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George F. Hanson, State Geologist & Director

PLEISTOCENE GEOLOGY OF SOUTHERN WISCONSIN

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PLEISTOCENE GEOLOGY

of

SOUTHERN WISCONSIN

A Field Trip Guide

With Special Papers

by

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Available from The Geological and Natural History Survey, The University of Wisconsin, 1815 University Avenue, Madison, Wisconsin, 53706.
Price $5.00.

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Part A

FIELD TRIP

by

Robert F. Black, Ned K. Bleuer, Francis D. Hole,
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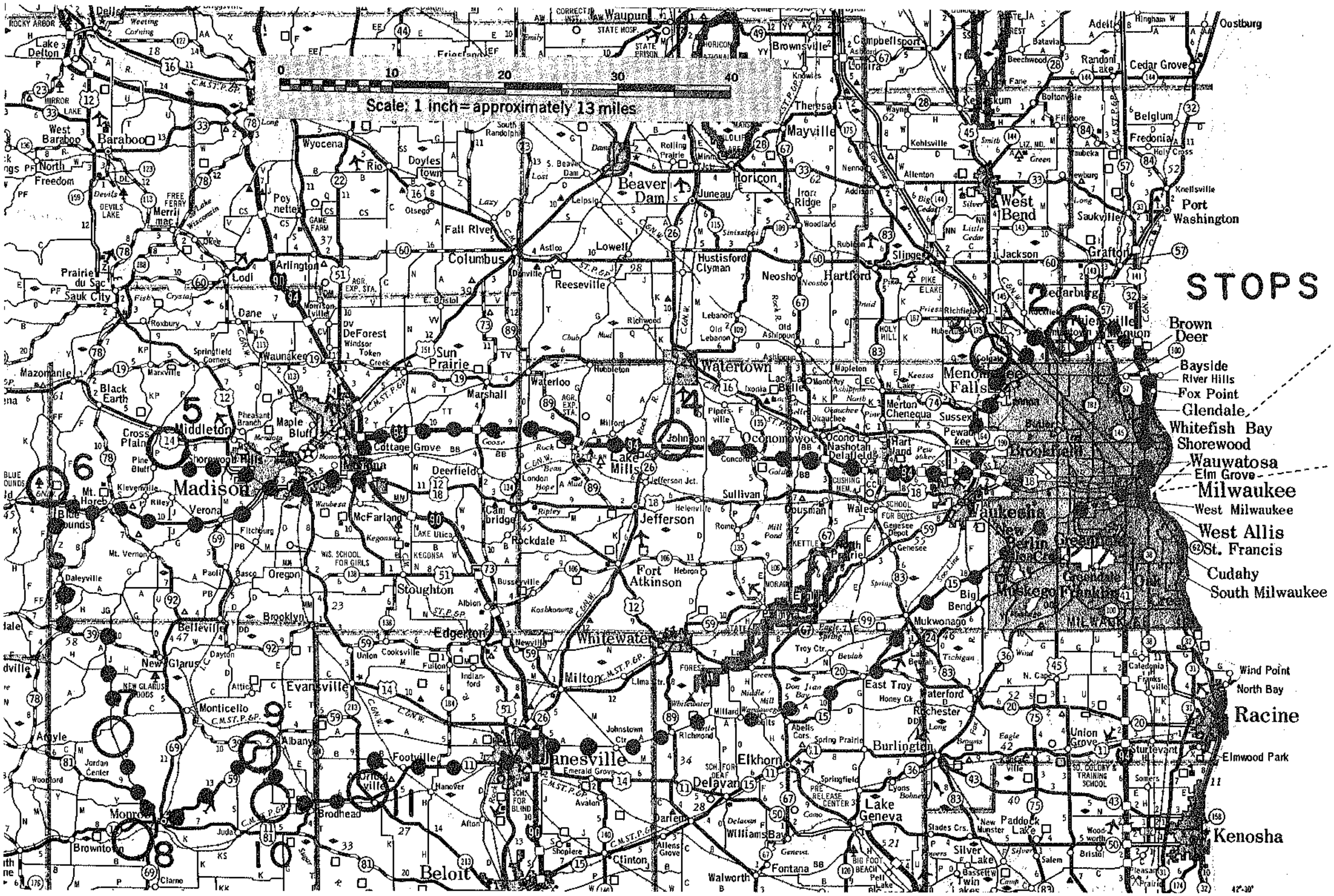


Fig. 1. Road map of southeastern Wisconsin showing route and stops

INTRODUCTION

This field trip is designed to show: (1) representative sections of the Pleistocene stratigraphy, (2) representative glacial features, particularly drumlins and landforms marginal to the Driftless Area, and (3) a glimpse of the Driftless Area itself. Two stops will be made in the Driftless Area, but unfortunately much of the geomorphology must be viewed in transit. Drifts of Wisconsinan and pre-Wisconsinan age will be seen at 9 of the 11 stops planned for the two-day trip (Fig. 1). The pertinent time stratigraphic units are the Valderan, Twocreekan, Woodfordian, and Altonian Substages of the Wisconsinan Stage, and one or more pre-Wisconsinan Stages (Fig. 2).

In organizing this field guide and field trip it has been desirable to place responsibility for certain areas, stops, and topics on single individuals. This has led to a subdivision of the report into ten parts involving three general areas. The three areas are designated loosely - Milwaukee, Madison, and Monroe. For each of these areas the appropriate portions of the road log, stop descriptions, and narrative reports were written respectively by Lasca, Black, and Bleuer. Hole prepared information throughout the road log on modern soils and Part F on the drumlins of Jefferson County. Maher compiled material on the pollen at Stop 2 in Part D on Twocreekan flora. All individuals assisted throughout in the general organization of the field trip and in the compilation and editing of this guide. Black, as organizer and editor, has attempted to coordinate the contributions of each, but full responsibility rests with each author cited for his particular part.

For convenience of the participants the road log, Part A, contains information on points of interest seen enroute as well as brief descriptions of each stop. Additional details of the stops, of the areas traversed, and of topics covered are included in the narrative reports, Parts B to J, inclusive. Each report is written to stand alone. Coverage depends on the objectives of the writer. The narrative reports are included, because (1) much of the published literature is a half century or more old, and hence, often difficult to obtain; (2) new studies, in large part in thesis form and mostly unpublished, need to be presented in some detail; and (3) other background information for some stops or topics is too lengthy to be included conveniently in the road log itself.

Black's contribution to this report was made during his employment with the University of Wisconsin-Madison. Bleuer's field studies were made as a student at the University of Wisconsin-Madison.

OUTLINE OF THE FIELD TRIP

The route and stops are shown in small scale on a road map (Fig. 1), on generalized maps of glacial deposits of Wisconsin (Fig. 3), of bedrock (Fig. 4), and of soils (Fig. 5). From Milwaukee the route is northerly to Stop 1 at Valderan deposits (see Parts B and C, by Lasca). From there the route leads south and west to Twocreekan (see also Part D, by Maher and Woodfordian drifts (Stops 2 and 3) and to Woodfordian drumlins (Stop 4) (see also Lasca, Part E, and Part F, by Hole). The route west from

Stage	Substage	Units		
Wisconsinan	Valderan			(Valders Till)
Wisconsinan	Twocreekan			Two Creeks Soil
Wisconsinan	Woodfordian	Peoria Loess		Bloomington and Younger Tills - Richland Loess
				Esmond Till
				Morton Loess
Wisconsinan	Farmdalian			Farmdale Silt
Wisconsinan	Altonian	Winnebago Formation	Roxana Silt	Capron Till
				Plano Silt
				Argyle Till
				Janesville Till - Janesville Gravel
Sangamonian				Sangamon Soil
Illinoian	Buffalo Hart			
Illinoian	Jacksonville			Ogle Till Winslow Till
Illinoian	Liman			
Kansan ?				Juda Gravel

Fig. 2. Pleistocene Time-Stratigraphic Units of Southern Wisconsin. In part after Frye, Glass, Kempton, and Willman (1969).

Milwaukee to Madison traverses much of the classical drumlin field of the Green Bay Lobe. The last stop (5) of the first day is southeast of the town of Cross Plains (west of Madison) at the margin of the Late Woodfordian moraine fronting on the Driftless Area (see Part G, by Black). Stay overnight in Madison.

Departure the second day is timed at 7:30 a.m. Driving southwestward from Madison the Driftless area is entered at Verona. Count on good weather to take advantage of the view of the Driftless area from Blue Mounds (Stop 6) while discussing the erosional history of the area (see Part H by Black). The route southwards toward Monroe is on uplands which command excellent views. Stop 7 enroute is concerned with Tertiary residuum on that upland (see Part I by Black).

In the Monroe area stops were selected, within travel limitations, to provide representative sections of the Early Wisconsinan and pre-Wisconsinan stratigraphy. An alternate stop description is included should one or more of Stops 8 to 11 be unavailable at the time of the trip. In order for participants to appreciate more fully the problems and the significance of the stops, Bleuer has prepared a complete report (Part J) on the Monroe area.

From Stop 11, west of Janesville, the buses will go directly to the hotel in Milwaukee, arriving about 7:00 p.m.

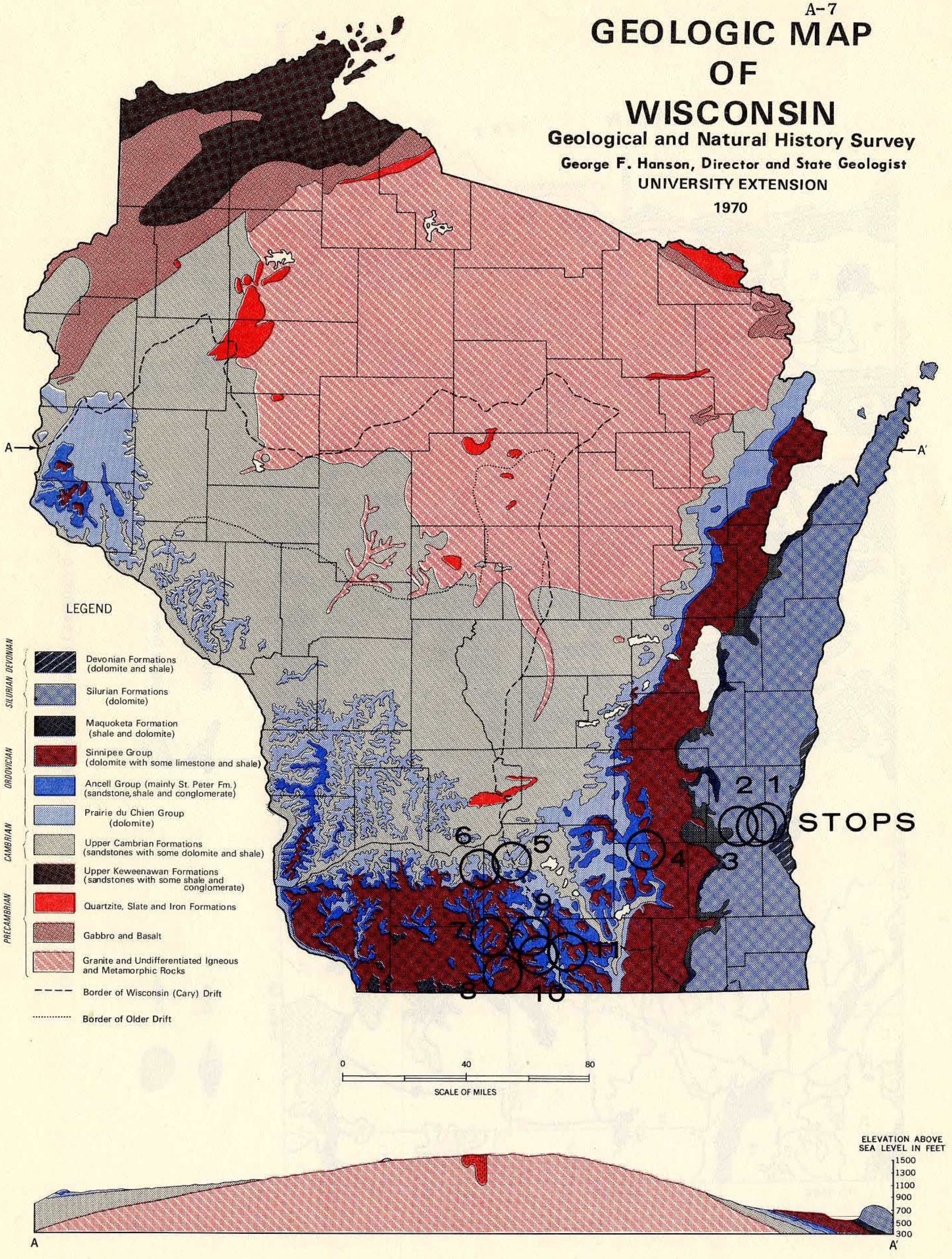


Fig. 4. Bedrock map of Wisconsin with route and stops added

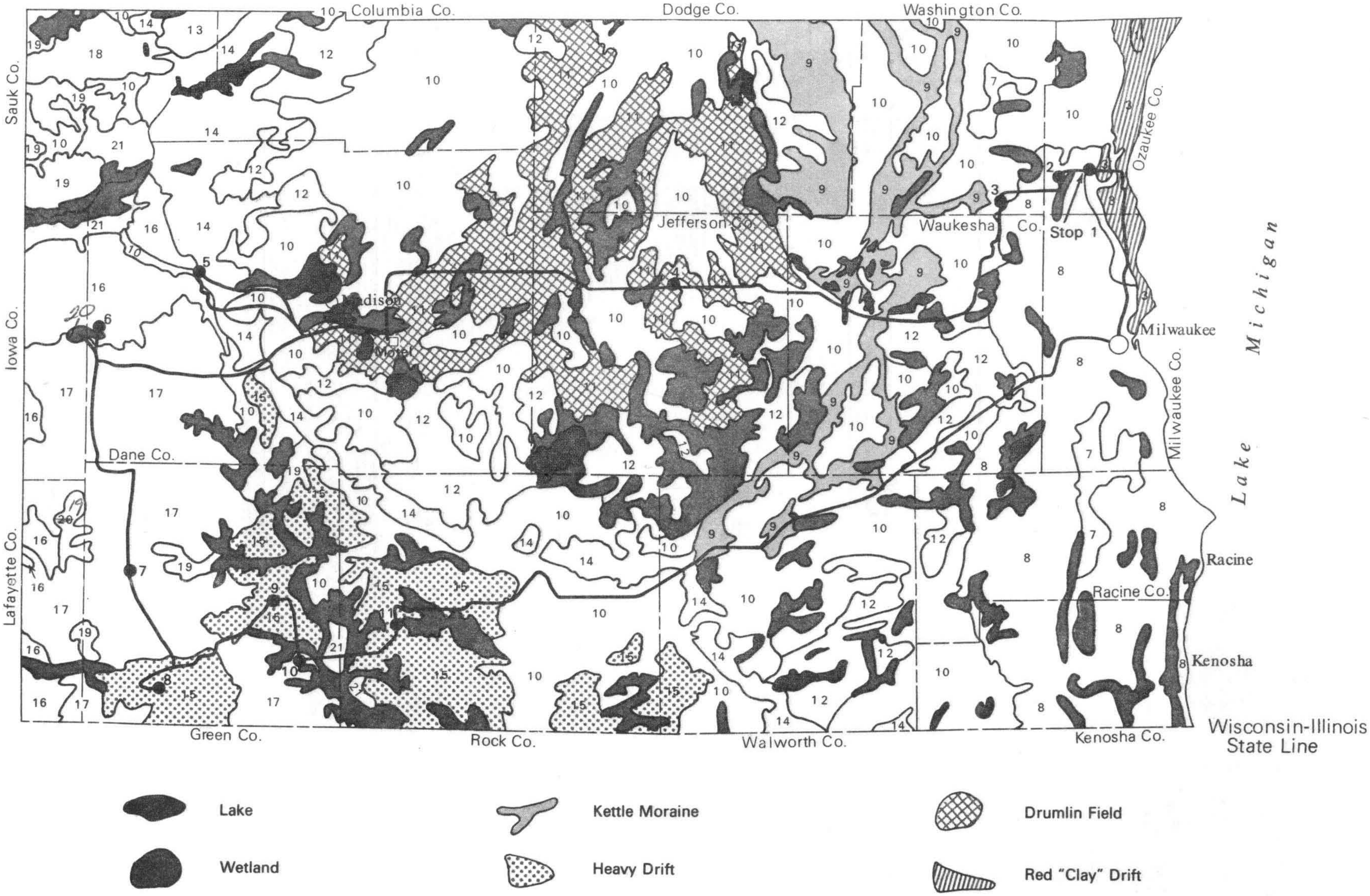


Fig. 5. Soils Map of Southern Wisconsin with route and stops added

LEGEND FOR SOIL MAP, FIGURE 5[1/]

Soils of the Red "Clay" Drift Region (largely Valderan parent materials)

1 - Nearly level red clayey soils (Kewaunee#, Oshkosh#, Poygan+ series) on ground moraine and glacio-lacustrine plains. (I20)

3 - Rolling to undulating red clayey (and loamy) soils (Kewaunee#, Hortonville#, Manawa#, Onaway## and Poygan+ series) on moraines. (I4, E4)

Soils of the Gray "Clay" Drift Region (largely Woodfordian parent material)

7 - Rolling clayey soils (Morley#, Blount# series), largely on moraines. (B9)

8 - Undulating clayey soils (Morely#, Blount#, Varna*, Elliott*) largely on moraines. (B19, B20)

Soils of the light brown "Loam" Drift Region (largely Woodfordian parent material)

9 - Hilly gravelly to loamy soils (Rodman*, Casco#, Theresa#, Hochheim*) of the Kettle Moraine area. (B3, B12)

10 - Nearly level to undulating silty soils (Plano*, Miami#, McHenry#, Lapeer#, Dodge#, Fox # series) on loess-blanketed ground moraine and some outwash plains. (B21, B22, B23, B24, B25, B30, B31)

11 - Rolling to level silty soils (Miami#, Dodge#, Pella+ series) on drumlins and intervening wetlands. (B13)

12 - Rolling silty and loamy soils (Ringwood*, McHenry#, Lapeer#, Brookston*) on moraines and associated pitted outwash. (B5, B14, B15)

13 - Rolling silty soils (Pecatonica#, Flagg#, Baraboo# series) in loess over till over quartzite. (B3)

14 - Rolling to hilly silty and loamy soils (Flagg#, Pecatonica#, Lapeer#, Boyer#, Dodge#, Pella+ series) in loess and till of terminal moraines. (B10, B15, B25)

Soils of the brown "Heavy Loam" Drift Region (Largely pre-Woodfordian parent materials)

15 - Rolling silty soils (Pecatonica#, Dodge#, Ringwood*, Durand* series) in loess over heavy loam till. (B5, B7)

Soils of the "Driftless Area"

16 - Hilly silty soils (Dubuque#, Palsgrove# series, with steep rocky land) in loess over residuum on limestone. (A6, A9)

17 - Undulating to gently rolling soils (Tama*, Dodgeville*, Ashdale*, Sogn* series) in loess over residuum on limestone. (A1, A2, A3)

18 - Rolling silty soils (Baraboo#, Skillett# series, with steep rocky land) in loess over quartzite. (A10)

20 ~~19~~ - Hilly clayey soils (Schapville*, Derinda#, Vlasaty# series) in loess over Maquoketa shale. (A4)

19 ~~20~~ - Hilly silty to sandy soils (Gale#, Hixton#, Norden# series with steep rocky land) of sandstone uplands, locally loess-covered. (D1, D5)

21 - Nearly level sands and sandy loams (Sparta*, Plainfield[0], Gotham#, Dakota*, Meridian# series) on outwash terraces. (C5, C8)

Miscellaneous soils

Wetland soils: peat[u], muck[u], wet mineral soils (Pella+, Poygan+ series) of alluvial flood plains, glacio-lacustrine plains and kettles. (J2, J7, J8, J9, J15)

1/Adapted by F. D. Hole from 1:250,000 overlay soil map (on U.S. Geol. Survey topographic quadrangles from Hole and Beatty, 1968). Symbols in parentheses, such as B12, are from the legend of the overlay soil map.

* Brunizems: Argiudolls or Hapludolls, developed under prairie vegetative cover.
\# Gray-Brown Podzolics: Hapludalfs (or Glossudalfs or Eutroboralfs), developed under deciduous forest cover.
\## Podzols: Haplorthods, developed under mixed coniferous and deciduous forest.
\+ Humic-Gleys and Low Humic-Gleys: Argiaquolls, Haploquolls, developed under wetland vegetation.
u Bog soils: Histosols, developed under Bog species.
0 Regosols: Udipsamments, developed under Jack pine and Hill's oak (*Pinus banksiana* and *Quercus ellipsoidalis*)

ROAD LOG

Primary Leader, STOPS 1-4, Norman P. Lasca

Mile

0.0 Depart 7:30 A.M. from Sheraton-Schroeder Hotel, 5th Street entrance. Proceed south to Michigan Street. See narrative reports by Lasca, Parts C and D, for details of the area traversed.

0.1 Turn right (west) and proceed one block to 6th Street.

0.2 Turn right (north). Move into left lane of traffic.

0.4 Turn left on expressway marked U.S. Highway 141 North.

8.3 Good Hope Road interchange, continue north on U.S. Highway 141.

The area lies in the "Eastern Ridges and Lowlands" province of Wisconsin. You are traveling over "Valderan" till deposited as ground moraine 4-12 feet thick in most places and dissected by post-glacial drainage. Woodfordian outwash is exposed in some areas, and ponded sediments occur in local depressions. The Valderan-Woodfordian boundary lies approximately 5 miles west of U.S. Highway 141 (see discussion STOPS 1 and 2, and regional report by Lasca, Part C).

11.8 Enter Ozaukee County.

13.7 Exit at Mequon Road - Wisconsin Highway 167. Turn left (west).

14.1 Junction Port Washington Road marked by three gas stations: Phillips, Enco, and Mobil. Turn right (north).

16.3 Turn left (west) on Highland Road.

18.6 Border of red clayey till, the Valderan-Woodfordian boundary of Thwaites (1943) and "red drift" boundary of Alden (1918).

20.5 Cross Wauwatosa Road.

20.8 Notice boulder field at left of road.

21.1 Turn right (north). Enter gravel pit.

STOP 1 - Highland Road Gravel Pit: SE$\frac{1}{4}$, SW$\frac{1}{4}$, Sec. 9, T 9 N, R 21 E, West Bend topographic quadrangle. See narrative report by Lasca, Part C, Stop 1.

Arrive - 8:30 A.M. Depart - 9:00 A.M.

The purpose of Stop 1 is to examine an exposure of the "red drift" described by Alden (1918) and later named by Thwaites (1943, p. 136) as drift of the Valders (Valderan) glaciation which "...

is readily distinguished from the Cary till because it is red and contains much more clay." Although the exposure, Stop 1, lies 2.5 miles outside (west) of the "red drift" boundary mapped by Alden (1918), recent work by Bruning (1970) indicates that the red drift at this locality is the same as that found to the east, but contains more clay. See narrative report by Lasca for discussion of the problem. The classical separation of the Valderan based on color does not apply in Northern Wisconsin or the Upper Peninsula of Michigan (Black, 1966) nor in the Lower Peninsula of Michigan (Farrand, and others, 1969). A similar situation may exist in southeastern Wisconsin.

In the Highland Road gravel pit the red drift ranges from 6 to 8 feet in thickness and overlies outwash sands and gravels of Woodfordian age (see description of Stop 2 for detailed stratigraphy and age determinations). The drift ranges in carbonate content from 30 to 35 percent; it is approximately 15 percent iron oxide (Fe_2O_3). The Munsell dry color ranges from 7.5YR 7/2, pinkish gray, to 10YR 7/2, light gray, and wet from 5YR 4/4, reddish brown, to 7.5YR 5/4, brown. The dominantly silty-clay drift contains a variety of pebbles and cobbles (dolomite, many of which are striated; granites; greenstone; etc.). The underlying outwash sediments consist of silts, sands, and pebble to boulder gravels. Cross bedding occurs in some areas.

21.3 Depart gravel pit turning right (west) on Highland Road.

22.3 Turn left (south) on Farmdale Road. Proceed to Ernst Brothers Gravel Pit.

22.6 Turn right (west) and enter pit.

Buses will stop at the main office. We will walk about 1/4 mile to the exposure of a Twocreekan forest. The dredging operations in the pond undercut the banks causing collapse. The Ernst brothers have requested that we remain at least 20 feet back from the edge of the banks.

<u>STOP 2</u> - Ernst Brothers Sand and Gravel Pit: S ½, NW ¼, Sec. 17, T 9 N, R 21 E, Waukesha topographic quadrangle. See narrative report by Lasca, Part C, Stop 2.

Arrive - 9:15 A.M. Depart - 10:00 A.M.

A complete stratigraphic section consisting of Woodfordian to Recent deposits is exposed in the west wall of the pit (see Fig. 6). Two ancient forests are buried in the exposed sediments. The lower forest consists mainly of spruce (<u>Picea</u>) (see floral report by Maher, Part D) and is overlain by pond sediments. Numerous stumps, logs, cones and needles are found in the forest layer. A radiocarbon date of 12,000 ± 190 B.P. (Kocurko, 1968) was obtained from the heartwood of an 150 year old <u>in situ</u> stump from the lower forest indicating that it is Twocreekan in age. The minimum age of the forest at time of death was 195 years as determined from tree ring counts. Many <u>in situ</u> stumps are found at the lower forest level and a moss mat is preserved over much of the area. Underlying the forest is a boulder clay (Munsell dry color 10YR 7/2, light gray, to 10YR 7/3, very pale brown; wet color 10YR 5/1, gray, to 10YR 5/3, brown) which grades downward into bouldery sands, or sands or in some areas gravel.

The upper forest grew in the peat overlying the pond sediments (Fig. 6); it is not dated, but is presumed to be fairly recent as the trees are primarily *Pinus* and *Quercus*, species found today in the conifer-hardwood forest of Northern Wisconsin. The pond sediments consist of partially indurated algal (*Chara*)-silty-clacareous mud with variable amounts of clay and peat. The detrital non-carbonate portion of the sediments consist mainly of silt-size grains (principally quartz), diatom remains, sponge spicules, plant debris, and some vertebrate remains. In addition, nineteen molluskan species were identified (Kocurko, 1968) from the pond sediments. The molluskan fauna suggest that the environment of deposition was a shallow pond with a pH that ranged from 7.0 to 8.16 and a summer temperature between 50 and 60°F (Kocurko, 1968; see topical report by Lasca). Based on the work of Kocurko (1968), and modified by investigations by Lasca and his students, the following sequence of late Wisconsinan events is suggested for the pit:

1. Deposition of outwash sands and gravels as the Woodfordian ice withdrew from the area prior to 12,000 B.P.

2. Development of a boreal forest with *Picea* the dominant species. Wood from an *in situ* stump dated at 12,000 ± 190 B.P. indicates the forest is Twocreekan in age.

3. Development of a shallow pond which drowns the forest during Valderan time.

4. Destruction of the pond during post-Valderan time and development of the peat deposit overlying the pond sediments. Development of a conifer-hardwood forest which was gradually replaced by the present southern hardwood forest.

23.6 Exit from Ernst Brothers Gravel Pit. Turn right (south) on Farmdale Road.

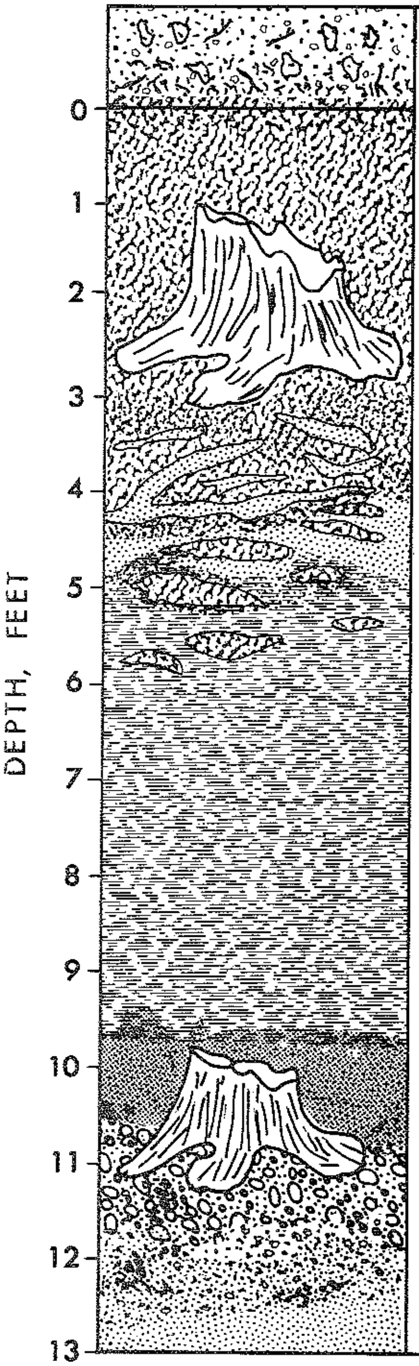
24.4 Turn right (west) on Highway F (Freistadt Road).

As we travel westward to the Kettle Interlobate Moraine, formed between the Green Bay and Lake Michigan lobes, we cross a series of recessional moraines and ice-marginal drainage channels formed during Woodfordian time.

28.8 Cross Fond du Lac Avenue (State Highways 145 and 167).

31.2 Turn left (south) on Goldendale Road (County Highway Y).

31.9 Cross U.S. Highway 41. Continue south.



Debris at surface.

Peat: varies from 3 to 6 feet in thickness and contains large wood fragments. *Pinus*, *Quercus*, *Betula*, and *Ulmus* pollen are found in the layer.

Upper forest: between 2 and 3 feet below the top of the peat. Underlain by approximately 1.5 feet of peat.

A 1 to 2 foot thick zone consisting of sand beds varying from 1/8 inch to $1\frac{1}{2}$ feet in thickness and interbedded with peat. Gradational into underlying pond sediments.

Pond sediments: consist of partially consolidated algal (*Chara*)-silty-calcareous mud with variable amounts of clay and in the upper portion interbedded layers of peat. The non-carbonate portion of the sediments is detrital and consists primarily of silt-sized grains, diatom remains, sponge spicules, Cladocera remains, and plant debris. Some vertebrate remains occur. 19 molluscan species occur. Gradational into underlying sands and sandy soil.

Lower forest: Twocreekan forest bed and moss mat radiocarbon dated 12,000 $\pm$190 B.P. Many *in situ Picea* stumps partially covered with sand. Forest floor preserved in some areas. Underlain by bouldery clay in many areas, grading downward into bouldery sands or sands or gravels.

Fig. 6. Generalized section, west wall of the Ernst Brothers Sand and Gravel Pit, Ozaukee County, Wisconsin (modified from Kocurko, 1968).

33.2 Turn left (southeast) on Appleton Avenue (Wisconsin Highway 175).

33.5 Turn sharp right (west) just past Sinclair gas station on Willow Creek Road.

From the top of the first hill note the change in topography as we enter the Kettle Interlobate Moraine. Chamberlin (1878, p.202) described the moraine as "... an irregular, intricate series of drift ridges and hills of rapidly, but often very gracefully, undulating contour, consisting of rounded domes, conical peaks, winding and, occasionally, geniculated ridges, short, sharp spurs, mounds, knolls and hummocks, promiscuously arranged, accompanied by corresponding depressions, that are even more striking in character."

34.5 STOP 3 Willow Creek Sand and Gravel Pit: NW$\frac{1}{4}$, NW$\frac{1}{4}$, Sec. 31, T 9 N, R 20 E, Waukesha topographic quadrangle. See narrative report by Lasca, Part C, Stop 3.

Arrive - 10:30 A.M. Depart - 11:15 A.M.

Walk into the Willow Creek Pit. We are at the east edge of the "Kettle Moraine" (Chamberlin, 1877 and 1878) formed between the Green Bay and Lake Michigan lobes of Late Woodfordian (Cary) age. No detailed geological work has been done in the pit, but Lasca regularly brings classes here to see the complex glacial features formed by fluctuations of the lobes. The glacial drainage was generally south through the area. The underlying bedrock is Niagaran dolomite of Silurian age.

The following features can be seen in the pit:

On the southeast side of the pit aeolian silt, $\frac{1}{2}$ foot to $2\frac{1}{2}$ feet thick overlies a highly variable Woodfordian till, 2 to 8 feet thick. Underlying the till are outwash boulder gravels, 1 foot to 8 feet thick, which are underlain by fine sands and silt, 1 foot to 5 feet thick. Many slump and collapse features are seen. Erratics include granite, greenstone, limestone, basalt, gabbro, copper, "Iron formation," and many others.

On the west side of the pit erratic boulders (as much as 4x5x3 feet), sands, gravels, till, and ponded sediments (rhythmites) are found within a few feet of one another.

Return to Willow Creek Road. Proceed west.

35.7 Turn left (south) on Colgate Road. Most of the Kettle Interlobate Moraine lies to the north and west.

36.8 Turn left (east) on County Line Road.

37.8 Turn right (south) on Highway V. Enter Waukesha County.

The area is underlain by a dolomite of Silurian age. The dolomite is quarried under the name "Lannon Stone," named for the nearby town of Lannon. The dimension stone and crushed stone industries contribute significantly to the local economy. In 1968, the production of limestone/dolomite from Waukesha County (essentially the Lannon area) was $3,254,000.

41.9 St. James School LUNCH STOP

Arrive - 11:30 A.M. Depart - 12:30 P.M.

42.2 Turn right (west) on Wisconsin Highway 74. Note the large exposure of Woodfordian outwash materials in the gravel pit on the right (north) side of the road prior to entering Sussex, Wisconsin.

43.5 Turn left (south) on Wisconsin Highway 164. Proceed to Interstate 94.

49.7 Turn right (west) on I-94 and proceed toward Madison.

53.6 Shortly after passing the Pewaukee exit, we enter the Kettle-Interlobate-Moraine system. The moraine system extends to an area near Oconomowoc. This is an excellent example of the complex marginal ice zone that developed between the Green Bay and Lake Michigan lobes. Moraines, kettles, various kame forms, ice channel fillings, pro-glacial lakes and marginal drainages are all visible from the bus.

61.0 Cross between Upper Nemahbin and Lower Nemahbin Lakes, kettle lakes in the Kettle-Interlobate-Moraine system.

63.8 Near the Oconomowoc exit notice the lake plain, a former pro-glacial lake bed formed during deglaciation of the area during the Woodfordian.

67.5 Enter Jefferson County.

We are entering the classical drumlin field of the Green Bay lobe in southeastern Wisconsin (Alden, 1905 and 1918). The general movement of the ice was from the north. Drumlin elongation generally parallels a north-south line with variations occurring at the margins of the lobe. See reports by Lasca, Part E and by Hole, Part F, in this Guidebook and also by Milfred and Hole (1970) for areal and topical discussions.

79.4 Turn right (north) at the Johnson Creek interchange (Watertown/Jefferson) and proceed north on Wisconsin Highway 26.

81.8 Turn right (east) on Emerald Road. Note drumlins.

82.7 Turn right (south) on Switzke Road.

84.4 Turn right (west) at the stop sign onto a dead-end road. At the unmarked junction, Switzke Road joins County Highway MM.

84.9 STOP 4 Switzke Road - Highway MM Drumlin: SW$\frac{1}{4}$, NE$\frac{1}{4}$, Sec. 7, T 7 N, R 15 E, Jefferson topographic quadrangle.

Arrive - 1:45 P.M. Depart - 2:15 P.M.

The purpose of the stop is to examine a cross section through a drumlin and to discuss drumlin formation. The drumlin lies in the well known drumlin field of the Green Bay lobe (Alden, 1905). Based on roadcut exposures the drumlins throughout the area consist of a variety of materials, most commonly till. In some drumlins glacial-fluvial gravels or sand lenses occur between layers of till.

In both the north and south walls of the Switzke Road drumlin, recumbantly folded gravels are in contact with till. The folded gravels and till suggest transport and injection of material in a frozen or partly frozen, but mobile state from an adjacent high pressure area into a low pressure zone (Gravenor and Meneley, 1958; Evenson, 1970; see topical discussion by Lasca). Micro- and macro-fabric analyses taken from the till at the west end of the exposure have nearly north-south trending maxima (Evenson, 1970). To date no detailed work on the fabric of either the gravels or adjacent tills has been done. See narrative report by Lasca, Part E, for more information on drumlins in this area.

Primary Leader, STOPS 5-7, Robert F. Black

Mile	
84.9	Go east on County Highway MM.
85.3	Turn right (south) on Switzke Road.
86.6	Turn right (west) on County Highway B.
88.3	Turn right (north) on Wisconsin Highway 26.
89.2	Cross under I-94 and immediately turn left (west) on it. I-94 west to Madison cuts transversely across the southern part of the Green Bay Lobe drumlin field. Unfortunately, all deep cuts are sodded so the nature of the till cannot be seen from the bus. From a due south orientation at Stop 4, the drumlins deploy more and more southwesterly as we approach Madison. See report by Hole, Part F, for more information on drumlins in Jefferson County.
91.0	Rock River.
93.5	Crawfish River, tributary to the Rock River. Aztalan State Park is 1.5 miles downstream (south). It has Late-Woodland, Indian, effigy mounds of Middle Mississippi culture and a partly reconstructed ancient village (Black, _et al._, 1965, p. 72-74).
97.7	Rock Lake, a large kettle, is 1/4 mile to the left (south). Numerous small sandy ice-stagnation features are found in this area and lap on the drumlins.
102.5	Enter Dane County.
103.4	Goose Lake and marsh on left (south) are the remnant of a much larger marshy lake that typified the bottom lands between drumlins in the area, before ditching by man during the last few decades. Mastodon, dated at 9,000-10,000 years B.P. (Dallman, 1968), and giant beaver remains have been found nearby in near-surface peat over marl. Peat, several tens of feet thick, has been excavated in places along I-94.
115.9	Take left (south) turn to I-90 toward Janesville and Chicago.
116.7	Quarry on left (east) is in Platteville Dolomite on St. Peter Sandstone (Ordovician). Striae on the dolomite parallel drumlin orientation--southwest.
120.1	Turn right (west) off I-90 on U.S. Highway 12-18. We will return to the Holiday Inn Motel southeast of this intersection for the night.
121.6	Junction U.S. Highways 51 and 12-18. Continue ahead.

122.0 Late Woodfordian pink sandy till in excavation in low drumlin on right (north).

123.5 Yahara River, tributary to the Rock River, between Lakes Monona and Waubesa at Monona, a suburb southeast of Madison. Most hills from here westward for a few miles are bedrock supported. Upper Cambrian sandstone and locally dolomite may be seen in artificial cuts.

128.6 Part of University of Wisconsin Arboretum.

129.6 At junction with U.S. Highway 18 continue ahead (west-northwest) on U.S. Highway 12-14.

131.6 Crest of Milton Moraine, a recessional from the Johnstown Moraine of Late Woodfordian age. The WMTV tower on left (south) side of highway is on the irregular crest which here trends northwest-southeast.

133.6 Bear right off U.S. Highway 12-14 at junction and turn left (west) on County Highway S, Mineral Point Road. Drive over rolling ground moraine of Late Woodfordian age. Bedrock relief is over 100 feet.

137.5 Crest of Johnstown Moraine of Late Woodfordian age. Note small kettles immediately inside the crest (east). House to southeast has 130 feet of drift to bedrock. For details of this area see narrative report by Black on Cross Plains Terminal Moraine, particularly Figure 1, for a topographic map.

137.6 Outer edge of the Johnstown Moraine at crossroads. Turn right (north) on Cleveland Road. Dolomite is only two feet below surface. Ponds to west were larger and drained north and west along the ice front. Gap in moraine to southeast is artificial. To west is the Driftless Area. Ridge is capped with Platteville-Galena dolomite (Ordovician).

138.1 Platteville Dolomite crops out at garage by house on left (west) side of road. Water from enlarged ponds to south apparently drained briefly across the road in front of the house, going north-northeast along the ice front.

138.6 Top of hill by radio tower. Continue straight ahead. Former ice front lies 0.3 mile due east (right) and 0.4 mile north (straight ahead). Fragmented dolomite (Platteville-Galena) may be seen in road ditches under a few inches of loess.

138.9 St. Peter Sandstone crops out in trees north of house on right (east). A few large erratic boulders of Precambrian rocks are found on the southwest side of the gully which is part of the drainage marginal to the former ice front.

139.0 Johnstown Moraine trends northwest-southeast across road.

139.1 Turn left (west) at bend in road.

139.4 Buses will stop at intersection of town roads so we may walk to various features shown on Figure 2 of narrative report by Black on Cross Plains Terminal Moraine. This is STOP 5.

We will walk about one mile and reboard the buses 0.3 mile west in front of the brownstone house. Please observe that we are on the private property of Dr. and Mrs. James M. Wilkie. They are attempting to conserve the flora, fauna, and geology of their lands. Walk carefully and, please, no breaking or removal of weathered rocks. Leave your hammers on the bus.

STOP 5 - Cross Plains Moraine and features marginal to the Driftless Area: N center $\frac{1}{4}$, Sec. 13, T 13 N, R 7 E, Cross Plains topographic quadrangle. See narrative report by Black, Part G.

Arrive - 3:30 P.M. Depart - 4:45 P.M.

No detailed geologic studies of this area have been undertaken, but Black regularly brings classes here to see the various glacial features fronting on the Driftless Area and the weathered bedrock exposed by melt water. An end moraine and former marginal lakes, a marginal drainageway and a subglacial drainageway may be seen in a very small area. The relationship of these features with the Driftless Area seems clear. However, the reconstruction that follows is based largely on landform interpretation with very limited subsurface data and no quantitative studies of the drifts. This is the Johnstown Moraine of Alden (1918) of Cary (Late Woodfordian) age.

The road cut at the road junction permits a glimpse of the sandy, bouldery till that makes up the end moraine. The high percentage of Precambrian shield rocks is striking. The large boulders scattered over the top of the moraine are characteristic. In front of the moraine, south of the town road, a gully exposes 8 feet of loamy silt on clean, poorly sorted sand and gravel that is at least 7 feet thick. Those deposits are considered lacustrine, initially derived from the ice front and later from the loess on the slopes surrounding the lake. Water from the enlarged ponds 1.5 miles to the south apparently flowed briefly along the former ice front into the blocked valley at the head of Wilkie Gorge in the southeast corner of Figure 2 of the Cross Plains Report. From there, for a time, it flowed northwestward along the ice front and westward through the drainageway in the center of that figure. The drainage waters carved several shallow channels in the weathered dolomite (Prairie du Chien) and exposed *in situ* solution-etched cherty residuum. Later the water flowed down Wilkie Gorge and probably under the ice toward the terminus about one mile northwest. The ice thus choked with till the lower part of the bedrock valley where we left the buses, damming a lake behind it, and diverting the water across the bedrock divide to the west. Later, during the stillstand and decay of the ice, the water cut Wilkie Gorge.

Red, loamy, cherty residuum on the Prairie du Chien dolomite south of the marginal channel suggests a truncated ancient soil of possibly Sangamonian age. The solution-etched, chert residuum from the Prairie du Chien also suggests considerable antiquity--probably more than the 13,000 years since glaciation.

139.7 Board buses in front of the Wilkie home and continue west and north across mouth of former small shallow lake to terminus of the Johnstown Moraine in Black Earth Creek Valley. Upper Cambrian sandstone crops out at valley level; Prairie du Chien dolomite rims the bluffs. The large gravel pits in the valley west (left) of the road are in outwash directly in front of the moraine.

141.4 Junction town road; turn right (east).

141.7 Junction U.S. Highway 14; turn right (east).

141.9 Gravel pits on left (north) are in drift at least 0.6 mile behind the outer limit of the terminal moraine.

142.5 Kettle pond to right (south) across the RR tracks. A retreatal moraine crosses the summit of the "island".

146.1 Junction U.S. Highway 14 and Evergreen Hill Road north. Continue straight ahead. The valley northward and eastward has many tens of feet of sandy drift deposited in Glacial Lake Middleton. The latest outlet is 0.5 mile north of the junction, at the foot of the bedrock hill.

147.0 Turn left (north) on access road to U.S. Highway 12 and continue south and east.

150.0 Junction U.S. Highway 12-14 and County Highway S (mile 133.6, enroute to Stop 5). Continue south and east on 12.

163.5 At junction of U.S. Highway 12-18 and I-90 continue straight ahead.

164.0 Turn right on access road to Holiday Inn Motel.

164.5 Holiday Inn Motel Parking Lot. Please take all valuables from bus. NOTE: Dinner is at your expense and your convenience. Those interested in sightseeing in downtown Madison and the University of Wisconsin should contact the trip leaders for a bus departing 8:30 P.M. and returning 9:30 P.M.

SECOND DAY - November 10, 1970

Depart Motel at 7:30 A.M. with all luggage.

Mile

164.5 Motel parking lot north to U.S. Highway 12-18.

165.0 Turn left (west) on U.S. Highway 12-18. Continue under I-90.

165.4 I-90 overpass. Continue west (straight on U.S. Highway 12-18). Repeat roadlog mile 120.1 to 128.6.

174.8 Bear right (north) on exit to U.S. Highway 18-151 south.

174.9 Turn left (south) on U.S. Highway 18-151 to Verona.

176.4 Gravel pits on left (southeast) are in outwash in a preglacial bedrock valley. More than one age of outwash may be represented. The upper part is Late Woodfordian.

177.4 The valley sides expose red and yellow St. Peter Sandstone capped with Platteville-Galena dolomite.

183.0 Center of Verona and junction with County M and Wisconsin Highway 69. Continue ahead on U.S. Highway 18-151.

183.8 Outer margin of Johnstown Terminal Moraine, fronting on thin ground moraine of Illinoian age, re Alden (1918).

184.3 Southwest facing crest of hill is outer limit of Illinoian glaciation, re Alden (1918). Enter Driftless Area.

185.0 Sugar River, in part a marginal glacial stream flowing south-southeast into the Rock River. Its valley contains thick sandy drift and numerous terraces that have not been studied. The valley was considered by Alden (1918) to have been a marginal glacial lake in Illinoian time. Rise westward onto the uplands of Platteville-Galena dolomite.

193.5 Junction Wisconsin Highway 92 in Mt. Horeb, a Norwegian community. Continue ahead on U.S. Highway 18-151.

197.9 Turn right (northwest) on road to "Cave of the Mounds". See Figure 1 of narrative report by Black on Blue Mounds for a map of the area.

198.2 Cave of the Mounds. Continue on Highway. Note sink holes and silicified blocks of the Niagara dolomite especially on left (south) side.

198.5 Turn right on County Highway F. This is the approximate base of the Maquoketa Shale (Upper Ordovician) which is exposed in the road ditches. Thin seams of dolomite are characteristic.

199.3 Buses will stop on the roadway on East Blue Mound so we may get off briefly. The buses will turn around in the County Park 0.2 mile ahead (north) and return for us. This is Stop 6A.

STOP 6A - East Blue Mound: SW$\frac{1}{4}$, NW$\frac{1}{4}$, Sec. 5, T 6 N, R 6 E, Blue Mounds topographic quadrangle. See narrative report by Black, Part H, particularly Figure 1.

Arrive - 8:15 A.M. Depart - 8:30 A.M.

East Blue Mound, about 1,490 feet above sea level, has an unusually large flat top cut into the Maquoketa shale (Upper Ordovician). Blocks of silicified Niagara dolomite are scattered thinly over the top and flanks of the mound. Dark yellow-brown loess (loamy silt) one foot to four feet thick, lies on top of the shale which has thin seams of dolomite at the surface. A few shallow depressions on the crest of the mound have standing water during much of the year.

The summit of West Blue Mound is 1.6 miles west and is separated from East Blue Mound by the headward reaches of steep north-flowing tributaries of Blue Mounds Creek that empties into the Wisconsin River about 11.5 miles north. The summit of West Blue Mound is much smaller than the summit of East Blue Mound, yet it is 1,720 feet above sea level. It is capped with Niagaran dolomite (Silurian) of which the upper 75 feet is entirely silicified. It also has 1 foot to 3 feet of loess on its rounded oval top. West Blue Mound is an outlier of the Niagara escarpment about 50 miles to the southwest in Illinois and Iowa and about 70 miles eastward in southeastern Wisconsin.

The erosional history of the area is not well understood. When and how did East Blue Mound lose its cap of Niagara dolomite? Was it silicified as is that on West Blue Mound? These and other questions are discussed in the narrative report on Blue Mounds. It is concluded that we can't really answer these questions until further facts are available. Black calls on glaciation to help strip the Niagara dolomite and upper part of the Maquoketa shale from East Blue Mound, but no definite proof has been found.

199.7 Board buses, now heading south on County Highway F, where we got off.

200.5 Turn right (west) on County Highway F.

201.0 RR underpass. Turn sharp right (northwest), and drive westward through the town of Blue Mounds.

201.4 Turn right (north) on access road to West Blue Mound. Pitted hillside on left (west) resulted from early prospecting for lead and zinc.

201.9 Turn left. Note kettles and dark red residuum.

202.2 Enter Blue Mounds State Park. Note blocks and rubble of silicified Niagaran dolomite on both sides of road.

203.0 STOP 6B - West Blue Mound, east side parking lot: NE$\frac{1}{4}$, NW$\frac{1}{4}$, Sec. 1, T 6 N, R 5 E, Blue Mounds topographic quadrangle. See narrative report by Black, Part H.

