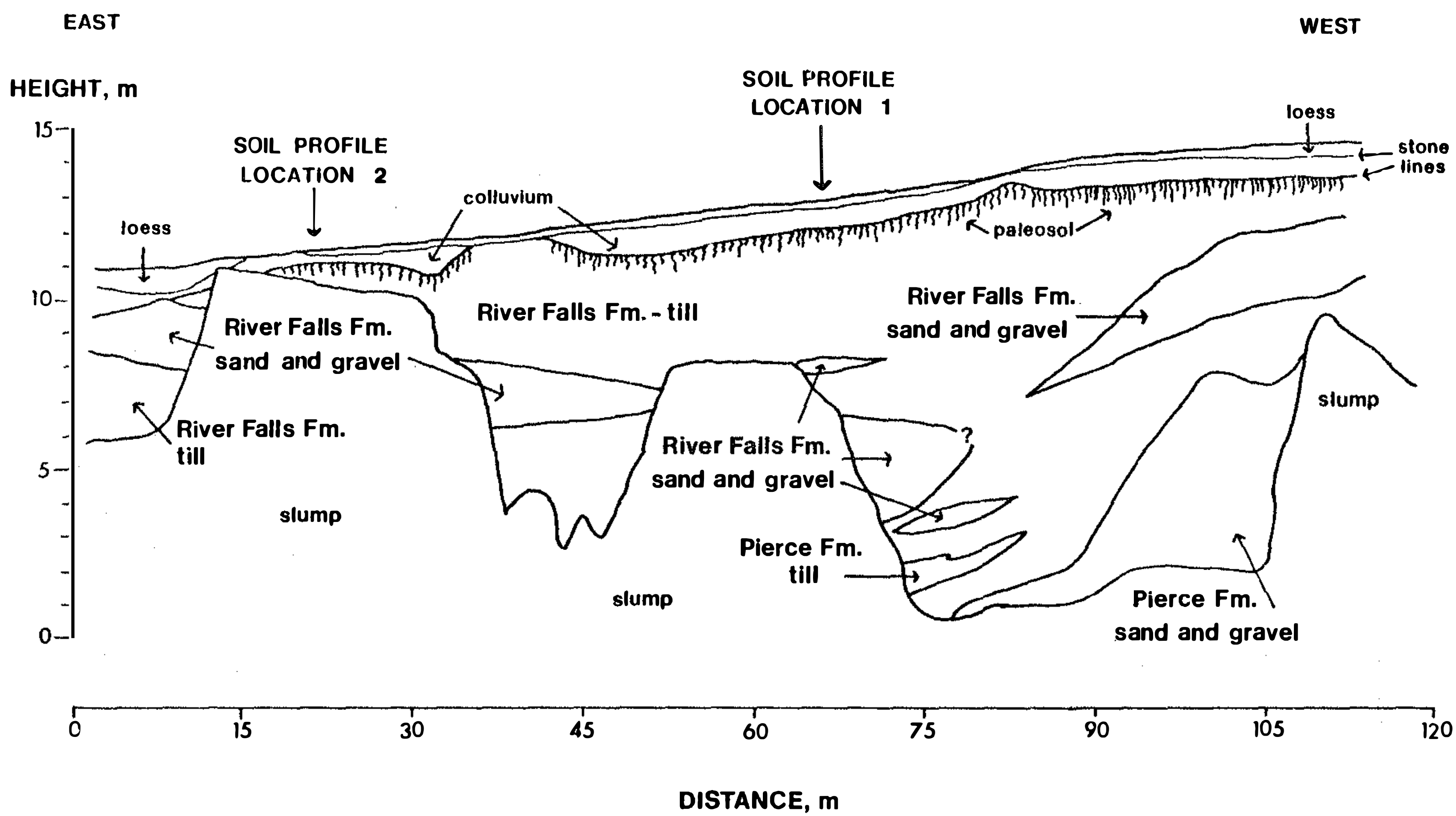


Figure 7.--Cross section of the southeast wall of the County Highway E gravel quarry in the River Falls Formation.

Table 5.--Section description, Profile 1, River Falls Formation type locality, St. Croix County, Wisconsin. Surface elevation approximately 355 m (1164 ft)

DEPTH (m)	HORIZON	DESCRIPTION
Wisconsinan loess		
0-0.20	Ap	Dark brown (10 YR 3/3) loam; weak, granular structure; very friable; clear, smooth boundary.
0.20-0.38	Bt1	Dark yellowish brown (10 YR 4/4) silty clay loam; moderate subangular blocky structure; friable; clear, wavy boundary.
River Falls Formation till with Sangamon Paleosol.		
0.38-0.76	2Bt2	Dark reddish brown (3 YR 3/4) sandy loam to sandy clay loam; moderate subangular blocky structure; friable; gradual, wavy boundary.
0.76-0.96	2Bt3	Reddish brown (5 YR 4/4) sandy clay loam; weak, subangular blocky structure; friable; gradual, wavy boundary.
0.96-1.40	2Bt4	Yellowish red (5 YR 4/6) sandy clay loam with greyish brown (10 YR 5/2) inclusions; weak, subangular blocky structure; friable; gradual, wavy boundary.
1.40-2.16	2C1	Yellowish red (5 YR 4/6) sandy clay loam with dark grey (10 YR 4/1) and light brownish grey (10 YR 6/2) inclusions; weak, subangular blocky structure; friable; abrupt, wavy boundary.
2.16-2.81	2C2	Strong brown (7.5 YR 5/6) sandy-clay loam with a thick band of reddish brown (5 YR 4/4) sandy clay loam; weak, subangular blocky structure; friable; gradual, wavy boundary.
2.81-3.50	2C3	Dark reddish brown (5 YR 3/4) sandy clay loam to sandy loam; strong, medium and course angular to subangular blocky structure; slightly compact in place, friable when removed; few lenses of dark grey (10 YR 4/1) till.

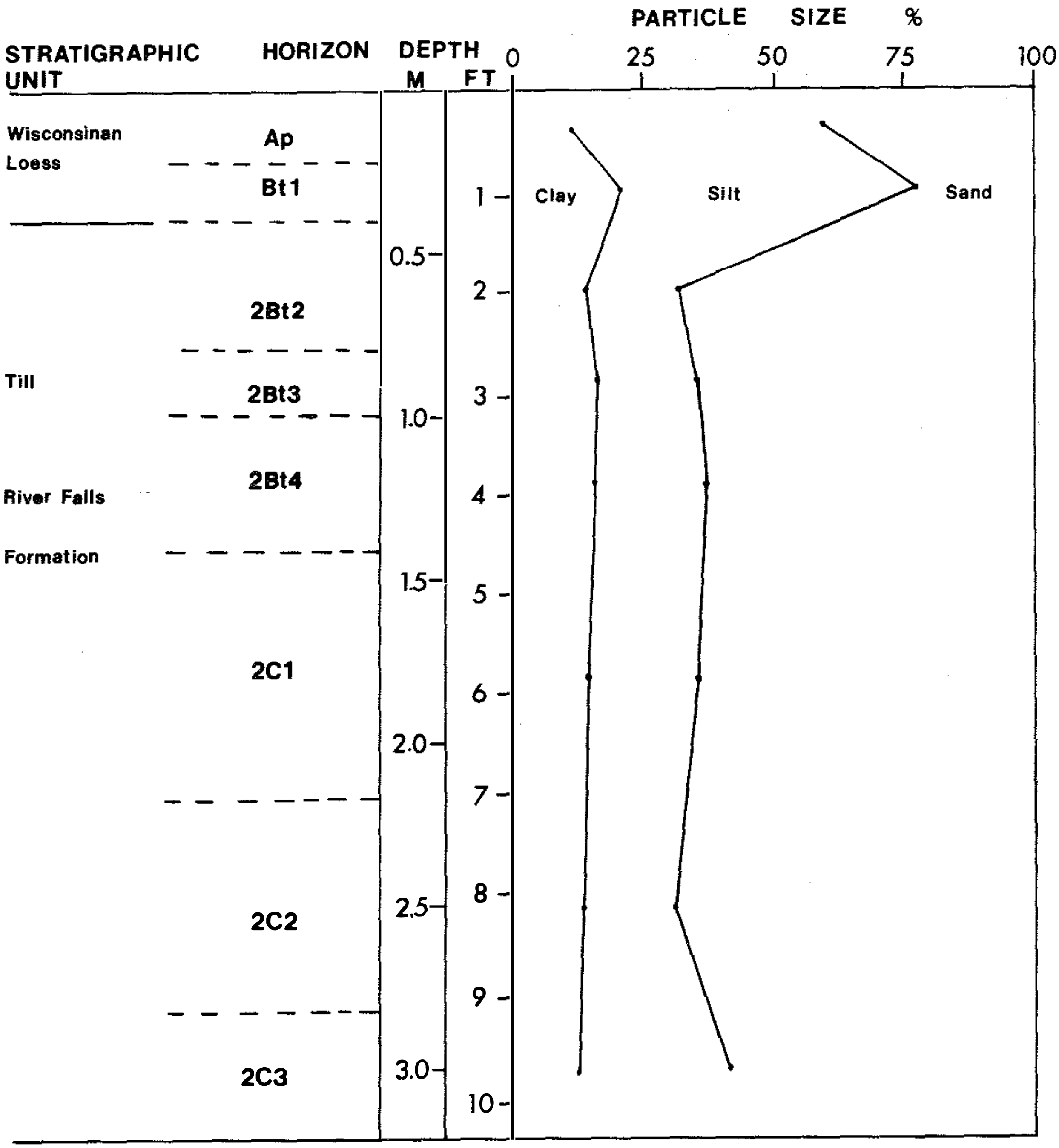


Figure 8.--Stratigraphy and particle-size data for Profile 1, County Highway E gravel quarry.

Table 6.--Section description, Profile 2, River Falls Formation type locality, St. Croix County, Wisconsin. Surface elevation approximately 357 m (1170 ft).

DEPTH (m)	HORIZON	DESCRIPTION
Wisconsinan loess		
0-0.24	Ap	Dark brown (10 YR 3/3) loam; weak, granular structure; friable; abrupt boundary.
Colluvium (slope-wash sediment)		
0.24-0.32	2Bt1	Brown-dark brown (7.5 YR 4/4) loam; moderate, subangular blocky structure; firm; clear boundary.
0.32-0.45	2Bt2	Dark yellowish brown (10 YR 4/4) loam; moderate, subangular blocky structure; firm, clear boundary.
0.45-0.74	2C	Brown-dark brown (7.5 YR 4/4) loamy sand; weak, subangular blocky grading to platy structure; friable; clear boundary.
River Falls Formation till with truncated Sangamon Paleosol.		
0.74-0.93	3Btb1	Brown (7.5 YR 5/4) sandy loam; weak, prismatic structure grading to moderate, subangular blocky; firm; diffuse, wavy boundary
0.93-1.16	3Btb2	Yellowish brown (10 YR 5/4) loam; weak, prismatic structure grading to moderate, subangular blocky structure; abrupt smooth boundary.
1.16-1.24	3C1	Strong brown (7.5 YR 4/6) sandy loam to sandy clay loam; massive structure; abrupt smooth boundary.
1.24-1.45	3C2	Reddish brown (5 YR 4/4) band of sandy clay loam; massive structure; abrupt smooth boundary.
1.45-6.0	3C3	Strong brown (7.5 YR 4-5/6) sandy loam; massive structure; clear, wavy boundary.
River Falls Formation sorted sand and gravel (undifferentiated)		
6.0-8.0	4C4	Brown (7.5 YR 5/4) loamy sand; massive or single grain structure; abrupt, wavy boundary.
8.0-9.0	4C5	Yellowish red (5 YR 5/8) sand; single grain structure; loose; clear, wavy boundary.
River Falls Formation till		
9.0 +	5C6	Brown-dark brown (7.5 YR 4/4) sandy loam massive, structureless; friable.

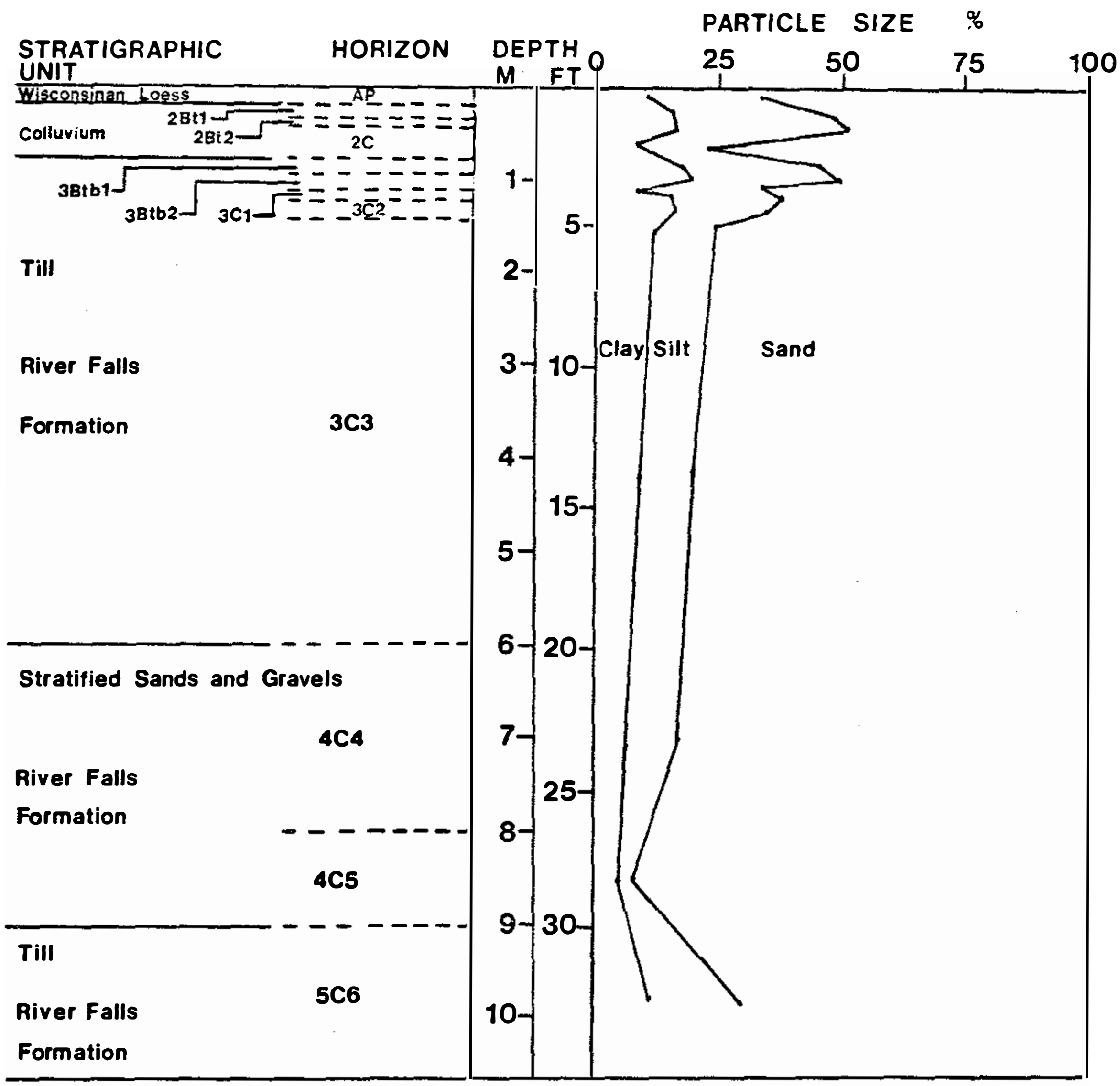


Figure 9.--Stratigraphy and particle-size date for Profile 2, County Highway E gravel quarry.

