Information Circular
Number 13

UNIVERSITY EXTENSION
The University of Wisconsin

Geological and Natural History Survey

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GLACIAL GEOLOGY OF TWO CREEKS FOREST BED, VALDERAN TYPE LOCALITY, and NORTHERN KETTLE MORAINE STATE FOREST

by
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Prepared for the 1970 Annual Meeting
of the
Geological Society of America

Madison, Wisconsin
November, 1970

Available from the Geological and Natural History Survey, University Extension, The University of Wisconsin, 1815 University Avenue, Madison, Wis. 53706. Price: $1.50

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INTRODUCTION

The primary purpose of Glacial Geology Field Trip No. 9 is to visit the internationally famous Two Creeks Buried Forest. Secondary purposes include visits to the type locality of the Valderan drift and to part of the scenic and geologically important Northern Kettle Interlobate Moraine. Because the Two Creeks stop is 102 miles from Milwaukee, only slight deviation from the shortest route is allowed for this one-day trip, and only a few brief stops can be accommodated in addition to the main stop at the Two Creeks Buried Forest.

To aid in photography at Two Creeks, the buses will drive directly to a small temporary shelter directly south of the Manitowoc-Kewaunee County line, on the west short of Lake Michigan. Arrival is timed for maximum light in the late forenoon to reach the east-facing bank. Please keep in mind that the site is a scientific area owned by The Nature Conservancy for future inclusion in the Ice Age National Scientific Reserve of Wisconsin. *Sample collecting and digging at the site are prohibited!*

From Two Creeks the buses will proceed to Hoffman's at Fox Hills, Mishicot, for lunch. Alcoholic beverages are not included in your meal ticket.

After lunch we will drive to the quarry of the Valders Lime & Stone Company, operating in the Niagara dolomite (Silurian), to see the relationship of striae to till that led F. T. Thwaites to name the Valders Substage of the Wisconsinan Stage. Please be forewarned that *you enter the quarry at your own risk* and that the walls are high and steep.

Our return to Milwaukee through the Northern Kettle Moraine State Forest regretfully will be late in the afternoon when light for pictures will be diminishing rapidly. Hopefully, you can take occasional pictures of classical ice-stagnation features enroute. Weather permitting, we will make one stop in which you can "debus" for quick pictures of striking moulin kames. Unfortunately, time will not permit stops for study of the various features.

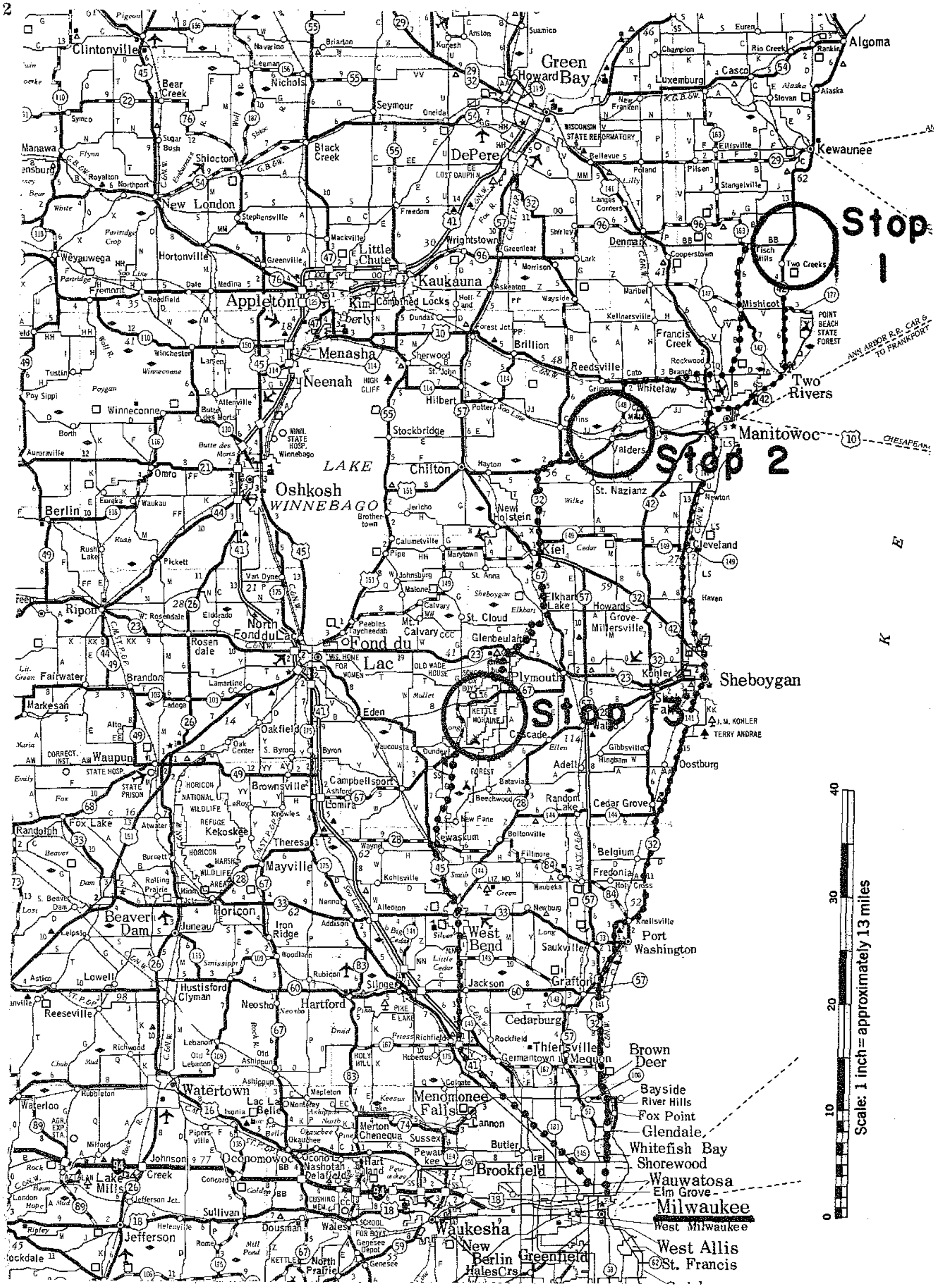
This guide is divided into four parts—a detailed road log (Part 1) with only brief stop descriptions, and three documentary reports, one for each of the three areas, to provide more detail on hard-to-find material. The three stops or areas are described as discrete entities for convenience both in writing and in reading. They are: Part 2—The Two Creeks Buried Forest; Part 3—Valderan type locality; and Part 4—Northern Kettle Moraine State Forest. To avoid duplication, reference citations for all four parts of this guide are listed at the end of the guide. For ease in location, figure numbers run consecutively through all four parts. No studies especially for this field guide were undertaken. It is obvious from the material presented herein that the writer has been aided materially by many people and with funds from various sources. These contributions are acknowledged gratefully.

MAPS

The following 15-minute topographic quadrangle maps of the U.S. Geological Survey may be used to follow the route:

Milwaukee	Kewaunee
Port Washington	Reedsville
Sheboygan Falls	Chilton
Sheboygan South	Kiel
Sheboygan North	Kewaskum
Howards Grove	West Bend
Manitowoc	Waukesha

Please note that these maps are not included in this guide. Part of the official road map of Wisconsin is reproduced in Figure 1, with the route and the three main stops shown. See Figure 2 for a map of the glacial deposits of Wisconsin, Figure 3 for a bedrock map of Wisconsin, and Figure 4 for a generalized map of the soils of the area covered in this guide.



Part of the official road map of Wisconsin, showing route and three main stops.

Fig. 1

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George F. Hanson, Director and State Geologist

Map of glacial deposits of Wisconsin, showing route and three main stops.

Fig. 2

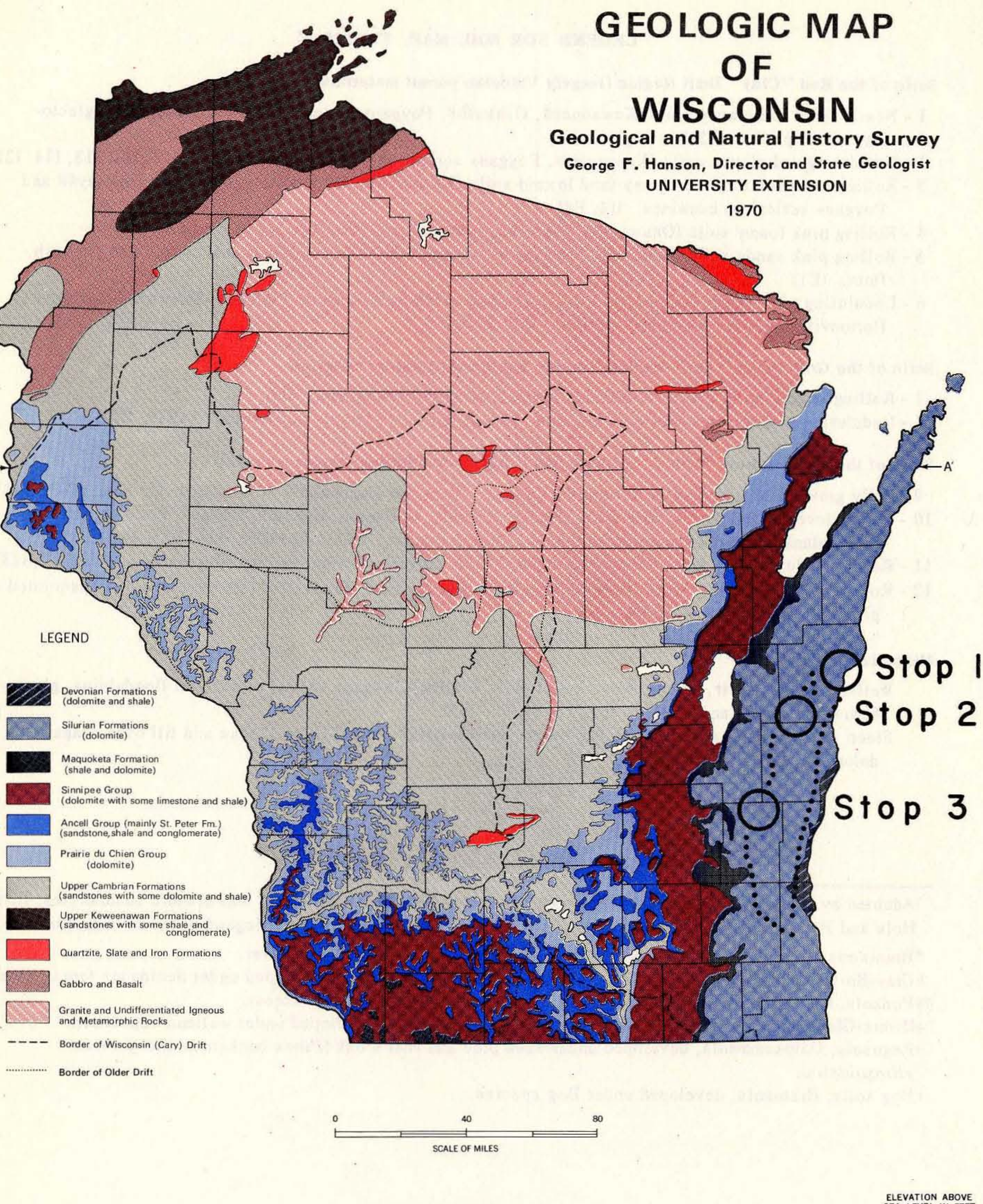


Fig. 3 Map of bedrock of Wisconsin, showing route and three main stops.

LEGEND FOR SOIL MAP, FIGURE 4[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)

2 - Undulating red clayey soils (Kewaunee#, Poygan+ series) on ground moraine. (I10, I11, I12, I13, I14, I21)

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

4 - Rolling pink loamy soils (Onaway##, Theresa#, Hortonville#, Fox# series) on moraine. (I6)

5 - Rolling pink sandy soils (Emmet##, Onaway##, Omega° series) on moraines and associated outwash flats. (E1)

6 - Undulating pink sandy loam soils, locally shallow to Niagara dolomite (Solona#, Onaway##, Longrie##, Hortonville# series) on ground moraine. (E5, E6)

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 (Morley#, 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. (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)

Miscellaneous soils

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

Steep shallow soils over bedrock (Kolberg#, Summerville* series) in thin loess and till over Niagara dolomite. (I3)

[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.

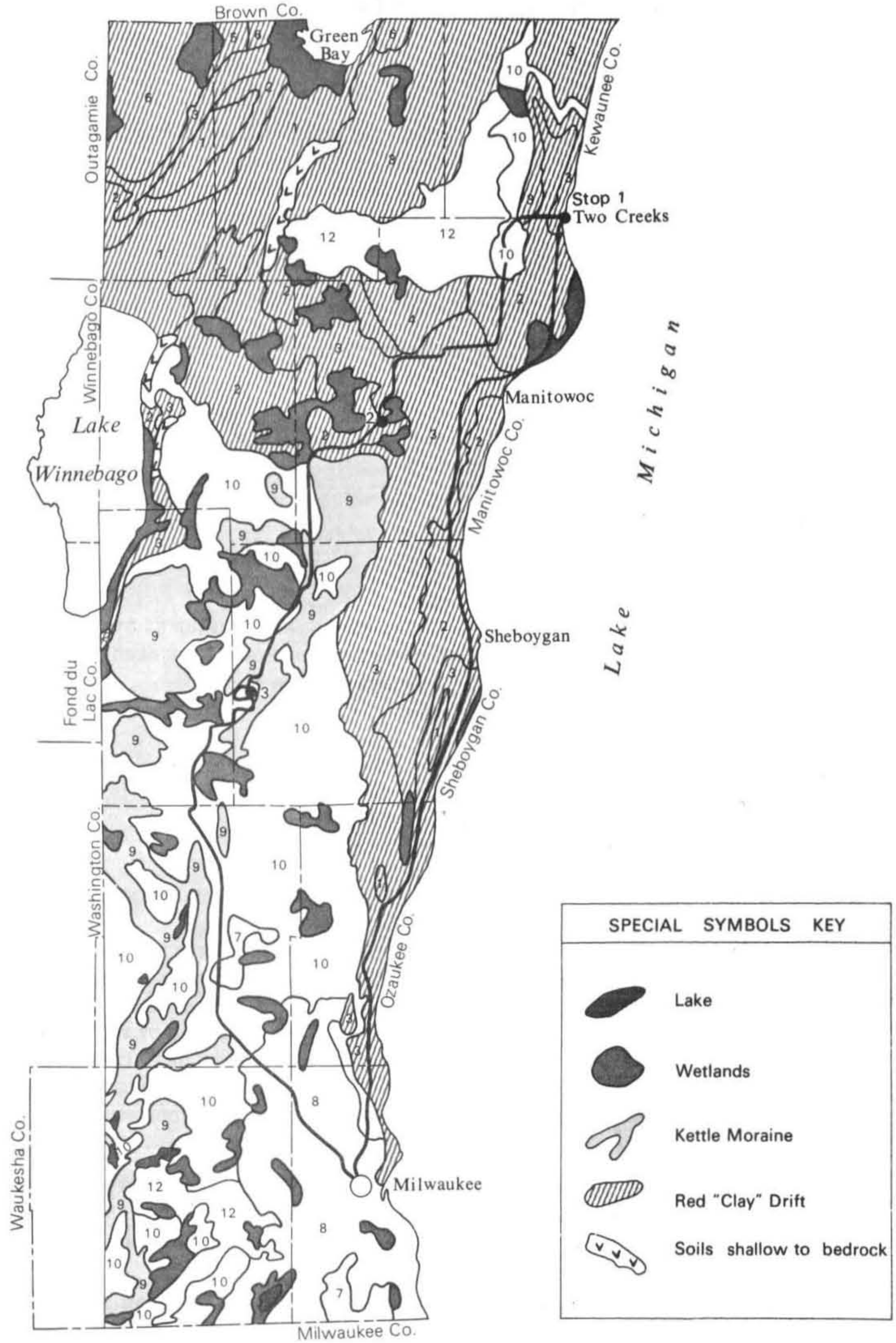
#Gray-Brown Podzolics; Hapludalfs (or Glossudalfs or Eutroboralfs), developed under deciduous forest cover.

##Podzols; Haplorthods, developed under mixed coniferous and deciduous forest.

+Humic-Gleys and Low Humic-Gleys; Argiaquolls, Haplaquolls, developed under wetland vegetation.

°Regosols; Udipsamments, developed under Jack pine and Hill's oak (*Pinus banksiana* and *Quercus ellipsoidalis*).

†Bog soils; Histosols, developed under Bog species.



Generalized soils map of the area covered by this field guide, showing route and three main stops. Prepared by Francis D. Hole, after Hole and Beatty (1968).

