OCCASIONAL PAPERS

ON THE

GEOLOGY OF MICHIGAN

FOR

1954

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DEPARTMENT OF CONSERVATION
Gerald E. Eddy, Director

GEOLOGICAL SURVEY DIVISION
Wm. L. Daoust, State Geologist

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FOREWORD

To the Director, and Commissioners of the
Department of Conservation:

Gentlemen:

I have the honor to present herewith reports on the geology and groundwater resources of two counties of the State, Van Buren and Oakland counties, by Mr. F. Wells Terwilliger, geologist on the staff of the Geological Survey Division, and Dr. Andrew J. Mozola of Wayne University, and recommend that they be published as Publication 48, of the Geological Survey Division, Department of Conservation, and be considered a part of the annual report for 1954.

As the population and commercial interests of the State increase, its water resources, both on the surface and underground, come more and more into use, and knowledge of this most vital resource becomes of paramount importance. The reports herewith presented offer contrast in the study of the water resources of an essentially rural area, Van Buren County, and of an essentially metropolitan area, Oakland County.

The report on Van Buren County is also a contribution to our knowledge of the glacial geology of the area, as Mr. Terwilliger has carefully detailed the reconnaissance of glacial geologists who earlier worked in the area. The Oakland County area has been adequately mapped so that Doctor Mozola's report is concerned mainly with occurrence of groundwater and the relation of that occurrence to recovery and utilization by the population and industry of a metropolitan area. The reports may serve as guide studies for similar areas elsewhere in the State.

Respectfully submitted,

WILLIAM L. DAOUST
State Geologist
May 1954

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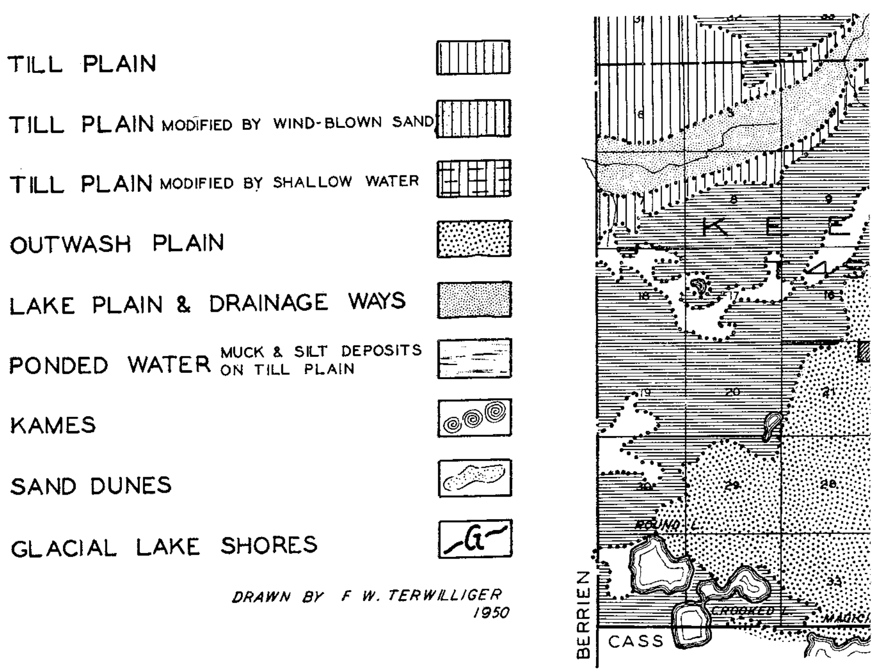
THE GLACIAL GEOLOGY
AND
GROUNDWATER RESOURCES
OF
VAN BUREN COUNTY, MICHIGAN

F. WELLS TERWILLIGER



THE GLACIAL GEOLOGY AND GROUNDWATER RESOURCES OF VAN BUREN COUNTY, MICHIGAN

By

F. WELLS TERWILLIGER

A thesis submitted to the School of Graduate Studies of Michigan State College of Agriculture and Applied Science in partial fulfillment of the requirements for the degree of Master of Science, Department of Geology and Geography, 1952

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THE GLACIAL GEOLOGY AND GROUNDWATER RESOURCES OF VAN BUREN COUNTY, MICHIGAN

INTRODUCTION

Previous Work

For some time it has been deemed desirable that a more detailed map than the 1924 edition of Leverett's "Map of the Surface Formations of the Southern Peninsula of Michigan" be made available to the public.

Leverett did an amazing amount of work in the years he spent interpreting the surface geology of this and other states. However, he mapped on a broad scale, and did not intend to show the detail which can be obtained when mapping on a county basis, and with topographic map control.

To fill the need for more detailed work, county mapping has been carried on for some years by Miss Helen M. Martin of the Geological Survey Division of the Department of Conservation, and Dr. S. G. Bergquist, head of the Department of Geology and Geography at Michigan State College. The maps thus prepared are being transferred to a state base on a scale of 4 miles to the inch. The finished map as printed will be on a scale of 8 miles to the inch.

This report presents the surface geology and glacial history of Van Buren County, and a discussion of its groundwater resources, and their general relationships.

Description of the Problem

In 1947, State Geologist G. E. Eddy suggested that a study be made of the water resources of Van Buren County. He felt that this county should receive special attention, inasmuch as it has a large number of irrigation projects, and the information obtained would be of great aid in planning future projects, especially those which were intended to be supplied by water from deep wells. Because adequate domestic supplies are encountered at relatively shallow depths throughout most of the county, very little is known of the occurrence of the deeper, heavier, and more dependable water supplies which are needed for irrigation purposes.

The problem originally was intended to embrace only a study of the water resources of the county. It soon became apparent that this would result merely in a listing of the wells drilled, their depths, and capacities; and a brief discussion of the stream flow within the county. Hence, no information would be made available for the areas which had not been test-drilled, and broad conjecture would be the only basis for future drilling in the blank areas. Therefore, at the suggestion of Dr. Bergquist, the problem was broadened to include detailed mapping of the surface geology in order to give some basis for analysis of these blank areas.

After the mapping was completed, all available well logs were gathered and analyzed with respect to their relation to the surface geology.

Procedures

The glacial mapping was done mainly from observations along the roads, with only short traverses on foot, either where roads were impassable or where it was desired to examine certain features more closely. The county has a very good net of section-line roads, and is covered by a soils map and topographic quadrangles.

Leverett's map (1924) was used as a guide. The soils map (Wildermuth, 1926) was used in connection with test borings, gravel pits, excavations, road cuts, and other openings in the ground to determine the character of the drift. The glacial features were identified by local observation of topography and soil types. The topographic sheets were used extensively in the field to determine elevations and relief, as well as to give a better over-all view of certain of the larger features.

As a preliminary to gathering water- and well-data, a request that a log be kept of the drift, and that all water encountered in the drift be noted was sent to oil well operators with each drilling permit issued. Theoretically this information should be included in every oil well log, but in practice the glacial cover is generally logged as "Drift" through its entire thickness. The operators cooperated very well with this request, and many excellent logs were furnished.

Further well information was obtained from the Van Buren County Health Department records, and from a number of forms circulated to the school children by the Geological Survey Division. It was noted in studying this information that the average landowner had a considerable lack of knowledge of his own water supply. As an additional source of information, a number of water

well drillers were questioned as to the average depth to satisfactory domestic water supplies in various sections of the county.

Acknowledgments

The writer wishes to acknowledge his indebtedness to the many people who assisted in the preparation of this paper: To Dr. S. G. Bergquist who has given freely of his time in making a preliminary reconnaissance of the area, offering much advice during the field work and writing, and field checking the mapping, the author is very grateful.

To the Geological Survey Division of the Michigan Department of Conservation, without whose sponsorship the work would have been impossible, the writer is indebted.

The writer wishes to express his sincere thanks to the individual members of the Geological Survey Division who were extremely helpful: Mr. G. E. Eddy for his active interest in the project; Miss Helen M. Martin for her many suggestions in the glacial mapping, and criticism of the manuscript; and Mr. Norman Billings, formerly with the Survey, for his aid in interpreting the groundwater data.

Chapter I

SURFACE GEOLOGY

Description of the Area

Van Buren County lies adjacent to Lake Michigan in the southwestern part of Michigan (fig. 1). It is somewhat larger than most of the counties in the Southern Peninsula, as it contains sixteen full civil townships and fractions of three others.

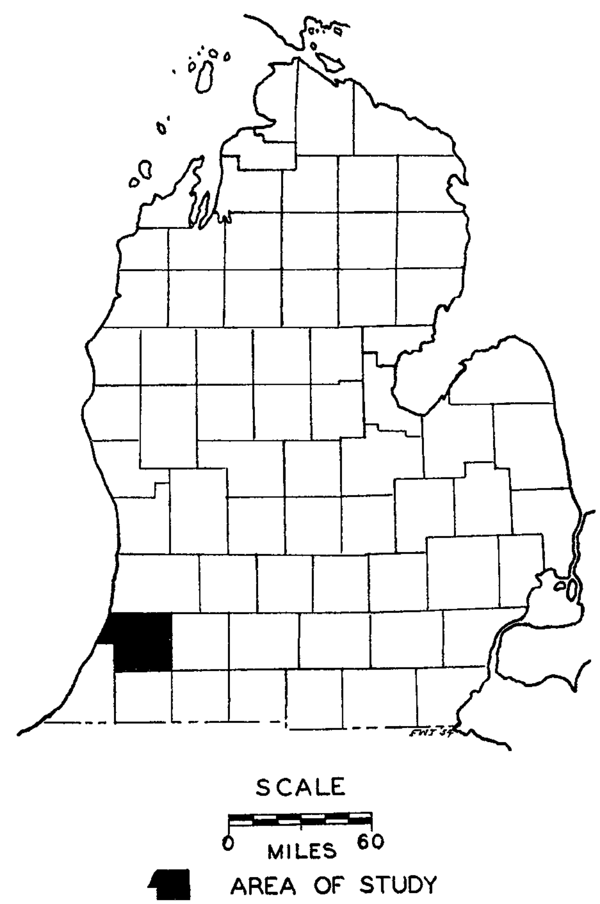


FIGURE 1

The major drainage system in the county is the Paw Paw River, covering an area of approximately 346 square miles. The next largest basin in the county is the drainage area of the South Branch of the Black River. The area of this basin is some 160 square miles. The headwaters of the Rocky River in the southeast, and Dowagiac Creek in the south-central parts of the county are tributaries of the St. Joseph River system and drain 56 square miles. A small area of 26 or 27 square miles in the northeast corner of the county is drained by the Kalamazoo River. The remainder of the county, about 37 square miles, is drained by small streams emptying directly into Lake Michigan (fig. 2).

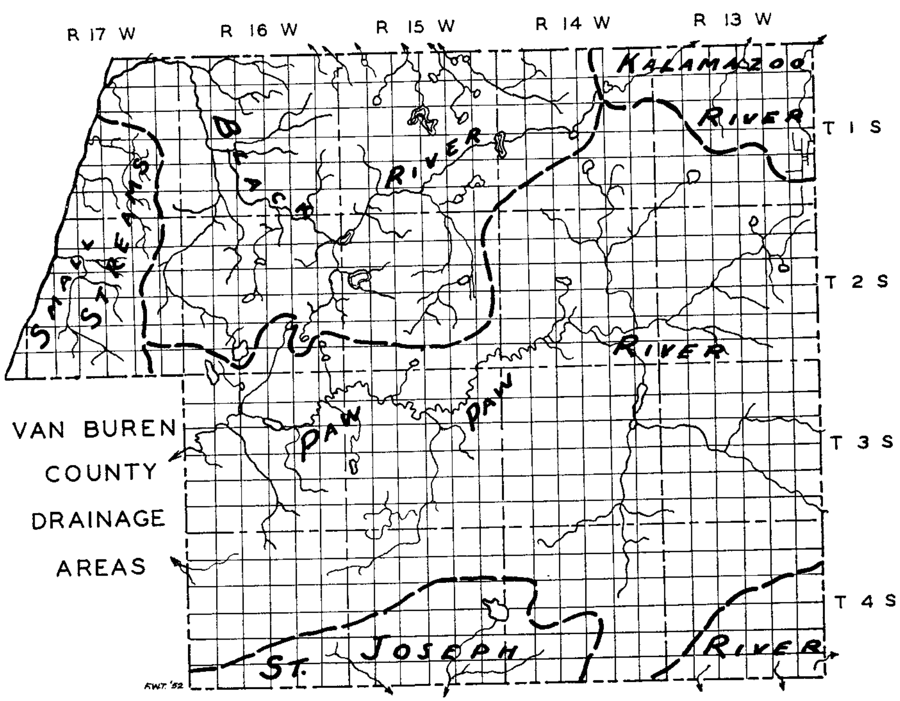


FIGURE 2

The soils of Van Buren County are predominantly sandy, but some heavier soils are in the central and western sections. The county also has several rather extensive deposits of organic soils associated with glacial drainageways and areas of ponded water. According to the "Soil Survey of Van Buren County" (Wildermuth, 1926,

p. 844) approximately 61 per cent of the area is covered by soils no heavier in texture than fine sandy loams. Sands and loamy sands predominate. About 11 per cent of the county is muckland and a little more than one-fourth of the soils in the county falls into the heavier textured classifications.

The topography of Van Buren County is characterized by a series of hilly morainic belts traversing the county from southwest to northeast. The highest point in the county is 1,060 feet in a moraine in the southeastern part. The general slope of the land is from this morainal tract westward to Lake Michigan. Nearly all of the land is sufficiently well drained for agriculture, excepting numerous bodies of marsh land and swamp, some of which are quite extensive. The slopes on most of the hillsides are quite steep, but generally not so steep as to allow excessive erosion because the open character of the soil is conducive to good absorption of rainfall (Wildermuth, 1926, p. 831).

General Surface Geology

The surface features of Van Buren County (pl. I) are associated with the activities of the Lake Michigan lobe of the Wisconsin ice sheet. The morainic systems in the county are the Kalamazoo, Valparaiso, and Lake Border.

The principal glacial drainage in the county was through the Dowagiac and Paw Paw River drainageways. The upper portions of the Dowagiac Drainageway later became incorporated in the glacial Paw Paw River system.

Glacial lake plains are located in the western and northwestern parts of the county. These deposits were laid down in the waters of Lake Glenwood and a smaller, unnamed glacial lake which lay mainly in Allegan County, with an extension south into Columbia Township of Van Buren County.

Two areas of lake deposition in the county are mapped as features related to ponded waters rather than to glacial lakes. These are the Brandywine Lake depression in Pine Grove Township and the extensive, low-lying tract surrounding the junction of Waverly, Arlington, and Columbia townships. Both of these areas contain thick organic deposits, signifying their existence as lakes long after the cessation of glacial activity. Furthermore, the presence of shore lines on all sides of the lakes indicate that their deposits are lacustrine rather than glaciolacustrine.

The Kalamazoo Morainic System

The Kalamazoo morainic system occupies the southeastern part of Van Buren County, including nearly all of Porter and Antwerp townships and parts of Decatur and Almena townships. This system is described by Leverett (1915, p. 174) as consisting of two ridges, separated by a gravel plain. However, in Van Buren County the system does not have this aspect, but consists of a series of three ridges connected by minor cross-ridges. Disconnected patches of outwash lie between these cross-ridges.

The greatest altitude of the moraine in Van Buren County is about 1,060 feet in section 35, Antwerp Township. The average elevation of the ridges is 950 feet or a little higher. Maximum relief within the moraine is 190 feet from the level of Paw Paw Lake (872 feet) to the high point in Antwerp Township. The Outer Ridge shows very little relief above the outwash flanking it on either side. The outwash between the ridges rises to an elevation nearly equal to the elevation of the general crest line of the intermediate and inner ridges. The back-slope of the Inner Ridge drops very sharply to a narrow till plain (?). The relief here is some 160 feet from the slope break to the ridge crest.

The ridges of the Kalamazoo Moraine exhibit strong knob and basin topography. The knobs stand 25 to 50 feet above the level of the outwash aprons, but internal relief is 50 to 75 feet, as the bottoms of the basins are 25 or more feet below the outwash level (Leverett, 1915, p. 176).

A minor ridge diverges from the inner border of the Kalamazoo Moraine in the vicinity of Wolf Lake in northeastern Almena Township, running southwest to a point on the East Branch of Paw Paw River just east of Paw Paw. Leverett (1915, p. 182) suggests that this ridge may be a connecting link between the Kalamazoo and Valparaiso systems. However, the writer believes that the ridge is continued in a series of somewhat isolated hills south of the river and north of Lawton. On the basis of this interpretation the ridge completely ties in with the Kalamazoo system. The hills are mantled by wind-blown material which tends to obscure their morainic character. Although indicated on Leverett's 1924 map, no mention of them is made in Monograph LIII.[1] The ridge is gently undulating and of low relief, rising but little above its outwash plain at the point of departure from the Inner Ridge. For most of its length to the East Branch of Paw Paw River the ridge is actually overtopped by the outwash, and only its back-slope is unobscured.

[1]Leverett, Frank, and Taylor, Frank., The Pleistocene of Indiana and Michigan and the History of the Great Lakes, U. S. Geol. Survey Mon. LIII, 1915.

The outwash associated with the Kalamazoo Moraine in Van Buren County in the main is spotty and broken. All but a small part of the outwash of the Outer Ridge lies outside of the county. A part of a large area of outwash in front of the Inner Ridge lies in southern Porter Township, and extends south and westward into Cass County. Several small patches of gravel deposits lie between the ridges in Porter and Antwerp townships. The largest continuous outwash plain of this system lying wholly within the county fronts the low, diverging ridge in Almena and Antwerp townships.