Section description 1 was made in June, 1980, and during the intervening four years, the exposure has retreated over 50 m as the result of quarry operations. Consequently, the materials presently exposed and the soil profile at this location bear little resemblence to table 5 and figure 8. In contrast, section description 2 was made in June, 1983, and is still relatively intact.

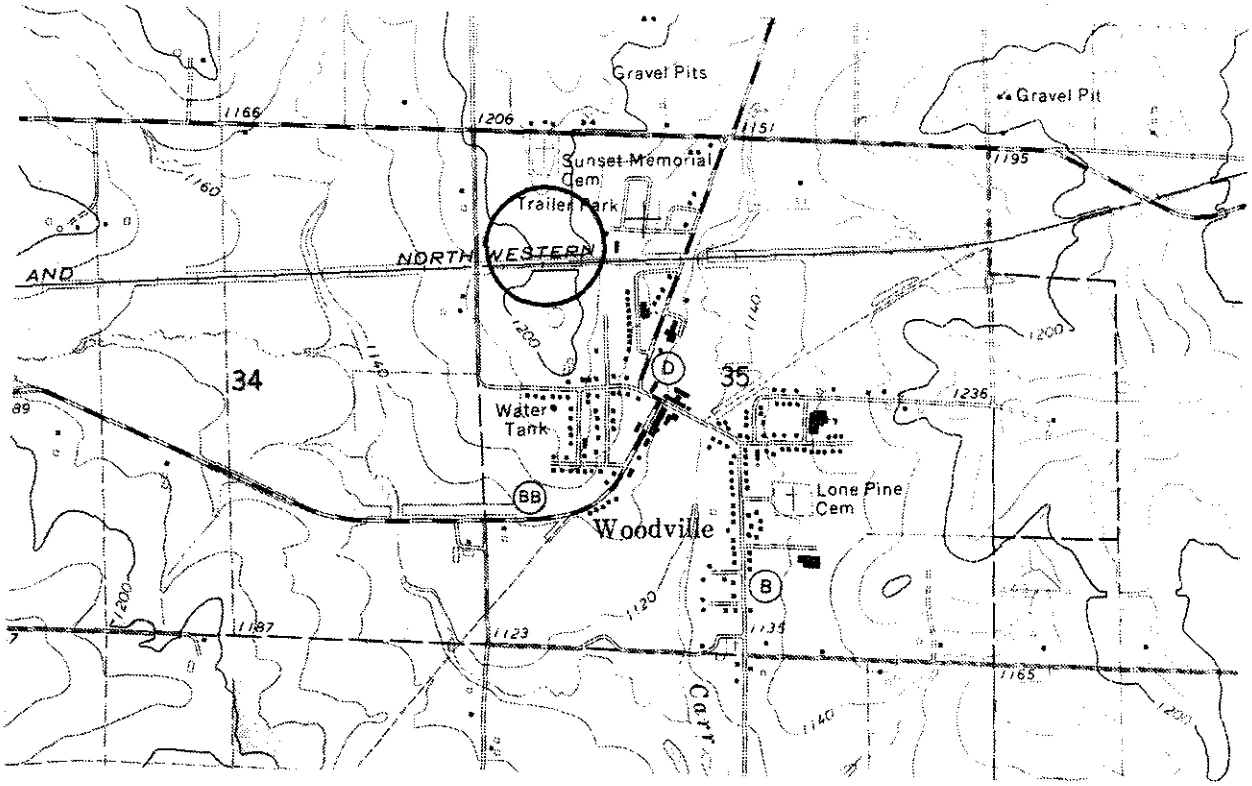
The till of the River Falls Formation ranges in texture from loam to sandy loam depending upon position in the solum, while color varies from yellowish brown (10 YR 5/4) to strong brown (7.5 YR 5/6) (tables 5 and 6). C horizon clay mineralogy at this location averages 40 percent montmorillonite, 25 percent kaolinite, 20 percent vermiculite, 10 percent mica (illite) and 5 percent quartz. These data compare favorably with samples from this site analyzed by the Iowa Geological Survey (53 percent expandables (montmorillonite plus vermiculite), 24 percent illite (mica) and 23 percent kaolite plus chlorite) (Hallberg, personal communication, April, 1983).

The loess cap at this exposure is interpreted to be late Wisconsinan in age on the basis of clay mineralogical data. Specifically, the high chlorite content of 15 percent suggests youngness for the loess because chlorite is generally weathered away in well-developed soils. The weakly developed pebble line beneath the loess (fig. 7) is interpreted to be west-central Wisconsin's equivalent of the Iowan Erosion Surface.

This surface has been shown in similar landscape positions in eastern Iowa to have formed during a loess deposition period between 22,000 and 17,000 B.P. (Hallberg and others, 1978). The colluvium below the upper pebble line (fig. 7) is loam to sandy loam textured (table 6) and appears to be derived from erosion of the underlying River Falls Formation till. The loamy colluvium, the underlying stone line, and the truncated paleosol at the top of the River Falls Formation (fig. 7) all indicate that a substantial erosional surface formed after the development of a mature soil in the River Falls Formation till. This also appears to be a situation analogous to eastern Iowa (Hallberg and others, 1978; Hallberg and others, in press). Thus, as in Iowa, the paleosol here is believed to be a truncated Sangamon soil and the stone line is apparently a late-Sangamon erosion surface. Consequently, if these interpretations are correct, the River Falls Formation must be Illinoian in age. This interpretation is supported by sola thicknesses in exposures of the till of the River Falls Formation in upland landscape positions. In these situations sola thicknesses of as much as 2.8 m are found; thickness which are approximately three times greater than those found in the till of the late-Wisconsinan St. Croix moraine.

STOP 3

Title: River Falls and Pierce Formations, Woodville Railroad Cut.



Location: SE1/4 NW1/4 NW1/4 sec. 35, T.29 N., R. 16 W., Baldwin East 7½-minute topographic quadrangle. North exposure in Northwestern Railroad cut, approximately 500 m west of County Hwy. D, Woodville, Wisconsin.

Author: Robert W. Baker (1984).

The Woodville railroad cut is a classic exposure that has been restudied periodically for almost an 80 year period. R. T. Chamberlin (1910) was the first Quaternary geologist to visit this site. He described two major units: a red northeastern (Superior Lobe) drift of probable Illinoian age overlying a grey northwestern (Keewatin) drift of probable Kansan age. Leverett's (1932) study of this exposure added a new unit--a second grey till at the base of the exposure containing a weathered zone that was separated from the upper grey till by a layer of peat and wood. Leverett assigned this unit to the Nebraskan Stage. However, because he realized that the weathered zone was not sufficiently large to have developed throughout the entire Aftonian Stage, he argued that the Nebraskan till must have first experienced a substantial period of erosion that formed a lowland, with swampy conditions and peat formation occurring in the later part of the Aftonian. R. F. Black's (1959;

Black and Reed, 1965) studies of this exposure only recognized the red and upper grey units. As mentioned previously in this report, Black interpreted the red till as an ablation till and the grey till as a basal till and suggested that both units were deposited simultaneously by the same glacier. Based on two radiocarbon dates of about 30,000 B.P. from the grey drift, Black assigned these units to a late Altonian (early Wisconsinan) event he named the Rockian.

The base of the exposure is currently obscured because of a combination of fill, slump, and vegetative cover. Consequently, in June, 1983, two deep boreholes were drilled at this site by the Wisconsin Geologic and National History Survey and a new lacustrine unit was discovered, and Leverett's second grey (Nebraskan) till was rediscovered (fig. 10). The section description of the railroad cut is given in table 7 and the stratigraphy and particle-size data are presented in figure 11.

The loess cap (table 7; fig. 10; fig. 11) is interpreted to be late Wisconsinan in age on the basis of its high chlorite content in the clay-size fraction. The underlying yellowish red (5 YR 4/6) sandy clay loam to reddish brown (5 YR 4/4) sandy loam till and strong brown (7.5 YR 4/6) to yellowish brown (10 YR 5/6) sand to loamy sand represent the River Falls Formation. The C horizon clay mineralogy of the till at this locality averages 40 percent montmorillonite, 25 percent kaolinite, 15 percent vermiculite, 15 percent mica (illite), and 5 percent quartz.

The Hersey Member of the Pierce Formation is exposed below the River Falls Formation. The Hersey Member at this site ranges in color from yellowish brown (10 YR 5/4) to dark grey (10 YR 4/1) and texturally from clay loam to loam. Clay mineralogy at this location averages 58 percent montmorillonite, 25 percent kaolinite, 15 percent mica (illite), 2 percent quartz, and no vermiculite, which again compares very favorably with samples from this site analyzed by the Iowa Geological Survey (55 per cent expandables (montmorillonite plus vermiculite), 25 percent kaolinite plus chlorite, and 20 percent illite (mica) (Hallberg, written communication, April 1983).

Beneath the Hersey Member lies the Woodville Member of the Pierce Formation. This is the "Nebraskan" till of Leverett. It is a strongly calcareous loam and ranges in color from grey (5 Y 5/1) to dark grey (10 YR 4/1). The clay mineralogy of the Woodville Member at this site averages 63.5 per cent montmorillonite, 21.5 per cent kaolinite, 14 percent mica, and no vermiculite. Again this compares well with Iowa Geological Survey analyses from this site which averaged 62 percent expandables (montmorillonite plus vermiculite), 23.5 percent kaolinite plus chlorite, and 14.5 percent illite (mica) (Hallberg, written communication, February, 1984).

The Woodville Member overlies the Eau Galle Member of the Pierce Formation, a yellowish brown (10 YR 5/4) to grey (10 YR 5/1) silty clay to clay. The clay mineralogy of the Eau Galle Member averages 65 percent montmorillonite, 20 percent mica, 10 percent kaolinite, and 5 percent chlorite. These data are corroborated by Iowa Geological Survey clay mineral analyses on samples from this site that averaged 66.5 percent expandables (montmorillonite plus vermiculite), 21.5 percent illite (mica), and 12 percent kaolinite plus chlorite (Hallberg, written communication February, 1984).

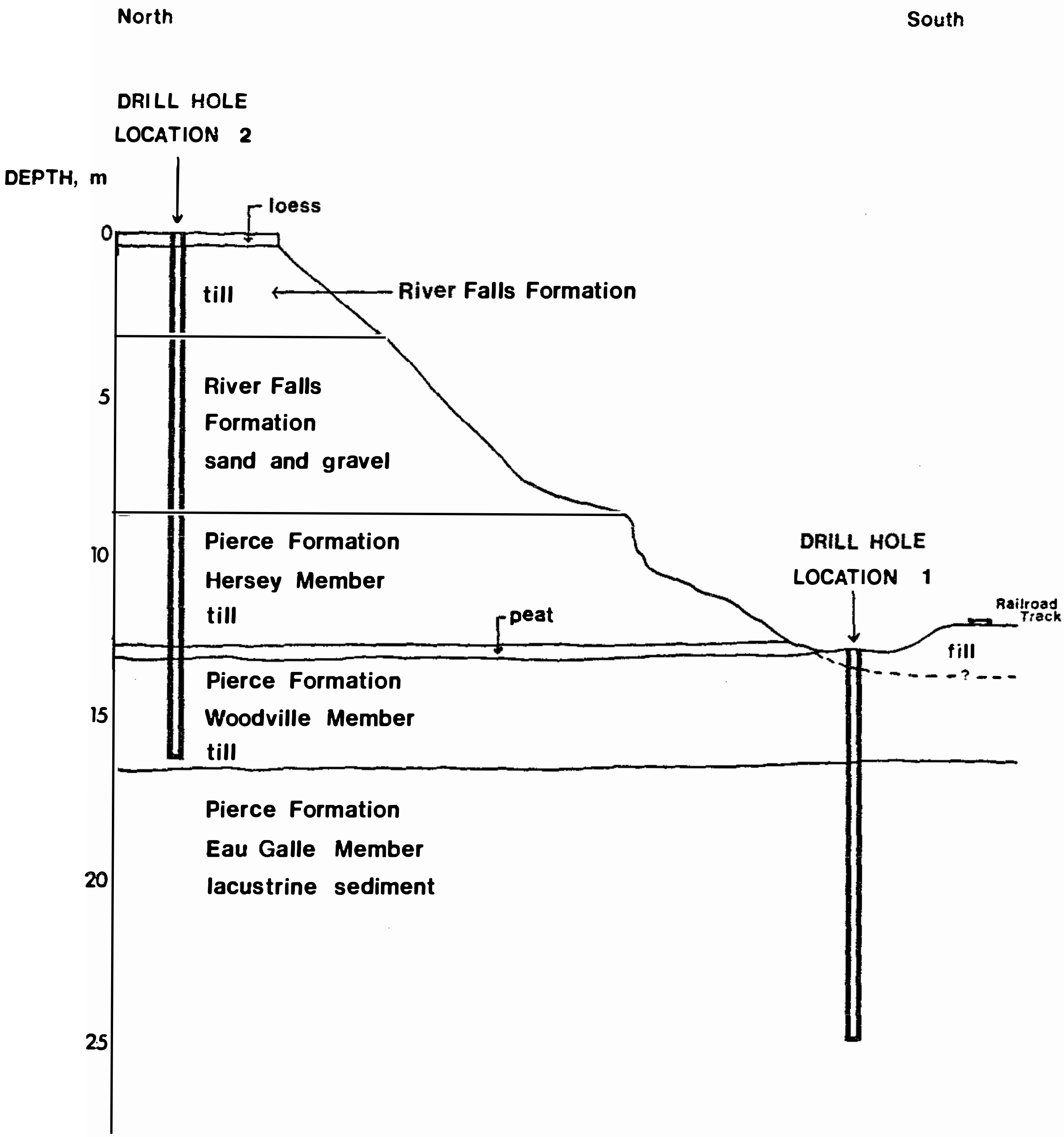


Figure 10.--Cross section of the Woodville railroad cut.

Table 7.--Section description Woodville railroad cut, St. Croix County, Wisconsin. Surface elevation approximately 370 m (1214 ft).

DEPTH (m)	HORIZON	DESCRIPTION
Wisconsinan loess		
0-0.28	A	Very dark greyish brown (10 YR 3/2) silt loam; moderate, granular structure; very friable; clear smooth boundary.
0.28-0.40	E	Brown (7.5 YR 5/4) silt loam; weak and fine subangular blocky structure; friable; clear smooth boundary.
River Falls Formation till		
0.40-0.53	2Bt1	Yellowish red (5 YR 4/6) light sandy clay loam; fine and moderate subangular blocky structure; friable; slightly sticky and slightly plastic; gradual smooth boundary.
0.53-0.73	2Bt2	Yellowish red (5 YR 4/6) sandy clay loam; medium and moderate subangular blocky structure; friable; slightly sticky and slightly plastic; gradual smooth boundary.
0.73-1.20	2Bt3	Yellowish red (5 YR 4/6) heavy sandy clay loam; moderate subangular blocky structure; friable; sticky and plastic; common, distinct light brown (7.5 YR 6/4) ped face coatings; gradual smooth boundary.
1.20-1.78	2Bt4	Yellowish red (5 YR 4/6) sandy clay loam; weak subangular blocky structure; friable to firm; sticky and plastic; common, prominant light brownish grey (10 YR 6/2) and (7.5 YR 6/4) mottles.
1.78-3.45	2C1	Yellowish red (5 YR 4/6) sandy clay loam; structureless massive; friable; sticky and plastic; few prominant (7.5 YR 6/4) mottles.
3.45-5.15	2C2	Yellowish red (5 YR 4/6) sandy clay loam; structureless massive; friable; sticky and plastic.
River Falls Formation sand and gravel (undifferentiated)		
5.15-12.27	3C3	Yellowish brown (10 YR 5/8) sand, course sand, and gravel; structureless single grain; noncalcareous; and brownish yellow sand and gravel; structureless, single grain.
12.27-13.50	3C4	Pale brown (10 YR 6/3) sand and gravel; structureless; single grain; calcareous.
Pierce Formation Hersey Member till		
13.50-13.80	4C5	Dark yellowish brown (10 YR 4/4) clay loam; structureless massive; very firm; sticky and plastic; noncalcareous.
13.80-14.00	4C6	Yellowish brown (10 YR 5/4) clay loam; structureless massive; very firm; sticky and plastic; noncalcareous.
14.00+	4C7	Dark grey (10 YR 4/1) loam; structureless massive; very firm; calcareous.