Fig. 4

Part 1
DETAILED ROAD LOG

Departure - 7:30 A.M.

Milwaukee to Two Creeks, STOP 1

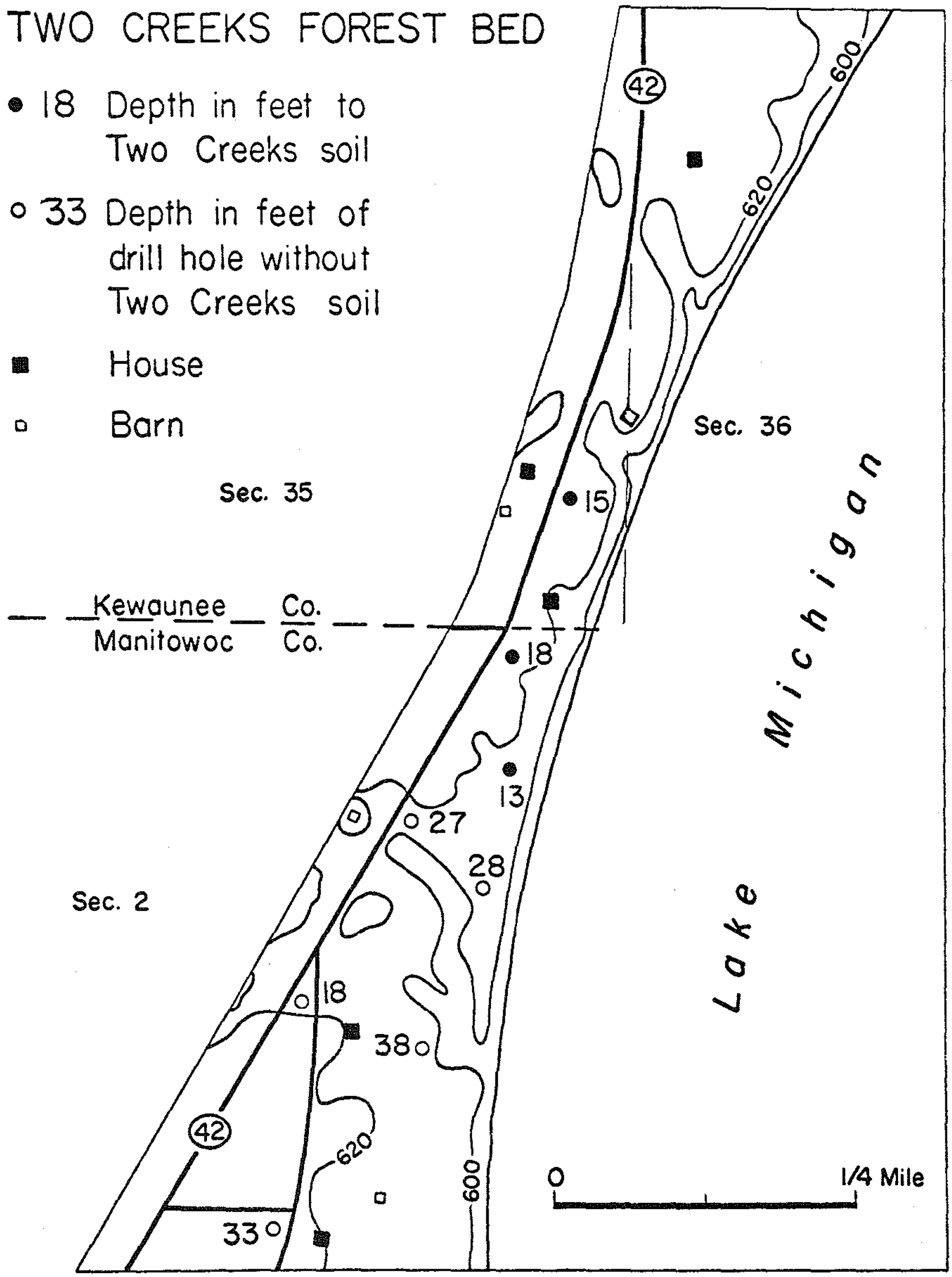
The route follows Highways 141 and 42 near and along the west shore of Lake Michigan, almost entirely in drift of Valderan age (Late Wisconsinan) (Figs. 2 and 4) and on the Niagara dolomite (Silurian age) (Fig. 3). Relief is slight, and only rare artificial exposures of the drift and of bedrock are visible from the bus. Especially in the vicinity of Sheboygan (Fig. 1), the route traverses ancient deposits of expanded Glacial Lake Michigan.

Cumulative Miles	
0.0	From hotel west on Wisconsin Avenue to Hwy. 141.
0.5	Turn north (right) on Hwy. 141.
5.0	Hwy. 141 north at Milwaukee River. This river formed at the junction of the Green Bay-Lake Michigan Lobes during Late Woodfordian time and was diverted by the Valderan ice (Fig. 2).
6.2	Hwy. 141 north; Milwaukee River on west.
6.5	Leave Milwaukee River Valley.
10.0	Hwy. 141 at Hwy. 100.
21.5	Hwy. 141 at Hwy. 57.
25.3	Hwy. 141 at Hwy. 33.
38.0	Hwy. 141 at Sheboygan-Ozaukee County line.
54.3	Hwy. 141 at Sheboygan River in Sheboygan. The Sheboygan River drains part of the North Kettle Interlobate Moraine (Fig. 1) of Late Woodfordian age and was also blocked and diverted in its lower reaches by Valderan ice (Fig. 2). Continue north on Hwy. 141.
65.0	Hwy. 141 at Manitowoc-Sheboygan County line.
78.0	Hwy. 141 at Hwy. 151 at Manitowoc.
79.6	Hwy. 141 at Manitowoc River. This river lies almost entirely within Valderan drift (Fig. 2) and heads on the Niagara cuesta (Fig. 3) near the northeast corner of Lake Winnebago (Fig. 1).
80.5	Junction Hwys. 141 and 42. Turn east (right) on Hwy. 42.
83.4	Hwy. 42 parallels the northwest shore of Lake Michigan.
88.5	Hwy. 42 at West Twin River in Two Rivers.
89.5	Hwy. 42 at East Twin River in Two Rivers. These river valleys contain abundant outwash sand and gravel of Late Woodfordian (?) and Valderan-post-Valderan age.
90.1	On east side of Hwy. 42 excavations show red clayey till of Valderan age over clean, well-sorted, yellow lake sand with red clayey till balls in upper part. The ridge was mapped as end moraine of Cary (Late Woodfordian) age with ground moraine of Valderan age on top (Thwaites and Bertrand, 1957, pl. 8). A northwest source for the sand is suggested by reconnaissance observations by Black, according to foreset beds, thickening and coarsening of the material.
100.0	Hwy. 42 at town of Two Creeks.
102.0	Hwy. 42 at Kewaunee-Manitowoc County line, **STOP 1.**

Arrive 10:00 A.M. - Leave 11:00 A.M.

Buses will park on Hwy. B, facing west. Please be careful in crossing Hwy. 42 to reach the temporary shelter on the lakeshore. Remember that the property is owned by The Nature Conservancy for future inclusion in the Ice Age National Scientific Reserve of Wisconsin. *Sample collecting and digging at the site are prohibited!*

See Figure 5 for a detailed topographic map of the area, Figure 6 for a typical diagrammatic section of the stratigraphy in the bank, and Figure 7 for a diagrammatic cross section along the bank. Details of the geology are presented in Part 2. Representative photographs of the buried soil and wood are shown in Figures 8-10. This site was used for filming of the CIC instructional movie, "The Story of Two Creeks" (Black, Clark, Hendrix, 1968). Protection of the excavation with a shelter was a necessary condition attached to the permit to expose the Two Creeks horizon. While



Detailed topographic map of the Two Creeks area, Stop 1.

Fig. 5

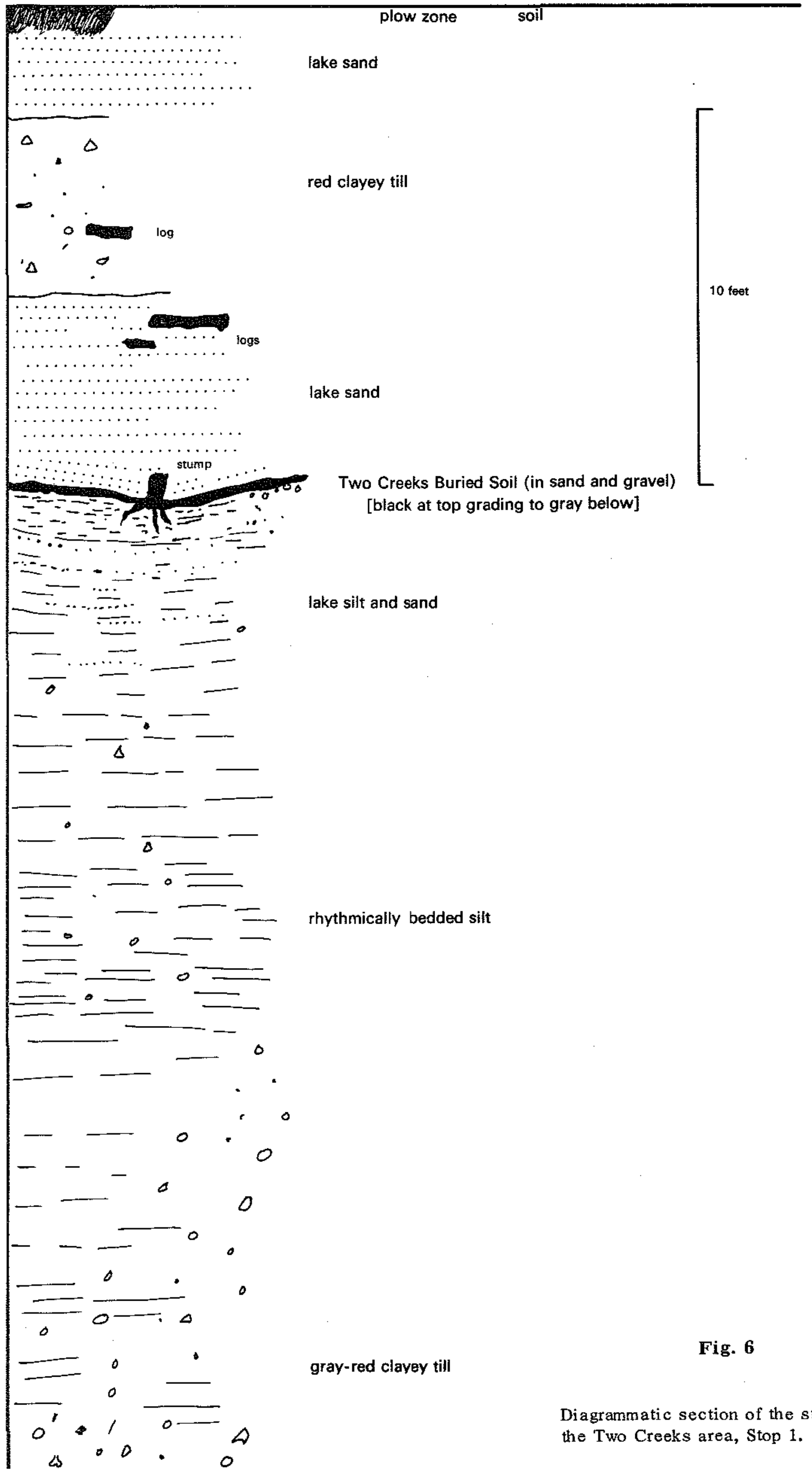


Fig. 6

Diagrammatic section of the stratigraphy at the Two Creeks area, Stop 1.

it lasts, it is available for public use by educational groups. They may obtain the key through the Chief Ranger at nearby Point Beach State Forest.

Other natural and artificial exposures of the Two Creeks horizon reveal somewhat different stratigraphy and buried micro landforms. In general the exposures show a gray to red clayey till or rhythmically bedded lake sequence at water level, and extending up the bank to a height of a few feet to 20 feet. The Two Creeks buried soil was formed on the lake beds and is an immature Podsol (Udorthent). The soil was modified by rising lake waters and covered by additional lake sediments immediately prior to the advance of the Valderan Glacier. That glacier folded and removed the soil from many places, but locally covered it with several feet of red clayey till. Additional lake deposits were laid down on top of the Valderan till. Thus, two glaciations and three lake levels well above those of present-day Lake Michigan are recognizable. The lowest two lake sequences are between the two drifts and are in turn separated by the Two Creeks buried soil.

Two Creeks, Stop 1, to Lunch Stop

Leave 11:00 A.M.

Cumulative Miles	
0.0	At junction of Hwys. BB and 42, going west. Rise 100 feet in elevation in the next 1.5 miles up onto the Niagara escarpment. Good view southeast of Lake Michigan basin. Road cuts disclose red clayey Valderan till and locally gravelly kames mapped as Cary (Late Woodfordian) end moraine with thin Valderan ground moraine (Thwaites and Bertrand, 1957, pl. 8).
4.0	Tisch Mills in valley of East Twin River is west border of above moraine, at junction Hwys. BB and B. Turn south (left) on Hwy. B.
6.6	Junction Hwys. B and 163. Continue south on Hwy. 163.
8.1	View east and southeast for next 2 miles of crevasse (?) fills of Valderan age (?).
10.6	Junction Hwys. 147, B, and 163 in Mishicot. South on Hwy. B. Mishicot, Hoffman House, and lower reaches of East and West Twin Rivers are in a lowland area mapped as Glacial Lake Shoto of post-Valderan age (Thwaites and Bertrand, 1957, pl. 8).
11.4	Junction Hwys. B and V. West (right) on Hwy. V.
11.7	Hoffman House, **LUNCH STOP.** (Your meal ticket does not include alcoholic beverages.)

Arrive 11:20 A.M. - Leave 12:30 P.M.

Lunch Stop to Valders Quarry, STOP 2.

Leave 12:30 P.M.

Cumulative Miles	
0.0	From Hoffman House east on Hwy. V.
0.3	Junction Hwys. V and B. Turn south (right) on Hwy. B.
4.3	West Twin River at Shoto, in dissected Glacial Lake Shoto basin (Thwaites and Bertrand, 1957).
4.6	Small kame to west.
4.9	Gravel pit to west is in a larger kame.
6.1	Junction Hwys. B and D. Turn west (right) on Hwy. D.
7.0	West margin of Glacial Lake Shoto at Junction of Hwys. D and Q (Thwaites and Bertrand, 1957, pl. 8).

11.6 Town of Branch in outwash of Cary age (Thwaites and Bertrand, 1957, pl. 8).

12.0 Junction Hwys. D and 10. Turn west (right) on Hwy. 10.

13.6 Junction Hwys. 10 and H. Continue west on Hwy. 10. Prominent knob and swale topography in vicinity of that junction and west to the vicinity of Cato is mapped by Thwaites and Bertrand (1957, pl. 8) as Cary (Late Woodfordian) end moraine with only local cover of Valderan drift. Valderan ground moraine over older deposits was mapped east of Hwy. H and also at Cato west and south to the Valders area (Stop 2). Thus, Thwaites and Bertrand (1957) considered that the Valderan ice left no prominent moraines and went over the older moraines and other unconsolidated features with little or no disturbance. This interpretation can no longer be accepted (Black, 1966). See Part 3 for details.

16.8 Junction Hwys. 10 and 148 in Cato. Turn south (left) on Hwy. 148.

20.2 Manitowoc River in Clark Mills.

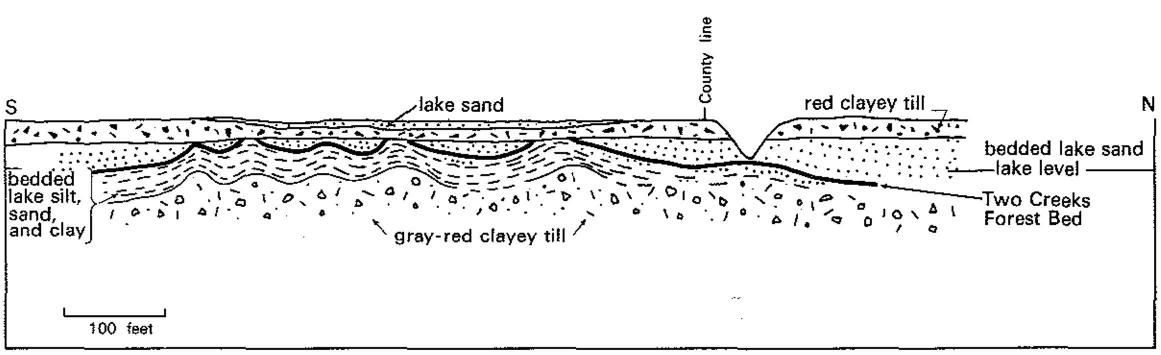
20.7 In next mile Hwy. 148 crosses four small north-trending drumlins of Cary (Late Woodfordian) age with a veneer of Valderan ground moraine (Thwaites and Bertrand, 1957, pl. 8).