Arrive - 8:45 A.M. Depart - 9:15 A.M.

We will leave the buses and walk up the observation platform for a view of East Blue Mound and the surrounding terrain cut into the Platteville-Galena dolomite and St. Peter Sandstone. The short steep north-flowing tributaries to the Wisconsin River are in marked contrast to the long gentle tributaries southward to the Pecatonica-Rock Rivers. Blue Mounds Creek north of the Mounds has much chert rubble (Dury, 1964), but the headwaters of the Pecatonica River to the south do not (Palmquist, 1965). Blue Mounds Creek is thought to be younger and more competent to move the chert rubble than the headwaters of the Pecatonica River. The discrepancy has not been explained.

The chert rubble around West Blue Mound is concentrated in block fields considered periglacial in origin (Smith, 1949). No studies have been made of their stability nor, even in recent decades, of their distribution. They are found up to one mile from the cap with seemingly little regard for slope angles. Colluviation seems to be exhuming some. The time of their origin is not known. If glaciation removed the partly silicified cap from East Blue Mound, then supposedly the chert rubble around West Blue Mound formed since. An Altonian glaciation terminating 30,000 years B.P., would require movements averaging two inches per year. Large blocks in an experimental site near Black Earth are moving now only one-tenth of an inch per year. A pre-Wisconsinan time can neither be supported nor denied.

203.2 If visibility warrants, a very rapid stop will be made at the observation platform at the west end of West Blue Mound.

<u>STOP 6C</u> - West Blue Mound, west side parking lot: SW$\frac{1}{4}$, NW$\frac{1}{4}$, Sec. 1, T 6 N, R 5 E, Blue Mounds topographic quadrangle. See narrative report by Black, Part H.

Arrive - 9:20 A.M. Depart - 9:30 A.M.

Small outliers of Niagaran dolomite may be seen to the southwest. The upland profile to the west was called the Dodgeville-Lancaster peneplain (Trowbridge, 1921) which is in disrepute (Thwaites, 1960; Palmquist, 1965).

One definite Precambrian pebble of distinctive siliceous conglomerate was found by Black under 18 inches of loess on the very top of West Blue Mound. The profile did not seem disturbed. Significance of the pebble is not known; nothing like it has been found since. Glaciation certainly can not be proved by evidence in the Blue Mounds area. However, the erosional history seems anomalous yet ignored.

203.4 Leave top of West Blue Mound.

204.2 Leave Blue Mounds State Park.

205.0 Turn left (east) on U.S. Highway 18-151.

205.5 Turn right (south) on County Highway F. Notice the thin loess and paucity of clay and chert residuum on the Galena Dolomite uplands to the south. Numerous rock cuts on both sides of the bus will show this almost to Stop 7. Individual exposures will not be singled out.

206.8 Continue straight ahead on County Highway Z; County Highway F turns right (southwest).

207.8 Small meanders in colluvium-alluvium derived largely from loess are seen on right (west). This creek is typical of the lower-order tributaries on the upland.

208.1 The road crosses to the left (east) side of the creek. St. Peter sandstone crops out on right. Many more exposures of the sandstone in the valleys and of the dolomite capping the uplands can be seen to the south.

210.5 Junction with County Highway E. Turn right (west) on County Highway Z.

210.6 Turn south on County Highway Z.

211.4 View of uplands to left (east).

211.8 Norwegian Lutheran Church started services on May 27, 1852. The first in the area.

212.1 Turn left (east) on County Highway Z. View left (north) to Blue Mounds.

212.4 Turn right (south) on Wisconsin Highway 78. Loess visible in road ditch at corner.

213.4 Junction County Highway A and Wisconsin Highway 78 in Daleyville. Turn left on Wisconsin Highway 78. Perry Lutheran Church at intersection is built of Galena Dolomite. Many exposures of St. Peter Sandstone may be seen to south.

216.7 Pleasant Valley Creek.

217.8 Enter Green County.

218.4 Turn left (east) on Wisconsin Highway 39. York Memorial Church is built of local Galena-Platteville dolomite. Numerous quarries may be seen along the route eastward, which also provides excellent views of Blue Mounds, 13 miles to the north.

222.7 Turn right (southwest) on County Highway J.

232.6 STOP 7 - Tertiary residuum: NE$\frac{1}{4}$, SW$\frac{1}{4}$, Sec. 30, T 3 N, R 7 E, Monroe topographic quadrangle. See narrative report by Black, Part I, particularly Figure 1 for a topographic map of the area.

Arrive - 10:15 A.M. Depart - 10:45 A.M.

Red clayey residuum and chert rubble from the solution of the Platteville-Galena dolomite have been seen from the bus at various places since we left Blue Mounds. However, the amount remaining on the flat uplands is very small in most places. Stop 7 contains the thickest section south of the Wisconsin River.

Results of various tests of one sample of clay from Stop 7, by Lee and Jackson, are summarized in Figure 2 of the narrative report by Black. Montmorillonite and chlorite are relatively abundant. No tests for vertical or horizontal variations have been undertaken at this site, and only limited studies have been made elsewhere in Wisconsin (see narrative report by Black on "Residuum and ancient soils of the Driftless Area of southwest Wisconsin"). The chert at Stop 7 has not been examined.

At Stop 7 most of the Galena Dolomite has been eroded. If we assume, on the basis of very limited data, that one foot of residuum represents about five feet of the original rock, then solution of only about 40 feet of dolomite is required for this deposit. Much more has been lost from the area. When and how was this accomplished? We don't know. On the basis of present rates of solution--say 0.5 inch per 1,000 years, the deposit represents:

$$\frac{40 \times 12 \times 1{,}000}{0.5} = 960{,}000 \text{ years}$$

As the deposit is truncated and solution rates diminish with cover, the deposit is much older. We seem reasonably safe to think of it as a holdover from a Tertiary weathering cycle.

Tertiary weathering has long been thought to yield kaolin rather than montmorillonite and chlorite. The end product of Pleistocene clay alteration is not markedly different from that of the clays in the residuum (Akers, 1961; Jackson, 1965). This makes truncated, patchy, buried soil profiles difficult to interpret and to date in southwestern Wisconsin.

Primary Leader, STOPS 8-11, Ned K. Bleuer

Mile

232.6 Continue ahead (south) on County Highway J. Red clay and chert residuum can be seen in several road cuts in the next two miles.

235.1 School Creek. Stratified brown silt overlies the pre-agricultural black A1 horizon in creek bank on right (west). Platteville Dolomite overlies St. Peter Sandstone on left (east).

237.8 Turn left (southeast) on Wisconsin Highway 81.

238.8 Junction with County Highway Y. Continue on Wisconsin Highway 81.

238.9 Turn right (south) on town road. Monroe is two miles to the southeast.

240.4 Turn right (west) on Wisconsin Highway 11.

Route is on the Platteville-Galena dolomite upland. To the north of this drainage divide is the Driftless Area; to the south is the area of "older" drift. The ridge has crest elevations ranging from 1060 to 1080 feet, higher than any ridge crests in the glaciated area to the southeast. The glaciated area between Monroe and the Sugar River to the east is like the Driftless Area in general character, being a maturely dissected dolomite landscape with little noticeable evidence of glaciation. However, in the glaciated area relief is slightly less, slopes are generally less steep, and drainage density is slightly lower.

The ridge one mile to the south (left) paralleling our route is made up mostly of lacustrine silts and sands and overlying outwash gravels that were deposited in waters dammed between the ice front and this upland.

243.2 Turn left (south) on town road.

244.0 Turn left (east) on town road. Gravel-capped ridges may be seen ahead.

245.5 Gravel pit on left (north) side of road.

STOP 8 - West Monroe Drift Sections. Monroe topographic quadrangle. See narrative report by Bleuer, Part J, for details and regional discussion.

Arrive - 11:15 A.M. Depart - 12:00 Noon

The Monroe ridges visited at this stop were recognized by Chamberlin and Salisbury (1886) as the southeast boundary of the Driftless Area. The ridges are composed of lacustrine sands,

WEST MONROE SECTION I

SW¼, SW¼, SE¼, Sec. 5, T 1N, R 7E; two miles west-southwest of Monroe; in roadside gravel pit.

Pleistocene Series
Wisconsinan Stage
Woodfordian Substage
Peoria Loess

4. Loess, silt loam to silty clay loam, thin variable thickness, 10YR 6/4-5/4, entirely within modern Alfisol.

Total: 0.5-2.5'±

Illinoian (or older) Stage

3. Sand, gravelly, calcareous from base of loess in 12' high north wall, where surface is eroded. In south wall, 50'+ wide x 20'+ high, gravel grades to sand eastward, upper 1-4' is noncalcareous with 5YR clay loam matrix, grading downward to partially leached, disrupted gravel 12' + thick with heavily corroded dolomite pebbles, and included masses of stratified sand and silt. Base of gravel at 10'+ marked by 10" ± stratified silt, dipping gently eastward; 6-10'± of in situ gravel lies below silt to pit floor. Transverse north-south cut between south wall and road in 1967 showed the upper heavy paleosol thickening, with apparent shearing, from 4' to 10' southward; base of corroded cobbly dolomite gravel dips 18' to road and contains irregular scattered masses of heavily altered gravel as in upper part, elongate "cobbles" of stratified sediments dipping southeastward, granular, disaggregated intermediate to basic igneous cobbles stretched and dipping southeastward, several blobs and lenses of fissile calcareous, oxidized Ogle-type till (s-51%, si-45%, c-4%), largest mass an irregular 2'x1.5'.

Total: 18'+

2. Silt, sand, alternating, in two power-auger holes.

Total: 45'+

1. Clay, silty, unoxidized, calcareous, basal material in two power-auger holes. Refusal.

Total: 8'±

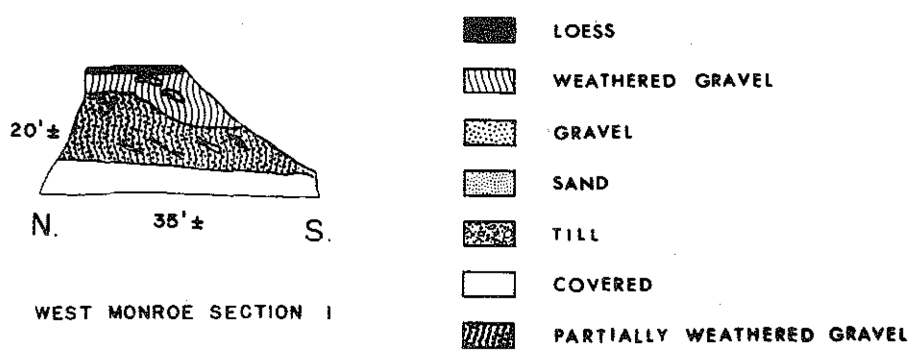


Fig. 7. West Monroe Section I

WEST MONROE SECTION II

NE$\frac{1}{4}$, SW$\frac{1}{4}$, SE$\frac{1}{4}$, Sec. 5, T 1N, R 7E; two miles west-southwest of Monroe; pit in crest of gravel ridge, 390'$\pm$ long (NNWxSSE), 220'$\pm$ wide, described summer 1967; lower pit opened and described fall, 1968.

Pleistocene Series
Wisconsinan Stage
Woodfordian Substage
Peoria loess

4. Loess, silt loam to silty clay loam, 10YR 5/4-4/4, entirely within modern alfisol.
Total: 0-4'$\pm$

Illinoian (or older) Stage

3. Gravel, till, sand, silt, upper 1-3' below loess is clay and iron oxide enriched, leached, 5YR - 7.5YR 4/2, with local mixing and contortion; north quarter of east face and north face show 10'+ medium outwash gravel over 25'+ fine- to medium-grained sand with interbedded silt, massively cross-stratified and ripple- bedded; south 200' of east face shows shear planes dipping 40° $\pm$ to east and southeast; sheared section is alternating fine gravels, sand, laminated and massive silts and till composed of various admixtures of these materials; intersheared gravel wedges increase in abundance northwestward until section grades to sheared and contorted gravel, and finally to undisturbed gravel.
Total: 25'$\pm$

2. Sand, interbedded silt, festoon cross bedding common at all scales; new lower cuts below south end of pit expose 30'+; earlier power augering on upper pit floor penetrated 40'+.
Total: 40'+

1. Clay, silty, unoxidized, calcareous at base of power auger hole. Refusal.
Total: 10'$\pm$

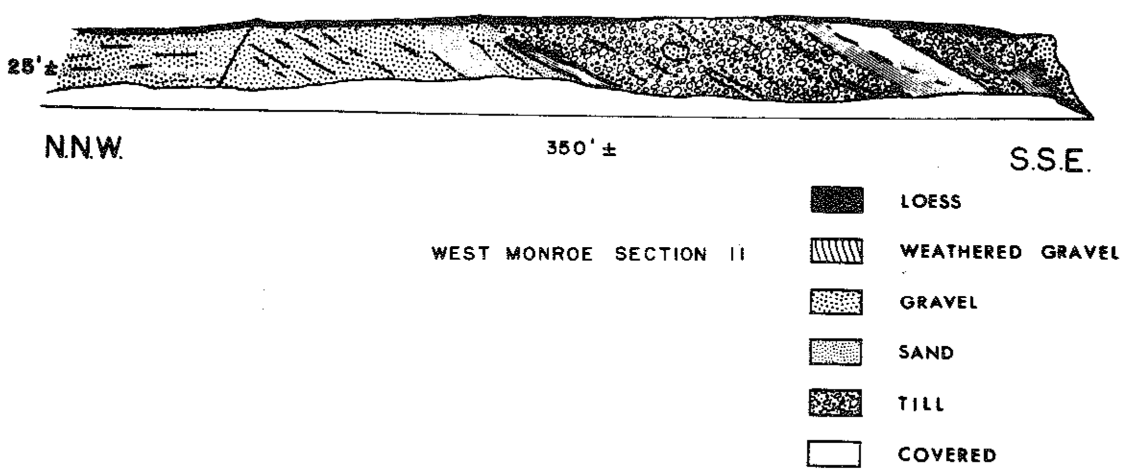


Fig. 8. West Monroe Section II

ALTERNATE STOP 8
NORTH JUDA SECTION

SW$\frac{1}{4}$, SE$\frac{1}{4}$, SW$\frac{1}{4}$, Sec. 36, T 2N, R 8E; 3/4 mile northeast of Juda; Brodhead, Wis.-Ill. 15' quadrangle; north wall of abandoned gravel pit on southwest slope of bedrock upland, 75' above Juda Branch.

Pleistocene Series
Wisconsinan Stage
Woodfordian Substage
Peoria loess

6. Loess, silt loam to silty clay loam, noncalcareous, 10YR 4/4-5/4 entirely within modern alfisol.

Total: 3'$\pm$

Altonian Substage

5. Sand, fine grained with interbedded silt, calcareous except in IIB3 in upper 1.9', predominantly sand in upper half, mostly gray-orange ground water-streaked silt in lower half scattered cross-stratification dips westward; basal 0-1' marked by prominent stone line with cobbles to 1' in diameter.

Total: 3.3'$\pm$

Illinoian Stage (?)
Jacksonville Substage (?)
Ogle till (in part secondarily deposited ?)

4. Till (?), irregularly interstratified with alternating silt or fine sand, noncalcareous, upper 2' loamy sands to sandy clay loam, with stratification controlling variable colors, 5YR 5/4-6/8 to 10YR 6/4, pebbles scattered throughout give till texture to most parts, abrupt lower boundary with solifluction (?) overfold to southeast, downslope. Lower 3.3' sandy loam, streaked with sandy silt bands, 10YR 6/4 streaked dark brown to red following textural changes; scattered pebble-rich zones.

Total: 5.3'$\pm$

3. Silt, bedded, noncalcareous, with scattered pebbly till-like layers, 10YR 6/4, streaked 5YR with ground water bands.

Total: 1.3'$\pm$

2. Transitional zone, complexly interbedded, oxidized silt, pebbly, few gravel lenses angling up from below.

Total: 1'$\pm$

Yarmouthian Stage (?)
Kansan Stage (?)
Juda gravel (informal new name)

1. Gravel, massive, multicolored matrix; dolomite pebbles rotten to 15'+ and igneous cobbles and pebbles disaggregated; clay and iron oxide accumulation heavy, 5YR colors in upper 17" above $\frac{1}{2}$-1" iron oxide band, alteration decreases gradually through 7'$\pm$ becoming slightly calcareous; gravel beds at east and dip westward.

Total: 15'+

Eroded south face shows thin loess over unaltered gravelly sand. Roadcut exposures west of pit and power auger holes nearby show definite Ogle till over bedrock.

silts, and clays overlain by coarse outwash. All these materials were overrun by glacial ice that complexly sheared and folded them. Blobs of calcareous sandy Ogle till have been emplaced within a well developed, sheared and over-thickened paleosol in the gravel. Unfortunately, the thick paleosol and the Ogle till will probably not be seen.

The purposes of the stop are to point out the possible stratigraphic relationships between this drift and the Ogle and Winslow tills, Illinoian (?) units correlated into the area from Illinois, and to emphasize the difficulties involved in interpreting weathering profiles in single exposures in this area.

245.5 Continue east on town road.

246.0 Honey Creek. The drainage is partly obstructed for several miles downstream at isolated dams of stratified fine-grained sediment.

246.2 Crossroads. Ridge on right (south) and left (north) is composed of stratified material like that seen at Stop 8.

247.3 Turn left (north) on Wisconsin Highway 69.

247.8 Turn right (east) on 30th Street.

247.9 Swiss Wheel Restaurant. LUNCH STOP.

Arrive - 12:15 P.M. Depart - 1:15 P.M.

Continue east on 30th Street.

248.1 Turn left (north) on 15th Avenue.

248.7 Turn right (east) on 20th Street.

249.0 Turn left (north) on 17th Avenue.

249.2 Turn right (east) on 16th Street.

249.4 Turn left (north) on 20th Avenue.

250.1 Turn right (east) on Wisconsin Highway 59 and follow it in a general northeasterly direction toward Albany.

252.5 Cross drainage divide. Drainage south and west is to the Pecatonica River and drainage north and east is to the Sugar River. The three ice advances affecting the area between the Sugar River and Monroe, represented by the Ogle, Winslow and Argyle tills, moved across or up drainage lines, creating proglacial lakes at various elevations and of different extent. The divide is breached at the head of Juda Branch, 4.5 miles southeast of here, at an elevation of 920 feet. It is likely that breach was the outlet of one or more proglacial lakes in the

Sugar River basin, or of Glacial Lake Brodhead (Leighton and Brophy, 1966). The dolomite landscape is essentially drift-less between Monroe and Stop 9.

258.4 Searles Creek. About one mile north (obliquely left) of here the preglacial valley is dammed by drift and the creek has been diverted through a small bedrock gorge. Diversions of this type characterize the area between the Sugar River and Monroe.

262.6 Turn right (south) into gravel pit and town dump.

263.0 STOP 9 - Near south end of Albany pit: SW$\frac{1}{4}$, NW$\frac{1}{4}$, Sec. 32, T 3 N, R 9 E, Brodhead topographic quadrangle. See narrative report by Bleuer, Part J, for details and regional significance.

Arrive - 1:45 P.M. Depart - 2:30 P.M.

The gravel ridge is an eskerine (?) form which rises from the Woodfordian fill in the Sugar River valley to the southeast and crosses bedrock hills of St. Peter Sandstone to the north. Water flow was northward. The gravel is probably a correlative of either the Ogle till (Illinoian ?) or the Juda gravel (Kansan ?) that will be seen at Stop 10.

This section is visited to show a Sangamonian or older weathering profile on gravel, to point out the problems involved in interpreting such profiles and to show one or more ice-wedge casts, indicative of post-Sangamonian periglacial conditions.

263.0 Return to Wisconsin Highway 59.

263.4 Turn right (east) on Wisconsin Highway 59.

264.5 Turn right (south) on County Highway F.

The Sugar River outwash surface, of Woodfordian age, is on the left (east). Here the valley is little more than one mile wide. One mile to the north, in Albany, the Sugar River has been diverted, probably by an ice block to a narrow channel cut through sandstone bedrock. The outwash surface passes to the east of town. The upland topography is developed on the St. Peter Sandstone, except on very narrow ridge crests of Platteville-Galena dolomite extending from the uplands to the west. Erosion of the differentially cemented sandstone produces an undulatory surface that in places can be mistaken easily for eroded kame or moraine topography.

268.1 Searles Creek. Searles Creek descends from the dolomite uplands 3 to 4 miles to the northwest onto an outwash-lacustrine (?) flat, over a mile wide, that can be seen in the distance to the right (west). Glacial deposits, now blocking the lower course of this former valley, will be seen at Decatur School and Stop 10 ahead. The creek was diverted to the east and cut a narrow, sinuous gorge through sandstone bedrock to intercept the Sugar River.

SOUTHWEST ALBANY SECTION

Pleistocene Series
Wisconsinan Stage
Woodfordian Substage
Peoria loess

4. Loess, silt loam to silty clay loam, noncalcareous, entirely within modern alfisol. Thickness highly variable. At center of east wall of north pit loess overlies unaltered gravel; laterally it overlies intensely weathered gravel or sand.

Total: 1-7'+

Altonian Substage (?)

3. Silt, only in southeasternmost wall, medium- to fine-grained, 10YR 6/4-4/4, calcareous with scattered interbedded sand, finely laminated, poorly developed stone line at base; dip about 10° NNE; grades upward into loess at south ridge crest; elsewhere upper surface covered; overlies weathered sand of unit 1 at south ridge crest.

Total: 0'2.5'+

2. Sand, fine- to medium-grained, 10YR 6/4, noncalcareous, well sorted. Occurs in stratified deposit up to 3' thick and 12' wide over calcareous gravel at north end of south pit; appears continuous with sand filling small ice-wedge cast. At least two other places show larger casts, truncated by colluvium and loess, usually in intensely weathered gravel. The casts cut and upturn stratification of host gravel. Relationship to unit 3 unknown.

Total: 0-4'

Illinoian (or older) Stage

1. Gravel, with interbedded sand; planar dips in gravel beds and cross-stratification in sand are northward; abundant faults, slump and depressional fill features. Gravel dips steeply northwestward from south ridge crest and is unconformably overlain by at least 10' of horizontally stratified, oxidized, leached medium-grained sand that pinches out onto crest. Lower part is gleyed and overlies 2' of leached, oxidized, clay-enriched gravel. Exposed gravel crest shows no gravel weathering under thin loess. Elsewhere gravel may be intensely weathered, iron stained, leached, and clay enriched with matrix of sandy clay loam, colors to 5YR 5/6-4/6, and thicknesses 0-12'±.
25'+ fine gravel encountered in power auger hole, at base of south end of north pit.

Total: 60'+

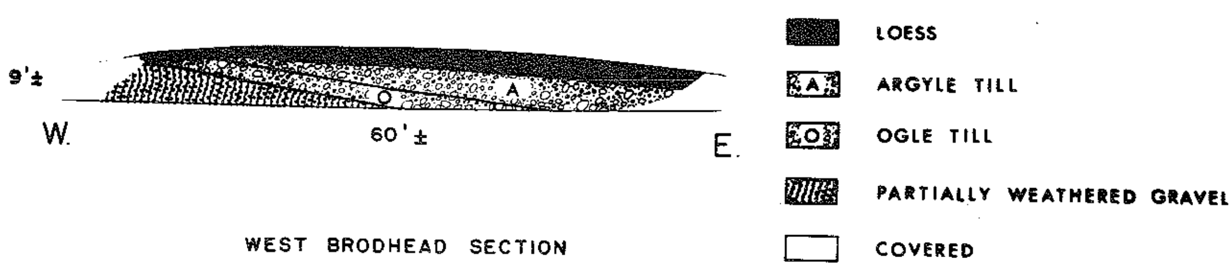


Fig. 9. West Brodhead Section

WEST BRODHEAD SECTION

Pleistocene Series
Wisconsinan Stage
Woodfordian Substage
Peoria loess

4. Loess, silt loam, noncalcareous, entirely within modern mollisol.

Total: 1.6'±

Altonian Substage
Argyle till

3. Till, IIB2 and IIB3 in upper 0.5-0.9'±; sandy loam, calcareous, 7.5YR 8/4 (dry), 7.5YR 7/6 (moist), friable, very pebbly, cobbly; sharp basal contact; expands to 2.6' thick about 20' east of crest; base of till rises to west, pinching out west of center of cut where loessal soil extends into Ogle (?) till.

Total: 1.3-2.6'±

Illinoian (?) Stage
Jacksonville Substage
Ogle (?) till

2. Till, sandy loam, 10YR 7/4-8/3 (dry), 10YR 6/4 (moist), friable, thin weak fissility, less stoney than till above; abrupt contacts above and below; base rises to west, intersecting west slope, where it pinches out and loessal soil extends into gravel below.

Total: 2.5'±

Yarmouthian (?) Stage
Kansan (?) Stage
Juda (?) gravel

1. Gravel, medium gravel and (or) medium-grained outwash sand; IVB2b (?) in upper 0.2-0.5', generally absent; 5YR 5/6, leached, medium- to coarse-grained sand, sandy clay loam matrix, abundant dolomite pebble ghosts; IVB3b (?) in remainder of exposed gravel; oxidized, calcareous, slight iron oxide coatings on sand grains; dolomite pebbles in upper 0.5-0.8' are ghosts; most below have partially leached rinds.

Total: 3.7'±

1967 power augering on south side of road penetrated 1'± loess, 3'± leached gravelly sand, 15'± fine gravelly sand, 34'± medium-grained sand.

UNIT	DEPTH FROM TOP OF UNIT	% < 200 MESH CO_3 CALCITE-DOLOMITE TOTAL	GRAIN SIZE GRANULE-SAND-SILT-CLAY	PEBBLE CONTENT: LIMESTONE	NIAGARAN DOLOMITE	DOLOMITE	CHERT	CLASTIC	ACID IGNEOUS	BASIC IGNEOUS	METAMORPHIC
ARGYLE TILL	10" 2' 6"	2-46-48 6-48-54	4-68-24-8 4-67-25-8	1	44	42	7		1	4	1
OGLE TILL	5" 12"	0-36-36 0-36-36	1-56-37-6 1-53-34-16		4	71	15	1	3	3	3
JUDA GRAVEL?					1	67	26	3		3	

Table 1. West Brodhead Grain Size and Pebble Data

268.9 Cross kame ridge at Decatur School.

Sand in these ridges is leached only a few feet under thin loess and appears to be equivalent to the lower gravel that will be seen at Stop 10.

269.4 Buses will stop on Wisconsin County F at the "T" intersection. We will walk to the road cut about 50 yards to the right (west) of that intersection.

STOP 10 - West Brodhead Section: SE$\frac{1}{4}$, SE$\frac{1}{4}$, SE$\frac{1}{4}$, Sec. 20, T 2 N, R 9 E, Brodhead topographic quadrangle. See narrative report by Bleuer, Part J, for further details.

Arrive - 2:45 P.M. Depart - 3:15 P.M.

This section is the most striking multiple till exposure in southern Wisconsin. It shows (in descending order) Woodfordian Peoria loess, Middle Altonian Argyle till, and Illinoian Ogle (?) till (which are units correlated from Illinois), and Kansan Juda (?) gravel, a new informally named unit.

The gravel is altered, suggesting Yarmouthian weathering, but the alteration could also be ascribed to groundwater movement. The Argyle till is typical of that exposed in several places in the prong west of the Sugar River, being sandy, pink, and rich in Niagaran dolomite pebbles. The lower, less sandy yellowish-brown till is correlated with the Ogle till- despite the lack of a paleosol at its surface - simply because of the closeness of this site to the typical Ogle till on the uplands to the south and west. The Janesville till (a new informally named unit) on the east side of the Sugar River has characteristics similar to those of the Ogle till and also seems to be older than the Argyle till. Unfortunately, the stratigraphic relationship between the Ogle till and the Janesville till is still not clear.

269.4 Turn left (east) on County Highway F.

271.1 Cross line of kames. The stratigraphic relationship of these materials to those at Stop 10 is unknown.

271.4 Descend onto the Sugar River outwash surface. Surface widens abruptly to three miles at Brodhead.

272.8 Turn left (north) on Wisconsin Highway 11.

273.0 Turn right (east) on Wisconsin Highway 11.

273.5 Enter Rock County.

275.0 Cross line of sand kames (?). The stratigraphic relationship of these materials, and a till associated with them, is uncertain.

NORTH ORFORDVILLE SECTION

Pleistocene Series
Wisconsinan Stage
Woodfordian Substage
Peoria loess
5. Loess, silt loam, noncalcareous mollisol in upper 3.2'+.

Total: 0.8'-4'±

Altonian Substage
4. Sand, fine- to medium-grained, dark silty matrix, filling small former ice-wedge truncated by loessial topsoil.

Total: 0-3'±

Janesville gravel
3. West half exposure - gravel, medium to coarse, heterogeneous, IIB2 in upper 1.5'; 1969 face showed gravel and sand giving way abruptly eastward to intensely altered zone described below; earlier faces showed gravel grading eastward to unaltered, westward dipping stratified gravel.
East half exposure- iron stained, leached gravel, gradational laterally to sequence described above, occurs as mass 15' in depth in deepest pipe-like extension, over 40' wide at top; parent material is a contorted, stratified gravel, dipping westward; thin iron-cemented layers are similarly contorted; parts resemble sandy till; leaching common several feet below zone of major iron staining; colors to 5YR 4/6; grades to in situ material near base; outside main mass are iron oxide coated, partially leached pipes of various sizes and orientations, rims of which cut across unaltered pebbles.

Total 15'+

Janesville till
2. Till, sandy loam (s-54%, si-34%, c-12%, average of 4 analyses), calcareous, increasing thickness west- southwestward to maximum of 4' in sheared thickened zone at west edge of pit wall below 10' intersheared till-gravel mixture; 10YR 6/4, weak thin fissility.

Total: 0.3-4'+

Janesville gravel (?)
1. Gravel, medium to fine, interstratified with thin bedded medium to coarse grained sand and pea gravel, vague imbrication of pebbles to east.

Total: 8'+

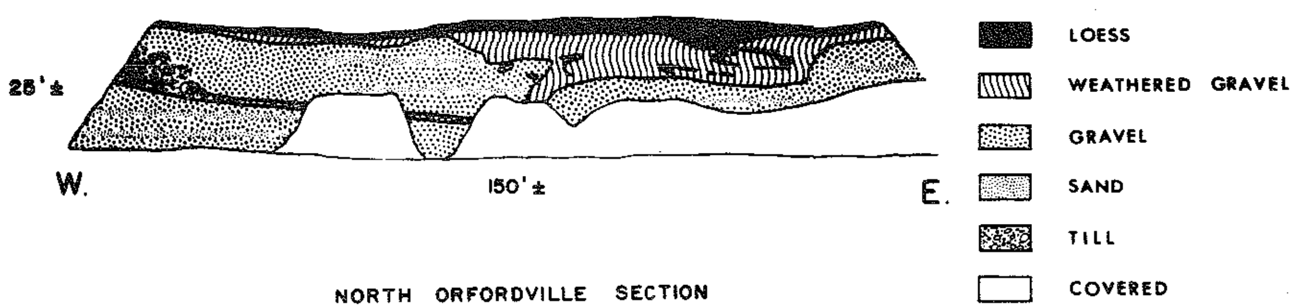


Fig. 10. North Orfordville Section

278.8 Turn left (northwest) on Wisconsin Highway 213.

279.1 Turn right (north) on town road.

281.1 STOP 11 - North Orfordville Section: NW$\frac{1}{4}$, SW$\frac{1}{4}$, NW$\frac{1}{4}$, Sec. 13, T 2 N, R 10 E, Brodhead topographic quadrangle. See regional report by Bleuer, Part J, for further details.

Arrive - 4:05 P.M. Depart - 4:45 P.M.

Massive, youthful-appearing gravel deposits, the southwestern-most known Janesville gravels, cap bedrock uplands at Orfordville and to the northeast. At this stop, a thin layer of Janesville till between two gravel units contains shear planes and micro fabrics indicating ice movement from the east-northeast. (In contrast, movement at Janesville was from the east-southeast). Water that deposited the lower gravels flowed westward. Poorly stratified ice contact gravel and gravelly till overlie the Janesville till and contain highly altered drainage "pipes". A large ice-wedge cast has been seen here, but is now gone.

279.3 Continue north on town road. The dolomite upland on the left is the west limit of significant topographic expression of the Janesville drift. The Janesville till is present in association with stratified materials in the eastward draining valleys.

282.6 Turn right (east) on County Highway B.

283.6 Bass Creek. The straightness and form of Bass Creek valley probably reflects glacial modification of a preglacial valley system.

A low esker (?) parallels the center of the trough, apparently issuing from a subdued group of kames 3/4 mile to the north and disappearing beneath Woodfordian valley fill about 2$\frac{1}{2}$ miles to the southwest. With Janesville ice apparently having entered this area from an easterly direction, water flow to the southeast during esker formation necessitates that stagnation of Janesville ice west of the Rock River occurred as a unit when subglacial discharge was able to drain out of the Bass Creek trough into the Rock River valley.

284.3 Turn left (north and east) off County Highway B onto town road.

284.4 Footville Monument on the right (south).

The Platteville Dolomite-St. Peter Sandstone contact is at the level of the top of the case-hardened sandstone pillar. This feature has been cited by some as evidence that this area has been free of ice and subject to subaerial erosion since Illinoian time. This seems unlikely, considering the apparent age of the surrounding Janesville drift.

Route into Janesville continues eastward over a dolomite upland capped patchily by Janesville till and kame gravel deposits.

288.3 Cross kame field of Janesville gravels.

288.6 Junction with Wisconsin Highway 184. Continue ahead (eastward).

289.6 Wisconsin Highway 184 goes left (north). Continue ahead (eastward) on town road.

290.2 Reference section for informally named Janesville till and Janesville gravel is in kame 1/4 mile on right (south).

294.5 Join Wisconsin City Highway 14. Continue ahead and angle right under RR bridge.

294.8 Turn left (northeast) on Wisconsin Highway 51.

294.9 Rock River.

295.0 Turn left (north) on Wisconsin Highway 51. Note various exposures of outwash gravel in terrace on right (east).

296.3 Turn right (east) on Black Road, on north side of Parker Pen Co.

296.4 Rise onto surface of Rock River outwash terrace.

296.6 From RR bridge view outwash apron to north to the Johnstown Moraine in the distance.

296.7 Pass gravel pit on right (south).

The economic importance of these valley-train deposits is obvious. The surface gravels have been considered the equivalent of the Johnstown Moraine of Late Woodfordian (Cary) age which is only a few miles to the north. However, various lines of evidence suggest that almost all the 400 feet of outwash in this valley predates the Johnstown Moraine.

297.5 Turn left (north) on Wisconsin Highway 26.

298.7 Turn right (east and southeast) on Wisconsin Highway 14.

301.1 Turn left (east) on County Highway A.

302.2 Cross local dolomite high.

303.0 Johnstown Moraine adjacent on left (north).

306.9 Johnstown Center.

Note massive northwestward-trending Darien Moraine (Delavan or Lake Michigan Lobe) ahead and to the right. It merges with the eastward-trending Johnstown Moraine (Green Bay Lobe) on the left. The re-entrant angle between the moraines at Richmond marks the southwesternmost extremity of the Kettle Interlobate Moraine.

311.8 Richmond.

Continue ahead on County Highway A through Millard and Tibbits to Wisconsin Highway 15 and follow it into Milwaukee City Center and the Hotel (about 45 miles). Arrival about 7:00 P.M. Total excursion 378 miles.

Part B

THE PLEISTOCENE GEOLOGY OF SOUTHEASTERN WISCONSIN--AN INTRODUCTION

by

Norman P. Lasca

CONTENTS

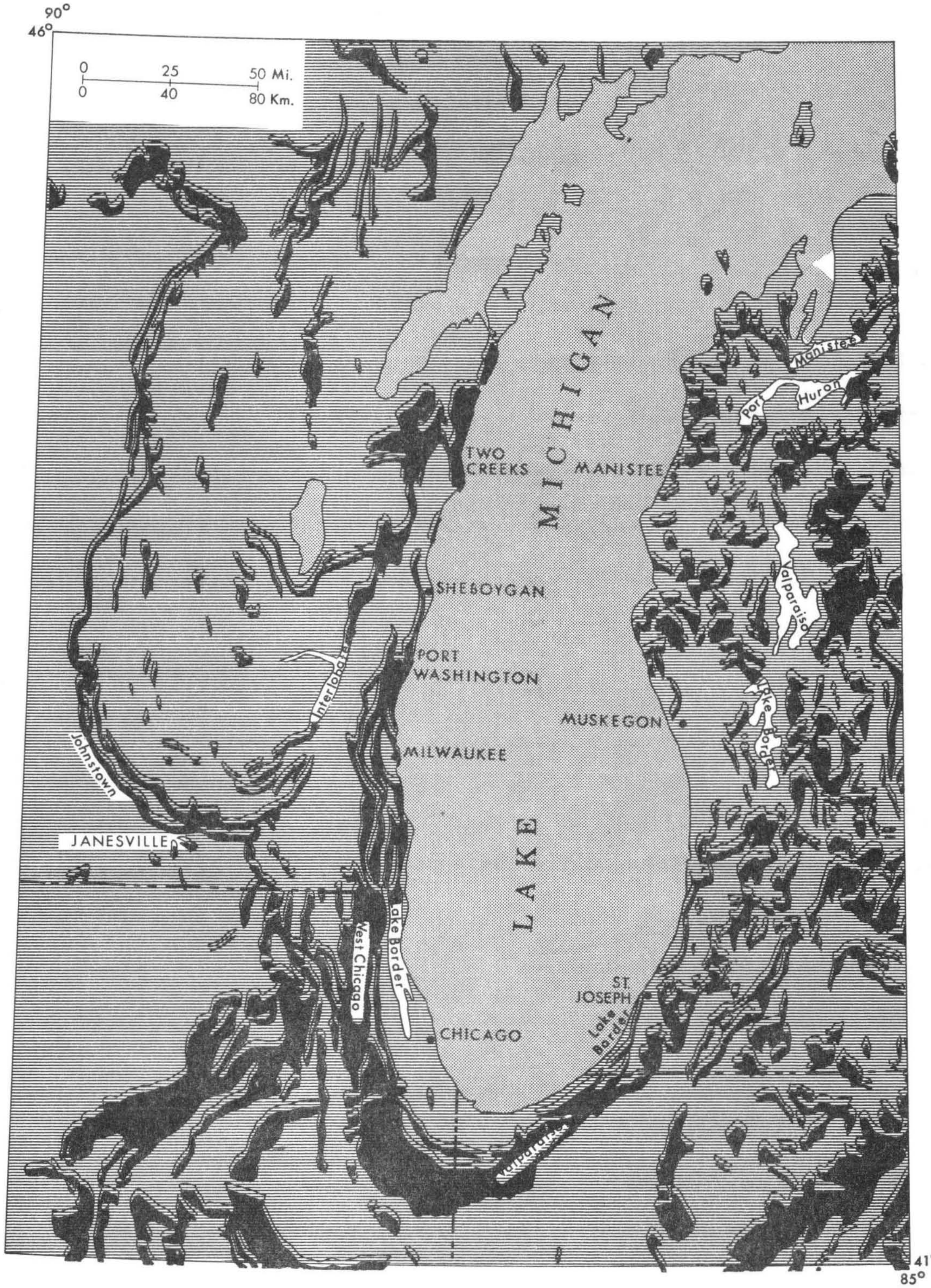


Fig. 1. End moraine systems in Wisconsin and adjoining states

THE PLEISTOCENE GEOLOGY OF SOUTHEASTERN WISCONSIN--AN INTRODUCTION

The Quaternary geology of southeastern Wisconsin was first studied in detail by Alden (1918) who defined the area as all parts of the state south of 44° N. latitude (Oshkosh) and east of 90° W. longitude (slightly west of the Wisconsin Dells, Baraboo, and Blue Mounds). Maximum relief is about 1,000 feet, but most commonly is less than 150 feet in the drift-covered area. Relief ranges from 100 to about 350 feet in the Kettle Interlobate Moraine. There are two drainage systems in the area: one tributary to the Great Lakes-St. Lawrence system, the other tributary to the Mississippi system. The underlying bedrock (Figure 4 of Road Log) is predominantly Paleozoic (late Cambrian to Devonian) sedimentary rocks, which form the west rim of the Michigan Basin, and consist of sandstones, limestones, dolomites, and shales. Precambrian rocks occur primarily in the extreme northwestern part of the area, and consist of igneous and metamorphic rocks.

The Pleistocene deposits of southeastern Wisconsin (Figures 2 and 3 of Road Log) are primarily Wisconsinan in age, although recent studies by Bleuer (this guide) report Illinoian and possible Kansan deposits further west in southern Wisconsin. The early Pleistocene history of the area is inferred from Bleuer's work and published studies done in the surrounding states.

Until recently the principal concerns of the glacial geologists in eastern Wisconsin were: (1) the Two Creeks forest bed (Goldthwait, 1907; Wilson, 1932, 1936; Thwaites and Bertrand, 1957; Broecker and Farrand, 1963) and (2) the problems of the ancestral lakes of the Lake Michigan basin (Leverett, 1889; Goldthwait, 1907; Alden, 1918; Bretz, 1953, 1964; Hough, 1958, 1963, 1966). In fact, although Chamberlin (1877, 1883a) discussed the Quaternary geology of eastern Wisconsin, it was left to Alden (1918) to map and interpret the glacial geology of southeastern Wisconsin. Since Alden's work, only a few specialized studies have been done (Kocurko, 1968; Bruning, 1970; Ghosh, 1970) or are in progress, and no general remapping has been attempted.

CLASSIFICATION OF THE PLEISTOCENE

Based on exposures in southeastern Wisconsin and in Illinois, Chamberlin (1894) named the last stage of continental glaciation the "East Wisconsin Stage", and in 1895, changed the name to "Wisconsin Stage." Chamberlin (1878, 1880) was apparently the first to differentiate glacial movements on the basis of topographic expression and to infer relative ages of deposits from weathering profiles. The initial basic subdivisions of the "Wisconsin" were made by Leverett (1899), who recognized four substages in the Early Wisconsin, and three substages in the Late Wisconsin. His subdivisions were not followed. Principal subsequent modifications to and correlations of the Wisconsin subdivisions were made by Alden (1918), Thwaites (1928, 1943), Thwaites and Bertrand (1957), Leverett (1929), Leighton (1933, 1957, 1960), Leighton and Willman (1950) and Frye and Willman (1960, 1963). The classification of the

Wisconsinan Stage (Figure 2 of Road Log) by Frye and others (1968) is used by most, but not all, geologists in Illinois and Wisconsin.

Under the present classification early Woodfordian "Tazewell" refers to: (1) deposits previously called Iowan in central Illinois, (2) all Tazewell deposits, and (3) "...the earliest Cary moraines as far as the morainal front represented by the Valparaiso and West Chicago moraines in Illinois and the Johnstown and correlative moraines in Wisconsin. /See Figure 1/ Middle Woodfordian 'Cary' refers to the deposits related to the Valparaiso, West Chicago, and Johnstown moraines as far as the front of the unnamed moraine at Sheboygan, /Port Washington/ Wisconsin Thwaites and Bertrand, 1957, Figure 1 ... but omits the youngest moraines that were generally included in the Cary before 1957.

"Late Woodfordian 'Mankato' refers to the deposits related to the unnamed moraine at Sheboygan, /Port Washington/ Wisconsin, and the younger deposits older than Two Creeks. Before 1957, these deposits were included in the Cary but were renamed Mankato when the type Mankato was found to be older than the Two Creeks deposits. In the pre-1957 literature, the term Mankato refers generally to the deposits younger than the Two Creeks deposits; they are /now/ called Valderan ..." /Frye and others, 1965, p. 53/.

PRE-WISCONSINAN DEPOSITS

Pre-Illinoian Pleistocene deposits most recently are reported from southern Wisconsin by Bleuer (this guide) who tentatively suggests that the informally named Juda gravel (Figure 2 of Road Log) is Kansan (?) in age. He reports that a paleosol is developed on top of the Juda gravel and that it is overlain by the Ogle till (?) of Illinoian age.

The Illinoian glaciation was first named by Leverett (in Chamberlin, 1896; Leverett, 1899), and the older drift in Wisconsin and Illinois was called "probable Illinoian" (Leverett, 1899). Illinoian drift was reported in northern Illinois and southeastern Wisconsin (Alden, 1918; Leighton and Brophy, 1961) but was later assigned a Wisconsinan age based on the work of Shaffer (1956) and Black (1962; see also Frye and Willman, 1960; and Frye, Willman, and Black, 1965). Bleuer (this guide) correlates drift in southern Wisconsin with the Illinoian drift of Illinois (Kempton, 1963; Kempton and Hacket, 1968a, 1968b; Willman and Frye, 1967; and Frye and others, 1969).

The Sangamon Soil, from which the Sangamonian Stage takes its name, was first named by Worthen (1873) and is found extensively in Illinois. Some Sangamonian deposits are reported from southern Wisconsin (Hogan and Beaty, 1963; Bleuer, this guide).

WISCONSINAN DEPOSITS

Although mention of the drift of southeastern Wisconsin occurs early in the literature, the first significant reference probably occurs in the report of Whittlesey (1851) in which the red and blue drift and lake clays of eastern Wisconsin and the Kettle Interlobate Moraine system (then called the "Potash Kettle country") are mentioned. Other geologists, such as Lapham (1847), Hall and Whitney (1862), and Bliss (1866), mentioned the glacial deposits in the area, but it was Whittlesey (1860, 1866, 1867) who first described the topography and origin of the Kettle Interlobate Moraine and provided general descriptions of three different drifts in Wisconsin. In 1869, Andrews challenged the theory that the Kettle Interlobate Moraine was of glacial origin, suggesting that it was formed by violent water action and that all the western drift was a water-laid deposit. Andrews' suggestion was not accepted. Whittlesey's concept of the origin of the Kettle Interlobate Moraine as due to glacial activity and the melting of ice blocks was accepted by Chamberlin (1877, 1878, 1880).

ALTONIAN SUBSTAGE

The Altonian Substage, named for the city of Alton, Illinois, is defined on the basis of the Roxana Silt (Frye and others, 1968) which lies conformably on Sangamon Soil. In Wisconsin, Black (1962) proposed the term "Rockian" for the latest Altonian advance. In southeastern Wisconsin, deposits of Rockian age are tentatively identified from Waukesha and Walworth Counties (west and southwest of Milwaukee respectively) where three radiocarbon dates were obtained from spruce (29,000 ± 900 B.P.: W-903; 30,800 ± 1,000 B.P.: W-901; and 31,800 ± 1,200 B.P.: W-638) found in an "oxidized sandy till and in overridden gravelly outwash" (Black and Rubin, 1967-68).

In southern Wisconsin Bleuer (this guide) describes and tentatively correlates with northern Illinois three Altonian units: the Capron till, the Argyle till, and the informally named Janesville till and gravel.

FARMDALIAN SUBSTAGE

The Farmdalian Substage is defined (Frye and Willman, 1960) as including the time of deposition of the Farmdale Silt and peat at its type locality along Farm Creek, east of Peoria, Illinois. No dated Farmdalian deposits occur in southeastern Wisconsin, but part of the thick outwash deposits in the southern part of the area were probably deposited at this time (Black, 1960b). From evidence in other areas of the State, during a portion of Farmdalian time in Wisconsin, there were cold climate, permafrost and periglacial phenomena (Black, 1964, 1965, 1969b, 1969c).

WOODFORDIAN SUBSTAGE

The Woodfordian Substage is named for Woodford County, Illinois (Frye and Willman, 1960) and is defined (Frye and others, 1968) "as the succession of rocks from the contact of Morton Loess on Farmdale Silt... upward to the base of the Two Creeks deposit ...." During Woodfordian time, the Wisconsinan ice, moving from the Lake Michigan and Erie lobes, reached its maximum extent in central Illinois between 19,000 and 20,000 radiocarbon years B.P. In both Illinois and Wisconsin the Woodfordian deposits were derived from many pulsations of the ice front. Although numerous radiocarbon dates help to establish the chronology in Illinois, none is available from southeastern Wisconsin as no organic remains have been found in the drift. The lack of radiocarbon dates continues to make correlation and dating of specific events difficult. As a result, separation of the Woodfordian glacial fluctuations is based primarily on morphology and directional indicators. Both are generally better than texture, lithology (clay minerals, carbonates, heavy minerals, etc.), and magnetic susceptibility in separating pulsations in a given sublobe (See discussion this guide; cf. Oakes, 1960; Olup, 1969).

The most prominent moraines in southeastern Wisconsin are those of middle Woodfordian time and include the Kettle Interlobate Moraine (Figure 1) formed by ice from Chamberlin's Second Glacial Epoch (1883a, p. 271f).

Late Woodfordian events are poorly understood in Wisconsin, and correlation of the Mankato and Port Huron moraines (Figure 1) of Minnesota and Michigan with moraines in Wisconsin remains conjectural.

Deglaciation of the Woodfordian ice in southeastern Wisconsin is time transgressive (cf. Black and Rubin, 1967-68), being earlier in the south than in the north. The conclusion is based on radiocarbon dates (Black and Rubin, 1967-68; Kocurko, 1968) and morphologic evidence of ice stagnation in the north.