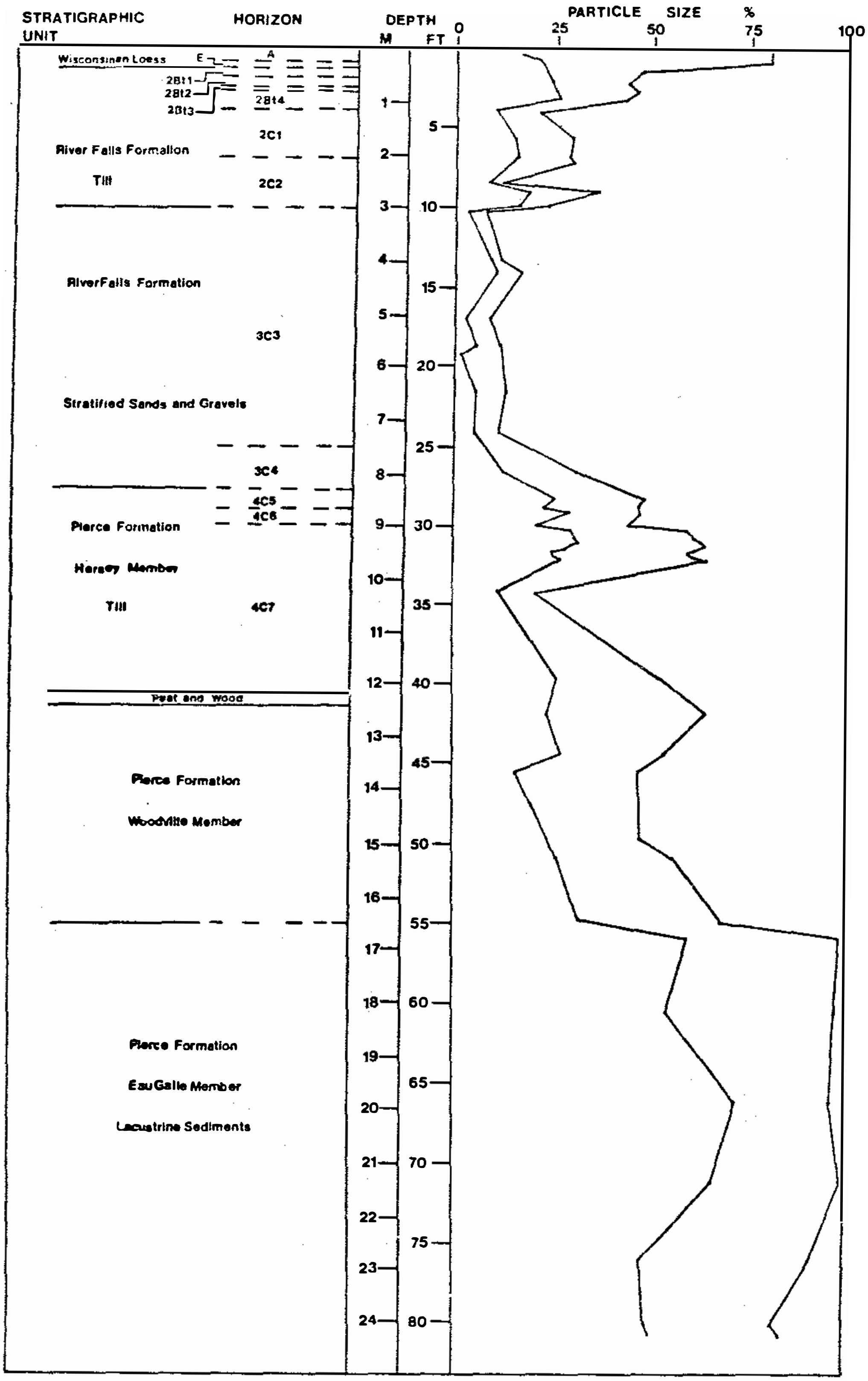


Figure 11.--Stratigraphy and particle-size data for the Woodville railroad cut.

Arguments have already been made at Stop 2 for an Illinoian age for the River Falls Formation. In addition, overwhelming evidence was presented in this report that, in contrast to Black's hypothesis, the River Falls Formation and the Hersey Member of the Pierce Formation were not only deposited by different glaciers but are also of considerably different age. The key lines of evidence in this regard are the differences in provenance, the reversed remanent magnetization of the Hersey Member, the contrasting normal remanent magnetization of the River Falls Formation, and the existence of a paleosol between the two units at many locations in St. Croix County, Wisconsin (although at this locality the paleosol was completely stripped from the Hersey member prior to deposition of the River Falls Formation.)

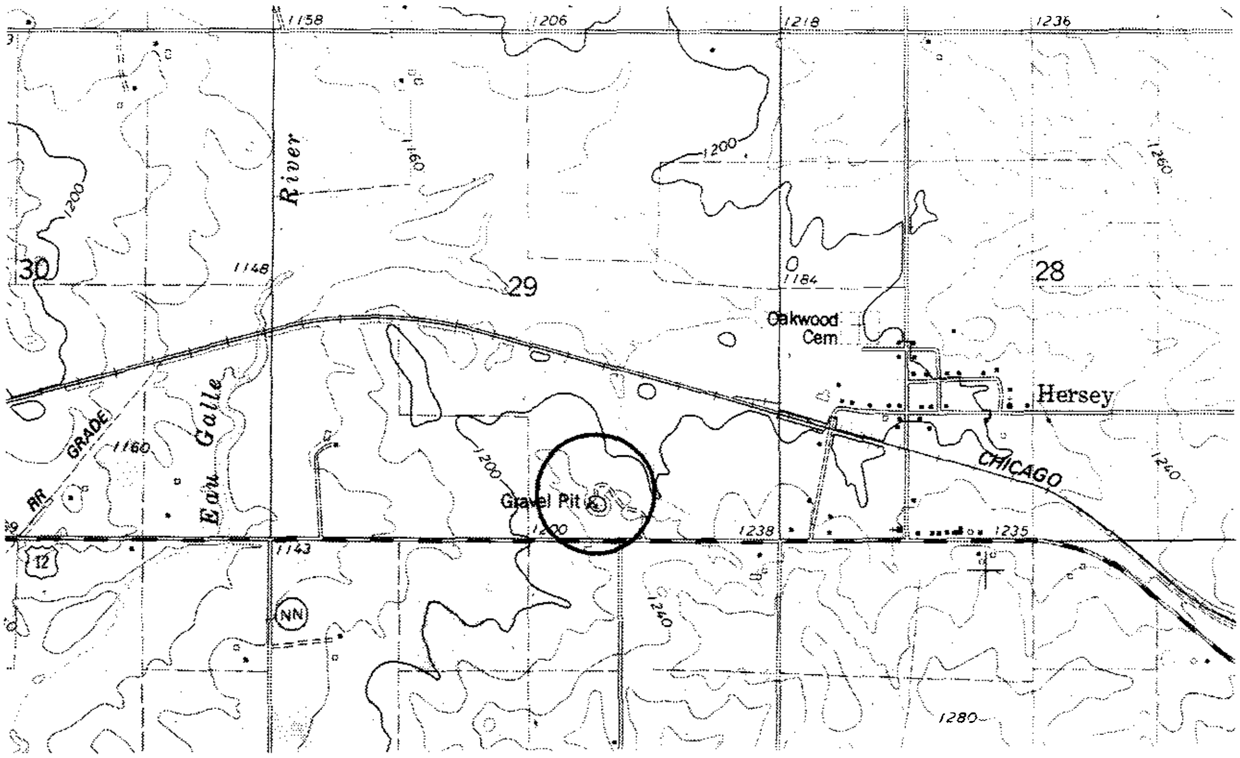
The Hersey Member contains disseminated lenses and nodules of peat and spruce at this location, which have yielded three "greater than" or "dead" and two finite radiocarbon dates. These organic materials are interpreted as having been eroded from the peat and wood bed separating the Woodville and Hersey Members during the overriding and deposition of the Hersey Member. As discussed previously, the present investigations leave no alternative but to conclude that the finite dates came from contaminated samples and that the "greater than" dates are accurate.

Paleomagnetic data indicate a pre-Illinoian age for the Hersey Member and, likewise, for the Woodville and Eau Galle Members because of their positions stratigraphically below the Hersey Member. Based on the textural and mineralogical data obtained to date, the Hersey and Woodville Members appear, tentatively, to correlate regionally with the Hickory Hills Till Member and the Aurora Till Member, respectively, of the Wolf Creek Formation of eastern Iowa. If this correlation is correct, the organic layer and the weathered zone at the top of the Woodville Member may be this region's equivalent of the Dysart Paleosol of Iowa.

The Eau Galle Member may have formed analogously to the Kinnickinnic Member of the Pierce Formation, in proglacial lakes dammed by the advancing ice that deposited the Woodville Member. It appears to have no regional correlative.

STOP 4

Title: Hersey Member of the Pierce Formation, U.S. Highway 12 gravel pit.



Location: SW1/4 SW1/4 SE1/4 sec. 29, T. 29 N., R. 15 W., Wilson 7½-minute topographic quadrangle. West wall of abandoned gravel quarry, 200 m north of U.S. Highway 12 and approximately 1 km southwest of the town of Hersey, Wisconsin.

Author: Robert W. Baker (1984)

This stop is the type section for the Hersey Member of the Pierce Formation. The section description is given in table 8 and the stratigraphy and particle-size data are presented in figure 12. The till at this location ranges in color from yellowish brown (10 YR 5/6) to dark grey (10 YR 4/1) and texturally from clay loam to loam depending upon position in the solum. The C horizon contains 9 percent finely disseminated organic matter, although, occasional large pieces of spruce are not uncommon. The clay mineralogy of the unweathered Hersey Member at this site averages 50 percent montmorillonite, 30 percent kaolinite, 15 percent mica (illite), 5 percent chlorite, and no vermiculite. These data differ significantly from the results of samples collected here and analyzed by the Iowa Geological Survey (35 percent expandables (montmorillonite plus vermiculite), 22 percent illite (mica), and 43 percent kaolinite plus chlorite) (Hallberg, written communication, April, 1983). Interpretation of this apparent discordance in clay mineralogy is not clear, unless it is assumed that the Iowa Geological Survey samples are anomolous; our studies have shown that the clay-mineral content, particularly the expandables, varies somewhat depending on position in the weathering profile.

Table 8.--Section description of type locality of Hersey Member of the Pierce Formation, St. Croix County, Wisconsin. Approximate surface elevation 372 m (1,220 ft).

DEPTH (m)	HORIZON	DESCRIPTION
Wisconsinan loess		
0-0.20	Ap	Very dark greyish brown (10 YR 3/2) silt loam; weak granular structure; very friable; abrupt, smooth boundary.
0.20-0.31	Bt1	Dark yellowish brown (10 YR 4/4) clay loam to silty clay loam; moderate subangular blocky structure; friable; clear, wavy boundary.
Pierce Formation, Hersey Member till with exhumed Yarmouth Paleosol.		
0.31-0.92	2Bt2	Brown to dark brown (7.5 YR 4/4) clay loam; moderate prismatic breaking to strong subangular blocky structure; friable; gradual, wavy boundary.
0.92-1.13	2Bt3	Brown to dark brown (7.5 YR 4/4) clay loam; strong subangular blocky structure; friable; clear, wavy boundary.
1.13-1.38	2Bt4	Yellowish brown (10 YR 5/6) clay loam; strong subangular blocky structure; friable; gradual, wavy boundary.
1.38-1.93	2BCk	Yellowish brown (10 YR 5/6) loam, strong angular blocky structure; firm; strongly calcareous; gradual, wavy boundary.
1.93-2.32	2CBk	Yellowish brown (10 YR 5/4) clay loam; moderate, angular blocky structure; firm; strongly calcareous; gradual, wavy boundary.
2.32-2.80	2C1	Yellowish brown (10 YR 5/4) laom; structureless; firm; strongly calcareous; gradual, wavy boundary.
2.80-3.18	2C2	Yellowish brown (10 YR 5/4) loam; structureless, massive; very firm; strongly calcareous; abrupt, wavy boundary.
3.18+	2C3	Dark grey (10 YR 4/1) loam; structureless, massive; very firm; strongly calcareous.