22.3 Town road to west. Turn west (right).

22.7 Quarry of Valders Lime & Stone Co., operating in Niagara dolomite (Silurian). **STOP 2.**

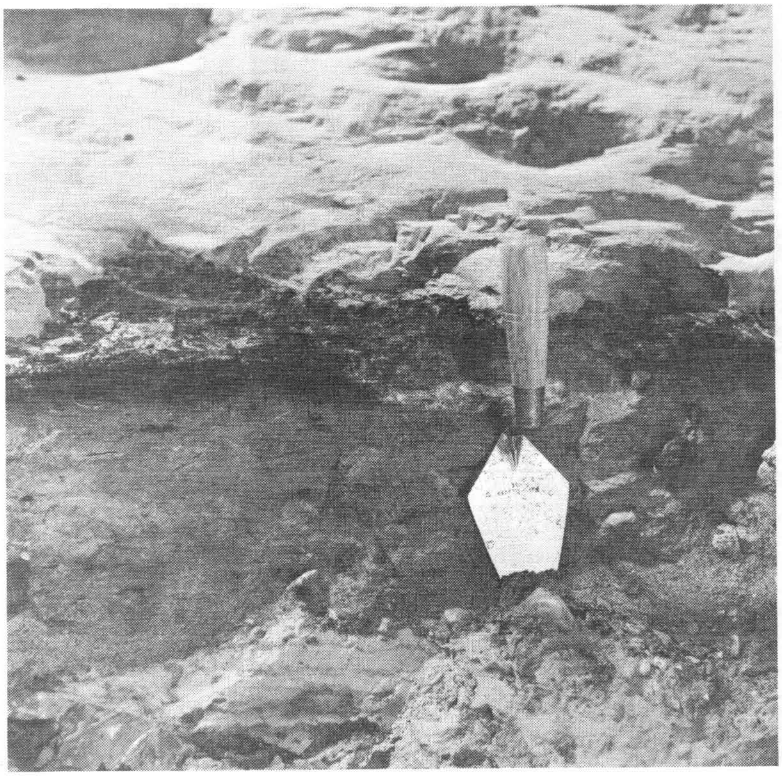
Arrive 1:20 P.M. - Leave 2:00 P.M.

Buses will park on the town road at the east side of the quarry. Striated and polished pavements are visible at the road and along the rim of the quarry both north and south. Figures 11-13 show the relations of striae and tills. The gray to yellow-brown stoney till of Late Woodfordian age (Cary) is seen only at the northeast and southeast corners of the quarry where it is on one set of striae trending south. In the eastcentral part of the quarry the bedrock surface is higher and only red clayey till of Valderan age is present on two sets of striae—the older is the south-trending set of Late Woodfordian age and the younger set trends westward. The red clayey till also lies on the gray stony till in other parts of the quarry, showing it resulted from a younger glaciation. The conclusion reached by Thwaites (1943) and by Thwaites and Bertrand (1957) is that Valderan ice stripped away the earlier gray stony drift only where it was thinly draped on bedrock highs, as at Stop 2, to leave its own distinctive striae here trending westward. The time separating the two tills is represented by the Twocreekan interval, which is not represented at the Valders Quarry by a buried soil. The composition and texture of the Late Woodfordian till at Stop 2 is influenced by the local Niagara dolomite, so it differs markedly from the equivalent drift at Two Creeks which contains Lake Michigan bottom deposits.



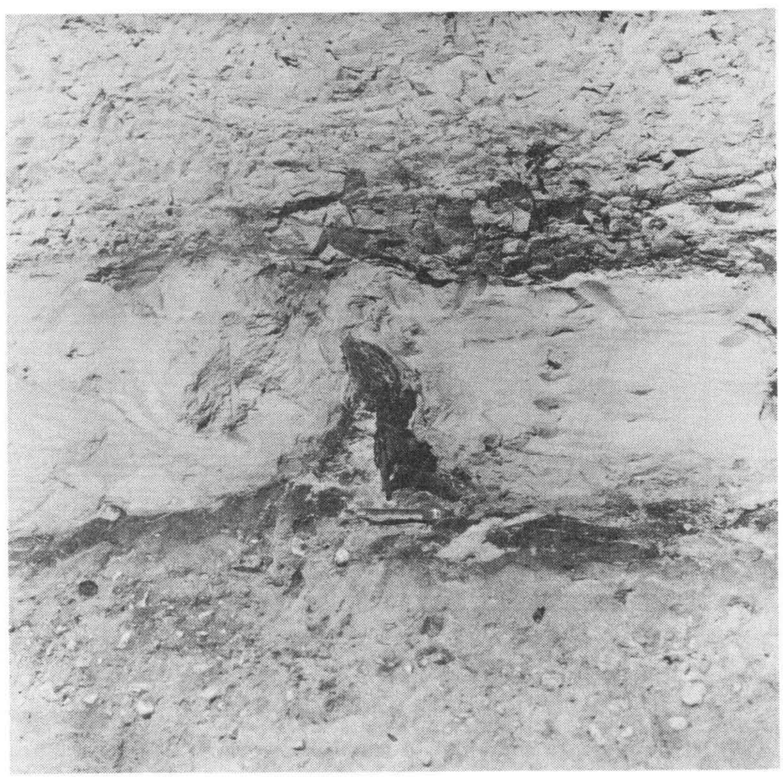
Diagrammatic cross section along the Lake Michigan shore at the Two Creeks area, Stop 1 (modified from Thwaites and Bertrand, 1957, Fig. 12).

Fig. 7



Two Creeks buried soil.

Fig. 8

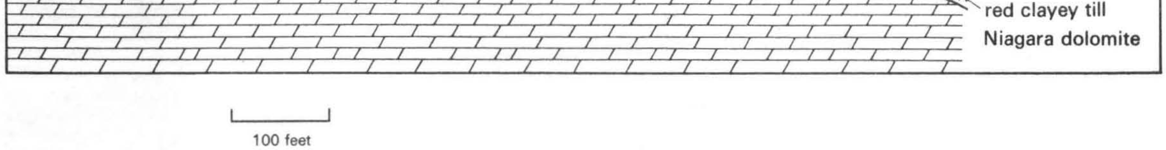


In situ stump in the Two Creeks buried soil.

Fig. 9

Spruce stumps and driftwood exposed in the shelter at Stop 1.

Fig. 10



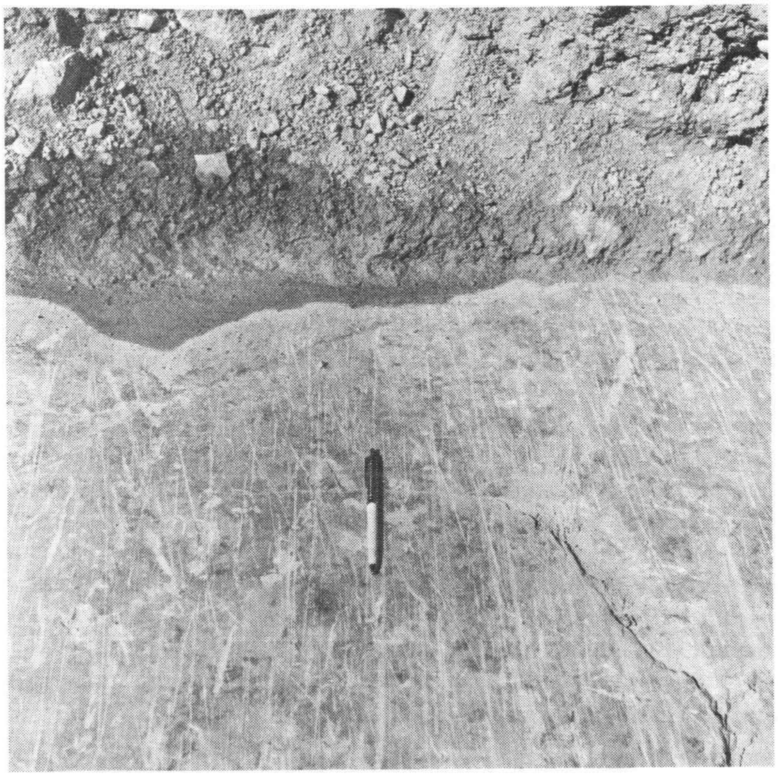
Stratigraphy and striae at the Valders Quarry, Stop 2 (modified from Thwaites and Bertrand, 1957, Fig. 7).

Fig. 11

Valders Quarry to North Kettle Interlobate Moraine, STOP 3

Leave 2:00 P.M.

Cumulative Miles	
0.0	Buses return eastward on town road.
0.4	Junction town road and Hwy. 148. Turn south (right).
0.7	Junction Hwys. 148 and 151 at Valders. Turn southwest (right) on Hwy. 151. Drive over Valderan ground moraine for several miles.
5.7	Approximate east border of prominent knob and swale area mapped as Cary (Late Woodfordian) end moraine with Valders ground moraine over most of it (Thwaites and Bertrand, 1957, pl. 8).
7.1	Approximate west border of above moraine. This is marked by sharp crevasse fills and other drift features resulting from ice stagnation.
8.9	Junction Hwys. 151 and 32. Turn south (left) on Hwy. 32. In next half mile cross over a narrow part of the former basin of Glacial Lake Oshkosh which was ponded in front of the Valderan ice (Thwaites, 1943), and then rise onto the Cary (Late Woodfordian) end moraine, part of the Northern Kettle Interlobate Moraine. A variety of small stagnant ice features may be seen on both sides of the road.
16.7	Sheboygan River at Kiel. Large gravel pits lie east (left) in kame terraces and outwash of probable Woodfordian age.
16.9	Junction Hwys. 32 and 57. Continue due south on Hwy. 57. Large gravel pits on both sides of the road are in landforms similar to those above. Slump structures and ice-shoved features with till on top may be seen. No detailed studies have been attempted.
	A large variety of ice-stagnation features may be seen along the route to Elkhart Lake and southward. This guide points out only a few.
22.7	Junction Hwys. 57 and A at town of Elkhart Lake. Turn west (right) on Hwy. A and follow it through town to the south and west. The lake, Elkhart Lake, has a maximum depth of 113 feet and is a kettle in the preglacial valley which is now also occupied by Sheboygan Marsh. It is the fourth deepest lake in Wisconsin. A well at Lakeside Park on the west side of the lake penetrated 240 feet of drift without reaching bedrock. The boundary between the Lake Michigan Lobe and the Green Bay Lobe lies at the southeast corner of the lake according to Alden (1918, pl. 3).
25.4	Junction Hwys. A and P. Turn south (left) on Hwy. P. This is part of the Kettle Moraine Drive, identified by small green and white signs along the route.
26.7	Junction Hwys. A and P at Glenbeulah. View of the main Interlobate Moraine to the south and east (Fig. 14). Turn west (right) on Hwy. A and follow Kettle Moraine Drive through town, passing the "Old Wade House." It served as a stage stop in the 1850's and has been restored and outfitted by the State Historical Society with antiques and replicas to preserve the atmosphere of the times a century ago.
	The plain northwest of Hwy. A between Glenbeulah and Greenbush was mapped as ground moraine (Alden, 1918), but was a lake for a short time. The hills farther northwest are bedrock supported.
29.5	Junction Hwys. A, T, and 23 in Greenbush. Continue southwest on Hwy. T (Kettle Moraine Drive).
30.3	Junction Hwys. T and Kettle Moraine Drive. Turn south (left) on Kettle Moraine Drive. This part of the Drive crosses the main axis of the moraine of the Green Bay Lobe. It is a summer-winter sports area. Figure 15 shows the Drive to the south and its relation to the major glacial features in part of the Northern Kettle Moraine State Forest and environs.
34.0	Greenbush Kettle on west, with descriptive plaque (Fig. 16).
34.2	Emerge from the knob and swale moraine onto an outwash plain that lies on the axis between the Lake Michigan and Green Bay Lobes (Fig. 15). Water flowed southwestward.
35.0	Junction Hwys. 67 and Kettle Moraine Drive. Turn west (right) on Hwy. 67, leaving the Drive.
37.7	Junction Hwys. 67 and V. Turn south (left) on Hwy. V.
38.2	Pass between two conical moulin kames 100 and 60 feet high for west and east respectively. Others visible in all directions. This group lies in the drift plain along the junction of the "end moraines" of the Green Bay and Lake Michigan Lobes (Fig. 15).

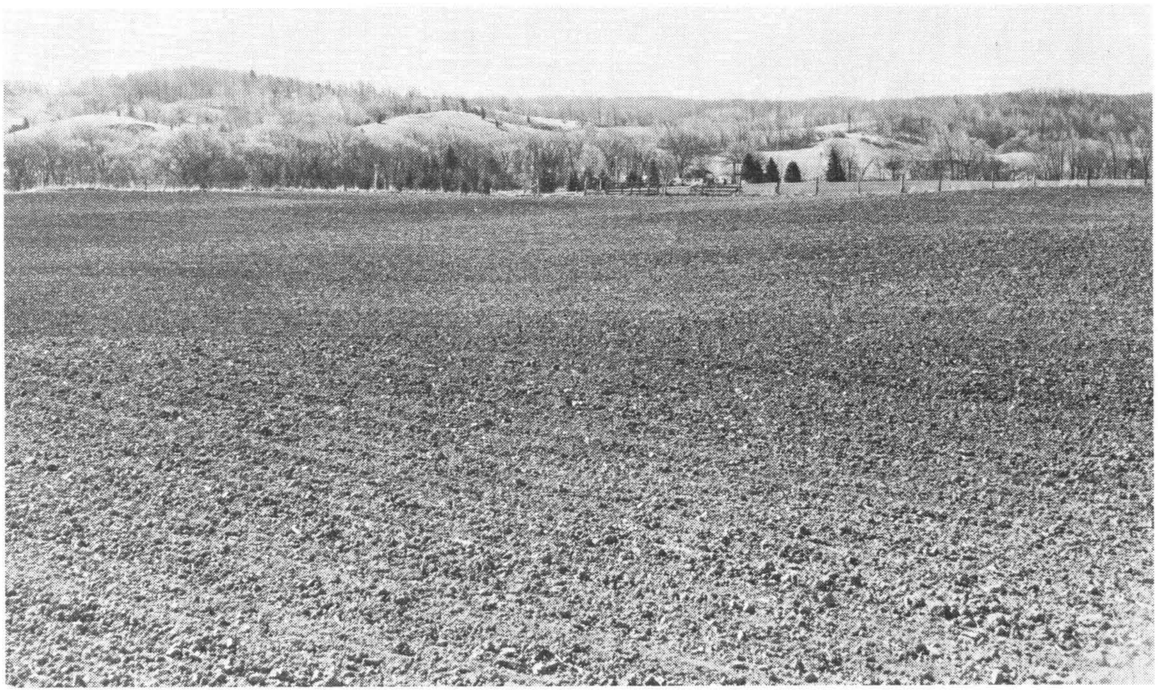


Late Woodfordian till and striae.
View north.

Fig. 12

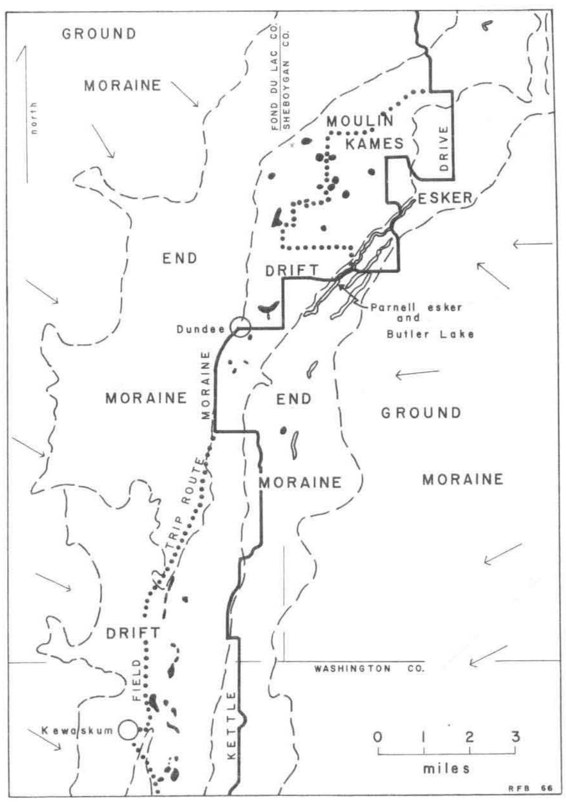
Valderan till and striae superposed on the Late Woodfordian striae.
View east.