The area between this minor ridge and the Inner Ridge is occupied by a broad, shallow valley with gently sloping sides. The entire expanse is delineated on Leverett's map (1924) as sandy drift, being of the type deposited by water issuing from the ice front. Although the drift on the west side of the valley is unquestionably outwash, the deposits on the eastern side are in the nature of a till plain,[2] whose character has been almost masked by a thick cover of windblown sand.

The axis of the valley is a line of glacial drainage which in the area east of Decatur flowed between the ice front and the inner slope of the moraine. At their highest stage the waters of this drainage probably rose to 800 or 820 feet. This fact was not recognized until after the map (pl. I) was drafted, and thus the area running from Lawton southwestward is shown as till plain. Actually, little evidence of this drainage is to be found on the ground, so possibly till plain is the proper designation. The area of till plain behind the weak ridge from Almena to Lawton may also have been washed somewhat by drainage during temporary periods of high water.

Lying between the till plain of the Kalamazoo morainic system and the forefront of the Valparaiso system is an extensive glacial drainageway. The character and development of this line of drainage will be discussed in the section of this paper dealing with glacial history and development of glacial drainage.

The Kalamazoo Moraine is composed mainly of sandy and gravelly drift. Some areas have a covering of bouldery clay, in most places only a few feet in thickness; however, boulders are prevalent throughout the moraine. Sand and gravel beds are quite thick, but

[2]Till plains are also known as ground moraines, glacial drift that was not disturbed after deposition, whereas the hilly areas are pushed up glacial drift. *Editor.*

are underlain by clay till at moderate depths in some areas, both in the moraine and in the outwash plain to the east (Leverett, 1915, p. 177). The log of a well in the southeast quarter of section 5, Porter Township shows 447 feet of drift. All the drift is sand and gravel excepting the basal 23 feet, which is logged as mud and gravel from 424 to 441 feet (17 feet) and as pea gravel from 441 to 447 feet (6 feet) resting on bedrock (Coldwater shale). A well in section 13, Antwerp Township has the following drift log:

	Thickness	Depth
Sand and gravel	240	240
Sand, reddish*		at 240
Sand and gravel	63	303

(*Possibly the top of Illinoian drift?)

This well is located in a break in the moraine just east of Mattawan where the surface lies some 100 feet lower than the adjoining ridges. Logs of other wells in the moraine show 350 to 450 feet of drift, predominantly sand and gravel with some "mud." A number of detailed well logs from this area are given in the appendix.

The Valparaiso Morainic System

The Valparaiso morainic system occupies the major portion of Van Buren County. The moraine is extremely bulky, but does not rise to the high altitudes of the Kalamazoo Moraine. The width of the moraine across its widest part in Columbia, Bloomingdale, and Pine Grove townships is about 18 miles. Several individual masses are up to five miles in width. The extreme width does not include the deployed patches of moraine lying on the till plain behind the main ridges.

The moraine in Van Buren County diverges from one very broad ridge in the south to three ridges in the north, and the whole system embraces many outlying moraines on the till plain to the west. Relief on the inner border ranges from 100 to 200 feet. Nearly everywhere the ridge crest is close to the inner border, but in the vicinity of Bloomingdale the maximum elevation of the ridge is reached about three miles from the inner margin. Except along the front of Kendall Ridge, the relief along the outer border is slight or altogether lacking because of the high level of the adjoining outwash. Locally this slight relief is exaggerated by the presence of deep pits in the outwash close to the boundary.

The topography of the main ridge is generally strong in Van Buren County except in the region surrounding Bloomingdale. Here it is of a quite subdued sag and swell type, and was originally mapped as till plain (Leverett, 1924). More detailed examination has led the writer to classify this area as morainic. This broad ridge is separated from a weaker ridge running through Gobles by two or three miles of till plain. The Gobles Ridge has only 15 to 20 feet of relief on its inner border, and is nearly overtopped by an area of outwash that fronts it. Separating this outwash from Kendall Ridge is the Brandywine Lake depression and drainage channel.

Kendall Ridge is the highest-standing and most rugged feature of the Valparaiso system in the county. Its maximum elevation of 980 feet is the highest point for the entire system. This ridge also exhibits the greatest amount of relief; the high point of 980 feet is 200 feet above the level of the drainage channel to the east. The front of Kendall Ridge is kamic in character with many gravelly knobs making up the abrupt eastern slope of this moraine. The moraine north of Kendall is made of knolls 60 to 80 feet in height. This area was formerly thickly set with boulders, some 8 to 10 feet in diameter. Leverett (1915, p. 183) mentions the occurrence of jasper conglomerate, a rock type generally associated with deposits of the Huron ice lobe. He attributes its presence here to the reworking of earlier deposits by the Wisconsin ice. The writer located a single large boulder of jasper conglomerate in a gravel pit in section 9, Pine Grove Township.

It is rather difficult to correlate the moraines along the outer border of the Valparaiso system. The writer believes Leverett was in error in interpreting Kendall Ridge as a possible cross-link between the Valparaiso and Kalamazoo systems. By studying the terraces along the sides of the Dowagiac Drainageway a consistent level at 760 feet was found on both sides of the channel opposite Kendall Ridge. A channel at the same elevation was found running along the east side of Prospect Hill, just south of the village of Paw Paw. The writer is of the opinion that Prospect Hill and the low moraine upon which Decatur is situated are contemporaneous with Kendall Ridge. The moraine running through and north of Decatur was mentioned by Leverett in Monograph LIII, but is not shown on his 1924 map. Like the moraines west of Lawton, it too, is mantled by wind-blown sand.

The weak ridge running through Gobles is separated from Kendall Ridge at its north end by a line of drainage leading northward from the Brandywine Lake depression. The two ridges seem to be separated two or three miles south of Gobles by a narrow, lower, and therefore later drainage channel leading southwestward. This channel now carries Brandywine Creek, the present outlet of Brandywine Lake. Between these two lines of drainage the Gobles Ridge is fronted by a slightly irregular outwash apron.

The continuation of the Gobles Ridge to the south of Paw Paw River is probably found in the morainic knobs and ridges projecting through the outwash in front of the main ridge. The extensive apron of outwash on the north side of the hill just west of Paw Paw seems to indicate a strong re-entrant in the ice front at the position of the present Paw Paw River valley. The writer believes this re-entrant to be the beginning of the break-through which allowed the Paw Paw Drainageway to cut the Valparaiso Moraine. This development will be outlined later in the section on glacial history. One of the knobs in this intermediate chain, in the area directly south of Cora Lake, is decidedly kamic in character. In a gravel pit in this knob several small boulders of jasper conglomerate were found.

The broad section of the Valparaiso Moraine in Arlington Township has two rugged armlike projections. One of these runs north to the vicinity of Bangor. Its peak is slightly above 800 feet and drops abruptly from this point on three sides, losing 100 feet of altitude in a distance of one-half to three-fourths of a mile. The second arm, referred to as Webster Hills, runs southward nearly to Hartford and is even stronger in character. Its relief above the bordering areas is up to 150 feet, with the highest point about 850 feet above sea level. The northern part along the Bangor-Hartford Township line and the southern tip, just across the Paw Paw River from Hartford are kamic. The main part of this section of the moraine is composed of knobs standing 60 to 80 feet above the intervening areas. Some of the basins are occupied by swamps, and others by lakes; several lakes are 20 to 30 feet below the general level of the valleys and swales. The entire section has an abrupt border on all sides with about 50 feet of relief (Leverett, 1915, p. 216).

Another broad section of the Valparaiso system occupies southern Lawrence Township. This tract, which has a northeasterly extension along the Lawrence-Paw Paw Township boundary, narrows to a fairly broad ridge southwestward across the southeast corner of Hartford Township and extends into Keeler Township. In general aspect, this area is not as rugged as the area in Arlington

Township. It does, however, have the same abrupt borders as noted in the section to the north except on its southeast side where the adjoining outwash rises above 800 feet in some places. A level to gently undulating area in sections 20 and 21, Lawrence Township might be mapped as till plain except for the fact that it stands well up within the moraine. Approaching the Berrien County line to the southwest, the moraine is nearly cut through by several swamps.

A number of more or less disconnected morainic islands lie behind the main bulk of the Valparaiso Moraine. An isolated hill covering about three and one-half square miles, south of Hartford, has a total relief of 180 feet above the surrounding till plain. This hill seems to be the link between the Webster Hills area and a high range of kamic hills south of Watervliet. This curving line of hills formed the right bank of a portion of the Paw Paw River Drainageway. Some of the more prominent morainic patches are: The area between Breedsville and Saddle Lake in Columbia Township; a fairly low ridge running from a point just west of Breedsville to Lacota; the hills between McDonald and Van Auken Lake in Bangor Township and a hill lying mainly in sections 16 and 17, Bangor Township.

Throughout the Valparaiso Moraine the topography and soils have a distinctive association. The broad, level tracts have mainly loam and silt loam soils, and the more rugged portions are characterized by sandy loams and loamy sands. According to Leverett (1915, p. 218) boulders were found in moderate number on the surface of this moraine. Most boulders are crystalline rocks some three feet or less in diameter. Most of the boulders are no longer evident, having been gathered for use in foundations or the filling of hollows. No great number of stone piles is visible in the fields although a few huge boulders of sandstone have been noted in several localities. The only ones visited by the author lie in the southeast quarter of section 17, Bangor Township. There were originally three boulders in this group, but one was "quarried" near the turn of the century to supply stone for a house in Hartford. The two remaining blocks of sandstone measure 24 by 21 by 21 feet and 30 by 18 by 15 feet along the sides and project 6 to 8 feet above ground (figs. 3 and 4). Their depth below the surface is unknown, but one was found to extend at least 6 feet below (Leverett, 1915, p. 218). Farmers report that many more sandstone boulders are encountered at or just below plow depth on this hilltop. It is believed

FIGURE 3

Boulders of Marshall sandstone on top of morainic knob in section 17, Bangor Township. These boulders were carried from the outcrop by the ice sheet, and left on top of the moraine when the ice melted. Three boulders were originally in the group, but one was "quarried" years ago to furnish stone for a house in Hartford.

that these boulders were quarried by the ice from the edge of the Marshall cuesta and transported to their present site superglacially.

Excepting two or three relatively small areas of outwash mentioned in the description of the Kendall and Gobles ridges, the main bulk of outwash in the Valparaiso system lies in the southern half of the county. The main ridge of the moraine lying in Lawrence and Keeler townships is fronted by an apron of outwash averaging four miles in width. The inner edge of this outwash nearly everywhere stands at 800 feet above sea level. This elevation overtops much of the moraine along its juncture, but the outwash is generally separated from the moraine by a series of pits 20 or more feet in depth. This pitting serves to differentiate the moraine from the outwash in areas where their soils are very similar.

FIGURE 4

Close-up of Marshall boulder. This view shows the cross-bedding which is characteristic of much of the Marshall sandstone. Notice how the effects of weathering have heightened the details and pitted the surface of the rock.

The thickness of the drift through the extent of the Valparaiso Moraine varies considerably.[1] The average seems to be in the neighborhood of 250 feet with extremes running from 146 feet in section 9, Lawrence Township to 532 feet in section 30, Waverly Township. In several belts trending northwest-southeast the drift ranges from 300 to 400 feet in thickness. These belts mark the courses of pre-glacial bedrock valleys. The thickest drift naturally is encountered where these buried valleys intersect morainic ridges. The place where the drift is only 146 feet thick in the Paw Paw Drainageway lies directly over a bedrock upland. From the logs of oil wells drilled it appears that the drift is mainly sand and gravel with small amounts of mud and clay. The amount of mud or clay logged seems to be somewhat greater in the till plains than

[1]A map showing drift thickness is on file in the office of the Geological Survey Division. Thicknesses are also shown in the appended well logs. *Editor.*

FIGURE 5

View of large gravel pit on south side of U. S. Highway 12 just west of Paw Paw. This pit shows much "crag" or cemented sands and gravels. Several beds of "crag" stand out from the left side of the pit. "Crag" is formed by the deposition of calcium carbonate around the individual cobbles and stones in a gravel bed. Such beds were cemented when the water table stood at a higher level than at present.

in the moraine. Very few of the well logs give sufficient detail to pick a contact between Wisconsin and Illinoian drifts. Throughout the northern part of Bloomingdale Township it appears that the Wisconsin drift sheet ranges from 140 to 240 feet in thickness. Other scattered wells indicate that the Wisconsin till may average around 160 feet in thickness in the moraine and be considerably thinner in the till plains. A number of gravel pits opened in kames throughout this morainic system exhibit a strong development of "crag," or cemented sands and gravels. Notable among these is the pit located on U. S. Highway 12 about five and one-half miles west of Paw Paw. Here the "crag" formation juts out very strongly from the sides of the pit and dips with the bedding. (figs. 5 and 6)

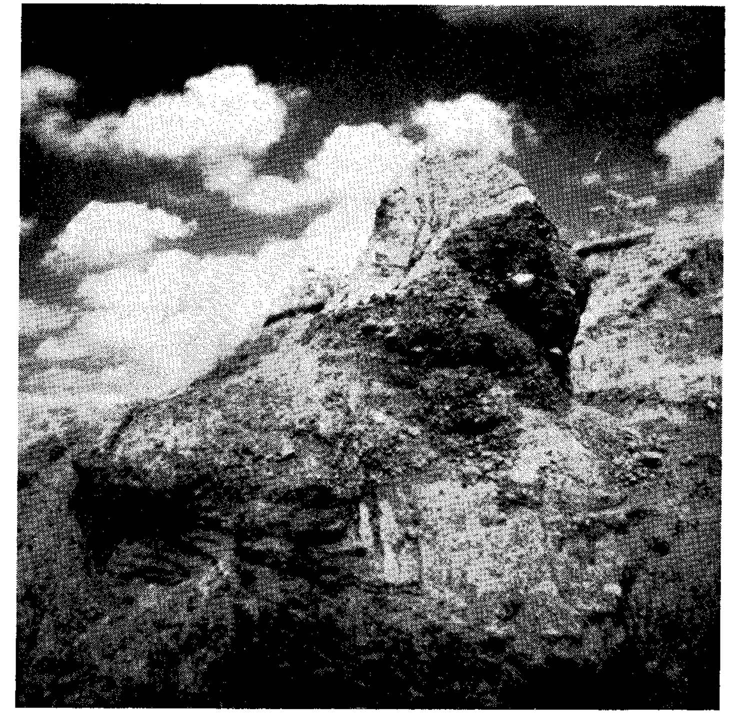


FIGURE 6

A pinnacle of "crag" in the bottom of a gravel pit north of Hartford. This view shows the great variation in size of pebbles and stones in the beds.

The Lake Border Morainic System

In Van Buren County the Lake Border morainic system is represented by one member, the Covert Ridge, a narrow feature of relatively low relief. Its width in Van Buren County varies from not much more than one-fourth to not quite one and one-half miles. The ridge roughly parallels the shore line of Lake Michigan, and is from one and one-half to four miles inland. No recognizable outwash fronts this ridge, although it may be present in some of the sandy materials on the till plain to the east. The gently sloping till plain behind the moraine was modified by the waters of Lake Glenwood which rose to an elevation of 640 feet.

Covert Ridge is composed mainly of clay till. In some places the surface is sandy, but in general the soils on the ridge are loams and sandy loams. The till is interbedded in places with sand and

FIGURE 7

A small, active sand dune in southern Bangor Township. The trees along the edge of this dune have been buried to a depth of four or five feet by the advance of the dune. At the time the picture was taken, a fifteen- to twenty-mile wind was blowing, and sand was continually moving over the crest of the dune.

gravel, but where the moraine has a sandy surface the core is usually of clay.

Much of the surface of the till plain behind the moraine is sandy and underlain at a shallow depth by clay. This has led to the development of water-logged soils of the Saugatuck series. The surface of the till plains both east and west of Covert Ridge, as well as part of the ridge itself, are spotted with roughly crescentic sand dunes. These dunes are rarely more than 10 feet in height, and few are more than a few hundred feet in width (fig. 7). The dunes are small, active, but seem to be stabilized easily by the planting of cover. Because of their small size and instability, they were probably developed when the original cover was removed by cropping.