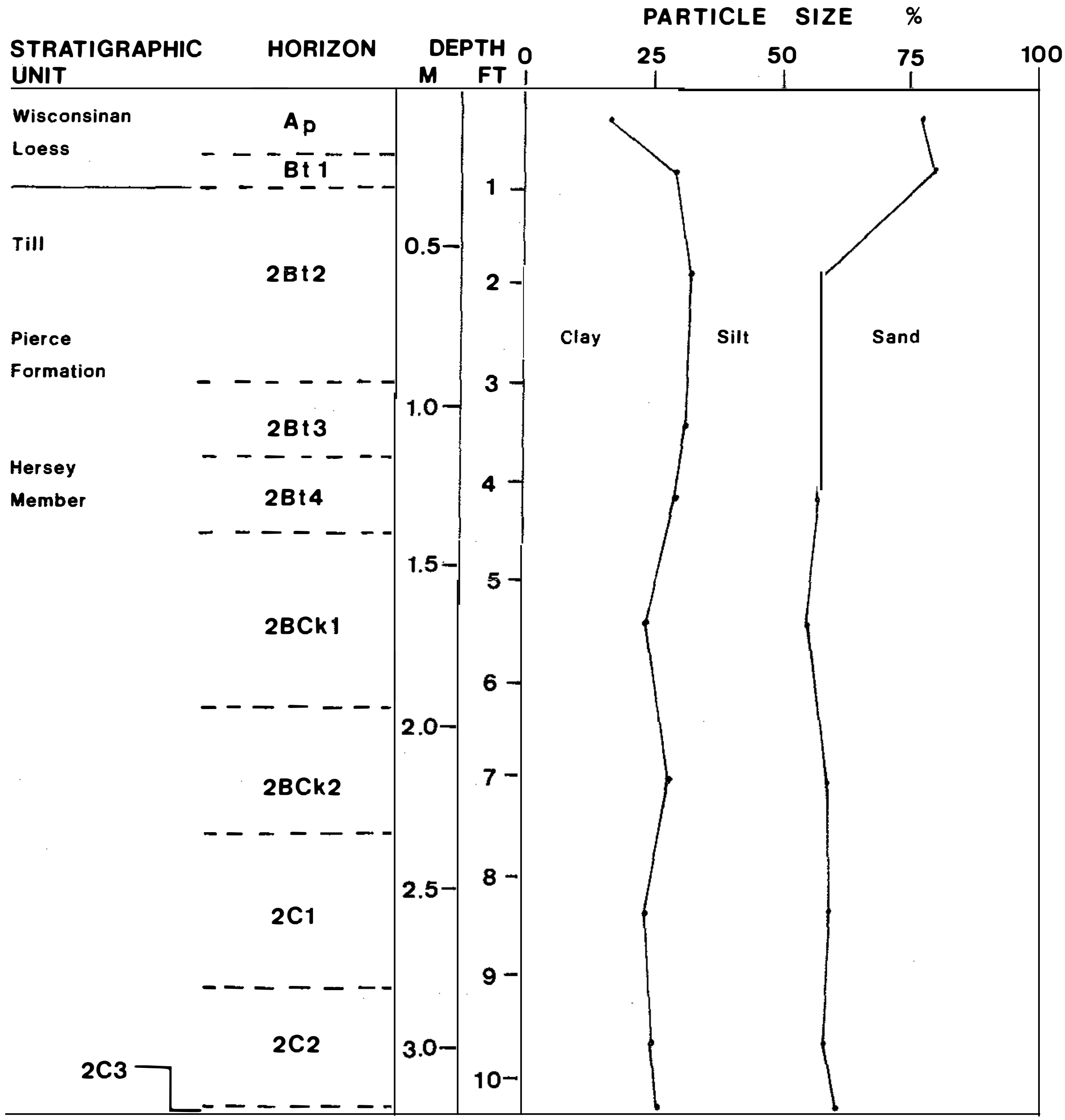


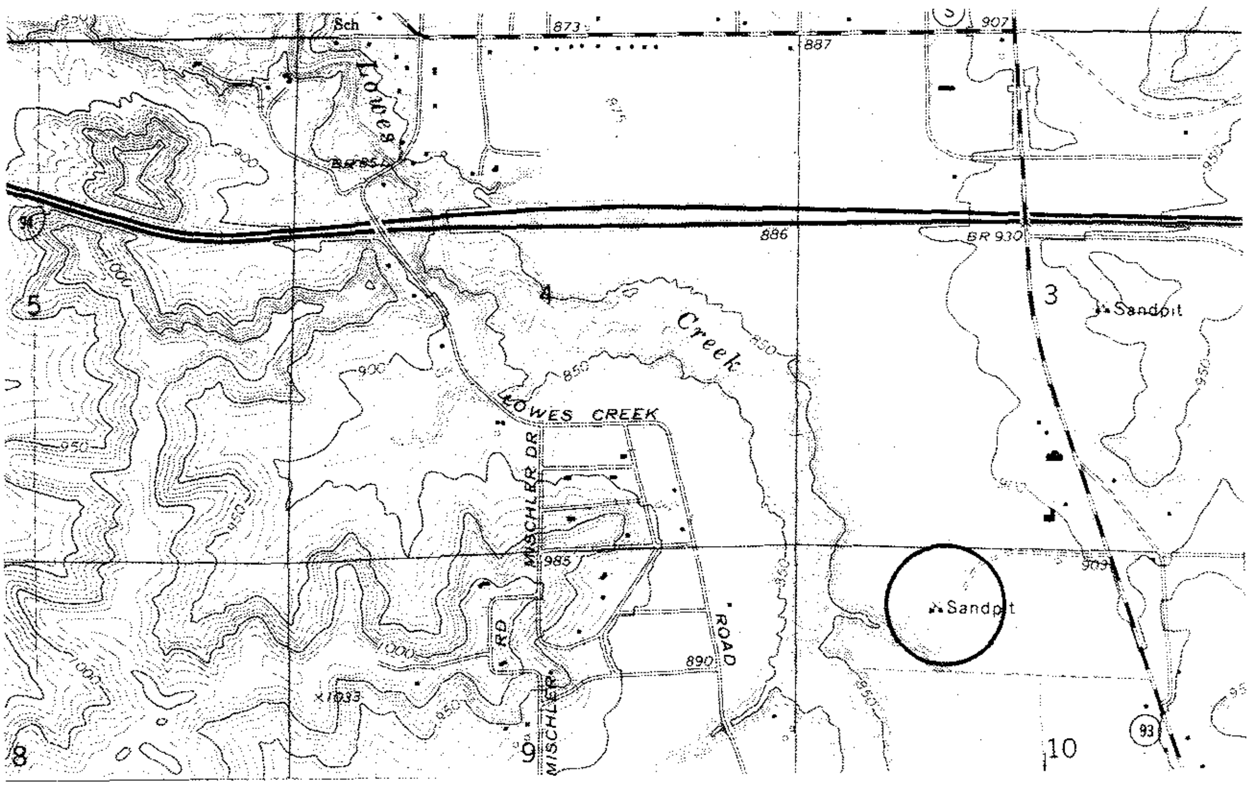
Figure 12.--Stratigraphy and particle-size data for the U.S. Highway 12 gravel quarry in the till of the Hersey Member.

Because of a lag concentrate of Superior Lobe indicators above the Hersey Member in this area and because till of the River Falls Formation outcrops in all compass directions within a radius of 7 km of this location, it is believed that this site was overridden and buried by the River Falls Formation during the Illinoian Age. Through subsequent erosion, the River Falls Formation must have been stripped away. This may indicate that the River Falls drift sheet was initially quite thin, as such "windows" are common occurrances in Pierce and St. Croix Counties, Wisconsin. If the preceding interpretation is correct, then the soil profile at this stop is technically and exhumed paleosol. Although it is possible that this solum was partially truncated during or after exhumation, before deposition of the Wisconsinan loess cap, it still represents one of the most well-developed examples of the Yarmouth Paleosol yet found in the Hersey Member. Please note that the paleosolum thickness at this site is about 2.4 m (7.8 ft) (fig. 12) and that oxidation, complete enough to remove the 9 percent organic matter and give the till a yellowish brown color, has occurred to a depth of 3.2 m (10.5 ft).

A lens of carbonate-cemented sand outcrops within the till of the Hersey Member on the northwest side of the pit. As discussed previously, the Hersey Member has been demonstrated to be pre-Illinoian in age. Consequently, the carbonate cement could have been precipitated any time since the pre-Illinoian. R. S. Lively has radiometrically dated the carbonate cement from this lens, using uranium-series methods, as 31,500 ± 500 B.P. (Lively, 1984). The significance of this age is discussed in Lively (1984).

STOP 5

Title: Kinnickinnic Member of the Pierce Formation, Eau Claire County Clay Pit.



Location: SW1/4 NE1/4 NW1/4 sec. 10, T.26 N., R.19 W., Eau Claire East 7½-minute topographic quadrangle. East wall of Eau Claire County clay pit, 300 m west of Wis. Highway 93.

Author: Robert W. Baker (1984)

A magnificent exposure of the Kinnickinnic Member of the Pierce Formation has been provided courtesy of Eau Claire County, Wisconsin, which has been mining the Kinnickinnic Member for use as a sanitary-land-fill liner. The borrow pit is over 10 m deep and has an area of over 10,000 m^2. The Kinnickinnic Member is a glaciolacustrine sediment that was deposited in an intricate network of ice-dammed lakes (fig. 2) and is 6.1 m (20 ft) thick at this location. Most of this unit consists of rhythmically bedded silt and clay. Particale-size analyses of the silt-clay couplets reveal that the silt layers average (19 samples) 4 percent sand, 78 percent silt, and 18 percent clay and that the clay layers average (19 samples) 0 percent sand, 20 per cent silt, and 80 percent clay. It is suggested that these textural data indicate that the rhythmically bedded silt and clay of the Kinnickinnic Member quality as true varve couplets.

Occasional thin (0.1 m or less), fine-sand layers occur within the varve-couplet sequence. These suggest that the water level in the proglacial lake system must have fluctuated periodically. In fact, a cut and fill structure with a 1 cm basal peat mat exposed at this locality during the summer of 1983, suggests that at least portions of the lake network may have been periodically exposed to subaereal conditions.

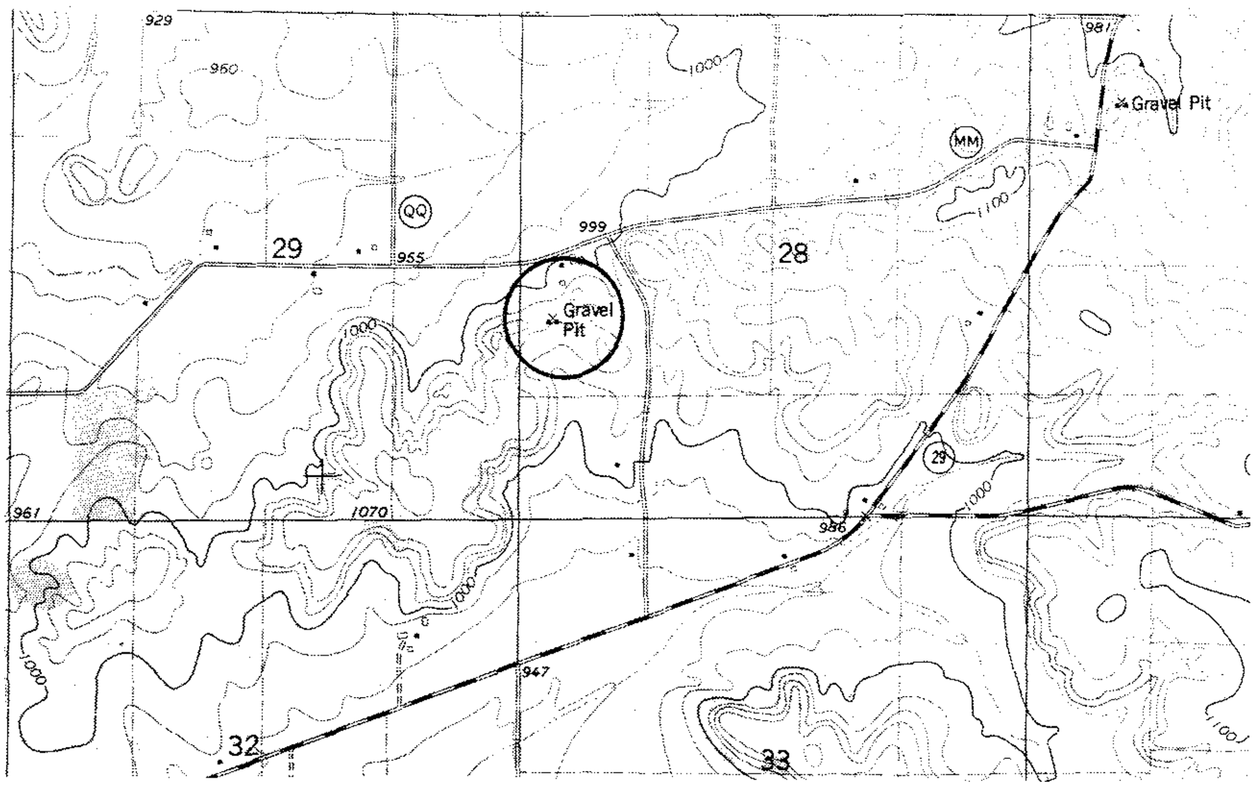
Preliminary palynological analysis of samples of the Kinnickinnic Member collected from a site approximately 1.5 km south of River Falls, Wisconsin, was conducted by L. J. Maher. The pollen, although rather sparse, was well preserved, with Pinus (yellow pine), Picea (spruce) Artemisia (sage), Cyperaceae (sedge), and Gramineae (grass) being major types (L. J. Maher, verbal communication, February, 1984). This pollen assemblage suggests that conditions similar to the modern boreal forest, except for the absence of white pine, may have existed near the pre-Illinoian glacial border here in Wisconsin.

A striking feature of the Kinnickinnic Member is the unique color differences common to most couplets; the clay layers are typically dark brown (10 YR 4/3) to dark yellowish brown (10 YR 4/6) and the silt layers are generally dark grey (10 YR 5/1). The color differences appear to be primarily caused by the fact that the red-clay layers contain almost three times as much free-iron oxides (3.8 percent) as do the greysilt layers (1.3 percent). Clay mineralogical differences do not appear to have played a significant role in the color differences as the red clay layers at this site average 45 percent montmorillonite, 24 percent kaolinite, 21 percent mica, and 10 percent vermiculite, while the grey silt layers average 50 percent montmorillonite, 25 percent kaolinite, 20 percent mica, and 5 percent vermiculite.

Several hypotheses are offered to explain the color banding within varve couplets. One possibility is roughly parallel to Flock's (1983) explanation for red and grey glaciofluvial sediments found in the late-Wisconsinan Savanna Terrace along the Mississippi River, that two different sediment sources were involved. Specifically, it is possible that because the proglacial lakes were narrow and multidigited, they may have received sediment by slopewash from weathered limestone uplands and/or red-till-mantled uplands, in addition to grey carbonate-rich glacial-rock flour. This could explain the iron oxide differences as well as the color zonation and clay mineralogy, provided that the two types of sediment settled differentially. Differential settling is not totally implausable because the rock flour is coarser textured and, being carbonate rich, might tend to flocculate to a greater degree than the slope-wash clays and, hence, might settle more rapidly. A second hypothesis involves postdepositional alteration of initially grey silt and clay couplets. Specifically, it is possible that the Kinnickinnic Member was deeply oxidized during the half to three quarters of a million years that have elapsed since it was deposited. A rise in the water table, perhaps during the Holocene, could result in preferential stripping of the free iron from the more permeable silt layers by lateral groundwater movement and give rise to the color and free iron oxide differences. The later hypothesis is supported by the fact that a perched-water table exists above the Kinnickinnic Member in areas where the color differences are most pronounced and by the fact that, in all exposures greater than 5 m (16.4 ft) high discovered to date, the couplets become uniformly grey below about 5.5 m (18 ft). Deep core sampling scheduled for the summer of 1984 should further test this hypothesis.

STOP 6

Title: The Trimbelle Moraine; a Pre-Illinoian Recessional Moraine, J. C. Rohl's Gravel Quarry.



Location: NW1/4 NW1/4 SW1/4 sec. 28, T.27 N., R.19 W., River Falls West 7.5-minute topographic quadrangle. South wall of abandoned gravel quarry on the J. C. Rohl property, County Hwy. MM, Pierce County, Wisconsin.

Author: Robert W. Baker (1984)

This stop will focus on the morphology and stratigraphy of the Trimbelle moraine, a dissected Pre-Illinoian recessional moraine, as well as the cemented gravels common to the Hersey Member of the Pierce Formation.

The retreat of the pre-Illinoian ice margin was apparently quite uniform until it reached the present Wisconsin state boundary. At this position, however, steady-state conditions must have existed sufficiently long for a rather extensive recessional moraine to be constructed on the northeast side of the present Mississippi River and for the proglacial-lake complex, in which the Kinnickinnic Member was deposited, to reach its maximum extent (fig. 2B).

The Trimbelle moraine, named after the town of Trimbelle, Wisconsin, approximately 10 km (6 mi) from this stop, is composed chiefly of ice-contact stratified drift and irregular lenses of till of the Hersey Member. It is covered with a cap of late-Wisconsinan loess of variable thickness. The moraine is also intermittantly cored by bedrock of, primarily, the Platteville Formation, which may account, in a large part, for its remarkable preservation.

The till lenses at this location are all less than 2 m thick and are oxided (10 YR 5/6) and leached. Their clay mineralogy averages 50 percent montmorillonite, 13 percent vermiculite, 27 percent kaolinite, 13 percent mica (illite) and 2 percent quartz. Vermiculite is absent in outcrops where unweathered Hersey Member is exposed. Till fabrics from lenses separated horizontally by about 25 m at this location show contrasting ice-flow directions (fig. 13) and support a morainal origin.

A section description from the west end of the exposure is given in table 9 and the stratigraphy and particle-size distribution are given in figure 14. Notice that there are three different parent materials at this location, a well-developed pebble line/erosion surface at a depth of 0.70 m (2.3 ft.), and a solum thickness of 2.62 m (8.6 ft.) (table 9).