TWOCREEKAN SUBSTAGE

The Twocreekan Substage (Frye and Willman, 1960) is named from the Two Creeks forest bed near Two Creeks, Wisconsin. The deposit at Two Creeks was discovered by Goldthwait (1907), but was not investigated in detail until later (Wilson, 1932, 1936); more recently, Thwaites and Bertrand (1957), West (1961), Broecker and Farrand (1963), and Black (1970) have reported on the locality.

Sequences somewhat similar to the type locality are found in other areas of Wisconsin; for example, the Ernst Brothers' sand and gravel pit--STOP 2 (see Part C by Lasca and Part D by Maher).

VALDERAN SUBSTAGE

The Valderan Substage was named by Frye and Willman (1960) and is based on the Valders till of eastern Wisconsin (Thwaites, 1943; Thwaites and Bertrand, 1957). "The base of the substage was defined as the contact of the Valders till on the Two Creeks deposits in east-central Wisconsin, but the upper limit was defined as an arbitrary radiocarbon age of 5,000 B.P." (Frye and others, 1968). To comply with the Stratigraphic Code, the upper limit was redefined as the top of the Cochrane till and its contact with post-Cochrane deposits described from the James Bay Lowland, Ontario, Canada (Hughes, 1956, 1965; Frye and others, 1968). At the present time the Valderan boundary in southeastern Wisconsin is being re-examined (see narrative report by Lasca this guide). The Valderan boundary, or "red drift," boundary of Alden (1918), was based on color alone, and Black (1966) demonstrated that color alone could not be used to distinguish Valderan deposits in northern Wisconsin or in Michigan's Upper Peninsula.

POST VALDERAN

In Wisconsin no radiocarbon dates record the withdrawal of the Valderan ice (Black and Rubin, 1967-68). Post Valderan time is distinguished by increasing temperatures and dryness. Pollen profiles indicate a vegetational change from spruce to pine and finally to the hardwood forests with some prairie vegetation (see, for example, West, 1961, and narrative report by Maher, this guide). The ice blocks left by the Valderan ice presumably melted over a period of several thousand years depending on their size and amount of burial. Subsequent fluvial erosion, mass wasting and weathering modified the topography forming the landscape we see today.

Part C

PLEISTOCENE GEOLOGY FROM MILWAUKEE TO THE KETTLE INTERLOBATE MORAINE

by

Norman P. Lasca

CONTENTS

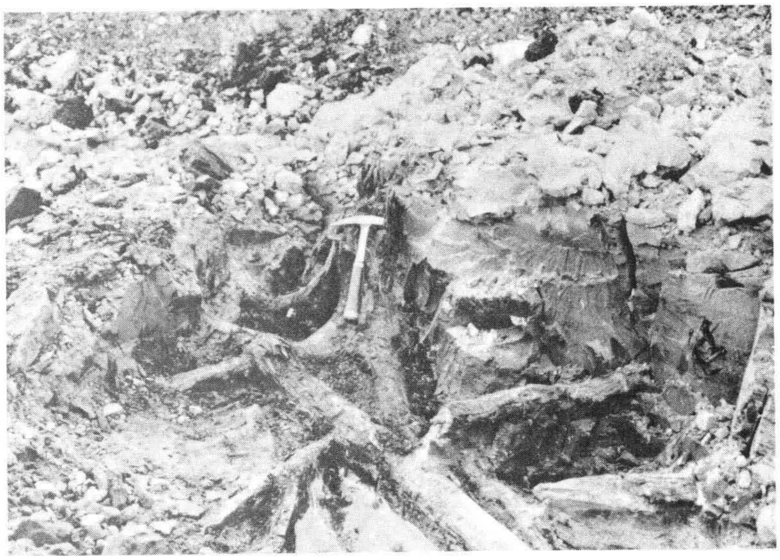


Figure 1. Stump from lower forest bed, Ernst Bros. pit. Compare Fig. 6, Part A. Photo by Kocurko, 1968.

Figure 2. Trench through Valderan and post-Valderan sediments. Ernst Bros. pit. Photo by Kocurko, 1968.

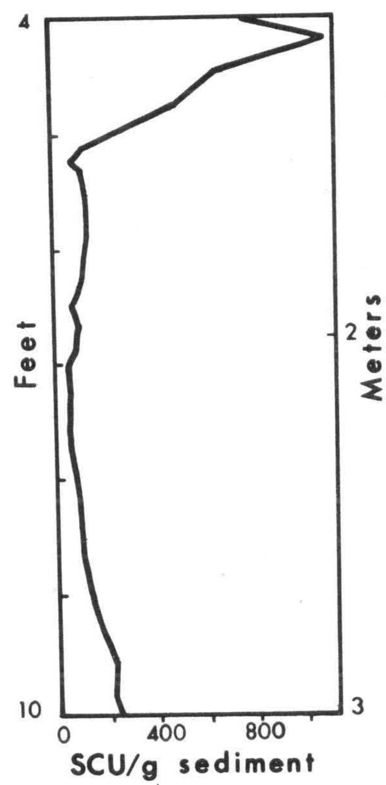


Figure 3. Sedimentary chlorophyl in pond sediments, Ernst Bros. pit. From Kocurko, (1968).

STOP 1. VALDERAN AND WOODFORDIAN DRIFT IN SOUTHEASTERN WISCONSIN

INTRODUCTION

Classical "red drift" (Alden, 1918) is exposed at the surface in part of southeastern Wisconsin. Alden's "red drift" was later named by Thwaites (1943, p. 136) as drift of the Valders (Valderan) glaciation which "...is readily distinguished from the Cary /Woodfordian/ till because it is red and contains much more clay."

West of the "red drift" lies the drift of the Lake Michigan glacier described by Alden (1918, p. 247) as "...bluish gray till of the ordinary type...." At present the red drift is generally referred to as Valderan, and the drift of the Lake Michigan glacier is referred to as Woodfordian.

THE "RED DRIFT"

Alden (1906, 1918) was the first to suggest that many of the red clay deposits in eastern Wisconsin were till and not lacustrine clays as had been suggested by Chamberlin (1877, p. 219-228). Alden (1918, p. 310-325) cited the following evidence for his conclusion: (1) stratified drift was overlain by red pebbly clay, (2) red pebbly clay was found at elevations above known lake levels, (3) the red clays contained erratics, and striated and glacially faceted stones, and (4) a series of parallel, moraine-like ridges consisting of red till. Thwaites (1943, p. 137) confirmed Alden's interpretation, citing as evidence "...disturbance of underlying deposits, and the termination of the red till in many places on ground higher than that outside its area."

Alden (1918, p. 313) described the red till as:

> ...varying from light terra-cotta red to brownish or purplish red, and on long exposure weathering to an ashen-drab. The color is very noticeable, giving a decidedly red tint to roads, excavations, and freshly plowed fields. In some places near the western margin of its area it becomes brownish or yellowish and is less easily distinguishable from the weathered part of the bluish till.

It was this till that Thwaites (1943) named Valders (Valderan) drift based on the type section at Valders, Wisconsin. Thwaites and Bertrand (1957), in northwestern Wisconsin, and Horn (1960), in Dodge County, reported the color of the Valders till as reddish brown (Munsell wet colors 5 YR 4/3 and 5 YR 4/4 respectively). These colors agree with my findings and those of Bruning (1970) from Ozaukee and Washington Counties.

THE DRIFT OF THE LAKE MICHIGAN GLACIER

Alden (1918, p. 323-324) describes the drift of the Lake Michigan glacier as:

> ...the bluish buff till sheet which was deposited by the glaciers of the later Wisconsin substage; and observations of this drift over thousands of square miles beyond the limits of the red-till area shows that it has been only very superficially modified by leaching and oxidation since its deposition. The stratigraphic relations and the conditions of deposition by the glaciers forbid any suggestion that the bluish till found beneath the red till is not the same as that exposed beyond its limits.

Elsewhere in Alden's report the till is described as:

> ...bluish-gray till of the ordinary type ... (p. 247) ...bluish till ... (p. 247) ... light bluish ... oxidized to light buff or even brownish ... (p. 251) ... buff-bluish till ... (p. 321) ... buff till ... (p. 323).

Alden's descriptions of the till based primarily on color are confusing and make correlation difficult.

Leighton (1933) correlated Alden's drift of the Lake Michigan glacier as Cary in age. Frye and Willman (1960) renamed the Cary drift "Woodfordian."

Many (Wilson, 1932; Thwaites, 1943; Murray, 1953; Thwaites and Bertrand, 1957; Black, 1966a, and 1970) have referred to the Woodfordian (Cary) till as gray (or shades of gray). By contrast, Horn (1957) described the Cary till in Dodge County, Wisconsin, as light yellowish brown or buff (Munsell wet color 10 YR 5/4) calcareous till derived from the underlying dolomite. Evenson (1970) found similarly colored till in the Woodfordian (Cary) drift of Jefferson County. In eastern Wisconsin, Peterson, Lee and Chesters (1967-68) described Cary till as yellowish brown in color which was easily distinguished from the reddish-brown Valders till. These colors agree with my findings and those of Bruning (1970) from Ozaukee and Washington Counties.

DIFFERENCES IN THE TILLS

Till color. Our investigations indicate that three basic till colors, with some local variations, are found in Ozaukee and Washington Counties.

Color A. Munsell dry color ranges from light gray (10 YR 7/2) to very pale brown (10 YR 8/3), and wet color ranges from light yellow brown (10 YR 6/4) to brown (7.5 YR 5/4). The most frequently observed dry color is very pale brown (10 YR 8/3), and wet is yellow brown (10 YR 5/4).

Color B. Munsell dry color ranges from pinkish gray (7.5 YR 7/2) to very pale brown (10 YR 7/3), and wet color ranges from reddish brown (5 YR 4/4) to dark brown (7.5 YR 5/4). The most frequently observed dry colors are light brown (7.5 YR 6/4) and pinkish gray (7.5 YR 7/2), and wet color is reddish brown (5 YR 4/4).

Color C. Munsell dry color ranges from light gray (10 YR 7/1) to very pale brown (10 YR 7/3) to brown 7.5 YR 5/4).

We believe that: (1) till color "A" is Alden's bluish-buff till, and that it is exposed at the surface throughout much of southeastern Wisconsin west of the red till (till color "B") (see also Horn, 1957, 1960); (2) till color "B" is the classic red drift or red till (Goldthwait, 1907; Alden, 1906, 1918; Wilson, 1932, 1936; Thwaites, 1943); and (3) till color "C", which we do not find exposed at the surface, is Alden's bluish-gray till underlying the red till near Lake Michigan.

Till of color "C" is found in some auger cores and underlies till of color "A" and "B" in several gravel pits, for example, the Ernst Brothers' sand and gravel pit (STOP 2). We find no red till (color "B") overlying buff till (color "A") anywhere in southeastern Wisconsin between Sheboygan and Milwaukee along the lake and west to the Kettle Interlobate Moraine. From the exposures we have seen in deposits of the Lake Michigan lobe, the red till overlies only gray till (color "C") in southeastern Wisconsin, except in areas where red till occurs in large isolated patches surrounded by buff till (color "A") and overlies outwash sediments. Note: The Oshkosh exposure (Alden, 1918, p. 323), in which red till overlies buff till, occurs in deposits of the Green Bay lobe. From this and other evidence (see discussion following) further investigations in southeastern Wisconsin appear necessary to establish the Valderan ice maximum, which at present is based on till color alone.

Iron oxide (Fe_2O_3). Our data from over 40 samples taken on both sides of the "red drift" (Valderan) boundary (Alden, 1918; see also Thwaites and Bertrand, 1957), in Ozaukee and Washington Counties indicate virtually no difference in iron oxide (Fe_2O_3) content. Bruning (1970) reports that iron oxide (Fe_2O_3) content ranges from 10.3 to 16.3 percent east of Alden's boundary, and from 9.0 to 15.0 percent west of that boundary. No apparent patterns or trends in iron oxide content were noted from the samples.

Preliminary studies (Ghosh, 1970) using X-ray analysis, colorimetry, and general analytical chemical techniques indicate the presence of two forms of iron, hematite and goethite, in the till. Additional attempts using infrared, DTA and electron diffraction techniques are in progress to identify the iron oxide coatings on the minerals which constitute the till. From our work in southeastern Wisconsin, it seems probable that hematite accounts for the pinkish gray and reddish brown colors (color "B") found in Valderan tills, and goethite accounts for the yellow and pale brown colors (color "A") found in the Woodfordian tills. As the iron oxide (Fe_2O_3) content of the tills is the same, the change in color is probably due to the relative amounts of hematite and goethite in the till.

Carbonate content and magnetic susceptibility. The carbonate content of the tills in Milwaukee, Ozaukee, and Washington Counties increases gradually from 22.9 percent at Lake Michigan, westward across the proposed boundary with no distinguishable break, to 45.6 percent about 12 miles west of Alden's boundary. East of the boundary magnetic susceptibility ranges from 28.6 to 107.1 x 10^{-6} c.g.s., and on the west it ranges from 25.0 to 132.1 x 10^{-6} c.g.s. (Bruning, 1970).

DISCUSSION

The cause of the difference in color between the tills from one side of Alden's boundary to the other is undetermined at this time. It may be caused by: (1) a chemical weathering phenomenon, or (2) by sediment from different source areas. The classical separation of the Valderan on the basis of color, which Black (1966a) pointed out does not apply in northern Wisconsin and in the Upper Peninsula of Michigan, may not apply in southeastern Wisconsin.

In Michigan, preliminary studies in Cheboygan County (Farrand and others, 1969) indicate no differences in color or grain size analyses between red-clayey till deposited by Valders, Port Huron, or pre-Port Huron ice; a radiocarbon date "of mosses sandwiched between two thick layers of reddish-brown sandy clay till yielded an age of 12,500-13,000 B.P. ..." (Farrand and others, 1969), indicating that reddish-brown till is not restricted to the Valders Stade in Michigan. Farrand (1970a, 1970b) is accumulating data relating lake stages to moraine sequences in Michigan's Lower Peninsula which suggest that the Valders advance may not have extended much south of Manistee in Michigan. Farrand (1970a) tentatively suggests that the Manistee Moraine is the southern extent of the Valders ice in Michigan.

In addition to the work in Michigan and to the studies mentioned earlier, measurements of till fabrics on both sides of Alden's boundary and studies of Lake Michigan beach sequences near Sheboygan, Wisconsin, are in progress to clarify the problem and establish the Valderan maximum in the southeastern part of the State.

STOP 2: THE ERNST BROTHERS' SAND AND GRAVEL PIT: A TWOCREEKAN FOREST LOCALITY

INTRODUCTION

A complete stratigraphic section (Figure 6 of Road Log) consisting of Woodfordian to Recent deposits is exposed in the west wall of the Ernst Brothers' sand and gravel pit. Although a large portion of the former pond and of the Twocreekan forest has been removed, the complete section is still visible. Two ancient forests are buried in the exposed sediments. The lower forest consists mainly of spruce and is overlain by pond sediments. Numerous stumps, wood, cones, and needles are found in the forest layer. Kocurko (1968) recorded a radiocarbon date of 12,000 ± 190 B.P. from the heartwood of a 150-year-old *in situ* stump from the lower forest (Fig. 1). Many stumps were in the upright position, had intact root systems, and were undamaged by abrasion. In addition, mosses and ferns were well preserved on the former forest floor.

Overlying the lower forest is a series of pond sediments. The sediments consist of partly indurated algae (Chara), silty, calcareous mud and variable amounts of clay and peat. The detrital non-carbonate portion of the sediments consists mainly of silt-sized grains (principally quartz), diatom remains, sponge spicules, plant debris, and some lacustrine vertebrate remains.

The upper forest grew in peat overlying the pond sediments (Fig. 2). Although the forest is not dated, it is presumed to be fairly recent. The trees are primarily Pinus and Quercus, species found today in the conifer-hardwood forest of northern Wisconsin.

FLORA

The flora found in the pond sediments consists primarily of water plants of the genus Chara (Kocurko, 1968). In the upper part of the section cattails and lily pad remains are abundant. Pollen as well as seeds, cones and leaves are found throughout the section, and suggest the presence of a forest near the pond.

The Characeae, phylum Chlorophyta (green algae), compose most of the pond flora. According to Wood (1952) who studied water systems containing Characeae in New England, Chara were affected in fresh water ponds primarily by pH (ranges from 6.5 to 9.5), salinity (generally 0 to 1.7 p.p.t.), and methyl orange determined alkalinity (generally 19 to 59 p.p.m.). The plants were best developed in shallow water (3 to 20 feet deep). However, Wood (1952) and Wood and Imahori (1965) found little or no correlation between plant occurrence and temperature, phenolphthalein determined alkalinity, or bottom sediment. Therefore, it appears that the Chara in the pond sediments at the Ernst Brothers' pit were deposited in a shallow, quiet fresh water environment with a slightly acid to alkaline condition and a very low salinity. Note: From studies of the molluscan fauna (see discussion following) we are able to restrict further the pond's environment.

Schumacher (1966) divided the sedimentary column (Figure 6 of the Road Log) into five major pollen zones as follow from bottom to top:

1. The pollen indicate the presence of a tundra vegetation and cold climate in the area immediately following the withdrawal of the Woodfordian ice. Sedges, grasses and Artemisia are the dominant non-aboreal pollen found (70 percent). Populus is the principal arboreal pollen found in the zone although Larix, Fraxinus and Salix occur.

2. During Twocreekan time a boreal forest occupied the area and consisted principally of Picea (40-52 percent), with much lower amounts of sedges, grasses and Ambrosia than occur in the tundra zone.

3. In early post Valderan time rapid destruction of the Picea forest occurred as a Pinus forest became dominant in the area. Quercus, Cyperaceas, Gramineae, and Artemisia pollens increase.

4. A gradual decrease in Pinus is accompanied by a general increase of Quercus, Betula, and Ulmus. This pine-oak forest-type pollen persists into the upper part of the section and suggests a warm, moist climate.

5. In the uppermost zone, there is a slight decrease in *Pinus* and *Quercus*, but they remain dominant. *Betula* and *Ulmus* decrease; *Tilia* is present and there is a marked increase in the non-aboreal pollen suggestive of a warm, dry climate.

Schumacher's results are similar to those of West (1961), Schweger (1969), and Maher (this guide).

Sedimentary chlorophyll determinations were made in the pond sediments to obtain information on the abundance of plants in and near the pond (Vallentyne, 1955). Results are summarized in Figure 3 (Kocurko, 1968). In general, sedimentary chlorophyll units (SCU) decrease from slightly over 200 to 34 SCU/gram and then gradually increase until, coincident with the *Quercus* maximum, there is a marked increase to 1109 SCU/gram. The fluctuations in sedimentary chlorophyll content suggest that chlorophyllitic plant communities (1) decreased in the area as the Valderan ice advanced, (2) then increased as Valderan ice withdrew, and (3) finally, there was a rapid increase in chlorophyllic plant growth as a warmer, dryer climate became dominant in post-Valderan time.

Kocurko (1968) also found a large population of Diatomacea in the non-carbonate portion of the pond sediments. Many species were found, but no detailed analysis was done. Some of the more common species reported were: *Cymbella gastroides*, *Cyclotella operculata*, *Epithemia argus*, *E. turgida*, and *Navicula oblonga*. There is a general increase in the number of organisms found progressively upward in the section.

FAUNA

Introduction. The pond sediments contain numerous invertebrate remains and some vertebrate remains. Because detailed work (Kocurko, 1968) on the molluscan fauna has been done, it is reported separately below. Although Kocurko did not attempt detailed studies of the other faunas in the pond sediments, he did find:

1. Numerous sponge spicules probably from the fresh water genus *Spongilla*.

2. Cladocera remains (class Crustacea, sub-class Brachiopoda) are abundant in the sediments, and consist principally of thoracic shields, claws, spines, and head shields.

3. Insect remains consist of chitinous shell, wings, and beetle appendages.

4. Remains of frogs, snakes, and turtles.

5. Fish remains tentatively identified as centrarchid (Sunfish), family Centrarchidae by Dalquist (*in* Kocurko, 1968). Other fish were identified by Taylor (*in* Kocurko, 1968) as *Perca flavescens* (Yellow Perch), family Percidae, and cyprinid (Minnow), family Cyprinidae. The latter specimens are catalogued as 25000 and 25001 in the National Museum of Natural History, Washington.

Molluscan fauna. Kocurko (1968) identified 19 molluscan species (Table 1) in the pond sediments. Among those reported, the most interesting are *Gyraulus parvus*, *Valvata tricarinata*, and *Valvata sincera*. All are found throughout the entire section of pond sediments. These species are suggestive of the environmental limits of the pond during its existence, and led Kocurko (1968) to conclude that the pond was a shallow alkaline body of water throughout its life.

Table 1

Freshwater Operculate Gastropoda

Amnicola leightoni F. C. Baker
Marstonia perlustrica (F. C. Baker)
Valvata sincera Say.
Valvata tricarinata (Say).

Freshwater Pulmonate Gastropoda

Acella haldemani ("Deshayes" Binney).
Bulimnea megasoma (Say).
Ferrissia parallela (Haldeman).
Fossaria obrussa decampi (Streng) Immature.
Fossaria parva (Lea).
Gyraulus deflectus (Say).
Gyraulus parvus (Say).
Helisoma anceps striatum (F. C. Baker).
Helisoma campanulatum (Say).
Helisoma trivolvis macrostoma (Whiteaves).
Lymnaea stagnalis jugularis Say.
Physa gyrina Say.

Sphaeriidae Pelecypoda

Pisidium variabile Prime.
Sphaerium rhomboideum (Say).
Sphaerium sulcatum (Lamarck). [= S. simile (Say)]

Table 1. Late Pleistocene Molluscan species from the pond sediments, Ernst Brothers' sand and gravel pit, Ozaukee County, Wisconsin. Modified from Kocurko (1968, p. 44); original identifications verified by Morrison (1967).

The pH and carbon dioxide limits of the water in which the molluscan species lived is known for some species. For example, *Gyraulus parvus* which survived throughout the entire life of the pond (Kocurko, 1968) is a species restricted to freshwater whose pH ranges from 7.0 to 8.16 and whose carbon dioxide content ranges from 8.16 to 30.56 p.p.m. (Clark, 1961). The occurrence of *Fossaria obrussa decampi* (Streng) throughout most of the section further restricts the pH of the water to between 7.42 and 7.7, and the fixed carbon dioxide range from 10.65 to 18.87 p.p.m. (Clark, 1961) during most of the pond's existence.

The temperature tolerance of Valvata sincera, the most sensitive species, which occurs throughout the entire section of pond sediments, suggests summer pond temperatures of between 50° and 60° F (Kocurko, 1968; cf. Park, 1965).

As Kocurko (1968) pointed out, most species found in the pond sediments are characteristic of slow moving, quiet, and sometimes stagnant water; all can survive in water less than 6.5 feet in depth (cf. for example, Ward and Whipple, 1918; Morgan, 1930; Taylor and Hibbard, 1955; Leonard, 1959; Hibbard and Taylor, 1960; Cornejo, 1961; Clark, 1961; and Park, 1965).

DISCUSSION

Based primarily on Kocurko (1968), modified by investigations of other students and myself, the following sequence of late Wisconsinan events is suggested for the Ernst Brothers' sand and gravel pit.

Prior to 12,000 ± 190 B.P. the Woodfordian ice withdrew from the area of the Ernst Brothers' pit, and an outwash-drainage system developed. A warmer climate during Twocreekan time permitted development of a boreal forest, the lower forest, with Picea the dominant species. Based on dendrochronology the forest existed a minimum of 195 years.

During the Valderan, the lower forest died. The cause of death was probably drowning from either (1) ponded drainage waters diverted by the advancing Valderan ice, or (2) from rising groundwater levels. An upward migration of the ground-water table could be caused by (1) increased water supply, or (2) an upward migration of the permafrost table, or (3) both. Gradually the forest was submerged as a shallow pond formed in the depression between two moraine (?) ridges. Concurrently, chlorophyllic plant communities decreased in the area (see p. C-8). The pond flora consisted primarily of water plants of the genus Chara, some of which secreted calcium carbonate, and are suggestive of clear, quiet, slow-moving water such as is found in a spring pond or spring-fed marsh with low acidity.

As the Valderan ice withdrew, destruction of the pond occurred. Chlorophyllic plants again invaded the area (see p. C-8)and peat formed as plant debris accumulated and the pond dried. The upper forest, consisting primarily of Pinus and Quercus, was established. As a warmer climate prevailed, the conifer-hardwood forest migrated north and was replaced by the present southern hardwood community that consists primarily of Acer, Quercus, and Betula.

STOP 3. THE KETTLE INTERLOBATE MORAINE

The first mention of "drift" in Wisconsin occurs in a report presented by Charles Whittlesey at the Fifth Meeting of the American Association for the Advancement of Science held in Cincinnati, in which he names the loose materials, consisting of sand, gravel, clay and boulders, which cover the bedrock as "drift." In the same paper, Whittlesey (1851, p. 56) first describes the features which later were called the Kettle Interlobate Moraine:

> ...the most remarkable accumulation of limestone pebbles and boulders, in masses, may be seen between Sheboygan and Fond du Lac of Lake Winnebago, being a series of peaks and hollows, from twenty to one hundred feet deep; very steep at the sides, without water; and constituting an elevated ridge of more than fifty miles in length, in places more than three hundred feet above Lake Michigan. It is known in the region as the "Potash Kettle" country.

Whittlesey (1860, p. 297-8) describes the "Potash Kettle" country as follows:

> ...imagine a region of drift moraines inverted. Instead of a surface thickly set with rounded hillocks, suppose it to be occupied by cavities of irregular size and depth.
>
> If the grinder of a mastodon is reversed and impressed upon a piece of wax, the depressions which result, will represent the drift cavities as contrasted with drift elevations. In travelling through such a region the explorer frequently finds them so near together, that he no sooner rises out of one than he is obliged immediately to descend into another, the diameter of which may not be more than twice or thrice its depth.

More important than his description of the "kettle moraine" was Whittlesey's (1860) correct interpretation of the origin of the moraine. He was the first to attribute its formation to glacier ice, and his comments (1860, p. 298-9) are worth quoting:

> ...in 1849, it occurred to me that these cavities could not be explained by the usual and well-known examples of aqueous deposits. Terraces and oblong ridges of sand or gravel might be formed by currents and eddies acting upon loose materials. It is not difficult to perceive how mounds, irregular elevations, and undulations could be thus built up by gradual accretion <u>above</u> the general surface.
>
> But the formation of a <u>system of depressions</u>, of a uniform character, over large tracts of country without natural mounds or ozars, is something quite different, in fact, quite opposite. And yet this has occurred in the drift, and must therefore be due to a phase of the drift phenomena.
>
> The rocks beneath the superficial materials in which these cavities are formed are everywhere polished and grooved by the drift forces.
>
> At the foot of the Alps, moraines are formed mechanically by the movements of glaciers, carrying forward earth and stones, that are finally left in rounded heaps on the more level country. Masses of ice become entangled with the loose materials, which in due time melt away and disappear.
>
> Without entering at large into a discussion of the drift force, I assume for the present purpose that, in the early

> periods of the drift epoch, it was glacier ice. Nothing else seems to be equal in energy to the results we observe ... /in Wisconsin/.

In the "kettle moraine" area, Whittlesey observed stratified and unstratified drift, kames, kettles, ridges, and other glacial features. He concluded that depressions occurred where an excess of ice was mixed in the sediments at time of deposition, and that moraines formed when the situation was reversed. Finally, to account for the formation of the entire "kettle moraine" area, Whittlesey suggested (1860, p. 301) that "...in the early days of the drift period, glacier ice predominated and as this diminished under the effect of increasing temperature, aqueous currents and floating ice prevailed." He thus suggests a glacial and glacial-fluvial origin for the topography seen in the Kettle Interlobate Moraine.

Andrews (1869) challenged the theory that the Kettle Interlobate Moraine was of glacial origin, suggesting that it was formed by violent water action and that all the western drift was a water-laid deposit. Andrews' suggestion was not accepted.

Whittlesey's (1851, 1860, and 1867) lucid descriptions and correct interpretation of drift and the origin of the Kettle Interlobate Moraine in Wisconsin provided the framework from which Chamberlin (1877, 1879, 1880, and 1883a) later developed his concepts of the glacial events in the Midwest. He confirmed that the Kettle Interlobate Moraine was formed by glacial activity and the melting of buried ice blocks.

Since the early work of Whittlesey and Chamberlin, almost no studies have been undertaken to determine the detailed glacial history of the Kettle Interlobate Moraine area. Alden (1904, 1918) was the last person to map the area as part of his reconnaissance geology of southeastern Wisconsin. Black (1969 and 1970) summarized the glacial geology of the North Kettle Moraine, and Gaenslen (1969) prepared a trip guide for the layman for the same area.

However, the Kettle Interlobate Moraine, formed between the Green Bay and Lake Michigan lobes of the Wisconsinan ice during the Woodfordian substage remains one of the most impressive glacial features in North America. As Alden (1918, p. 235) described it, the Kettle Interlobate Moraine is the "...master topographic feature of the whole series of glacial deposits in eastern Wisconsin. It was this which first attracted the attention of early explorers and led eventually to the refinement of glacial studies of the present day throughout this whole region."

In an early paper presented before the Wisconsin Academy of Sciences, Arts, and Letters in 1876, Chamberlin (1879) detailed the relations of ice movements to the formation of the moraine. He cited five methods for determining directional movements of the ice in Wisconsin: (1) grooves found on the bedrock surface, (2) source areas of the drift, (3) abrasion of bedrock surfaces, (4) the trend of elongate domes of polished bedrock, and (5) the general position of glacial deposits and the resulting topography. Assembling all the available data, Chamberlin (1879, p. 208) then concluded:

> Between Lake Michigan and the adjacent Kettle range, the direction was obliquely up the slope ... southwestward, towards the range. On the opposite side, between the Green Bay valley and the range, the course was ... obliquely down the slope, southeastward, toward the range. In the Green Bay trough, the ice stream moved up the valley to its watershed, and then descended divergingly the Rock river valley. Between the Green Bay valley and the Kettle belt on the west, the course was up the slope, westward, or southwestward, according to position. These movements ... exhibit a remarkable divergence from the main channel toward the margin of the striated area, marked by the Kettle range.

Alden (1981, Pl. IV) summarized the data on striations, drumlin orientations, and fluted forms collected by earlier workers to show the regional movements of ice from both the Green Bay and Lake Michigan lobes, and thus confirmed Chamberlin's conclusion.

Chamberlin (1879, p. 202-204) provides the best description of the Kettle range, which is now known as the end moraine of the late Woodfordian ice, and includes the Kettle Interlobate Moraine:

> The superficial aspect of the formation is that of an irregular, intricate series of drift ridges and hills of rapidly, but often very gracefully, undulating contour, consisting of rounded domes, conical peaks, winding and, occasionally, geniculated ridges, short, sharp spurs, mounds, knolls and hummocks, promiscuously arranged, accompanied by corresponding depressions that are even more striking in character. These depressions, which, to casual observation, constitute the most peculiar and obtrusive feature of the range, and give rise to its descriptive name in Wisconsin, are variously known as "Potash kettle," "Pot holes," "Pots and kettles," "Sinks," etc. Those that have most arrested popular attention are circular in outline and symmetrical in form, not unlike the homely utensils that have given them names. But it is important to observe that the most of these depressions are not so symmetrical as to merit the application of these terms. Occasionally, they approach the form of a funnel, or of an inverted bell, while the shallow ones are mere saucer-like hollows, and others are rudely oval, oblong, elliptical, or are extended into trough-like, or even winding hollows, while irregular departures from all these forms are most common. In depth, these cavities vary from the merest indentation of the surface to bowls sixty feet or more deep, while in the irregular forms the descent is not unfrequently one hundred feet or more. The slope of the sides varies greatly, but in the deeper ones it very often reaches an angle of 30° or 35° with the horizon, or, in other words, is about as steep as the material will lie. In horizontal dimensions, those that are popularly recognized as "kettles" seldom exceed 500 feet in diameter, but, structurally considered, they cannot be limited to this dimension, and it may be difficult to assign definite limits to them. One of the pecularities of the range is the large number of small lakes,

without inlet or outlet, that dot its course. Some of these are mere ponds of water at the bottom of typical kettles, and, from this, they graduate by imperceptible degrees into lakes of two or three miles in diameter. These are simply kettles on a large scale.

Next to the depressions themselves, the most striking feature of this singular formation is their counterpart in the form of rounded hills and hillocks, that may, not inaptly, be styled inverted kettles. These give to the surface an irregularity sometimes fittingly designated "knobby drift." The trough-like, winding hollows have their correlatives in sharp serpentine ridges. The combined effect of these elevations and depressions is to give to the surface an entirely distinctive character.

These features may be regarded, however, as subordinate elements of the main range, since these hillocks and hollows are variously distributed over its surface. They are usually most abundant upon the more abrupt face of the range, but occur, in greater or less degree, on all sides of it, and in various situations. Not unfrequently, they occur distributed over comparatively level areas, adjacent to the range. Sometimes the kettles prevail in the valleys, the adjacent ridges being free from them; and, again, the reverse is the case, or they are promiscuously distributed over both. These facts are important in considering the question of their origin.

The range itself is of composite character, being made up of a series of rudely parallel ridges, that unite, interlock, separate, appear and disappear in an eccentric and intricate manner. Several of these subordinate ridges are often clearly discernible. It is usually between the component ridges, and occupying depressions, evidently caused by their divergence, that most of the larger lakes associated with the range are found. Ridges, running across the trend of the range, as well as traverse spurs extending out from it, are not uncommon features. The component ridges are themselves exceedingly irregular in height and breadth, being often much broken and interrupted. The united effect of all the foregoing features is to give to the formation a strikingly irregular and complicated aspect.

In summary, the moraine is a complex range, varying in width from one to thirty miles (Chamberlin, 1879). It has a vertical thickness of as much as 300 feet, and is composed of local as well as erratic materials both stratified and unstratified. The moraine was deposited by both glacial and glacial-fluvial processes and is frequently flanked by outwash sediments on its outer edge and between ridges of the morainic system. The glacier which deposited the moraine was in part controlled by the presumed preglacial drainage systems and the underlying bedrock. Because of its complexity and the fact that only reconnaissance work has been done in the area, details of the events surrounding the formation of the "kettle moraine" are imperfectly known. Detailed studies using new topographic maps and aerial photographs in conjunction with surface and subsurface data are necessary before the history of the Kettle Interlobate Moraine can be fully known (Black, 1969a).

Part D

TWO CREEKS FOREST, VALDERS GLACIATION, AND POLLEN GRAINS

by

Louis J. Maher, Jr.

CONTENTS

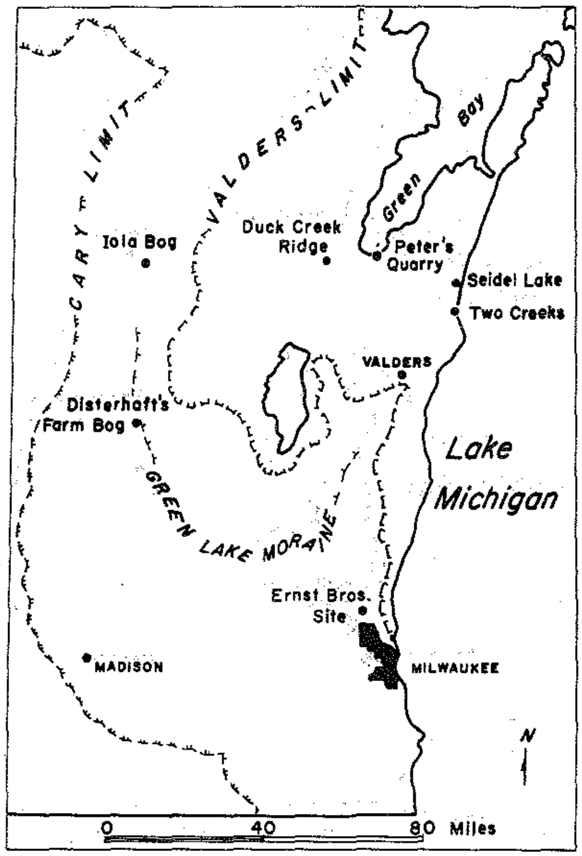


Figure 1. Map of Eastern Wisconsin

TWO CREEKS FOREST, VALDERS GLACIATION, AND POLLEN GRAINS

INTRODUCTION

Lake Michigan had stood at a high level for several years back at the turn of the century, and its waves had produced fresh exposures in the cliffs between Manitowoc and Kewaunee, Wisconsin. While tracing out abandoned beaches to the south of the little town of Two Creeks in 1905, James W. Goldthwait came upon a buried organic layer that contained a considerable quantity of peat and tree trunks. Goldthwait (1907) described this locality in glowing terms, clearly stating that the layer represented a forest that had been overrun by a final advance of the last ice sheet.

Few Pleistocene sites in the United States have acquired more prominence in the geological literature than Two Creeks. At the type site (exposures along the Lake Michigan shore line in sections 2, 11, 13, and 24, T 21N, R 24 E have generally been regarded as the type area) and at numerous other localities in the Green Bay - Fox River Lowland, organic materials found beneath the till provide undoubted evidence of an ice border fluctuation of considerable distance. The Twocreekan Substage is now given a major position in the Wisconsinan Stage (Frye *et al.*, 1968).

The Two Creeks forest bed at the type locality is typically only a few inches thick (Black, 1970). The bed is contained within a sequence of contorted lacustrine clays and sands that lie under the red Valders till and on top of gray till of late Cary age (Thwaites and Bertrand, 1957). The clays under the forest bed are crudely laminated (varved?) and accumulated in water ponded by the retreating Cary ice. Thwaites and Bertrand (1957) suggest that the Two Creeks site became dry land when the Cary ice receded far enough north to open eastward-flowing drainageways across northern Michigan into the St. Lawrence Valley. The woodland that grew at Two Creeks was inundated by water ponded by the advance of Valders ice. An accumulation of silt and sand covered the Two Creeks horizon; those lake sediments contain numerous fragments of peat and driftwood. The Valders ice overrode the area, depositing red clayey till over the lake sediments. The Valders type locality is situated at Valders, Wisconsin, some 20 miles southwest of Two Creeks (Fig. 1). Finally more lake sediments accumulated over the till in a proglacial lake formed by the retreating Valders glacier.

Based on similarity of position in the stratigraphic column, the Two Creeks interstadial in the past has been equated with the renowned Alleröd interstadial (pollen zone II) of northwestern Europe. This correlation seemed more firm when Thwaites and Bertrand (1957, p. 831) concluded that the Two Creeks carbon-14 dates averaged about 11,400 years B.P., a figure that falls about in the middle of the Alleröd. The correlation of these two events in the New and Old Worlds did much to enhance the belief of synchronous changes in the major glacial events throughout the world. It was not long before authors were reporting "Two Creeks oscillations" in the eastern and western United States, Canada, and even South America.

However, Broecker and Farrand (1963) reexamined the carbon-14 dates of Two Creeks material and concluded that the most recent and precise determinations cluster around 11,850 radiocarbon years B.P. Because the material overridden by Valders ice was killed at the end of Two Creeks time, Broecker and Farrand conclude the Two Creeks interval is older than the Alleröd and may perhaps be more nearly equated with the older Bölling interstadial of Europe. The Bölling is more poorly documented and far less obvious than the Alleröd. If the assumption is made that late-glacial fluctuations of relatively short duration can be correlated precisely between Europe and America, then American workers should have a chance to find a new Alleröd equivalent. To date there appear to be no obvious indications of a glacial fluctuation similar to--but just younger than--the Two Creeks/Valders sequence.

Before proceeding, it is necessary to define some terms as they will be used in this report. Frye et al. (1968) have redefined the Wisconsinan Stage of the Pleistocene to conform to certain principles of the Code of Stratigraphic Nomenclature (American Commission on Stratigraphic Nomenclature, 1961). I choose not to use their terms "Valderan" and "Twocreekan" as those terms are redefined in a sense different from the original usage of Thwaites (1943) and Thwaites and Bertrand (1957, p. 855-859). Rather I will follow the practice of West (1961, p. 766) in which he used the purely local terms of late-glacial and postglacial. He defined the late-glacial in Wisconsin as beginning at the retreat from the Green Lake Moraine of Cary age and extending to the time of retreat of Valders ice from its maximum position (Fig. 1). Postglacial would extend from the end of the late-glacial to the present. In this sense the late-glacial includes two stratigraphic units. The first, the Two Creeks interval, comprises the laminated lake clays under the forest bed as well as the forest bed itself. The second late-glacial unit, the Valders interval, includes the Valders till as well as the lake silts that lie between the till and the forest bed. Younger deposits, then, are defined as postglacial.

It is clear that the various strata of the late-glacial section are time-transgressive in this part of southeastern Wisconsin, and it would seem obvious that carbon-14 dates might help to clarify the time sequence. Most of the radiocarbon dates in the type area have come from the forest bed or its equivalents, and little information is available to tie down either the beginning or the end of the late-glacial or the time of the maximum extent of the Valders ice. As I will indicate later, indirect evidence suggests the whole late-glacial interval in Wisconsin hardly can be longer than 1500 years. I suggest very tentatively that the Two Creeks interval extended from 12,500 years B.P. to 11,800 years B.P., whereas the Valders interval ended before 11,000 years B.P.

BIOTIC REMAINS ASSOCIATED WITH THE TWO CREEKS FOREST HORIZON

Wilson (1932, 1936) described the general biotic remains of the Two Creeks forest bed. Cheney (1930) and Culberson (1955) reported on its mosses, and West (1961) and Schweger (1969) published pollen studies dealing with the late- and post-glacial intervals of eastern Wisconsin. The mollusks, mosses, wood, and pollen are of species that can be found in Wisconsin today; the authors generally agree that the Two Creeks interval was somewhat cooler than today, but by an unknown amount.

Trees known to be in the Two Creeks flora on the basis of macrofossils include abundant black spruce (*Picea mariana*) and larch (*Larix laricina* = tamarack) with some white spruce (*Picea glauca*) (Schweger, 1969). Wilson (1936) reported balsam fir (*Abies balsamea*) wood had been found in the sands above the forest bed. The greatest number of annual rings reported in the literature, from the type Two Creeks, was 142 (Wilson, 1936). This would seem to be the minimum number of years for tree growth at the type Two Creeks site although it would be a more certain figure if the tree had been rooted in place.

West (1961, p. 771) identified the pollen in the Two Creeks forest bed at two locations at its type area. Although there were traces of pollen from a number of trees and herbs, spruce pollen made up 70 to 90 percent of the total pollen in all but two levels. These two low-spruce levels had amazing percentages of soapberry (*Shepherdia canadensis*) pollen. As no other worker has found such a quantity of this pollen type in other samples, West must have encountered an anther or flower of the plant in the sediment. At any rate, soapberry must have been present at the site.

Schweger (1969) analyzed two buried organic horizons in the vicinity of Green Bay, Wisconsin. The Duck Creek Ridge and Peter's Quarry sites (Fig. 1) were both correlated with the Two Creeks interval on the basis of similar stratigraphy; a *Larix* log at Duck Creek Ridge was radiocarbon dated at 11,640±350 years B.P. The pollen at both sites was rather equally divided between spruce and sedge although minor amounts of a number of other pollen taxa were recorded.

PALYNOLOGICAL CORRELATION OF THE TWO CREEKS, VALDERS, AND EARLY POSTGLACIAL INTERVALS

West (1961) carried out an ingenious study designed to show the effect of the Two Creeks/Valders oscillation on pollen sedimentation in Wisconsin lakes and bogs. West analyzed the sediment in Disterhaft's Farm Bog outside the limits of Valders till, and he compared its pollen diagram with that of Seidel Lake, a basin formed *on* the Valders Till (Fig. 1). Spruce pollen predominated in the lower sediments of both sites. West believed he could relate especially high spruce percentages in zone 2 of the Disterhaft diagram to the Two Creeks interval. He believed the overlying zone 3 with somewhat reduced spruce percentages and increased herb (especially *Artemisia*) percentages would represent the Valders interval. West felt that his pollen zone 4, represented by increased spruce pollen, was the lowermost zone in the entirely postglacial Seidel Lake sediment. West drew the top of his zone 4 in both sites where the spruce pollen percentages declined markedly in abundance and were replaced by pine pollen.

Schweger (1969) studied another core outside the margin of Valders

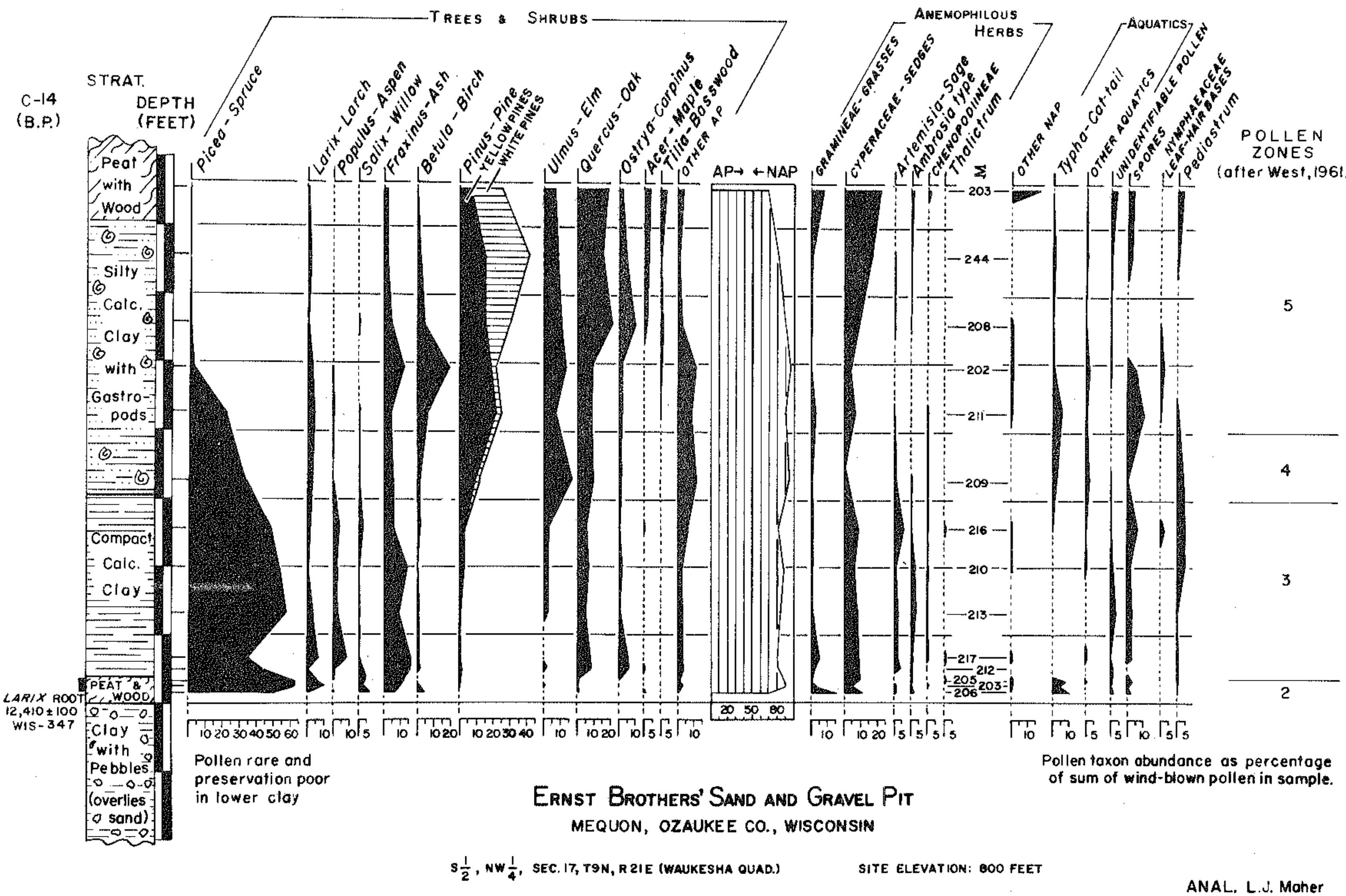


Figure 2. Pollen diagram of the Ernst Bros. Sand and Gravel Pit

till in order to verify the findings of West. Schweger's diagram for Iola Bog (Fig. 1) shows zones very similar to West's Disterhaft site.

As this report is written, none of the diagrams of West (1961) nor Schweger (1969) has radiocarbon control on its zone boundaries. Somewhat similar pollen fluctuations in the lower parts of other diagrams in the Midwest have radiocarbon dates that tend to fit West's conclusions (see Kirchner Marsh in Wright, Winter and Patten, 1963), but the agreement is not perfect. Cushing (1965, p. 412) has cited one problem concerning the correlation of higher values of *Artemisia* (sage or wormwood) pollen in the lower part of Midwestern diagrams with the Valders interval. *Artemisia* has many species that grow in dry areas; Cushing questions whether a drought indicator should be equated with the Valders glaciation unless some radiocarbon dates are available in a core like the Disterhaft site.

ERNST BROTHERS' SAND AND GRAVEL PIT

A pollen diagram of the Ernst Brothers' site (Stop 2) is shown in Figure 2. Pollen samples were collected from the exposed face of the pit with the help of Dietmar Schumacher who prepared a preliminary pollen diagram as a class project. Pollen in the near surface peat was too badly preserved to count.