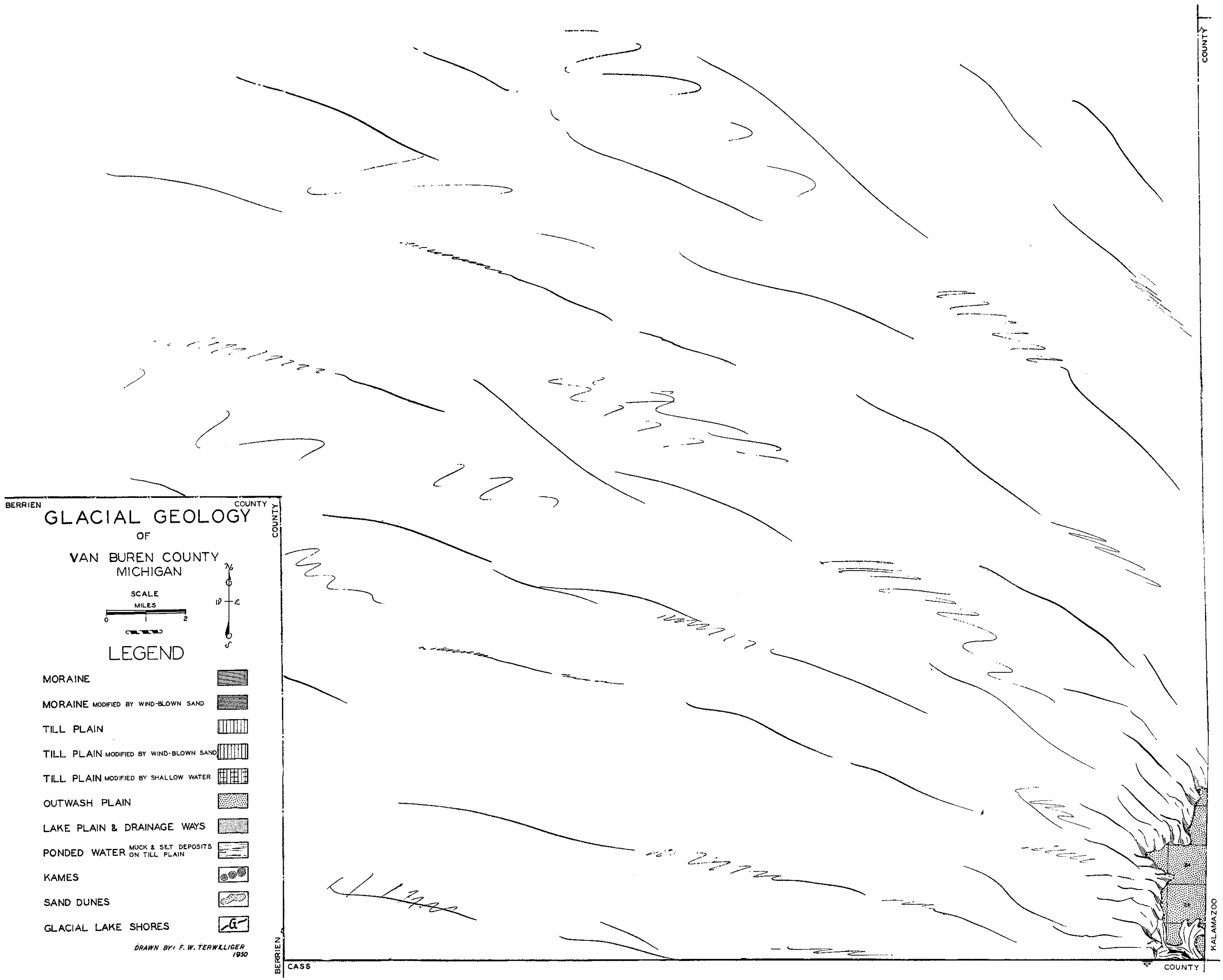


FIGURE 9
First stage of glacial retreat in Van Buren County

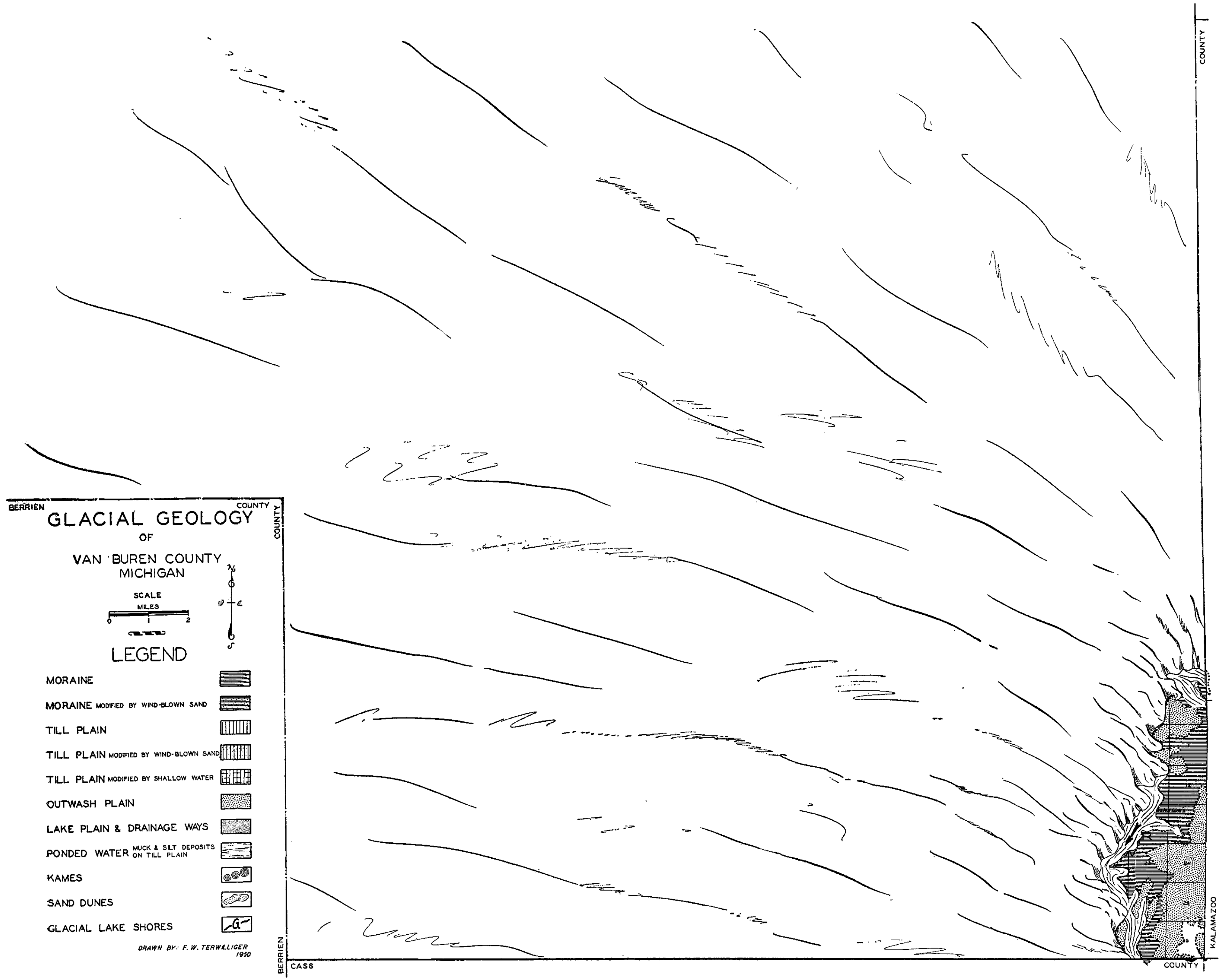


FIGURE 10
Second stage of glacial retreat in Van Buren County

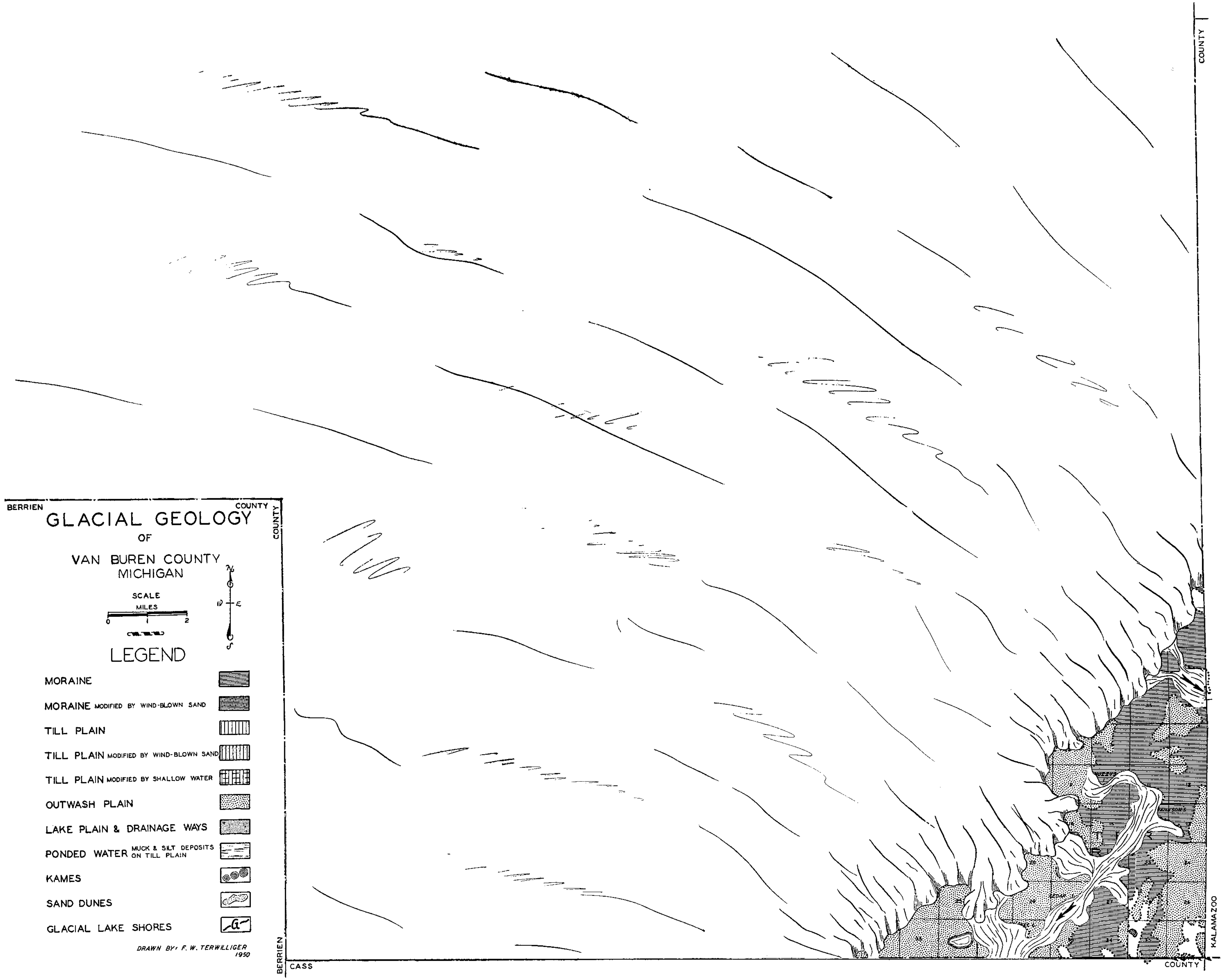


FIGURE 11
Third stage of glacial retreat in Van Buren County

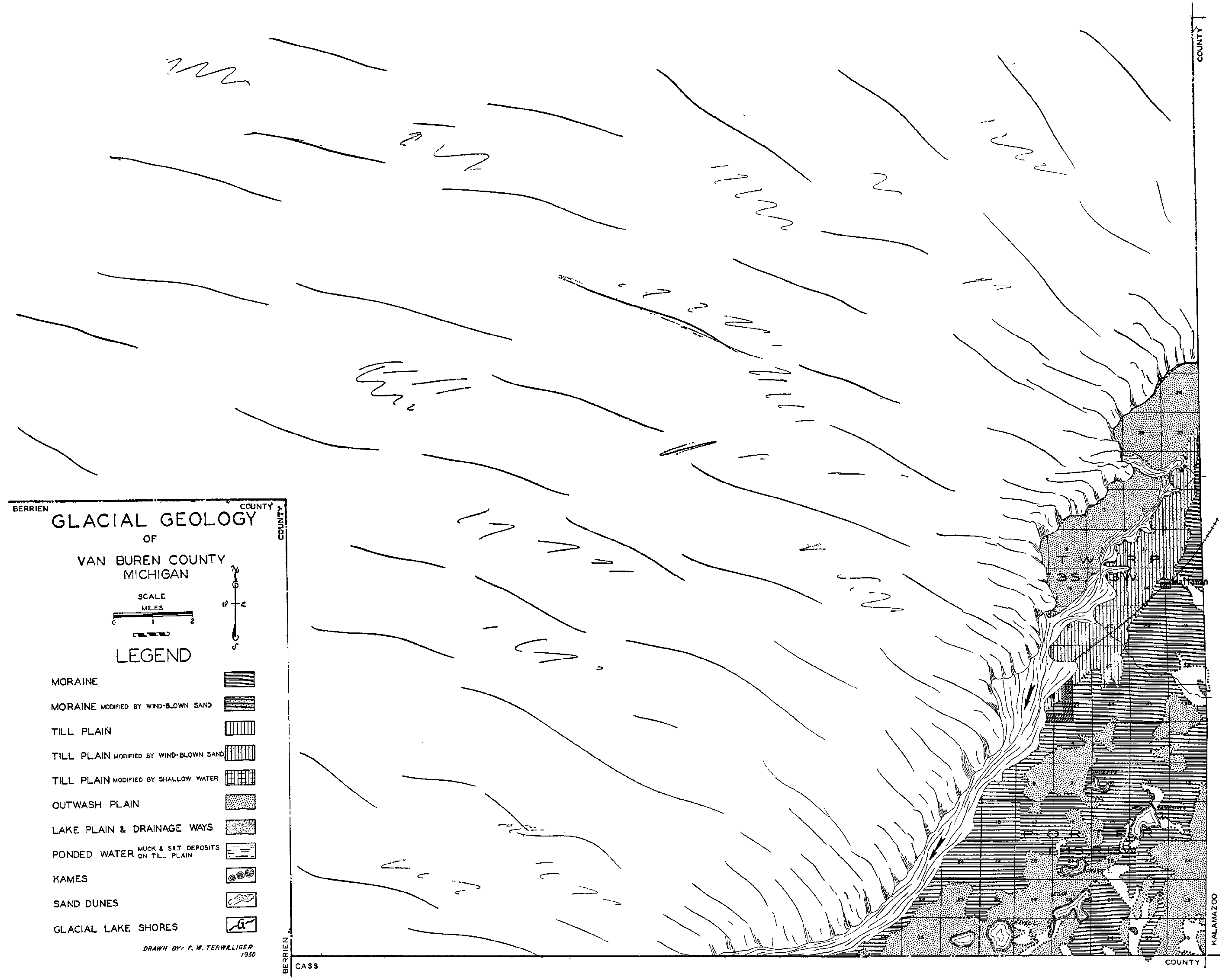


FIGURE 12
Fourth stage of glacial retreat in Van Buren County

Chapter II

GLACIAL HISTORY AND DEVELOPMENT OF GLACIAL DRAINAGE

General

The surface features of Van Buren County are all included in the Cary substage of Wisconsin glaciation. From their bulk, it is believed that both the Kalamazoo and Valparaiso moraines mark readvances of the ice after retreats of unknown magnitude. The Lake Border Moraine also marks a readvance of the ice after a retreat into the basin occupied by Lake Michigan. This belief is borne out by the varved glaciolacustrine deposits directly underlying the till plain behind the moraine. No direct evidence of readvance was found in Van Buren County in connection with either the Kalamazoo or Valparaiso moraines, but Flint (1947, pp. 250-51) ascribes this relationship to the formation of the Valparaiso Moraine.

The first definite stand of the ice in the county was at the position of the Outer Ridge of the Kalamazoo Moraine. Successive retreats and halts gave rise to the intermediate and inner ridges and the weak ridge in Almena Township. After retreating an unknown distance, the ice readvanced to the position of Kendall Ridge and its correlatives. The ensuing retreats and possible small readvances formed the remaining subdivisions of the Valparaiso morainic system.

Following the deposition of the morainic outliers in the till plain back of the Valparaiso Moraine, the ice retreated to an undetermined position in the Lake Michigan basin. It was during this stage that the varved deposits were laid down in lakes behind the area occupied subsequently by the Lake Border Moraine.

Following a brief halt after its retreat into Lake Michigan, the ice readvanced to the position of Covert Ridge of the Lake Border morainic system. This marks the final stand of the ice in Van Buren County. The youngest deposits associated with glaciation in the county were laid down in the shallow waters of Lake Chicago and its embayment in the valley of the Black River.

Kalamazoo Morainic System

The first stand of the ice in Van Buren County was along the crest of the Outer Ridge of the Kalamazoo Moraine in southeastern Porter Township. During this interval of relative stability the drainage from the portion of the ice front within Van Buren County was southeastward into St. Joseph County (fig. 9).

Figure 10 depicts the ice standing on the position of a ridge intermediate between what are commonly termed the Outer Ridge and the Inner Ridge of the Kalamazoo Moraine. During this phase a line of drainage was developed through Bankson Lake southward to the Rocky River in Cass County by way of Sheldon Creek. This water eventually entered the St. Joseph River at Three Rivers.

The ice front then retreated to the general line marked by the Inner Ridge (fig. 11). Here the main flood of water, after passing over the outwash plain, flowed south and west through Cedar Lake to the chain of lakes in Cass County which form the headwaters of Dowagiac Creek.

The final phase of drainage in the Kalamazoo episode was developed as the ice stood on the position of the weak ridge in Almena Township (fig. 12). South of Lawton, in Antwerp Township, the ice front was somewhere not far behind the Inner Ridge. A line of drainage heading in the swampy area in northeast Antwerp Township flowed between the ice front and the back-slope of the Inner Ridge, passing over an area shown on the map (pl. I) as till plain. As the water left little or no evidence of its passage, this line of drainage is mainly inferred.

Valparaiso Morainic System

The question as to whether the Valparaiso Moraine should be classified as recessional or terminal must be decided on the basis of evidence outside Van Buren County. No indication of retreat and readvance was uncovered by the writer in the part of this moraine lying in Van Buren County. The history of the formation of the Valparaiso system is marked by a series of retreats and halts and represents a period of general fluctuation.