Much of ice-contact sand and gravel at this locality is lithified with carbonate cement, as is most of the sand and gravel of the Hersey Member in western Wisconsin. Samples of the carbonate cement from this stop were radiometrically dated as 350,000 B.P. using uranium-series methods by R.S. Lively of the Minnesota Geological Survey (Lively, 1984). This pre-Illinoian age agrees well with reversed remanent magnetization of the till of the Hersey Member, and with the infinite or "greater than" dates from organic matter from within the till of the Hersey Member discussed earlier. The origin of the carbonate cement is discussed in Lively (1984).

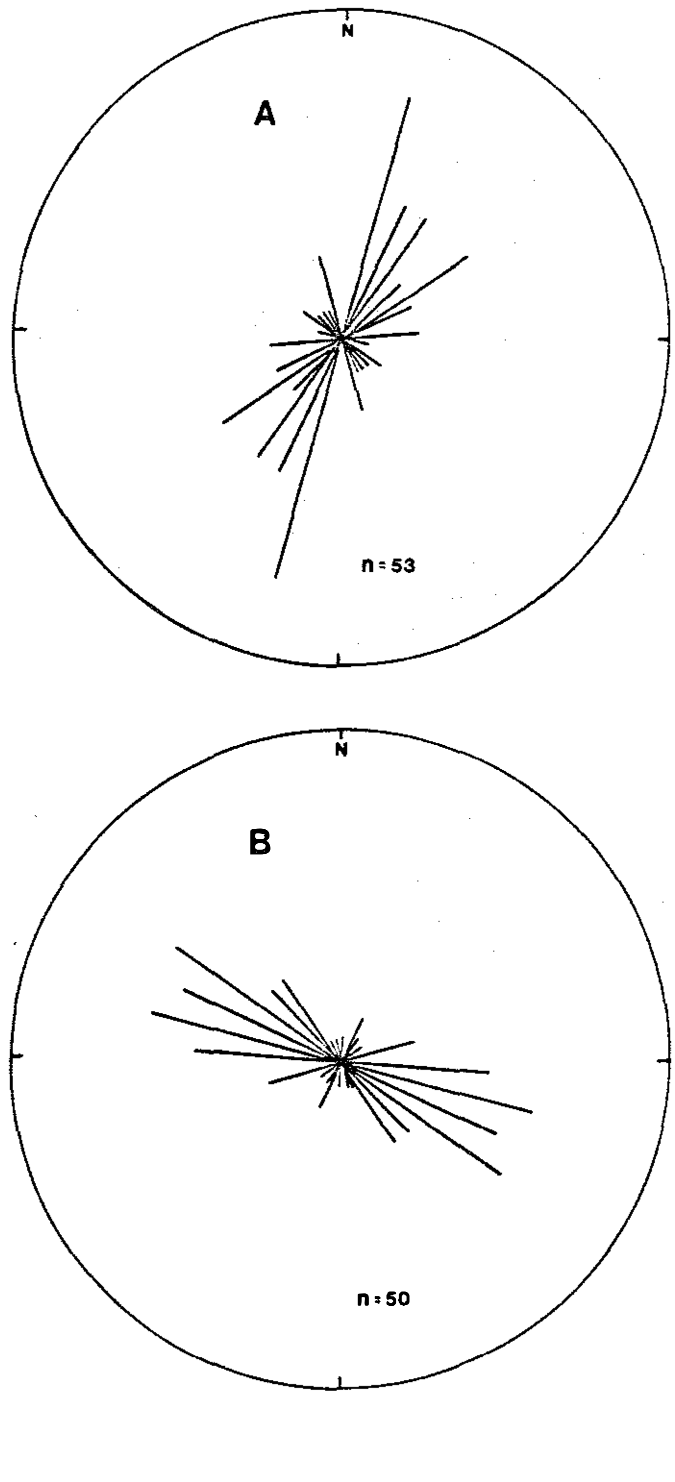


Figure 13.--Till-fabric diagrams for the Trimbelle moraine, County Highway MM; n is the number of clasts measured.

Table 9.--Section description of pre-Illinoian Trimbelle moraine, Pierce County, Wisconsin. Approximate surface elevation 317 m (1,040 ft.)

DEPTH (m)	HORIZON	DESCRIPTION
Artificially mixed sediment		
0.70-0		Disturbed sediment; dumped material.
Wisconsinan loess		
0-0.12	A	Very dark greyish brown (10 YR 3/2) silt loam; weak, granular structure; friable; clear, smooth boundary.
0.12-0.34	E	Brown-dark brown (10 YR 4/3) loam; weak, subangular blocky structure; friable; many krotovinas filled with A horizon material; gradual, wavy boundary.
0.34-0.46	EB	Dark yellowish brown (10 YR 4/4) silt loam; weak, subangular blocky structure; friable, clear wavy boundary.
0.46-0.70	Bt1	Dark yellowish brown (10 YR 4/4) silt loam; moderate, subangular blocky structure; many silt coatings on ped faces; firm; clear, wavy boundary; distinct pebble line at lower boundary.
Pierce Formation, sand and gravel (undifferentiated)		
0.70-0.98	2Bt2	Strong brown (7.5 YR 4/6) gravelly sandy clay loam; weak, subangular blocky structure; friable; clear, wavy boundary.
0.98-1.19	2Bt3	Yellowish brown (10 YR 5/6) to dark yellowish brown (10 YR 4/4) gravelly sandy clay loam to clay loam; subangular blocky structure; friable; clear, wavy boundary.
1.19-1.59	2Bt4	Yellowish brown (10 YR 5/6) very gravelly sandy clay loam; weak, subangular blocky structure; friable; clear, wavy boundary.
1.59-1.86	2Bt5	Dark yellowish brown (10 YR 4/6) very gravelly sandy clay loam; weak, subangular blocky structure; firm; gradual, wavy boundary.
1.86-2.13	2Bt6	Dark yellowish brown (10 YR 4/6) very gravelly sandy loam; weak, subangular blocky structure; friable; gradual, wavy boundary.
2.13-2.41	2CB1	Dark yellowish brown (10 YR 4/6) extremely gravelly loamy sand; single-grain structure with clay bridging between coarse fragments; gradual, wavy boundary.
2.41-2.62	2CB1	Dark brown (10 YR 3/3) very gravelly loamy sand; single-grain structure with clay bridging between particles; manganese straining common; abrupt, smooth boundary.
Pierce Formation, Hersey Member till.		
2.62+	3C	Yellowish brown (10 YR 5/8) sandy clay loam; massive; firm.

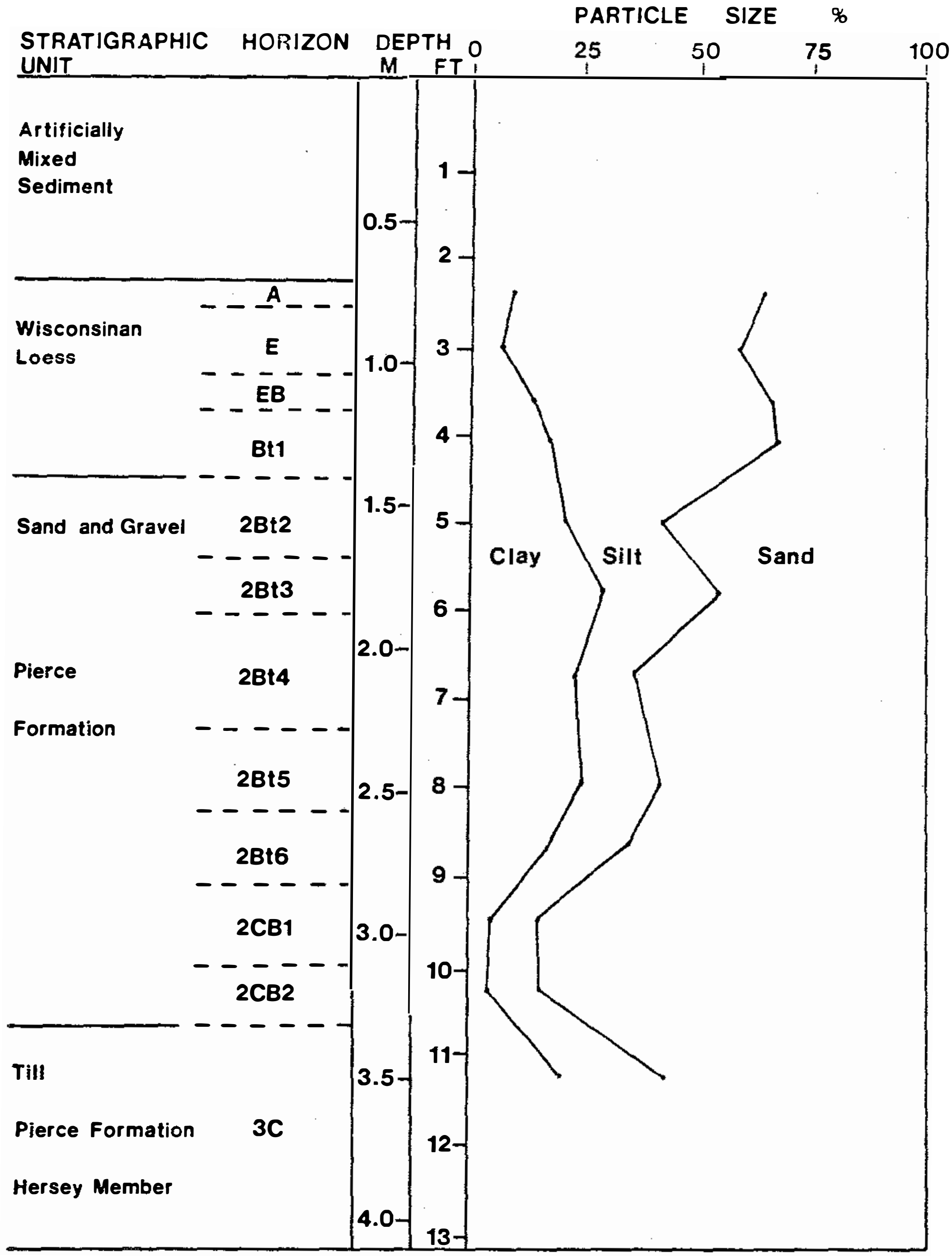
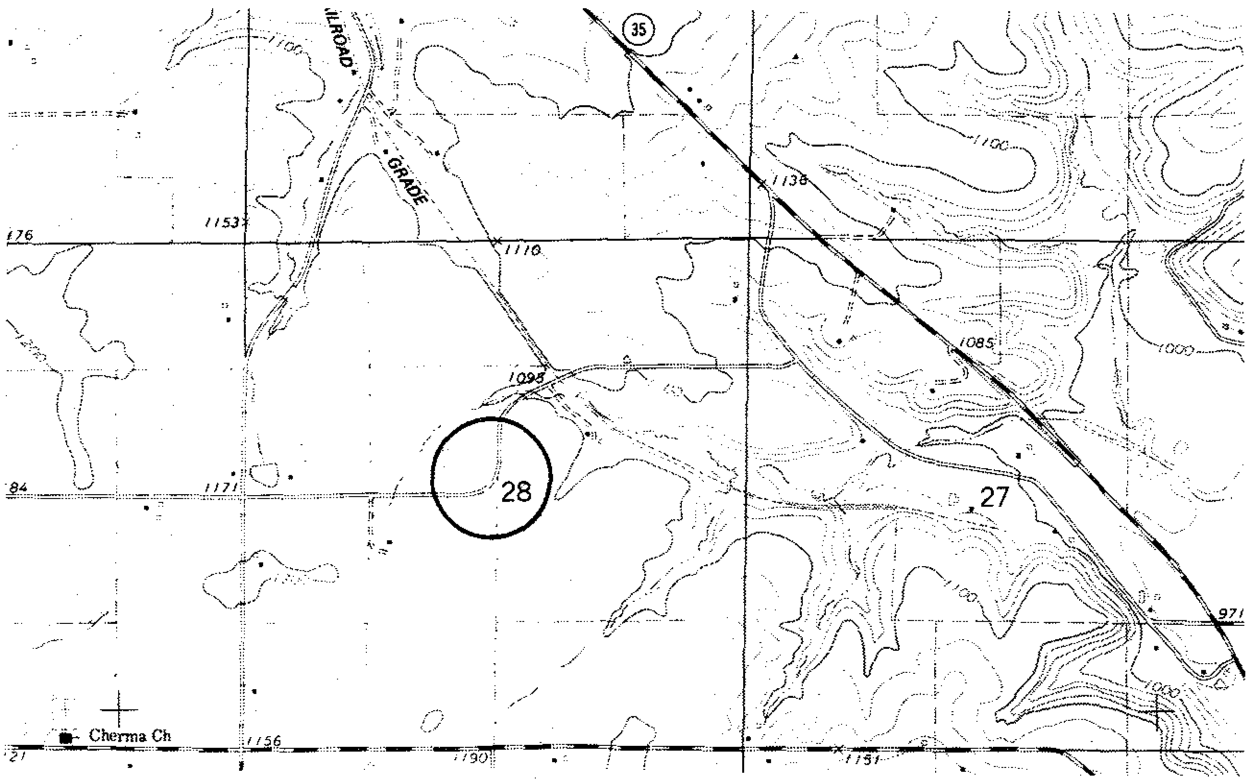


Figure 14.--Stratigraphy and particle-size data for the Trimbelle moraine, County Highway MM.

STOP 7

Title: River Falls Formation with a relect Sanagmon Paleosolum; Pleasant View Road Exposure.



Location: SW1/4 SW1/4 NE1/4 sec. 28, T.27 N., R.18 W., River Falls East 7½-minute topographic quadrangle. West wall of abandoned gravel quarry on Pleasant View Road.

Author: Robert W. Baker (1984)

This stop is the reference section for the River Falls Formation, which, because of its upland-interfluve landscape position, contains one of the better preserved paleosols in this unit. The till of the River Falls Formation at this site rests unconformably on stratified sands and gravels of the Hersey Member of the Pierce Formation. The section description is given in table 9 and the particle-size and engineering-property data are presented in figure 15. From figure 15 it can be seen that bulk density, shear strength, and shear-strength parameter Ø (internal-friction angle) generally increase in the argillic horizon and

Table 10.--Section description River Falls Formation, Pierce County, Wisconsin. Surface elevation approximately 357 m (1,170 ft).

DEPTH (m)	HORIZON	DESCRIPTION
Wisconsinan Loess		
0-0.23	Ap	Brown to dark brown (10 YR 4/3) silt loam; weak, granular structure; very friable; wavy boundary.
0.23-0.35	BA	Dark yellowish brown (10 YR 4/4) loam; weak, subangular blocky structure; very friable; abrupt, wavy boundary.
River Falls Formation till with Sangamon Paleosol.		
0.35-0.40	2Bt1	Brown to dark brown (7.5 YR 4/4) sandy clay loam; moderate, subangular blocky structure; friable; clear, wavy boundary.
0.40-0.94	2Bt2	Reddish brown (5 YR 4/4) sandy clay loam; moderate, subangular blocky structure; friable; common patches of sand; diffuse wavy boundary.
0.94-1.35	2Bt3	Reddish brown (5 YR 4/4) sandy clay loam; moderate, subangular blocky structure; friable; clear, wavy boundary.
1.35-2.20	2BC	Yellowish red (5 YR 4/6) sandy loam; moderate, subangular blocky structure; friable; clear, wavy boundary.
2.20-2.54	2C1	Reddish brown (5 YR 4/4) sandy clay loam; massive, structureless; very friable.
Pierce Formation stratified sand and gravel (undifferentiated).		
2.54+		Olive yellow (2.5 YR 6/8), with bands of dark brown (7.5 YR 4/4) loamy sand; structureless, massive; friable.