The sand and gravel of the Ernst Brothers' site rest on moraines shown as Cary in age by Thwaites and Bertrand (1957). At the exposure where the pollen samples were taken, the outwash sands are covered by three feet of clay with pebbles that is essentially barren of pollen. This interval may well represent colluvial material slumped from the till ridge at the east side of the pit. A *Larix* root from the forest layer provided a radiocarbon date of 12,410±100 years B.P. (WIS-347). Norman P. Lasca (1970, personal communication) stated that Isotopes, Inc. measured a radiocarbon date of 12,000±190 years B.P. on wood from a *Picea* stump in the same horizon. Because both dates fall within the Two Creeks interval (Frye *et al.*, 1968), and because the pollen percentages are similar to the *type* Two Creeks forest layer and to pollen zone 2 of West (1961), I assume that the sediments above the lower peat layer postdate the Two Creeks interval.

The pollen grains in the compact pond clay above the forest bed (Fig. 2) are better preserved than those in the forest bed itself. The temporary decrease in spruce pollen and the relatively high values of nonarboreal pollen including *Artemisia* match pollen zone 3 of West (1961); the absence of cat-tail pollen and most aquatics during this interval suggests a cooler time possibly related to the Valders ice advance.

One other good reason to believe that the Valders interval is present in this zone of compact clays stems from the demonstration by West (1961) that the oldest sediments in Seidel Lake--sediments that postdate the retreat of the Valders ice--still were dominated by spruce pollen. Many pollen diagrams from the Midwest show a rapid transition from older sediments dominated by spruce pollen to younger sediments dominated by pine pollen. The drop in spruce pollen generally occurs about 11,000 years B.P. (Wright, 1968, p. 946). If that is the case, the recession of the Valders ice from its maximum position must predate the spruce pollen decline; the local postglacial would then have begun more than 11,000 years B.P., and the Valders glaciation would be quite a short event!

The pollen diagram from the Ernst Brothers' site differs from other diagrams from Wisconsin in that there is a relatively slow rise in pine pollen during a gradual decline of spruce. Wright (1968) makes a very convincing case that pine trees were absent from the Midwest during the late-glacial and that they migrated into the area rather late. Although I will not discuss the problems to pollen analysts that arise from the late arrival of pine, the pine curve in the Ernst Brothers' diagram is interesting. By the time spruce has fallen to a value of a few percent, the morphology of the pine grains shows an abundance of white pine type; *Pinus strobus* is the only tree in this region with such a pollen grain. Wright (1968, p. 951-952) stated that white pine arrived in eastern Minnesota 7200 years B.P. and reached northwestern Minnesota 2700 years B.P.

Although the late-glacial and early postglacial record at the Ernst Brothers' site seems reasonably complete, I believe it would be a mistake to take it at face value. It should be remembered that the Valders interval is represented by pond sediments rather than till or outwash. This site lies a few miles west of the moraines that have been mapped as Valders (Thwaites and Bertrand, 1957, p. 833). Although it is tempting to consider the ponding of water at the Ernst Brothers' site as somehow related to the presence of Valders ice, this is by no means proven.

I believe that a very simple hypothesis may be invoked to explain the sedimentary record of this site (cf. Lasca, this guide). When Schumacher and I collected the pollen samples, we noted that the bedding in the lower compact clays met the horizontal layers of the fossiliferous gastropod-rich clays at a slight angle; it looked like an angular unconformity. If the Cary moraine or outwash had some blocks of buried ice, it is possible that the lower forest bed grew before a closed basin had formed (Cushing, 1965, p. 412; McAndrews, 1966, p. 54-55; Florin and Wright, 1969). With some melting of the buried ice block, the forest bed could subside below the water table, and pond sediments could form. As the ice block melted entirely, the earlier pond sediments could be tilted, and the basin then filled completely with pond sediments and peat.

If the stratigraphy at this sand pit is the result more of a melting block of Cary ice rather than the nearby presence of the Valders glacier, then we must ask ourselves one further question: What really is the evidence for the presence of Valders till in this part of Wisconsin? Black (1966a) has demonstrated that red color is not a reliable indicator of Valders till, and he has reduced markedly the area that was once thought to have been covered by Valders ice. I would not be surprised if the red "Valders" till several miles east of the Ernst Brothers site were shown to have Two Creeks material lying *on* it rather than under it. Would anyone care to look?

Part E

THE DRUMLIN FIELD OF SOUTHEASTERN WISCONSIN

by

Norman P. Lasca

CONTENTS

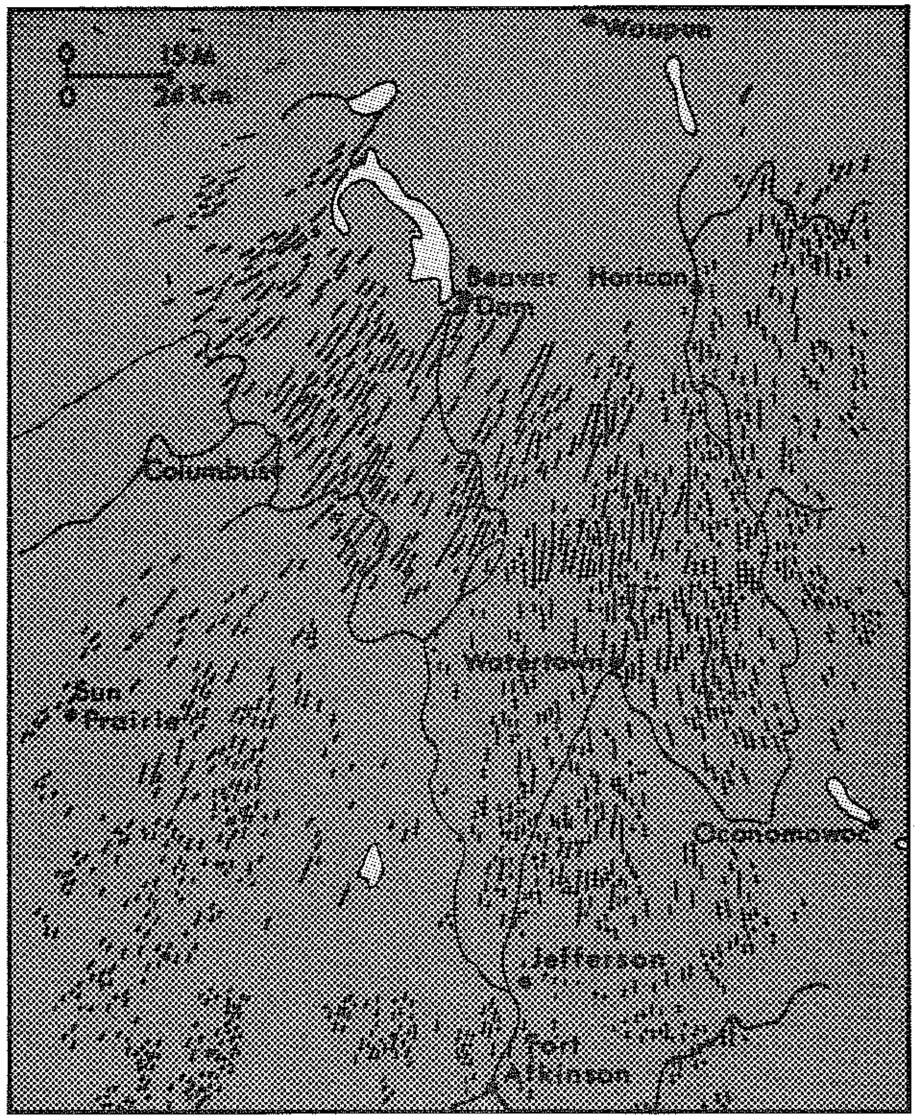


Figure 1. A portion of the drumlin field of southeastern Wisconsin

THE DRUMLIN FIELD OF SOUTHEASTERN WISCONSIN

INTRODUCTION

The term "drumlin" apparently was first used by Bryce (1833) to describe elongate hills of gravel in the British Isles that were generally steep on one side and gently sloping in all other directions. The first term used in this country to describe similar features was "lenticular hills" (Hitchcock, 1876). Chamberlin (1883a) called the accumulation of drift into elongate, circular or dome-shaped hills, "mammallary hills." He noted that in Dodge and Jefferson Counties the mammallary hills were replaced by long, paralled ridges. In 1887, Chamberlin (p. 204) reported that the terms "mammallary, lenticular and elongate ridges /are/ now frequently included under the term drumlins...." It is these ridges that form the major portion of the classical drumlin field of southeastern Wisconsin.

Upham (1892) used the term "drumlin" to describe:

> ...drift hills.../consisting/ at least superficially and in most cases throughout their entire mass of till or boulder clay, being unstratified clay, sand, gravel and boulders, mingled indiscriminately together, which therefore must be attributed to deposition by ice without modification by the assorting and stratifying action of currents of water. They have usually an oval form, with smoothly rounded top and steep slopes, especially at the sides....

A year later Chamberlin (1893) reported that Buell mapped over 2,500 drumlins in southeastern Wisconsin. Chamberlin's two reports established the term in the glacial literature of this State. Alden (for example, 1904, Pl. 5) used drumlins to determine ice movement and later (1905, 1918) wrote the first significant reports describing the drumlin field of southeastern Wisconsin.

DISTRIBUTION AND ORIENTATION OF THE DRUMLINS

Alden (1905) mapped about 1,400 drumlins in southern Wisconsin. Approximately 80 percent were in deposits from the Green Bay glacier. The drumlin axes generally are oriented parallel to glacial striations on nearby bedrock. Later studies (Alden, 1918) suggest that this trend occurs throughout southeastern Wisconsin (Figure 1).

In some instances there is as much as a 50° divergence between striations and drumlin axes, suggesting previous ice movement over the area, or local changes in basal ice flow directions. Because bedrock exposures are relatively rare in the area (Alden, 1905, 1918), drumlins are better indicators of the last glacial movement than striations. The reasons for this are: (1) the abundance of drumlins, and (2) their close conformity to glacial flow directions established from other data, for example till fabric studies.

Each set of drumlins appears to correspond to a set of marginal or terminal moraines (Alden, 1905, 1911) which mark the limit of glacial advance or readvance. The areal and topographic relations suggest that, in some cases, morainal deposits were superimposed on drumlin topography, but in others, drumlin forms merge into morainal deposits with kame-kettle topography (Alden, 1905). In some places, ice-channel fillings occur along or between drumlins, but none has been observed crossing a drumlin.

The relation of drumlins to the pre-glacial topography is not clear. In some places drift is over 300 feet thick, and the lack of subsurface data in other areas makes it difficult to determine the configuration of the underlying bedrock surface. In those areas of southeastern Wisconsin where the subsurface is known, drumlin clusters appear to have no relation to the underlying topography (Alden, p. 16).

Many drumlins in southeastern Wisconsin are found in groups side by side with their long axes either overlapping, or, "...if not actually overlapping, the axes are rarely in perfect alignment, being either side by side or in tandem. Usually as one drumlin begins to tail out the head slope of another rises at one side or the other" (Alden, 1918, p. 17). Adjacent drumlins are separated commonly by distances greater than the short axes of the drumlins.

Although drumlins have many diverse shapes, the typical drumlin shape is that of an elliptical form or an elongate ovoid. Alden reports (1905, p. 19) "...91 variations in size, form, and height of the simple, single-crested drumlin." Other variations in size and shape are common, and, although the single-crested form dominates, "...double- and triple-crested forms, forms with double tails, and also twins and triplets occur" (Alden, 1905, p. 42). In general, in the southeastern Wisconsin drumlin field (Figure 1), drumlin length increases toward the axis of movement of the former glacial lobe. In some areas Alden reported drumlins approximately four miles in length. A statistical analysis of characteristics of 320 drumlins from Jefferson County is discussed in Hole's topical report (Part F).

STRUCTURE AND COMPOSITION OF THE DRUMLINS

Generally the drumlins of Wisconsin are composed of clayey to sandy clay till which commonly contains structural elements such as fabric or joints. In some drumlins stratified beds occur in patches that grade laterally into the till. Rarely the stratified beds of sand, gravel and clay are folded such as those seen in the Switzke Road-Highway MM drumlin (Figure 2. cf. Road Log). In drumlins where folded beds occur, the overlying material and the drumlin surface are undisturbed.

Alden (1905) analyzed the drift at 250 localities with the result that "...85 to 90 percent of the coarser material in the body of the drift is of local derivation" (p. 36). The surface boulders, presumably carried englacially and then deposited as the ice stagnated and melted, are 85 to 90 percent crystalline rocks erratic to the area. The high concentration of local material in the drumlins indicates that the drift was carried in and deposited by basal ice, thereby forming the drumlins in this area.

From the subsurface data obtained by Alden (1905), very few drumlins are rock cored. In fact, there are rock knobs and ledges which probably would have formed excellent nuclei for drumlin formation, if that were the method of formation, but which are barely covered with drift. Alden concluded that there was no relation between drumlin formation and the bedrock surface configuration.

ORIGIN OF DRUMLINS

The following discussion is based primarily on the early geologic literature of the United States. For those interested in a more complete review of drumlin formation see Charlesworth (1957).

Shaler (1870) suggested that the lenticular drift hills (drumlins) in the vicinity of Boston were remnants of a drift sheet that was modified by fluvial action and waves and whose form was due to the underlying bedrock. He later (1888) modified this view suggesting that drift from the first glacial epoch was reworked and eroded primarily by ice action. A further modification of Shaler's theory was proposed by Hitchcock (1876) and Wright (1877) in which they suggested that terminal moraines were overridden by readvancing ice to form drumlins.

Tarr (1894) wrote that the overriding (erosional) theory had been generally abandoned, but he restated it when he affirmed (p. 404) that: "It is certain that glacial erosion can produce drumloidal forms..." Tarr argued that drumlin distribution, as well as the wide variety of drumlin forms, could be attributed to glacial erosion of either pre-existing moraines or drift sheets of varying thickness. Other evidence in support of an erosional theory cited by Tarr was: (1) the similarity of roches moutonnées and rock hills to drumloidal forms, (2) the drumloidal, or partly lenticular, forms found in overridden moraines, and (3) the flutings that are found on some drumlins. The theory requires a two stage process of formation: first, deposition of either stratified or unstratified material by any process in front of or under glacial ice; and then, second, erosion of the material by continued advance or by readvancing glacial ice.

Another hypothesis, first suggested by Kinahan and Close (in Tarr, 1894) to account for drumlin formation in Ireland, was the construction method whereby material was deposited subglacially in a succession of layers. The method was compared to the growth of sand bars in rivers. Davis (1884), Chamberlin (1883a, 1883b) and Salisbury (1892) suggested that the constructional (depositional) hypothesis was applicable to drumlin formation in this country.

Tarr (1894) argued that the constructional theory does not satisfactorily explain drumlin formation. He listed (p. 395-397) the following objections to the hypothesis: (1) it does not explain how material is deposited subglacially in small, narrow localized areas; (2) if variations in flow movement occur, then drumlins should be related to topography and sediment source areas, which is not the case; (3) the irregular distribution of drumlins is not adequately explained; (4) most drumlins do not have the internal layering required by the hypothesis; and (5) the presence of stratified drift in drumlins must be explained.

Even though objections to the constructional (depositional) hypothesis were raised, the idea had merit, and with modifications appears to account for drumlin formation in many cases (see discussion following). Alden (1911, p. 734) made the point that a readvancing glacier produces stress transverse to the flow direction:

> These stresses...would facilitate spreading of the ice about obstructing piles of drift and their being shaped into drumlins rather than their obliteration by erosion. It might also induce localized deposition in piles or ridges which would later be shaped and might be added to by plastering on of drift.

Upham (1892) suggested that drumlins were deposited from englacial drift. He envisioned drift being carried upward by a shearing movement of basal ice into a faster moving englacial zone. The englacial material would then gradually become super-glacial material as ablation occurred. With either burial by snow or by overriding ice, the material would be moved forward and down, forming drumlins. Upham (1892, p. 356) explained the technique as follows:

> ...differential and shearing movement...gathered the stratum of englacial drift into great lenticular masses...thinly underlain by ice and overridden by the upper ice flowing downward to the boundary and bringing with it the formerly higher part of the drift stratum to be added to these growing drift accumulations.

Two arguments cited by Chamberlin (1893, p. 259-260) against the theory were: (1) locally derived quartzite erratics are found scattered throughout the entire mass of many drumlins, and (2) local quartzite erratics are found only in the lee ends of drumlins which lie directly on top of quartzite ledges. If the drumlins were formed by englacial materials as described by Upham, neither of these features found in many drumlins in Wisconsin is explained. The arguments of Chamberlin and others prevailed. Upham (1895, p. 195) wrote "...that drumlin accumulation was not usually...dependent on the process of the englacial becoming superglacial by ablation and afterward being enveloped by the ice...."

The several theories of drumlin formation were summarized by Chamberlin and Salisbury (1906, p. 360-361) as follows:

> The origin of drumlins has been much discussed, but there is as yet no generally accepted conclusion, and the subject is still under active inquiry. Opinion is chiefly divided between the views (1) that they were accumulated beneath the ice under special conditions and (2) that they were developed by the erosion of earlier aggregations of drift, much as roches moutonnées are developed. Under the first of these general views, it has been suggested (1) that the bars of rivers give the clue to the origin; (2) that protuberances of rock gave occasion for the lodgment; (3) that the balance between load and strength of movement furnishes the key to their explanation, a slight but not excessive overload being the condition

> necessary for their development; and (4) that they may be, in some way, connected with longitudinal crevasses.

A year later Fairchild (1907, p. 429-430) discussed drumlin formation:

> Drumlins are shaped by the sliding movement of the lowest ice, that in contact with the land surface. This fact implies that the whole thickness of the ice sheet participated in the motion. Such motion was not due to gravitational stress on the ice mass over the drumlin area, because the general slope of the drumlin area is up hill, but was produced by an effective thrust on the marginal ice by the pressure of the rearward mass. As the ice sheet thinned by ablation there came a time when the driftloaded ice in contact with ground was subjected to less vertical pressure and to relatively greater horizontal pressure by the deep ice in the rear, and was pushed forward bodily. In this fact is believed to lie the key to drumlin formation.

Alden (1918) felt that Fairchild's explanation of drumlin formation was applicable to the drumlins of the Green Bay lobe.

Smalley and Unwin (1968) recognized that special, infrequently occurring, subglacial conditions were necessary for drumlin formation to occur. The conditions they proposed were: (1) a dilatent material, till, consisting of boulders, cobbles, and pebbles in a dense clay-water system, and (2) a stress developed at the ice-till interface causing continuous deformation of the till. Smalley and Unwin (1968) theorize that drumlins form when an intermediate stress level develops at the ice-till interface causing shear deformation of the underlying till. The zone in which the critical stress level is achieved lies between the ice margin (low stress level) and the thicker, upglacier (high stress level) areas (see Figure 3).

The distribution of drumlins in southeastern Wisconsin (Alden, 1905, 1911, 1918) indicates that drumlins formed in a zone several miles behind the ice front. The drumlin zone continues upglacier, but does not extend to the center of the ice lobe. The theory proposed by Smalley and Unwin (1968) may account for the drumlin distribution pattern in southeastern Wisconsin.

TILL FABRICS

When a velocity gradient occurs in a flowing medium, shear is produced causing particles in adjoining flow layers (lines or surfaces) to align parallel to the flow velocity. Therefore, to explain till fabric, one must explain how shearing conditions are created in the till. It is, therefore, approporiate to review some theories of particle orientation, especially as they relate to tills.

Holmes (1941), in his extensive discussion of mechanisms which cause stone orientation in till, reported that stones: (1) usually tend to become aligned with their long axes parallel to glacial flow direction, but (2) may also tend to become oriented transverse to flow direction.

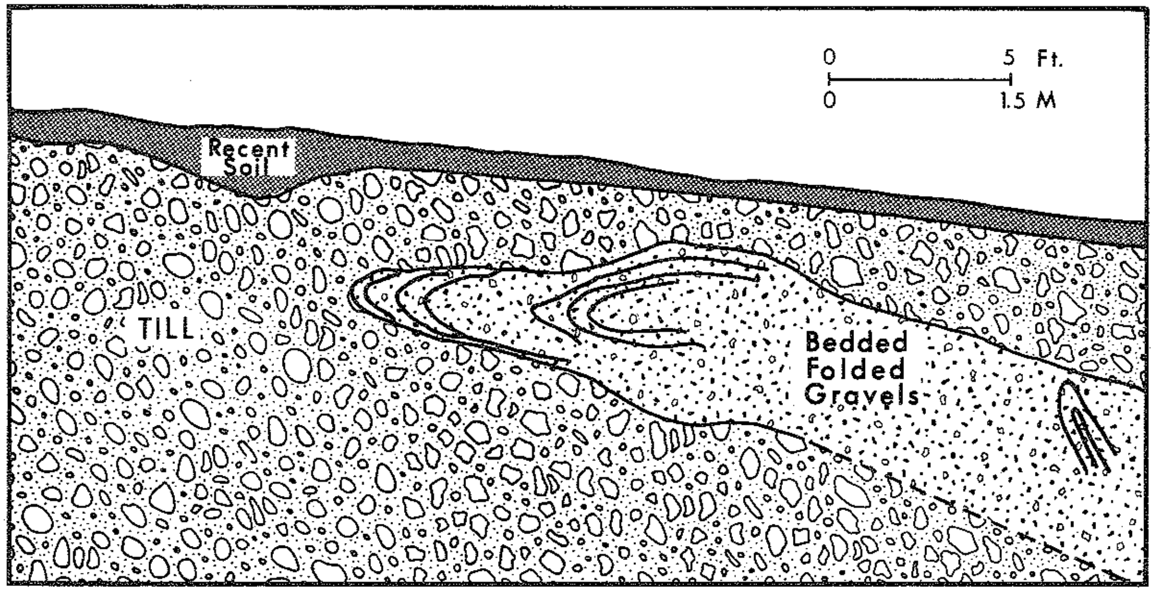


Figure 2. Diagrammatic illustration of the Switzke Road-Highway MM drumlin

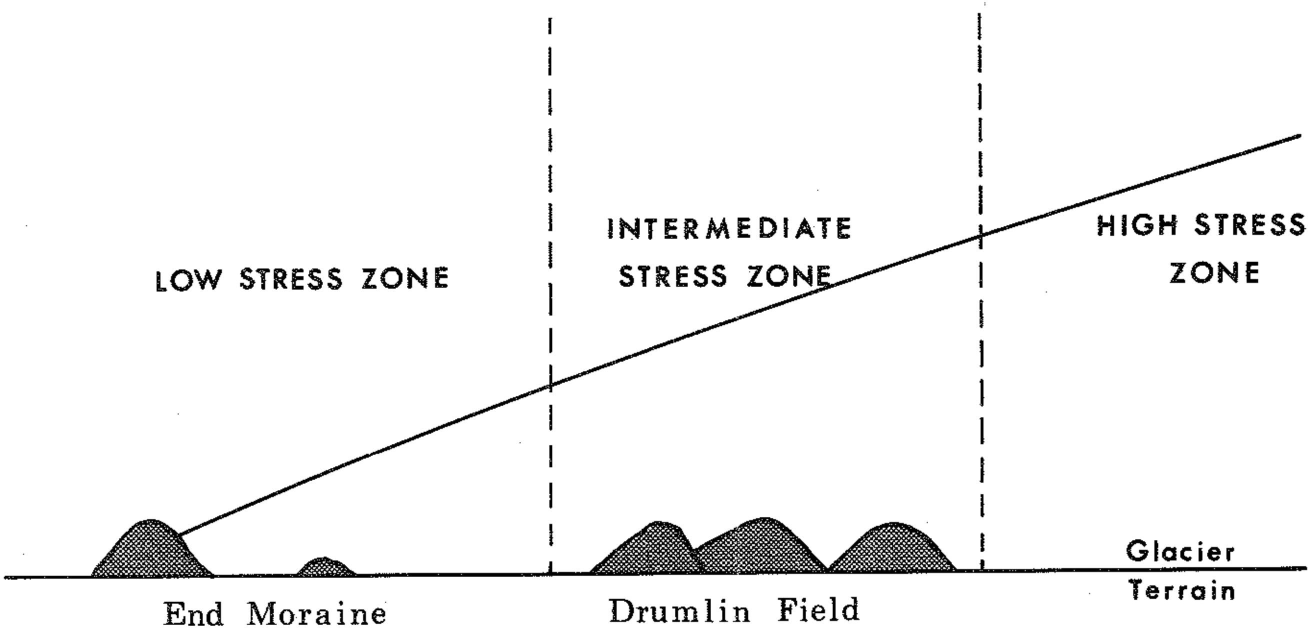


Figure 3. Diagrammatic cross-section at the margins of an ice sheet illustrating critical stress regions at the base of the ice.

He attributed parallel alignment to the dragging of stones along the ice/till interface and along basal shear planes in the ice. Transverse orientations developed when stones, totally immersed in the ice, were rotated about their longest axis and rolled into place.

Three-dimensional fabric analyses were performed by Harrison (1957) on tills in the Chicago area. Harrison (p. 291) suggests that "...the bulk of the ground moraine fabric is inherited, with only a slight degree of modification, from that fabric which is developed in the transportational environment." The fabric is produced by material moving up along the slip planes in the glacial tectonite. Later, during stagnation and recessions, the oriented englacial material is deposited with little or no reorientation of the original fabric. Thus, most till is deposited as ablation occurs in the basal zone of glaciers, and till fabric is preserved from the original flow environment as melting takes place.

Although the processes suggested by Holmes and Harrison account for some till fabric orientations, Glen and others (1957) demonstrated that ice flow alone can cause stone orientation parallel to flow direction. Therefore, no drag is necessary at the ice/till interface or in slip planes to produce orientation of stones in till. However, they recognized that collisions of stones would affect fabric orientations.

Support for the theory of Glenn and others (1957) is found in the earlier conclusions of Manley and others (1955): (1) that without interaction between particles, rotation of the particle remains constant over long periods of time, and (2) that with increased interaction between particles, the distribution of particle orbits and, hence, particle orientation is affected.

Glen and others (1957, p. 201-202) summarize the effects producing preferred particle orientation parallel to flow:

1. Free flow in ice without particle collision.
2. Collisions between oblate stones.
3. Dragging of stones over either a stationary layer or a plane of discontinous shear.

The following effects produce orientation transverse to flow:

1. Long periods of free flow; no particle collisions.
2. Prolate stone collisions.

In conclusion, Glen and others (1957) state that the processes influencing orientation are very different for macro- and micro-fabrics.

However, the work of Evenson (1970) in Jefferson County indicates a close correlation between micro- and macro-fabrics (Figure 4). Evenson (1970, p. 40-41), following Glen and others (1957), reports that till in Jefferson County was affected by:

1. Short transport,
2. High frequency of stone collisions producing a parallel orientation of prolate stones, and
3. Possible dragging over a stationary or slow-moving layer.

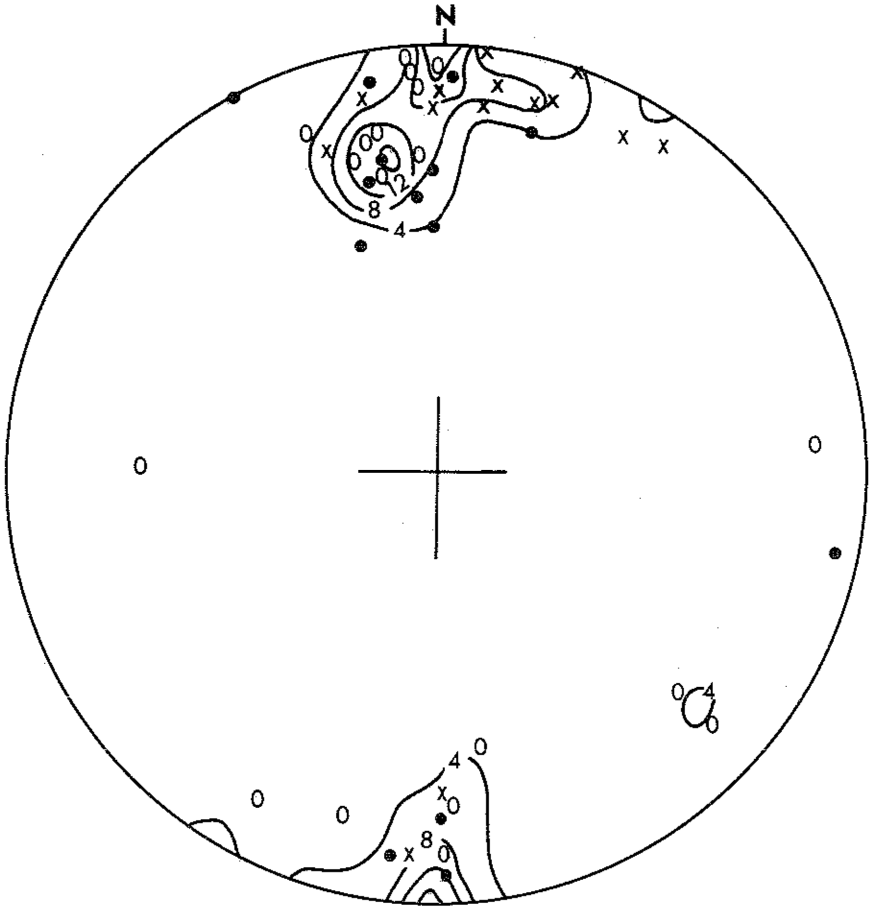


Figure 4. Composite diagram of fabric analyses performed in the Jefferson Co. area, Wisconsin.

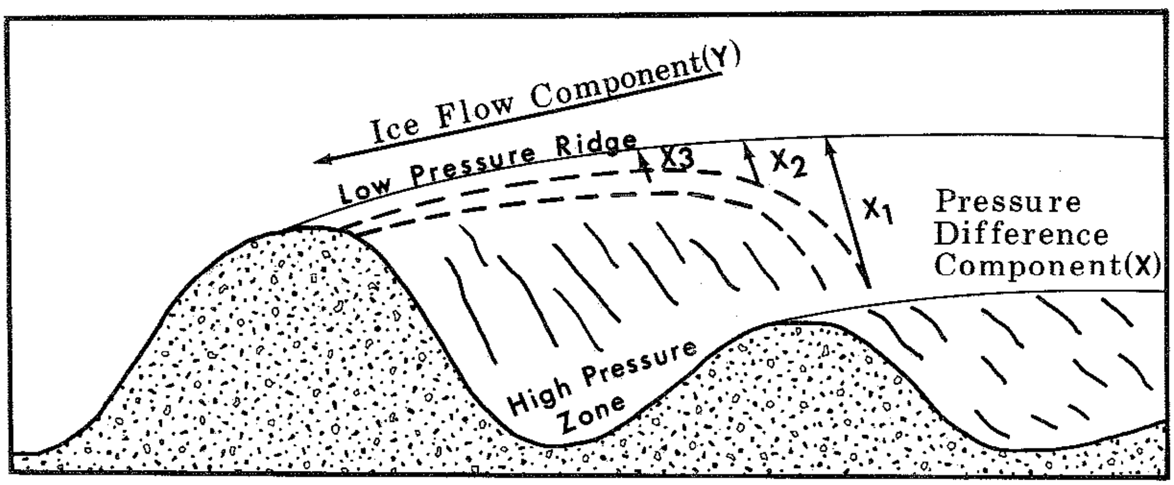


Figure 5. Diagrammatic illustration of the path of a particle moving from a high pressure zone to a low pressure zone.

MacClintock and Dreimanis (1964) demonstrated that complete reorientation of fabric elements can occur to depths of 35 feet when overridden by continental ice, and minor deformation may occur to depths of 65 to 70 feet. The critical point is that particle orientation, or reorientation, can be produced subglacially in thick sequences of till. The particle orientation, and hence fabric, is probably caused by shearing in the till as overriding occurs. Thus, it appears that orientation parallel to flow can develop in basal till, thereby eliminating the problems of possible orientation of materials deposited by melting ice (cf. Harrison, 1957).

Using the theory of Glen and others (1957) and the findings of MacClintock and Dreimanis (1964), we can account for various alignments of fabric elements, but cannot explain their upglacier plunge. Three general theories have been suggested to explain the plunge of fabric element long axes: (1) the slope theory, (2) the ice shear theory, and (3) the till shear theory. The slope theory suggests that plunge is caused by the slope over which the ice moves. If this theory is correct, a strong correlation should exist between the slope angles and fabric elements deposited near the ice/till interface. There are some situations where the slope theory is valid, for example development of fabric in flow tills (Boulton, 1968). However, in many situations the theory does not apply (for example, Cowan, 1968; and Gravenor and Meneley, 1958). In Jefferson County, Evenson (1970) reports that there is so little correlation between slope angle and fabric element plunge that plunge is not a function of slope.

Both Harrison (1957) and Wright (1957, 1962) suggest that ice shearing can cause alignment of fabric elements as materials move upward along shear planes developed in the ice. Because shear planes usually dip upglacier, the fabric elements should also have an upglacier plunge. Wright (1957 and 1962) attributes the upglacier plunge of fabrics recorded in drumlins to orientations developed during transportation in the shear planes of the glacial tectonite. Although movement along shear planes clearly orients particles parallel to glacial flow and with an upglacier plunge (cf. Harrison, 1957, p. 286; Boulton, 1968), the difficulty that remains is how orientation of particles is preserved during the melting process. As was pointed out by Boulton (1968), marginal ice melting produced slump and flow till movements which nearly totally destroyed fabric orientation in the relict shear planes. The ice shear theory appears to be of questionable validity until it can be demonstrated that orientations are unaffected by the melting process.

The till shear theory assumes that tills behave as viscous liquids in response to stress. Long axis orientation is caused by shear. For example, Gravenor and Meneley (1958) suggest that alignment of fabric elements parallel to flow can be developed as till moves subglacially in response to pressure gradients beneath the ice. Evenson (1970) reports that the differential pressure theory of till shear satisfactorily explains the fabrics found in the drumlins of Jefferson County. Figure 5 illustrates how a particle moves in a shear zone in response to a pressure gradient. "The component of ice flow (Y) is assumed to be a constant, while the component due to pressure differences (X) which is normal to the ridge side decreases as the particle moves into the area of lower pressure. To simplify the analysis the surface XY can be approximated, over small areas, by a plane" (Evenson, 1970, p. 47). The particles move upward along curved shear zones in the plane XY. In this case, upglacier imbrication results from the shape of the shear zone, while orientation parallel to the flow is caused by shearing as the materials are transported from high to low pressure zones (Evenson, p. 50).

The pressure differential theory is especially interesting when we look at the Switzke Road-Highway MM drumlin (Figure 2). As reported by Evenson (1970), recumbently folded gravels are in contact with till. The folded gravels and till suggest transport and injection of material in a frozen, or partly frozen, but viscous state from an adjacent high pressure area into a low pressure zone. Micro- and macro-fabric analyses from the west end of the exposure have nearly north-south trending maxima (Evenson, 1970). To date no detailed work has been done on the fabric of either the gravels or of the adjacent tills.

As was indicated earlier, till reacts to stress created by overriding ice (cf. MacClintock and Dreimanis, 1964), resulting in reorientation of fabric elements in the overridden deposit. In addition, MacClintock and Dreimanis (1964, p. 141) report that "shear planes in till are seldom recognized except at those places where lacustrine clay and silt was dragged in, serving also as lubricant along the surfaces of displacement." The surfaces are upward curving shear planes caused by stress applied from above by the overriding ice.

From the work of Gravenor and Meneley (1958) and of MacClintock and Dreimanis (1964) it is apparent that till fabric elements can be oriented subglacially and in response to differential pressures beneath the ice. The fabric studies of Evenson (1970) and the recumbently folded injected gravels in drumlins, such as the Switzke Road drumlin, suggest that the drumlins in southeastern Wisconsin were formed beneath the ice as frozen or partially frozen, but viscous, till sheared in response to overriding ice.

JEFFERSON COUNTY DRUMLINS

Field relations indicate that the drumlins of Jefferson County were formed by glacial readvance over previously deposited tills and outwash sediments (Alden, 1905, 1911; Evenson, 1970). The drumlins contain locally derived materials, as well as erratic materials from great distances. In general, the drumlins consist of loam to sandy-loam till which commonly contains boulders. In some drumlins stratified beds occur, and rarely, stratified beds are folded such as those seen in the Switzke Road-Highway MM drumlin (Figure 2).

Because both the material overlying folded beds and the drumlin surface are undisturbed, it is suggested that subglacial lateral pressures caused injection of plastic materials into the drumlin at time of formation. If the distorted beds had formed by slumping during drumlin collapse, as melting of buried ice blocks occurred, the overlying beds as well as the surface of the drumlin would also be distorted.

In addition, the upglacier plunge reported by Evenson (1970) in drumlin till fabrics is attributed (a) to orientation developed as material moved from high to low pressure zones under the ice, and (b) to upcurving shear zones created by overriding ice.

The distribution of drumlins in Jefferson County and other parts of southeastern Wisconsin (Alden, 1905, 1911, 1918; Hole, Part F, this guide) indicates that drumlins are found in an intermediate zone between the former ice front as marked by moraines, and a point several miles or tens of miles upglacier.

Drumlin distribution in Jefferson County, the injected gravels and till fabrics which suggest subglacial movement and shearing of materials in response to pressure gradients beneath the ice, and the composition of the till are consistent with and tend to support Smalley and Unwin's theory (discussed earlier) of drumlin formation.

Late Note

Analyses of till from 24 drumlins in Jefferson County at depths of about 1.5 meters showed the following average percentages of the <2.00 mm fraction: sand 72%, silt 17%, clay 11% (Allan, 1967).

Part F

DRUMLIN MORPHOLOGY AND SOIL RELATIONSHIPS IN JEFFERSON COUNTY, WISCONSIN

by

F. D. Hole

CONTENTS

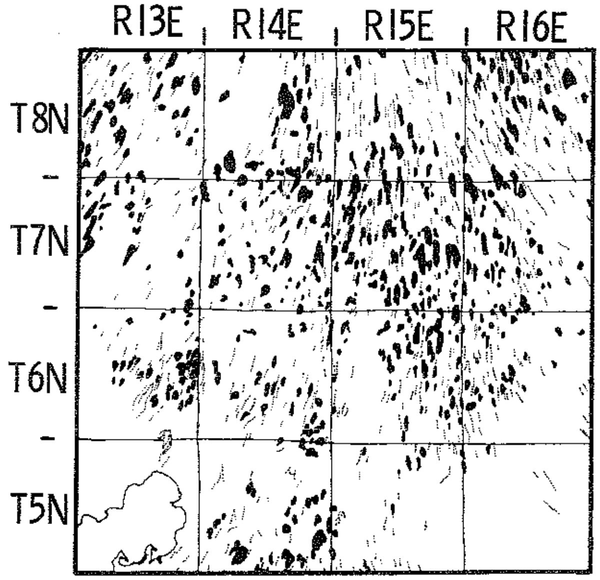


Figure 1. Drumlins of Jefferson County. Solids are drumlins; dashed lines are drumlinoid features

DRUMLIN MORPHOLOGY AND SOIL RELATIONSHIPS IN JEFFERSON COUNTY, WISCONSIN

INTRODUCTION

Jefferson County, Wisconsin lies in the heart of the drumlin field of southeastern Wisconsin (Alden, 1918). The county is just north of the Johnstown Moraine which marks the southernmost extension of the late Woodfordian (Cary) ice of the Green Bay lobe in Wisconsin. Thirty-three miles separate the eastern limit of the county from Lake Michigan and 24 miles lie between the southern county line and the Illinois State Line (Figures 1 and 2).

Alden (1918, p. 254) defined drumlins as hills showing "clearly the moulding effect of the advancing ice," of "elongated ovoid" shape, "of which the widest part of the basal outline and the highest part of the crest are generally not more distant from the stoss end than one-third the length of the major axis, and whose major axis parallels the direction of movement of the glacier...." He included double-tailed, double and triple crested drumlins and those with subordinate overlapping crests in his descriptions.

This paper is based on a MS Thesis by R. J. Allan (1967) under the direction of the author. The purpose of this study was to analyze data for the drumlins of Jefferson County by means of multiple regression equations to explore relationships between parameters used to define these hills. Origin of fines in drumlin soils was also investigated in connection with the soil survey. Information on dimensions, orientation and arrangement of drumlins was obtained from the U.S. Geological Survey topographic map quadrangles (scale, 1:24,000 contour interval 10'). Particle size distribution and carbonate content of till and soils were determined in the laboratory for samples taken from 24 representative drumlins (Figure 3).

DIMENSIONS, COMPOSITION AND DISTRIBUTION OF DRUMLINS AND THEIR SOILS

A statistical analysis of properties of 320 drumlins (Figure 1) as measured on topographic quadrangles, indicates (Allan, 1967): (1) average drumlin length (Figure 4) is 3,053 feet, (2) breadth at widest point is 951 feet, and (3) height at crest is 48 feet (Figure 5). The two peaks in the curve of Figure 5 are yet to be explained. Numerical analysis does not support the hypothesis that they represent the influence of two textures of till (the somewhat more sandy one of which approximately overlies St. Peter Sandstone in western townships). The average north-south spacing of drumlins is 6,096 feet or double their length. On the basis of particle size distribution analysis of the sandy loam glacial till samples from 24 drumlins (figure 3), the average gravel content (material > 2mm) is 27 percent, and of the fine earth (<2mm) 72 percent is sand, 17 percent silt and 11 percent clay. The removal of carbonates in the laboratory increased the proportion of sand slightly. Figure 6 is a map, based on 24 analyses, of carbonate distribution in drumlin till in the county.

A study of soil profiles developed at crest sites both in loess-covered and loess-free drumlins (Figure 2 and 7) showed decreasing clay content from the main B horizon (Bt) to the C2 horizon (till) (Figure 8). Both Allan and Hole (1968) and Borchardt, et al. (1968) found evidence of incorporation into loamy drumlin-crest soils (Lapeer loam, Figure 9) of eolian silt and clay equivalent in amount to an eight-inch surficial deposit. Borders of lower-lying lacustrine plains have some overwash of colluvial sand and gravel (Saylesville loam, Figure 9). These workers postulate that in southern Jefferson County, wherever no distinct leached loess cap occurs on drumlin crests examined (Figure 7), the eight-inch increment of loess was mixed into and washed down the profiles of Lapeer soils, accounting for about half of the clay now in the Bt soil horizons. Soils that developed in distinct loess coverings (one half to one meter thick) have more clay in the Bt horizon than do soils without loess covering (Figure 10). The leached loess cap of the silty soils (Dodge, Theresa series; see Milfred and Hole, 1970) may possibly rest on a buried pre-loess Lapeer loam, not recognized as such because no buried A1 horizon has survived to mark the contact.

ORIGIN OF DRUMLIN FORMS

The statistical model of a drumlin derived from these analyses is a streamlined hill nearly three-fifths of a mile long, a fifth of a mile wide and 50 feet high (Table 1). In the range of textures studies (50 to 80 percent sand content in the till) no relation was found between dimensions and till texture.

The origin of drumlin forms must still be ascribed to the action of the ice in collecting and moulding materials. The nature of this action is discussed in Lasca's topical paper in this guide.

The arrangement of drumlins in clusters, as in T.6N., R.13E. (Figure 1) may provide clues to the genesis of these hills. It may reflect: (1) the pre-drumlin distribution of materials and subglacial landforms over which the ice moved; (2) the original pattern of ice movement, which suggests a possibility that the drumlins were formed, not by the main ice mass, but rather by finger-shaped lobes about five miles wide and twice as long that rapidly moved forward from the main body of the glacier and constituted the last stage of glacial advance; or, more likely; (3) a modification of the original pattern of drumlins brought about by erosion by meltwaters, particularly at times of breaking of ice dams, and by burial of drumlins at lower elevations under outwash, glacio-lacustrine deposits and peat.

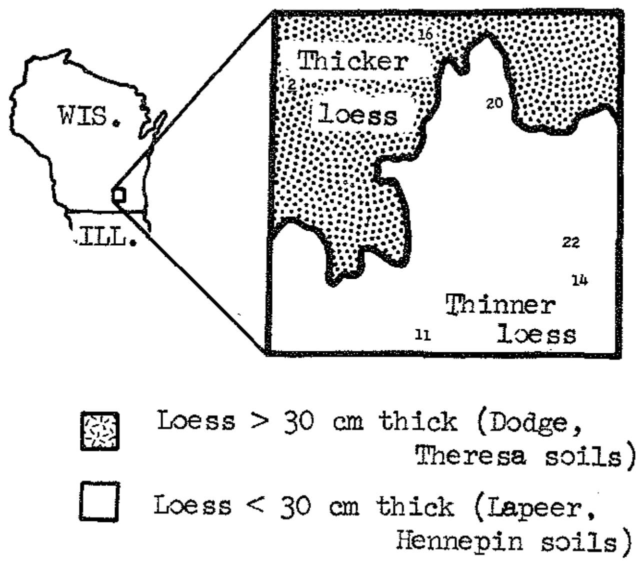


Figure 2. County location and general distribution of loess blanket.

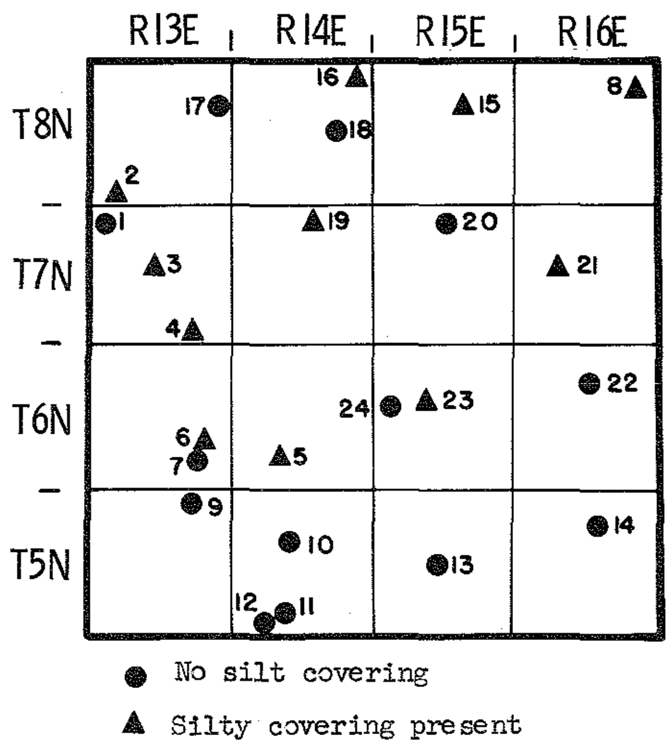


Figure 3. Location of soil and till sampling sites (1965).

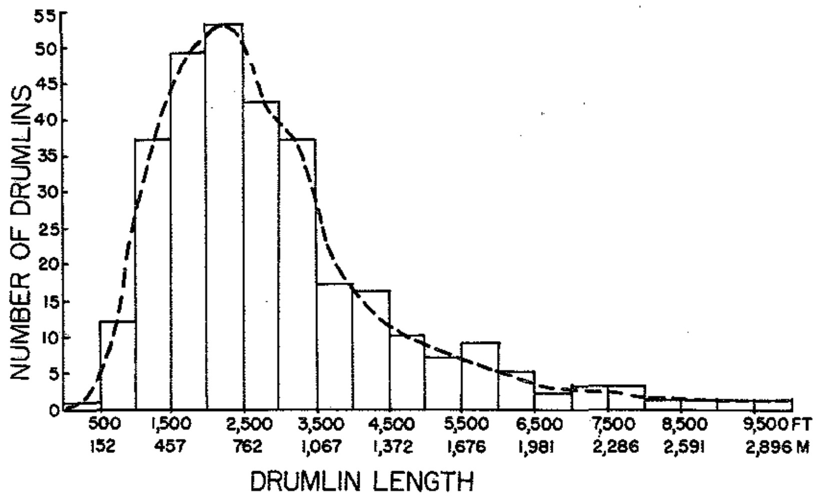


Figure 4. Drumlin length distribution among 320 drumlins.

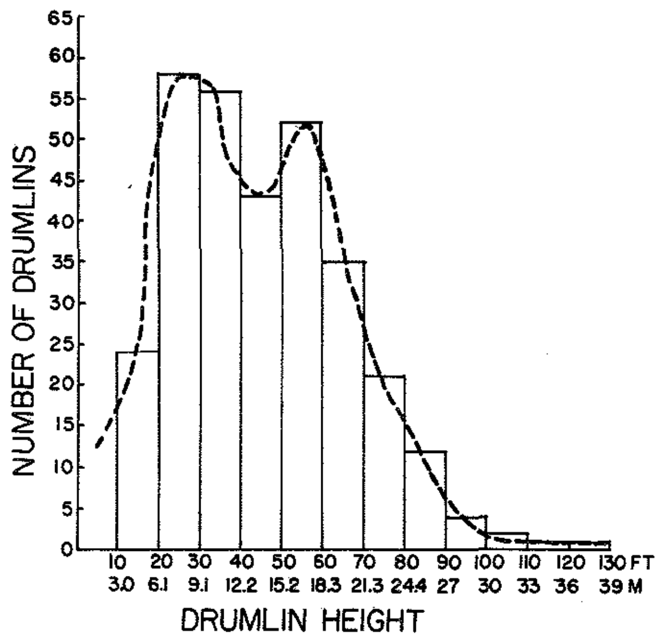


Figure 5. Drumlin height distribution among 320 drumlins.