The first stand of the ice in the formation of the morainal ridges of this system was along the west side of the Dowagiac Drainageway. At the front of Kendall Ridge a great deal of water activity resulted in the development of a series of kamic knolls. South of Kendall Ridge the ice front must have begun to develop the re-

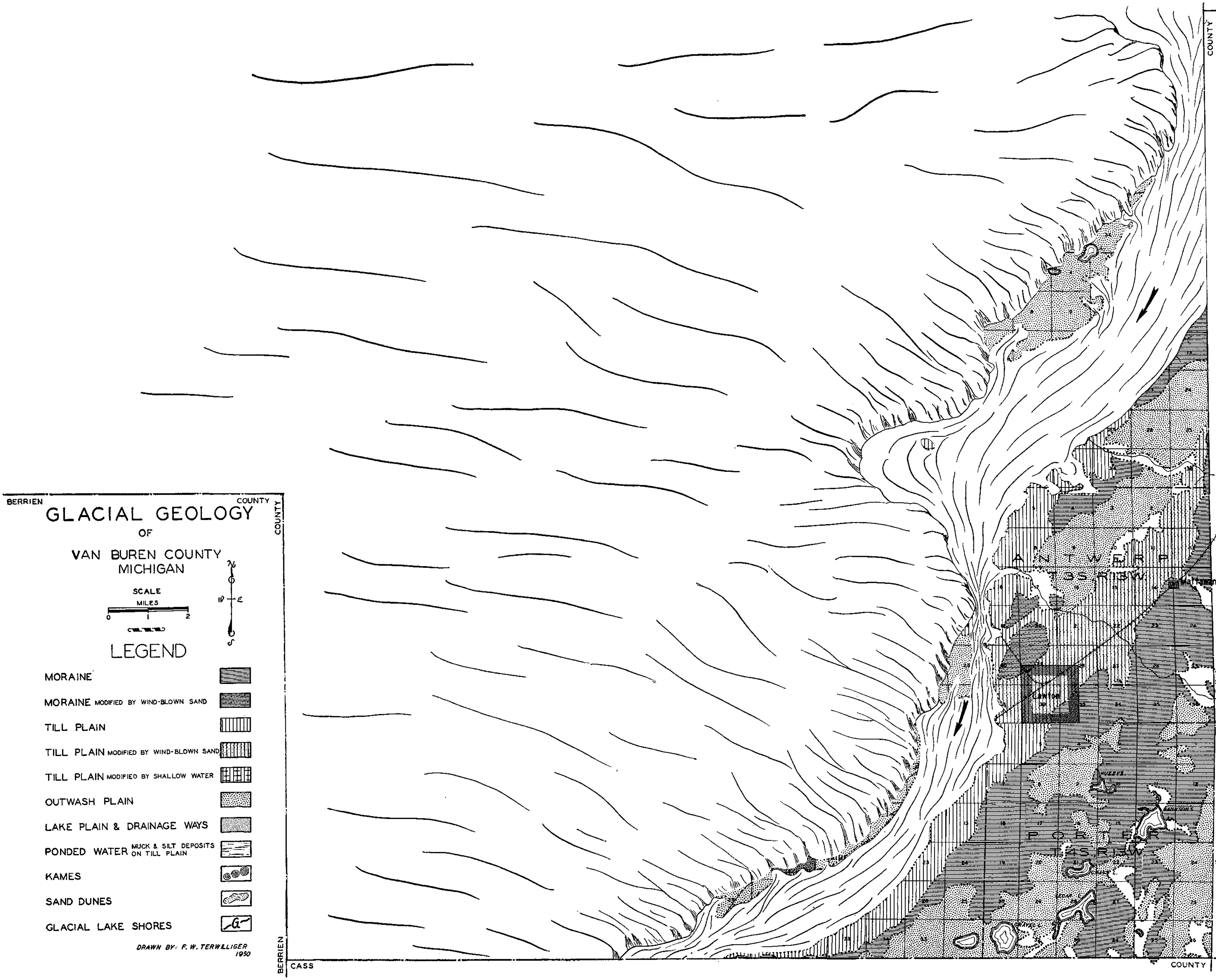
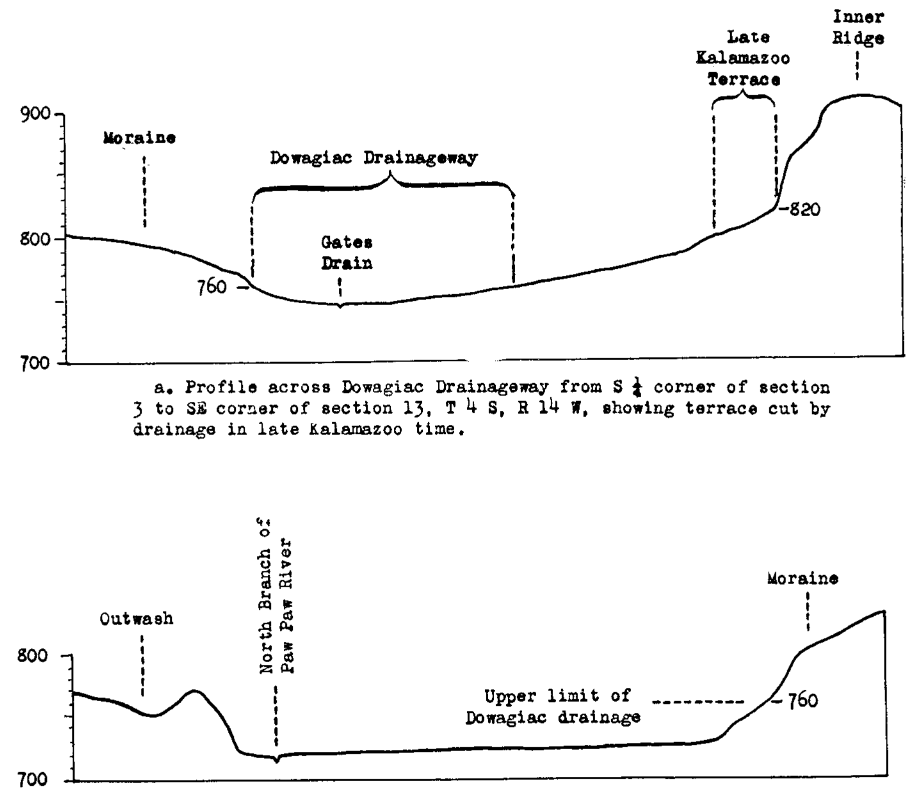


FIGURE 13
Fifth stage of glacial retreat in Van Buren County

entrant which eventually gave rise to the break-through for the Paw Paw River Drainageway. Continuing southward, the front of the ice probably extended through Prospect Hill south of Paw Paw and onto the low moraine running through Decatur (fig. 13).

While the ice was resting in this position, a large volume of water passed down the Dowagiac Drainageway. This water, which flowed southwestward along the ice margin, was augmented by glacial Kalamazoo River entering the drainageway in the vicinity of Plainwell in Allegan County. The level of the water is marked by a terrace along the east side of the valley at an elevation of 760 feet above sea level (fig 8). According to Leverett (1915, p. 219) the drainageway emptied into Lake Dowagiac at an elevation near 720 feet. Other lakes, no doubt, were present throughout the length of the spillway, especially in those areas now occupied by exten-



a. Profile across Dowagiac Drainageway from S ¼ corner of section 3 to SE corner of section 13, T 4 S, R 14 W, showing terrace cut by drainage in late Kalamazoo time.

b. Profile across Dowagiac Drainageway from center of section 9 to E ¼ corner of section 23, T 2 S, R 13 W.

FIGURE 8

sive mucklands. These lakes were connected by narrower channels such as those running on the east and west sides of Prospect Hill. The levels of the lakes may have been raised periodically by temporary ice dams in the constricted channels.

The second stand of the ice is marked in the northern part of the county by the ridge upon which the village of Gobles is situated. South of the re-entrant in the Paw Paw River valley the ice front may have stood along the outermost series of more or less disconnected morainic outliers in front of the main ridge. The prominent hill just west of Paw Paw is one of these (fig. 14).

During this phase, a channel was opened on the west side of Prospect Hill where formerly the water in the Dowagiac Drainageway had passed to the east of the hill. This second channel was somewhat lower than the first, allowing the water in the upper part of the system to subside. The level of the bank of the lower channel is about 750 feet. Undoubtedly, a certain amount of ponding occurred in the Paw Paw River valley re-entrant, and some of the ponded waters occupied a portion of the till plain in central Waverly Township. Although no shore lines were observed in the field, their absence is not significant. Bodies of shallow water which fluctuate in level may not leave any shore features, especially when one or more sides are banked against the face of the glacier.

Following retreat of the ice from the ridge passing through Gobles, the glacier made a third halt. In the northern part of the county it began to build the bulky moraine in the western half of Bloomingdale Township (fig. 15). South of the Paw Paw River the front of the ice lay along a line running south and west from the northwest corner of Paw Paw Township. In crossing Hamilton and Keeler townships the ridge thus built up is somewhat separated from the main Valparaiso ridge by outwash. In southern Keeler Township the outwash covers the ridge in some places. During this interval the drainage remained essentially the same as in the preceding phase. It seems entirely possible that ponding of water began to take place at this time in the present muckland area of northeastern Arlington Township.

The fourth halt of the ice continued the building of the moraine in Bloomingdale Township to the north. In the southern part of the county the ice stood upon the main ridge of the Valparaiso Moraine. The front of the ice in Lawrence Township lay on the west side of Brushy Creek in sections 22, 27, and 33; and con-