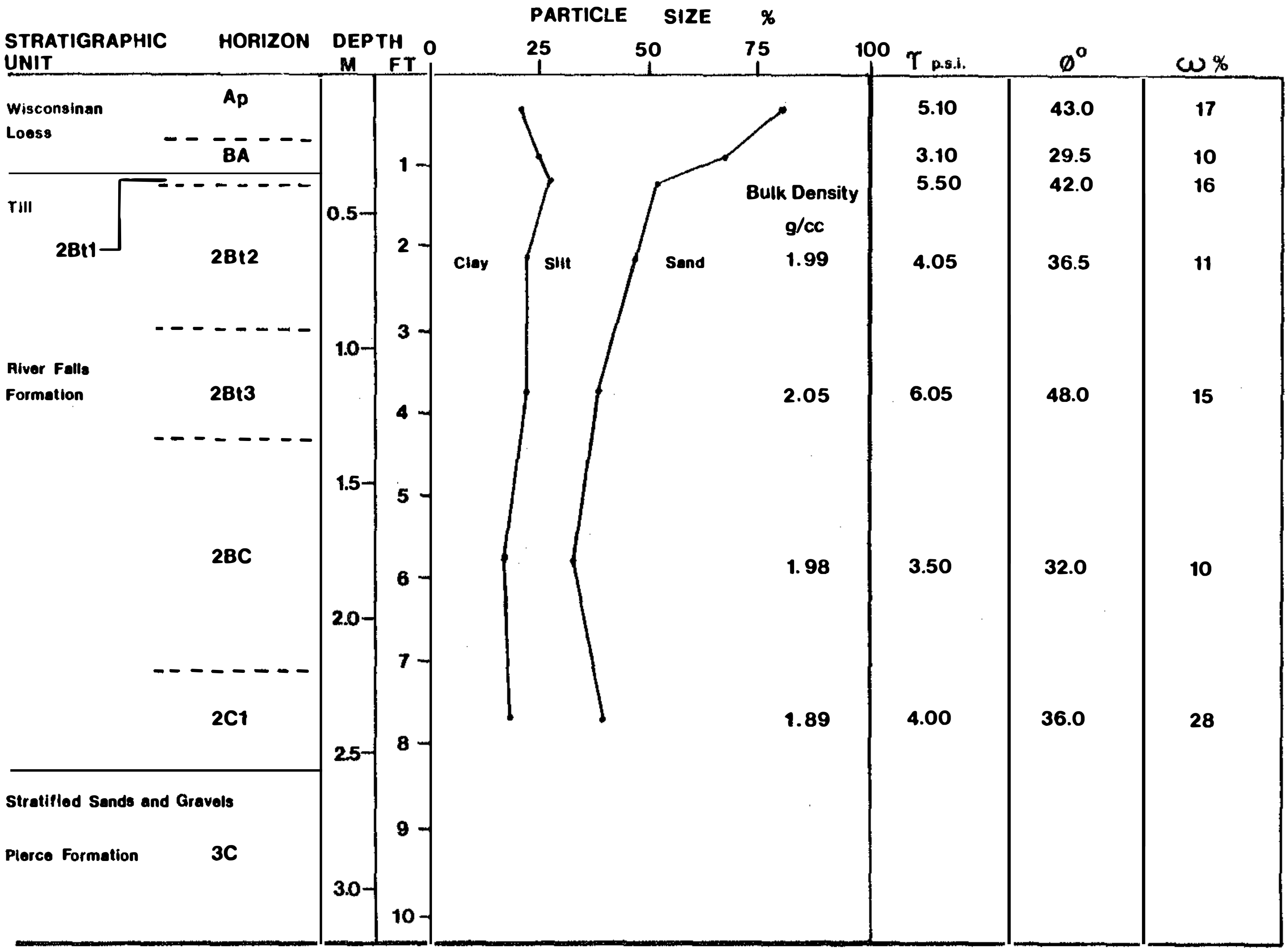


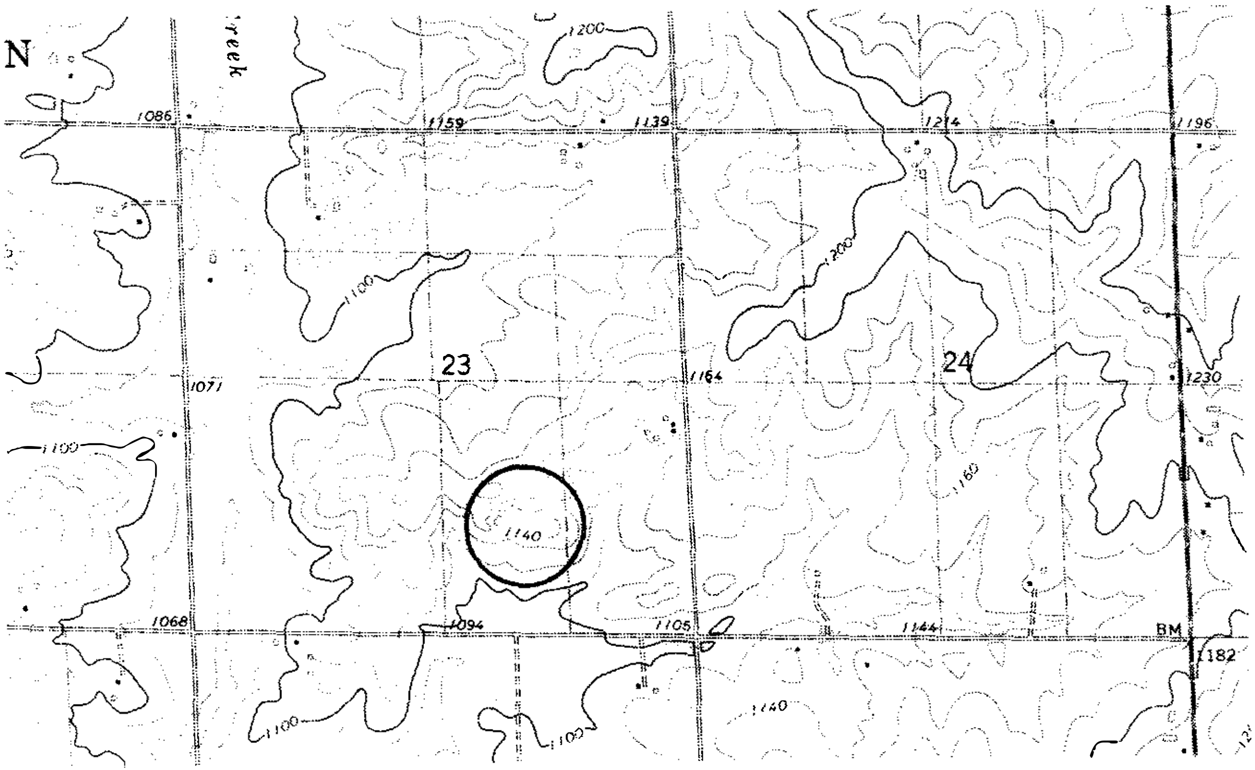
Figure 15.--Stratigraphy, particle-size, and engineering data for the River Falls Formation. τ is the shear strength in pounds per square inch (p.s.i.), ϕ is the internal-friction angle, and ω is the moisture content.

decrease in the C horizon. These trends are probably, to a great degree, related to the presence of translocated clays in the B horizon, causing an increase in unit cohesiveness.

If the estimated age of the River Falls Formation, discussed earlier on this trip, is correct, the solum developed in the till at this locality is a Sangamon Paleosol. The paleosolum thickness of 2.2 m (7.2 ft.) (fig. 15) approaches the maximum value of 2.8 m (9.2 ft) found in the River Falls Formation.

STOP 8

Title: Hersey Member of the Pierce Formation, Gillman Township Gravel Quarry.



Location: NE/4 SW1/4 SE1/4 sec. 23, T.27N., R.16W., El Paso 7½-minute topographic quadrangle. North wall of gravel quarry, southwest of Spring Valley, Wisconsin.

Author: Robert W. Baker (1984)

The section at this stop exposes a complex assortment of loess, colluvium (slope-wash sediment), sand and gravel, till, and erosional surfaces/pebble lines (fig. 16). A section was described from the north wall of the pit (table 11) and another from the south wall (table 12). The stratigraphy and particle-size data for these sections are given in figures 17 and 18, respectively.

The north-wall exposure is capped by a thin mantle of late-Wisconsinan loess and till-derived loamy colluvium from sands of the River Falls Formation, and a second pebble line separates the River Falls Formation from a wedge of till of the Hersey Member of the Pierce Formation. The Hersey Member contains a truncated Yarmouth Paleosolum (figs. 16 and 17).

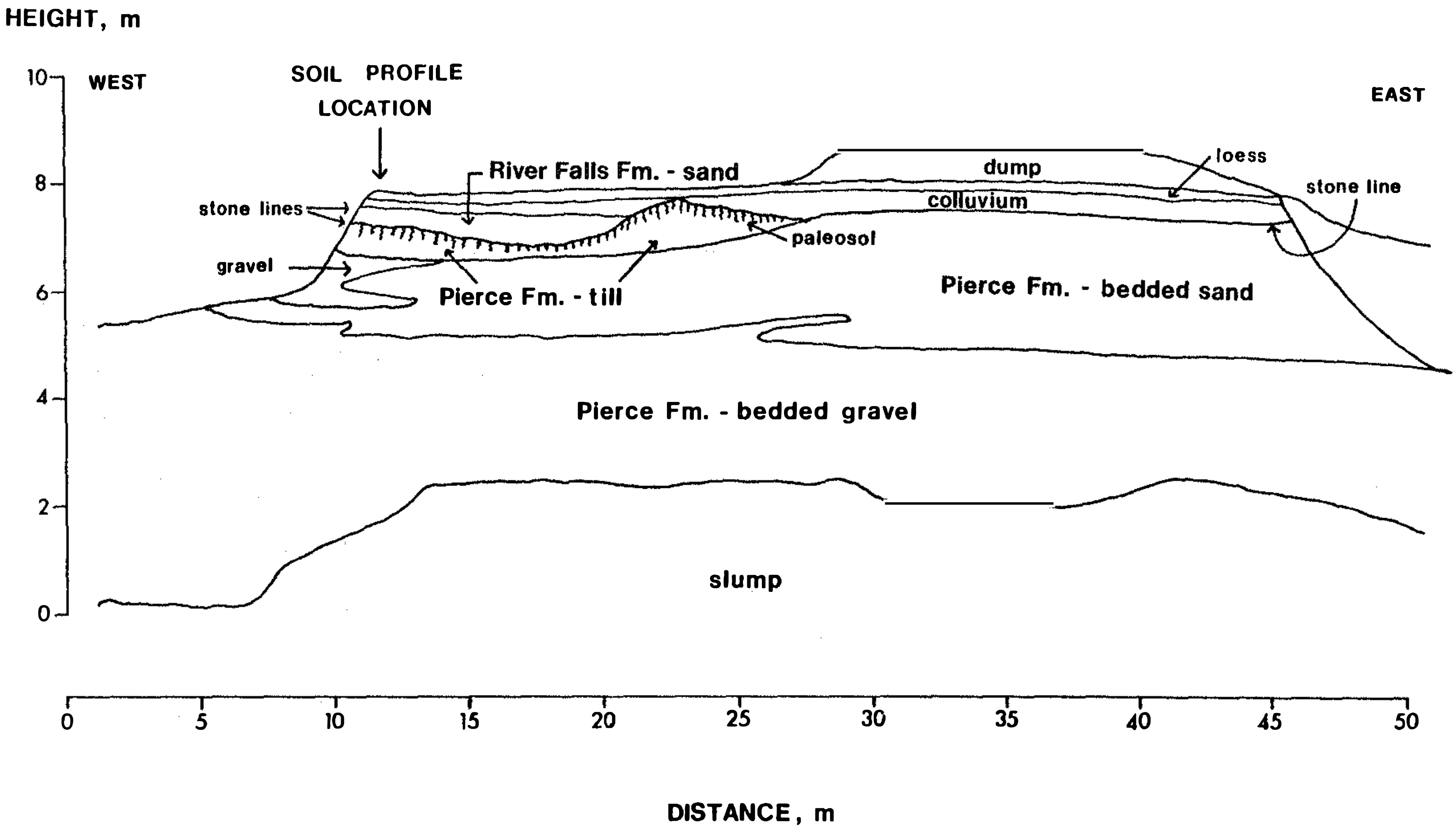


Figure 16.--Cross section of the north wall of the Gillman Township gravel quarry.

Table 11.--Section description north wall of Gilmman township gravel quarry. Surface elevation approximately 348 m (1,140 ft).

DEPTH (m)	HORIZON	DESCRIPTION
0-0.01	Oi	Partially decomposed leaves, twigs, and grasses.
Wisconsinan loess		
0.01-0.07	A1	Very dark greyish brown (10 YR 3/2) silt loam; moderate, granular structure; friable, abrupt boundary.
0.07-0.11	A2	Very dark greyish brown (10 YR 3/2) silt loam; moderate, granular structure; friable; abrupt boundary.
0.11-0.33	E	Dark yellowish brown (10 YR 4/4) silt loam; moderate, platy structure; friable; abrupt boundary.
Colluvium		
0.33-0.41	2Bw	Dark yellowish brown (10 YR 4/4) loam with sandy inclusions; weak, subangular blocky structure; friable; clear boundary.
0.41-0.53	2Bt1	Brown to dark brown (10 YR 4/3) silt loam; moderate, subangular blocky structure; friable; clear boundary.
0.53-0.70	2Bt2	Dark yellowish brown (10 YR 4/4) loam; moderate; subangular blocky structure; firm; clear boundary.
0.70-0.80	2C1	Dark yellowish brown (10 YR 4/4) sandy loam; massive, structureless; abrupt lower boundary with pebble line.
River Falls Formation sand (undifferentiated)		
0.80-1.98	3C2	Dark yellowish brown (10 YR 4/6) sand; single grain, structureless; loose; clear wavy lower boundary with pebble line.
Pierce Formation, Hersey Member, till, with truncated Yarmouth Paleosol.		
1.98-2.39	4Btb	Yellowish brown (10 YR 5/6) sandy loam; moderate, subangular blocky structure; many distinct mottles; very friable; clear wavy boundary.
2.39-2.72	4Cb1	Yellowish brown (10 YR 5/6) sandy loam; massive, structureless; friable; clear boundary.
Pierce Formation sand and gravel (undifferentiated)		
2.72+	5Cb2	Yellowish brown (10 YR 5/4) stratified sand and gravel; single grain, structureless; loose.

