GLACIAL DEPOSITS OF WISCONSIN

SAND AND GRAVEL RESOURCE POTENTIAL

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GLACIAL DEPOSITS OF WISCONSIN
Sand And Gravel Resource Potential

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INTRODUCTION

This report was written to accompany the map, "Glacial Deposits of Wisconsin: Sand and Gravel Resources Potential" by David W. Hadley and James H. Pelham, which was prepared by the Wisconsin Geological and Natural History Survey in cooperation with the State Planning Office, Department of Administration. The map, which is based on all available published and unpublished glacial mapping in the state, represents a summary of the current state of knowledge concerning the surficial glacial deposits of Wisconsin.

The purpose of the map and this report is to indicate the sand and gravel resource potential of Wisconsin glacial deposits. Wisconsin sand and gravel resources are a product of the glacial ice age. Thus, determinations of the distribution of the different types of glacial deposits is critical to determining the location of potential sand and gravel deposits.

The report briefly discusses glaciation and glacial deposits, including definitions of the more important types; lists, describes and evaluates the sources used in compiling the map; describes the methods used in map compilation; lists and describes the map units used; discusses the probability of finding commercial deposits of sand and gravel in each of the mapping units; and discusses the need for additional geological mapping of Wisconsin's glacial deposits. Finally, an annotated bibliography of the sources used in compiling the map is provided, together with an index map.

GLACIATION AND GLACIAL DEPOSITS

About one million years ago, significant changes in world climate brought about the beginning of what geologists refer to as the Pleistocene Epoch, popularly called the "Ice Age." At centers in Canada, the rate of snow accumulation began to exceed the rate at which the snow melted, and as the snow continued to accumulate, the pressures deep in the snow mass changed the snow to ice. In time, these vast accumulations of ice attained thicknesses of almost two miles. The high pressure at the base of the ice caused it to begin to spread laterally, and part of this flow moved into what is now Wisconsin. In time, the climate moderated, the rate of melting once again exceeded the rate of accumulation, and the ice retreated to the north.

Study of the glacial deposits of North America shows that there were four major advances and retreats of the ice. It is believed that almost all of the glacial deposits exposed at the surface in Wisconsin were deposited by the fourth of these advances. This time period is known as the Wisconsin Stage, since it was in Wisconsin that deposits of this age were first studied in detail.

As the ice of the fourth advance moved into Wisconsin, differences in topography and in the rate of ice accumulation in the source areas caused the ice front to split into a series of tongue-like lobes. Four major lobes of ice entered Wisconsin. One moved down the Lake Michigan basin, a second down Green Bay, a third moved southwestward across the northern peninsula of Michigan along the east side of the Keweenaw Peninsula, while the fourth moved southwestward down the axis of the Lake Superior basin into the extreme northwest corner of the state.

As the glacial ice moved outward from the centers of accumulation, it picked up vast quantities of rock and soil materials. These materials were subsequently deposited along its route of travel and at or near the margins of the ice. The general term for materials deposited through glacial action is glacial drift.

There are two major material types characteristic of glacial deposits. The first of these is till, which can be defined as unsorted and unstratified drift deposited directly by and under a glacier, either during glaciation or at the time of glacial melting, without subsequent reworking by meltwater from the glacier. It consists of a heterogeneous mixture of clay, sand, gravel, and boulders.

The second major class of glacial materials is termed outwash, which can be defined as stratified material (chiefly sand and gravel) which has been removed or washed out from a glacier by meltwater streams and deposited beyond the margin of the glacier.

In addition to differentiating areas of till from areas of outwash, glacial geologists will normally map a number of other glacial features which are characterized primarily on the basis of their morphology and inferred method of formation. Some of the more important of these features are defined below. These definitions are largely paraphrased from those given in the "Glossary of Geology," published by the American Geological Institute (1972).

Moraine: A mound, ridge or other accumulation of unsorted and unstratified glacial drift, predominantly till, deposited chiefly by the direct action of glacial ice.

End Moraine: A moraine produced at the front of an actively flowing glacier.

Terminal Moraine: A moraine formed at or near a more or less stationary edge, or at a place marking the cessation of an important glacial advance. The term is sometimes used as a synonym for end moraine.

Recessional Moraine: An end moraine built during a temporary but significant halt or pause in the final retreat of a glacier. Also a moraine built during a slight or minor readvance of the ice front during a period of general recession.

Interlobate Moraine: A moraine formed along the line of junction of two adjacent glacial lobes which have pushed their margins together.

Ground Moraine: A fairly even, thin layer of till, having a gently rolling surface, and formed from the rock debris dragged along in, on, or under a glacier or ice sheet.

Outwash fan: A fan shaped body of outwash deposited by meltwater streams in front of the terminal moraine of a glacier.

Outwash Plain: A broad, outspread, flat or gently sloping sheet of outwash deposited by streams flowing in front of or beyond the terminal moraine of a glacier, and formed by coalescing outwash fans.

Valley Train: A long, narrow, body of outwash deposited by meltwater streams in front of or beyond the terminal moraine of an active glacier and confined within the walls of the valley below the glacier.

Outwash Terrace: A dissected valley train, or a bench-like deposit extending along a valley downstream from an outwash plain or terminal moraine; a flat-topped bank of outwash with an abrupt outer face.

Kettle: Steep-sided, usually basin- or bowl-shaped depression, in deposits of glacial drift. It often contains a lake or swamp, and is thought to have formed by the melting of a large detached block of stagnant ice that had been wholly or partly buried in the glacial drift.