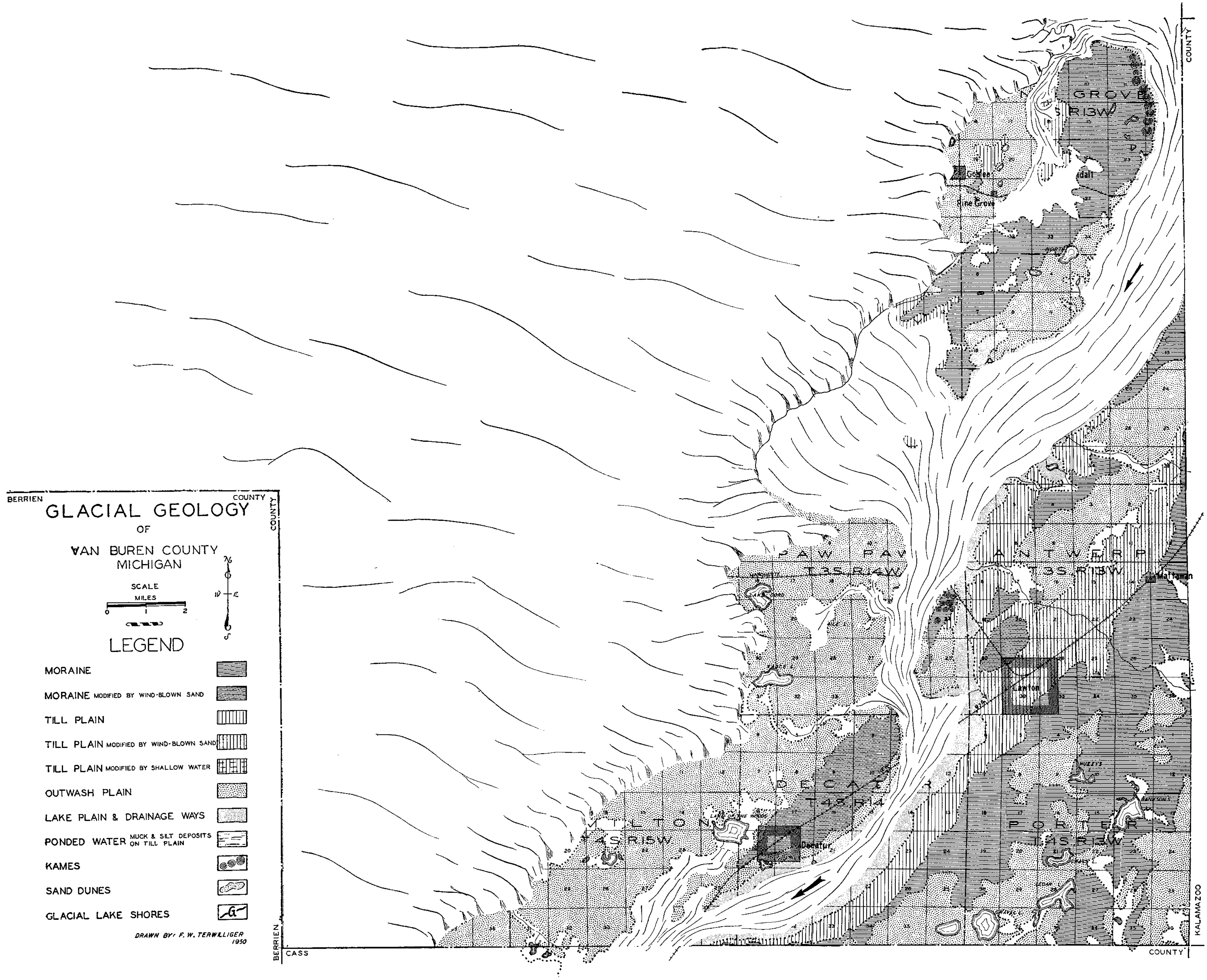


FIGURE 14
Sixth stage of glacial retreat in Van Buren County

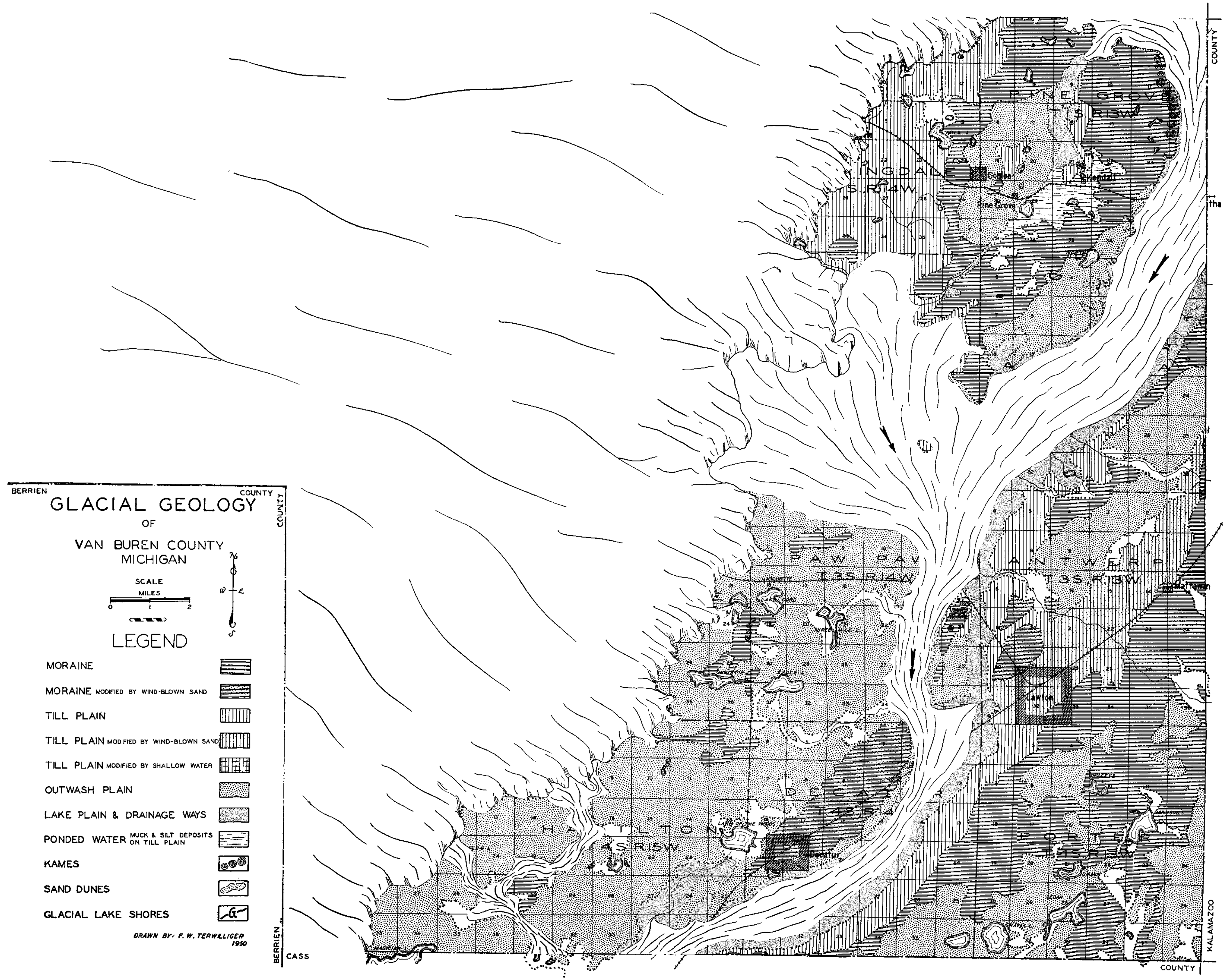


FIGURE 15
Seventh stage of glacial retreat in Van Buren County

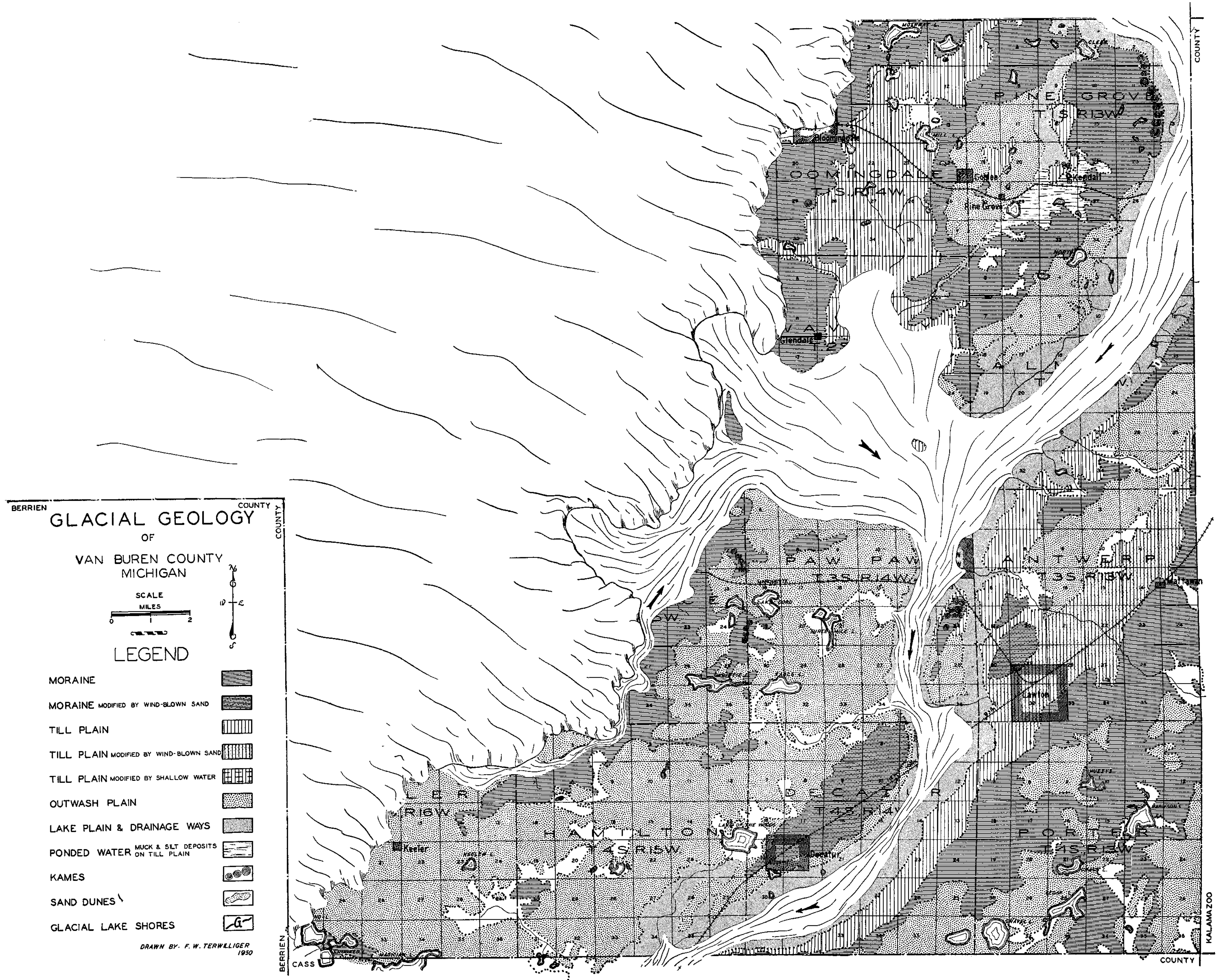


FIGURE 16
Eighth stage of glacial retreat in Van Buren County

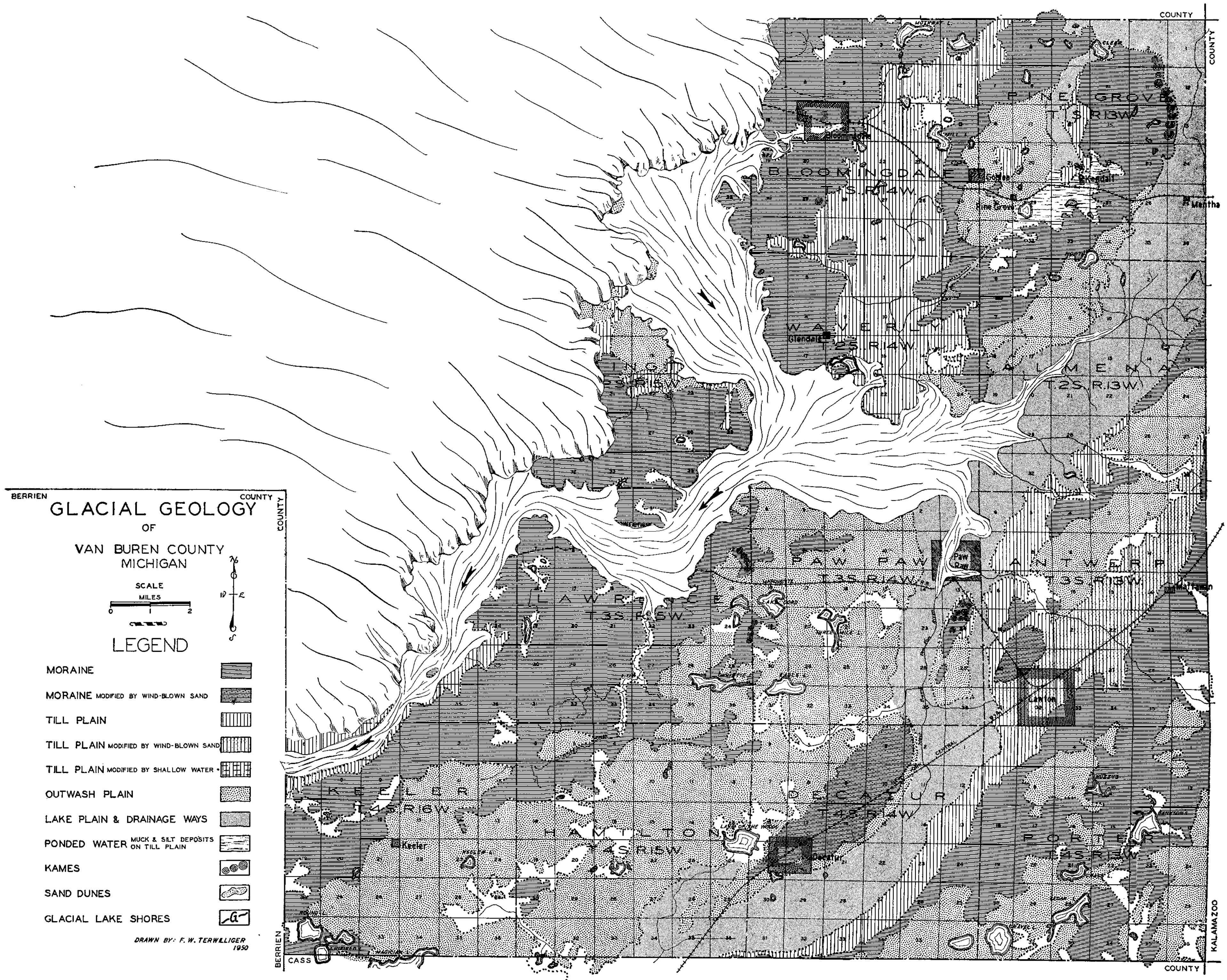


FIGURE 17
Ninth stage of glacial retreat in Van Buren County

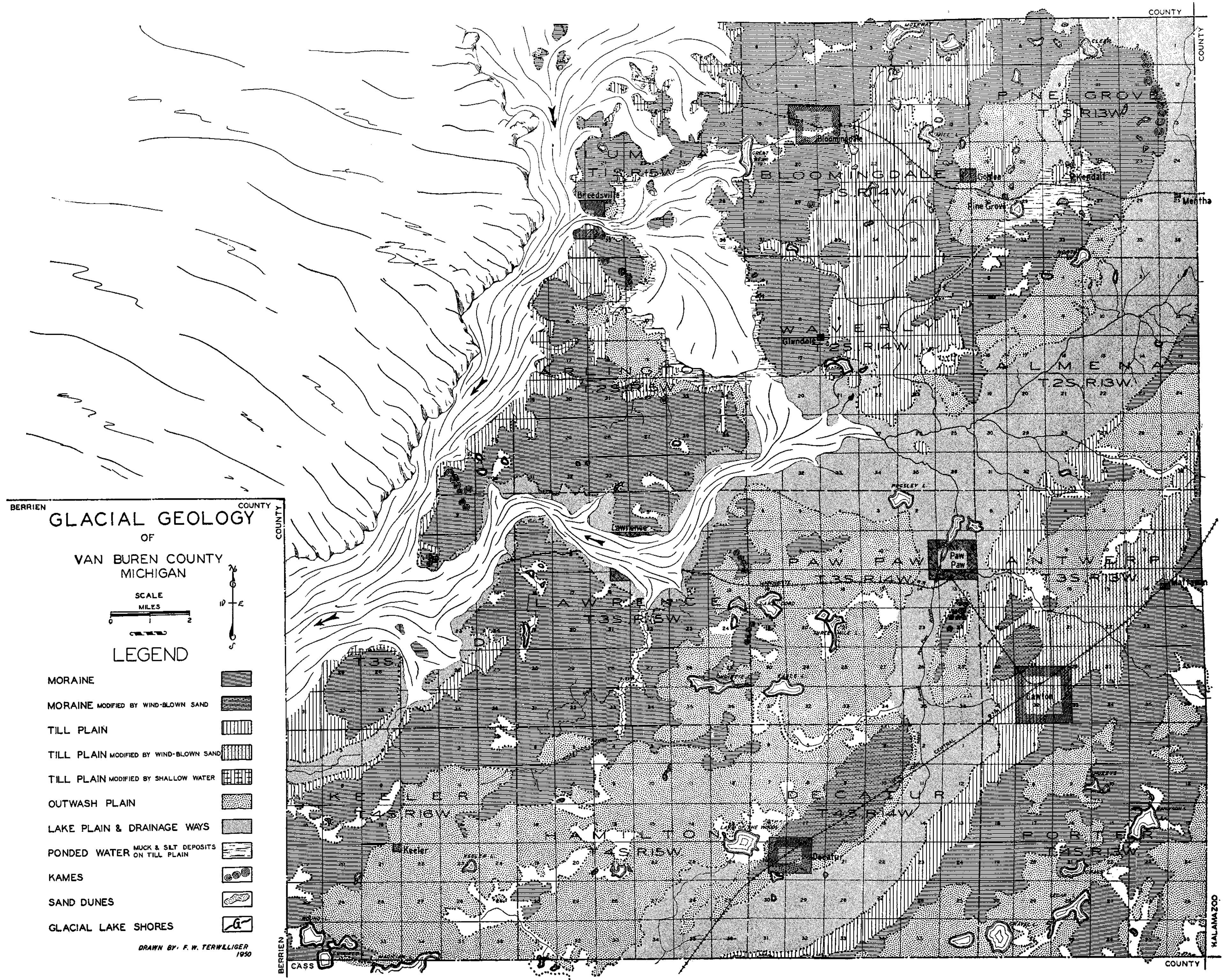


FIGURE 18
Tenth stage of glacial retreat in Van Buren County

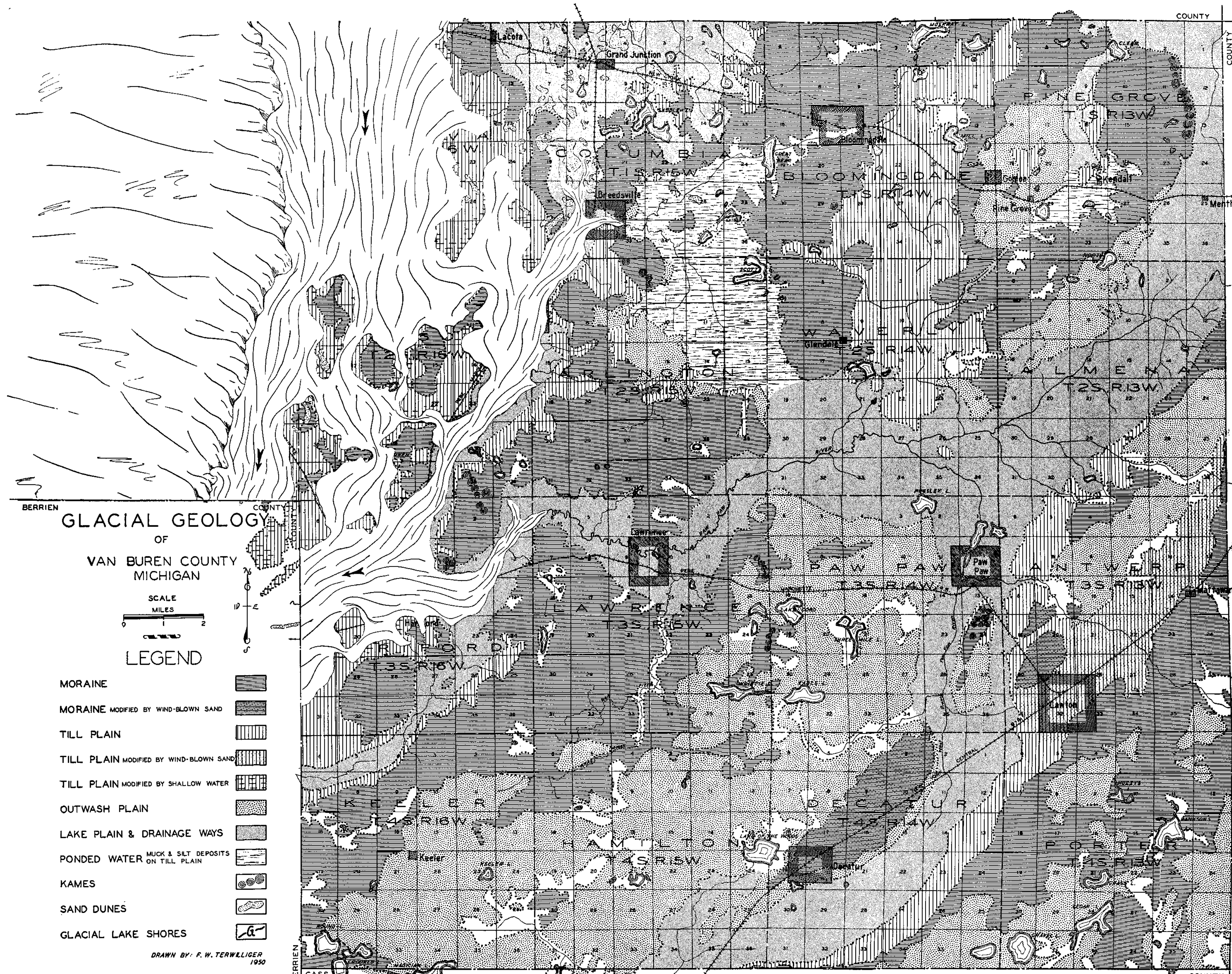


FIGURE 19
Eleventh stage of glacial retreat in Van Buren County

tinued southwestward through Keeler Township into Berrien County (fig. 16).

At this time the area of ponded water in Arlington Township was enlarged, and may possibly have caused such a lowering of the water level in the Dowagiac Drainageway as to have cut off drainage for a short interval. It is believed, however, that drainage was past Paw Paw during most of this stage.

When the ice retreated to its fifth position, the lowland area in Arlington and Columbia townships was completely opened to accommodate much of the water coming down the Dowagiac Drainageway. At the same time the channel below Paw Paw was deserted by glacial meltwaters, and the Paw Paw River Drainageway had its inception. At first the Paw Paw River drainage followed the present course of the Paw Paw River as far as the village of Hartford. Here it turned southward and circled the hill lying just to the south of the village (fig. 17). The elevation of terraces in southeast Arlington Township cut during this time is about 715 feet. The portion of the Dowagiac Drainageway south of Paw Paw to the center of Decatur Township became tributary to the Paw Paw River system, and is now occupied by the South Branch of the Paw Paw River.

The next retreat of the ice ended with the ice standing in its sixth position of the Valparaiso episode. This retreat opened the present course of the Paw Paw River to drainage discharge (fig. 18). The volume of water flowing down the upper part of the drainageway was much reduced, due to the opening of a channel through Bangor from the north. Most of the west side of this channel was formed by the ice which stood on the ridge through Lacota in Geneva Township and the sharp range of hills near McDonald in the southern part of Bangor Township.