Fig. 13



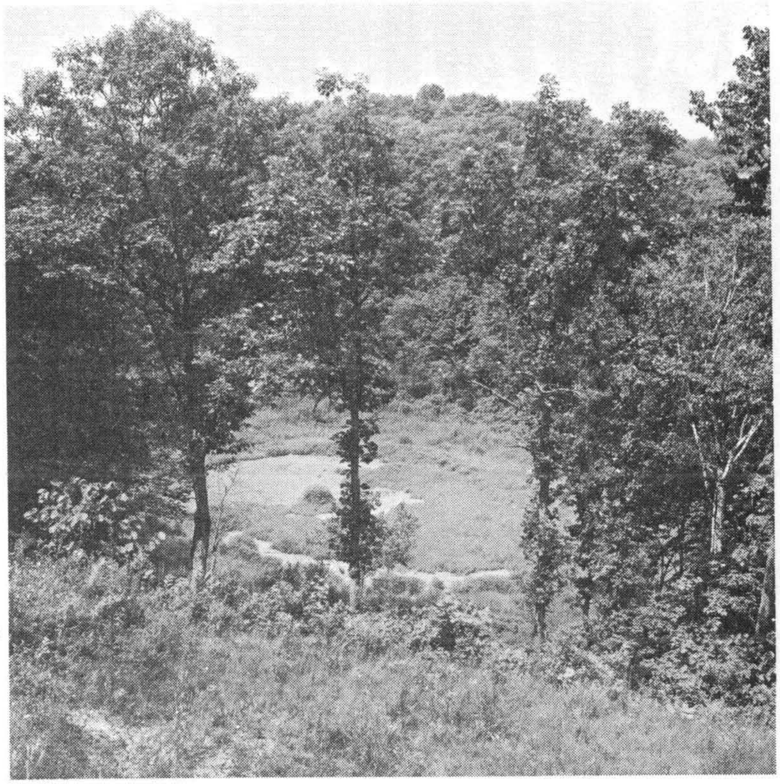
Kettle Interlobate Moraine south of Glenbeulah.

Fig. 14

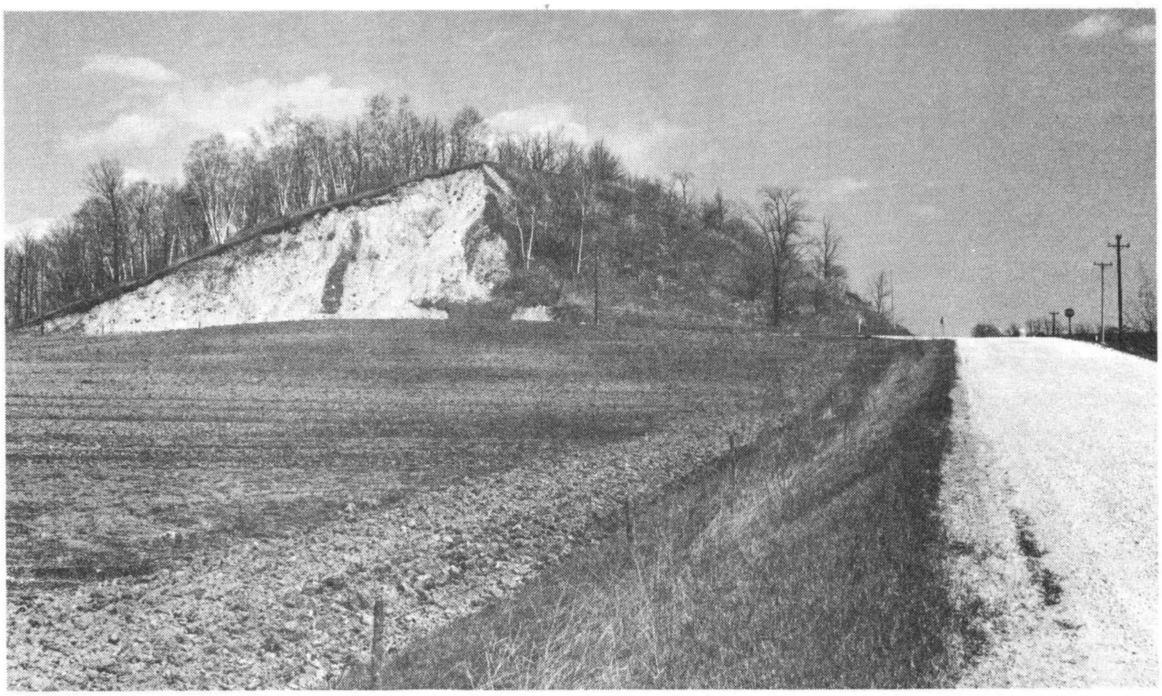


Part of the Northern Kettle Moraine State Forest and environs, showing the Kettle Moraine Drive, the route of this excursion, and their relation to some major glacial features.

Fig. 15



The Greenbush kettle.
Fig. 16



Garriety Hill, a moulin kame.
Fig. 17

39.2 Small moulin kame, 50 feet high, on east is called Garriety Hill (Fig. 17). The road cut discloses various kinds of drift. We will pause for a window look.

39.25 Junction Hwys. V and town road. Turn west (right) on town road to go around the section to the southwest.

40.0 Turn left (south).

40.5 Turn west (right).

40.75 Turn south (left) at junction of town roads.

41.25 Turn east (left) at junction of town roads.

42.1 **STOP 3** on town road to view moulin kames to north. We will take 10 minutes only to "debus" for photos. Continue eastward.

42.2 Junction town road and Hwy. V. Continue eastward and southward on Hwy. V.

43.0 Note Parnell esker to east which lies on west margin of Lake Michigan "end moraine" but east of drainage junction with Green Bay Lobe (Fig. 18).

43.1 Cross Parnell esker.

43.2 Junction Hwy. V and Kettle Moraine Drive. Turn abruptly west (right) on Kettle Moraine Drive. Parallel then cross Parnell esker.

43.7 Road to south is scenic view of Parnell esker and Butler Lake. We will stop only if light is good for photographs.

44.9 Junction town roads and Kettle Moraine Drive. Turn south (left) on Kettle Moraine Drive.

45.4 Entrance to Dundee Mountain, a moulin kame, on west (right).

46.0 Junction Kettle Moraine Drive and Hwy. F. Continue south then west on both.

46.8 View south (left) to small moulin kame.

47.0 Dundee. Turn southwest (left) on Hwy. 67. This is part of end moraine of Green Bay Lobe.

47.4 Junction Hwys. 67 and G. Turn south (left) on Hwy. G. Drive on border between "end moraine" of Green Bay Lobe on west and drift plain now occupied by the Milwaukee River to east. The front of the "end moraine" of the Lake Michigan Lobe lies 1-1.5 miles to the east. Numerous ice-stagnation features may be seen on all sides along the route south to Kewaskum.

54.7 Junction Hwys. G and S. Continue south on Hwy. S.

56.7 Junction Hwys. 28 and S in Kewaskum. Turn west (right) on Hwy. 28.

57.1 Junction Hwys. 45 and 28. Turn southeast on Hwy. 45.

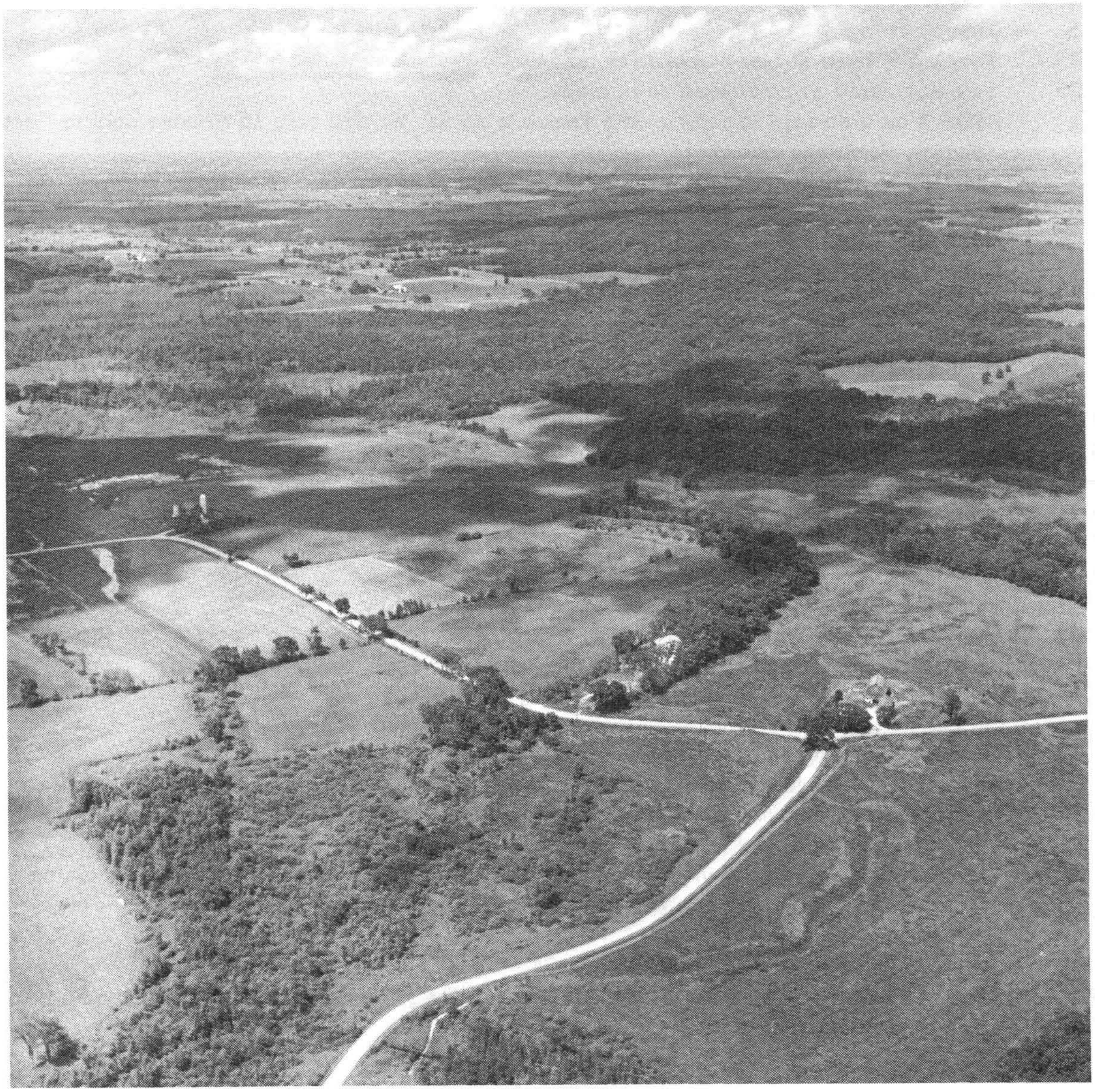
61.3 Approximate boundary of Alden (1918) between drifts of the Green Bay and Lake Michigan Lobes.

64.3 Junction Hwys. 45 and 33 in West Bend. Milwaukee River turns eastward and flows through broad lake plain within the drift of the Lake Michigan Lobe. Continue south on Hwy. 45. The route to Milwaukee traverses a succession of end and recessional moraines and ground moraine of the Late Woodfordian glacier. No studies have been done that would change Alden (1918, pl. 3). Details are not presented here.

75.5 Junction Hwys. 45 and 41. Continue south on Hwy. 41.

98.0 Arrive at hotel in Milwaukee at approximately 5:00 P.M. (slightly later if photographic stops are made other than at Stop 3).

TOTAL TRIP 234.4 MILES



Parnell esker.

Fig. 18

Part 2
THE TWO CREEKS BURIED FOREST

INTRODUCTION

Two Creeks is a small town 10 miles north of Two Rivers, near the west shore of Lake Michigan in east-central Wisconsin (Fig. 1). James W. Goldthwait in 1905, while studying abandoned shorelines of eastern Wisconsin, observed portions of a buried forest soil with trees and logs exposed along the lakeshore southeast of the town. His report (Goldthwait, 1907) brought to the scientific community a brief description of what has since become an internationally famous stratigraphic horizon, the Two Creeks Buried Forest. The time interval represented in part by the buried forest has been called Twocreekan (Frye and Willman, 1960). It is a substage of the Wisconsinan Stage (Frye, Willman, Rubin, and Black, 1968), and as suggested by them, represents the radiocarbon interval about 11,000 to 12,500 years B.P.

This find of buried organic matter was not the first in Wisconsin. Notices of buried wood in southern Wisconsin go back to the 1840's, and Whittlesey (Owen, 1852, p. 436) mentioned the presence of buried wood in a dug well at Appleton, 45 miles west of Two Creeks. Lawson (1902) and Thwaites (1943, p. 136) mention other localities. Because of its exposure along the lakeshore, the Two Creeks site was visited frequently, even though it was not studied in detail for decades after its discovery.

Wilson (1932 and 1936) first started detailed studies of the fossil assemblages of trees, mosses, mollusks, insects and pollen. A stratigraphic section appeared in Alden (1932, p. 43). Thwaites and Bertrand (1957, pp. 855-864) summarized the available information on the geology of the locality which was one of the stops for INQUA, Excursion C (Black, Hole, Maher, and Freeman, 1965) and other field trips (e.g., Thwaites, 1953; and Prouty, 1960). Other workers checked particularly on mosses (Culberson, 1955), pollen (West, 1961), and radiocarbon age (Broecker and Farrand, 1963). The site also has been used in a Committee for Institutional Cooperation (CIC) Instructional Improvement Program (Black, Clark, and Hendrix, 1968). Several other localities with equivalent-age buried forest horizons are now known in Wisconsin (Fig. 19), but the type locality is still the best exposed and best known.

Several isolated occurrences of the buried forest are found along the lakeshore in the vicinity of Two Creeks. That which is most accessible today is directly south of the Kewaunee-Manitowoc County line at a small temporary shelter (Fig. 1). The property is owned by The Nature Conservancy and is being held as part of the future "Ice Age National Scientific Reserve" of Wisconsin (National Park Service—Wisconsin Department of Natural Resources, 1968).

OUTLINE OF STRATIGRAPHY

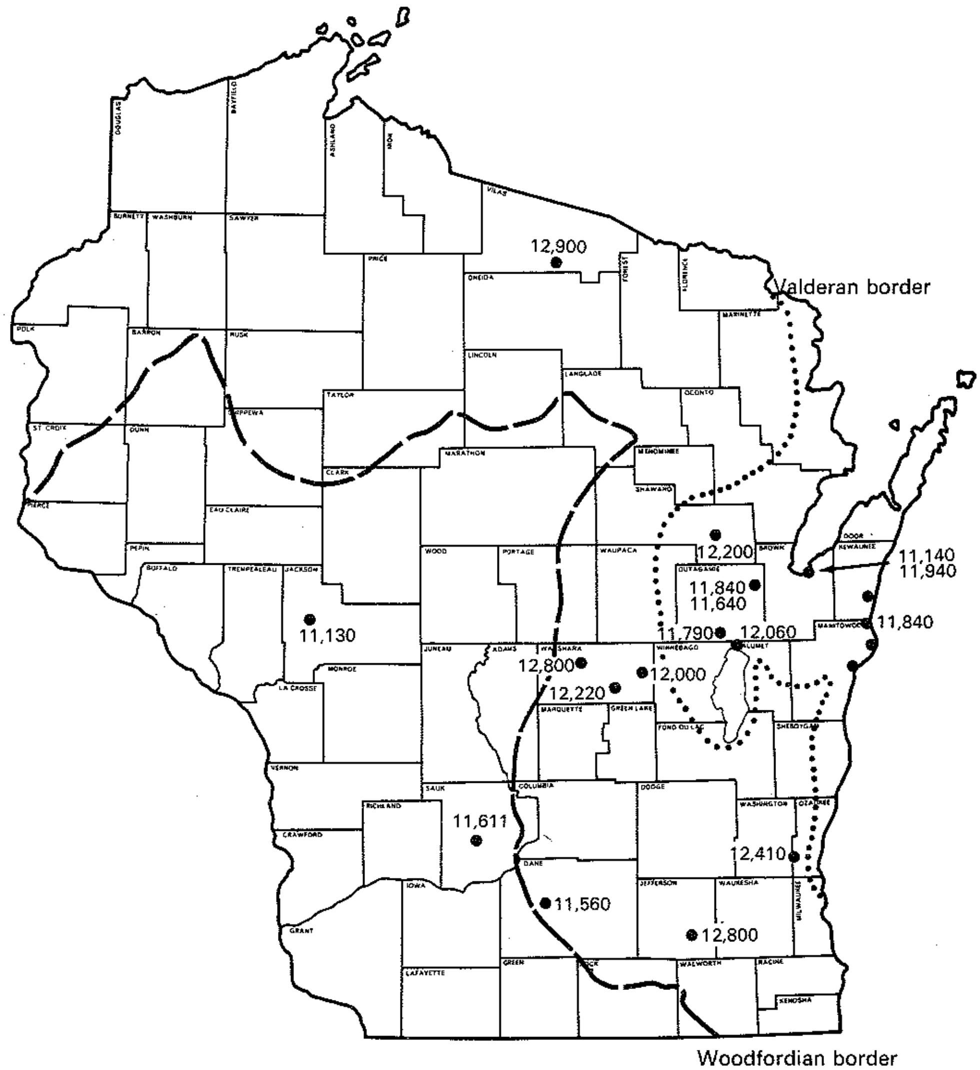
In the bank of Lake Michigan, which rises today about 30 feet above water level (Fig. 5), is a detailed sequence of deposits (Fig. 6) which depict vast changes in climate and in geologic events from a time perhaps 14,000 radiocarbon years ago to the present. Stratigraphically, the bank shows at water level a compact, red to gray clayey till and massive lake deposits of similar appearance (5 YR 6/3 light reddish brown to 7.5 YR 6/2 pinkish gray dry and 5 YR 5/2 reddish gray to 2.5 YR 5/4 reddish brown wet). The till and massive lake sequence contain small amounts of silt, sand, gravel, and cobbles. According to well logs, the till rests directly on the Niagara dolomite of Silurian age which is 40 to 80 feet below lake level. The till grades imperceptibly upward and laterally into the massive lake sequence which, in turn, grades into rhythmically bedded clay with some silt and sand. The rhythmically bedded deposits locally extend from below lake level to as much as 20 feet above. The till and lake deposits represent the Late Woodfordian glacial sequence which was deposited probably between 14,000 and 12,000 radiocarbon years ago.