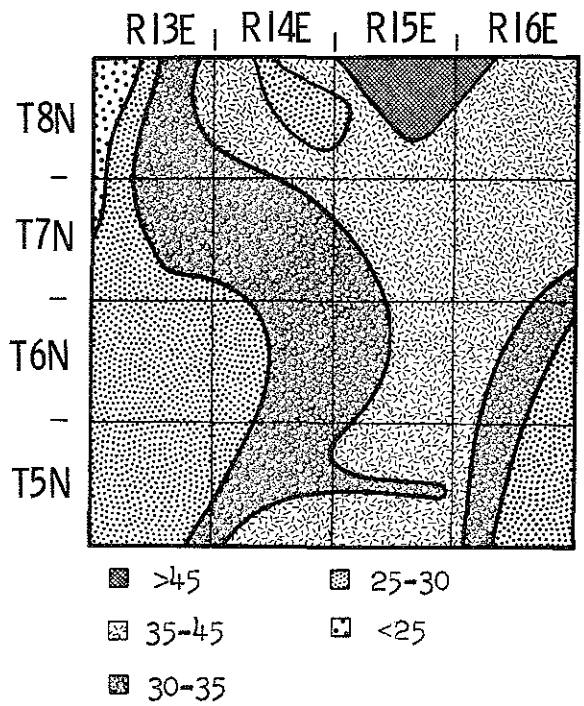


Figure 6. Percent $CaCO_3$ eq. in till of drumlins.

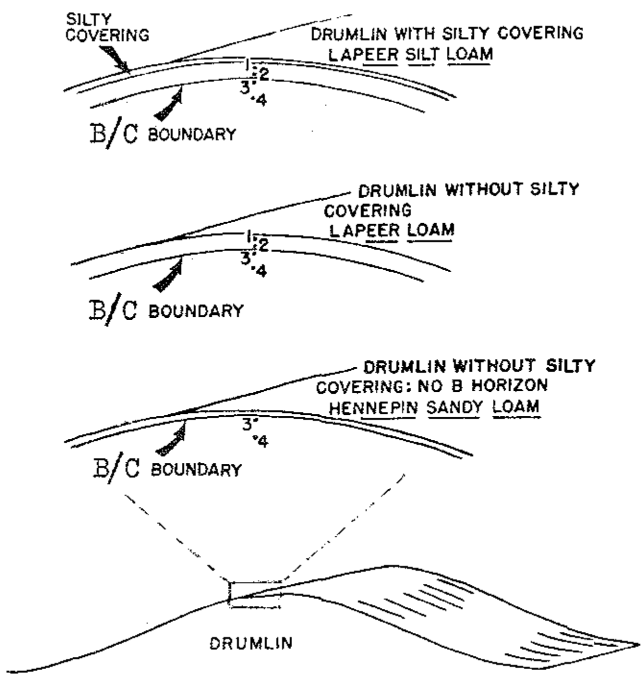


Figure 7. Soil horizons from which samples were taken. Bt = main B horizon; B3 = lower B horizon, 5 cm above the B/C boundary; C1 = till 5 cm below the B/C boundary; C2 till about 50 cm below the B/C boundary.

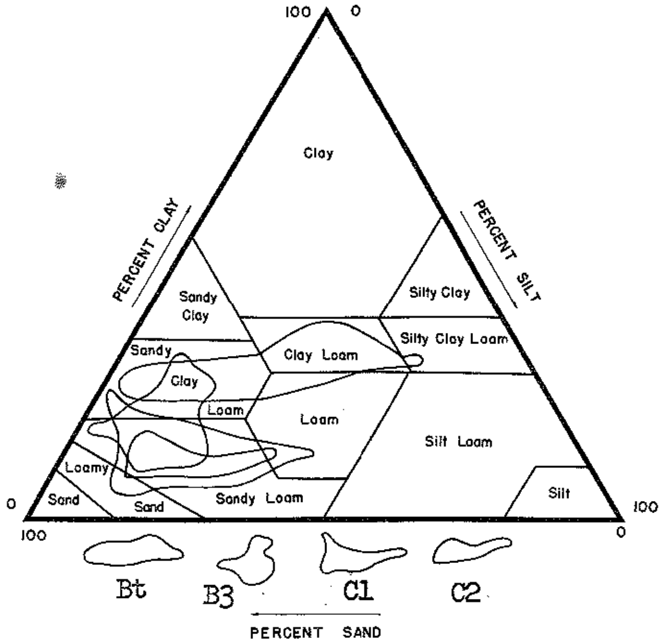


Figure 8. Texture of four soil horizons. Boundaries enclose clusters of data points (not shown) for the horizons enumerated in the caption to Figure 7.

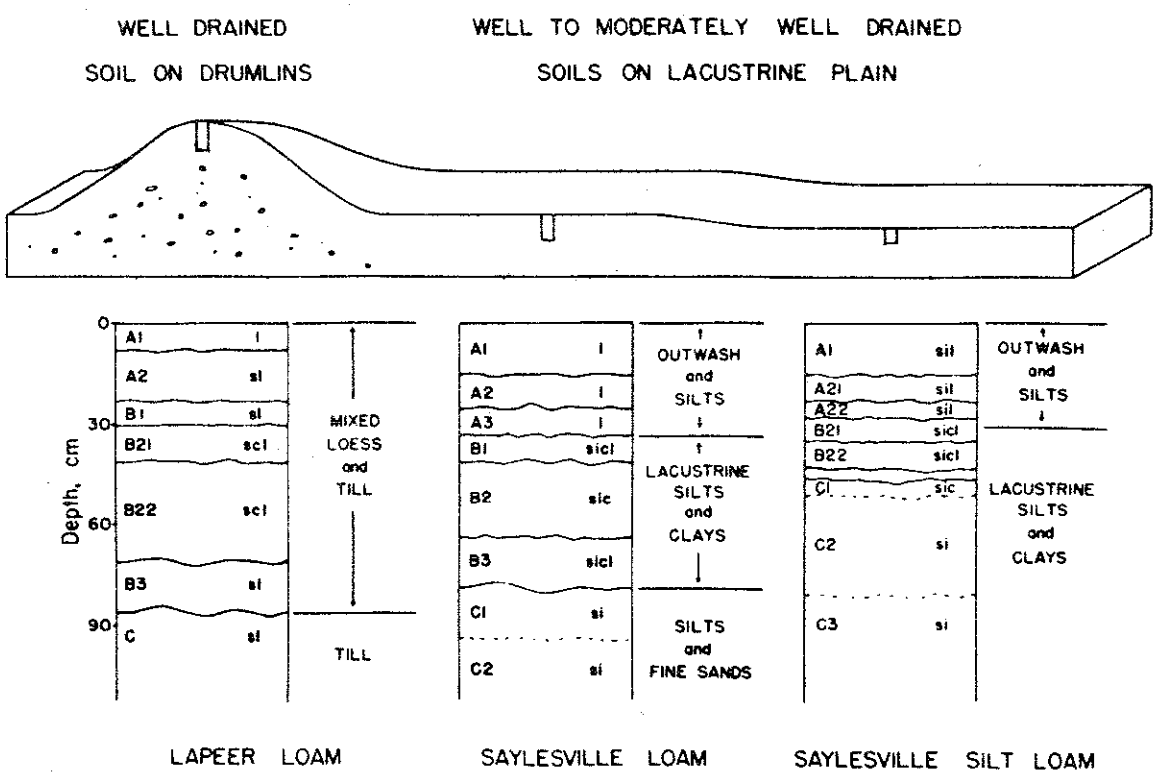


Figure 9. Landscape positions of two soils, one on a drumlin (Lapeer) and one near-by in lacustrine silts and clays (Saylesville).

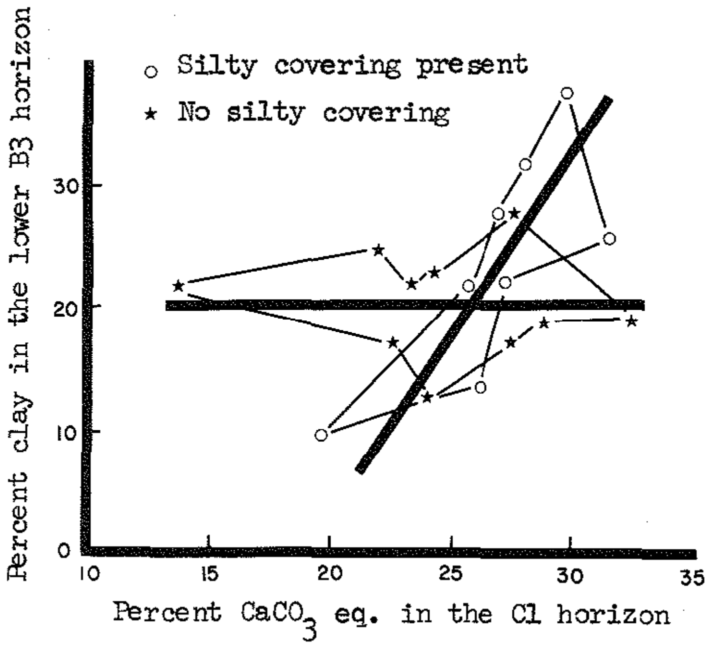


Figure 10. Relationship between clay content of the lower B horizon (B3, at 5 cm above the B/C boundary) and percent $CaCO_3$ eq. in the till (Cl horizon, at 5 cm below the B/C boundary), and presence or absence of loess cover above.

Parameter	Mean	S.D.	Parameter	Mean	S.D.
Drumlin Breadth	951'	445'			
Drumlin Length	3053'	1726'	$CaCO_3$ equivalent (%)	34.3	5.6
Number of Summits	1	0.7	Sand content (%)	70.7	7.5
Angle of main axis north of east	82^o	16^o	Silt content (%)	17.4	6.0
			Clay content (%)	11.5	2.2
Angle between main axis of a drumlin and the axis of the drumlin up-ice from it	12^o	11^o	Gravel content (%)	27.0	11.9

Table 1. Mean Values and Standard Deviations of Dimensions, Dispositions, Texture and $CaCO_3$ Equivalent of Drumlins in Jefferson County, Wisconsin.

Part G

CROSS PLAINS TERMINAL MORAINE AND RELATED FEATURES

by

Robert F. Black

CONTENTS

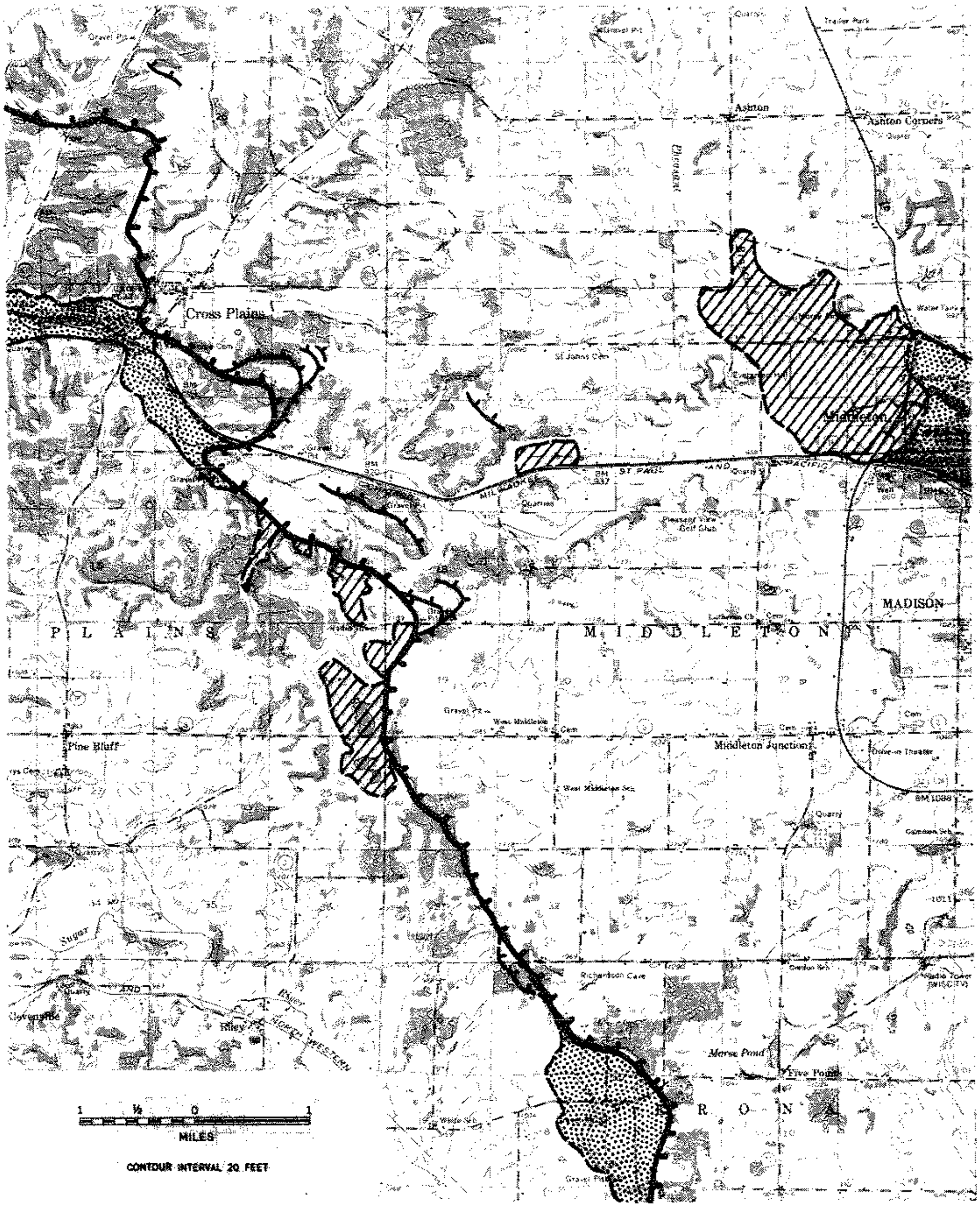


Figure 1. Portion of Cross Plains quadrangle showing glacial deposits

CROSS PLAINS TERMINAL MORAINE AND RELATED FEATURES

INTRODUCTION

The terminal moraine of the Late Woodfordian or Cary ice advance (Part A - Figs. 1 and 2; Figs. 1 and 2) is about 10 miles west of Madison, in the vicinity of the town of Cross Plains. At Cross Plains, and for many miles northward and southeastward, the Late Wisconsinan ice sheet ground to a halt on the Southwestern Wisconsin Uplands, marking the east boundary of the Driftless Area with a young moraine. The moraine, part of the Johnstown Moraine, extends southward in a broad curve through Adams and Sauk Counties into Dane and Rock counties. It follows an irregular arcuate course across the Baraboo Range and then becomes partly obscured in the Wisconsin River Valley near Sauk City. The moraine's minutely irregular course was controlled by local topography in the deeply dissected uplands in the vicinity of Cross Plains. From there the moraine trends south-southeasterly to Verona, Brooklyn, Evansville, and Janesville. Its name comes from its prominent front and abrupt reentrant angle near the town of Johnstown, east of Janesville, Rock County. For convenience in this report, that part of the Johnstown Moraine near Cross Plains will be referred to as the Cross Plains Terminal Moraine, or Cross Plains Moraine.

The deployment of the Johnstown Moraine of the Green Bay lobe was one of the first major glacial phenomena to be worked out in the State. The moraine was described by Chamberlin (1877, 1878, 1880, 1883a, and 1883b) as the terminal moraine of the Second Glacial Epoch and cited as the most important discontinuity in the Pleistocene Epoch in Wisconsin. Alden (1918) in his detailed reconnaissance of southeastern Wisconsin clearly defined and described the moraine and its associated features. His paper still stands as a model today, and contains the only published information on the former front in the vicinity of Cross Plains. Cline (1963) prepared a generalized map of surficial deposits of part of the area. Cline (1965) also included generalized maps showing bedrock topography, thickness of Quaternary deposits, and physiographic units and deposits of Quaternary age for all the area.

The Cross Plains area contains a typical portion of the Johnstown Moraine on the uplands and deposits of a typical proglacial stream in Black Earth Creek Valley. This is the only area known to the writer where the terminal moraine rests directly on well exposed, weathered, dolomitic bedrock, and where small formerly marginal proglacial lakes, a marginal drainageway, and a subglacial drainageway can all be seen in a small area.

Most of the length of the terminal moraine in southern and central Wisconsin fronts on broad outwash plains, in large proglacial lake deposits, or against older drift. There the relation of the moraine to its adjacent features is clear, but the observer must visit a large area with map in hand to appreciate it. In contrast, the glacial features associated with the moraine in the vicinity of Cross Plains are more varied and yet as definitive as one could hope to see, all preserved in a neat little package. The area is one of increasing urbanization, and preservation of parts of the front and its associated phenomena is not yet assured.

No studies specifically for this Stop on GSA Field Trip No. 4 have been attempted. Much of this summary of the literature and of our State of knowledge was assembled earlier for the National Parks Service (Black, 1966). The critical review of this narrative by Charles L. Matsch is acknowledged gratefully.

GENERAL DESCRIPTION OF THE MORAINE

Alden (1918, p. 212-213) described the distribution and topographic relations of the Johnstown Moraine between Verona and the Wisconsin River as follows: "Crossing an ancient valley at Verona, where it is cut through by Badger Creek, the moraine continues northwest up a second old tributary to Sugar River. For 1-1/2 miles north of the line of the Chicago, Milwaukee and St. Paul Railway the glacier occupied the valley and left its moraine crowded against the west slope, being separated therefrom by only a sharp narrow ravine 35 to 40 feet in depth. One side of this ravine, which was probably kept open by the southward flow of the glacial waters, is of nearly bare Lower Magnesian limestone /now called Prairie du Chien/ the other is formed by the abrupt front of the moraine. Through the next 1-1/2 miles the moraine front rises abruptly 60 to 80 feet from a flat terrace to a well-marked ridge crest, back of which a belt one-half to 2 miles in width, marked by gentle sags and swells and several ponds, extends to a very indefinite inner margin. Near the north line of Verona Township the moraine crosses the old valley and ascends 120 feet to the crest of the Trenton-capped /now called Platteville/ ridge beyond. Wells indicate thicknesses of 18 to 80 feet for the moraine in Verona Township, the average of 16 measurements being 46 feet. In sec. 5 the moraine is cut through by a narrow ravine 80 to 100 feet in depth, whose lower slopes and bottom expose the St. Peter sandstone and Lower Magnesian limestone.

"Outside the moraine near the town line the limestone crest of the ridge is covered only by thin clay soil and scattered boulders which probably came from the moraine or the ice front itself. Here for the first time, tracing it from the southeast, does the moraine reach the Driftless Area and mark the limit of glaciation for this part of the State. For 85 or 90 miles northward from this point no earlier glacier is known to have extended farther west in Wisconsin than the Green Bay Glacier of the later Wisconsin substage; and from this moraine front westward to the Mississippi, a distance of 75 to 80 miles, no unmodified glacial drift has ever been found. The relations of the Green Bay Glacier and its deposits to this thoroughly dissected erosion topography are instructive. For 2 miles in southwestern Middleton Township the ice front lay along the east slope and crest of the rock ridge and deposited its moraine there and in the heads of the ravines which cut the western slope. It is remarkable that no outwash deposits lead down these ravines away from the moraine. Possibly most of the water drained backward down the east slope of the ridge beneath the ice. In sec. 30 the rock ridge swings westward about a mile across the line into Cross Plains Township. The ice did not press forward to the head of the valley thus extended but deposited its moraine across the valley in such a manner as to leave the upper part an enclosed basin 60 to 80 feet in depth. The west front of the morainal dam is bordered by a narrow flat terrace deposited in a temporary lake which occupied the basin. From this terrace the slope rises abruptly 30 to 40 feet to a narrow crest marked by parallel ridges and sharp kettles and many boulders from which a long gentle slope drops down eastward to an indefinite inner margin. Mr. Voss's well near the top of this slope, at a point about 30 feet lower than the crest, reached rock at a depth of 130 feet.

"North of this valley is a high limestone divide between the Sugar River basin and the Black Earth Valley. The rock ridge, before it was covered by the drift, had a relief of 140 to 200 feet on the south and of 300 feet or more on the north. In overriding this ridge obliquely a notch or reentrant three-fourths mile in depth was developed in the glacial margin. This indicates that the extreme frontal slope of the ice rose about 200 feet in the first mile from the edge. The moraine ascends the south slope, its crest reaching, in the SE $\frac{1}{4}$ sec. 18, T 7 N, R 8 E, the highest elevation thus far attained, 1,239 feet above sea level. Just how much drift there is at this point is not known, but rock is exposed in the slope and reached in wells 80 to 100 feet lower beneath 20 feet of drift within half a mile. An average of the thicknesses of drift penetrated in the moraine in Middleton Township by 10 wells is about 60 feet. Continuing northwestward the front of the moraine runs for a mile along the crest of the south bluff of the Black Earth Valley as a small marginal ridge 150 to 200 feet above the bottom of the partly filled valley to the north, where it blocks the heads of two ravines. In the NW $\frac{1}{4}$, sec. 13, T 7 N, R 7 E (Cross Plains Township), it drops down the slope into the valley where, in crossing obliquely, its relief is lost in the general filling of moraine and outwash deposits.

"In the NE $\frac{1}{4}$ sec. 11 a narrow marginal ridge 15 to 20 feet high extends up the north slope of the valley and thence across the heads of ravines and intervening ridges one-fourth mile or less back of the crests of the bluffs, which rise abruptly 100 to 140 feet from the flat floor of the partly filled valley. The surface of this drift is thickly strewn with erratic boulders, but outside its margin not a piece of drift is found in the thin clay soil. Within the marginal ridge, drift marked by slight sags and swells mantles the rock ridge, but the moraine is not bulky and its inner limit is poorly defined.

"The converging of valleys from the east and northeast at Cross Plains led to the ice front crowding forward slightly into the narrow opening between the heads of opposite salients. Here the moraine is pitted with slight sags through a width of a mile and has a relief of 20 to 40 feet above the flat outwash plain to the west. The contrast between the craggy bluffs capped with Lower Magnesian limestone outside the moraine and the smoothly rounded slopes within it is very striking in the vicinity of Cross Plains.

"Northwestward from Cross Plains to the Wisconsin River valley, a distance of about 10 miles, the limit of glaciation is generally plainly marked by a narrow marginal ridge with plentiful boulders. This ridge is a few rods in width and rarely more than 20 feet high, but it is traceable continuously across a greatly dissected topography of five rock ridges 200 to 250 feet in height and four intervening valleys. After leaving the valley at Cross Plains the surface shows, for the most part, only the smooth undulating contours of ground-moraine topography. It looks as though the bulk of the morainal deposit was not formed at the limit of the advance in this part but is represented by the morainal belt which leaves the marginal ridge just north of Cross Plains and thence northward lies about 2 miles farther east.

"For a mile north of Cross Plains the ice pressed against the east slope of the rock ridge fitting snugly into the ravines, as shown by the little marginal ridge which encircles their heads. The crossing of this first ridge causes a reentrant of nearly three-fourths mile, the ice having pushed forward in the next valley. Two to three miles farther northwest a reentrant of one-half mile resulted from overriding a ridge 250 feet high, the ice pressing forward in the valley west of Marxville. So also on the broad low tract near Wisconsin River the ice extended about a mile farther west than on the narrow crest on the south, which rose 300 to 400 feet higher.

"The deposit which separates from the marginal ridge north of Cross Plains merges with it again in the broad valley west of Roxbury. The limits of this morainal belt are very indefinite, its presence usually being indicated only by sags and kettles which pit the surface. A mile west of Martinville, however, in adjacent parts of secs. 11, 12, 13, and 14, T 8 N, R 7 E (Berry Township), some of the most strongly marked morainal topography within the region occurs. One bulky ridge which appears to be drift has a relief of 160 feet on the west; and its crest stands 1,249 feet above sea level, or about 400 feet above the rock bottom of the partly filled valley at Marxville, 3 miles to the northwest. The average thickness of drift penetrated by 16 wells in this morainal belt in the towns of Cross Plains and Berry is about 55 feet. These depths range from 25 to 95 feet, several of them not reaching the base of the drift."

The above statement is a clear description of that part of the Johnstown Moraine in the vicinity of Cross Plains. When the conditions and methods of study imposed upon Alden (1918) in his reconnaissance of all southeastern Wisconsin are taken into account, his accomplishments and insight into the Pleistocene geology of the region are nothing short of remarkable. His map published at a scale of four miles to the inch, could not show all the details portrayed by the new topographic quadrangles at about 0.4 mile to the inch and 10-foot contour interval, nor by aerial photographs. Still only details of the story need be changed.

Alden (1918, p. 209-217) clearly recognized that not all the drift in the Johnstown Moraine was deposited during the one substage, that the thickness of the drift varied markedly from segment to segment of the moraine, and that the outermost front of the Johnstown Moraine was not everywhere synchronous nor even representative of equal periods of time. Alden (1918, p. 220-222) also demonstrated that the bulk of the pebbles and stones in the moraine were derived from rocks that crop out in the vicinity and that only 5 to 20 percent were derived from Precambrian igneous and metamorphic rocks from northern Wisconsin, upper Michigan or Canada. Keweenaw copper nuggets from upper Michigan and one diamond, presumably from Canada, are among the least common constituents. Dolomite, chert, and sandstone of the local formations are most abundant.

Drillers logs of holes west of Cross Plains suggest that till is present 1 mile to 2 miles west of the prominent end moraine (Cline, 1963 p. 8).

DETAILS ALONG THE ROUTE

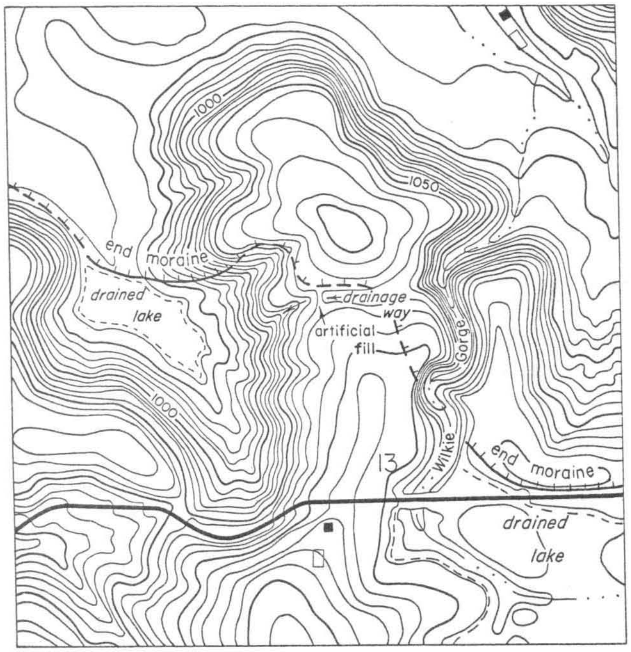
A portion of the Cross Plains topographic map is reproduced in Figure 1, showing the outer edge of the Cross Plains Terminal Moraine (Fig. 3), some of the fronts established during retreat, a position occupied briefly beyond the main front, and some of the former lakes and outwash as interpreted by the writer largely from aerial photographs. An interpretation of the general events follows.

The two small ponds in sections 24 and 25, 2.5 miles east of Pine Bluff, are now separated by Mineral Point Road (County Highway S). They are the remnants of a former single proglacial lake that filled the basin to about 1155 feet in elevation. The lowest pass from that basin to the west into the headwaters of the Sugar River is about 1175 feet; no evidence that the former lake ever drained through it has been found. Instead it seems to have drained northward across a bedrock ridge of the Platteville limestone (formerly Trenton of Alden, 1918) at about 1155 feet into the adjacent proglacial lake at the same elevation. That lake was short lived, being held in by ice that only temporarily filled the valley 0.4 mile east of the radio tower in the extreme northeast corner of section 24. (The "gravel pit" on the U.S. Geological Survey topographic map, 0.5 mile eastward in the SE $\frac{1}{4}$, SW $\frac{1}{4}$, sec. 18, is actually a small quarry in the Ordovician dolomite).

Water from the two lakes to the south flowed northward marginal to the ice from the vicinity of that pit, past an outcrop of the St. Peter Sandstone on the southwest side of the valley, and into another small proglacial lake in section 13, at an elevation of about 1090 feet. The terminal moraine lies on the northeast side of that valley, although large Precambrian crystalline erratic boulders are scattered southwest of the intermittent stream. Water from the proglacial lake in section 13 briefly flowed across the bedrock spur in the center of Figure 2, through the drainageway indicated (Fig. 4). It left bare weathered dolomite and residual chert of the Prairie du Chien Group exposed in ridges between bifurcating distributaries as the water plunged westward from the steep face (Fig. 5). The bare dolomite and chert are solution etched into bizarre forms (Fig. 6). Large erratic boulders of granite, gabbro, and intermediate igneous rocks are scattered on the dolomite (Fig. 5). That drainageway apparently was occupied only for a short time by the overflowing lake waters which soon began cutting Wilkie Gorge as they flowed under the ice. Water from about 2.3 miles along the front of the Late Woodfordian glacier thus flowed northward along the front, from one proglacial lake to another, until finally cascading to the lowland in section 13.

The amount of material deposited directly by the ice in this part of the Johnstown Moraine varies markedly from point to point. Alden (1918, p. 218) records the log of a well at the home of Mr. Voss (NW $\frac{1}{4}$, sec. 30, T 7 N, R 8 E) believed to be that which is 0.2 mile east of the moraine and road junction at 1166 feet on County Highway S, 3.0 miles east of Pine Bluff. The well penetrated 75 feet of clay and 55 feet of sand and gravel to the St. Peter Sandstone. However, the writer has found dolomite just two feet below the surface of the gently dipping slope of the outwash apron of the Cross Plains Moraine, in the extreme southeast corner of section 24. Dolomite crops out one-half mile north, in the

CROSS PLAINS SITE



North-center 1/4, sec. 13, T 7N, R 7E
Middleton Quadrangle — 7.5 min.

0 1/4 Mile

Figure 2.

Portion of Middleton Quadrangle T.7N., R.7E.

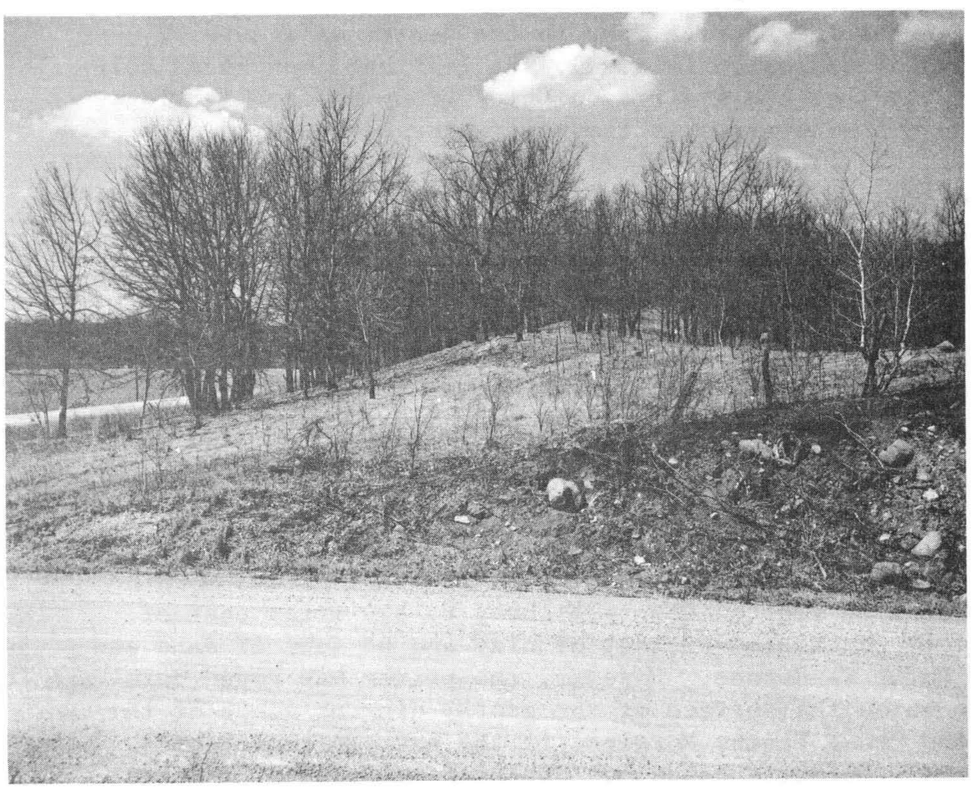


Figure 3.

Cross Plains Moraine

same ridge. Thus, the thickness of till in the moraine seems to be no more than 40 feet at its crest which lies on the west rim of a preglacial valley. The moraine is even thinner north and south from County Highway S. A marked low pass in the moraine immediately south of County Highway S was made by the County Highway Department while "borrowing" for fill for that highway immediately west of the moraine. The amount of fill in the basin of the proglacial lake bissected by County Highway S likely is several tens of feet, although no subsurface exploration has been attempted. Erratics have been found on the west side of the basin in the vicinity of the farm houses. Whether carried there by ice rafting or by glacial ice directly is not known.

The gully crossing the drained lake basin in the southeast corner of Figure 2 exposes eight feet of silt on clean, poorly-sorted sand and gravel. The base of the section was not seen, but a hand auger revealed seven feet of the sand and gravel without reaching bottom. The upper silt resembles loess, but it contains more clay and sand than normal loess. Probably it was derived from loess, blanketing the slopes, that was washed into the former proglacial lake on top of deltaic sediments and outwash. The axis of the former valley occupied by the proglacial lake in the southern part of section 13 lies to the east of Wilkie Gorge, about in the position of the town road that descends to the north along the east margin of Figure 2. That axis is choked with glacial debris. Wilkie Gorge exposes Prairie du Chien dolomite (formerly Lower Magnesian limestone of Alden, 1918) up to the vicinity of the town road crossing the southern part of Figure 2. The end moraine to the east of the gorge is only about 20 to 40 feet thick. The moraine north of the drainageway (Figure 2) is less. The upper part of the Prairie du Chien dolomite, as indicated by oolitic chert and sandstone layers in dolomite, crops out on the south side of the drainageway up to 1080 feet, and locally on the flanks of the spur at about the same elevation to the north.

The solution effects in the Prairie du Chien dolomite on the Wilkie property might have been accomplished in the 13,000 radiocarbon years the rock presumably has been exposed. However, a longer time seems more logical in view of the appearance of the chert. The writer suspects that the solution phenomena were formed during some earlier weathering cycle and exhumed by the glacial meltwater. The reddish color of the solum locally outside the moraine hints that a Sangamonian soil might be present, but Tertiary residuum is megascopically similar. No detailed laboratory studies have been attempted to distinguish them.

Black Earth Creek valley contains many tens of feet of glacial outwash (Dury, 1964, p. 11; Cline, 1963, p. 8) whose bottom has not been reached in the vicinity of Cross Plains. The gravel pit operations one mile southeast of town expose at least 50 feet of coarse gravelly outwash. This outwash built up in the valley, damming the mouths of downstream tributaries and forming lakes or swamps in them. Whether all the outwash is Late Woodfordian in age is not known. According to Dury (1964, p. 11), Black Earth Creek is "manifestly underfit". Its large meanders formed with recession of the Late Woodfordian ice (p. 17).

The flow of upper Black Earth is sustained mostly by ground water discharge (Cline, 1963). Ground water locally is confined under artesian conditions beneath till. Sandstone of Late Cambrian age and the sand and

Figure 4.

Drainageway
T.7N., R.7E.

Figure 5.

Igneous erratic
on dolomite

gravel outwash are hydraulically connected.

The Late Woodfordian ice retreated slightly from its maximum position in several places north and south of Cross Plains. Only a few of the retreatal moraines are indicated on Figure 1. One forms a conspicuous ridge trending northwesterly on top of and west from the prominent bedrock-supported "island" in Black Earth Creek valley, three miles southeast of Cross Plains. That "island" and another 1.5 miles eastward formed distinct barriers to ice flow and to the later melt water that passed westward both on the north and on the south. Small kettles with ponds are conspicuous on their north sides. Many tens of feet of lacustrine sediments were penetrated by a drill south of the eastern island.

Loess on top of outwash and on the moraine in Black Earth Creek valley obviously means that some loess postdates the withdrawal of the Late Woodfordian ice from its extreme position at the Johnstown Moraine (Dury, 1964, p. 13).

Short-lived lakes occupied temporarily most parts of Black Earth Creek valley during and since the deglaciation of the Late Woodfordian ice. Only one relatively recent small lake and Glacial Lake Middleton (Alden, 1918) are shown on Figure 1. Glacial Lake Middleton has had a long and complex history which is not clearly understood. Alden (1918, p. 265-266) has written: "When the ice front lay across the big rock hill in the midst of Black Earth valley 3 miles west of Middleton the glacial waters cut an outlet through the outer moraine and eroded a channel in the outwash deposits that form the flat bottom of the valley westward to the Wisconsin. Near the glacial front a small terrace of gravels was formed. With the recession of the ice front to the next position a mile farther east the waters were ponded and discharged around the south side of the rock hill. The small lake basin at this place is now occupied by a marsh. At the third stand of the ice front this lake extended westward through a narrow sag in the moraine and received the outwash gravels that formed the terrace on the north side of the railway 1 to 2 miles west of Middleton. At the fourth stand the glacial front was at the moraine extending southward from Pheasant Branch at the west end of Lake Mendota basin, and the waters expanded in a lake about 3 miles in extent, covering the flat northwest of Middleton. To this temporary lake F. T. Thwaites, who has made a somewhat detailed study of the deposits, has given the name glacial Lake Middleton. The waters continued to discharge westward and washed into this basin much assorted drift material. Several wells on the moraine penetrate 80 to 201 feet principally of sandy drift, showing that a considerable valley underlies the ridge. This valley also continues westward beneath the lake flat. The moraine rises 60 to 80 feet above the marsh to the east, but from its crest a nearly flat terrace extends westward to a slight marginal slope which drops down to the lake flat. This margin of the terrace may be traced northward from the village a short distance east of the north-south road. The moraine, terrace, and lake beds are now cut by a ravine through which Pheasant Branch drains the basin to Lake Mendota. The sides of this ravine near the bridge north of Middleton expose 10 to 15 feet of clean white stratified sand, with cross-bedding dipping westward. According to W. J. Schneider, driller, Middleton, several wells on the lake flat penetrate 100 to 226 feet of drift.

Log of John Schroeder's well, three-fourths of a mile north of Middleton, Wisconsin

	Feet
Sand	100
Peat	1
Clay	125
Cambrian sandstone	2
	228

Log of well at post office, Middleton, Wis.

	Feet
Sand	60
Blue stony clay with wood at depth of 92 feet	73
Cambrian sandstone	2
	135

"A well one block west of that at the post office encountered wood beneath 52 feet of sand and above 80 feet of drift. The well at the American House penetrated 60 feet of sand and 60 feet of underlying blue clay, probably glacial till. It is not known that all the sand was deposited in the lake; some of it may have been deposited in connection with the advance of the ice. Some of the wells penetrate 40 feet or so of clay, which may be lacustrine silt, above a thick deposit of sand. The peat penetrated by Mr. Schroeder's well may indicate an interval of exposure and vegetal growth which was pre-Wisconsin so the 125 feet of clay underlying the peat may be a remnant of an earlier filling. The wood encountered in other wells may be evidence of similar conditions, or may have been brought with the drift and not have grown where it was found."

It seems clear that the uppermost lake sediments in Glacial Lake Middleton rest on till in Middleton and northward. The sediments at the west side of the lake are typically various shades of brown medium sand with fine to coarse facies and interspersed silty clay zones. Pebbles are thinly scattered throughout. The finer sediments, in part rhythmically bedded, are more common in the lower part and cleaner sand in the upper part of the deposit. Till was not penetrated, nor was bedrock reached. Sediments in the eastern part are at least locally similar to those in the west. The writer found no organic matter in any power auger holes he drilled, although early drillers reports suggest it is abundant. As none has been found of Woodfordian age in the State, the possibility that it is Farmdalian or Altonian seems strong. If so, it suggests the lake existed more than once.

Glacial Lake Middleton formed at the waning of the Late Woodfordian ice and was drained apparently during Twocreekan time. A minimum time is set by one sample of larix (identified by B. F. Kukachka, U.S. Forest Products Laboratory, Madison, Wisconsin) at the top of marl and under 10 feet of peat, about 20 feet above present Lake Mendota (850 feet). It was radiocarbon-dated as 11,560 $\pm$ 350 years (W-2015). The location lies immediately east of Middleton as shown on Figure 1 (specifically NW $\frac{1}{4}$, SE $\frac{1}{4}$, sec. 12, T 7 N, R 8 E). The wood should date the shrinkage of formerly expanded glacial Lake Mendota to that level of about 870 feet which lay between the water level of Glacial Lake Middleton (about 940 feet) and present Lake Mendota (about 850 feet). Opening of drainage down the Yahara River to the south (as today) would have drained Glacial Lake Middleton abruptly to the intermediate level radiocarbon dated. That is the level of the drift barrier southward prior to downcutting of the channel.

Numerous other sandy lake deposits are found both north and south of Middleton on upland surfaces at various elevations up to at least 1,040 feet. No detailed study of them has been attempted. The writer in his reconnaissance has concluded tentatively that many deposits were laid down in lakes with ice margins; they were not necessarily connected with each other or with Glacial Lake Middleton which they presumably predate slightly.

Cline (1965, pl. 2) shows the position of the outer margin of the Johnstown and Milton Moraines. The latter lies east of the area of Figure 1. It has been interpreted as a retreatal phase of the Johnstown Moraine in the Madison area (Alden, 1918) yet synchronous with the Johnstown Moraine to the south in the Rock River Valley (Oakes, 1960). In the Madison area several exposures behind the Milton front reveal the overriding of lacustrine deposits by ice which left till unconformable on the stratified deposits. Unfortunately neither the lacustrine deposits nor the till has been mapped in three dimensions, nor have they been dated precisely to determine their proper fit in the chronology of events.

SUPPLEMENTAL INFORMATION

In the southern part of Figure 1, and not on the route of the field trip, a deep drainageway is shown cutting through the moraine in the center of section 5. The drainageway passes the portal of Richardson Cave, the largest in Dane County and presumably preglacial. It is in Prairie du Chien dolomite that is exposed also along the marginal drainageway extending southward into the outwash area. Bedrock is exposed in the roadcuts and in the gravel pits in sections 8 and 9 in that outwash area. Drilling between the gravel pits disclosed bedrock at a depth of only a few feet, yet tens of feet of gravel are exposed in the pits. Thus, the moraine and outwash both are only a relatively thin veneer mantling and smoothing a stream-dissected bedrock topography.

One of the deeper preglacial bedrock valleys can be traced from the gap in the moraine, south of County Highway PD, northeastward to Five Points and Morse Pond, and thence northeasterly to the steep-walled valley northwest of the WISC radio and TV tower (southeast corner of Figure 1). The St. Peter and Platteville-Galena formations crop out on both sides of the valley which is occupied partly by kettle lakes, the largest being Morse Pond. Typically along the Johnstown front, areas of outwash were localized by preglacial topographic lows in the bedrock. There the glacier could maintain its thickness with a lower surface elevation, which in turn concentrated surface runoff at those points. The highest bedrock ridges have negligible outwash, as is seen along the front to the north; the lowest areas have the most. The discharge point at Verona (passed through on the second day of the field trip) is larger and topographically lower than those shown on Figure 1, and consequently contains far more outwash. The same principle applies to the Rock River valley at Janesville where still lower topography concentrated many times more runoff and several hundred feet of outwash, not all of which can be attributed to the Late Woodfordian ice.

The contrast between drift-mantled surfaces behind the Johnstown front and the thinly loess-mantled surfaces beyond the front can be seen easily from the bus (we will see much more of the Driftless Area on the second day of the trip). The topographic map (Figure 1) shows somewhat more irregularity of topography in front of the moraine than behind, but the effect of glaciation close to the front has been one mainly of filling in the lower areas rather than of eroding the higher areas. Drift on many of the uplands behind the front is only a few feet thick, but in valleys it is tens of feet thick. The main valleys in front of the moraine have also been filled with tens of feet of outwash and loess-derived colluvium. Hence, only valley sides and tops of hills beyond the front show the paucity of cover.

Erosion by frost action, gravity movements, and surface runoff may have been far greater during glacial times than now, but present rates are phenomenally rapid (Black, 1969b). From data gathered over a seven-year period at a field station four miles west-northwest of Cross Plains average rates of erosion today on typical non-forested slopes in southwest Wisconsin are 1 foot to 3 feet per 1,000 years. Extrapolation of those rates to the last periglacial times in southwest Wisconsin, 15,000 to 20,000 radiocarbon years ago suggests that 10 to 50 feet of material have been removed from the slopes since then.

Pinnacles and castellated spires develop quickly in friable sandstone and are fairly commonplace within the Driftless Area. Some may date only to Woodfordian times, but others must be older. Small pinnacles may be seen one mile west of Pine Bluff, on the south tip of a spur of St. Peter Sandstone. A larger pinnacle is in a roadside park on Highway 92, 1.5 miles northwest of Mt. Vernon. Devils Chimney 2.3 miles southeast of Mt. Vernon (New Glarus quadrangle) is still larger. Both of these pinnacles are thought to be related to a former glacial lake that occupied the West Branch of Mt. Vernon Creek. The details of these and other pinnicles in the area are beyond the scope of this discussion.

The problem of whether the Driftless Area was ever glaciated or not cannot be answered from evidence in the Cross Plains area. Ice seemingly went 1 mile to 2 miles west of Cross Plains in Black Earth Creek Valley, but no evidence of older drift has been found on this part of the uplands.

The thin young loess cover and paucity of residual materials on the bedrock outside the front prove only that any older loess and residuum have been removed or that they were never deposited. Both older loess and residuum are found elsewhere in the Driftless Area, and they should be in the Cross Plains area. Their removal from the hills and completely out of the drainage network as well is not explicable in terms of runoff experienced today. Dury (1964 and 1965) would have increased precipitation and the writer would use earlier glaciation to explain their absence. Some of these aspects are discussed further with reference to Stop 6 at Blue Mounds and Stop 7 during the second day of the field trip.

Figure 6. Solution etched chert residuum

Part H

BLUE MOUNDS AND THE EROSIONAL HISTORY OF SOUTHWESTERN WISCONSIN

by

Robert F. Black

CONTENTS

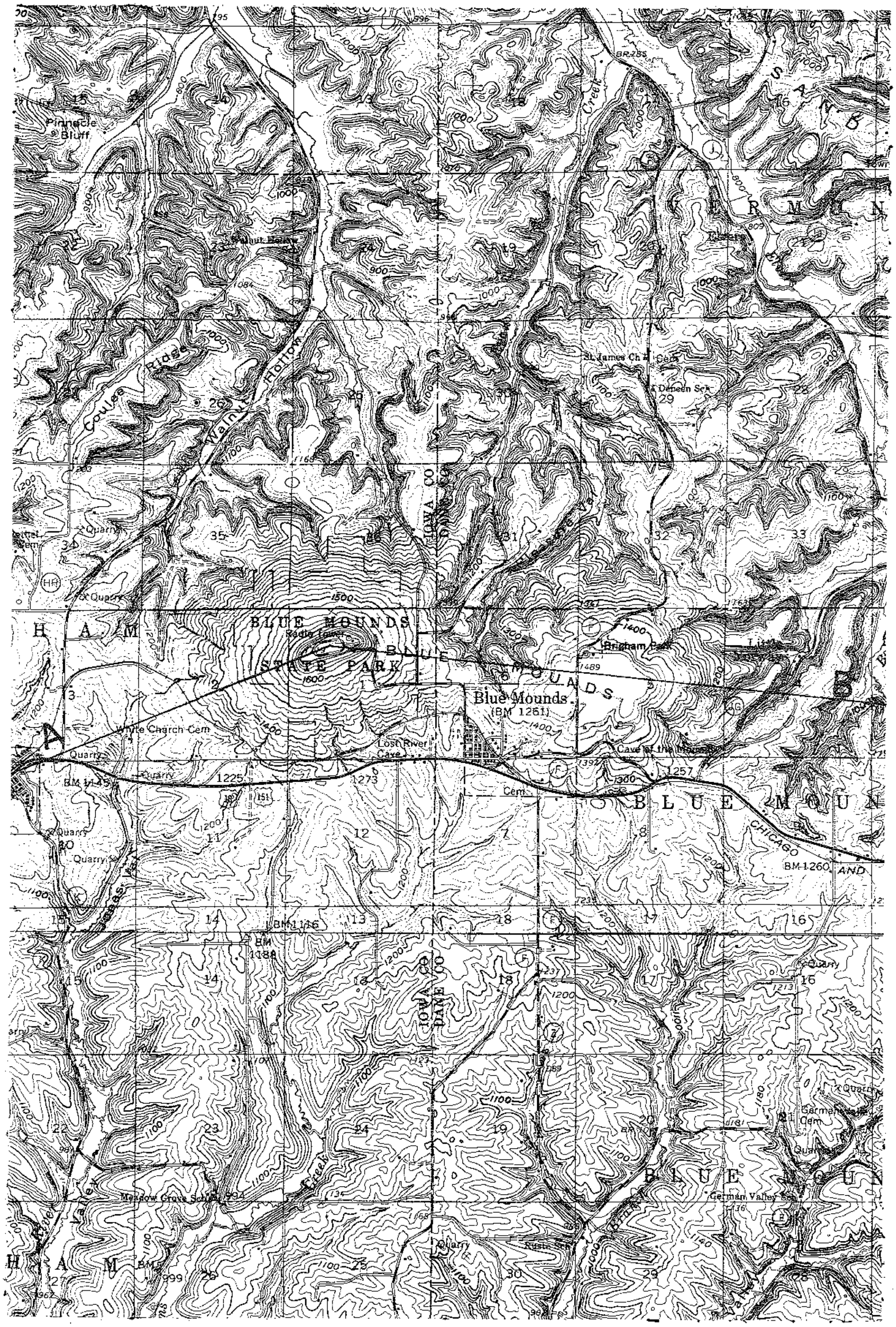


Figure 1. Topographic map of the Blue Mounds area, portions of the U.S. Geological Survey Quadrangles - Blue Mounds and Blanchardville.