During this phase the main line of drainage in Van Buren County was southward from a lake lying principally in Lee, Clyde, and Valley townships of Allegan County; and extending south into Columbia Township, Van Buren County. This lake received the main discharge from the Lake Michigan lobe of the ice sheet, as well as the Grand River discharge and water from the Kalamazoo River. The large delta mapped in Valley Township, Allegan County (T 2 N, R 14 W) (Leverett, 1924) was formed in this lake at the mouth of glacial Kalamazoo River. This lake was not fully mapped except in Van Buren County. Its elevation, fixed by shore lines in section 16, Columbia Township, is very close to 684 feet

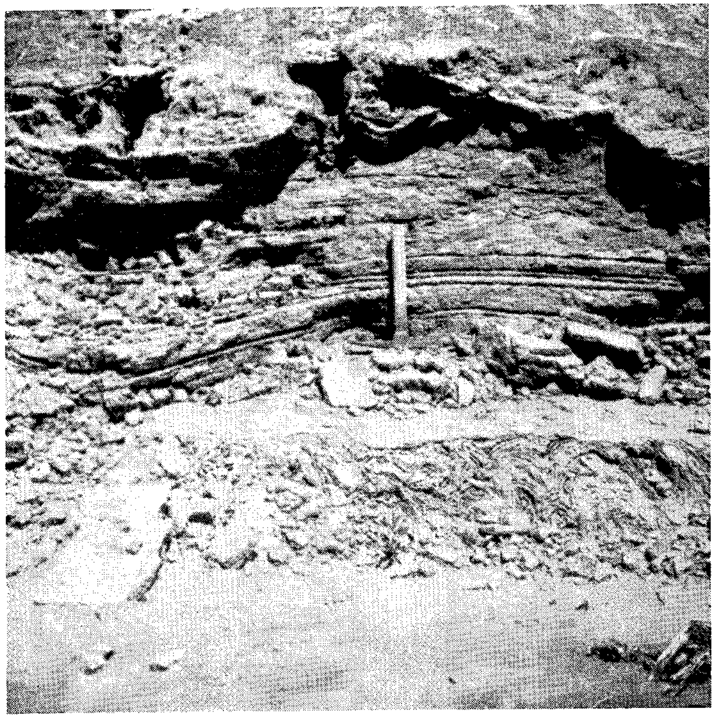


FIGURE 20

Two sets of varves shown in deposit along ditch on north side of road between sections 21 and 28, South Haven Township. The lower set of varves was deposited in a lake formed in front of the ice which had retreated into the Lake Michigan basin following Valparaiso time. These varves were crumpled under the foot of the ice as it advanced to the position of the Lake Border Moraine. The upper set of varves was deposited in the waters of Lake Glenwood following Lake Border time. Elsewhere in this exposure the two layers of varves are separated by a small amount of till.

above sea level. The floor is nearly level and almost all sandy. It is proposed that this lake be named Lake Pullman, after the village located in Lee Township, Allegan County.

In withdrawing across the till plain west of Bangor, the ice made several temporary halts to form the isolated morainic islands surrounded by till plain. The ice finally retreated an unknown distance into the Lake Michigan basin, closing the Valparaiso interval of morainic development.

Lake Border Morainic System

Before the ice readvanced to the site of the outermost moraine of the Lake Border system, a large lake lay in front of it. Varved

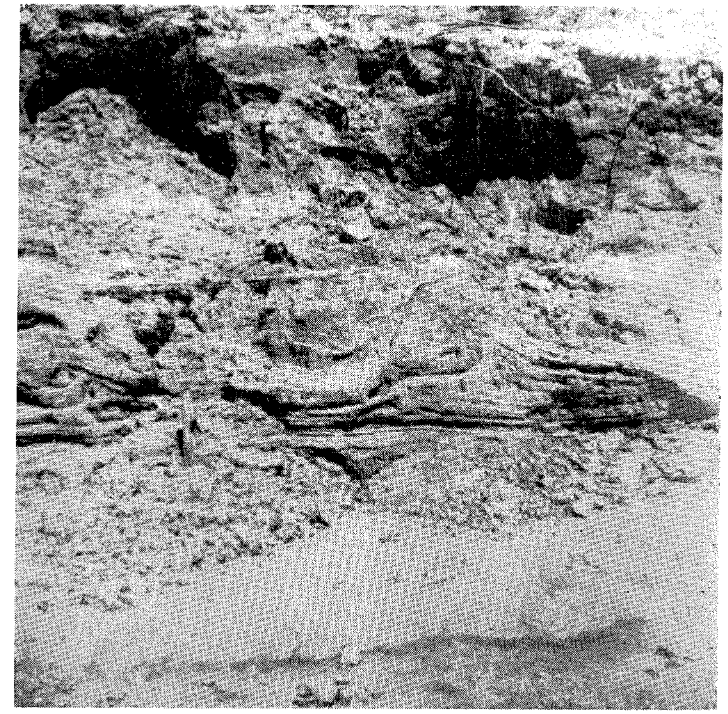


FIGURE 21

Another view of the two layers of varves in roadside ditch in the southeast quarter of section 21, South Haven Township.

sediments were laid down in this lake, and they are exposed in several places. One of the most notable of these is at Miami Park Beach in Allegan County, just three miles north of South Haven. Here the varves exposed in a bluff are capped by 20 to 25 feet of pebbly clay till.

The only exposure of the varved sediments of this lake noted in Van Buren County is along the south line of the southeast quarter of section 21, South Haven Township, just east of U. S. Highway 31, where two sets of varves are exposed. Throughout part of the exposure the two sets are separated by a foot or so of till, but in the section photographed (figs. 20 and 21) no separation is apparent. The upper foot of the lower beds is crenulated and crumpled, strongly indicating a readvance of the ice over them. The upper set of varves is composed of sediments laid down in the waters of Lake Chicago during the Glenwood stage. Unfortunately, this exposure is now obscured by recent slump of the slopes.

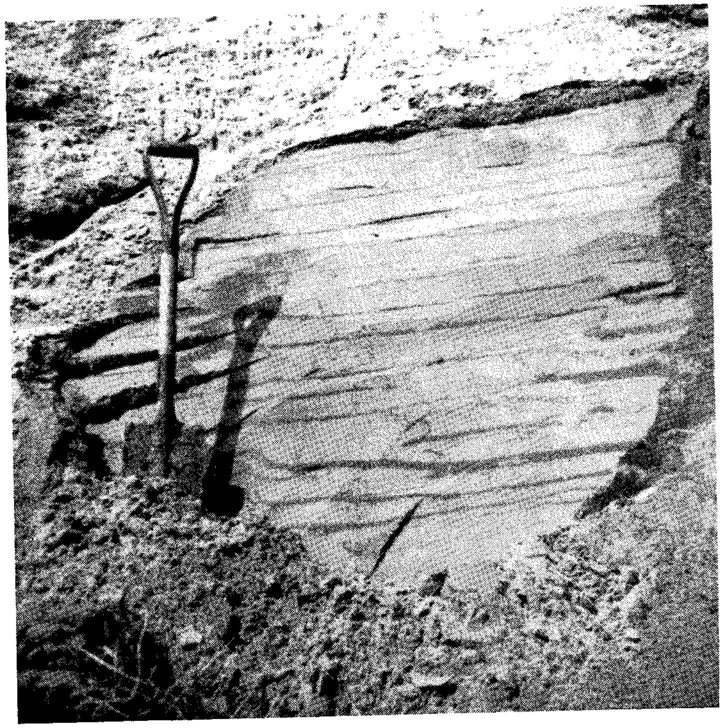


FIGURE 22

Seasonally banded sand in the Lake Glenwood embayment in section 6, Geneva Township. The dark streaks are sand containing iron oxides and organic material which were flocculated and deposited during the winter. Where the face of the sand pit has been exposed to wind action, the looser summer sand has been blown away, and the better cemented or more coherent winter layers are festooned at the edges.

Readvancing from the Lake Michigan basin, the ice passed over the lake sediments and halted along the site of Covert Ridge, the outermost of the three ridges making up the Lake Border system. This ridge is the only member of the Lake Border system developed in Van Buren County (fig. 19).

During the formation of Covert Ridge nearly all of the Bangor till plain was inundated by a shallow sheet of meltwater flowing along the front of the ice. The level of this water probably reached as high as 670 to 675 feet above sea level. This drainage eventually made its way to the Chicago Outlet into the Desplaines Valley (Leverett, 1915, p. 225).

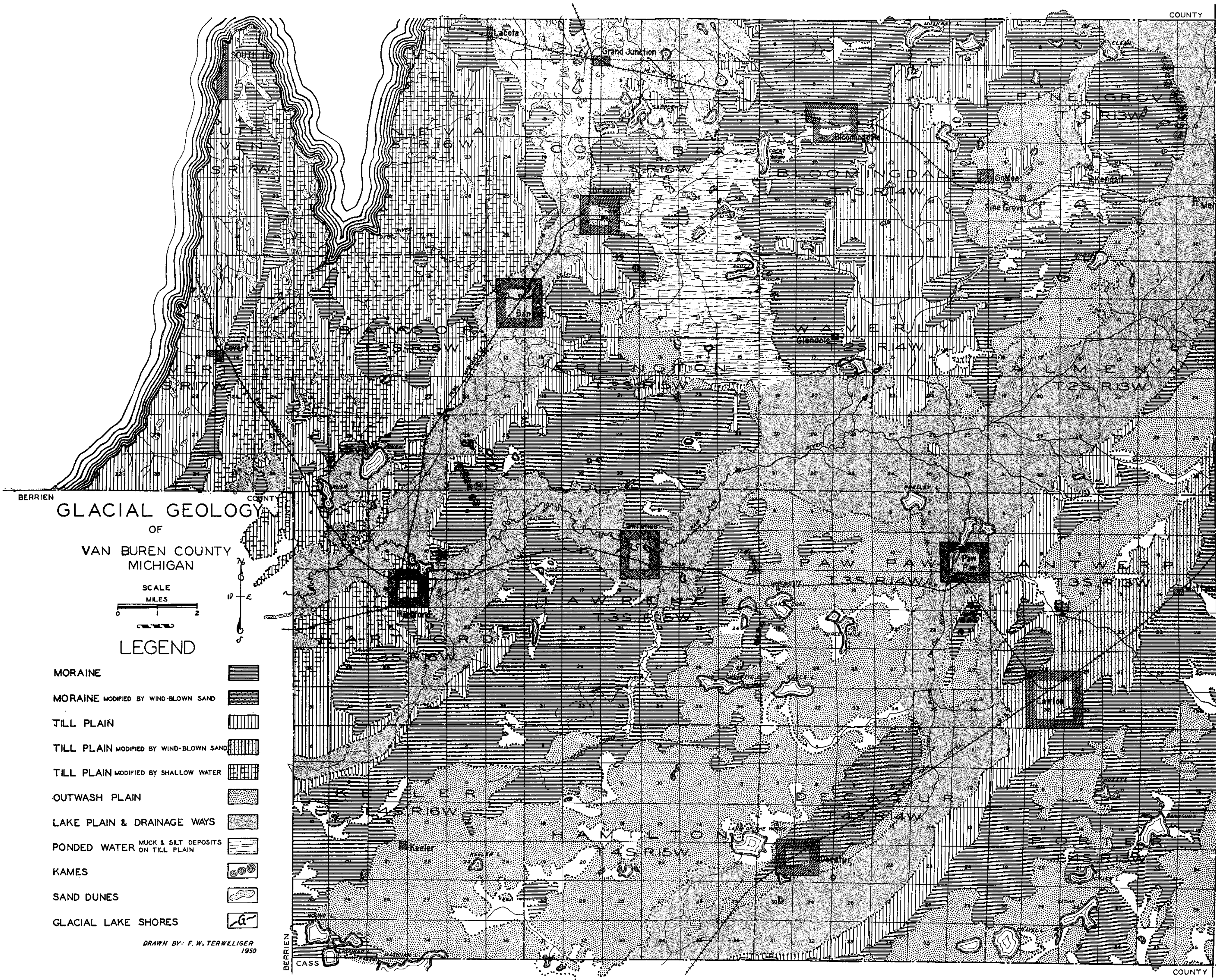


FIGURE 23
Shore lines of Lake Glenwood

Lake Chicago

The Glenwood beach of Lake Chicago which crosses the west end of Van Buren County roughly parallels the shore of Lake Michigan (fig. 23). Its distance from Lake Michigan varies from about one mile at South Haven to two and one-half miles in the central part of Covert Township. A large embayment of the lake extended into the present valley of the Black River (fig. 19). A section of color-banded lacustrine sands deposited in this embayment is exposed in a sand pit located in the southwest quarter of section 6, Geneva Township. The writer believes that this banding represents seasonal sedimentation, the darker streaks being made up of organic material and iron oxides flocculated and deposited during the winter season (fig. 22).

A possible Calumet shore line at 615 feet is suggested in section 9, Covert Township, in what appears to be a foredune ridge. However, this evidence is so fragmentary that the feature was not mapped. No other prominent shore features were observed in Van Buren County.

Chapter III

GROUNDWATER RESOURCES

General

The source of groundwater supply in Van Buren County is in the glacial drift. Although the Coldwater Limestone carries fresh water in certain limited areas, it is not a dependable reserve because of low permeability and spotty porosity.

Obtaining a satisfactory domestic water supply in the county presents no particular difficulties, except in one or two "problem areas." The inherent variability of glacial drift precludes making generalizations over any great area. In many places the variation in depth to water supplies of adjacent farms may be as great as 25 or 50 feet.

A fairly good coverage of information on domestic water supplies was obtained by conferences with several water well drillers and through examination of water well information submitted to the Geological Survey Division in 1946 by school children.

Some one hundred and fifty to two hundred irrigation systems are in the county, of which about twenty-five are supplied from wells. The remainder obtain water from lakes, streams, and ponds. Because of adequate rainfall from 1949 to 1952, the need for irrigation was not acute, and a number of systems which were installed just after the war were offered for sale. Undoubtedly another series of dry years similar to years of insufficient rainfall previous to 1949 will again cause an increase in the need for and use of irrigation.

The writer believes that a greater proportion of new systems when installed will draw water from wells, rather than from surface supplies as in the current common practice. The object of this discussion is to present as clearly as possible the over-all picture of groundwater supplies in Van Buren County, pointing especially toward supplies sufficient for irrigation purposes.

Municipal Water Supplies

With the exception of South Haven, most of the municipal water systems in the county draw their supplies from wells. According to information in the files of the Michigan State Health Department, most of the supplies do not require treatment before use.

South Haven, drawing its water supply from Lake Michigan, employs both filtration and chlorination to render the water safe for drinking. A condensation of data on the municipal supplies is given in the table following.

TABLE I

MUNICIPAL WATER SUPPLY

Name	Source of Water	Hardness (ppm)
Bangor	Wells 75′ deep in sand and gravel	260
Decatur	Wells 120′ deep in gravel	190
Gobles	Wells 112′ deep in gravel	272
Hartford	Flowing wells 38′ deep in gravel Tubular well 58′ deep	250
Indian Grove Subdivision (South Haven)	Well 88′ deep in sand and gravel	—
Lawrence	Wells 90′ to 106′ deep in gravel	240
Lawton	Well 44′ deep in sand	228
Linden Hills (Sec. 7, Covert Twp.)	Well 20′ deep in sand	—
Palisades Park (Sec. 8, Covert Twp.)	Well 40′ deep in sand	—
Paw Paw	Wells 85′ deep in sand and gravel	215
South Haven	Lake Michigan. Intake—2,300′ of 20″ pipe in 30′ of water*	143

*Note: This system is being enlarged (1951).

Flowing-Well Districts

Much of the area of Van Buren County is unfavorable for flowing wells due to the open character of the drift and lack of aquicludes to produce hydrostatic head. However, several small districts of flowing wells are in the county. A number of these are described in U. S. Geological Survey Water Supply Paper 182 (Leverett, 1906, pp. 119-126). Some of the artesian flows reported in that paper have lost their pressure and certain new artesian areas have been developed. Most of the flowing-well districts are located in recesses in moraines, in glacial drainageways, on outwash plains, and on low ground near lakes. In several of the districts near lakes the aquifer is struck 40 or 50 feet below the surface of the ground, where the head is higher than the level of the lake. The artesian areas will be described in further detail in the discussion of groundwater resources by townships.

Almena Township

The depth to suitable water supplies in Almena Township ranges from 0 (surface springs) to about 100 feet. In sections 12 and 13 a number of springs which supply potable water issue from the foot of the moraine. Throughout the Dowagiac Drainageway in the northeastern, central and southwestern parts of the township the wells are from 20 to 38 feet in depth and are non-flowing. Two flowing wells of low head were drilled in the drainageway by Mr. Earl Sanders of Lawton. One in section 20 was completed at a depth of 70 feet and the other in section 29 is 45 feet deep.

In the northwest quarter of the township well depths range from 27 feet at the outer edge of the outwash to 40 or 50 feet in the center of the outwash apron. Wells in the morainic area in sections 5, 6, and 7 approach 100 feet in depth.

Along the weak morainic ridge in the southeastern part of the township wells may be completed at depths of from 30 to 100 feet, depending on their topographic position. In the six sections in the extreme southeast, mostly outwash plain, wells average 50 feet in depth.

An area containing flowing wells is located partly on the moraine and partly on the till plain in sections 12 and 13, just south of Wolf Lake. A three-inch well drilled to a depth of 70 feet at the Community House of the Wolf Lake State Fish Hatchery penetrated four feet of "soil," 51 feet of clay hardpan, and 15 feet of water-bearing gravel. When completed, the well flowed at the rate of 60 gallons per minute with a head of seven feet before installation of a check valve. A farm well situated three-tenths of a mile to the west is 68 feet deep and flows at an estimated rate of 40 gallons per minute. A third well in the area, five-tenths of a mile west of the Community House is of unknown depth. In winter it has a head of one foot, but in summer the water level is about six feet below the surface. A two-inch well 30 feet deep at the residence of Mr. H. Hatt, about three-fourths of a mile southeast of the Community House has a steady, year-round flow with a head of seven feet. This well evidently taps a higher aquifer than the aquifer that supplies the wells in the drainageway as it is at a higher elevation on the back-slope of the moraine, and is underlain by clay hardpan to a depth of 80 feet. Two springs, one-eighth and one-fourth of a mile southwest of the Hatt well having estimated flows of 90 and 194 gallons per minute, respectively, boil out of the clay hardpan.

Antwerp Township

Wells drilled on the Inner Ridge of the Kalamazoo Moraine in the southeast part of Antwerp Township range from 90 to 144 feet in depth. The depth to water is somewhat less on the outwash plain in sections 25 and 36 where wells average 60 feet in depth.