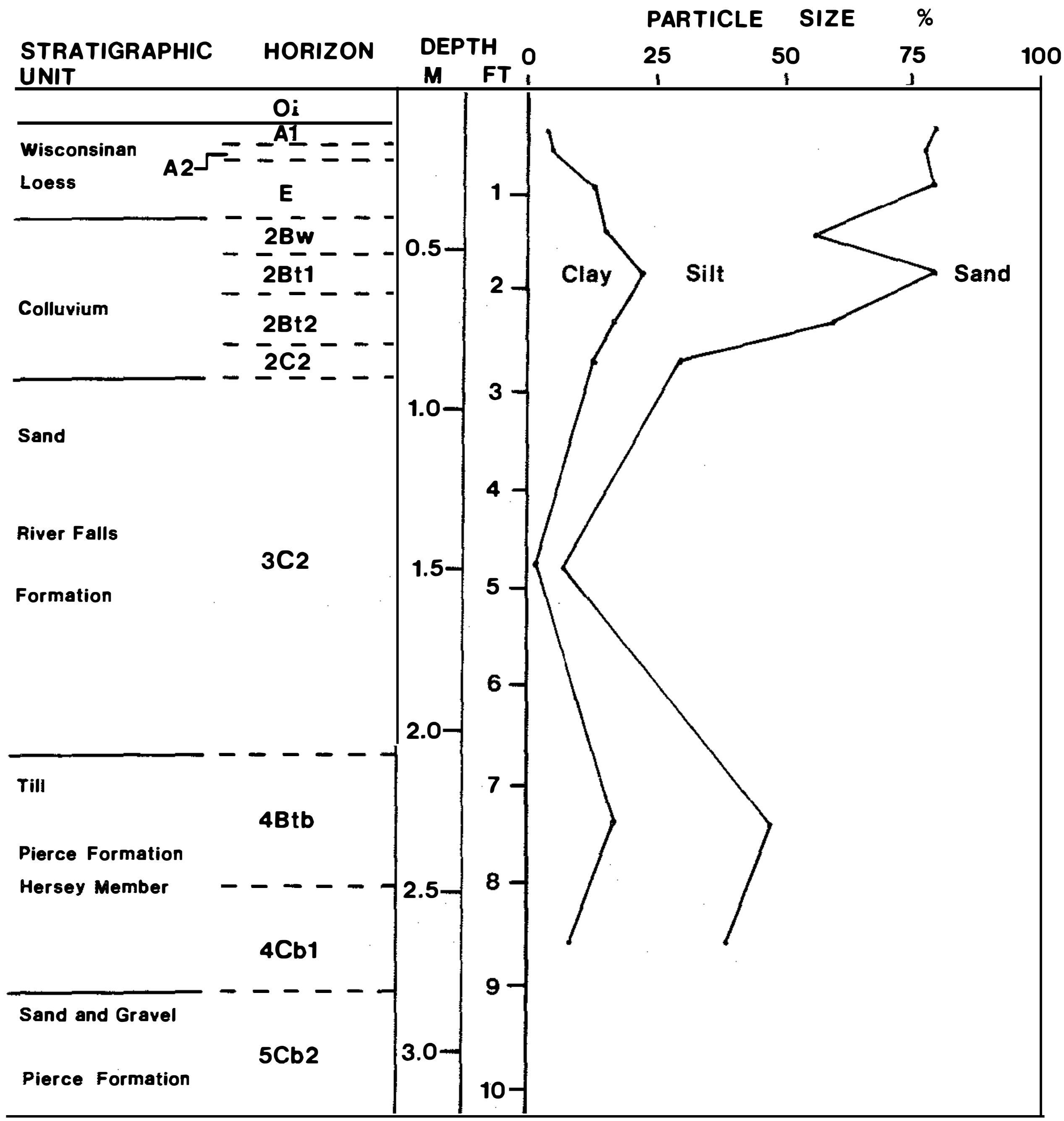


Figure 17.--Stratigraphy and particle-size data for the north wall of the Gillman Township quarry.

Table 12.--Section description Hersey Member of Pierce Formation, south wall of Gillman Township Gravel Quarry. Surface elevation approximately 347 m (1,138 ft).

DEPTH (m)	HORIZON	DESCRIPTION
Wisconsinan loess		
0-0.12	A	Very dark greyish brown (10 YR 3/2) silt loam; weak, granular structure; very friable; abrupt boundary.
0.12-0.22	E	Dark greyish brown (10 YR 4/2) silt loam; weak, platy structure; very friable; clear boundary.
0.22-0.41	Bt1	Dark yellowish brown (10 YR 4/4) silt loam; moderate, subangular blocky structure; friable; clear boundary.
Pierce Formation, Hersey Member till.		
0.41-0.59	2Bt2	Dark yellowish brown (10 YR 4/4) loam; moderate, subangular blocky structure; friable; clear boundary.
0.59-1.39	2C1	Dark yellowish brown (10 YR 4/4) sandy loam; massive, structureless; firm; abrupt boundary, 0.02 m sand layer at lower boundary.
1.39-1.89	2C2	Dark yellowish brown (10 YR 4/6) sandy loam; weak, subangular blocky structure; firm; clear boundary; poorly defined 0.03 m sand layer along lower boundary.
1.89-2.39	2C3	Yellowish brown (10 YR 5/6) sandy loam; weak, subangular blocky structure; firm; abrupt boundary
Pierce Formation sand and gravel (undifferentiated)		
2.39+	3C4	Yellowish brown (10 YR 5/8); structureless; single grained; loose.

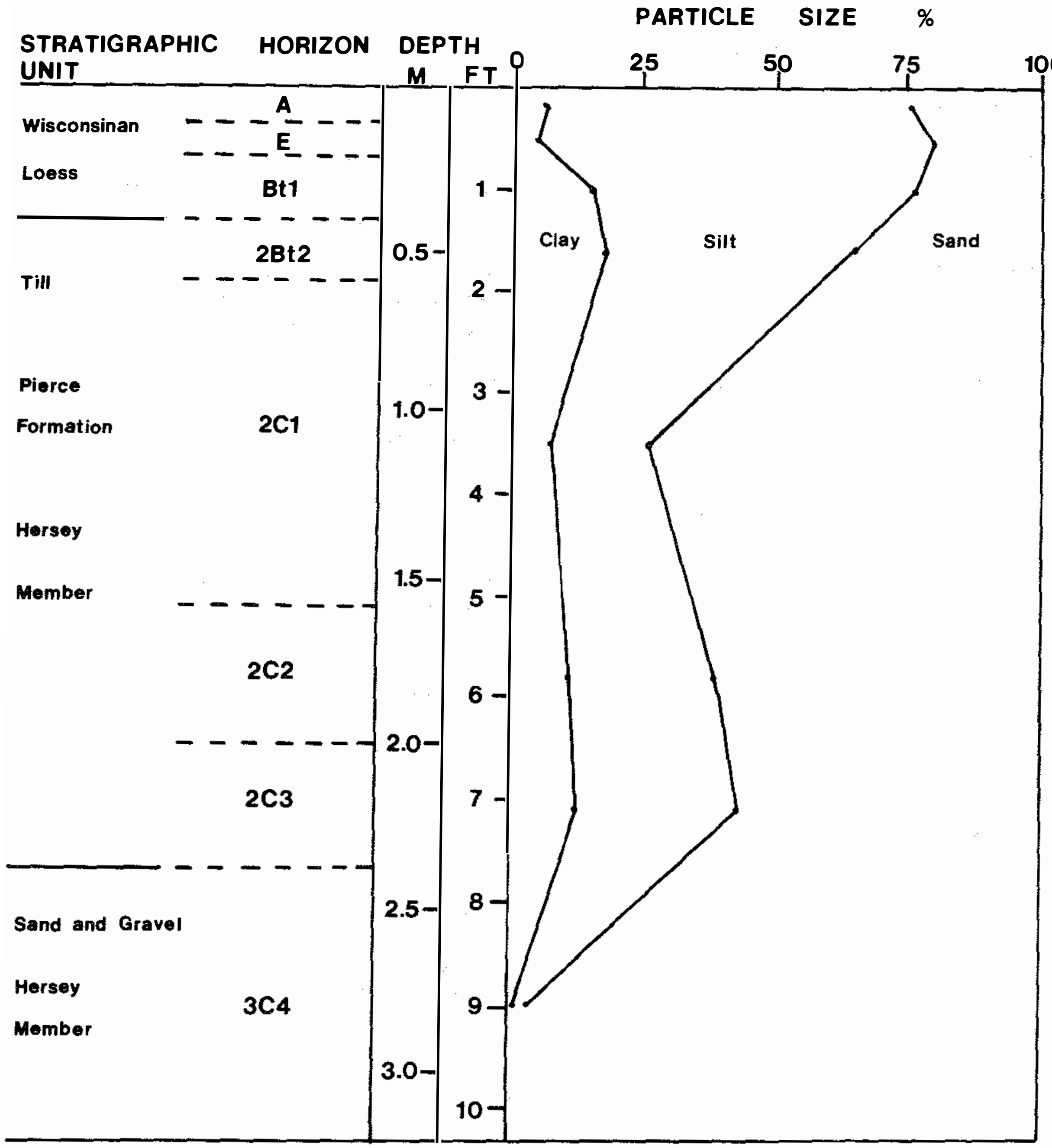


Figure 18.--Stratigraphy and particle-size data for the south wall of the Gillman Township quarry.

The significance of the two pebble lines at this locality is not totally clear. The upper stone line appears to equivalent to the late Sangamon erosion surface seen at Stop 2. However, the lower stoneline and the truncated paleosolum in the Hersey Member are difficult to correlate regionally. One possibility is that the erosional surface (pebble line) and truncation of the Yarmouth Paleosol occurred during the Illinoian Age, during the advance of the Illinoian ice sheet into this region. Further studies, particularly deep core drilling, may verify if this erosional surface is of wide regional extent and perhaps shed more light on its origin.

The south-wall exposure is capped by about 0.4 m (1.3 ft) Wisconsinan loess, underlain by approximately 2.0 m (6.5 ft) of till of the Hersey Member of the Pierce Formation, and an unknown thickness of sand and gravel of the Hersey Member. The C2 and C3 horizons have moderately developed structure and moderate increases in clay content as compared to the C1 horizon (fig. 18). However, it is believed that these are localized phenomena related to the presence of several thin (1 to 2 cm) sand lenses in these horizons. It is possible that the clays were produced by weathering of the high-permeability sands and have been locally translocated downward immediately below the lenses.

Carbonate cemented sand and gravel, common at this locality, was dated by uranium-series methods by R. S. Lively of the Minnesota Geological Survey. The cement at this locality dated as 245,000 ± 40,000 B.P. (Lively, 1984) which is younger than the date obtained on the cemented Hersey Member at Stop 6.

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URANIUM-SERIES DATING OF CALCITE CEMENTED SANDS AND GRAVELS IN MINNESOTA AND WISCONSIN

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INTRODUCTION

Throughout the drift-covered regions of western Wisconsin and eastern and central Minnesota, there occur glacially derived outwash sands and gravels that contain subareally deposited calcium carbonate cement. These sediments may be overlain by glacial tills or may be correlative with recognized till sequences. Within the sand and gravel deposits, the calcite cement either occupies interstitial voids or was deposited as rinds developed around the below pebbles. The thickness of the deposits range from centimeter-thin layers to several meters of uniformly cemented sediment. The areal extent of the deposits is variable and depends upon the location and local drainage.

Interest in these deposits has been very limited. They are too small and isolated to show up on most maps and there has been no particular reason to study their occurrence. Recently, however, in an effort to establish a late Pleistocene uranium-series speleothem chronology in the Upper Midwest (Lively, 1983), the cemented sediments have gained importance as a possible link between the subsurface speleothem chronologic data and surface glacial events.

This paper presents age data obtained from calcite cemented glacial outwash in Minnesota and Wisconsin using the uranium-series-disequilibrium-dating technique (Ku, 1976). Although still in the preliminary stages, the study has produced consistant ages from some of the deposits and has identified the problems that prevented ages from being calculated from the others. Remobilization of uranium isotopes and the presence of non-radiogenic, detrital thorium, in particular, are problems which must be resolved in order to obtain reliable age information. The goal of the study is to produce a chronometric data base from surface calcite cements. The age data will be used to study the chronology of climatic and hydrologic changes that produced the calcite cements. In addition, a surface chronology can be compared with that derived from speleothems. Together, they may provide a chronologic record of late Pleistocene events that extends from the present to 350,000 B.P., well beyond the range of C-14.

GEOLOGIC SETTING

Six samples of secondary calcite cement were collected from five sites in west-central Wisconsin, north and south of River Falls. Both grey (Hersey Member) and red (River Falls Formation) tills of pre-Illinoian and probable Illinoian age, respectively, have been identified in the region (Baker and Simpson, 1981), but at only one of the sites was till of the River Falls Formation actually overlying the till of the Hersey Member. Most of the sample sites were associated only with Hersey Member deposits. The calcite cements collected from Wisconsin were formed in gravels or medium to fine sands. The cement was uniformly distributed throughout the gravels, sometimes reaching a thickness of 3 to 4 meters. Incorporated within some of the gravels were ghosts of Platteville limestone from which all of the carbonate had been leached. More detailed descriptions of these sites and their areal extend are found elsewhere in this guidebook.

Paleomagnetic data collected from the till of the Hersey Member and from associated proglacial lake sediments of the Kinnickinnic Member, place the age of the Hersey Member in the range of 460,000 or 730,000 B.P. (Baker and others, 1983). The sand and gravel deposits beneath the till are thus older than the maximum (350,000 B.P.) age range of uranium-series dating. The ages for the calcite cements may, therefore, extend from the present to greater than 350,000 B.P., as the cement could have been precipitated at any time after the sediment was deposited.

Two sites in Minnesota were sampled. One is along the St. Croix River valley, south of Taylors Falls (SE1/4SW1/4SW1/4 sec. 35, T.34 N., R. 19 W.), where cemented gravels resting on Jordan sandstone occur under grey till of the Grantsburg Sublobe. Intact till balls of both red (Superior Lobe) and grey till in the proglacial gravels suggest that the gravels were transported only a short distance before being overriden by ice. This deposit differs from those in Wisconsin in the way that the gravel has been cemented. In particular, rather than being uniformly cemented, a dense, horizontal shelf has formed directly below the till-gravel contact. Moving down through breaks in this shelf, groundwater has formed large vertical columns of cemented gravel. Where uncemented gravel has been removed, the columns hang like huge stalactites. In areas where the till and uncemented gravel have been eroded, columns as much as 3 meters high and 1 meter in diameter are left standing in the open. Similar formations are also found at one other location several kilometers to the south.

At the second Minnesota site, in the Minnesota River valley (T. 112 N., R. 34 W.), calcite cements occur in thick ice-contact gravels overlain by Des Moines Lobe till. On the east side of the river in sec. 11, an abandoned gravel pit contained a large block of cemented gravel from which dateable material was collected. On the west side of the river, in sec. 23, two separate cemented gravels have been exposed, but no dateable calcite samples were obtained.

In Minnesota, the calcite cements have formed where the gravels are currently exposed along valley walls. The gravels serve as the discharge zone and the calcite cements form where the groundwater emerges. In Wisconsin, the cemented gravel deposits are now part of an upland surface and are in recharge rather than discharge areas. The topography of the uplands is subdued and the regional water table has been lowered in elevation as a result of downcutting by surface streams. The original drainage patterns that produced the cemented gravels are not easily reconstructed, although they probably were similar to the current valley-wall exposures in Minnesota.

The carbonate-rich glacial tills and limestone fragments contained in the gravels are the principal sources of the dissolved calcium carbonate in the groundwater. As oxidizing groundwater infiltrates through soil layers, it collects gaseous carbon dioxide. This decreases the pH of the groundwater and increases the solubility of calcium carbonate. As the carbonate in the till and gravel is dissolved, oxidized (+6) uranium is also taken into solution. Thorium, which is insoluable under near surface conditions remains behind (Stchepotjeva, 1944). As long as the water remains oxidizing and there are no major changes in the pH, both the carbonate and uranium (which is carried as a carbonate complex) will remain in solution. When the groundwater reemerges from the gravel, calcite precipitation may then occur, either by the loss of carbon dioxide to the atmosphere and the consequent rise in pH of the water or by evaporation. At this stage, the accompanying uranium is incorporated into the calcite structure, free of radiogenic (Th-230) thorium (Gascoyne, 1977). The radioactive decay of U-238 and U-234 and the ingrowth of the daughter product Th-230, form the disequilibrium system by which an age of calcite deposition can be calculated.