BLUE MOUNDS AND THE EROSIONAL HISTORY OF SOUTHWESTERN WISCONSIN

INTRODUCTION

West Blue Mound (1716 feet) and East Blue Mound (about 1490 feet above sea level) rise 300 to 500 feet above the general level of the surrounding upland cut in the Galena-Decorah-Platteville dolomites of Ordovician age (Figs. 1-4). West Blue Mound is capped with 85 feet of dolomite and chert of Niagaran (Silurian) age; all dolomite in the upper 75 feet is completely silicified (Thwaites, 1960, p. 26). Between the 1630-foot and 1380-foot contours the mound is ringed by gentle slopes on the Maquoketa Shale (upper Ordovician) (Figs. 1 and 2). The flat surface of East Blue Mound (Fig. 3) is developed in the Maquoketa Shale; only 80 feet remain according to one drill hole (Cline, 1965, Pl. 4) (Fig. 2). Relatively few fragments, up to four feet across, of the younger silicified Niagaran unit are scattered over the top and flanks.

West Blue Mound is an outlier of the Niagaran escarpment that lies about 50 miles to the southwest in Illinois and Iowa and about 70 miles eastward in eastern Wisconsin. Other smaller and lower outliers in southwestern Wisconsin, closer to the escarpment, can be seen from the top of Blue Mound. None occurs in southeastern Wisconsin where Martin (1932, p. 65-66) thought glaciation had destroyed them.

Outliers of flat-lying strata or gently-dipping cuestas are common in many parts of the world. As isolated hills capped with resistant rocks readily correlated with those of the nearby units, they have been considered the result of normal but long-term erosion processes. However, remote outliers owe their existence to peculiarities in the development of the drainage network which in turn result commonly from unusual structures, properties of the rock, and position with respect to drainage divides. In this regard West Blue Mound seems entirely fit with its resistant cap and its position on a major drainage divide. However, East Blue Mound does not seem fit. It lies adjacent to West Blue Mound on the same drainage divide, but is capped with fissile shale with thin beds of dolomite at the very surface. Loess only 1 foot to 4 feet thick covers the shale. Soil profiles examined only in the field, suggest it is not older than Late Wisconsinan. The slopes established on the Maquoketa shale are similar for both mounds, yet East Blue Mound has a much larger and flatter top than West Blue Mound.

One must conclude from the various evidence that East Blue Mound was protected by a fairly resistant cap until very recently. That cap was several times the area of the cap on West Blue Mound. An obvious question then is, "How was the cap removed?" This and other questions, such as when was it removed, of what was it composed, are explored only briefly and qualitatively in this note. The writer concludes that early Pleistocene glaciation is a logical but not proved explanation for the removal of a cap of partly silicified dolomite.

A critical review of this report by Charles L. Matsch is acknowledged gratefully.

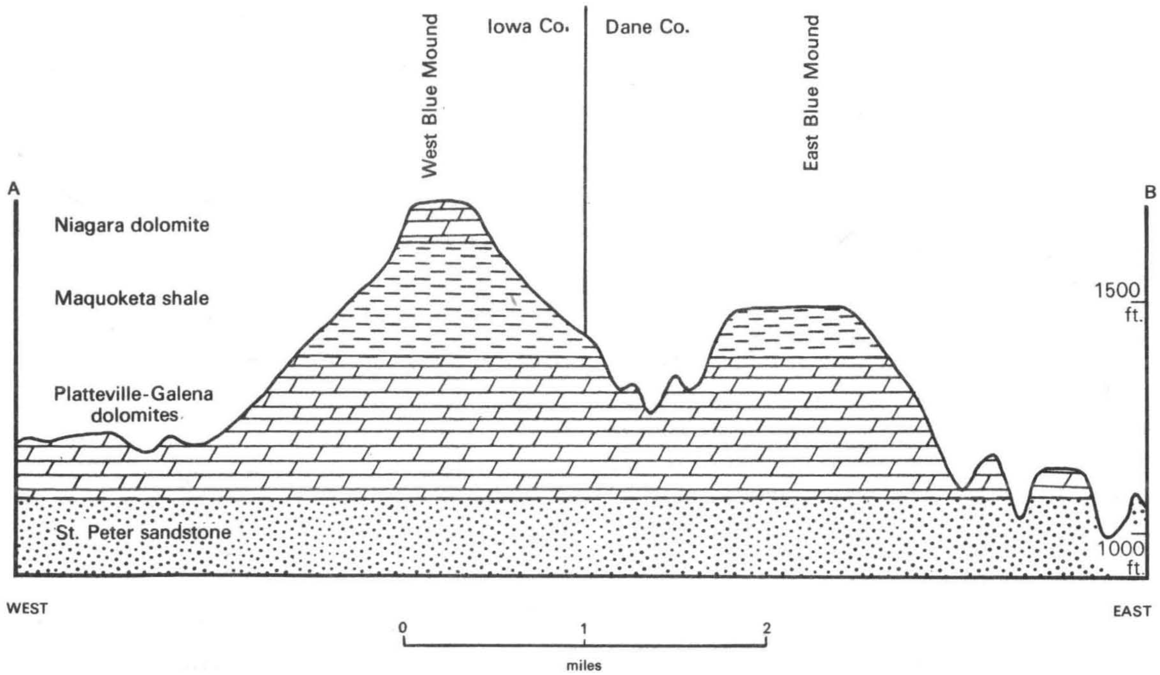


Figure 2. Cross section through Blue Mounds, from east to west

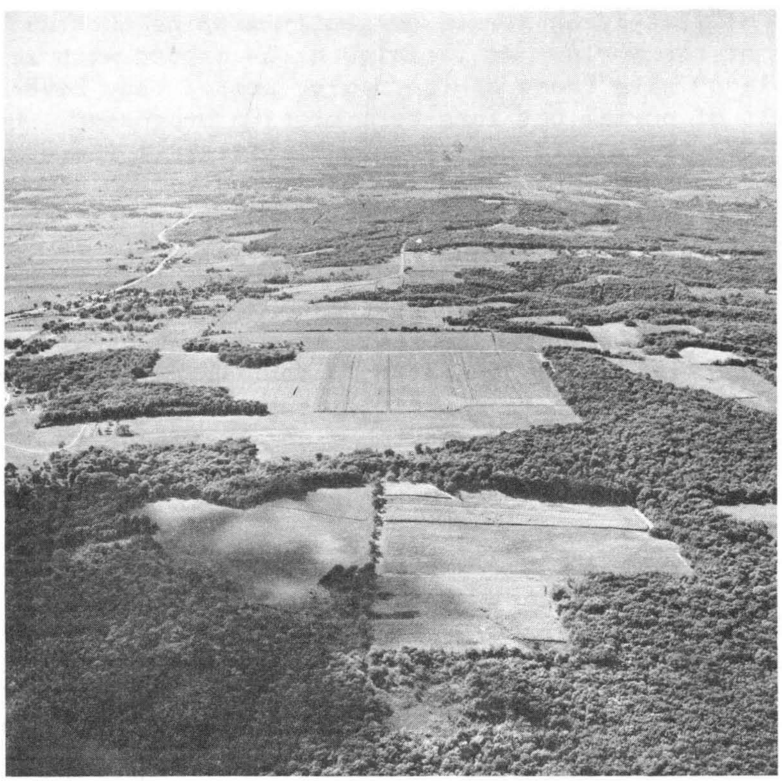


Figure 3. Air view westward across the flat top of East Blue Mound to West Blue Mound

EROSIONAL HISTORY

Southwestern Wisconsin, the Western Upland of Martin (1932, p. 41-80), long has been known as the Driftless Area (Chamberlin and Salisbury, 1885). There, seemingly subaerial erosion has been modifying the landscape continuously since Mesozoic times. Unfortunately, little agreement exists among investigators as to the ages of the present-day landforms or their significance in the evolutionary history of the region. Chamberlin and Salisbury (1885), Trowbridge (1921), Martin (1932), Thwaites (1960), Akers (1964), Palmquist (1965), and Black (1969b) provide background and references to the conflicting interpretations.

The basic conflicts of thought referred to are: (1) one or more cycles of peneplanation versus non-cyclic cuesta formation, and (2) glaciation versus non-glaciation. Pediplanation was considered and dismissed (Thwaites, 1960). Although Black believes the case for pediplanation should be reopened, it cannot be done here.

PENEPLANATION VERSUS CUESTA FORMATION

Most early workers postulated the existence of one or more peneplains of Cretaceous to Pleistocene age. The "only criterion" used to recognize a peneplain surface was the "even skyline" (Thwaites, 1960, p. 26). The lack of accurate topographic maps led some investigators into giving more than one name to parts of what really are the same surface. Most later workers, except notably Bates (1939) and Horberg (1946), accept the cuesta hypothesis of Martin (1932) or ignore the problem. Thwaites (1960) and Palmquist (1965) cover the known details.

No one has proposed that either East or West Blue Mounds are remnants of erosional surfaces or peneplains. A residual flat-topped outlier capped with weak shale and thin seams of dolomite is an anachronism that seemingly has been dismissed with little thought.

As listed by Thwaites (1960, p. 17), the evidences cited for peneplanation are: (1) the even skyline, (2) beveling of rock formations, (3) a bridge connecting two cuestas, (4) the level plain of central Wisconsin, (5) level tops and terraces on quartzite, (6) entrenched meanders, and (7) upland gravels. Thwaites (1960) shows that each can be interpreted in another manner unrelated to peneplanation. He does not deny that many changes in level of land and sea took place, but only that the evidence of either complete or nearly complete cycles of erosion in southwestern Wisconsin is not convincing.

Palmquist (1965) studied in great detail the relationship of structure and lithology to the accordant summits, apparent discordance of drainage, meandering valleys with misfit streams, and upland gravels in the area south of the Wisconsin River. His study included among other things: (1) detailed geologic mapping of the Blanchardville Quadrangle (south of Blue Mounds), (2) construction of a regional structure map, (3) study of alluvial fill in the Pecatonica River Valley by power auger, and (4) a morphometric analysis of 14 drainage basins. He concluded in part that: (1) the present surface and drainage pattern appear to be everywhere and at all scales influenced by structure, (2) the gross drainage pattern reflects variations in regional dip, (3) the locations of divides are controlled by slightly beveled structural highs, (4) location and trend of valley meanders appear to be influenced by joint trends, (5) a state of dynamic equilibrium is indicated by conformance to the laws of drainage composition, a hypsometric integral below 0.60, a high index of drainage equilibrium, and a general similarity between basins where departures are relatable to lithology, (6) size ratios between valley and river and the asymmetric cross section of the bedrock valley of the Pecatonica River suggest underfitness, but the stratigraphy of the valley fill does not, (7) peneplain remnants are lacking in the area, and (8) present evidence neither suggests nor precludes past peneplanation.

Palmquist (1965), using assumed rates of erosion, suggests that the present drainage configuration is Pleistocene, i.e., pre-Illinoian. This is in agreement with information from Illinois where it is considered that deep incision of valleys occurred probably in Kansan time (Frye, 1963; Frye, Willman, and Black, 1965, p. 45).

Black (1969b) published data that reveal the rapidity of present-day erosion of hillsides in Wisconsin. He attempted to show that not even the periglacial slopes of 15,000 to 20,000 radiocarbon years ago likely are preserved today because of the removal since then of 10 to 50 feet of friable sandstone and thin bedded dolomite.

Thus, a peneplanation hypothesis based on the recognition of remnant forms does not seem to be justified in southwestern Wisconsin.

GLACIATION VERSUS THE DRIFTLESS AREA

The deeply dissected Upland of southwestern Wisconsin is strikingly different in appearance from the rest of the state (Martin, 1932). Since 1823, when Keating pointed out the absence of granite boulders, few geologists who visited the area have failed to comment on its distinctiveness. Chamberlin and Salisbury (1885) and Martin (1932) provide a full bibliography of the previous works.

The effect of Chamberlin and Salisbury's preliminary paper was essentially to bring to a halt further work on the subject. Dissenters who would dare to attempt to contradict them were few (e.g., Sardeson, 1897; Squier, 1897 and 1898), and they had considerable difficulty in getting material published. Black (1960a) reawakened interest with his conclusions that the Driftless Area had been glaciated and much, if not all, of it in the Wisconsinan Stage. Support of these conclusions has come particularly from Allen F. Agnew (unpublished ms.), Akers (1961 and 1964), Palmquist (1965), and Trowbridge (1966). Regretfully, the evidence for glaciation as summarized in Frye, Willman, and Black (1965) lies largely outside the area covered by this field trip. Only part of the indirect evidence of Palmquist (1965) can be seen.

A detailed review of the evidence for glaciation cannot be attempted here. Suffice it to say that positive evidence of glaciation comes from abundant but thinly and widely scattered Precambrian rocks and Paleozoic chert and sandstone that rest on younger formations under loess. A large drift deposit near Muscoda has been opened for aggregate since MacClintock

(1922) identified it. It is in the center of the Driftless Area and is interpreted as evidence of a former front of ice that came from the northwest. Ice-contact deposits grade eastward into coarse deltaic deposits and into rhythmically bedded, clayey silt and sand. Those deposits were covered in part by fluvial sediments from the east up to levels of about 60 feet above the present Wisconsin River. They seem unquestionably to be early Pleistocene in age. Kame-like deposits with constituents of local materials topographically above source areas, anomalous clay minerals and rubbles and other features best explained by glaciation are relatively common north of the Wisconsin River (Akers, 1961 and 1964). Many of those deposits lie under loess apparently younger than 30,000 radiocarbon years old. However, in 1968 Black found a loess deposit with in situ Sangamonian soil profiles near the base near Hillsboro in the east-central part of the Driftless Area.

ANOMALOUS FEATURES AROUND BLUE MOUNDS

Around Blue Mounds the paucity or absence of coarse chert and silicified rubble in the streams and on the flatter divides is puzzling if the region has been undergoing long-continued down wasting only by processes now affecting the landscape (see Part A this guide). Both the Niagaran and Galena Dolomites are exceedingly rich in siliceous material. Abundant blocks of chert and of silicified dolomite of various sizes up to 25 feet across lie on the shale slopes of West Blue Mound, but fewer and smaller blocks flank East Blue Mound. Deployment of the blocks into fields as much as one mile downslope from the Niagaran cap is considered the result of former periglacial mass movements radially outward over the shale slopes of 3-7 degrees (Smith, 1949) (Fig. 5).

Power auger exploration by Black and Palmquist (1965, p. 114) in the upper reaches of the Pecatonica River revealed almost no coarse siliceous residuum in low-gradient streams, yet Dury (1964, p. 17-21) by hand auger and seismic exploration found appreciable rubble in Mound Creek which is a much steeper stream flowing to the north from Blue Mounds (Fig. 6). The disparity is striking.

Black in 1960 by bucket auger found one faceted Precambrian siliceous conglomerate pebble in a joint crack under 18 inches of yellow-brown loess on the highest part of West Blue Mound. Nothing like it has been found since. The top of the mound, reportedly a prairie at time of settlement (Sherman Frame), had not been disturbed below six inches by plowing.

On East Blue Mound numerous checks with a soil probe show only a maximum of four feet of clayey-silt loess over dolomitic shale. The loess is commonly 2 to 4 feet thick and yellow-brown or dark yellow-brown below a humic-rich surface. Locally it is olive-brown or yellowish-red near the base. All is leached; local manganese and iron oxides are in minor amounts near the base. Small, very shallow, undrained depressions with ponded water occur on the highest or eastern part, and also have four feet of loess below them where they were checked. Blocks of chert and silicified dolomite of Niagara age are scattered thinly over the surface and lie in the loess. Shale and dolomite bedrock locally and

Figure 4. View northward, showing the profiles of West and East Blue Mounds

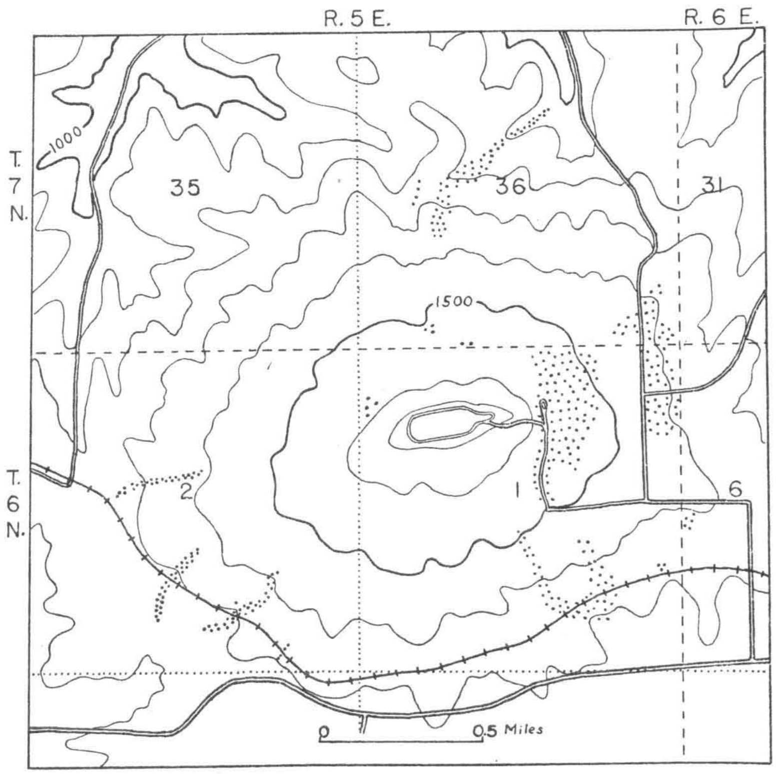


Figure 5. Generalized map of the Blue Mounds Area showing by stippling the location of block fields

and blocks of the chert are disturbed by plowing. The soil profiles in the loess have not been studied in the laboratory, but they do not appear to be older than Late Wisconsinan.

Thwaites (1960, p. 28-30) in studying the slopes in the Driftless Area concluded that most are convex upwards and that they are in equilibrium, meaning that the regolith must be undergoing removal at the same rate as it is being formed. Further, he concludes that divides have been lowered concurrently with the formation of the valleys. Neither conclusion holds for Blue Mounds. From map inspection alone (Fig. 1) one sees that the slopes on the Maquoketa Shale of both mounds are concave upward. Although the apex of West Blue Mound is convex upward on the silicified dolomite, intuitively one could not say it is downwasting as fast as the shale below. The general effect of undrained depressions with standing water on East Blue Mound is to produce a slightly concave upward surface on its summit.

As would be expected, Palmquist (1965, p. 59) found drainage density directly related to the percent of Maquoketa Shale present. Two basins studied in the Blue Mounds area contain the shale. Their profiles (Palmquist, 1965, p. 66, profiles A and G) (Fig. 6) show the lithologic control of the Niagaran Dolomite or its absence. Longitudinal gradients of rills and first order channels in dense array could lead to the concave upward slopes on the Maquoketa. One would expect to find then that block fields would be concentrated on flatter positions if those blocks had moved outward at some time in the past by mass movements and were now stable. Neither their distribution nor their possible movement today have been studied since Smith (1949). However, inspection of Figure 5 and the block fields from the air do not suggest an obvious correlation in either distance traveled or slope angle with numbers of blocks. Surface inspection suggests they are stabilized in colluvium and that the fines are being washed away from them. No studies to determine their activity have been attempted.

DISCUSSION AND CONCLUSIONS

If the Niagara dolomite formerly capping East Blue Mound was not silicified as is that on West Blue Mound, the rock should have been more soluble. Thus, its removal and the preservation of the small silicified cap on West Blue Mound are easily explained. However, the cross section in Figure 2 shows that more than half the thickness of the Galena-Decorah-Platteville Formations also has been removed nearby, including the bulk of the very cherty Galena. However, much of the Maquoketa Shale also has been planed off. Silicified blocks on top and on the flanks indicate that at least part of the Niagaran dolomite on East Blue Mound also had been silicified. Why would solution of the Niagaran dolomite and the dolomite layers in the Maquoketa Shale penetrate so uniformly over the entire top of East Blue Mound? Water just does not dissolve many tens of feet of such material over so large an upland area so uniformly. The Niagaran is typically massive and unjointed; the dolomite seams in the Maquoketa are thin and irregular. An irregular karst topography should be present on the mound if solution was the main process of downwasting.

Water has gone through the Maquoketa Shale in the past to produce the underlying "Cave of the Mounds" in the Galena Dolomite. The present-day depressions with standing water on top of the Mound are considered the result of differential solution. However, relief is exceedingly slight. The summit is too flat for mass wasting processes to have operated to any significant degree. Thus, only one agency--that of glacial ice--seems capable of beveling the top of East Blue Mound to so flat a surface.

The lowering and shifting of the drainage divide of Military Ridge between the steep, short, northward-flowing tributaries to the Wisconsin River and the gentle, long, southward-flowing streams of the Pecatonica system have been somewhat uneven. If the divide was shifted southward only during the later Pleistocene by the greater ability of the north-flowing streams to erode, one would expect the Blue Mounds area to shift less because of its established durability. This seems to fit the present situation. This assumes that the present course of the Wisconsin River was established in early or middle Pleistocene so that relatively little shifting and lowering could occur in the time available.

Acceptance of glaciation for removal of the upper part of East Blue Mound is merely an "easy way out". By itself the available direct evidence does not prove glaciation. However, one also must ask where is the cherty residuum from the surrounding Galena Dolomite or, for that matter, the Niagaran? All the latter and much of the former unit have been removed, yet only a small amount of siliceous residuum remains on the flatter uplands or in the gentle water courses. Why does there seem to be more in the steeper north-flowing streams than in the gentle south-flowing streams? The latter can not move the rubble today. The steeper north-flowing streams probably are competent enough during floods, although no studies have been attempted to demonstrate this. If we fall back on greater run off in the past (Dury, 1965), the presumable younger and certainly steeper tributaries to the Wisconsin River should be flushed cleaner than the south-flowing streams. It seems easier to account for the removal of the bulk of the chert rubble by an early Pleistocene glaciation, and to consider the existing rubble in the steeper water courses to be a lag during rapid down cutting since.

Only one stream - the headward reaches of the Baraboo River at Hillsboro (50 miles northwest of Blue Mounds)--is literally choked with rubble to a depth of about 90 feet. Interestingly too, that is the only area where loess with established Sangamonian soil profiles _in situ_ has been found in the Driftless Area.

If the chert residual rubble had not been flushed from the Driftless Area during the early Pleistocene, the area of the dolomitic uplands should have more of the characteristics of the Missouri portion (Springfield and Salem plateaus) of the Ozarks than they have (Thornbury, 1965, p. 262-276). Calling on periglacial processes will not do--they cannot remove the rubble from the whole system any more than streams in gentle water courses. However, what would be the effect of markedly increasing precipitation as called for by Dury (1965)? Increased runoff might flush away the residuum, but it could not plane off the top of East Blue Mound. Furthermore, the timing seems wrong. Certainly one would expect the steeper north-flowing streams to be flushed before the gentler south-flowing streams, but their residuum belies this.

Assuming the Driftless Area has been glaciated, how many times and when did it last occur? No definite answers can be given at this time. The loess on East Blue Mound appears from field inspection to be no older than that lying above 29,300-year old charcoal to the west (Black and Rubin, 1967-68; Hogan and Beatty, 1963). Older loess is found 50 miles northwest as well as to the south in Illinois. Was this older loess never deposited on East Blue Mound or was it removed? We don't know.

If the outermost chert blocks moved to their present positions after Altonian time (about 30,000 radiocarbon years ago) they would need to move at an average rate of two inches per year (Black, et al, 1965, p. 76). This is many times larger than the average rate of movement today of large blocks in an experimental site 10 miles to the north. There the large blocks are only moving 1 to 3 mm per year today on dolomite and sandstone. Presumably movements over shale slopes are greater and would have been much faster during periglacial times in Wisconsin, about 15,000 to 30,000 radiocarbon years ago (Black, 1965 and 1969b). However, we cannot yet say when the blocks started to move nor when they stopped. They now appear stabilized, but no measurements have been made to clarify the situation.

It seems obvious that no clear cut answers can be given to explain the differences in East and West Blue Mounds. One must be a "believer" in an interpretative picture based on too few facts.

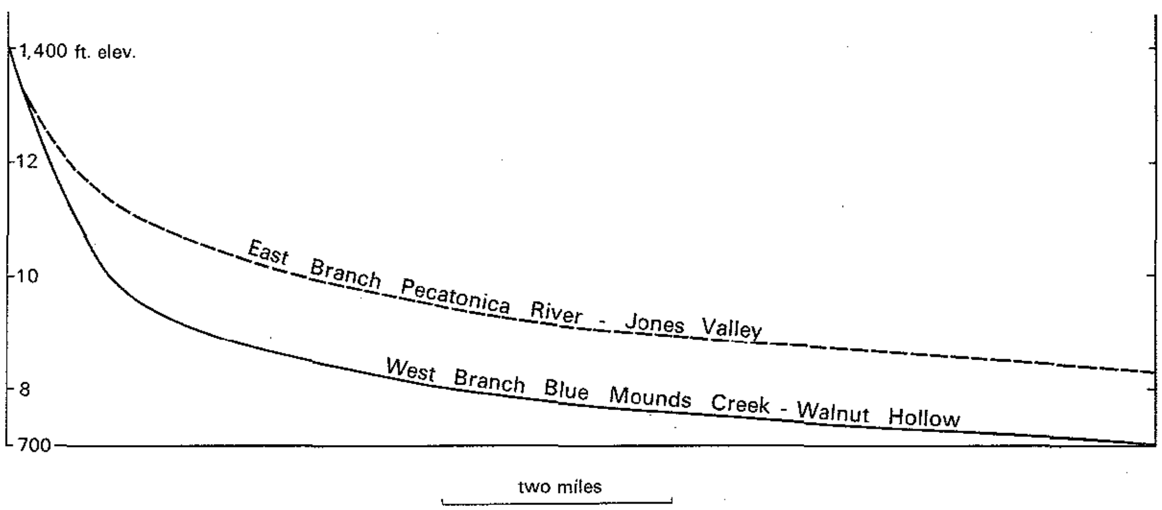


Figure 6. Longitudinal profiles of upper Mounds Creek and the head-waters of the Pecatonica River

Part I

RESIDUUM AND ANCIENT SOILS OF THE DRIFTLESS AREA OF SOUTHWESTERN WISCONSIN

by

Robert F. Black

CONTENTS

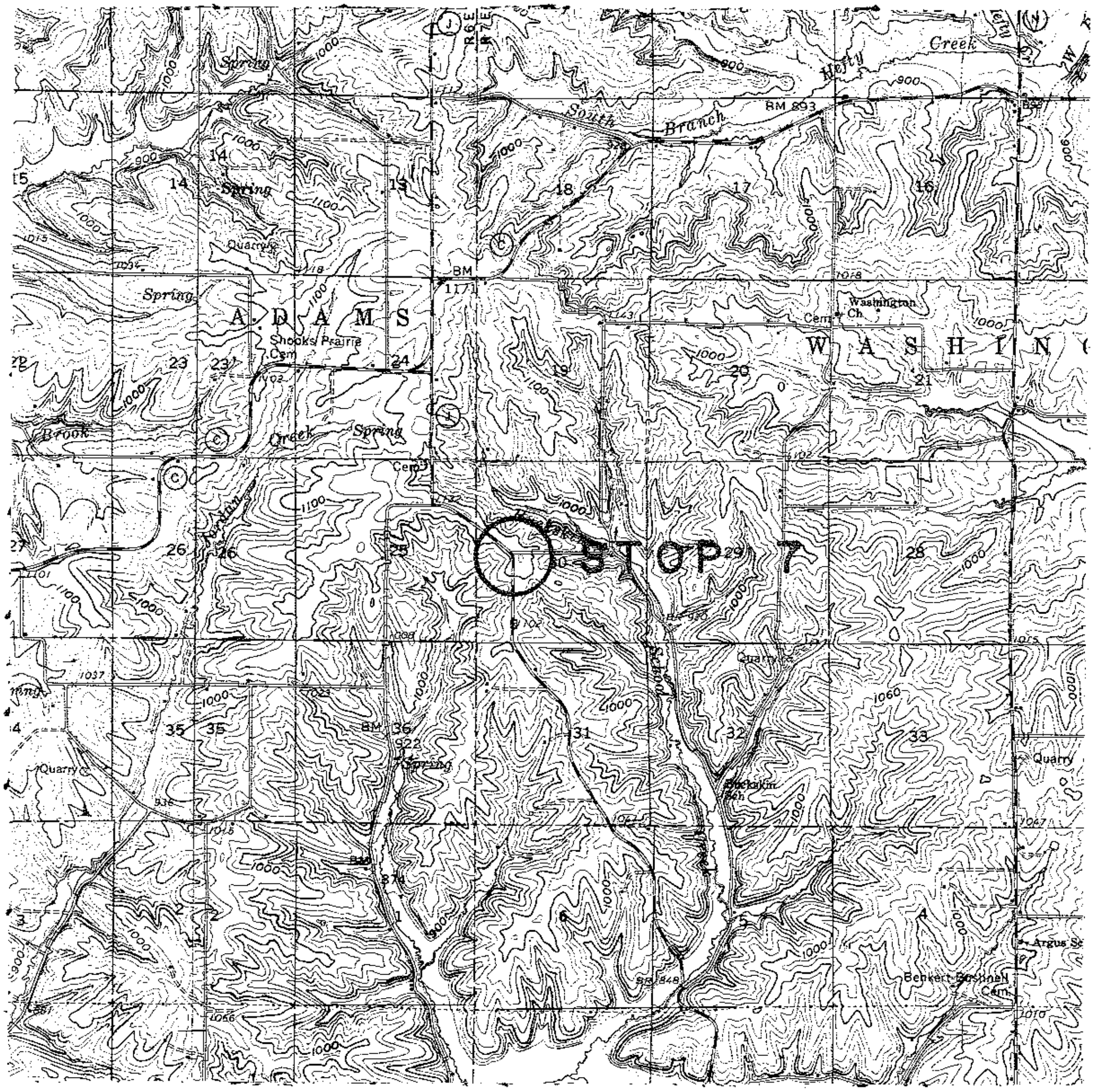


Figure 1. Part of U.S. Geological Survey topographic quadrangles - South Wayne and Monroe

RESIDUUM AND ANCIENT SOILS OF THE DRIFTLESS AREA OF SOUTHWESTERN WISCONSIN

INTRODUCTION

The Driftless Area of southwestern Wisconsin has widespread Cambro-Ordovician dolomites which contain abundant clay and chert. If those rocks have been undergoing subaerial weathering since Mesozoic times, the residuals from solution should be thick and widespread unless they have been flushed from the system. Clays presumably could have been washed or blown out readily. Coarse chert rubble would have required more rapid runoff than that of today to be removed; at least only a few streams today seem to be moving it. The broad flat uplands should retain reasonably thick accumulations; the gentle lower-order streams should be armored.

Only one stream valley is known--that of the upper Baraboo River at Hillsboro--that has been choked with debris to a depth of tens of feet. All others examined have relatively small amounts of rubble compared with the total supposedly left by the solution of many tens or hundreds of feet of rock. Most uplands also seem to have relatively little residuum, yet small pipes and pockets of clay and chert in the dolomite penetrate to depths of many tens of feet. Mass movements are commonly associated with karst formation. In karst pockets crudely bedded deposits are found.

In a qualitative way the amount of residual clay and chert is approximated and then compared with the total that should have been left from the rocks now gone. The character of the residuum is discussed briefly. Time of formation of the residuum is shown to be difficult to date. No unique characteristics of the residual clays have permitted the infallible distinction of supposedly Mesozoic-Tertiary weathering from that of the Pleistocene. Truncated Pleistocene soils thus can be confused readily with older materials. Only one small area of soils as old as Sangamonian has been established; those soils are in loess. Rapid erosion at the present time, and even more rapid erosion by glacial ice, periglacial processes, and wind in the past are presumed to have removed most residuum and ancient soils.

Stop 7 (Fig. 1) is made at the thickest deposit of <u>in situ</u> residuum known south of the Wisconsin River. The site is perhaps significantly on one of the highest and flattest remnants of the Galena-Platteville erosion surface in this region. However, the specific point is neither on the highest nor the flattest part of that remnant. Careful subsurface exploration might disclose a thicker remnant, but road cuts across that remnant generally disclose less than two to four feet of residuum. No subsurface exploration in the vicinity of the stop has been attempted to see whether the deposit represents an unusually thick karst filling.

RESIDUUM IN THE DRIFTLESS AREA

Distribution and Amount

Chamberlin and Salisbury (1885, p. 239-258) compiled all the available information on the character, amount and distribution of residuum in the Driftless Area. Their figures from nearly 1,800 localities have been quoted widely, but unfortunately are very misleading. They neither indicate where in the Driftless Area with respect to distance from the Mississippi River their data were obtained, nor whether or not their values include the thickness of the loess. Thwaites (1960, p. 27) and the writer believe they included the loess or the entire thickness of surficial soil. For example, they mention (p. 254) that the "...amount of superficial clay, including loam, but not including the sand beneath it, is somewhat less in regions where sandstone is the underlying rock than where limestone takes its place." The clay loam can only have been derived from loess. The quartz sandstones have some clay, but they do not weather to clay loams. Furthermore, (p. 245) "...all the earths examined [under the microscope] reveal the presence of minerals apparently derived from the Archean crystalline series." That assemblage is typical of loess but not of residuum. Probably also most figures were obtained in the zinc-lead district in the extreme southwest corner of the state. Their figures for the unconsolidated cover are: average value--7.08 feet; slopes--4.61 feet; narrow ridges--8.06 feet; broad uplands--13.55 feet; broad ravines without streams--6.93 feet; and valleys--18.17 feet.

The writer has kept notes on all occurrences of residuum seen on traverses of most roads in the Driftless Area, but he has not systematically attempted to survey in three dimensions the distribution of the residuum. Spot determinations of thicknesses mean little on an areal basis--unless a reliable means of projection is available. None seems to be. The general conclusions reached by the writer are: (1) Significant *in situ* residuum derived by direct solution of bedrock is not found in the valleys nor on those slopes steeper than 3 to 5 degrees--all unconsolidated material there has been transported, reworked, and redeposited as colluvium or fluvial deposits, and most has been derived from loess; (2) only the ridge crests retain appreciable residuum; (3) the broader ridges tend to have more residuum over-all than the narrower ridges; (4) the Prairie du Chien dolomite in the east-central part of the Driftless Area tends to have thicker residuum than the Galena Dolomite in the southern part; and (5) most residuum lies in small karst pockets, tubes, and conduits of various shapes and orientations that are dissolved in places tens of feet below the surface--the adjacent uplands commonly have little or no residuum.

Systematic mapping of the distribution of karst features in the dolomites has not been done. Again the difficulties of working with the three-dimensional distribution of such features under the loess blanket has prohibited much study. The opening of many quarries in recent years now helps, but quarry operation is not economical in the more weathered rock with abundant karst features, so a built-in bias still exists.

Locally accumulations of 0.5 foot to 3 feet of clay and some chert are common, but they undoubtedly cover much less than five percent of the total Driftless Area. Accumulations of 4 to 10 feet are rare and certainly cover less than one percent. The writer "guesses" that all clay and chert residuum could form a uniform layer one foot thick in less than five percent of the total Driftless Area. Some appreciation of the extent of residuum can be had from the bus on the route from Madison to Blue Mounds and Monroe. That route covers typical uplands cut in the Galena-Decorah-Platteville dolomites. Stop 7 is made at the most extensive and deepest site of residuum known south of the Wisconsin River.

Source

Analyses by weight of insolubles in the Cambro-Ordovician dolomites (Steidtmann, 1924, Appendix, Table 1) are 31.12 to 40.16 percent (three samples) in the Trempealeau (Cambrian), 1.37 to 26.26 percent (44 samples) in the Prairie du Chien (Lower Magnesian), 0.82 to 28.46 percent (61 samples) in the Galena-Platteville /Black Earth/, and 0.26 to 8.20 percent (53 samples of which all are outside the Driftless Area) in the Niagaran. (In contrast the Niagaran at Blue Mounds is almost entirely silicified--see Part H.) Silica (SiO_2) in samples for which insolubles were not given is 44.57 percent (1 sample) in the Trempealeau, 1.09 to 17.03 percent (7 samples) in the Prairie du Chien, 1.26 to 7.03 percent (13 samples) in the Galena-Platteville, and .022 to 6.32 percent (27 samples) in the Niagara. The wide scatter in the results and the knowledge that most samples were collected without obvious chert leaves considerable latitude in the use of these values. For convenience, all the dolomites are assumed to contain 10 percent by weight of insolubles.

Bulk density of the clay derived from the dolomites is very low (in many instances in the field, solution of dolomite cobbles leaves clay residues the same size as the original cobbles). Let us assume for convenience, however, that it is one-half that of the dolomites. Clay residuum at 10 percent by weight thus would be equivalent to 20 percent of the original thickness of the rock.

The Silurian (including the Niagaran) dolomites have an approximate maximum thickness in Wisconsin of 600 feet, the Galena-Platteville dolomites--355 feet, the Prairie du Chien dolomite--275 feet, and the Trempealeau dolomite about 50 feet (Ostrom, 1967). The Driftless Area is about 10,000 square miles. In very rough approximations the percent of the total area covered today by the Niagaran is practically zero, by the Galena-Platteville-2,500 square miles, by the Prairie du Chien-2,000 square miles, and by the Trempealeau perhaps 500 square miles. Thus, something like half the Driftless Area has dolomite as the surface rock today.

We don't know whether all formations extended uniformly over the Driftless Area or what their compositions may have been. (M. L. Jackson, oral communication April 2, 1970, on the basis of mica characteristics in the Devonian shale of southeastern Wisconsin believes it was buried at least 10,000 feet.) Nonetheless, surfaces exposed today in the Cambrian dolomite could conceivably have been covered by 1,000 feet of dolomite and an additional 1,000 feet of sandstones and shales up to the Devonian rocks. Using the assumed average, the dolomites alone could leave by solution 200 feet of clay residuum and several tens of feet of chert; this does not include the associated 1,000 feet of clastics. If only half the Galena-Platteville dolomite is removed by solution, it should leave 35 feet of clay residuum plus many feet of chert--probably over 10 feet. Obviously no such volume of waste can be found today on the hills of in the valleys around Blue Mounds where both the Niagara and upper half of the Galena-Platteville dolomites are gone--or anywhere else in the Driftless Area for that matter. The bulk of the wastes has been removed from the system.

Age

Black (1969b) attempted to show that creep processes today on hillsides are stripping 1 foot to 3 feet per 1,000 years of loose sandstone and dolomite. Presumable rates were even faster in the past when prairies were more widespread or when periglacial climates dominated. Why then aren't those rubbles choking the drainage lines? If they have not been flushed out during the Pleistocene, then either the present rates over a seven-year period are not reliable or they are not indicative of past rates.

Moreover, the mass movement rates do not include solution which in dolomite in Wisconsin averages perhaps one-half to three-quarters of an inch per 1,000 years under present climates. Thus, one inch of dolomite would yield 0.2 inch of residuum in 2,000 years or slightly less.

If these rates are representative, it suggests that mass movements easily will keep slopes stripped clean as solution slowly generates new material. Only the flattest surfaces or depressions could accumulate residuum.

Accumulation of clay by solution at 0.1 inch per 1,000 years would suggest also that deposits 6 inches thick accumulated in situ would be on the average 60,000 years old; a two-foot thickness would represent 240,000 years; an eight-foot section (as at Stop 7), 960,000 years, etc. Obviously, as the clay or overlying soil increased in thickness, permeability and rate of solution would decrease so thick accumulations of clay, as at Stop 7, are considered much older--i.e., of Tertiary age. Any further speculation at this time seems unwarranted, for data are too limited. We can reasonably assume, however, that the bulk of the Tertiary wastes were stripped away from all the Driftless Area in marked contrast with the Ozarks where they seem still to be abundant and widespread (Thornbury, 1965, p. 262-276). The mechanism of stripping, presumably by glaciation, has been discussed in connection with Blue Mounds, Part H.

Character

The residuum derived from the dolomites consists principally of red clay and chert. The particular stratigraphic horizons most recently subjected to solution determine whether either clay or chert can dominate in the residuum. The erosional history from the beginning of solution up to the present day determines which, if any, is left on the landscape.

Clay--The clay is almost invariably red to dark red-brown with minor yellow mottlings; grays have been produced by very local reducing conditions. Small amounts of silt and sand also are characteristic. The clay is fissile in the lower part of thick deposits and blocky in the upper part and in thin soil sequences.

Stop 7 is one of three localities in the Driftless Area for which a reasonably complete quantitative analysis of the clay by various methods (See Table 1) has been made (see Alexiades and Jackson, 1966, Table 1, p. 41, Dubuque silt loam and residuum from dolomite, Wis. for the other two. The former is considered a buried soil - IIC_1, residuum from dolomite in northcentral Sauk Co. The latter is residuum of Prairie du Chien dolomite in southwest Sauk Co. - both north of the Wisconsin River.) The relatively high content of expandable clay and of chlorite in all three sites does not support the simple concept of laterization under long tropical weathering often cited as characteristic of the Tertiary. In the upper Mississippi Valley the weathering of soils in the Pleistocene has been very complicated and much new information is appearing from various places on clay transformations (Jackson, 1965 and 1968).

Earlier X-ray studies by Akers (1961) on 24 samples of residuum directly overlying the various bedrock units in the Driftless Area showed only three in which kaolinite was predominant (see Table 2). In most samples a mixed-layer clay mineral complex predominated. The complex was interpreted by Akers (1961, p. 16) to have been derived by weathering of dioctahedral illite (mica), the primary clay constituent in the dolomite. Akers concluded that the illite decreases during weathering and vermiculite increases, only to decrease as montmorillonite increases as an end product. Supposedly the illite became hydrated, lost much of its potassium, and was taking on cations of calcium and magnesium from the dolomite. Akers found vermiculite and chlorite in negligible amounts or absent in the dolomite. Significantly Akers (1961, p. 18) found a transition from the base to the top of thick residuum--the upper presumably more weathered portions were dominated by well-organized montmorillonite with no vermiculite and very little illite. However, distinguishing true residuum from loess that acquires the characteristics of residuum, as clays and various ions move down in the profile, has not been possible in many places. At least a contaminated or mixed residuum-loess zone is recognized locally. Representative sections in which two or more samples in vertical sequence were studied are summarized in Table 3. The transition at Stop 7 from base to top has not been studied.

Aker's analyses shown that the clay residuum, while not everywhere uniform, is not sufficiently different from formation to formation to be distinctive. Fanning and Jackson (1967, Table 3, p. 257) found slight differences in the zirconium content of coarse silt in the residuum of the Prairie du Chien and the Galena Dolomite and significantly more in residuum from the St. Peter Sandstone). Many, but not all, anomalous pebble concentrations (like re-worked Windrow gravel, Andrews, 1958) and rubbles in the Driftless Area showed a marked departure in the clay minerals associated with them. Some contained significantly higher illite and vermiculite, others kaolinite. Akers concluded also that the alteration process outlined above characterizes the glacial deposits of western Wisconsin. As those studied are all late Wisconsinan in age, the time required for the clay alterations apparently is only a few tens of thousands of years. The climates were generally colder and wetter and only briefly warmer and drier than now.

The downward migration from the loess of clay-sized particles and of various ions into the residuum, now, during the Pleistocene, and even earlier, is a process obviously important in determining the composition

TABLE 1

Clay composition less than 2 microns at Stop 7.[1/]

Mineral	Percent	Method[2/]
Montmorillonite	26	Cation Exchange Capacity
Vermiculite	8	K fixation
Mica	11	Total K_2O
Kaolinite	22	Selective dissolution analysis
Chlorite	14	Thermogravimetry
Amorphous	21	Selective dissolution analysis
Total	102	(On iron oxide-free basis)

Free Fe_2O_3 by dithionite - 6.3 percent.

Clay less than 2 microns is 75.5 percent of sample.

1/ Sampling and analyses by S. Y. Lee and M. L. Jackson, Dept. of Soil Science, University of Wisconsin-Madison.

Field Location--Monroe Quadrangle, NW ¼, NE ¼, SW ¼, Sec. 30, T 3 N, R 7 E. Road cut on County Highway J. Depth about six feet.

2/ Analyses checked semiquantitatively by X-ray diffraction analysis. Completed February 24, 1970. See Alexiades and Jackson (1965, 1966, and 1967) for details of the methods.

TABLE 2

Relative proportions of the types of clay minerals in the decomposed bedrock and residuum of southwestern Wisconsin, as determined from solvated slides.1/

Formation and Sample No.	Illite					Kaolinite					Vermiculite*					Mixed-layer				
	p	l	m	s	t	p	l	m	s	t	p	l	m	s	t	p	l	m	s	t
Galena-Platteville																				
57W112**	x									x										x
60W10					x			x			x					x				
59W86					x				x		x					x				
St. Peter sandstone																				
57W82					x				x					x		x				
Prairie du Chien dol.																				
60W91					x				x							x				
60W37**					x			x							x	x				
60W23				x					x					x		x				
60W27				x				x							x	x				
60W50					x				x							x				
60W29				x			x									x				
60W92				x				x							x	x				
60W33				x				x				x				x				
60W54		x					x									x				
60W36					x				x							x				
60W58								x								x				
60W34		x				x											x			
60W22								x							x	x				
60W15					x	x					x					x				
Upper Cambrian sandstone																				
59W60**							x								x	x				
59W68**				x			x									x				
57W27**		x						x								x				
58W121**				x			x									x				
59W69									x							x				
60W24		x				x														x

Proportional designations are: p--predominant, l--large, m--medium, s--small, and t--trace.

*Vermiculite, although believed to be a part of the mixed-layer alteration, is differentiated herein on the basis of its non-expandability with solvation, as distinguished from the expandable portion herein designated as mixed-layer.

**Samples of decomposed bedrock, all others are of residuum.

1/ From Akers (1961, Table 1, p. 19)

TABLE 3

Relative proportions of the types of clay minerals in various stratigraphic sections in southwestern Wisconsin, as determined from solvated slides.1/

Sample Number	Illite					Kaolinite					Vermiculite					Mixed-layer				
	p	l	m	s	t	p	l	m	s	t	p	l	m	s	t	p	l	m	s	t
59W83 lo.					x				x							x				
59W85 bs.					x				x					x		x				
59W86 g.					x				x		x									x
60W11 lo.							x									x				
60W12 g.					x					x				x		x				
60W49 cl.			x					x				x							x	
60W50 cl.				x				x								x				
60W36 p.					x				x							x				
60W37 p.					x			x							x	x				
60W26 lo.	x						x								x	x				
60W25 bs.					x			x							x	x				
60W22 p.							x									x				
59W69 u.				x					x							x				
59W68 u.				x			x									x				
58W126 bs.					x				x						x	x				
58W121 u.				x			x									x				
59W59 cl.					x			x					x			x				
59W60 u.							x								x	x				

Proportional designations are: p--predominant, l--large, m--medium, s--small, and t--trace.

Identificational designations are: lo.--loess, bs.--buried soil, g.--Galena-Platteville, p.--Prairie du Chien, u.--Upper Cambrian, and cl.--clay lens.

1/From Akers (1961, Table 5, p. 23-24)

of the clays. (See narrative report by Hole Part F). If present world-wide conditions are an indication, eolian dust has contributed much to the composition of the ancient clay residuum or soils (e.g., Rex, et al., 1969; Borchardt, Hole, and Jackson, 1968). However, Parham and Austin (1969) attribute lateral and vertical variations in clay mineralogy in the Decorah shale and in the Glenwood Formation of Minnesota to source distances and to transgressive seas. Such variations in the bedrock and the effects of Cretaceous weathering (Sloan, 1964; Parham and Hogberg, 1964; and Frye, Willman, and Glass, 1964) on the clays in the residuum have not been evaluated in Wisconsin. Presumably some of the kaolin clay deposits north of the Wisconsin River (Buckley, 1901; Ries, 1906; Weidman, 1907; and Andrews, 1958) and much of the residual iron ores, including the Iron Hill member of the Windrow Formation (Andrews, 1958), can be assigned to that weathering cycle (Strong, 1882; Irving, 1883; and Austin, 1963). Some residual clays apparently are pre-Late Cambrian (Weidman, 1907). Hematitic boulders are scattered on up land surfaces south of the Wisconsin River and are thought to be glacial erratics. However, these various topics are beyond the scope of the present discussion.