Above the rhythmically bedded deposits locally are layers of yellow-brown sand and gravel from a few inches to 4 feet thick. They are considered shallow water, near shore, and beach deposits resulting from wave and current action on the underlying deposits. The buried forest (Figs. 8-10) rests on and is formed in the beach and lake deposits. The buried soil profile varies markedly according to whether it is developed in the rhythmically bedded clayey sequence or in the coarser sands and gravels. The forest horizon ranges generally from 1 inch to 12 inches in thickness, but locally is cut out. It is undulating in the bank (Fig. 7), in part related to gentle knob and swale topography on which the soil formed and in part due to warping by the overriding Valderan ice. Trees in it are radiocarbon dated at 11,840 years B.P. (Broecker and Farrand, 1963). The most mature tree, according to published information, has 142 growth rings. All the larger pieces of trees and stumps in the shelter are spruce (B. F. Kukachka, Forest Products Lab., Madison, Wis.). White spruce cones are common in the plant debris.

On top of the forest bed are light yellow to dark yellow lake sands, fine to coarse in texture. Locally, red colors are present. The sands are a few inches to 6 feet thick, but locally are also absent. They contain numerous fragments of organic matter and portions of reworked soil. They are considered to be the result of the rising lake level in front of the advancing Valders ice.

On top of them rests 2 to 12 feet of red (5 YR 6/3 light reddish brown dry to 2.5 YR 5/4 reddish brown wet) clayey till of Valderan age, estimated at 10,000 to 11,500 radiocarbon years B.P. The till contains portions of the soil and logs incorporated from the buried soil, and local patches of sand incorporated from the lake deposits above and below the forest soil. Vertical prismatic fracture is pronounced in exposed cliffs in marked contrast to the Late Woodfordian till.

Local lake accumulations consisting of massive to well-bedded sands are found on top of the till. They are as much as 4 feet thick. The finer portions are commonly red silt and very fine sands from the reworked Valders till; they are interstratified with coarser yellow-brown sands and some gravel. Presumably they were laid down during the waning of the Valderan ice. A modern soil disrupted by plowing is formed in the Valderan till and in local patches of the youngest lake sands.



● Twocreekan organic matter in buried deposit, with age in radiocarbon years.

Fig. 19

TWOCREEKAN RADIOCARBON DATES SHOWN ON FIGURE 19

Date	County	Sample No.	Material	Remarks
12,800±220	Jefferson	WIS-48	Spruce	In basal peat
12,410±100	Ozaukee	WIS-347	Tamarack	In basal peat
11,560±350	Dane	W-2015	Tamarack	In basal peat
11,611±600	Sauk	M-812	Charcoal	In fire pit
11,130±600	Jackson	W-1391	Wood	In sand under peat in meander scar
12,800±400	Waushara	UCLA-632	Organic	4 feet above bottom of kettle
12,000±500	Waushara	W-641	Peat	Under lake clay-silt
12,220±250	Waushara	W-762	Peat	Under lake clay-silt
12,060±700	Winnebago	W-1183	Peat and spruce	Under till
11,790 Average	Outagamie	L698D	Spruce	Under till
11,840 Average	Outagamie	L698B	Spruce	In buried soil
11,640±350	Outagamie	W-1110	Tamarack	In buried soil
11,840 Average	Manitowoc	L698C	Wood	6 to 12 inches below buried soil
11,140±300	Brown	W-590	Wood	Under till
11,940±390	Brown	Y-147x	Wood	Under till
12,200±350	Shawano	W-2357	Spruce	With pond deposits
12,900±300	Vilas	I-3780	Organic	Basal lake deposits

DESCRIPTION OF THE BURIED SOIL

The buried soil is generally only a few centimeters thick, varying locally apparently in degree of development because of former topography, moisture, and texture of material, and in part by truncation from subsequent rising lake waters. An incipient Podsol, with impeded drainage (Udorthent) similar to that under northern conifers in some wetlands today, typifies much of the soil on former knobs; in bogs and swales transported organic litter is characteristic.

A typical sequence that represents a fairly thick profile at one point at the shelter follows (Hole, 1967):

	Depth Below Surface cm	
IIO1b	492-494	Black (10 YR 2/1, moist) mucky peat; weak fine platy, plates consisting of dense mat of organic fibers and shreds, including twigs and roots; friable; medium acid (pH 6.0); abrupt wavy boundary. (0 to 1 cm thick.)
IIA1b	494-498	Black (10 YR 2/1) silt loam to muck; massive to strong fine platy; friable; medium acid to moderately alkaline (pH 6.0 to 8.0), with effervescence of discrete particles when flooded with dilute HCl; abrupt wavy boundary.
IIA21b	498-505	Gray to light gray (10 YR 5/1-7/1) fine sandy loam; with distinct to prominent, few medium mottles of dark yellowish brown to yellowish brown (10 YR 4/4-5/6). These occur adjacent to joints or cracks in the substratum; some of the brown-coated joints extend clear through the solum in places, up into the overburden; massive; friable; calcareous; abrupt wavy boundary. (5 to 15 cm thick.)
IIA22b and Bhirb	505-525	Grayish-brown to gray (10 YR 5/2-5/1) fine sandy loam with 15% of surface, particularly along joints, occupied by prominent coarse mottles as described above; locally a gravelly sand loam; massive; friable; calcareous; clear smooth boundary. (15 to 30 cm thick.)
IIC1b	525-535	Grayish-brown (10 YR 5/2) silt loam and fine sandy loam with some pockets and seams of gravel; iron stains along joints, as described above, but somewhat fewer; massive; friable; calcareous.

Particle size, free ferric oxide, and calcium carbonate equivalent are shown in Table 1 for another buried profile near the shelter, and for comparison with the modern soil above it.

G. B. Lee and F. D. Hole (1970, ms.) classify the buried soil as a typic Udorthent.

"The modern soils in the cultivated field are naturally well drained, developed in 15 to 75 cm of loamy covering over Valders till, and include two phases of the Hortonville loam, a Gray-Brown Podzolic transitional to Podzol. On rises is a weakly developed bisequal soil (Alfic Haplorthod of the new classification system: Soil Survey Staff, 1960, 1967) in which a Podzol soil profile is faintly developed in the middle of the A horizon of a somewhat degraded Gray-Brown Podzolic (Alfic Haplorthod). In slight depressions the incipient Podzol is not present and the surface soil (Ap horizon) is relatively thick and dark (Mollic Glossudalf)."

A profile of the modern soil follows (G. B. Lee and F. D. Hole, 1970, ms.):

Soil Profile		Hortonville loam, dark surface variant.
Ap	0-25 cm	Black (10 YR 2/1 moist) and grayish-brown (10 YR 5/2 dry) loam; moderate medium granular structure; friable moist; neutral to alkaline; abrupt boundary.
A2	25-36 cm	Brown (10 YR 5/3 moist) and pinkish-gray (7.5 YR 6/2 dry) fine sandy loam; weak medium platy structure; plates break into weak medium subangular blocky aggregates; patchy, yellowish-brown (10 YR 5/2 dry) stains on ped surfaces; friable moist; a few pebbles; alkaline; clear boundary.
B1	36-46 cm	Brown (7.5 YR 5/4 moist) and light brown (7.5 YR 6/4 dry) silt loam; moderate, fine to medium, subangular blocky structure; pinkish-gray coatings on ped faces; slightly sticky wet, hard dry; alkaline; clear boundary.
IIB2t	46-71 cm	Reddish-brown (5 YR 5/3-4/3 moist) clay loam; moderate, coarse prismatic structure, prisms break into strong, medium angular blocky peds; sticky wet, hard dry; a few pebbles; alkaline; clear boundary.
IIC1	71-102 cm	Reddish-brown (5 YR 5/3 moist) loam to clay loam; moderate, coarse prismatic structure; prisms break into moderate, medium, angular blocky peds; sticky wet, hard dry; a few, mainly dolomitic, pebbles and cobbles; calcareous matrix; gradual boundary.
IIC2	102-224 cm	Reddish-brown (5 YR 5/3 moist) clay loam; coarse prismatic structure; prisms break into coarse blocky peds; light brownish-gray (2.5 YR 6/2 moist) coatings on vertical faces of prisms. These coatings effervesce strongly in dilute acid; ped interiors effervesce moderately; a few, mainly dolomitic, pebbles and cobbles; abrupt boundary with underlying pro-Valderan mud flows.

Table 1. Some analytical data for two soils at the Two Creeks Site, Manitowoc County, Wisconsin[1]

MODERN SOIL
Hortonville loam, dark surface variant
(Mollic Glossudalf[2])

Horizon & Depth (cm)	G[4]	S[5]	Si[6]	C[7]	Free Fe_2O_3	$CaCO_3$ equiv.
	P. S. Distribution[3]					
	%					
O (0.5-0)	--	--	--	--	--	--
Ap (0-25)	0	35	47	18	1.52	0
A2 (25-36)	tr.	60	24	16	0.58	0
B1 (36-46)	N.D.	N.D.	N.D.	N.D.	N.D.	0
IIB2t (46-71)	tr.	31	34	35	1.69	0
IIC1[8] (71-102)	16	39	36	25	0.67	40
IVC5[9] (368-406)	0	28	60	12	0.45	57

BURIED SOIL
Twocreekan peaty loam, buried variant
(Fibristic Udorthent[2])

Horizon & Depth (cm)	G[4]	S[5]	Si[6]	C[7]	Free Fe_2O_3	$CaCO_3$ equiv.
	P. S. Distribution[3]					
	%					
VOb (406-414)	--	--	--	--	N.D.	N.D.
VIBgb (414-434)	10	39	41	20	0.51	35.2
VIC1b (434-440)	tr.	82	11	7	0.22	42.0
VIIC4b[10] (460-480)	10	5	64	31	0.83	34.0

[1]Data from Lee and Hole (1970)
[2]Classification according to the new soil classification system of the U.S.D.A. (Soil Survey Staff, 1960, 1967)
[3]Particle size distribution
[4]G = gravel (2.0 mm dia.); not included in the sum of s, si, and c which total 100%
[5]S = sand (2-0.05 mm dia.)
[6]Si = silt (0.05-0.002 mm dia.)
[7]C = clay (0.002 mm dia.)
[8]Valders till
[9]Pro-Valders mud flow
[10]Glacial Lake Chicago deposits

DETAILS FROM EARLIER STUDIES

Because the earlier literature on the Two Creeks site is not widely available, some extracts and summaries are presented here.

Goldthwait (1907, p. 61) wrote: "Two miles south of the village of Two Creeks (in section 24) the freshly cut lake cliff showed in July, 1905, a remarkable cross-section of an interglacial forest bed. Laminated red clays formed the base of the section, up to two or three feet above the water. Above this, and separating it from a twelve-foot sheet of stony red till, was a conspicuous bed of peat, sticks, logs and large tree trunks, which unmistakably represent a glaciated forest....The till immediately above the forest bed, besides containing characteristic subangular striated stones and red clay similar to the clay in the stratified beds below, all absolutely unassorted, was plentifully mixed with broken branches and twigs. In the underlying forest bed the stumps were well preserved, the wood being soft and spongy like rotten rubber, but retaining all the appearance of its original structure. Several logs and stumps lay pointing significantly towards the southwest, the direction in which the ice sheet probably moved at this place. One little stump, however,...with its ramifying roots firmly fixed in the laminated red clays, stood erect as when it grew there, but it had been broken short off at the top, where the ice sheet, dragging its ground-moraine along, had snapped off the top without uprooting the tree. Around each root the red clay was discolored to a light drab, showing the effect of acids derived by decay, in contact with the iron-bearing clays. There was no mistaking the only half-excavated condition of the deposit. Clearly this surficial sheet of red till records a final advance of the ice sheet over a surface of laminated red clays, which here, at least, had been clothed with a forest. The trees were broken and generally overturned by the ice, and buried beneath the twelve-foot sheet of till. The wonder is that so much of the over-ridden forest should be preserved, and at least one stump in it remain erect."

Goldthwait (1907, p. 59) also mentioned that at one point in the vicinity of Manitowoc a peat bed 3 feet thick formed the upper part of the 10-foot cliff, with laminated clays containing sticks and branches below. In another place a bed of old logs and sticks lay buried beneath 15 feet of clay, near the base of the cliff. Thus were recorded, in part, the location and description of two segments of the Two Creeks Forest Bed.

No immediate study was made of the forest bed although F. T. Thwaites visited the area several times between 1922 and 1930. Wilson (1932) undertook a preliminary investigation and later amplified his work (Wilson, 1936). He first studied the forest bed where it was exposed for one-half mile along the lakeshore in sections 11 and 13, T 21 N, R 24 E. He also mentioned that the same forest bed was exposed three miles to the north on the lakeshore and in a ravine about a quarter of a mile to the west in section 35, T 22 N, R 24 E, Kewaunee County.

Wilson (1932) studied closely the forest bed for only about 100 feet along the lakeshore and through a vertical range of only several inches. He interpreted the forest bed to lie on top of varved clays and silts and under additional lacustrine silts and sands deposited between the retreat of ice and its re-advance which laid down till on top. Locally the lake beds were 12 feet thick. The till on top of the lacustrine sediments was about 8 feet thick. At the site most of the wood is spruce (*Picea mariana* and *Picea canadensis* [*glauca*]) and hemlock. The wood is soft and easily broken and checks and breaks into short sections on drying. Tissues, however, are not destroyed and microscopic sections can be made of them. Where wood and peat are in contact with the red till, there is a zone in the clay a few inches wide of greenish-gray color due to deoxidation of the iron. The logs occur most frequently in the lacustrine sediments directly above the forest bed, but are also in the overlying till. Wilson found one stump *in situ* with the butt of the broken log almost attached. The roots of this stump extended along the forest bed peat. On a portion of the root that had been exposed above the ground during the interstadial period was found a bracket fungus. It is *Polyporus* but the species was not determined. All the logs that had not been broken by subsequent handling showed ragged splintered ends as a consequence of glacial action.

Wilson (1932) studied the growth rings in sections of six logs. The greatest number of rings in one section was 82; the average was about 60. Five of the logs showed by the width of successive rings a marked decrease in the rate of growth in their last 12 years of life at the Two Creeks site. One log taken from the red till directly above the forest bed showed little decrease until the last year of its growth. That particular log was white spruce (?), *Picea canadensis* [*glauca*]. The first 5 logs were considered by Wilson to represent the growing conditions of the forest bed at the site, whereas the log taken from the till above was considered as having been transported by ice from a different environment farther north. When the log taken from the red till was compared with the others, an extreme difference in size and growth rate was noticeable. That log was twice the diameter of any of the others although it had only the average number of growth rings. The width of the rings did not agree with that of the forest bed trees.

The growth rings could not be compared exactly with reference to particular years, because it was not known whether all the trees were destroyed in the same year or whether they were all alive at the time the ice advanced. However, Wilson considered it probable that the largest log having been brought in by the ice was felled several years before the trees that had grown at the site studied.

Detailed study of wood sections by Wilson showed that certain small rings of the forest bed trees occurred at years approximately corresponding to those in which wide growth rings occurred in the transported log from the overlying till, and vice versa. If excessive moisture was one of the primary factors for small growth rings in the trees, as is suggested by the character of the flora and fauna, then trees growing in higher ground would not have been similarly affected and probably would do better in wet years.