ANALYTICAL TECHNIQUE

Whenever possible, calcite samples for age analyses were chosen to minimize the noncarbonate detrital component. They were also chosen to avoid any primary limestone or dolomite fragments within which the radiogenic isotopes would be in radioactive equilibrium. Clean pieces of macrocrystalline calcite occupying larger void fillings were hand picked for processing. Disseminated calcite cement in the sand or fine gravels that could not be physically separated from the non-calcite (detrital) fraction was dissolved in acid, and non-calcite fraction removed by filtering.

The samples to be analyzed were placed in dilute nitric acid, to which was added Th-228/U-232 tracer. Uranium and thorium isotopes were extracted from the solution and purified using standard ion-exchange techniques (Thompson, 1973; Gascoyne, 1977). Following further purification by solvent extraction, the samples were evaporated onto stainless steel planchets and placed in an alpha spectrometer, which measures the alpha radiation from uranium and thorium as a function of time. Activity ratios, uranium concentrations, and Th-230/U-234 ages were calculated with a computer program modified from one developed by Thompson (1973). (Activity refers to the number of decay events per unit time and indicates that the measured ratio is not an abundance ratio. An activity ratio of one indicates radioactive equilibrium. To determine an age, the Th-230/U-234 activity ratio must be less than one). The calculated ages represent the elapsed time between the deposition of the calcite and the present. The age range of the uranium-series method is from 350,000 B.P. to the present, with a normal statistical-counting error of between 5 to 10 percent.

In order to obtain reliable uranium-series ages, the following criteria must normally be met: (1) the sample must remain a closed system with no radionuclide migration after the time of deposition; (2) there must be no Th-230 incorporated in the sample during calcite deposition, indicating that the detrital content should be low and the Th-230/Th-232 activity ratio should be high; (3) samples should contain greater than 0.1 parts per million (ppm) of uranium and have good chemical recoveries. These requirements are those normally applied to speleothem age dating, where the detrital content is low and samples usually behave as closed systems. Meeting these requirements for surface carbonate cements is more difficult, primarily because the gravel-calcite samples contain large amounts of detrital material. Non-radiogenic Th-230 absorbed onto the detrital phase may be removed and introduced into the sample during acid dissolution of the calcite. In addition, the porous gravels and cements allow easy infiltration of oxidizing groundwater. Uranium may be leached from the carbonate after deposition, artifically changing the disequilibrium relationship between uranium and thorium.

RESULTS AND DISCUSSION

The results of the uranium-series dating are shown in table 1. Ages ranging from 32,000 to greater than 350,000 B.P. were calculated for all of the Wisconsin samples except for Wisconsin BB-8304. As was suspected, the most significant problems that reduced the reliability of the age dates were associated with the presence of non-radiogenic, detrital thorium and post-depositional loss of uranium. Uranium loss was most evident in sample BB-8304, where the Th-230/U-234 activity ratio was greater than one and no age could be calculated. In a closed system, with no isotope migration, the activity ratio should not exceed one. Unless the activity ratio actually does exceed one however, loss of uranium from any single sample cannot be identified. Multiple analyses from each site are one means of testing this. If the deposit has remained a closed system multiple analyses should produce a single age, within the statistical-error limits.

Of the ten remaining samples in table 1, all but BB-8301 have low Th-230/Th-232 activity ratios (less than 10). Th-232 activity indicates that thorium has been introduced into the sample from outside as a component of the detrital phase. As a result, it must be assumed that the chemically similar Th-230 isotope was also present in the detrital phase and was incorporated into the sample. It is possible to estimate the detrital Th-230 content by multiplying the Th-232 activity by the detrital Th-230/Th-232 activity ratio in the detrital phase. The difficulty lies in identifying what the detrital Th-230/Th-232 activity ratio is for a particular sample or region. Schwarcz (1980) has discussed in detail problems associated with detrital thorium and techniques to correct for its presence. Milske and others (in press) have successfully applied an isochron analysis to correct for detrital thorium in a group of speleothems. The isochron analysis requires multiple analyses from contemporaneous samples. No multiple samples were collected from Wisconsin, but in Minnesota, a group was obtained from Taylors Falls. The isochron technique briefly described below was used successfully to derive

Table 1.--U-238 and Th-238 concentrations, isotope activity ratios, and calculated ages

Sample Number	U (ppm)	^{232}Th (ppm)	$^{234}U/^{238}U$	$^{230}Th/^{234}U$	$^{230}Th/^{232}Th$	Age ($x10^3$ years)
Wisconsin						
BB-8301	1.25 ± 0.02	0.13 ± 0.01	1.022 ± 0.017	0.982 ± 0.024	30.6 ± 2.3	(350)
BB-8302	0.57 ± 0.01	2.00 ± 0.12	1.049 ± 0.018	0.864 ± 0.021	0.8 ± 0.04	(210 ± 15)
BB-8303	0.41 ± 0.02	0.89 ± 0.09	1.500 ± 0.072	0.976 ± 0.049	2.1 ± 0.1	(245 ± 40)
BB-8304	0.43 ± 0.01	--- ---	1.323 ± 0.017	1.236 ± 0.021	--- ---	--- ---
BB-8305	2.37 ± 0.02	2.47 ± 0.13	1.057 ± 0.005	0.254 ± 0.003	0.8 ± 0.04	(32 ± 1)
BB-8306	0.72 ± 0.01	0.54 ± 0.02	1.079 ± 0.014	0.892 ± 0.016	4.0 ± 0.04	(226 ± 14)
Minnesota						
Taylors Falls						
MGS-245	0.51 ± 0.01	0.01 ± 0.003	1.183 ± 0.025	0.025 ± 0.003	9.7 ± 6.1	
MGS-259	0.57 ± 0.02	0.08 ± 0.02	1.120 ± 0.034	0.043 ± 0.007	1.1 ± 0.3	2.7 ± 0.2*
MGS-262	0.48 ± 0.01	0.22 ± 0.04	1.127 ± 0.031	0.093 ± 0.010	0.7 ± 0.1	
MGS-235	1.02 ± 0.02	0.03 ± 0.01	0.886 ± 0.015	0.069 ± 0.004	7.4 ± 1.7	7.8 ± 0.5**
Minnesota River Valley						
MGS-295	2.52 ± 0.05	0.04 ± 0.01	1.229 ± 0.018	0.013 ± 0.001	2.8 ± 0.4	(1.4 ± 0.)

** Age corrected using a $^{230}Th/^{232}Th$ activity ratio of 0.49 ± 0.01 at t = 0
( ) No correction was made for detrital ^{230}Th activity in these samples
* See text and figure 1

an age for the calcite deposition at Taylors Falls. Samples MGS-245, 259, and 262 were collected within a meter of each other from the same exposure of cemented gravel and were presumed to be the same age. Samples of the same age and with the same detrital Th-230/Th-232 activity ratio will plot as a linear array in coordinates of Th-230/Th-232 and U-234/Th-232. The slope, intercept, and associated errors are obtained from a least-squares-regression analysis of the data (York, 1969). The slope of the array is a function of the sample's age and the y-intercept is the present Th-230/Th-232 activity ratio in the detrital phase. The slope and the associated errors (one sigma), are then used to calculate the age of calcite deposition. If the results from the multiple analyses do not plot as a linear array, then it is probably invalid to assume closed system behavior. The slope in figure 1 of 0.0246 + 0.0015 determined from 3 data points was used to calculate an age or 2,700 + 200 B.P. The y-intercept, which is also the current detrital Th-230/Th-232 activity ratio of 0.48 + 0.01, was corrected for 2,700 years of radioactive decay to give an initial ratio of 0.49 + 0.01. This latter value was used to correct the age of MGS-235 from 8,200 to 7,800 B.P.

Without using the isochron analysis the varying amounts of detrital Th-230 incorporated within the three individual samples would have produced in three different ages. Neither those nor any individual age results would have been reliable indicators of the true age of the calcite deposition. Single or even multiple ages from a deposit, although providing information on the uranium-series isotope systematics, cannot be treated with confidence unless the ages are corrected for any detrital Th-230 component that may be present.

The greatest uncertainty in the calculated ages is associated with the Wisconsin samples. These are all single analyses from separate sites. The till of the Hersey Member and the associated gravels are known from the paleomagnetic data to be older than the 350,000 B.P. (Baker and others, 1983). This prevents assigning a 350,000 year age limit to the outwash deposits that could have provided control on how old the uranium-series ages might be. A possible lower-age limit on the ages is provided by the geomorphic position of the gravels in relation to present and past drainage. That is, the age of the cements should be older than the change in base level that lowered the discharge zones below the elevation of the cemented gravels. Sample BB-8301, which contains no detrital thorium (table 1) and has an age greater than 350,000 B.P. indicates that indeed some of the calcite cements may exceed 350,000 years in age. It is worthy to note that even with the uncertainties mentioned above, some finite ages were obtained. This suggests that calcite deposition (possibly cyclinical) was occurring in western Wisconsin during much of the time the gravels were an active part of the groundwater-discharge system.

The calcite cements from Minnesota have a good older limit on their ages, with the Des Moines Lobe and Grantsburg Sublobe tills that cap the gravels. The maximum age of the cements cannot be older than about 15,000 B.P. (Wright and others, 1973). With the detrital content kept to a minimum and the use of the isochron analysis, it was possible to refine the results of the Taylors Falls samples and produce a reliable age for the

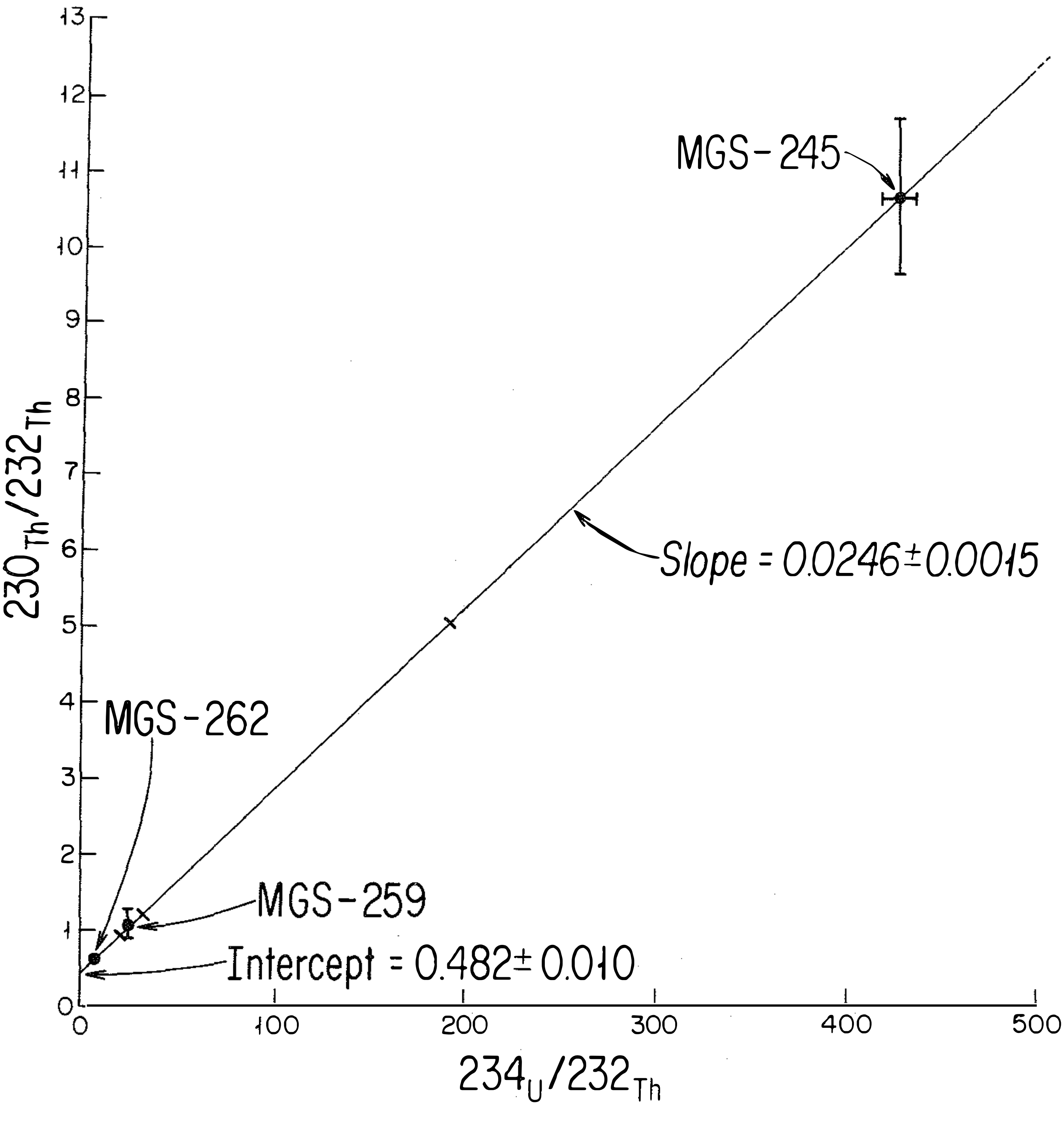

Figure 1.--Isochron plot of uranium and thorium activity-ratio data from Taylors Falls cemented gravel.

calcite deposition. Assuming the oldest Taylors Falls sample was from the initial valley wall, the secondary calcite began to accumulate at about 8,000 B.P. and continued for at least 5,000 years. It is entirely possible that calcite is still being deposited today, at some distance behind the currently exposed face. Little can be said about the Minnesota River valley sample except that, for part of that deposit, the cement had recently accumulated.

SUMMARY

The results reported in this paper come from preliminary attempts to age date surface-calcite cements using the uranium-series-disequilibrium-dating technique. Eleven samples were analysed, 6 from Wisconsin and 5 from Minnesota. Five out of the 6 samples from Wisconsin resulted in ages, ranging from 32,000 to greater than 350,000 B.P. The greater than 350,000 B.P. age is considered to be the most reliable, as it is the only one without detrital Th-230 contamination. The 4 other results represent apparent ages only, due to the presence of uncorrected detrital Th-230. Multiple analyses, found to be necessary for accurate age determinations, could not be carried out in this initial sampling. These results, although only preliminary, do suggest that the process of calcite cementation began in western Wisconsin prior to 350,000 B.P. and continued through much of the late Pleistocene. Further analytical work with the Wisconsin sites may provide dates for changes in the physical and chemical parameters that affected calcite deposition.

The 4 samples in Minnesota resulted in ages that ranged from 1,000 to 8,000 B.P. The data from three contemporaneous samples from the Taylors Falls site were analyzed by an isochron method and produced a single age of 2,700 B.P. for that part of the calcite cement. In addition, the isochron analysis calculated a value for the detrital Th-230 activity in this deposit. The value was used to correct for detrital Th-230 in the older sample at the same site, resulting in an age of 7,800 B.P. These dates are consistant with the limiting (15,000 B.P.) age of the overlying Des Moines Lobe till (Wright and others, 1973). The single age from the Minnesota River valley sample is, like those from Wisconsin, only an apparent age as no correction was made for detrital Th-230. However, it does suggest very recent calcite deposition.

Overall, the results are encouraging. The Taylors Falls samples from Minnesota demonstrated that reliable ages can be obtained from cemented surface gravels using the combination of an isochron technique and multiple analyses to correct for detrital Th-230 and identify post-depositional-uranium migration. While there is no assurance that all sites will be suitable, the need for late Pleistocene surficial chronology extending beyond the range of C-14 makes the effort worthwhile. The next step in the study is to resample the Wisconsin sites and use the isochron technique to try and derive dependable ages for the calcite cements.

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