Chert--The chert residuum is various shades of white, grey, yellow, red, and brown. Small irregular pieces are in part the complete original masses in the dolomite and are in part derived by the splitting up of large masses that were a foot or two across. Etched surfaces are common. The chert rubbles of the Driftless Area have received even less study than the clay residuum. Bramlette (1921) made specific petrographic examinations of the Oneota chert in outcrops, but only Akers (1964) has attempted to find a means of distinguishing the various Cambro-Ordovician cherts in the residuum and of correlating them in the field and laboratory with parent sources. Because of the complexity of the problem, he concentrated on distinguishing between the cherts of the Prairie du Chien (Lower Ordovician) and those of the Platteville-Galena (Middle Ordovician).

To that end Akers collected samples from each stratigraphic horizon in the Ordovician and subjected them to various tests and studies. By arc-spectographic determination of their trace elements he did not find any diagnostic differences. They are secondary replacements that consist of micro-crystalline to cryptocrystalline quartz and chalcedony. Textural analyses seemed also to be of little value in distinguishing them. However, the oolites and lack of fossils (except algae) in the Prairie du Chien, and the abundant fossils and lack of oolites and algae in the Galena cherts were diagnostic. From these characteristics, Akers (1964) was able to show that numerous ridges in the central Driftless Area had chert rubbles stratigraphically too high on younger formations. No such study has been attempted south of the Wisconsin River, but occasional field examination of chert rubbles has not demonstrated any deposit to be stratigraphically too high.

Sandstone blocks in the Driftless Area also have been shown to be stratigraphically up out of place or are otherwise anomalous. None will be seen on this field trip, as those studied are much farther west and north of our route. Consequently, the reader is referred to Akers (1964) and Palmquist (1965) for a discussion of them and a review of the earlier literature.

ANCIENT SOILS

Few studies of ancient soils in the Driftless Area have been attempted, largely because their occurrences are rare and they are not easily recognized. Generally they are buried at the base of thick youthful loess in which zonation is not seen (Glenn, et al., 1960). Two paleosols were reported by Hogan and Beatty (1963) in the extreme southwest corner of the State. The upper, beneath as much as 19 feet of loess, is a silt loam loess a few inches thick and with fragments of spruce charcoal dated at 29,400 ± 700 years B.P. (Hogan and Beatty, 1963; date corrected later to 29,300 ± 700 years B.P.-Black and Rubin, 1967-68). The lower paleosol is about two feet thick; they call it a truncated B horizon in reddish clay underlain by dolomite. The writer in field observations considered it residuum disturbed by mass movements or glaciation. Its areal distribution was limited to a few feet; similar patches were found in only two other places in a radius of a few miles. Hogan and Beatty (1963) suggested the lower paleosol was similar to Sangamonian soils in Iowa and distinguished it from dolomite residuum on the basis of its higher vermiculite content. Akers (1961) considered it residuum on the basis of his X-ray work (see Table 2, Sample 59W86).

Black in 1968 distinguished in a loess sequence near Hillsboro a very thin Altonian (Early Wisconsinan) and a thicker Sangamonian soil profile only partly disturbed by mass movements under Peoria loess. The field designations were confirmed by Herbert D. Glass (written communication, May 28, 1968) on the basis of clay mineralogy compared with type material from Illinois.

The Hillsboro area is the only one so far identified in which complete *in situ* soil profiles older than Late Wisconsinan have been confirmed. The existence there in a small area only of thin Roxana and Loveland loesses raises the issue of why they are not found (or identified) elsewhere in the Driftless Area. Part of the answer seems to lie in the rapid erosion rates of today and presumably the even greater rates in the Late Pleistocene (Black, 1969). The writer also wishes, however, to attribute their absence in part to the burial of much of the Driftless Area by ice accumulated in great part *in situ* from snow during Altonian time (Early Wisconsinan) and older glaciations. That ice should have joined with the major lobes east and west of the Driftless Area, but would not have done much work in modifying the landscape. It would prevent the deposition of most loess during Illinoian and Early Wisconsinan time and would explain many fresh-looking anomalous features in the Driftless Area. It would not negate still earlier glaciation which is required to explain other obviously old phenomena.

Part J

GLACIAL STRATIGRAPHY OF SOUTH-CENTRAL WISCONSIN

by

N. K. Bleuer

CONTENTS

GLACIAL STRATIGRAPHY OF SOUTH CENTRAL WISCONSIN

INTRODUCTION

This report concerns the glacial geology of that part of south-central Wisconsin that is east of the classical Driftless Area and south and west of the prominent Woodfordian moraines. It includes most of Rock and Green Counties and parts of Dane, Walworth, and Lafayette Counties (Fig. 1). It is covered on the following 15' topographic quadrangles: South Wayne, Monroe, Brodhead, Janesville, Shopiere, Delavan, New Glarus and Evansville.

The glacial deposits of this area have been interpreted in several ways, but they have never received more than reconnaissance study. In the more recent past, the materials have been considered all Illinoian, all Rockian (early Wisconsinan), or part Farmdale and part Illinoian. Most recently, however, detailed studies of physical characteristics of tills and weathering profiles in adjoining parts of Illinois have shown that a more complicated early Wisconsinan and Illinoian glacial stratigraphy exists in the subsurface and the surface. An attempt was made in this study to distinguish mappable surficial units in south-central Wisconsin and to correlate those units, where possible, with equivalents in Illinois.

Five mappable glacial till units are recognized in this area (Table 1). The nomenclature of the Illinois State Geological Survey for northwestern Illinois was used during the mapping of four rock stratigraphic units, the Capron, Argyle, Ogle, and Winslow tills. Additional informal terms, the Janesville till, Janesville gravel, and the Juda gravel are introduced.

The tills are distinguished and correlated with the Illinois units primarily on the basis of grain size distribution. Further, pebble content, particularly Niagaran dolomite content, is useful in differentiating till and gravel deposits in Wisconsin. Many other mineralogic parameters, including crystalline pebble counts, heavy and light mineralogy, and fine carbonate content, were tested and found to be of no significance in distinguishing units. Macro- and micro-fabric work pertinent to the origin of the Janesville till were of questionable reliability.

Exact boundaries of till units (Fig. 2) are drawn only in a few places because of their general obscurity. Commonly, till units thin into almost driftless landscapes or into areas where only upland gravel deposits of questionable age are present. In places, physically similar tills of different age merge.

New evidence is presented concerning the questionable relationship between the Ogle and Winslow tills. However, the relationships between the Ogle and Winslow tills, the Ogle and Janesville tills, the Janesville and Argyle tills, and the Janesville and various "lower tills" are still somewhat uncertain.

Surface soil development and degree of landscape modification can be used only locally in comparing ages of these deposits. Preglacial topography of relatively high relief affected initial deposition of the glacial materials and enhanced subsequent erosion of them, and their weathering profiles, over most of the area. Quantification mineralogically of the

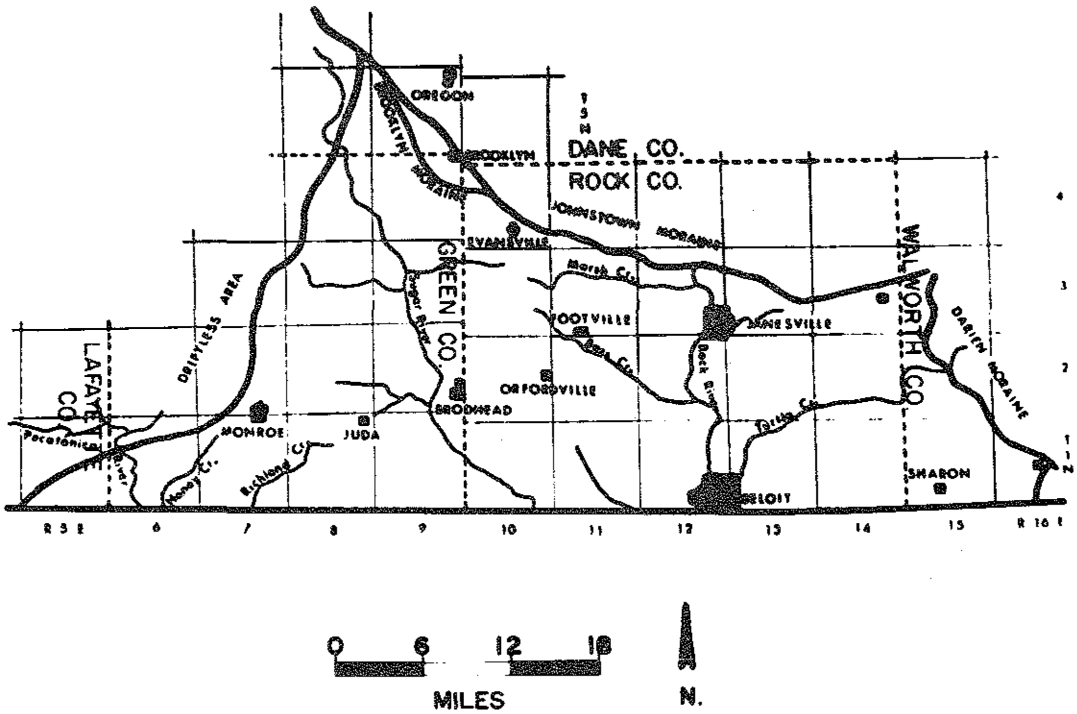


Figure 1. Area of study

STAGE	SUBSTAGE	UNIT	MEAN GRAIN SIZE SAND	SILT	CLAY	NIAGARAN PEBBLE %	COMMENTS
WISCONSINAN	WOODFORDIAN	MISCEL-LANEOUS					DUNE SAND, PEORIA LOESS, ICE-WEDGE SAND FILLS, OUTWASH, BACKWATER, AND ALLUVIAL DEPOSITS.
	ALTONIAN	CAPRON TILL	34	42	23	48	CORRELATED WITH ILLINOIS UNIT. UNDERLIES FARMDALE SILT IN ILLINOIS, OVERLIES PLANO SILT IN ILLINOIS (23-27 AND 35-41,000 YRS. B.P.)
		ARGYLE TILL	62	28	10	29	CORRELATED WITH ILLINOIS UNIT.
		(?)					
		JANESVILLE TILL	47	40	13	14	TENTATIVE NEW NAME YOUTHFUL ICE-CONTACT GRAVEL COMMON. UPPER AND LOWER CONTACTS NOT SEEN.
ILLINOIAN	JACKSONVILLE	WINSLOW TILL	23	50	27	1	CORRELATED WITH ILLINOIS UNIT.
		(?)					
		OGLE TILL	47	42	11	8	CORRELATED WITH ILLINOIS UNIT.
KANSAN		JUDA GRAVEL					TENTATIVE NEW NAME. PALEOSOL AT TOP, BELOW OGLE TILL?

Table 1. Classification of Pleistocene deposits in south-central Wisconsin

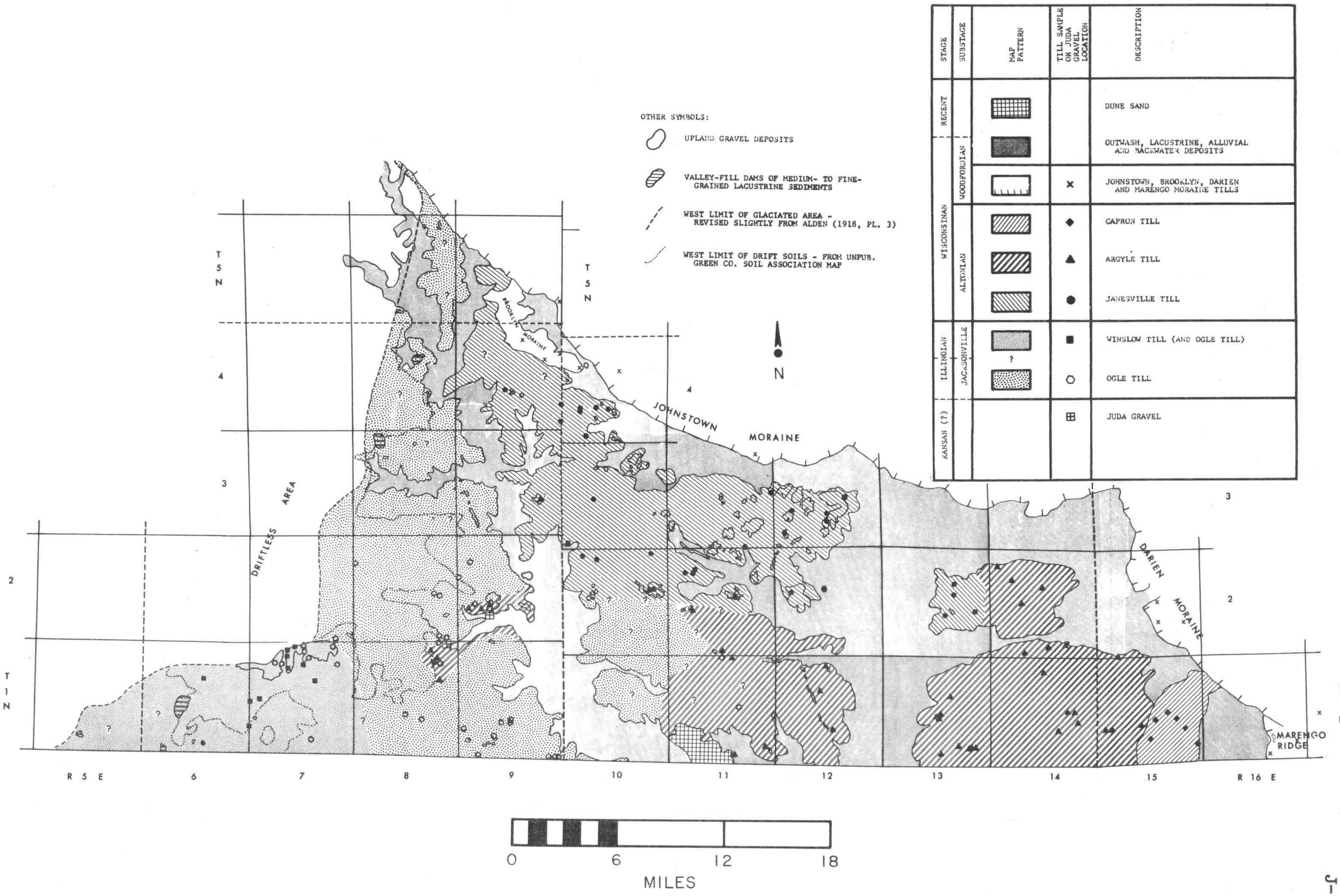


Figure 2. Map of Pleistocene deposits in south-central Wisconsin

degree of weathering on various tills was generally unsuccessful for this reason.

Raw data, detailed section descriptions, and statistical summaries referred to in this report are found in Bleuer (in preparation).

PREVIOUS WORK

Background information essential to the understanding of the Pleistocene of south-central Wisconsin includes previous Wisconsin studies, as well as more recent detailed stratigraphic studies in adjoining parts of Illinois.

Chamberlin (1877, Fig. 3, p. 202; Pl. VII) originally believed that ice of the Green Bay lobe had extended south of Johnstown Moraine and that ice of the Lake Michigan lobe had extended west of the Marengo Moraine to an area of juncture on the west side of the Rock River during an earlier glacial epoch (Fig. 3A). This interpretation was based on the distribution of "Waterloo" quartzite erratics in the drift. Chamberlin (1883, Pl. 9) later modified this interpretation, concluding that Lake Michigan lobe ice alone covered the area (Fig. 3B). According to Alden (1918, p. 161), this change reflected Chamberlin's lack of confidence in the validity of the distribution of quartzite erratics.

The stratified drift ridges of the Monroe area were first described by Chamberlin and Salisbury (1886). Hershey (1897) considered them to represent the "western end of one of the main belts" of the Kansan stratified drift in Illinois.

In 1894 Chamberlin applied the name East Wisconsin to the deposits of the second glacial epoch and East Iowan and Kansan to older deposits, which included McGee's upper and lower tills in Iowa and their equivalents. The latter were mapped in this area, the East Iowan - Kansan boundary following the Rock River valley (Fig. 3D).

Buell (1895) distinguished successive "southward" and "southwestward" quartzite boulder trains in this area. West of the southward train and east of the Driftless Area, an area of older Lake Michigan lobe drift was mapped (Fig. 3C). Buell was the first to recognize the drumlinoid topography east of the Rock River associated with the southwestward train, which he equated with McGee's upper till in Iowa.

By 1899 Leverett had shown the existence of the Illinoian glacial stage. Thus, older drift in Illinois and Wisconsin was considered "probable Illinoian" (Leverett, 1899, Pl. VI) and the younger drift, the Iowan, was again distinguished, the border of which was actually mapped by Hershey (Fig. 3E).

Alden (1904) studied the outwash terraces in the Rock River and Turtle Creek valleys and presented results of many pebble counts from the older drift. Alden (1918), in a definitive paper, concluded that all upland materials in the area were probably Illinoian in age (Fig. 3F).

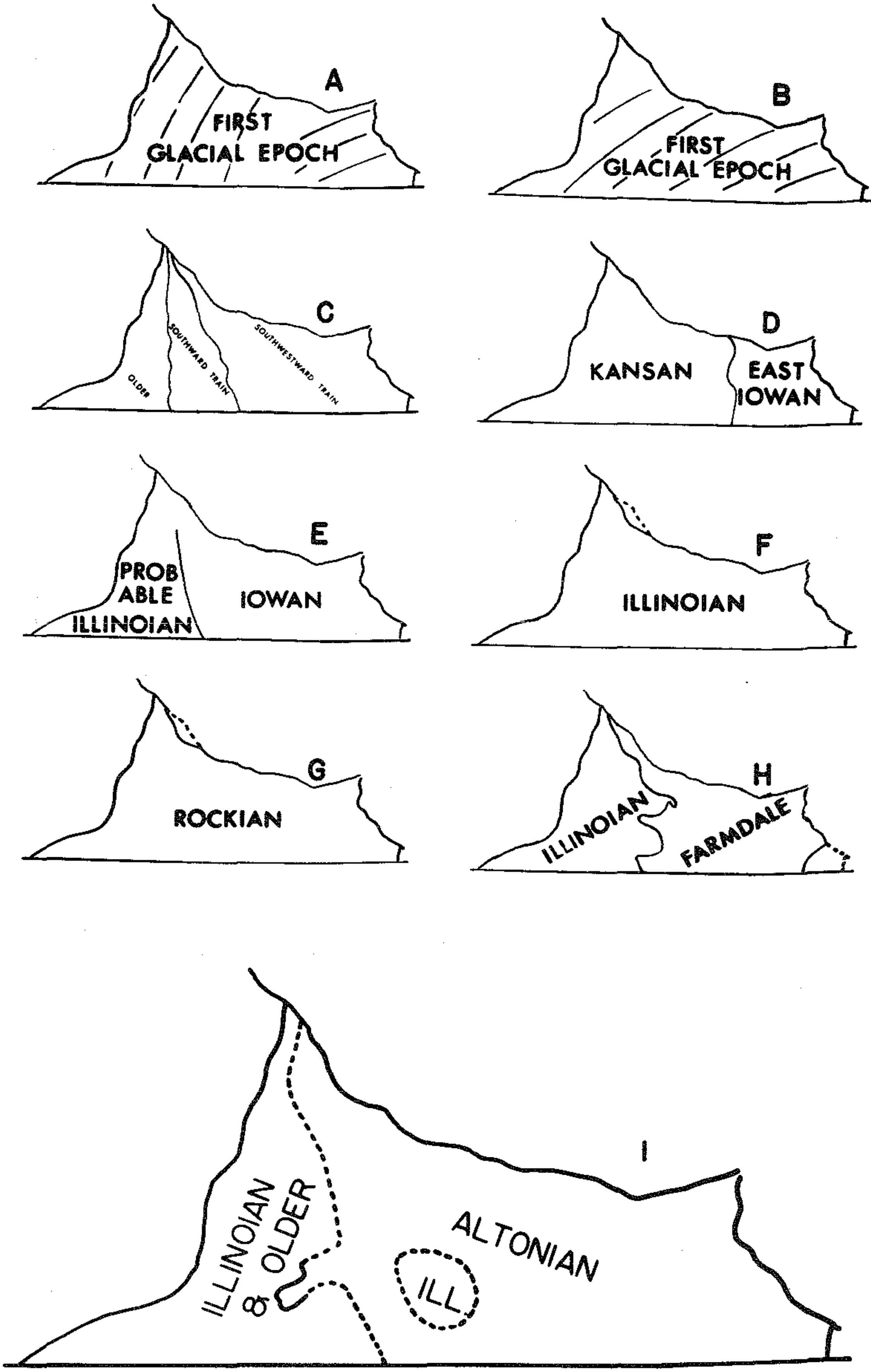


Figure 3. Maps showing previous interpretations of the ages of glacial deposits in south-central Wisconsin

The west boundary of the Belvidere lobe (Leighton, 1923) in Illinois entered Wisconsin along the front of the north-south trending Capron Ridge that continues through Sharon, Wisconsin, and that is overlapped by the Darien Moraine 5 miles north of the Wisconsin-Illinois boundary. This mapping in Illinois was later corroborated by Shaffer (1956).

Shaffer (1956) concluded that all materials west of the Capron Ridge in adjoining Illinois were Farmdale in age and correlated them with Leighton's Farmdale loess, which was thought to be earliest Wisconsin in age.

Frye and Willman (1960) renamed this drift in Illinois the Winnebago drift and assigned it to the Altonian Substage of the Wisconsinan Stage of glaciation.

Black (1962) saw no conclusive evidence of deposits older than Rockian (late Altonian) in Wisconsin (Fig. 3G). He had earlier (1958) described 31,000 year old wood in till south of Lake Geneva.

Leighton and Brophy (1961 and 1966) concluded that Farmdale ice in Illinois and Wisconsin reached the east side of the Sugar River valley. The Farmdale-Illinoian boundary made a marked reentrant to contain the Footville monument within the area mapped as Illinoian, and included the Brooklyn Moraine in that area mapped as Farmdale (Fig. 3H). This boundary is strikingly similar to the Iowan boundary postulated by Leverett (1898) and the southwestward boulder train boundary of Buell (1895). The Shelbyville Moraine of Tazewell age was mapped at the east edge of this area along the continuation of the Capron Ridge from Illinois.

A complex subsurface and surface stratigraphy has been reported by Kempton (1963) and Kempton and Hacket (1968a and 1968b) for an area in adjoining north-central Illinois. A Woodfordian sequence overlies Farmdalian interstadial deposits dated at 24,000 to 26,000 years B.P. that in turn overlie deposits of Altonian age, primarily the Winnebago till. Within this unit are Upper and Middle Winnebago tills, separated by interstadial deposits dated at 32,000 to 41,000 years B.P. These overlie Lower Winnebago tills and Sangamonian and older deposits in the subsurface. Mapping extended westward barely beyond the Rock River.

Willman and Frye (1967) mapped Altonian deposits in adjoining Illinois from the Woodfordian moraines on the east to the Driftless Area on the west. This interpretation was revised (Frye and others, 1969) with the mapping of Capron, Argyle, Ogle and Winslow till units abutting southern Wisconsin. The Capron and Argyle tills of the Winnebago Formation of Altonian age are the former Upper and Middle Winnebago tills. The Ogle and Winslow tills of Illinoian age are mapped from localities near the Rock River to the Driftless Area. Tills in this and other recent studies in Illinois are differentiated primarily on the basis of grain-size distribution and clay mineralogy.

Altonian, Illinoian and older (Kansan ?) deposits are recognized in the present mapping (Fig. 3I). The west limit of the Altonian deposits roughly corresponds to the west limit of the Farmdale or Iowan deposits mapped by earlier workers. However, two distinct Altonian drifts are mapped in different parts of this area. The Brooklyn Moraine overlaps these deposits and is considered Woodfordian in age. Two Illinoian (?) tills are mapped, primarily west of the Sugar River, and Kansan (?) gravels are recognized.

SUMMARY OF GLACIAL HISTORY

Although the drift stratigraphy of south-central Wisconsin is still incompletely known, a general Pleistocene history can be outlined. The earliest known glacial deposits are outwash and, possibly, eroded ice-contact deposits, named the Juda gravel, that are preserved beneath younger tills near Juda and Brodhead and, perhaps, near Monroe. This and later ice advances west of the Rock River moved westward across or up preglacial drainage lines. Various lines of evidence suggest that these materials are at least as old as Kansan.

A period of weathering ensued and is recorded by paleosols in gravel in at least two places. This may represent Yarmouthian weathering.

The Ogle till of Illinoian age overlies the Yarmouthian (?) paleosol, but in most places it rests directly on bedrock or on thin dolomite residuum. Ogle ice probably entered the area from the east. In only a few places, associated kame features attest to local stagnation, although possible correlatives in the northwestern part of the area, isolated crevasse-fills, kames and kame terraces beyond the limits of thin upland till, attest to the large scale stagnation of one or more ice sheets. The enigmatic Winslow till may be evidence for another earlier glacial episode.

Thick relict paleosols preserved on the Ogle till in a few places probably record part of Sangamonian weathering. Their absence in most places, and the usual thinness of the Ogle drift record the extreme subaerial erosion, enhanced by periglacial conditions, to which they have been subjected.

Three times during the Altonian Substage of the Wisconsinan Stage ice sheets of distinctly different regimen, bearing loads of distinctly different composition, entered south-central Wisconsin from the east. The first, represented by the Janesville till and the Janesville gravels, suffered massive stagnation and left ice-contact gravels spread over the uplands west of Janesville. Little evidence of this stagnation is present east of the Rock River, where the till has been covered by later ice. Later, ice represented by the Argyle till constructed a lineated drumlinoid topography east of the Rock River, burying the Janesville till type. It partially filled the deeper bedrock valley system west of the Rock River, and deposited a few upland eskerine forms immediately west of Beloit. Evidence suggests massive stagnation of both of these Altonian ice sheets west of the River, but normal retreat east of the River. This suggests the Rock River, with its buttress-like west valley wall, had a great effect on the demise of these glaciers.

A brief episode of subaerial weathering affected the Argyle drift prior to the deposition of the Capron till near the east margin of this study area. Spruce twigs accumulated in pond silts, and a poorly drained black soil developed on the Argyle till near Clinton. These organic remains and inclusions of weathered Argyle till (?) in the Capron till probably date that mid-Altonian interval. Retreat of the Capron ice coincides with the beginning of the Farmdalian Substage.

These drift deposits were greatly affected by accelerated subaerial erosion due to permafrost conditions accompanying the return of ice during the Woodfordian. Ice-wedge casts in drifts of almost all ages, often truncated, and covered by colluvial debris, attest to these widespread permafrost conditions. Locally, removal of material by subaerial erosion was substantial.

Mantling all deposits is a single, eastward-thinning windblown silt, the Peoria loess, that was derived from the west. Local dune sand blown from the Sugar River valley and possible additions of silt from the Rock River valley are the meager contributions from valleys that carried most of the outwash discharge from Woodfordian ice to the north and east.

GLACIAL STRATIGRAPHY

PEORIA LOESS

The landscape of south-central Wisconsin is draped with a ubiquitous cap of loess. Thicknesses vary considerably due to initial deposition and to Recent erosion, but generally decrease from west to east. Thicknesses of 3 to 4 feet are common on flat uplands, and thicknesses greater than 7 feet are known near Albany and Monroe. Loess is very thin on the hilly bedrock between Brodhead and Beloit. However, loess is thicker on the east side of the Rock River near Beloit, probably because the Rock River valley served as a local silt source and because drift slopes are much more gentle there.

The loess is noncalcareous throughout, even where not entirely within the B horizon of the Recent soil profile. Pre-settlement southern Wisconsin was a patchwork of grassland and deciduous forest, so that soil profiles on the loess vary greatly.

Only one stratigraphic unit, the Peoria loess, has been recognized in this map area, probably because the loess is relatively thin and partially eroded and because of the common deep, grey-brown podzolic or intergrade soil profiles. In southwestern Grant County the bases of thick loess sections have been dated at 24,600± 1100 years B.P. (Black, 1960a) and 29,300± 700 years B.P. (Hogan and Beatty, 1963). The subjacent Roxana silt has been recognized overlying Illinoian tills in northwestern Illinois, but not in southern Wisconsin.

CAPRON TILL

Distribution and character

In the southeastern part of T.1N., R.15E., a till ridge enters Wisconsin from Illinois, where it has been called the Capron Ridge. The surface till found on the ridge has been named the Capron till, of the

Winnebago Formation of Altonian age in Illinois (Frye and others, 1969). This name is used in this report of the northward continuation of the unit (Fig. 2).

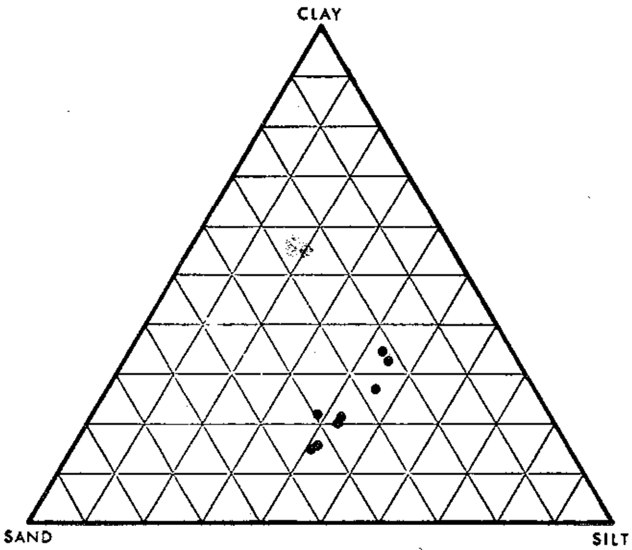


Figure 4. Particle size for the Capron till

The till correlated with the Capron till of Illinois shows average sand-silt-clay percentages of 34-43-23, although, as in Illinois, two distinct modes exist (Fig. 4). One mode, represented by three samples, shows average sand-silt-clay percentages of 24-45-31. It is found as the surface till in several borings and as a distinct unit below the other type in another boring. A sandier mode shows average sand-silt-clay percentages of 40-42-18. Particle size percentages of lower and upper Capron till phases in Illinois are 25-43-32 and 43-33-24 (Frye and others, 1969, Fig. 3, p. 10). The till is moderately compact, and the clayier phase exhibits weak subangular blocky structure. Colors range from 7.5 YR 5/4 to 7.5 YR 6/4.

Pebble counts from two localities show an average of 48 percent Niagaran dolomite pebble indicators, buff to grey finely crystalline to microcrystalline dolomite, the highest of any counts in this study area (Fig. 5).

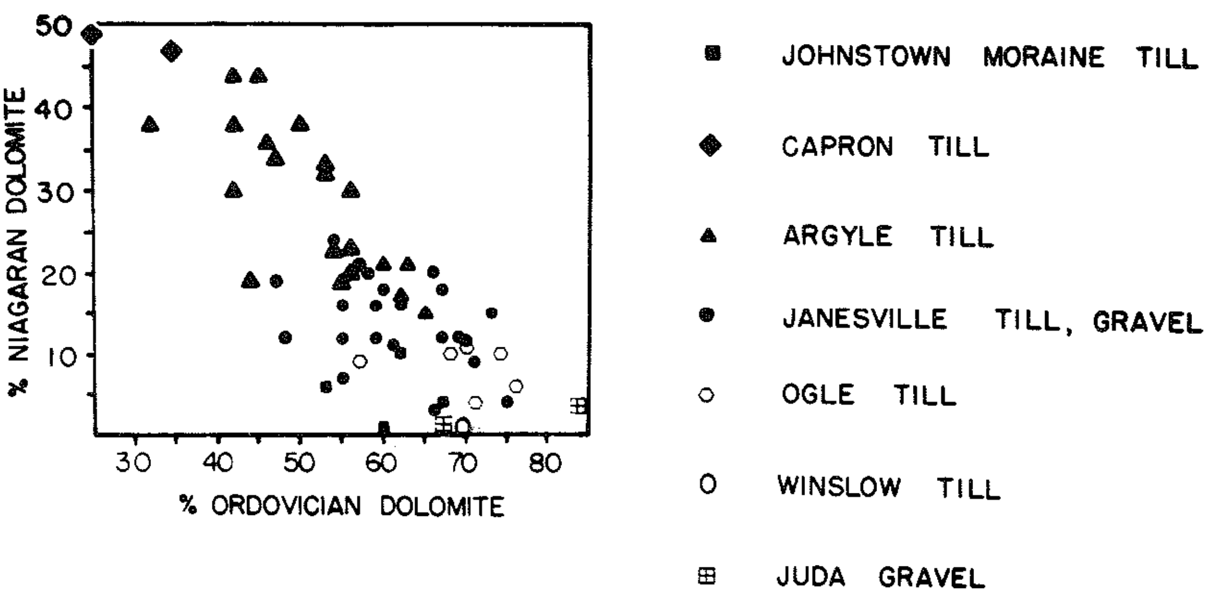


Figure 5. Summary of Niagaran dolomite pebble content of tills and gravels

Actually, almost all the dolomite in the Capron till (averaging 78 percent) is probably Niagaran because the ridge is immediately in the lee of the Silurian outcrop. Westward, pebbles in the older tills are diluted by Ordovician dolomites. Depth of leaching averages 40 inches through a 6- to 24 inch thick silt cap in two exposures measured.

The surface tills of the ridge are easily distinguished from the light brown sandy Woodfordian tills in the Darien Moraine to the east and the sandy Argyle till to the west. They are less red than the till in the Marengo Moraine, but have a similar grain size distribution. Niagaran dolomite pebble content is much greater than in the Argyle till.

An intermediate clay mineral composition and an intermediate Devonian black shale content led Frye and others (1969, p. 6) to the conclusion that the ice that deposited the Capron till moved down the west side of the Lake Michigan basin. The dearth of shale and the high Niagaran dolomite content here, in addition to the obvious north-south trend of the Capron Ridge, substantiate this hypothesis.

Geomorphology

The Capron Ridge rises 20 to 60 feet above the gently westward-sloping Woodfordian outwash plain that separates it from the Marengo Moraine 4 miles to the east. At its northeasternmost extent it is overlapped by the more rugged Woodfordian Darien Moraine. The south half of the west margin rises 20 to 60 feet above the subdued west and west-southwest trending drumlinoid features that characterize the surface of the older Argyle till. The north half of the west margin rises above a dissected outwash plain through which the faint outlines of buried lineated forms are visible. Thus, all boundaries are marked by obvious topographic discontinuities.

The surface has been smoothed by mass wasting processes to a greater degree than that of the Woodfordian moraines, which are only slightly younger, because of the less sandy till forming the ridge and because of the absence of stratified ice-contact material so characteristic of the Darien and Johnstown Moraines.

Stratigraphy

Drift thicknesses of over 35 feet were penetrated by power auger at several sites on the ridge crest. At the north end of the crest near the SE$\frac{1}{4}$, NE$\frac{1}{4}$, Sec. 14, T.1N., R.15E. several borings hit bedrock within 2 to 6 feet.

Borings in high knolls in the eastern part of the ridge penetrated only 5 and 20 feet of typical Capron till over sandier Argyle till. Thus, some of the relief of the moraine is due to a core of older Argyle till or to bedrock highs. No traces of inter-till organic material were found in the auger borings that extended into the Argyle till. In a small borrow pit in SE$\frac{1}{4}$, SW$\frac{1}{4}$, SE$\frac{1}{4}$, Sec. 5, T.1N., R.15E. the Capron till lies with almost vertical contact upon medium-grained outwash sand. A leached, dark brown, loamy material, similar to B2 horizons on the sandy Argyle till to the west, is found in a zone along and near the contact and in patches in an adjacent roadside exposure. These appear to be inclusions and may indicate mid-Altonian weathering of the Argyle till prior to the deposition of the Capron till.

Work in northern Illinois has shown that the Capron till is below the Farmdale Silt and above the Plano Silt and bracketed by dates of 23-26,900 years B.P. and 35-41,000 years B.P., respectively (Frye and others, 1969, p. 22). Thus, the Capron till is clearly of latest Altonian age.

Black (1958) reported the occurrence of an "erratic spruce log from pinkish till ... on the uplands south of Lake Geneva ... dated as 31,800 $\pm$ 1200 years old.... The pinkish till is identical to that in the Marengo moraine and similar to that in Alden's Illinoian drift, supposedly correlative with Shaffer's Farmdale." In the area of the log's discovery the "yellow-brown, stony-sandy drift" of the Darien Moraine was thought to be a patchy cover over the "distinctive pinkish clay-silt-sand till with few pebbles" of the Marengo Moraine. Although the log may have been incorporated in Marengo till, it was thought that it might date "the original advance of the ice that deposited the pinkish till, seemingly the original Farmdale advance."

The similarity noted between the till in the Marengo Moraine and Alden's Illinoian was based upon the comparison of the Marengo till with the nearby till of the Capron Ridge, rather than with the several sandier till types now known to the west. A sample of the till in which the log was incorporated was furnished by R. F. Black, and sand-silt-clay percentages were found to be 39-43-18. The till was a 7.5 YR 6/4 (moist) color. This grain size distribution closely matches that of the coarser extremes of both the Capron and Marengo tills in Wisconsin, but the color is more like that typical of the Capron till than the 5 YR color typical of the Marengo till in Wisconsin. Sand-silt-clay percentages of 44-43-13 determined for till from a borrow pit at the base of the hill from which the log came are more similar to the Capron till. Thus, the log could have come from either the Marengo till of Woodfordian age or the Capron till of Altonian age on the basis of grain size alone, but more likely from the Capron till on the basis of color.

The date is only somewhat younger than Illinois dates on the Plano Silt that underlies the Capron till in Illinois, but is considerably older than Illinois dates on Farmdalian materials. If it is assumed that the log was incorporated in the Capron till from deposits equivalent to the Plano silt, it represents Rockian time (Black, 1962), which ended with the overriding of a 32,000 year old spruce forest in southern Wisconsin. The definition of Rockian time must be restricted to that time represented by the Capron till, because it is now known from evidence in Illinois that the tills west of the Capron Ridge are all older than 32,000 years. This restriction has been made subsequent to 1965 (Frye and others, 1965, Fig. 3, p. 46; p. 54).

ARGYLE TILL

Distribution and character

A sandy loam surface till between the Capron Ridge and the Sugar River is traceable from Illinois, where it has been named the Argyle till, a unit of the Winnebago Formation of Altonian age. This name will be used herein for the northward continuation of this unit.

The distribution of the Argyle till is extremely patchy west of the Rock River, although it is known with certainty as far west as Juda in extensions up Juda Branch and Riley School Branch (Fig. 2). It is not known north of its poorly defined boundary with the Janesville till. It is a continuous surface till on the east side of the Rock River.

The first lithologic characterization of this till by Hershey was reported by Leverett (1899, p. 132) as follows: "Hershey's chief criterion in mapping the inner border of the Iowan is a change in the character of the till ... that to the east ... being more sandy than that to the west and displaying a pink tint not noted to the west." These criteria remain valid to this day.

Tills correlated with the Argyle till of Illinois are characterized by their extremely sandy nature, sand-silt-clay percentages averaging 62-28-10 (Fig. 6). Considered as a texturally defined unit, this till type differs from older tills in its higher content of Niagaran dolomite pebbles, averaging 29 percent, although the ranges of the Argyle till and the older Janesville till overlap in this respect (Fig. 5). A pinkish color typically 7.5 YR 7/4 to 8/4 (dry), 6/4 (moist) is somewhat characteristic of the Argyle till, but not necessarily so. The Janesville till is sometimes a similar color. The till is structureless and friable. No other characteristics were found to be diagnostic.

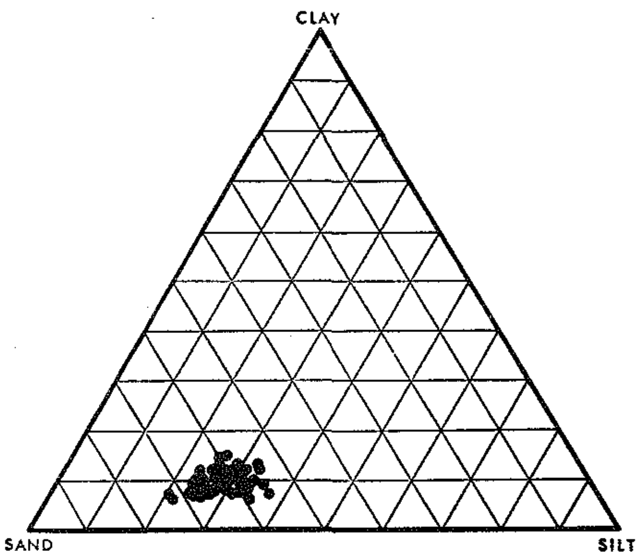


Figure 6. Particle size for the Argyle till

Depth of leaching in 27 exposures or borings on the east side of the Rock River averaged 46 inches through an average of 32 inches of loess. Depth of leaching measured in only four partially eroded (?) exposures on the west side of the Rock River averaged 38 inches through an average of only 5 inches of loess. These measurements are on upland crests in most instances, but are variable and hard to interpret because of the sloping nature of almost all areas and the probability that varying amounts of weathered material have been removed by subaerial erosion.

The flow of Argyle ice, as mapped in Wisconsin, was from the east-northeast in the eastern half and from the east-southeast in the western half. This is clearly indicated by fluted forms, striae and drift distribution. High Niagaran dolomite content necessitates flow over or along the Niagaran escarpment. Precluded, then, is an "axial glacial flow pattern by way of Green Bay" as suggested for the Argyle till in Illinois on the basis of shale pebble and clay mineral data (Frye and others, 1969, p. 6). If the Argyle till, as mapped in Illinois and Wisconsin, is truly a single rock unit, the meaning of this difference in interpretation is unclear.

Geomorphology east of the Rock River

Between the Capron Ridge and the Rock River outwash terrace is the area of distinctly drumlinoid topography that was first recognized by Buell (1895). The lineations are not parallel everywhere east of the Rock River, contrary to Alden (1918, Pl. III) and Leighton and Brophy (1966, Fig. 2, p. 484). The topography south of Turtle Creek has a general west-southwest lineation, but individual ridges are oriented between this trend and east-west. Orientations of upland crests north of Turtle Creek are west-northwest and suggest a locally divergent flow. This diversity of orientation may be in part due to the effect of bedrock topography upon glacial deposition.

Drainage is deranged and youthful, and, except for those areas adjacent to Turtle Creek or the Rock River valley, the drainage is almost wholly controlled by the subdued constructional topography. Much of the area is a series of broad, imperfectly drained to poorly drained lineated lowlands between low, gently sloping lineated hills. Local relief is less than 60 feet within the area. These aspects of the topography are enhanced by the relatively undissected bedrock surface on the east side of the Rock River (LeRoux, 1963, p. X24, Pl. 4).

Geomorphology west of the Rock River

West of the Rock River the topography is grossly different. Although exposures are more numerous than on the east side of the River, few show glacial materials. Much of the landscape is maturely eroded and more like a driftless than a glaciated area, beginning on the west side of the Rock River. The surface morphology is, in most instances, entirely bedrock controlled. The greater dissection of the bedrock surface, as compared to the area east of the Rock River, probably had a profound effect upon the deposition of the Argyle and older tills, and on their subsequent erosion. Local relief is as much as 120 feet.

Within the confines of the bedrock valley system, however, thick youthful valley fill has created several striking derangements or reversals of drainage, particularly in western Newark Township, T.1N., R.11E. The local lack of integrated drainage in such areas resembles its larger scale counterpart on the east side of the Rock River. However, only subsurface study can prove the assumed association of the Argyle till with this topography.

Stratigraphy east of the Rock River

The upland surfaces east of the Rock River are underlain by Argyle till capped by thin loess. No significant ice-contact stratified material is known. Power auger holes in the poorly drained lowland tracts have penetrated interbedded quiet-water fine-grained sands and silts, or outwash gravel over Argyle till. Organic-rich pond silts containing spruce twigs overlie peat, outwash and till at a farm pond excavation in one low-lying area (Clinton Section, SW¼, SE¼, Sec. 14, T.1N., R.14E.). On the north slope of the drumlinoid ridge directly to the south of the Clinton Section, hand augering has shown 5 feet of Peoria loess over an organic-rich, sandy A1 horizon, which overlies gleyed, leached, sandy loam till. Robert Engel of the Soil Conservation Service discovered this relationship during routine soil mapping.

Although the surface till is in most places a very sandy loam, drilling on several uplands has shown a less sandy till at depths of 5 to 20 feet. It is exposed as the surface till in the farm pond excavation mentioned above and under a cover of 2 feet of sandy till in the Turtle Townhall Section (SW¼, NW¼, Sec. 22, T.1N., R.13E.). In the latter exposure the contact is undulatory but abrupt and is marked only by a thin zone of groundwater oxidation. One section is known nearby in which the till types are interlayered, but whether this is due to intershearing or to ablation processes is not known. Sand-silt-clay percentages of these lower tills (ten samples) average 47-38-15 (Fig. 7).

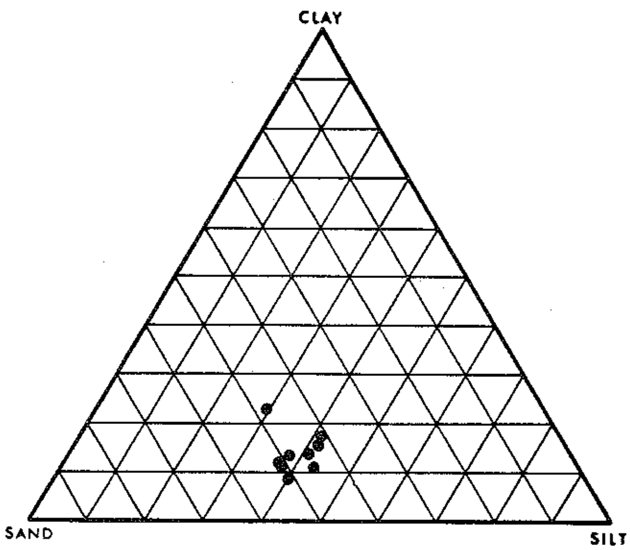


Figure 7. Particle size for the "lower" tills of the Rock River

It is possible that the two textural till types are basal and ablation tills. However, the widespread distribution of the sandy till and the absence of accompanying water-laid stagnation deposits could argue to the contrary. Pebbles in the Turtle Section show marked east-west orientations in both units and weakly argue against an ablation till origin for the upper, but this could also be explained by post-glacial movement down the west-southwest facing slope. In the same section the tills differ in pebble content as markedly as in texture. The upper till is rich in Niagaran dolomite, as is characteristic of the Argyle till, and the lower till is richer in local dolomite.

Assuming that two distinct tills are present, it must be realized that the upper sandy till may or may not be the direct cause of the lineated landscape. The configuration of the top of the lower till in this area has not been studied in the subsurface.

The average sand content of surface tills in this area and those to the west that are correlated with the Argyle till is 61 percent, considerably higher than the 54 percent of sand in the Argyle till where defined in Illinois (Frye and others, 1969, p. 26). Therefore, the relationship between the two tills in this area and the type Argyle till is not entirely clear. The problem stems partly from the lack of close control, particularly to the west, that makes lateral variations in till properties difficult to trace and the continuity of certain till units difficult to establish.

A till with characteristics similar to the lower till in this area occurs stratigraphically below the Argyle till north of Turtle Creek. That till and the lower tills here are tentatively correlated with the Janesville till defined west of Janesville.

Stratigraphy west of the Rock River

The Argyle till becomes discontinuous and thin west of the dolomite bedrock ridge on the west side of the Rock River.

Sands and gravels of the two Beloit eskers overlie the till on that upland. The westernmost and largest of these, that described by Chamberlin (1877, pp. 216-217; Fig. 10, p. 217), climbs and falls with the terrain in eskerine fashion. Air photo study suggests that water movement during its formation was south-southeasterly. This and all other such upland gravel deposits in this study area were mapped as belts of Illinoian "end moraine" by Alden (1918, Pl. III). However, the orientations of the ice-contact stratified deposits are not necessarily controlled by ice-marginal positions. Rather, bedrock topography largely determined the direction of outwash discharge through the stagnating ice mass and the nature of initial crevassing in the ice. The concept of eskers necessarily draining toward the ice margin is not necessarily true in an area where ice moved obliquely across or directly up major preglacial valley systems. Proglacial lakes stood at the front of the ice, and sufficient hydrostatic head necessary for the formation of eskers could have been available after subglacial drainage had been opened up-ice. In this case, drainage was probably into the Rock River valley.

Sheet sand and dune sand that cover much of the area immediately east of the Sugar River in T.1N. were mapped by Alden (1918, Pl. III). This mapping has been refined only slightly here. Air photos show well developed blowout dunes that were formed by west winds sometime after Woodfordian outwash deposition in the Sugar River valley. The sand is everywhere noncalcareous. There is no evidence of substantial loess above, below or within the sand, which suggests that most of it may be contemporaneous with loess deposition. The sand lies immediately atop a paleosol on the Argyle till in the SE$\frac{1}{4}$, SW$\frac{1}{4}$, Sec. 25, T.1N., R.12E. and directly on bedrock in exposures and borings nearby.