The moss floor of the forest bed contained the most extensive group of plants found in the remains. The moss material, identified by L. S. Cheney, was divided into 19 species. All the mosses are of existing species but are in general more northerly in their modern distribution than the Two Creeks Forest Bed location. Nearly all are found in northern Wisconsin but the present southern limits of a few are in Canada.

Peat in the forest bed was poorly formed and in some parts of the exposure was wanting entirely. Wilson (1932) concluded from this, as well as from some other organic remains, that the Two Creeks Forest Bed was not exactly a lowland forest but rather a dry forest at one stage of its existence. In places the mosses and other plant remains accumulated as a silty peat such as can be found in any spruce forest today. It is from this peat that the microfossils were secured.

Seven species of mollusks were identified from the forest bed by F. C. Baker to whom Wilson sent specimens. These were from three levels in the forest bed. They agree ecologically with other organic remains from their respective horizons. One Pleistocene form was reported–from the clay immediately beneath the forest bed. The individuals in higher levels represented existing species.

The mollusk *Fossaria dalli* (Baker) was considered Pleistocene on the basis of its large size. Its habitat was wet mud above water. Two other species of mollusks, *Pupilla muscorum* (Linn.) and *Succinea avara* (Say.), both represent forest forms and suggest arrival of trees at the same time as a few grasses and mosses. Directly on the surface of the clay occurs a mixture of spruce cones, needles and forest mosses. Mixed with the mosses are shells of land mollusks *Succinea avara* and *Vertigo ventricosa* (Morse). One moss was peculiarly restricted to the lowest level of the forest bed. This is *Bryum cyclophyllum* (Schwaegr.)–a forest form that seems to have been first to establish itself on the Two Creeks forest floor. Other plants in this horizon represented only by a few pollen grains and spores are grasses, heaths, birch, Jack pine *(Pinus banksiana* Lamb.) and a species of *Asplenium.* Fungi were abundant; some were lichens and others were representative of *Dematicae.* Dark beetle excavations were found on the logs and may represent two genera.

Culberson (1955), with the aid of W. C. Steere, found eight species of mosses that are associated with floras of more northern affinities.

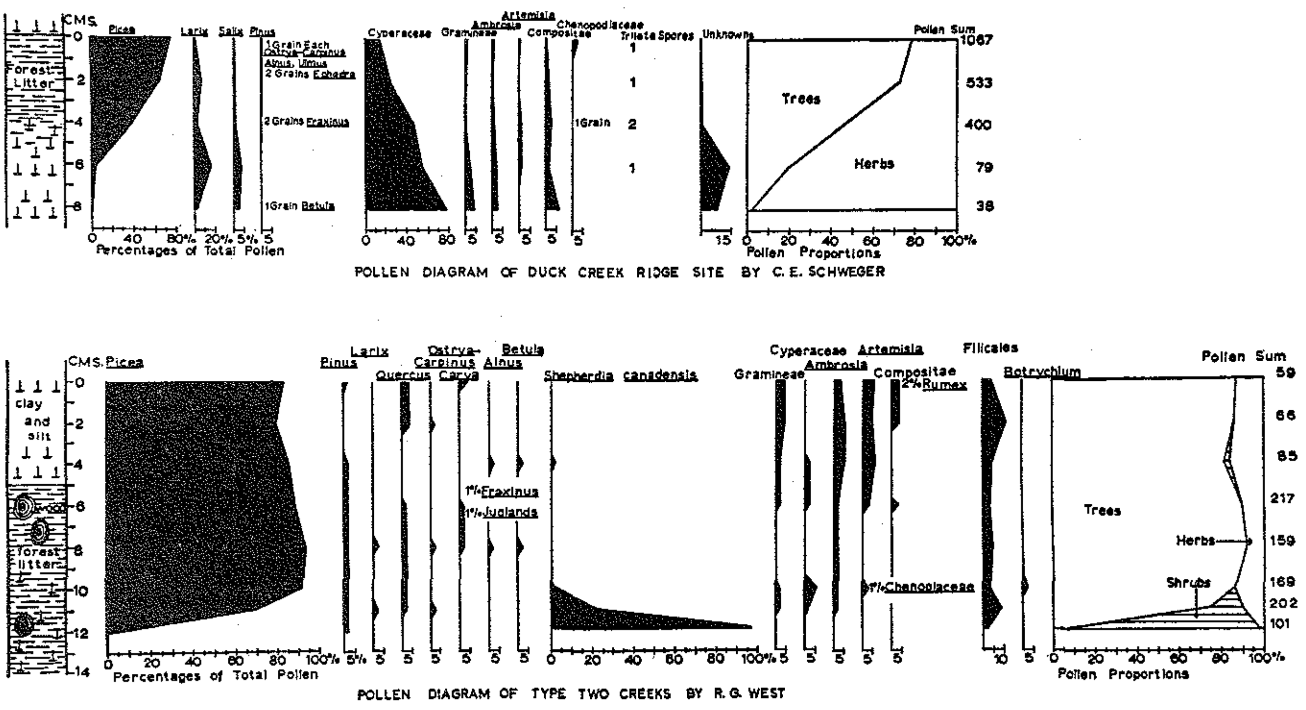
Wilson (1932 and 1936) thus recorded an early phase with aquatic and semi-aquatic mollusks, an intermediate phase with moist to dry woodland mosses, and a final phase of flooding with aquatic mollusks and mosses. The pollen spectra in Figure 20 by West (1961) and Schweger (1966) give additional details of the vegetational changes during Twocreekan time. See also Schweger (1969) and Maher (Geol. Soc. Amer. Field Trip Guide No. 4) for additional details on other sites. The abundance of *Shepherdia canadensis* (buffalo berry) pollen at the base of the sediments indicates early colonization by this shrub of the land surface exposed by the lowering of the lake level (West, 1961). *Shepherdia canadensis* is a northern and mountain plant found in forest clearings and on sandy shores particularly in the boreal spruce forests. Thus the plant's behavior at the beginning of the Two Creeks interval exactly parallels its present behavior. The phase with *Shepherdia* was short lived, and *Picea* forest succeeded the pioneer community as indicated by the high frequencies of *Picea* pollen. White spruce dominated over black spruce. The flooding of the forest litter by the upper silts was accompanied by a large decrease in pollen frequency. At the same time the NAP total, including *Ambrosia, Artemisia* and other composites, rises slightly. This may reflect the opening out of the regional forests associated with the Valders re-advance, but then there is also the possibility that some of the pollen in the silts is secondarily derived.

The vegetation of the Two Creeks interval is clearly boreal in character. Originally Wilson (1932) compared its climate with that of northern Minnesota today. In his later paper (1936) he suggested that the climate was not necessarily as severe as this for the plants also represent pioneer organisms of denuded areas under certain conditions and are not reliable indicators of a severe climate. West (1961) finds the interpretation of the pollen profiles from this and other nearby sites to be complicated and open to more than one interpretation. He concludes, however, that the spruce forest was able to survive along the margin of the Valders ice, although with openings. At least the climate of Two Creeks time was not necessarily much more severe than that of today in the area. Schweger (1966 and 1969) found only simple pioneering boreal wetland species present. Roy (1964) in a study of the Pleistocene non-marine mollusca of northeast Wisconsin concluded also that these species represented climates very similar to that of northern Minnesota today.

Pollen studies of other sites of Two Creeks age in Wisconsin have also been done by West (1961), by Schweger (1966 and 1969), and by others whose work has not been published. Schweger (1969) found distinctive differences in the flora in those sites where more time was available. Local variations in the forest litter and macrofossils at these various Two Creeks locations also are appearing (Black, Hole, Maher, and Freeman, 1965, p. 68). No vertebrate remains have been found in dated Twocreekan materials in Wisconsin yet mastodons in deposits possibly of that age and younger are known.

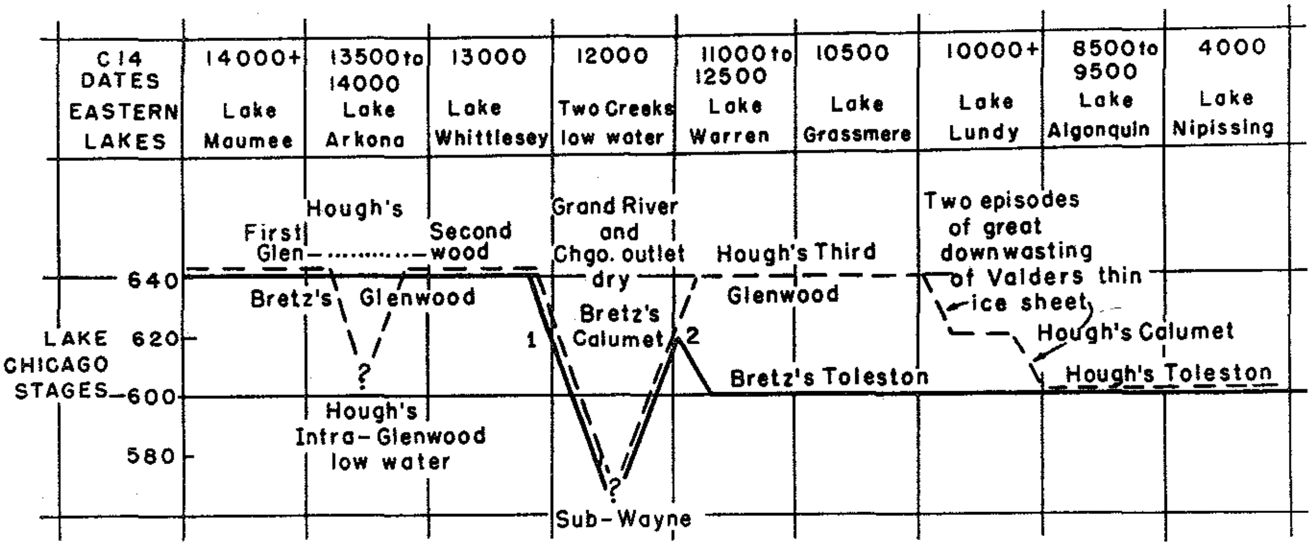
Wood fragments of Twocreekan age are especially common in the Valderan till, but locations in eastern Wisconsin where Twocreekan soil profiles are *in situ* are less common (Fig. 19). Particularly good exposures have been seen in borrow pits in the SW 1/4 and NE 1/4, SE 1/4, sec. 19, T 23 N, R 19 E, Outagamie County (Piette, 1963). Another is in the SE 1/4, NW 1/4, sec. 15, T 22 N, R 15 E. Detrital organic litter of Twocreekan age in lacustrine sediments is found at several places, such as the SE 1/4, SE 1/4, sec. 22, T 24 N, R 21 E, Brown County, and the SW 1/4, SW 1/4, sec. 6, T 21 N, R 23 E, in Manitowoc County. All these sites are in borrow pits, are of very limited extent, and do not lend themselves to use by the public. The type section remains unique.

The controversy of the varve-dated chronology calling for Two Creeks to be 19,000 years old (Antevs, 1962) versus the radiocarbon dates of 11,840 years (Broecker and Farrand, 1963) requires that we examine information available from much of northeastern United States and Canada as well as the European transatlantic correlations. This goes far beyond the scope of this paper. Suffice it to say that the radiocarbon-controlled chronology has been accepted by a majority of workers.



Pollen spectra of Two Creeks Forest Bed (Black, Hole, Maher, and Freeman, 1965, p. 67, Fig. 5).

Fig. 20



Diagrammatic depiction of two contrasting interpretations of fluctuations of water level of Glacial Lake Chicago.

Fig. 21

YEARS BEFORE THE PRESENT (based on C-14 dates)	LAKE STAGE IN THE LAKE MICHIGAN BASIN (elev. above sea level)	PREDOMINANT FOREST TYPE: SOUTH HAVEN POLLEN PROFILE	PREDOMINANT FOREST TYPE: HARTFORD BOG POLLEN PROFILE	WISCONSIN CHRONOLOGY
0 2,500	Lake Michigan (580) Algoma (595)		Oak-Pine	
3,500	Nipissing (605)		Oak-Hickory-Pine	XEROTHERMIC
4,000 5,000 6,000 8,000	Chippewa (230) Payette and related stages of "Lower Algonquin" lakes of Stanley (Depth from top of pollen profile in inches)	1 30	Oak-Pine Pine Jack Pine	10 (Depth from top of pollen profile in feet) Opening of North Bay Outlet ICE RETREAT 21
8,500	Algonquin (605) Toleston (605) Calumet (620)	106	Spruce-Fir (declining)	VALDERS MAXIMUM
11,000	Bowmanville (below 580)			TWO CREEK INTERSTADIAL
13,000	Glenwood (640)		Spruce fir *See pollen diagrams for details* 32	CARY

Radiocarbon years, lake levels, forest succession, and chronology in the Lake Michigan basin (Zumberge and Potzger, 1956, Fig. 4).

Fig. 22

CONCLUSIONS AND SIGNIFICANCE

When it is recognized that the forest bed is established on lacustrine sediments and yet covered by lacustrine sediments all of which in turn lie between two tills, something of the magnitude of the glacial history inferred becomes apparent. To this we must add still more lacustrine sediments and windblown materials on top of the younger till at the Two Creeks Forest Bed locality. This means we must take into account at least three lakes whose levels have been up to a point more than 30 feet higher than that of present Lake Michigan. One lake followed the basal till, one swamped the forest bed horizon, and one came in on top of the younger till. These fluctuations are of an order of magnitude beyond that which can be achieved merely by increasing precipitation. Changes in the outlet or outlets of Lake Michigan were involved. We cannot confine our analysis of this problem only with a study of Lake Michigan. Several of the Great Lakes (Hough, 1958) must be taken into account and their story integrated with the Pleistocene history of the St. Lawrence, Hudson, and Mississippi river valleys. For convenience of the reader, a diagrammatic depiction of two contrasting interpretations of fluctuations of water level of Glacial Lake Chicago are recorded in Figure 21. The differences of opinion of interpretation of field data between Bretz (1959, 1964 and 1966) and of Hough (1958, 1963 and 1966) are by no means resolved. Black would agree with Bretz (1966) that a lake level at 620 feet (equal to the level along Highway 42 at Two Creeks, Fig. 5) was post-Valders farther south, near Port Washington. It seems likely that the lake sands on the Valders till at Two Creeks are local in occurrence, but a Calumet or other level of Glacial Lake Chicago has not yet been ruled out. Discussion of this problem goes beyond the scope of this particular paper and includes glacial lakes and drainage in northern United States and in Canada from the Rockies to the Atlantic and from Hudson Bay to the Gulf of Mexico. It even involves indirectly the arguments of Antevs (1962) (cf. Hughes, 1965) on transatlantic correlations and dating. Although complex, the history of the Great Lakes is truly a fascinating subject (Hough, 1958).

Precise correlation of the age of the till at the base of the cliff has not been made. It is certainly Late Woodfordian, possibly a younger unit of the Cary or subsequent slight re-advance such as the Mankato or Port Huron of other states. The till locally is gray but Black has found mostly red at the site. Gray drift is supposedly characteristic of the Port Huron of Michigan (Wayne and Zumberge, 1965), whereas red drift that is post-Cary and pre-Two Creeks is generally considered representative of the Mankato of Minnesota (Wright and Ruhe, 1965). The Port Huron moraine (Wayne and Zumberge, 1965, p. 72) was described by Taylor (Leverett and Taylor, 1915, p. 293) as "one of the best developed and most clearly defined moraines in the Great Lakes region" and this status has been accorded this moraine by every glacial geologist who has worked in Michigan since that time. The Port Huron moraine was dated by Hough (1958, p. 278) at 13,000 years ago. It was correlated across Lake Michigan by Thwaites and Bertrand (1957, Fig. 1) with an unnamed moraine near Sheboygan, Wisconsin. If true, then presumably the Port Huron would extend to the north and encompass the Two Creeks site. However, new data from Michigan disproves some of these findings (Farrand, Zahner, and Benninghoff, 1969). A Cary-Port Huron Interstade with tundra plants is dated at 12,500 to 13,000 years B.P. and lies between two red-brown sandy tills previously correlated with the Valders.

If the above correlation is correct that the basal till at the Two Creeks Forest Bed is of Port Huron equivalent, then the history of the lake sequence would begin at about 12,000 to 13,000 years ago. Pollen spectra and chronology of Lake Michigan water levels from the Michigan side are shown in Figure 22 for that time to the present. Stumps and other organic matter *in situ* are to be found at various depths below the water of Lake Michigan, adding to our knowledge of the low water levels (*e.g.,* Somers, 1968, who reports stumps in growth position at a depth of 32 feet and 6,700 radiocarbon years old in the Straits of Mackinac). Thwaites and Bertrand (1957) summarize the meager information on lake levels in the Two Creeks area. Obviously more detailed studies must be done before a clearer picture can be obtained.