In the northwest part of the township wells on the outwash plain fronting the weak moraine range from 15 to 65 feet in depth with an average of 40 feet, but on the moraine the depth of wells increases to 80 or 90 feet.

The village of Mattawan is situated partly on moraine and partly on till plain. As the village has no municipal water system each house has its own well. The depths of these wells range from about 20 feet on the till plain to 90 feet on the moraine.

Lawton has a village water supply, but many home owners have private wells also. The village well is 44 feet deep, but most of the individual water supplies come from a depth of 20 to 30 feet.

Arlington Township

In Arlington Township the wide range in well depths varies directly with the relief. On the rugged morainic areas the wells are from 80 to 140 feet deep, whereas on the till plains the wells are from 20 to 70 feet in depth.

An artesian area in sections 11, 12, 13, and 14 is described in Water Supply Paper 182 (Leverett, 1906, p. 124), but the pressure of the wells has been reduced to such an extent that they no longer flow. A well drilled in section 13 was completed at a depth of 25 feet, with a static level five feet below the surface. Most of the wells drilled near Scott Lake in section 1, northeast of the old artesian area, are 40 feet deep and non-artesian, but one on the north side of the lake is reported to be flowing.

An oil test drilled on the Kenneth Judd property in the NE¼ NE¼ NE¼ of section 27 encountered fresh water in the Coldwater Limestone at a depth of 301 feet, with a static level 120 feet below the surface.

Bangor Township

The water table is relatively high throughout the entire till plain area of Bangor Township, and pitcher pumps are in use in many of the fields where small diameter driven wells have been installed for convenience. The majority of farm wells are about 50 feet deep, although some are as deep as 70 or 80 feet, depending on

topographic position. The municipal water supply for the village of Bangor is derived from a well which is 75 feet deep. An artesian area in and around section 18, mentioned by Leverett (1906, p. 125), yields flowing water.

Bloomingdale Township

Nearly all of Bloomingdale Township is an area of deep water supplies. Excepting wells in the village of Bloomingdale, most of the wells reported are more than 50 feet, and many are 90 to 100 feet in depth.

On the till plain and low moraine in the northeast quarter of the township the wells average 60 feet in depth, with a static level 15 to 25 feet below the surface. The log of an oil well in section 2 reports a flow of water at 20 feet, but artesian water is not universally encountered in this area. It is possible that such flows come from perched water bodies which have their intake areas nearby.

Wells reported in the northwest quarter of the township, on the moraine, are from 55 to 75 feet deep. A well drilled for oil in section 8 showed no flowing water when the drive pipe was run, but when the pipe was pulled during plugging operations, a full 8-inch stream of water flowed two or three feet over the top of the pipe. No other flowing water has been reported from this part of the township.

In the southwest quarter of the township wells average 90 feet in depth and the water reaches within 10 to 20 feet of the ground level.

Although no data are available for wells located in the southeast quarter, surface conditions seem to indicate that water may be obtained at 50 or 60 feet. This supposition has been corroborated by general statements from several water well drillers.

In the immediate vicinity of Mill Lake, including parts of sections 13, 14, 23, and 24, where the wells are about 50 feet deep, the static level is approximately 25 feet below the surface of the lake. A well one-half mile northwest of the lake, in section 14, is 100 feet deep and has a static level only 18 feet below ground surface.

The artesian area in and around the village of Bloomingdale is described briefly in Water Supply Paper 182 (Leverett, 1906, p. 126). The wells are about 40 feet deep, and originally flowed with a head of nine feet which has since lowered. Leverett stated that the altitude of the land surface north of the railroad tracks is too great to permit flows; however, many oil wells drilled in the north part of town encountered water which flowed over the top of the drive pipe. The depth to this aquifer is reported to be from 40 to 50 feet.

Columbia Township

The surface features of Columbia Township are an east-west trending moraine flanked on the north and south by lake plain and a glacial drainage channel about 2 miles wide that extends along the west side of the township.

In the drainage channel it is probable that the few habitations are supplied with water from "spike" wells—shallow, small diameter, hand-driven wells. No specific data on this area are available, but the prevalence of pitcher pumps in the farmyards indicates that the water supplies are obtained from depths of 20 feet or less. The ground surface is mainly flat and featureless with marshy spots and ponds occupying the lower areas, indicating a uniformly high water table.

The writer was unable to obtain specific data regarding wells in the morainic area except in the village of Breedsville which lies partly on a southern extension of the moraine. The house wells in Breedsville range in depth from 18 feet near a branch of the Black River to 90 and 105 feet on the moraine. Because of the high water table, indicated by the numerous lakes in the area north and south of the moraine, water should be obtained nearly everywhere within the adjacent moraine at an elevation no lower than the lake plain; in other words at a maximum probable depth of 90 to 100 feet.

Water wells in the northeast part of the township range in depth from 20 feet or less on the lake plain to 40 and 80 feet on a small area of till plain in sections 1 and 12.

On the lake plain upon which the village of Grand Junction is situated, most of the water wells are from 28 to 35 feet in depth. If the site of a well is on one of the numerous dunes, its depth will likely be greater.

The southeast quarter of the township produces satisfactory water from wells 15 to 30 feet in depth. Several deeper wells are reported—one 110 feet deep in the northwest quarter of section 26, and two about 70 feet deep in the same section just northeast of Stillwell Lake. An oil test in the NE¼ NE¼ NE¼ of section 34 produced a hole full of fresh water from the Coldwater Limestone at a depth of 425 feet. Several other wells drilled for oil in this quarter of the township had a hole full of water in the drift at depths of 50 feet or more. Complete records of the drift in these wells are included in the appendix.

Covert Township

Water-supply conditions in Covert Township are extremely variable. In certain locations along Covert Ridge it has proved very difficult, if not impossible, to obtain adequate water supplies. Difficulty in drilling satisfactory wells on the till plains on either side of the ridge has also been encountered in some places. At some locations the glacial drift is clayey throughout its entire thickness; at others the sand containing water is too fine to screen out and yields water only with great reluctance. It is possible that artificial gravel pack wells might solve some of the problems, but the average home owner cannot afford such an expense.

In and around the village of Covert a good aquifer is struck below clay at a depth of 80 feet. The static level of wells in this bed varies from 15 to 30 feet, depending on the well location. It is interesting to note that the village as platted, before any drilling had been done, closely coincides with the extent and spread of this aquifer. Conditions of water supply change rapidly in all directions from the village.

In the southern part of the township wells maintain a depth of nearly 80 feet for a distance of a mile beyond Covert, then become shallower as the county line is neared. The owner of a gas station and store in the southwest corner of section 28 has been unable to obtain water from any but a shallow driven well, although an exploratory well drilled for oil not more than 500 feet from his property struck a plentiful supply of water at 250 feet below the surface.

Eastward from Covert onto the till plain, the wells rapidly become shallower—only 15 to 30 feet in most locations. On the east flank of Covert Ridge, about a mile southeast of the village, two dry locations were drilled in the fall of 1951.

To the north and northwest from Covert the variation of well depths is extremely irregular. Most of the wells are not more than 50 to 60 feet deep, but two wells near the north township line are about 175 feet in depth.

Westward from the village to the belt of dunes on the lake plain the wells are predominantly shallow. In the dunes the depth of water is entirely dependent on the elevation of the well head, as the water table is about the level of the surface of Lake Michigan.

Decatur Township

In the Dowagiac Drainageway which crosses Decatur Township from northeast to southwest water is encountered just below the surface, although most of the wells are finished at depths of from 12 to 20 feet. Along the northwest side of the channel an artesian aquifer with a head of 12 feet is reached at depths of 80 to 100 feet.

Wells drilled on the crest of the Inner Ridge of the Kalamazoo Moraine average 75 feet in depth. Eastward, onto the outwash plain near Gravel Lake, the depth of wells decreases to about 40 to 50 feet.

In the northwest part of Decatur Township, north of the drainage channel, wells range in depth from 40 to 75 feet with an average of 60 feet on both outwash plain and moraine. A well drilled for oil in section 10 encountered artesian water in gravel at 114 feet. During drilling operations with a light rotary rig, the water flowed through a hole full of mud when the rig was shut down for a short time. Just south of this location, in section 14, an oil test is reported to have flowed fresh water at the rate of 500 gallons per minute from a depth of 216 feet in the Coldwater Limestone. An exploratory oil test in section 32 struck a heavy flow of water at 160 feet. The stream is said to have flowed six and one-half feet over the top of a 10-inch drive pipe at an estimated rate of 1,000 gallons per minute. A water well for which no log is available, was drilled at the celery washing plant in Decatur and reportedly was finished in an artesian aquifer at about 150 feet.

Geneva Township

The westward sloping upland of Geneva Township is cut by numerous sharp stream valleys. In general, the wells are deepest in the eastern part and become shallower to the west.

In the vicinity of the village of Lacota, in section 1, most wells are about 35 feet deep, but one well is reported to be 97 feet in depth. In sections 23, 24, 25, and 26 the average well is finished at about 45 feet, but may be as shallow as 14 feet.

Throughout the two central ranges of sections wells range from 20 to 40 feet in depth except in sections 9 and 10, where several

wells are 65 to 75 feet deep. An oil test in the southeast quarter of section 9 logged water at 65 feet and a hole full of water at 340 feet. Another test in the southeast quarter of section 16 reported a hole full of water at 125 feet.

The westernmost third of the township receives its water supply from wells, most of which are 16 to 35 feet deep although several exceptions have been recorded; one a 120-foot well on the banks of the Black River in section 29. An oil test in the southwest quarter of section 20 had a hole full of water at 210 feet. Other aquifers were encountered at higher levels in the hole.

Hamilton Township

In the eastern two-thirds of Hamilton Township the wells are shallowest in the southeast and become progressively deeper toward the northwest. Wells drilled in the drainage channel in sections 25 and 36 are 20 feet deep and have a static level of 10 feet. A mile to the west, wells are from 20 to 30 feet in depth and the water level stands 10 to 20 feet below the surface. In the area surrounding Lake of the Woods the wells range from 25 to 40 feet and do not deviate much from this in the entire northeast quarter of the township.

On the till plain occupying the central and western part of the township, wells range from 40 to 60 feet in the central part to 20- and 25-foot depths in the west. The static level is about 20 feet in the deeper wells, but varies in the shallower wells from 10 to 15 feet.

Hartford Township

No wells more than 60 feet deep were reported in Hartford Township excepting one on the moraine in section 32 which is 115 feet and has a static level of 75 feet. Wells throughout the remainder of the township are from 35 to 58 feet deep.

Leverett (1906, pp. 121-122) mentions four flowing-well districts. The first, around Rush Lake in the northwest, no longer produces flowing water. The second, along the valley of the Paw Paw River, may be in the same aquifer which supplies the flowing well at the waterworks in the village of Hartford. The third district, in section 31, still produces flowing wells with much reduced head. The fourth district, near the headwaters of Pine Creek in sections 27, 28, 33, and 34, continues to yield flowing water. A well on the farm of Mr. Dave Friday when completed at 41 feet had a head of about three feet. This well was gauged roughly by the writer in 1949 and found to be flowing at the rate of about 17 gallons per minute with a head of not more than two feet. The drop in head within a period of a year or two was possibly due to sanding up of the screen, as other wells in the area did not drop appreciably during the same period.

Keeler Township

In the outwash areas of Keeler Township domestic wells range in depth from 20 and 25 feet to 40 feet and water can probably be obtained at even shallower depths near swampy areas. An irrigation well in section 34 which struck the first water at 20 feet was finally completed at a depth of 80 feet. A pump test of this well yielded 400 gallons per minute with an eight-foot drawdown after one hour. Another irrigation well 110 feet deep is located in section 21, but no pump test results are available.

Wells drilled in the morainic area northwest of the village of Keeler are from 60 to 80 feet in depth. Shallow wells are secured north of the moraine, in the Paw Paw drainage channel which extends through the northwest quarter of the township.

Lawrence Township

Information concerning water supplies in Lawrence Township is very meager and only general statements could be made by well drillers who are familiar with the area. In the higher morainic area wells range from 80 to 130 feet in depth, although wells shallower than 80 feet are not exceptional where the surface expression is more subdued. On the outwash area in the southeast part of the township, a continuation of a similar area in the adjoining part of Hamilton Township, water is obtained from wells drilled 25 to 35 feet deep. Near Christie Lake, in the center of the outwash area, well depths decrease to 10 to 20 feet.

Although the two municipal wells at Lawrence in the Paw Paw River valley are 90 and 106 feet deep, domestic water wells in the valley do not need to be drilled as deep to obtain satisfactory supplies because of the high water table.

Paw Paw Township

The eastern third of Paw Paw Township lies in the Dowagiac Drainageway which is split into two channels by the morainic knob known as Prospect Hill. Water is obtained from wells in the channels at depths of from 20 to 50 feet; most wells are less than 35 feet deep, whereas wells drilled on Prospect Hill are 125 and 150 feet in depth. Flowing wells of low head are reported along the shore of Maple Lake, just north of the village of Paw Paw, but no data are available as to their volume of flow. A peculiar set of conditions is found at Brownwood Lake in sections 2 and 3 where wells on the south side of the lake encounter an artesian aquifer at 50 feet but wells on the north side of the lake must be drilled 80 to 90 feet to secure water. This deeper water zone is not known to produce flowing water either in the vicinity of the lake or in the adjoining parts of Waverly Township to the north.

Wells in the area of outwash in the southwest quarter of the township range generally from 30 to 80 feet in depth. Shallower wells are on the north side of Eagle Lake where good water may be had at depths of 10 to 25 feet. One flowing well 24 feet deep is located on the north side of Three Mile Lake in section 22. An irrigation well completed at 68 feet was drilled on the property of Mr. Jerry Mandigo, just east of Three Mile Lake. The static level of this well is three and one-half feet below the surface, and a pump test at the rate of 1,300 gallons per minute produced a drawdown of 28 feet.

In the northwest quarter of the township, on the moraine and high outwash, wells are from 70 to 90 feet deep and the water level stands about 50 or 60 feet below the surface. Wells in the Paw Paw drainage channel are shallower, and an oil test drilled in section 5 encountered good water sands all the way from 43 to 93 feet.

Pine Grove Township

Parts of the two eastern tiers of sections in Pine Grove Township are in the western side of the Dowagiac drainage channel. Well depths in the channel are from 10 to 20 feet, increasing to 40 or 45 feet on the area of outwash apron flanking the channel in sections 27, 32, and 33.

On Kendall Ridge, a rugged, kamic moraine, some wells are completed in a shallow aquifer at 20 feet, but other wells in the area, particularly in the village of Kendall, are from 70 to 115 feet deep.

In the drainageway west of Kendall Ridge in section 3, wells are about 15 feet in depth. Although little data are available, wells drilled throughout the length of this channel, an old outlet of lake

Brandywine, should strike water at no more than 20 feet. Wells located on the outwash plain east of Gobles and on the low moraine running through the village range in depth from 35 to 112 feet—the average depth is about 50 feet.

Porter Township

Porter Township lies within the Kalamazoo morainic system excepting part of the northwest quarter which is in the Dowagiac Drainageway. Most of the wells drilled on the Inner Ridge of the moraine are from 70 to 80 feet deep, decreasing in depth down the back-slope of the moraine to 20 or 30 feet in the drainage channel. Several wells in section 4 on the very crest of the ridge are 130 feet in depth. An oil test in the SE¼ SE¼ SE¼ of section 5 encountered a good water zone at 174 feet. In sections 17 and 20 some wells are as much as 100 feet in depth. Throughout the length of the intermediate ridge running southward from sections 2 and 3 and passing east of Cedar Lake, the wells average 75 feet in depth. At the extreme south end of the ridge in section 34 wells become shallower, and good wells are made at depths of from 40 to 60 feet. Along the crest of the Outer Ridge wells are 100 to 140 feet in depth, the deepest ones being in sections 1 and 12.

No data are available concerning the depths of wells in the areas of outwash in front of the Outer Ridge and the outwash between the outer and intermediate ridges. Wells drilled in the basin around Bankson Lake are from 20 to 30 feet deep, although depths increase very rapidly at a short distance from the lake. Wells on the outwash in sections 9 and 16, in front of the Inner Ridge, average 75 feet in depth, whereas wells in the area immediately surrounding Huzzy Lake at the east end of the outwash are only 20 or 30 feet deep. The log of a well drilled for oil in section 9 reported a very good water zone at 144 feet and about 140 feet of water in the hole at 273 feet. Another oil test one-half mile south in section 16 is said to have encountered a flow of water at 500 feet, presumably in the Coldwater Limestone as bedrock was logged at 475 feet.

The outwash plain around Gravel and Cedar lakes in the southwest part of the township yields good water supplies at depths of from 40 to 90 feet. The deepest wells are located along the county line in section 32. In the vicinity of the two lakes wells are 20 to 30 feet deep. A well drilled for oil in the northeast quarter of section 28 encountered quicksand and water at 335 feet and a hole full of water at 408 feet in a sand at the base of the drift.

South Haven Township

South Haven Township embraces an area in which it is almost impossible to finish a satisfactory well. It is actually contiguous to a similar area described in Covert Township, west of Covert Ridge. An oil test drilled in the northeast quarter of section 22 logged mud and clay throughout the entire thickness of the drift and a note was included to the effect that no water was encountered. However, a house well in the southwest quarter of the same section produces an ample supply of water from an aquifer at 68 feet. After several attempts, the owner of a service station south of South Haven in section 10 finally secured a well with a static level 60 feet below the surface, in sand at 87 feet. Some shallow wells are obtained in parts of the till plain; a well in section 28 and another in section 35 are only 20 feet deep. It is possible that the shallow wells tap perched water bodies inasmuch as other nearby wells, in section 26 in particular, are completed at about 85 feet.