The Argyle till type is not known north of Bass Creek and only four scattered exposures of the till are known west of the Beloit-Afton area. Between them are a few exposures of till of unknown correlation, two exposures of Ogle (?) till with a Sangamonian-Recent soil profile (NE$\frac{1}{4}$, NE$\frac{1}{4}$, NE$\frac{1}{4}$, Sec. 4; SE$\frac{1}{4}$, SE$\frac{1}{4}$, SE$\frac{1}{4}$, Sec. 15, T.1N., R.11E.) and one exposure showing dolomite rubble over Sangamonian (?) paleosolic material (NW$\frac{1}{4}$, SE$\frac{1}{4}$, NE$\frac{1}{4}$, Sec. 35, T.2N., R.10E.; observed first by Keith Schmude, Soil Conservation Service). Between these exposures bedrock is at or near the surface and soils are developed in thin loess or in thin, weathered and unidentifiable till. No exposures of calcareous till are known within the 3 to 5 miles east of the Sugar River valley south of the latitude of Brodhead, although youthful valley fill in western Newark

Township, T.1N., R.11E., has not been drilled and is tentatively assumed to be composed of Argyle drift. No exposures of the Argyle till type are known on the uplands west of the Sugar River. However, from a point 3 miles west of Brodhead to a point 3/4 mile southwest of Juda, exposures of the sandy, pink, Niagaran pebble-rich Argyle till type are again found. The easternmost of these is fully 13 miles west of the westernmost known Argyle till exposure. Therefore, it is concluded that a distinct Sugar River - Juda Branch tongue of Argyle ice may have existed, which was similar to the Pecatonica Lobe in Illinois (Frye and others, 1969, Fig. 2, p. 8-9). The effect of subglacial topography on channeling a finger of Argyle ice into the broad confluence of valleys west of Brodhead and up Juda Branch is clear.

The westernmost Argyle till exposure is in the NW$\frac{1}{4}$, SE$\frac{1}{4}$, Sec. 2, T.1N., R.8E., southwest of Juda. The unusually stony till there comprises the core of a ridge (terminal moraine?) blocking Juda Branch. Lacustrine silts cover the upstream and downstream ridge flanks. Similar till has been identified in an auger hole in the small valley directly north and in an exposure above the south valley wall of Riley School Branch to the south. High level sands and silts capping a well-developed paleosol in the North Juda Section (SW$\frac{1}{4}$, Sec. 36, T.2N., R.9E.) may have been deposited in a lake locally dammed by the ice in Juda Branch. Juda Branch is the western outlet of Lake Brodhead (Leighton and Brophy, 1966), a lake dammed in the Sugar River valley by Farmdale ice, in essence the Argyle ice of this report, at its presumed westernmost extent many miles southeast of the Juda area.

Within the area of this protuberance into Juda Branch is the West Brodhead Section in the SE$\frac{1}{4}$, SE$\frac{1}{4}$, Sec. 20, T.2N., R.9E., one of the finest multiple till exposures in southern Wisconsin. There a till correlated with the Argyle till, 2.6 feet thick, immediately underlies Peoria loess and overlies a till correlated with the Ogle till. Beneath the Ogle till is a gravel that shows evidence of weathering, presumably prior to deposition of the Ogle till.

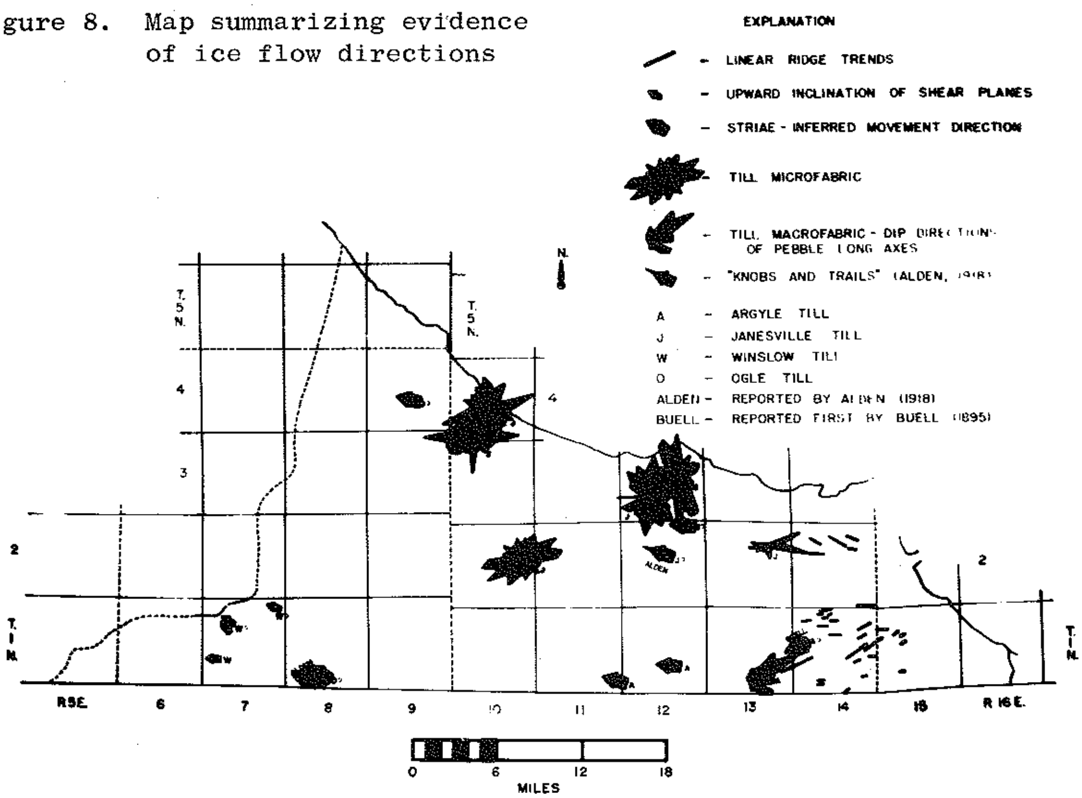
The Argyle till in the West Brodhead Section and in numerous other exposures to the west is very sandy, pink and Niagaran dolomite-rich. The total Niagaran dolomite pebble content, 44 percent, is as great as in the Capron till far to the east, at a point immediately in the lee of the Silurian outcrop. This must be interpreted to mean that the pebble fraction of the Argyle till here is composed largely of englacially-transported, relatively far-traveled materials.

In the absence of a weathered zone atop the 2.5 feet of yellowish-brown, less sandy Ogle till, and despite the sharp erosional contact between the two tills, one might infer that the lower till is a "lodgement" till with much locally derived material and that the Argyle till is an ablation till of the same ice sheet rich in foreign material. It is primarily the nearby occurrence of discrete, mappable Ogle and Argyle till types at the surface that argues for the presence of two distinct depositional units here. This interpretation requires that the entire Sangamon Soil be removed prior to the deposition of the Argyle till, but it also assumes that the lower till is a correlative of the Ogle till and not of the Janesville till or any other Lower Winnebago till such as is thought to exist in northeastern Illinois. Although the Janesville till on the east side of the Sugar River and the Ogle till on the west side of the River are thought to be of different ages, they are physically indistinguishable in the field. They are both thought to be older than the Argyle till, but their interrelationship is actually unknown.

Between the West Brodhead Section and Brodhead are numerous upland sand and gravel deposits. Directly north of the section at Decatur School is a subdued sand ridge believed to be composed of the same gravel and sand unit that is exposed at the base of the section. To the east in Sections 22, 23, 26 and 27 and to the southeast in Sections 28 and 29 are youthful ice-contact stratified deposits that would seem to represent stagnation features of the Argyle ice. However, pebble counts in the gravels do not show the high Niagaran pebble content characteristic of the Argyle till, and their possible correlation with an older unit must be considered.

In Sections 23 and 26, T.3N., R.9E., is an area of sand hills intermingled with eroded knobs of St. Peter Sandstone. Drilling in the SE$\frac{1}{4}$, Sec. 23 yielded possible Argyle till below 10 feet of medium-grained sand and gravel. Other possible occurrences of the Argyle type till farther north are found in an exposure in the SE$\frac{1}{4}$, SE$\frac{1}{4}$, Sec. 21, T.4N., R.9E., and at the base of a power auger hole in a nearby gravel pit in the NE$\frac{1}{4}$, NE$\frac{1}{4}$, Sec. 27, T.4N., R.9E. In the exposure, a westward-thinning sandy till wedge is sheared between gravels that overlie a till similar texturally to the Ogle and Janesville tills. This till, in turn, overlies a clayey till similar to the Winslow till in the Monroe area and stratified silts and clays. These rest on residual soil on bedrock. None of the latter occurrences of possible Argyle till presently warrants northward extension of the mapped area of the till.

Figure 8. Map summarizing evidence of ice flow directions



The only striae associated with the Argyle till are those oriented 280° in western Beloit and 290° in Sec. 25, T.1N., R.11E. (Fig. 8). The latter orientation is controlled largely by the small northwestward trending valley up which the ice was directed. One set of striae, noted by Buell (1895, p. 494), is oriented 255° and parallels the lineated landforms west of Clinton.

JANESVILLE TILL AND JANESVILLE GRAVEL

Distribution and character

The name Janesville till is introduced informally herein to designate the pre-Woodfordian surface till north of Bass Creek on the west side of the Rock River. The till is lithologically and texturally unlike the Woodfordian tills to the north and the Argyle till to the south and east. However, it is lithologically indistinguishable, except for a slight, but significantly higher clay content, from the Ogle till to the south and west. Although much contradictory evidence exists regarding its stratigraphic position, it is considered a distinct mapping unit of early Altonian age, perhaps a correlative of one of the lower Winnebago tills in north-central Illinois (Kempton and Hackett, 1968 a and b).

Prominent gravel deposits with a distribution similar to that of the Janesville till west of the Rock River are informally named the Janesville gravel. A convenient reference section for both till and gravel is the West Janesville Section in the NW$\frac{1}{4}$,N E$\frac{1}{4}$, Sec. 31, T.3N., R.12E. There, a collapsed wedge of Janesville till lies within an ice-contact deposit of coarse Janesville gravel.

The main occurrence of the till is in an area west of the Rock River bounded generally by Janesville, Afton, Hanover, Orfordville and Evansville (Fig. 2). The north boundary is the 1 to 3 mile-wide Marsh Creek outwash flat that separates the area from the Johnstown Moraine of Woodfordian age to the north. The Bass Creek valley marks the approximate boundary on the south, although Janesville till and gravel are present across the valley at Hanover and at Footville. The western extent of its major topographic expression is a digitate line following the east wall of the bedrock ridge that extends north-northwestward from Orfordville to a point about 3 miles west of Evansville. It is within this area that the till is intimately associated with ice-contact stratified drift.

East of the Rock River is a small area with a surface till that is tentatively correlated with the Janesville till west of the River. This area is surrounded on the north, west and south by Woodfordian valley-train deposits, but on the east its erosional topography meets the lineated constructional topography of the overlying Argyle till.

Tills herein referred to as Janesville till are distinguished in the field primarily on the basis of their sand-silt-clay percentages, averaging 47-40-13 (Fig. 9). Grain size distribution easily

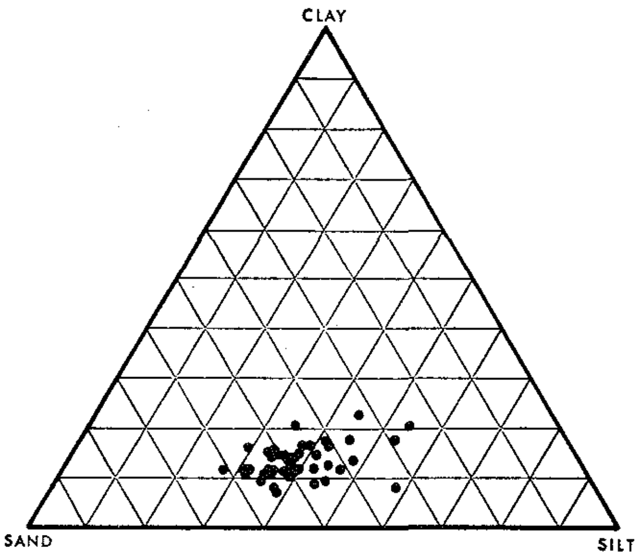


Figure 9. Plot of sand-silt-clay percentages for the Janesville till

distinguishes the Janesville till from the Argyle till, but it does not aid in differentiating the Janesville till and the Ogle till in the field, although statistically the Janesville till has a very slight, but significantly greater clay content than the Ogle till. The Janesville till as a unit may be distinguished from the Argyle and Ogle tills on the basis of its Niagaran dolomite pebble content, which averages 14 percent (Fig. 5). However, the pebble contents of all three tills overlap, and this criterion is not reliable in the field. Janesville till is typically of a 10 YR 6/4 (moist) color, but it has a pink case in some exposures. It often shows thin, platy frost partings in surface exposure and is generally loose and friable. No other characteristics studied were found to be of diagnostic value.

Depth of leaching measured in four exposures east of the Rock River averages 32 inches through an average of 20 inches of loess. Depth of leaching in ten exposures west of the Rock River averaged 40 inches through an average of 15 inches of loess. Such measurements are of little value in comparative work because most of the area is in slope, and variable quantities of material have been removed by subaerial erosion.

Geomorphology

The Janesville till and gravels lie on a maturely dissected bedrock upland, the primary drainage lines of which are controlled by shallow bedrock. Scattered deposits of till and ice-contact stratified material, such as the gravel and sand knolls common along the south valley wall of Marsh Creek west of Janesville and along the north valley wall of Bass Creek between Hanover and Afton, cause abundant but minor alterations of drainage. The western third of the Janesville till area shows a relative dearth of the ice-contact materials except in the Evansville area.

Slopes on the gravels comprising kames, kame fields, crevasse fills and eskerine ridges commonly exceed 30°, and many probably have been modified little since their ice-contact origin. One unmodified ice-block depression is present in an area of thicker drift in northwestern Janesville. In general, the topography of individual gravel forms appear extremely youthful.

One eskerine (?) ridge just west of the Footville monument in Sections 30 and 31, T.3N., R.11E., and in Sec. 5, T.2N., R.11E., seems to originate in a small group of kames in Sec. 30 and disappears below valley fill in Sec. 5. Its form and poorly exposed cross-bedding suggest that it was deposited by waters flowing nearly in an up-ice direction, to the southeast, similar to the deposits associated with the Argyle till to the south. Thus, the whole Janesville ice mass west of the Rock River probably stagnated as a unit after active ice had left the Bass Creek and Rock River valleys, opening the valleys to subglacial meltwater discharge. The restriction of massive stagnation forms of both the Janesville and the Argyle drift to the west side of the Rock River suggests that the wide valley, with its buttress-like west wall, was a natural line of detachment for ice whose motion was perpendicular to it.

The topography of the presumed Janesville till area east of the Rock River is entirely bedrock controlled except for small areas of thicker drift, hummocky topography and drainage diversion in Sections 23 to 26, T.2N., R.13E. These areas have not been explored in the subsurface, however, and could be remains of the younger Argyle till. The lineated surface form of the Argyle till clearly extended west of its present limit, thus a cap of Argyle till, in addition to an unknown amount of Janesville till, must have been removed by post-Altonian subaerial erosion. This erosion was enhanced by the available relief adjacent to the Rock River valley that was probably even greater sometime prior to deposition of Woodfordian outwash. Bedrock is commonly at the surface or under thin loess or very thin till, and, except in one instance, no upland gravel deposits are present. Thus, the Janesville till terrain on the east side of the Rock River is grossly different from the Janesville till terrain on the west side of the River. Despite this fact, surface tills in each area are tentatively considered the same.

The Footville monument in the NE$\frac{1}{4}$, NE$\frac{1}{4}$, Sec. 31, T.3N., R.11E., is within the area of Janesville till and gravels. The monument is like others in south-central Wisconsin, being a more durable, cemented column of St. Peter Sandstone. Iron oxides and siliceous cement case-harden with weathering. The top of the monument is at the level of, and only a few feet from, the dolomite-sandstone contact in the upland to the northeast.

The monument was considered by Alden (1918, p. 141) to be:

> ...an indication of the lapse of a considerable geologic interval since the glaciation ....
>
> The pillar, which stands about 10 yards from the low sandstone slope, has a height of about 15 feet and a maximum diameter at the base of 10 or 12 feet, and has developed by erosion ... of the sandstone which originally connected it with the adjacent slope. The significant feature is that the isolation of the pillar, which in this particular position must have taken considerable time, has evidently been accomplished since the Illinoian glaciation of the area, and it is inconceivable that such a small tower could have withstood the abrasion of the vast amount of ice which passed over this spot....

Leighton and Brophy (1961, p. 29) considered the "standing rock" to be within the continuation of their Illinoian drift area of Illinois, and note: "Such an erosional feature is too advanced for it to have been developed since the Farmdale glaciation ... it is the product of Sangamon weathering and erosion." A marked reentrant of the Illinoian boundary encompassed the monument in their later mapping of the Farmdale-Illinoian boundary into Wisconsin (1966, Fig. 1).

Black (1969b), however, has found that the weathering and erosion that produces some of the monuments in south-central Wisconsin and the Driftless Area are very rapid. Some may have been initiated as fractured, glacially plucked surfaces in the lee of bedrock uplands (R. F. Black, personal communication).

The monument is within an area of Janesville till and gravels, although no such deposits cap the adjacent upland. A Janesville gravel deposit, the low, partially buried eskerine (?) ridge mentioned above, is present less than $\frac{1}{2}$ mile to the west within the trough now occupied by Bass Creek. Although the stratigraphic position of these Janesville drift deposits is not entirely clear, they do seem to be of Altonian age, and to set a maximum age on the Footville monument.

Stratigraphy

West of Janesville, gravel and finer-grained outwash materials commonly cap bedrock, and no till is present. In places the Janesville till overlies and/or underlies localized patches of outwash, as in T.3N., R.12E. Elsewhere, the till occurs as wedges within the gravel, as in the West Janesville Section. In the North Orfordville Section (SW$\frac{1}{4}$, NW$\frac{1}{4}$, Sec. 13, T.2N., R.10E.) the till overlies outwash and is capped by ice-contact gravels. Sand deposits south of Bass Creek near Hanover (SE$\frac{1}{4}$, Sec. 15, T2N., R.11E.) were shown by borings to be underlain by the Janesville till type.

Till correlation west of Orfordville is difficult because of the merging of lithologically and texturally similar Janesville and Ogle tills. Problems in this area are exemplified by the East Brodhead Section (SE$\frac{1}{4}$, SW$\frac{1}{4}$, Sec. 17, T.2N., R.10E.) where, between gravels, is a till with grain-size distribution like that of the Janesville or Ogle tills, but with a very high, Argyle-like content of Niagaran dolomite pebbles. The correlation of this and several nearby sand deposits is left in doubt.

The Janesville till mapped east of the Rock River is thought to be the same as the loamy till present below the Argyle till south of Turtle Creek, as discussed under Argyle till.

Soil development on most of the Janesville gravel deposits consists of a thin "beta-B" zone beneath thin loess. The thin soil and its association with common youthful constructional landforms initially led to the conclusion that the Janesville till and gravels were of latest Altonian age, post-dating the Argyle till. Of necessity, the Janesville ice would have entered the area from the north. But it is clear that the comparison of a landscape characterized by constructional gravel forms in the Janesville till and gravel area and a landscape lacking such forms in the Argyle till areas has led to this confusion. As discussed in the following paragraphs, the initial conclusion has been rendered untenable, and the deposits have been assigned to a sub-Argyle till position.

Microfabrics at Orfordville and near Evansville indicate ice movement from the east or northeast and corroborate evidence gained from shear plane orientations at Orfordville. Microfabric data nearer the Rock River are less diagnostic, and interpretations of ice flow either from the north or southeast could be made (Fig. 8).

Knobs and trails, or half cones, found under gravel by Alden (1918, p. 204, Pl. XXI) in Sec. 16, T.2N., R.12E., clearly show ice movement from the east-southeast (Fig. 8). Near this spot in 1969, 2 feet of pink Janesville till of typical grain-size distribution and low Niagaran pebble content was found below 15 feet of Woodfordian outwash gravel. The bedrock contact was not exposed however. Striae with a similar east-southeast orientation directly underlie valley-train deposits in southern Janesville.

Orientation data showing east to west ice movement near Evansville and east-northeast to west-southwest movement at Orfordville could have been produced by ice movement into the area from the north or from the east. Fabric data of questionable quality at Janesville and to the east could fit either a north or eastern origin. Alden's find, however, gives concrete evidence of a southeastern origin near Janesville, although its association with Janesville till is not definitely proven. If Janesville ice entered the area from the east, it must predate the advance of Argyle ice.

Mineralogical data suggest that the Janesville deposits are not related to the deposits of the Johnstown Moraine of Woodfordian age to the north. Unlike the Janesville till, the Woodfordian materials are characterized by altered heavy and light mineral suites. This suggests that they are derived partly from local weathered drift. It might be argued, then, that the Janesville deposits cannot be only slightly older (late Altonian) deposits derived from the north, because Farmdalian weathering probably could not have altered the volume of material necessary to so markedly affect the Woodfordian deposits.

The till unit on the east side of the Rock River that is correlated with the main Janesville deposits is separated from the Argyle till by a marked topographic discontinuity and is surely pre-Argyle in age.

On the basis of these considerations, it is concluded that the Janesville till is pre-Mid-Altonian in age, logically the correlative of one of the Lower Winnebago, Early Altonian-aged tills described in Illinois (Kempton and Hackett, 1968a and b).

OGLE TILL

Distribution and Character

Between the Sugar River valley and the Driftless Area is a surface till (Fig. 2) that seems continuous with the Ogle till of Illinoian age in Illinois (Frye and others, 1969, p. 24). This name is adopted herein for the correlative till in Wisconsin.

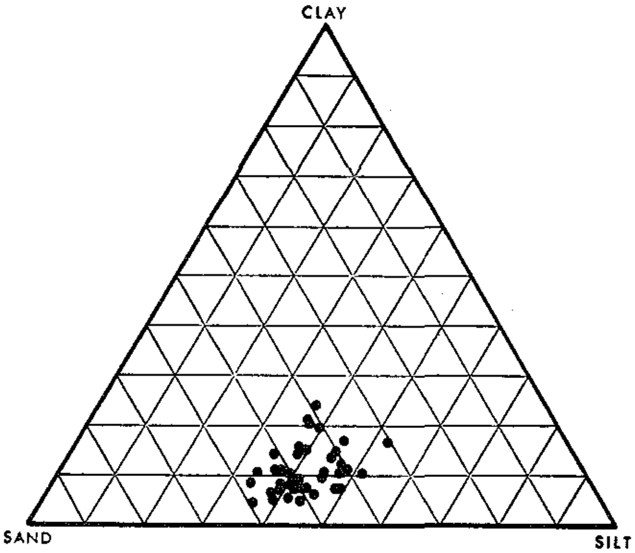


Figure 10. Plot of sand-silt-clay percentages for the Ogle till

Tills in Wisconsin that are correlated with the Ogle till of Illinois are characterized primarily by distinctive sand-silt-clay percentages, averaging 47-42-11 (Fig. 10). On this basis, the till type is easily distinguishable in the field from the Argyle and Winslow tills, but not from the Janesville till. The low Niagaran dolomite pebble content of this texturally defined unit, averaging 8 percent, sets the Ogle type till apart from the westernmost Argyle tills, but it is otherwise undiagnostic (Fig. 5). The oxidized color of the Ogle till is invariably 10 YR 6/4 (moist), like most occurrences of the Janesville till and some occurrences of the Argyle till. Thin, platy, frost-parting structure is typical in surface exposures.

Depth of leaching measured in eight exposures or borings averaged 58 inches through 24 inches of loess. Although the weathering profiles in most of these partially eroded exposures are little different from those on the Argyle till, the deepest and/or the most heavily clay-enriched or the reddest profiles in this study area are found on the Ogle till. B horizons deeper than 6 feet, under 1 to 4 feet of loess, are known in places. The base of the leached zone on these materials is generally near the base of the iron oxide and clay enriched B horizon. B3 horizons are usually 5 inches thick or less. A power auger hole on the flat upland surface in eastern Monroe (SE$\frac{1}{4}$, SE$\frac{1}{4}$, Sec. 35, T.2N., R.7E.), penetrated 4.5 feet of loess, over 4 feet of B2 material, 2 feet of B2 and B3 material and more than 7 feet of the calcareous Ogle till type.

Intense weathering profiles deeper than 15 feet are known on the gravels in the Monroe area, although most deposits are leached and clay enriched less than a few feet under thin loess. The most weathered material typically has a noncalcareous clay loam matrix enclosing rotten dolomite pebbles and rotten igneous cobbles. These gravels may be ice-marginal deposits correlative with the Ogle till; they may be older.*

The distribution of the Ogle till is tentatively mapped far north of its actual known extent (Fig. 3) in order to include, as correlatives, numerous old, isolated upland sand and gravel deposits discussed below.

On the basis of shale pebble and clay mineral data, Frye and others (1969, p. 6) reasoned that the Ogle ice that invaded Illinois followed an "axial glacial flow pattern by way of Green Bay." The direction of

* See Late Note p. J-35.

Ogle ice movement in Wisconsin was apparently westward and west-northwestward as indicated by the distribution of the Ogle till and by striae reported by earlier workers. This would seem to indicate a source more directly to the east. The Wisconsin striae, however, may record an earlier ice advance or may reflect the effects of local topography on ice flow. The dearth of Niagaran dolomite pebbles would be consistent with the Illinois data. However, I believe that the origin of what is called Ogle till in Wisconsin and Illinois is still open to question.

Geomorphology

The topography in the Ogle drift area is controlled almost entirely by the maturely dissected bedrock. Tills are found in places as erosional remnants on broad, flat upland tracts and on hill flanks, but rarely are found on narrower bedrock upland crests. The area has generally less steep slopes, lower drainage density and less relief than the adjoining part of the Driftless Area. It lacks the deep valley fill characteristic of parts of the Argyle drift area east of the Sugar River, and it lacks the upland constructional gravel forms characteristic of the Janesville till area east of the Sugar River. Topographic differences exist that reflect various ages of drift on the east and west sides of the Sugar River, but some of these differences probably result from differing regimens of glacial deposition.

Isolated, dissected bedrock spurs, with or without present throughflowing deranged drainage, are present throughout the area. Although some may have been cut directly by subglacial or ice-marginal meltwater, many of them are probably at least in part a result of superposition from a higher old drift surface. Later piracies have left some such features high and dry. Once drainage was confined in bedrock valleys, the adjacent preglacial valley fill drift was relatively protected. Alden (1918) noted the presence of such drift dams and diverted drainage, and like Hershey (1897), assumed that the present drift surfaces are everywhere nearly the same as the original drift surfaces. Many such occurrences in this area, however, suggest superposition and the removal of a considerable volume of glacial sediment.

Stratigraphy

Exposures of Ogle till are common in the area southwest of Brodhead in T.1N., R.9E., and till-derived soils are mapped to a much greater extent there than in the area immediately to the east of the Sugar River (unpublished Green and Rock County soil maps). The relationship of this till to the overlying Argyle till is shown in the West Brodhead Section, discussed earlier. Ogle till wedges are present in the gravels of a small series of kames in Sections 28 and 32, T.1N., R.9E., and Ogle till is associated with the gravel and sand ridges in the Monroe area.

In the Greenwood Cemetery Section in southeastern Monroe (NW$\frac{1}{4}$, SE$\frac{1}{4}$, NE$\frac{1}{4}$, Sec. 2, T.1N., R.7E.) the till lies over the main bodv of finely bedded lacustrine sands that make up the lower part of the ridges to the west. No weathering break is seen atop the sand here nor, apparently, in the numerous exposures showing till over gravel and sand seen by Alden in the railroad cuts southwest of Monroe (1918, p. 147-148). Power augering and surface exposures show that the upper till described by Alden is the same as that called Ogle elsewhere.

The upper gravels in the ridges west of Monroe in Sec. 5, T.1N., R.7E. (West Monroe Sections I and II) locally show evidence of deposition close to an ice front. They contain coarse, unstratified gravel masses of ice-contact origin, ice block collapse features or localized, jumbled accumulations of igneous cobbles and boulders that were probably carried englacially. These gravels are commonly 10 to 25 feet thick and overlie 10 to 30 feet of medium- to fine-grained lacustrine silts and sands with thin interbedded gravels. Below these, power augering has shown up to 15 feet of gray silty clay on dolomite residuum. Some samples of the lowest material appear laminated. Because of their poor quality, they can only be assumed to represent the fine-grained basal deposit of a proglacial lake sequence - perhaps that recording the advance of Ogle ice.* The materials were deposited in water ponded between the ice on the southeast and the northeast-southwest trending dolomite upland about one mile to the northwest.

The main east face of West Monroe Section II is cut by numerous southeasterly- to easterly-dipping shear planes and is composed primarily of tough, massive, silty till composed of locally incorporated water-laid silts and sands. Wedges of sand, gravel and stratified and massive silt are complexly sheared into this mass. The till becomes richer in pebbles and gravel wedges north-northwestward, reflecting progressive incorporation into the ice of the stratigraphically higher gravels in a down-ice direction. On cursory examination, this would probably be considered a "coarsening upward" body of proglacial lacustrine and outwash sediments that were finally overrun by the associated ice. However, an alternative hypothesis suggested here is that the shearing may represent the effects of an ice advance later than that which deposited the bulk of the stratified sediments.

Weathering profiles on the Monroe gravels vary tremendously. In many upland places little more than a thin "beta-B" zone occurs below loess. Elsewhere, highly clay enriched, weathered gravels exceed 15 feet in thickness. In both Monroe pits, only about 1 to 3 feet of altered gravel is present beneath less than 4 feet of loess. The West Monroe I section showed, in 1968, a wedge overthickened by shearing, 4 to 10 feet thick, of highly altered gravel with colors reaching 5 YR 4/6 to 5/6 (moist) and with a matrix of tough, sandy clay loam to clay. As in several other places nearby, the most extreme weathering is associated with local concentrations of basic and intermediate crystalline cobbles and boulders. Below this, extending to road level about 18 feet from the surface, is a partially weathered gravel containing a mixture of ghost dolomite cobbles and pebbles and small masses of weathered clayey gravel like that above. Discrete shear planes, oriented like those in the main pit, are paralleled by abundant stretched, disaggregated basic igneous cobbles. Inclusions of elongate cobble-sized masses of stratified sand and silt are common, but more remarkable is the inclusion in the highly weathered gravel of several irregular masses and lenses of the calcareous, oxidized, fissile Ogle till type (sand-silt-clay % =

*See Late Note p. J-35

51-45-4).

The time relationship between the Ogle till and the sand and gravel section here is important in relation to other exposures in the Monroe area and in relation to the regional stratigraphy. At the West Brodhead Section and the North Juda Section, for instance, the Ogle till is thought to overlie older weathered gravels. In several places near Monroe, including the West Monroe Sections I and II, gravels contain post-weathering northwestward-rising shear planes and/or recumbent folds in weathered material and in unaltered deposits. In the SW$\frac{1}{4}$, SW$\frac{1}{4}$, NW$\frac{1}{4}$, Sec. 1, T.1N., R.7E., the sands and silts that are overlain by Ogle till on the adjacent flat upland (Greenwood Cemetery Section) are contorted and sheared, and contain stretched, disaggregated igneous cobbles, although only a very meager zone of weathering is present.

Possible interpretations of these Monroe deposits are: (1) that the west Monroe gravels and lacustrine sediments that were deposited in water dammed between the ice front and the dolomite upland to the northwest, are either older than, or equivalent to the Ogle till. Gravel, paleosol and till were overrun by a later ice advance, perhaps that represented by the silty Winslow till (as correlated from Illinois), which is present nearby. Frozen masses of existing Ogle till, along with masses of stratified sediments, where sheared into the paleosol. Or (2) that the gravels and paleosol were overrun by Ogle ice. Ogle till was injected into the paleosol in a somewhat fluid state, or melted from debris-rich ice blocks that were sheared into the paleosol.

If the first interpretation is true, and the Ogle till is Illinoian, the Winslow till, also considered Illinoian in Illinois, must be much younger. If the second interpretation is true, and the Ogle till is Illinoian, the gravels may be Kansan. The Winslow till may be a correlative of the gravels or may occur stratigraphically below them. At the present time, the meager evidence favoring each of these hypotheses is evenly balanced.*

The age and origin of numerous isolated deposits of sand and gravel within the western and northwestern area mapped as Ogle till remain in question. Some of these are hillside crevasse-fill, kame or kame-terrace deposits formed during ice stagnation in situations similar to those described for northern Illinois by Flint (1931), and others are vestiges of once more extensive valley fills of coarse- to fine-grained outwash and lacustrine deposits that presently dam bedrock valleys. Similar deposits elsewhere can be considered probable correlatives of tills mapped near them, but many such deposits in this area could be considered correlatives of more than one unit. In the extreme northwestern part of the study area no tills occur in the vicinity of the gravels, and correlation is even more conjectural. Soil thicknesses are quite variable although most are less than a few feet thick. Part of this variability and the youthfulness of many profiles can be explained by subaerial erosion.

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* See Late Note p. J-35.

Several such gravel knolls occur near Monticello and Dayton, particularly along the west valley walls of the Sugar River. A major valley dam of sand and gravel occurs northeast of Monticello, and a dam of stratified silts and clays occurs southwest of Dayton. Other deposits occur west of Belleville, east of Basco and east of Paoli. Bradley (1935) considered the Paoli deposits to be part of a large end moraine complex. However, much of what was mapped as moraine is clearly knobby erosional topography on the surface of differentially cemented St. Peter Sandstone. Other deposits nearby are merely chert gravel accumulations of the Reedstown Member (proposed name, Ostrom, 1967), the basal part of the St. Peter Sandstone. Low Niagaran dolomite pebble content probably rules out correlation of these deposits with the Argyle till, although there is no reason why Argyle ice could not have been eroding and depositing local materials in this area. The deposits are tentatively considered equivalent to or older than the Ogle till. The large gravel deposits west of Albany (Southwest Albany Section, NW$\frac{1}{4}$, Sec. 32, T. 3 N., R. 9 E.) cannot clearly be assigned to the Ogle ice advance or to that represented by the older Juda gravels. They are in places highly weathered and must be considered at least as old as Illinoian.

WINSLOW TILL

Distribution and Character

The Winslow till was defined by Frye and others (1969, p. 25) and was mapped in the northwesternmost glaciated area of Illinois. This till type was previously recognized in Wisconsin by Fanning (1964), and it later constituted the parent material for the Carno and Cadiz soil series on the new (unpublished) Green County, Wisconsin, soil map. The name Winslow till is adopted herein for what is thought to be the correlative till type in Wisconsin.

The distribution of the Winslow till in Wisconsin (Fig. 2) is generalized from the unpublished Green County soil map. Exposures are known only south and west of Monroe, between the Driftless Area and the Illinois state line.

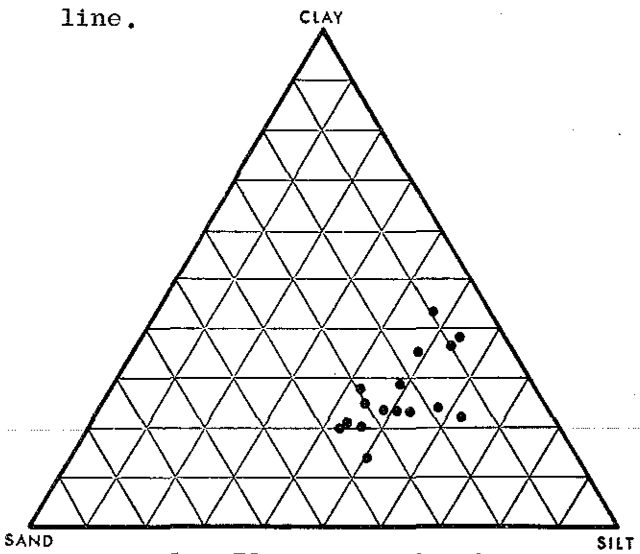

Figure 11. Plot of sand-silt-clay-percentages for the Winslow till

Tills in Wisconsin that are correlated with the type Winslow till are distinguished on the basis of sand-silt-clay percentages, which average 23-50-27 (Fig. 11). Niagaran pebble content is as low as in the Ogle till, and pebble content appears to be of no diagnostic value locally in differentiating questionable tills or gravels (Fig. 5). No other characteristics have proven of diagnostic value. The color of the Winslow till is commonly 10 YR 6/4 (moist), and it generally displays a sub-angular blocky structure in surface exposures.

The Winslow till is the only till unit in this area that can be recognized on the basis of a soil series mapped in a modern soil survey. The unpublished Green County Soil Survey recognizes the Cadiz and Clarno Series, soils developed on silty clay loam or clay loam glacial tills in the Monroe area. These are forest and forest-prairie intergrade soils developed in 15 to 45 inches of loess over calcareous till. The definite correlation of the Cadiz Series, however, has not yet been established (Klingelhoets and others, 1968, p. 21). Soil profiles on the Winslow till that were examined in this study were extremely youthful, perhaps owing to partial erosion.

The clayey nature of the Winslow till is anomalous in an area dominated by loamy to sandy loam tills. Fanning (1964) concluded, on the basis of clay mineral studies, that the till was shale-derived, like the parent materials of the Morley soils of eastern Wisconsin. However, considering the dearth of shale bedrock nearby, the dearth of shale pebbles in the till, and considering the fact that ice probably moved up-valley into proglacial lakes, it seems probable that the Winslow till is composed largely of locally overridden and incorporated fine-grained lacustrine sediments.

The Winslow till mapped in Illinois is thought to have been of axial Green Bay lobe origin on the basis of clay mineral and pebble data. Few new Wisconsin data are available to solve this problem. If, as seems quite possible, most of the till is of local origin, most standard petrographic studies lose meaning.

Geomorphology

The Winslow till is found on bedrock valley sides and contributes little itself to the topography of the area.

Numerous rock gorges south of Monroe are associated with remnants of fine-grained lacustrine sediments that dam valleys of all sizes. The Winslow ice is thought to be that responsible for the formation of the bulk of these deposits, because in two instances south of Monroe the Winslow till appears to cover or to be interstratified with such deposits. Hershey (1893) thought that the dams were originally of only local extent and that lake waters discharged over bedrock lows and eventually cut deep gorges. It is clear, however, that the lacustrine valley fill sediments once covered much larger areas than they do now, and probably filled entire valley systems. Because the ice moved up-valley, ponding the lakes in front of it, it follows that the gorges may have been cut by lake waters discharging beneath stagnant ice, scattered blocks of which protected and preserved the dams (F. T. Thwaites, personal communication to R. F. Black). The stagnant ice blocks need not have been long lived, because soon after bedrock incision was begun, and before much valley fill was removed, the lower drainage courses were probably opened, allowing rapid down-cutting to begin. Lateral erosion would have ensued only after equilibrium was established, and the valley-fill - a huge amount of it- would have been removed, except where the gorges protected adjacent deposits.

Stratigraphy

The stratigraphic relationship fo the Winslow till to any material other than lacustrine silts and clays has not been demonstrated in Wisconsin.* In the NW$\frac{1}{4}$, NW$\frac{1}{4}$, Sec. 19, T. 1 N., R. 7 E., two power auger borings showed the Winslow till to lie on and to be intimately interstratified with silty clays and silts. Thus, this and many of the isolated silt and clay drift dams southwest of Monroe may be related in time to the Winslow advance.

The Winslow till of Illinois is assigned to the Jacksonville Substage of the Illinoian Stage of glaciation, based upon its occurrence below gravels thought to carry the Sangamon Soil. The isolated occurrence of the till in Wisconsin and Illinois, surrounded on the south and east by Illinoian deposits, certainly argues for an Illinoian or older age.

JUDA GRAVEL

Distribution and Character

In exposures a few miles west of Brodhead (West Brodhead Section) and a mile north of Juda (North Juda Section), weathered gravels occur stratigraphically below till. Some question remians as to whether the gravel below calcareous till in the West Brodhead Section contains a true paleosol. Therefore, the North Juda Section, located in the SW$\frac{1}{4}$, SE$\frac{1}{4}$, SW$\frac{1}{4}$, Sec. 36, T. 2 N., R. 8 E., is designated the reference section for a gravel unit informally named the Juda gravel.

The pebble content of the Juda gravel does not distinguish it from nearby deposits. However, a low Niagaran pebble content, averaging only 3 percent, would presumably distinguish it from gravel correlative of the nearby Argyle till (Fig. 5).

Geomorphology

Where not covered by the Ogle or Argyle tills, the gravel or sand surface has been subjected to erosion since pre-Ogle time. Smooth, low sand and gravel knolls north of the West Brodhead Section may be composed of a Juda gravel correlative. The gravels in the low linear ridge west of Albany may also be correlatives, as may some of the isolated deposits found to the northwest. The gravel is responsible for distinctive surface form only very locally.

Stratigraphy

Exposed in the upper part of the North Juda Section are about 3 feet of Woodordian Peoria loess overlying a similar thickness of Altonian

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*See Late Note p. J-35

lacustrine sands and silts. The continuation of the surface alfisol into the lake sediments to a total depth of nearly 50 inches suggests the possibility of a thin paleosol in the lake sediments. Similar deposits at this high position are unknown in the immediate vicinity, but fine-grained lacustrine deposits are common in the surrounding lowlands. Many are a result of proglacial lacustrine sedimentation due to damming of the Sugar River drainage by the Argyle ice.

A stone line separates these deposits from 7.5 feet of weathered, irregularly interstratified till (?), silts and sands below. The upper 5 feet has mostly till texture with pebbles scattered throughout, but it contains thin streaks of sand and silt. The lower part is mostly stratified silt with a gravelly transition zone at the base. The materials are entirely noncalcareous and are streaked with groundwater controlled bands ranging from 5 YR 5/4 to 10 YR 6/4. The upper part of this may be a secondarily reworked equivalent of the Ogle till which caps uplands to the north and west.

Below this and extending to the base of the pit is a rotten dolomite gravel with flat-lying to westward dipping bedding. Matrix grains in the upper 7 feet are thickly coated with iron oxide and clay, and the mass is completely leached above an iron oxide cemented band 20 inches below the top of the gravel. Pebbles are slightly calcareous below. Weathering to the depth and extent of that in the overlying till and silts alone is greater than the maximum known on Ogle till deposits in Wisconsin. Thus it is reasoned that two superposed paleosols may be present below Altonian lacustrine sediments, although the development in gravel may be a simple downward continuation of that immediately above. This gravel is tentatively named the Juda gravel.

The gravel underlying the Ogle and Argyle tills in the West Brodhead Section is a probably correlative of the Juda gravel. It is partially leached in only a few places, but it is greatly enriched in iron oxide and somewhat in clay in the upper 0.3 foot. Dolomite pebbles are partially corroded and oxidation continues to a depth of nearly 4 feet, the entire exposed gravel section. The upper zone could be a truncated weathered zone, but it could just as easily be interpreted as a pseudo-soil developed by concentrated groundwater movement.

Other possible correlatives are the gravels west of Albany, the Monroe gravels and any of several isolated upland sand and gravel deposits in the western part of this study area, and the Winslow till.

If in these exposures a weathered gravel does occur below the Illinoian Ogle till, it represents a Kansan glaciation and a Yarmouthian interglacial interval in Wisconsin.

SOILS

Soils information has been of value in interpreting the glacial deposits of this area. Data have been gleaned from the Green and Walworth County Soil Surveys that have been completed but not yet published, and from the

Rock County Soil Survey currently underway.

Till soils mapped in the area can be grouped into three categories. The first includes the Clarno and Cadiz series which are those soils with thin loess overlying calcareous silt loam or silty clay loam till; in the area this includes the Winslow till. The parent material of these soils is similar to that of the Morley soils, but it has a thicker (15 to 45 inches) loess cap. The second category includes the Miami and similar series which are developed in loess overlying calcareous loam or sandy loam till; in the area this includes the Capron till and partially eroded surfaces of the Argyle, Janesville and Ogle tills. The third category includes the Ogle, Argyle, Flagg, Durand and similar soils that are developed in loess over weathered till; in the area this includes less severely eroded surfaces of the Argyle, Janesville and Ogle tills. The paleosolic soils are those with loess thicknesses varying from 0 to 50 inches with a solum thicker than 45 inches. Where loess is thicker than 40 inches, the underlying tills are weathered more than 10 inches.

In several areas the clayey till soils were mapped far to the east of known Winslow till localities, such as on lower valley slopes near Juda and as far east as the Sugar River valley. Only stratified lacustrine silts, clays and sands, under thin loess were found in these places in subsurface reconnaissance during this study.

A clay and heavy mineral study of ten Recent and paleosolic profiles was made in an effort to determine the relative and absolute ages of the tills in this area. Camparisons were made between their development and that of paleosols of known age that have been studied by others. Most sampled profiles were on gently sloping to flat upland surfaces. (Zircon + tourmaline + sphene)/hornblende ratios, epidote/hornblende ratios, garnet/hornblende ratios, percent depletion, and "weathering mean" values were calculated for heavy minerals (see Brophy, 1959; Willman and others, 1966; Jackson and Sherman, 1953). D.I. ratios (Willman and others, 1959) were determined from X-ray diffraction traces of glycolated $< 2\mu$ clay. In only one profile was other than random vertical variation of heavy mineral parameters found. In that profile, developed in Ogle till on a flat upland (Greenwood Cemetery Section), ratios and percent depletions were well in excess of those reported for Sangamonian profiles in Illinois. D.I. ratios in all cases were gradational through loess and through paleosol, probably indicative of superimposed Recent soil development. The mixing of the mineralogy of the profiles is logically the product of intense mass movement downslope related, in part, to periglacial conditions.

GEOMORPHIC DEVELOPMENT

Some characteristics of the regional geomorphology have been discussed under the headings of individual stratigraphic units, but certain aspects of the geomorphic development will be discussed below.

Gross aspects of the landscape are controlled by preglacial topography, original inequities of glacial deposition, erosion by confined glacial meltwater, and deposition of outwash, lacustrine and alluvial valley fill. Extreme variability in paleosol development on tills and the general thinness of drift suggest that postglacial erosion has also greatly changed the surface of the older surfical deposits. Furthermore, much of the present topography may reflect post-Middle Altonian, pre-Woodfordian erosion.

Frye and others (1969) make particular note of the...

> unusually intense episodes of erosion to which the region /northwestern Illinois/ has been subjected. This region was virtually surrounded by glacial ice during early Woodfordian time when the Green River Lobe was at its maximum extent. This glacial configuration contributed to a climate that accentuated solifluction, sheet wash, and eolian scour and deposition. Similar, but probably less intense, conditions existed during late Altonian time, and perhaps during the building of the massive Bloomington Moraine.

Numerous ice-wedge casts in materials of several ages are truncated by weathered colluvium and Peoria loess in the area of this study. In his study of ice-wedge casts here and throughout Wisconsin, Black (1965) concluded that the permafrost condition necessary for the development of ice-wedge polygons in Wisconsin occurred "during a particularly cold period that logically would be related to a glacial advance ... Truncation /of the casts/ by colluviation and mass movements ... ceased prior to the deposition of the bulk of the loess over them." The loess deposition began about 29,000 years ago (Hogan and Beatty, 1963). The time of most severe permafrost conditions in Wisconsin was believed to correspond to the Wisconsinan glacial maximum about 20,000 years ago.

Special note has been made of an intense period of post-Altonian, early Woodfordian or pre-Woodfordian erosion. Both studies mentioned above suggest directly or indirectly that periglacial mass-movement on the relatively steep bedrock slopes of south central Wisconsin had a significant effect upon the landscape.

CONCLUSION

Several glacial till or gravel units have been differentiated in south-central Wisconsin. Grain size and some petrographic criteria seem to be useful in their definition and mapping. However, the age and mode of origin of several of these units remain in question. Remaining problems concern: the age and origin of the Winslow till and its relationship to the Ogle till;* the genesis of, and the relationship between, the Argyle till, "lower" tills east of the Rock River, and the Janesville till; the age and source of the Janesville till; the origin of apparent paleosols in gravel below till; and the stratigraphic unit responsible for the lineated topography east of the Rock River.

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* See Late Note p. J-35.

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*LATE NOTE

Drilling completed after the submission of this manuscript has shown that the Winslow till lies below the sheared paleosol, outwash and lacustrine sediments of the West Monroe sections. It overlies thin lacustrine silt and residual clay. Furthermore, it underlies Ogle till and thin gravel in the SE$\frac{1}{4}$, NE$\frac{1}{4}$, NW$\frac{1}{4}$, Sec. 3, T. 1 N., R. 7 E., south of Monroe. Therefore, it is now clear that sheared and contorted outwash gravels and lacustrine sediments throughout the Monroe area were overridden by Ogle ice during Illinoian time. Because of the presence, locally, of intense weathering on these stratified sediments, and the sheared paleosol at West Monroe Section I, it is concluded that the bulk of these sediments were deposited during the retreat of the Winslow ice and do not correlate with the Ogle till. It is concluded that the Monroe ridges are but erosional remmants of a proglacial outwash and lacustrine fill of considerable extent, and it is concluded that the Winslow till is of Kansan age and that it is probably correlative with the Juda gravel.

The author is indebted to the Wisconsin Geological and Natural History Survey, particularly to M. E. Ostrom and to Roger Peters, for making these key borings. A report summarizing the Illinoian and Kansan stratigraphy of south-central Wisconsin is in preparation.

Part K

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