When one considers the magnitude of water fluctuations through hundreds of feet during only some thousands of years, the present-day fluctuations of a few feet are relatively insignificant. Nonetheless, exceedingly rapid shoreline erosion (up to 40 feet per year at Manitowoc in 1905) (Goldthwait, 1907), forces one to appreciate some of the consequences of minor lake-level fluctuations. At the present time, water levels in Lake Michigan are high after having been low for many years. As a result, shoreline erosion at the Two Creeks Forest Bed has been minimal until this past year. When the site was first found by Goldthwait and then subsequently when Wilson had opportunity to examine the location, water levels also were relatively high. This permitted shore erosion to expose the forest bed which then was covered for decades by slump and vegetation.

Part 3
VALDERAN TYPE LOCALITY

Thwaites (1943, p. 136) named and defined the Valders because of the uncertainty of former correlations of moraines across the heavily vegetated region around Lake Superior. He said: "Drift of this age is readily distinguished from the Cary [Late Woodfordian] till because it is red and contains much more clay." Frye and Willman (1960) modified the spelling and defined the Valderan Substage as the youngest time-stratigraphic subdivision of the Wisconsinan Stage. Drift of Valderan age lies locally on Twocreekan soil of about 11,000 to 12,500 radiocarbon years B.P. (Frye, Willman, Rubin, and Black, 1968; Black and Rubin, 1967-68). The Valderan Substage has not been dated anywhere in Wisconsin (Black and Rubin, 1967-68), although ice seems to have advanced over the buried forest at Two Creeks very shortly after it was killed by rising lake waters. Thus, Valderan time there should date about 11,800 years B.P. We now know that not all red clayey tills in Wisconsin are Valderan, nor are all Valderan drifts red and clayey (Frye, Willman, and Black, 1965; Black, 1966). This also seems true in Michigan (Farrand, Zahner, and Benninghoff, 1969) and in Minnesota (Wright and Ruhe, 1965). Additional details on the Valderan drift south of the type locality are brought out by Lasca in Field Trip Guide No. 4.

The Valderan till was originally considered a lake deposit (Chamberlin, 1877, pp. 219-228) but was later (Alden, 1918, pp. 310-324) shown to be true till. Thwaites (1943, p. 137) found no recognizable moraines within the Valderan area and no unequivocal records of lakes impounded by the Valderan ice. However, it now seems clear that moraines are present up-ice from the front mapped by Thwaites, and the actual terminus was in many places in marginal lakes that provided red silt and clay to give the red color to the soil which Thwaites used to determine the front. Bedrock striae and critical exposures unavailable to Thwaites now serve to modify Thwaites' boundaries (Black, 1966), but they do not serve to alter the general conclusion that the Valders ice was relatively thin and that the glaciation was weak and short lived. Exposures of the Valderan till on proglacial lacustrine beds and also covered by lacustrine sediments are now available, but will not be seen for lack of time.

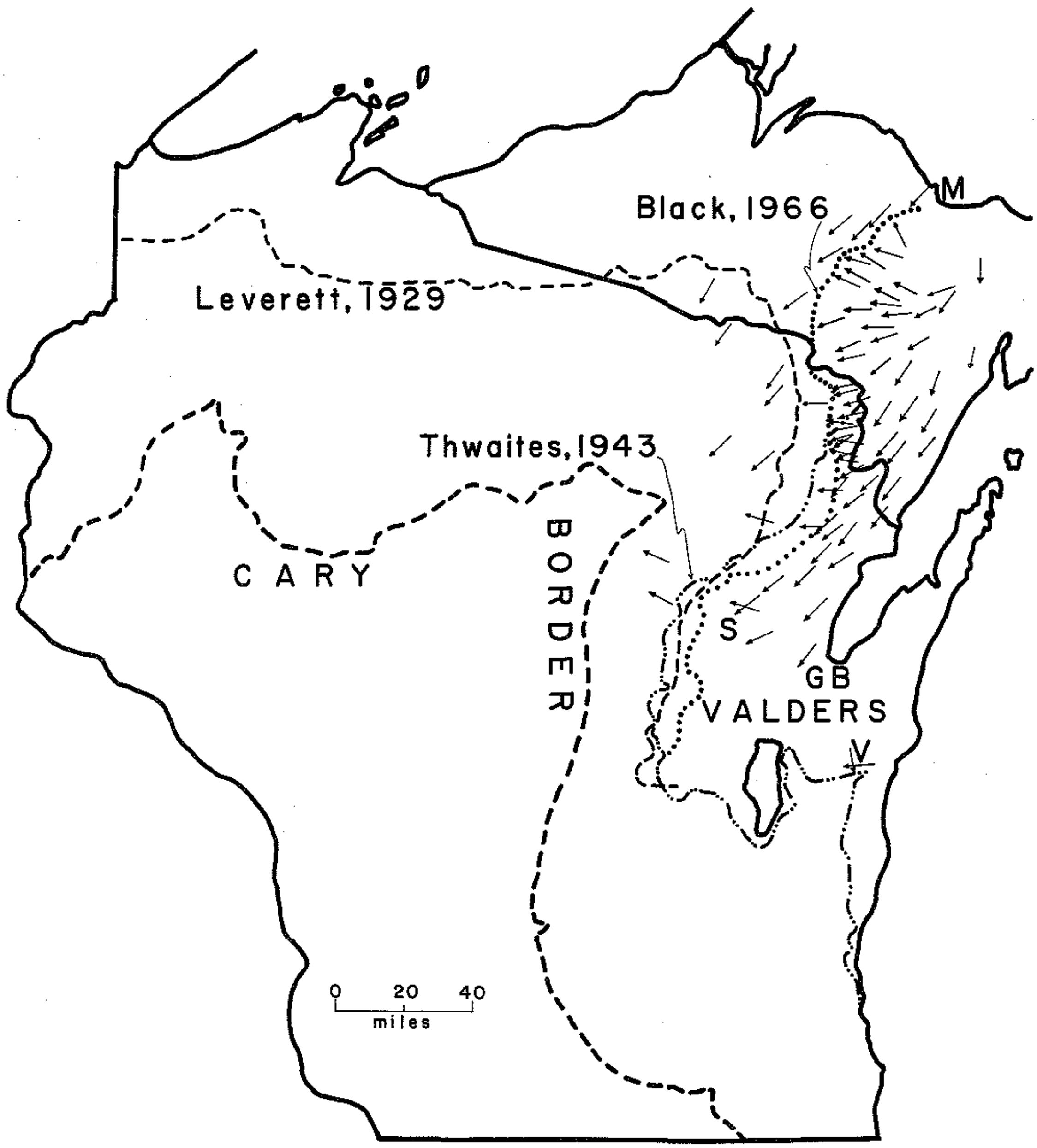
The type locality at Valders (Figs. 1 and 11-13) and many other places (Black, 1966) show clearly that an early gray stony drift with one set of bedrock striae beneath has been partly replaced locally with a red clayey drift with striae of different orientation. Invariably the older striae are deeper, broader, and better developed than the younger striae. In places, as at Valders, the two sets are almost at right angles.

On the southwest side of the Green Bay Lobe, the early striae (Late Woodfordian or Cary) trend northwesterly and the younger (Valderan) southwesterly (Black, 1966) (Fig. 23). The reverse is true at Valders, on the east side of the Green Bay Lobe (west side of the Lake Michigan Lobe). There the Cary striae average 175 degrees and the Valderan striae average 260 degrees (360-degree compass). Farther north on the west side of the Green Bay Lobe the striae relations at the border of the Valderan-Cary drifts change again (Fig. 23).

Texturally the Valderan till is highly variable even in a small geographic area (Lee, Janke, and Beaver, 1962), ranging from clay to loamy sand. Clay loam, clay, loam, and sandy loam in that order are the most common textures in the red drift. The red color is attributed to finely disseminated iron oxides in sediments laid down in Glacial Lake Chicago and reworked by the Valderan ice (Murray, 1953). The heavy mineral assemblages of texturally unlike Valderan and Cary tills are essentially identical (Murray, 1953). Epidote dominates with lesser quantities of opaque minerals, hornblende, apatite, garnet, and others. Most clay-sized particles are quartz and dolomite. Locally, red clayey tills separated by radiocarbon-dated Twocreekan soils can only be distinguished by their stratigraphic position.

Thwaites and Bertrand (1957) did not recognize that the Valders ice left end moraines or prominent ice-stagnation features, apparently because they considered gravelly materials automatically to be pre-Valderan. Thus in their interpretation, the Valderan ice rode over large portions of the Kettle Interlobate Moraine with eskers, kames, crevasse fills and other features supposedly without modifying them. The fallacy of their argument is demonstrated by the work accomplished at the type locality—the Valders Quarry. If we accept the upper red clayey till there as Valderan, then its associated striae on bedrock and the removal of many feet of gray stony drift of Late Woodfordian age attest to considerable work by that part of the ice sheet that was within a mile or so of its terminus. Features of sharp unequivocally constructional form, like the Brillion Ridge (a Valderan esker, Suttner, 1963), would surely have been modified extensively by the thicker ice miles behind the front. Erosion elsewhere by Valderan ice has been extensive (Piette, 1963; Black, 1966) and fluted forms are common (Black, 1966). Only relatively few locations with *in situ* buried soils of Twocreekan age have been found (Fig. 19). The contact under red clayey till where it should be is almost everywhere erosional–unconformable. Black (1966) thus has based the boundary of the Valderan glaciation, not on the red color of the soil or drift, but on the bedrock and surficial direction indicators, and on the end moraines, outwash aprons and other features indicative of the margin of the post-Twocreekan ice sheet.

Kewaunee soils (*Spodic Alfisols* and *Alfisols*) are developed on the red drift in the vicinity of Valders.



Relationship of Valderan striae to Late Woodfordian striae in northeastern Wisconsin and part of Upper Michigan (Black, 1966, Fig. 1).

Fig. 23

Part 4

GLACIAL GEOLOGY OF NORTHERN KETTLE MORAINE STATE FOREST

INTRODUCTION

Since its designation in 1937, the Northern Kettle Moraine State Forest and environs have been one of the more popular public recreational areas in Wisconsin. The center of the Forest is only 45 miles north of Milwaukee (Fig. 1) and serves especially the heavily populated area from Chicago north to Green Bay. The Forest contains many excellently developed and representative glacial features which are internationally famous, but others even more important or striking lie just outside it. Its kettles were the first in the world to be described adequately and interpreted correctly (Whittlesey, 1860 and 1866; Chamberlin, 1877 and 1878; White, 1964). Alden (1918, p. 308) cited the area east and northeast of Kewaskum (Fig. 2) as "...one of the finest examples of terminal-moraine topography in the United States."

The Northern Kettle Moraine State Forest includes some 24,000 acres in a very irregular area about 22 miles long and 1 to 4 miles wide (Fig. 1). It extends from the vicinity of Glenbeulah in Sheboygan County southwesterly and then southerly to the vicinity of County Highway H, about three miles southeast of Kewaskum, in Washington County. The Forest encompasses much of the area along the common boundary between Fond du Lac and Sheboygan counties.

The Northern Kettle Moraine State Forest lies athwart the internationally famous Kettle Interlobate Moraine. The moraine, as the name implies, was built between two ice lobes—the Green Bay Lobe on the west and the Lake Michigan Lobe on the east (Alden, 1918, pp. 308-309)—during Woodfordian time, between 13,000 and 22,000 radiocarbon years ago (Black and Rubin, 1967-68). This is the "...master topographic feature of the whole series of glacial deposits in eastern Wisconsin" (Alden, 1918, p. 235) which first attracted the attention of early explorers. The moraine consists of silt and sand and coarse, angular to well-rounded rock fragments of the local light grey Niagara (Silurian) dolomite particularly, but also igneous and metamorphic rocks of Precambrian age from northern Wisconsin, Upper Michigan, and Canada. The composition and texture of the drift comprising the moraine varies markedly from place to place within the area. The drift was dumped between the two lobes of ice as they butted against each other and was also deposited under and on top of the dirty ice along that junction during the final stagnation and destruction of the ice. Hence, some debris was deposited directly from the ice, but other material was displaced and reworked by gravity movements and running water. Glacial-fluvial and glacial-lacustrine deposits are especially common. The buried blocks of glacial ice subsequently melted out, pitting the surface with thousands of irregular kettles from a few feet to several miles in extent.

A privately owned area within the northcentral part of the Forest, northeast of Dundee (Fig. 1), contains one of the most striking groups of moulin kames to be found anywhere in the world (Figs. 15 and 17). Several less well-developed or less "showy" moulin kames in another group east and north of Kewaskum have been destroyed for construction aggregates.

Relatively few studies have been made of the glacial phenomena in the Kettle Interlobate Moraine or of their detailed history. Much of what we know was learned 50 to more than 100 years ago when Wisconsin's outstanding glacial geologists of that heyday were active in their reconnaissance studies of the state. The Kettle Interlobate Moraine was last mapped by Alden (1918) as part of a reconnaissance in southeastern Wisconsin and has hardly been touched since. Black (1969) summarized the status of knowledge of the geology of the Forest without benefit of fieldwork. This report is copied almost *in toto* from that reference. Gaenslen (1969) has prepared a trip guide of the area for laymen, utilizing published works. An earlier field guide includes part of the area (Alden, 1932). Much study is needed to modify Alden's findings significantly or to understand fully the history of individual forms or even of many large units. Different interpretations are possible within the framework of existing data. However, it seems clear that several local fluctuations of the two lobes were involved during Woodfordian time. The junction thus is a zone of partial mixing or interstratifying of material from each lobe. Outwash gravel and other glacial deposits were reworked and redeposited, commonly on pre-existing ice, as the junction shifted back and forth.

The area is so large and diverse that it is not feasible nor necessary for purposes of this report to describe each feature. Rather, part of the area is subdivided largely by air-photo interpretation into mappable units or groups of similar geomorphic features (Fig. 15). These are not pure units because of the almost infinite detail available within any relatively small segment. Nonetheless, they serve to emphasize such features as end moraines and stagnate-ice or "dead-ice" moraine with knob and swale topography, moulin kames, outwash, eskers, crevasse fills, kettles and the like.

GENERAL DESCRIPTION OF THE MORAINE

In 1876 T. C. Chamberlin orally presented a paper to the Wisconsin Academy of Sciences, Arts, and Letters on the extent and significance of the Wisconsin Kettle Moraine (Chamberlin, 1878). In those days when great geologists were formulating principles of the concepts of glacial geology, Chamberlin was a true giant among them (Fenton and Fenton, 1952). Although today some of his words and phrases are no longer popular and editors would cut and prune his remarks in order to save space, Chamberlin's description of the moraine bears the test of time so well that this writer feels compelled to quote him directly. In describing the surface form of the moraine he wrote:

"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 kettles,' '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 peculiarities 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." (Chamberlin, 1878, pp. 202-204).

Chamberlin in actuality was referring to the surficial features of the end moraine of what is now called the Late Woodfordian or Cary ice as it was deployed through the entire state of Wisconsin and not just the interlobate moraine in what is now the Northern Kettle Moraine State Forest. Nonetheless, his description can scarcely be improved upon for the area.

In speaking of the nature of the material, Chamberlin (1878, p. 205) emphasized that "...*all* the four forms of material common to drift, *viz.:* clay, sand, gravel, and boulders, enter largely into the constitution of the Kettle range, in its typical development. Of these, gravel is the most conspicuous element, *exposed to observation.*" Chamberlin (1878, p. 210) further recognized that most bedrock units in Wisconsin and Upper Michigan were represented in any one section of the drift, including native copper from Keweenaw Peninsula, but that the bulk of the drift was derived locally. Thus, most gravel is composed of the local white to very light gray Niagara dolomite, well rounded by water work. However, we now know that more than one local advance of ice was involved and that reworking of outwash gravel by later advances was commonplace. Hence, some constructional forms contain nonstratified gravel instead of till. Deposition of the reworked gravel directly from ice without water working took place.

Other details of the moraine in Wisconsin were presented early, and it was compared with its counterpart in other states (Chamberlin, 1877 and 1883). In the latter paper, the term "interlobate moraine" was first introduced (Chamberlin, 1883, p. 276) and properly diagnosed as to origin in contrast to normal medial moraines. A reconstruction of the ice flow directions demonstrates conclusively the lobate character of the ice and the opposing movements of the junction of the two lobes. This gross story has changed little in the intervening century.

Chamberlin's important role in the development of the concepts of glacial geology would not have been possible were it not for the clear observations and lucid writings of his predecessors of whom, in connection with the Kettle Interlobate Moraine, Charles Whittlesey is singled out. It was he (White, 1964) who in the mid-1800's first recognized the "kettle moraine" and correctly interpreted the origin of the kettle holes to buried glacial ice rather than to drifting icebergs as was in vogue at the time. This was truly astonishing insight, and is but one of the major accomplishments of that amazing man.