A study of the records of wells located on Covert Ridge reveals that although the wells are nearly all deep, depths are variable. Within the small area around Maple Grove School, including sections 13, 23, and 24, the shallowest well recorded is 104 feet deep, and the deepest well reaches 183 feet. The average depth at which wells are finished in this area and on the rest of the ridge in South Haven Township is about 160 feet. A few wells on the ridge reach just to the water table, 8 to 15 feet below the surface. However, these shallow wells often go dry in the summer, and so are quite unsatisfactory.

A well drilled for oil in the northeast quarter of section 24 encountered a good aquifer at 70 feet and another at 150 feet. Water from a gravel bed at the base of the drift at 495 to 500 feet filled the hole to within 100 feet of the surface as fast as the tools could be pulled from the hole. Another test well in the northeast quarter of section 36 passed through a layer of gravel at about the same depth but the log contains no reference to water. These two holes indicate the trend of a deep, pre-glacial, bedrock valley sufficiently deep to have cut through the Coldwater formation completely and into the underlying Ellsworth shale at the base of the drift. Further drilling is strongly recommended along this valley trend in the event some industry requiring large amounts of water desires to locate near South Haven.

Waverly Township

Although some shallow wells are on the moraine and till plain in the northeastern part of Waverly Township, most wells are from 60 to 80 feet deep. A well drilled for oil in the SW¼ SW¼ SE¼ of section 12 encountered water at 50 to 128 feet in such quantity that the drillers could not bail the hole dry. Another test in the NW¼ SW¼ NW¼ of section 13 logged sand and gravel throughout 170 feet of drift and carried water in the hole all the way from 30 to 170 feet.

Along the moraine running through the hamlet of Glendale, wells are from 90 to 155 feet in depth. The ground surface drops sharply just west of Glendale to the bed of an extinct lake where good water supplies are obtained from wells 20 and 30 feet deep. A flowing well 6 feet in depth is located in a re-entrant of the moraine in the southwest quarter of section 17. An oil test in the SW¼ SW¼ SW¼ of section 19 encountered a flow of water from pea gravel at 120 to 160 feet. The drift thickness at this location is 480 feet, and in nearby wells it ranges from this thickness to more than 500 feet.

Wells located in the drainage channel occupying the southern half of the township are generally shallow. Flowing wells with a head of 2 feet are obtained at a depth of 30 feet in sections 31 and 32 along the Paw Paw River.

SUMMARY

The analysis of groundwater data as presented in this report indicates that satisfactory domestic water supplies are obtained throughout the county at depths of 160 feet and less. The average depth of domestic wells for the entire county is more than 50 feet.

Most of the wells drilled to secure water for irrigation exceed 100 feet in depth. Many of the shallower aquifers which are adequate for domestic water supplies do not yield a sufficient volume to satisfy irrigation requirements.

A general relationship between glacial geology and the depth of wells is evident. Satisfactory wells are completed in the drainage channels and river valleys at depths less than 40 feet, generally between 10 and 30 feet. The depths to aquifers in the moraines

vary with the relief of the feature and the texture of the drift. Those moraines which have strong relief are of light-textured materials such as sands and gravels. The excellent underdrainage and lack of aquicludes in these moraines necessitate deep penetration to obtain water. The heavier textured and generally weaker moraines yield water at shallower depths because of the higher water table. The depth to water supplies in areas of outwash is consistent over relatively wide areas and nearly everywhere approximates the average for the county as a whole. The depths of wells on till plains differ greatly and in some areas obtaining a water supply is difficult or nearly impossible.

The only potential source of water in the bedrock is the Coldwater Limestone, and its value as an aquifer is problematic. The porosity and permeability of this bed change from place to place, and the changes are unpredictable. At certain locations the limestone may yield copious amounts of fresh water, but at other locations nearby the bed may be non-productive of water. It is possible that the fresh water may be polluted in and around oil fields because the limestone has been used as a salt-water disposal bed.

A deep, pre-glacial valley is indicated in the bedrock on the east side of South Haven Township. This valley is well worth further investigation as an important potential water source. Other areas of exceptionally thick drift might also be explored to determine whether or not basal gravels that contain water are present.

APPENDIX

The following pages contain a number of representative well logs from Van Buren County. Where available, one log is shown for each section of a township. Formations deeper than the base of the glacial drift are given in detail only where water information is contained. The logs are arranged alphabetically by townships, and numerically within each township by section numbers. As nearly all of these logs are excerpts from oil well logs, the permit number, operator, farm name and well number are shown, in addition to the location of the well. The approximate location of each well is shown on the accompanying map (fig. 24).

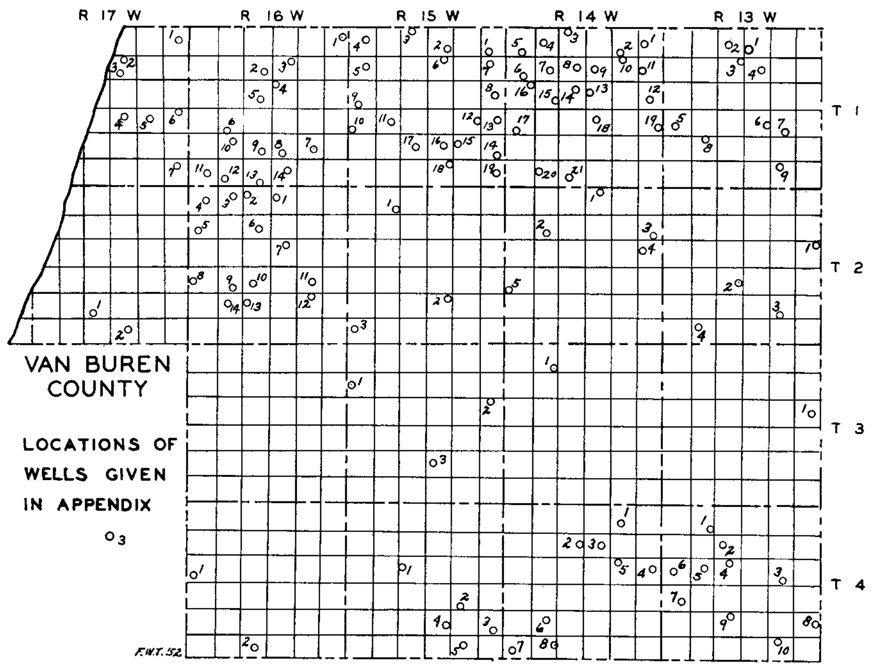


FIGURE 24

WELL LOGS

ALMENA TOWNSHIP (T 2 S, R 13 W)

1. NE¼ NE¼ NE¼ section 13. Elev. 815.4 feet above sea level
Permit No. 16004; A. J. Gilmore—Rhodes No. 1

PLEISTOCENE:		
Glacial Drift:	Thickness	Depth
No record	24	24
Sand and gravel	33	57
Sand	28	85
Mud	19	104
Mud, sandy	95	199
Sand and gravel	21	220
Gravel	16	236
Sand and gravel	36	272
Sand	8	280
Sand and gravel	16	296
Gravel	9	305
Sand and gravel	16	321
Sand and mud, sandy	23	344
Gravel	22	366
MISSISSIPPIAN:		
Coldwater:		

2. NE¼ NE¼ SE¼ section 21. Elev. 722.2 feet above sea level
Permit No. 14949; W. A. Moffat—Thomas No. 1

PLEISTOCENE:		
Glacial Drift:		
Sand (water)	22	22
Mud, sandy	24	46
Gravel (water)	24	70
Pea gravel (water at 86-88′)	18	88
Mud, muddy (sandy?)	25	113
Sand	21	134
Mud, sandy	11	145
Sand and gravel	17	162
Mud, blue with gravel (Pre-Wisconsin?)	21	183
MISSISSIPPIAN:		
Coldwater:		

3. SE¼ SE¼ SW¼ section 26. Elev. 831.5 feet above sea level
Permit No. 16515; W. D. Gannett—Burns & Tavso No. 1

PLEISTOCENE:		
Glacial Drift:		
Sand and gravel	218	218
Gravel	62	280
Sand and gravel	20	300
MISSISSIPPIAN:		
Coldwater:		

4. SE¼ NW¼ NW¼ section 32. Elev. 725.7 feet above sea level
Permit No. 6623; Daily Crude Oil Co.—Harter No. 1

PLEISTOCENE:		
Glacial Drift:	Thickness	Depth
Sand	20	20
Sand and gravel	79	99
Sand, heaving and gravel	51	150
Gravel	33	183
Gravel and mud	37	220
MISSISSIPPIAN:		
Coldwater:		

ANTWERP TOWNSHIP (T 3 S, R 13 W)

1. NE¼ NW¼ SE¼ section 13. Elev. 861.7 feet above sea level
Permit No. 6792; Union Oil Co. & D. Ford—Mary McNulty No. 1

PLEISTOCENE:		
Glacial Drift:		
Sand and gravel	240	240
Sand, reddish	at	240
Sand and gravel (Pre-Wisconsin?)	63	303
MISSISSIPPIAN:		
Coldwater:		

ARLINGTON TOWNSHIP (T 2 S, R 15 W)

1. SE¼ SE¼ SE¼ section 5. Elev. 712.5 feet above sea level
Permit No. 6042; R. W. Bloss—Schemenauer No. 1

PLEISTOCENE:		
Glacial Drift:		
Clay	93	93
Sand	167	260
Clay	38	298
Sand	94	392
MISSISSIPPIAN:		
Coldwater:		

2. NE¼ NE¼ NE¼ section 27. Elev. 797.8 feet above sea level
Permit No. 14506; Ohio Oil Co.—Kenneth Judd No. 1

PLEISTOCENE:		
Glacial Drift:		
Mud and gravel	20	20
Sand	205	225
Mud and gravel	50	275
Gravel	10	285
MISSISSIPPIAN:		
Coldwater:		
Shale, blue	16	301
Lime (120′ of fresh water overnight)	19	320

3. NE¼ SW¼ NW¼ section 31. Elev. 724.5 feet above sea level
Permit No. 15085; S. L. Godfrey—Neil Fish No. 1

	Thickness	Depth
PLEISTOCENE:		
Glacial Drift:		
Sand (water)	86	86
Sand and mud	76	162
Sand, yellow (water)	42	204
Sand, muddy	71	275
MISSISSIPPIAN:		
Coldwater:		
Shale, blue	135	410
Lime, "Coldwater" (water)	30	440

BANGOR TOWNSHIP (T 2 S, R 16 W)

1. NW¼ SW¼ NW¼ section 3. Elev. 655.8 feet above sea level
Permit No. 17138; N. L. Stevens—Minardo No. 1

	Thickness	Depth
PLEISTOCENE:		
Glacial Drift:		
Sand (water at 100′)	140	140
Gravel	50	190
Sand	4	194
Mud, blue (may be Coldwater in part)	31	225
MISSISSIPPIAN:		
Coldwater:		

2. SW¼ NW¼ NW¼ section 4. Elev. 655.6 feet above sea level
Permit No. 14719; Harris Oil Co.—Springett No. 2

	Thickness	Depth
PLEISTOCENE:		
Glacial Drift:		
Drift	25	25
Sand and mud	80	105
Mud	70	175
Sand, heaving	30	205
Gravel (160′ of water at 205′)	10	215
Mud	10	225
MISSISSIPPIAN:		
Coldwater:		

3. SE¼ NW¼ NE¼ section 5. Elev. 650.8 feet above sea level
Permit No. 14749; Harris Oil Co.—Effie J. Willis No. 1

	Thickness	Depth
PLEISTOCENE:		
Glacial Drift:		
Mud and sand	110	110
Sand, mud and gravel	36	146
No record	54	200
Gravel (hole full of water at 255′)	70	270
MISSISSIPPIAN:		
Coldwater:		

4. SW¼ SW¼ SE¼ section 6. Elev. 642.6 feet above sea level
Permit No. 14878; Harris Oil Co. & Del Fortney—Stepansky No. 1

	Thickness	Depth
PLEISTOCENE:		
Glacial Drift:		
Sand and mud	44	44
Sand (25′ of water)	21	65
Sand and mud	32	97
Gravel and mud	58	155
Mud	30	185
MISSISSIPPIAN:		
Coldwater:		

5. SW¼ NE¼ SW¼ section 7. Elev. 671.1 feet above sea level
Permit No. 14914; Harris Oil Co.—M. Stewart No. 2

	Thickness	Depth
PLEISTOCENE:		
Glacial Drift:		
Sand (water at 26′)	100	100
Sand and mud	92	192
Mud and gravel (125′ of water)	13	205
MISSISSIPPIAN:		
Coldwater:		

6. C—NW¼ SE¼ section 9. Elev. 660.1 feet above sea level
Permit No. 9939; Socony-Vacuum Oil Co.—C. E. Funk No. 1

	Thickness	Depth
PLEISTOCENE:		
Glacial Drift:		
Sand, gravel, and mud	257	257
Gravel, blue and mud	16	273
Gravel and mud	34	307
MISSISSIPPIAN:		
Coldwater:		

7. C—NW¼ NE¼ section 15. Elev. 704.1 feet above sea level
Permit No. 9452; M. Bliss Keeler—Burnsworth No. 1

	Thickness	Depth
PLEISTOCENE:		
Glacial Drift:		
Mud and sand	130	130
Sand	15	145
Mud and gravel	26	171
Sand, heaving	82	253
Gravel	28	281
Mud and gravel	6	287
MISSISSIPPIAN:		
Coldwater:		

8. SW¼ SW¼ NW¼ section 19. Elev. 682.5 feet above sea level
Permit No. 10192; Central Development Co.—R. A. Barker No. 1

	Thickness	Depth
PLEISTOCENE:		
Glacial Drift:		
Drift	165	165
Gravel	30	195
Drift	80	275
MISSISSIPPIAN:		
Coldwater:		

9. SE¼ SW¼ SE¼ section 20. Elev. 667.2 feet above sea level
Permit No. 2485; Sharer, Trexler, & Williams—Sheldon No. 1

	Thickness	Depth
PLEISTOCENE:		
Glacial Drift:		
Sand and mud	139	139
No record	66	205
Sand, heaving	46	251
Gravel and sand	6	257
Mud and gravel	43	300
MISSISSIPPIAN:		
Coldwater:		

10. SW¼ NE¼ SW¼ section 21. Elev. 668.2 feet above sea level
Permit No. 7351; Andy Hoyt—Nutting No. 1

PLEISTOCENE:		
Glacial Drift:		
Sand and muck	140	140
Sand, heaving	50	190
Sand	22	212
Gravel and mud	23	235
MISSISSIPPIAN:		
Coldwater:		

11. NW¼ NW¼ SE¼ section 23. Elev. 659.2 feet above sea level
Permit No. 6679; Little Four Oil Co.—Joe Getz No. 1

PLEISTOCENE:		
Glacial Drift:		
Sand	210	210
Gravel and sand	65	275
Boulders and mud	10	285
MISSISSIPPIAN:		
Coldwater:		

12. NW¼ NW¼ NE¼ section 26. Elev. 661.1 feet above sea level
Permit No. 5894; Christ Shrock—Church Brothers No. 1

PLEISTOCENE:		
Glacial Drift:		
Sand	120	120
Mud, blue (Pre-Wisconsin?)	20	140
Sand	188	328
MISSISSIPPIAN:		
Coldwater:		

13. SW¼ NW¼ NW¼ section 28. Elev. 664.6 feet above sea level
Permit No. 9796; Michahoma Oil Co.—C. Starz No. 6

	Thickness	Depth
PLEISTOCENE:		
Glacial Drift:		
No record	39	39
Gravel, fine	151	190
Gravel, coarse	25	215
Gravel, fine	5	220
Gravel, fine and sand	50	270
MISSISSIPPIAN:		
Coldwater:		

14. SE¼ SE¼ NW¼ section 29. Elev. 668.1 feet above sea level
Permit No. 14597; Lund & Weinberg—Wm. & Alva Nutting No. 1

PLEISTOCENE:		
Glacial Drift:		
Sand	10	10
Clay	18	28
Sand (water)	5	33
Clay	47	80
Sand (water)	50	130
Clay	75	205
Sand (water)	27	232
Clay, blue	18	250
Sand, fine (water)	15	265
Clay and gravel	8	273
MISSISSIPPIAN:		
Coldwater:		
Shale, soft	4	277
Lime shell (salt water)	11	288

BLOOMINGDALE TOWNSHIP (T 1 S, R 14 W)

1. SW¼ SW¼ NW¼ section 1. Elev. 761.3 feet above sea level
Permit No. 8590; Leonard C. Sleep—Pullin No. 1

PLEISTOCENE:		
Glacial Drift:		
Clay	15	15
Shale (?) and clay	68	83
Sand, heaving	132	215
Gravel	20	235
Sand and mud	23	258
Gravel and sand	27	285
MISSISSIPPIAN:		
Coldwater:		

2. SE¼ SW¼ SW¼ section 2. Elev. 773.3 feet above sea level
Permit No. 14482; E. W. Leeder—Ampey No. 4

PLEISTOCENE:		
Glacial Drift:		
Mud, sandy (flow water at 20′)	21	21
Sand (water at 120′)	269	290
Gravel	28	318
MISSISSIPPIAN:		
Coldwater:		