The Greenbush Kettle (Fig. 16), two miles south of Greenbush on the Kettle Moraine Drive, has been favored with a geological marker sign for years. It is one of the most symmetrical, deep circular depressions visible from the road. Many others are more irregular but just as typical whether with or without water in them.

In brief, the Northern Kettle Interlobate Moraine is conspicuous because of its more abrupt irregularity and sharpness of feature compared with the undulating ground moraine with smoothly contoured drumlins and till-covered bedrock rises on both sides. The light grey gravel of the Interlobate Moraine also contrasts markedly with the reddish-brown and light yellowish-brown sandy till of the ground moraine. Neither its maximum elevation (1,311 feet at Parnell tower, 5.8 miles northeast of Dundee) nor its general relief of 100 to 200 feet are significantly different from the till plains and drumlins adjoining. However, it is characterized by major lowlands at 950 to 1,000 feet, such as those occupied by Long Lake and the East Branch of the Milwaukee River. The flatness of such lowlands and the abrupt rise of drift deposits flanking them also emphasize the glacial features.

DRAINAGE

The Kettle Interlobate Moraine lacks an integrated drainage network. Many closed depressions drain through the coarse gravel below and do not need surface streams for drainage. Others intersect the groundwater table and have perennial ponds or lakes. Elkhart Lake, a large kettle north of the Forest, with high land around it, drains westward to Sheboygan Marsh and the Sheboygan River. Crystal Lake, next south of Elkhart Lake, has no outlet. However, Mullet River flows by only one-fourth mile to the southwest in its arc around the north end of the Kettle Moraine Forest, and then southeasterly and eastward in a tortuous route to join the Sheboygan River at Sheboygan Falls. Interestingly, those two rivers have adjoining headwaters, and their uppermost courses are parallel yet flowing in opposite directions about one mile apart northwest of Long Lake. Both rivers have very intricate courses to Lake Michigan, probably in part controlled by fracture patterns in the stagnating ice which permitted the supraglacial streams to superpose themselves on the underlying drift and bedrock.

The East Branch of the Milwaukee River, flowing southward into the Milwaukee River southeast of Kewaskum, drains most of the Northern Kettle Moraine Forest proper. Its course follows the trend of the moraine and generally lies almost precisely on the reconstructed boundary between the two lobes of ice. (This is somewhat west of the boundary indicated by Alden, 1918, pl. 3.) Probably its origin dates back to the initial abutment of the ice of the two lobes where it developed in the axial depression along that junction. It has remained apparently in that position since.

In the wastage of the Lake Michigan Lobe, however, additional channels were formed on the stagnating ice. Mink Creek lies in a channel that starts about two miles northeast of Parnell and flows generally southerly past Beechwood in a course with abrupt right-angle bends. These seem also to reflect the fracture pattern of the ice as the initial stream was let down on the surface below. Many other examples exist in the area, but no detailed three-dimensional field study of any of them has been attempted. They need to be integrated into the history of the moraine.

ORIGIN OF THE GLACIAL FEATURES

Figure 15 shows the distribution of some glacial features that characterize certain parts of the area. For convenience in the classification, each unit is named for the most abundant or striking feature or features it contains. These units are: ground moraine (and drumlins), drift, end moraine (or stagnate-ice or dead-ice moraine), and special features such as moulin kames and eskers. Ground moraine with drumlins and till-covered bedrock rises comprises most of the area up-ice from the front of both lobes. Small stagnate-ice features in that unit are common. The orientation of drumlins, fluted forms, and striae recorded by earlier workers and summarized by Alden (1918, pl. 4) show clearly the regional movements of the ice of both lobes. Arrows on Figure 15 show local trends of the ice recorded by drumlinoid or fluted forms. Even though the general deployment of ice shown by Alden (1918, pl. 4) is not expected to be changed in gross form, detailed fieldwork is needed to show ice movement in relation to individual segments of the moraine. Bedrock striae formed in early advances during Woodfordian time are not everywhere parallel with the alignment of molded forms—the last to be produced.

In the area of Figure 15, stratified drift, including outwash, glacial-lacustrine deposits and other water-formed features, are almost as prevalent as end moraine or stagnate-ice or dead-ice moraine formed more directly by the ice. The washed surfaces and deposits reflect in part the cleaner ice of the two lobes juxtaposed and in part the concentration of runoff along the junction of the two lobes. The normal surface gradient up-ice in each lobe would have led water to the junction of the lobes, from which its escape could only have been to the south along that junction. Such water-worked stratified drift varies in size from the coarse, bouldery material of glacial streams to the sand, silt, and clay in ponded water. Drift obviously has formed in places on buried ice blocks to leave pitted outwash; elsewhere it seems that entire portions of stream beds or lake sediments have been dropped down as continuous ice below melted out. Most parts of the well-washed drift, however, were formed adjacent to ice, but not on it. Original stratification is preserved.

Even during deglaciation the widening and northward migrating gap between the two lobes effectively concentrated glacial-fluvial activity between the lobes. Thus, it was the locus for many striking forms. Eskers and moulin kames formed under the stagnate ice, and their subglacial waters also flowed toward that same gap. Crevasse fills, topographically commonly like short eskers, were formed in crevasses open to the sky in part by supraglacial streams and in part by mass movement of surface debris into the crevasses.

Small moulin kames are scattered throughout much of the area, but none is better developed or displayed than those in the group northeast of Dundee (Fig. 15). There, in the widest part of the washed drift area, are some of the best moulin kames to be found anywhere in the world. Beautifully conical hills, such as McMullen, Conner, and Johnson, rise at the angle of repose of the material more than 100 feet above the flat, washed, drift plain surrounding them. Numerous smaller kames, only a few tens of feet high, are commonly less conspicuous among the drift ridges and are too small to show on Figure 15. Many are just as symmetrical as the larger ones in the lowlands. Other more irregular moulin kames, such as Dundee Mountain (which has a geologic marker), are also present and grade into crevasse fills or into ice-walled lake deposits (openings so enlarged that lakes formed within the glacial ice walls). Such forms originated where melt waters on the ice dropped through moulins or crevasses, dumping their detritus at the base. Openings ranged from nearly vertical, circular pipes (moulins) to very elongate fractures and rounded to irregular large openings; commonly, water and debris were fed into the fractures at more than one place along the sides and ends of crevasses, building irregular forms below the ice. Many large fractures were fed not just with running water, but also with mud flows, debris slides, and the like. Ponded water in some also trapped deltas and lacustrine sediments. Thus, the material in such features as moulin kames and crevasse fills ranges from normal till, through the available sizes of water-transported material, to ponded sediments. The cross section of Garriety Hill is typical (Fig. 17). It shows rounded to angular gravel, sand, silt and clay deposited as unsorted till in irregular masses, and as sorted sediment in alluvial flows, pond sediments, and the like.

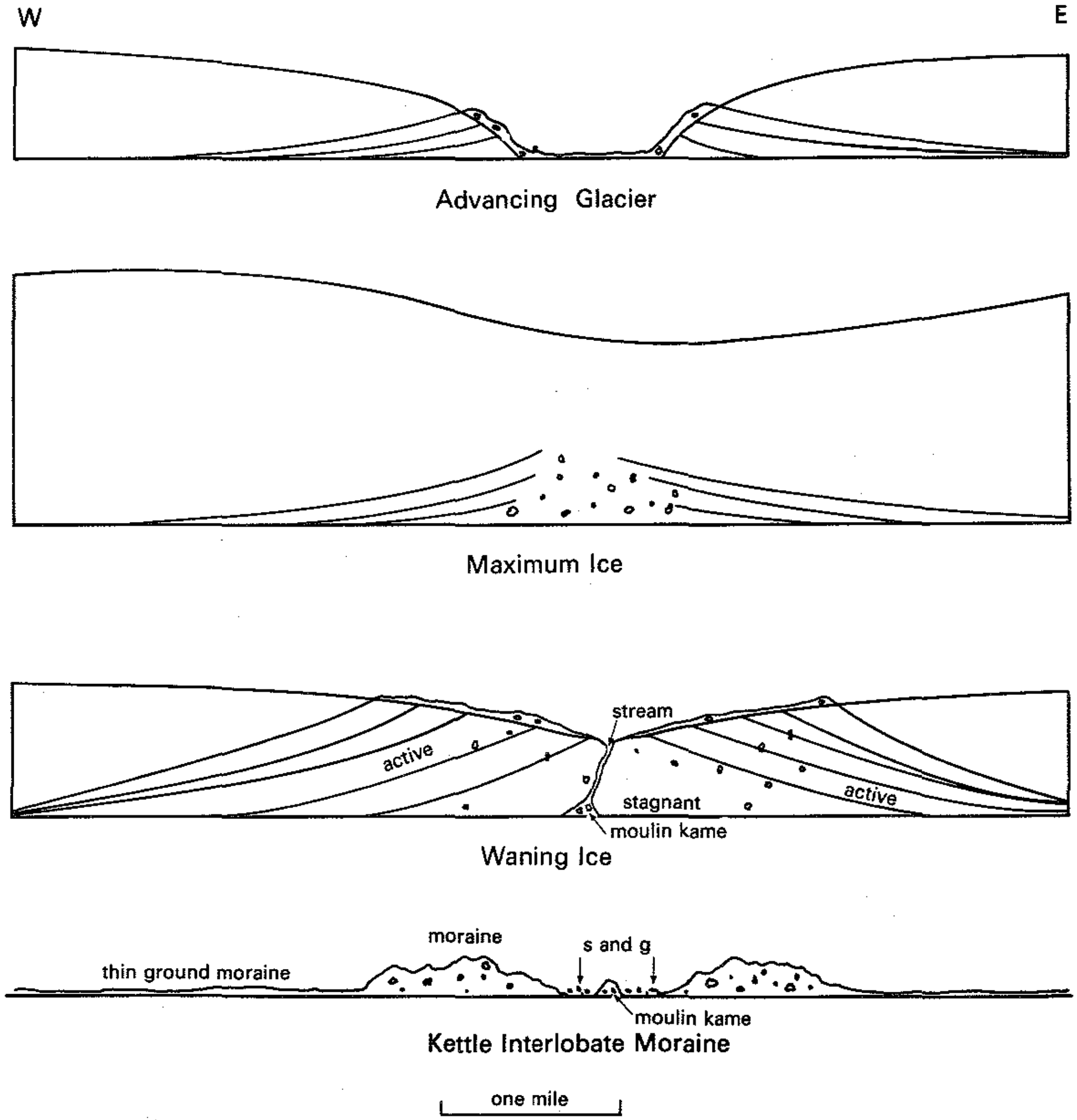
Water that formed the northern group of moulin kames drained westward under the ice to join the drainageway through Long Lake Valley. Their channels are readily discernible on aerial photographs.

End moraine and stagnate-ice or dead-ice moraine are not differentiated on Figure 15 because of their general similarity of origin. The terms are used loosely here for lack of detailed understanding of their genesis. They might have been subdivided for descriptive purposes into those areas characterized by elongate ridges and valleys and those with circular knobs and swales. In the interlobate area all are believed to result from ice stagnation and the melting out of blocks of ice of the appropriate geometry to fit the surface depressions. Such geometry is predicated on the movement of the ice at the time the ice and debris were mixed, on its fractures, or on the manner of burial by overriding ice, of outwash, debris slides, etc.

The detailed deployment of the moraines in the Northern Kettle Interlobate Moraine is of considerable interest in the reconstruction of events as related to the flow of ice. From the vicinity of Kewaskum north to Dundee and to Long Lake, the trend of the Interlobate Moraine is almost north. From Long Lake the Interlobate Moraine turns fairly abruptly to the northeast to Elkhart Lake where it again swings to the north. At least part of the explanation of the bends may lie in the topography of the bedrock which unquestionably has exercised some control on the deployment of the ice. The deep preglacial valley at Sheboygan Marsh and Elkhart Lake must have provided relatively easy access for the ice of the Green Bay Lobe, leading it more rapidly and farther to the southeast than was possible over the bedrock hills south of that marsh. The hills restrained the ice of the Green Bay Lobe, allowing the ice of the Lake Michigan Lobe to push farther westward. Such kinks and bends in the terminal area are commonplace along the entire Late Woodfordian front in Wisconsin. They are of considerable importance in understanding the development of such features as are found in the Northern Kettle Interlobate Moraine, but space does not permit their reconstruction here. Much fieldwork is called for to unravel the details of their history.

Small moulin kames in the stagnate-ice moraines are probably contemporaneous with the related features, immediately preceding kettle formation. However, the precise timing of the formation of the main group of moulin kames versus the main moraines to west and east is conjectural.

The writer hypothesizes (Fig. 24) that shortly after the two lobes butted together, the thickness of ice gradually increased from 100 to 300 feet at the start to a thickness perhaps of several thousand feet when the ice extended southward into the center of Illinois. Ablation, particularly by melting aided by a surface stream at the junction of the two lobes, would be countered by ice movement from the base of the ice sheet diagonally upward to that junction at the surface. Upward flow at the terminal zones of glaciers is commonly at angles of 10 to 45 degrees, bringing debris from the base toward the surface to replace ice lost in the ablation zone and to maintain the surface profile of the glacier. When ice was at its maximum thickness at the junction, the basal debris may not have reached the surface. As the ice thinned during the waning of the Late Woodfordian glaciation, that debris would intersect the surface. As thinning continued to perhaps 200 or 300 feet of ice, fractures penetrated in favorable places, aided by meltwaters, to the bottom of the glacier. In them the moulin kames, eskers, and crevasse fills began to grow. However, at that time the thicker ice back from the junction was continuing to move forward even though the terminal zone was stagnate. The shear planes and flow layers that brought debris up from the base presumably angled obliquely downward and away from the actual surface junction of the two lobes to the general location of the main moraines on both sides of the drift area. At the locus of the moraines, basal ice and debris were interstratified by flow of ice while the basal ice closer to the junction was stagnated and remained relatively free of debris. Thus, the two main moraines, one for each lobe, are in a sense end moraines even though they do not mark the terminal position of the ice nor were they deposited at the outer edge of the ice. They represent the outer edge of the *active* ice for each lobe and were separated by a zone of *stagnate* ice shaped like a very broad, low wedge with its apex upward, at least during the waning of the glaciation. It seems relatively clear that stagnation took place over much of the area because so many small ice-contact, washed-drift features are superposed on all other forms.



Hypothetical sequence of events postulated to explain the origin of some glacial features of the Northern Kettle Interlobate Moraine.

Fig. 24

CONCLUSIONS

Many details of the reconstruction of the events that led to the surface features in the Northern Kettle Interlobate Moraine are imperfectly known. New topographic maps and aerial photographs unavailable to Alden (1918) and earlier workers now permit an analysis of surface forms to be made in far more detail than was possible for him in his reconnaissance study. Surface analysis, however, is only part of the story. Serious mistakes have been made in the past in the interpretation of glacial forms by morphology alone. Subsurface exploration must be carried on concurrently before a firm foundation can be laid that would permit us to change significantly the gross picture of the Kettle Interlobate Moraine as commonly accepted. Such detailed study has had little economic incentive, but should be undertaken before gravel pit operations remove or modify evidence that might be the key to part of the story. A beautiful story can be constructed on evidence available, but an even larger part of the story is still unsupported in fact. The prospects in future study are especially intriguing.

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Information Circular 13

ERRATA

Page 8
Mile 54.3. Since the road log was set up Highway 141 bypass around Sheboygan has been opened.

Page 9
Add to the title "Topography derived from U. S. Geological Survey Quadrangle Kewaunee and Manitowoc."

Page 14
On Figure 11 reverse "gray stoney till" and "red clayey till."

Page 15
Mile 16.9. Highway 57 on the U. S. Geological Survey Topographic Quadrangle is Highway 67 on the new Wisconsin State Highway Map.

Mile 26.7, second line. Add period after town and delete rest of paragraph beginning with passing the "old Wade House"...

Mile 29.5. Insert comma in lieu of period at the end of the line and insert the deleted material from mile 26.7, namely: passing the "old Wade House." It served as a stage stop in the 1850's and has been restored and outfitted by the State Historical Society with antiques and replicas to preserve the atmosphere of the times a century ago.

Page 18
Figure 16 add "View westward."

Page 18
Figure 17 add "View eastward."

Page 20
Figure 18 add "View northeastward."

Page 29
Figure 21 add "After Bretz 1959, Figure 3. Dates are round-number approximations of spot dates during each lake stage.

Page 32
Figure 23 add "V shows location of Valders Quarry."

Page 39
Add to the references cited "Black, Robert F., 1969, Glacial geology of northern Kettle Moraine State Forest, Wisconsin: Wis. Acad. Sci., Arts and Letters, Trans. v. 57, pp. 99-119."