Kame: A steep-sided hill, mound, knob, hummock or short irregular ridge composed chiefly of poorly sorted and stratified sand and gravel, deposited by a sub-glacial stream as a fan or delta against or beyond the terminal margin of a melting glacier, and generally aligned parallel to the ice front. The term has undergone several changes in meaning but is still often employed to describe deposits of poorly sorted sand and gravel whose exact mode of formation is uncertain.

Esker: A long, low narrow, sinuous and steep-sided ridge or mound composed of irregularly stratified sand and gravel that was deposited by a stream flowing between ice walls or in an ice tunnel in or under a continuously retreating glacier, and which was left behind when the ice melted.

Pitted Outwash Plain: An outwash plain marked by many irregular depressions, kettles, shallow pits, or pot holes. Also called a pitted plain.

Ice Contact Deposit: Stratified drift deposited in contact with melting glacial ice, such as an esker, kame, or a feature marked by numerous kettles such as a pitted outwash plain.

Glacial Lake: A lake held in place by the blocking of natural drainage at the edge or front of a glacier or ice sheet, such as a lake ponded by ice moving across a valley, or a lake occurring along the margin of a continental ice sheet.

Glaciolacustrine: Pertaining to, derived from, or deposited in glacial lakes. Especially said of the deposits composed of suspended particles brought by meltwater streams into lakes bordering the glacier.

Drumlin: A low, smoothly rounded, elongated and oval hill, mound, or ridge of compacted till, built under the margin of the ice and shaped by its flow, or carved out of an older moraine by readvancing ice. The longer axis is parallel to the direction of movement of the ice. It generally has a blunt nose facing in the direction from which the ice approached, and a more gentle slope tapering in the other direction.

Drumlin Field: A landscape characterized by swarms of closely spaced drumlins separated by small marshy tracts.

Crevasse: A deep and nearly vertical split, crack, or fissure in a glacier or other mass of land ice caused by stresses resulting from differential movement over an uneven surface.

Crevasse Fill: A short straight ridge of stratified sand and gravel believed to have been deposited in a crevasse in a wasting glacier, and left standing after the ice melted.

SOURCES OF INFORMATION

This section includes a general description of the sources used in compiling the new state glacial map. A more detailed description of each of the sources utilized, including an index map, is given in the bibliography.

The principal source used in compiling the new map was a map of the glacial features of Wisconsin compiled by F.T. Thwaites (1956) at a scale of 1:1,000,000. The original map is held on open file by the Wisconsin Geological and Natural History Survey and served as the basis for the page-size map of Wisconsin Glacial Deposits which has been widely distributed. The latter map is included as Figure 1. Over much of the western portion of the state, the map by Thwaites (1956) served as the sole data source and the new map therefore represents nothing more than an enlargement of the earlier map within this area.

Much of the new map, and of the 1956 map by Thwaites is based on three published maps. The earliest of these is a map of southeastern Wisconsin by W.C. Alden (1918), which was published by the United States Geological Survey. The second is a map of a portion of northeastern Wisconsin prepared by Thwaites (1943) and published by the Geological Society of America. The third, by Thwaites and Bertrand (1957), is a map of the Door County Peninsula published by the Geological Society of America. All three of these maps were published at a scale of 1:250,000.

The primary source of information over much of northern and north-central Wisconsin is an air photo analysis carried out by the Photographic Interpretation Research Division of the U.S. Army Cold Regions Research and Engineering Laboratory (1969) in conjunction with planning for Project Sanguine. This study resulted in a series of maps at a scale of 1:48,000. The report had a limited distribution, but copies are held both at the offices of the Wisconsin Geological and Natural History Survey, and at the Map Library in Science Hall on the UW-Madison campus.

Another valuable source of published information is a series of Water Supply Papers published by the United States Geological Survey in conjunction with the Wisconsin Geological and Natural History Survey. These reports include surface geology maps of Racine and Kenosha, (Hutchinson, 1970), Waushara (Sommers, 1965), Portage (Holt, 1965), and Waupaca (Berkstresser, 1964) Counties. In addition to the county reports, a more recent publication (Bell and Sherrill, 1974) encompasses portions of Taylor, Lincoln, Clark, Marathon, and Wood Counties.

The final published source is a report on the soils and forest ecology of Menominee County by Milfred, Olson, and Hole (1967) which includes a map of the glacial deposits of the county.

In addition to the published reports, recent work by the Wisconsin Geological and Natural History Survey has resulted in maps of the surficial deposits of Dane, Waukesha, and Walworth Counties. These maps, which were derived from the published soils maps, are held on open file at the survey offices. In addition, the glacial geology of Walworth County is currently being mapped by the author and preliminary findings from this study were incorporated into the state map.

Finally, a recent M.S. thesis at UW-Madison by A.R. Nelson (1973) includes a glacial map of portions of Lincoln, Langlade, and Oneida Counties.

The author also consulted with those workers he knew to be actively engaged in mapping the glacial geology of Wisconsin. These included Prof. David Mickelson of UW-Madison, Prof. Allen Schneider of UW-Parkside, and Mr. Adam Cahow of UW-Eau Claire. The contributions of these geologists is gratefully acknowledged.

METHOD OF COMPILATION.

The first step in compiling the summary map was to reduce all of the available data to a common scale and fit them to a common base map. The scale chosen for compilation was 1:250,000, which is twice the scale of the finished map. U.S.G.S. one degree by two degree quadrangle maps were used for base maps in this compilation. Changes in scale were accomplished either by using photographic techniques, or through the use of an opaque projector. The data from each source, after being corrected to the compilation scale, was plotted on transparent plastic film overlays of the appropriate quadrangle.

Considerable difficulty was encountered with the early published maps of Alden (1918) and Thwaites (1943, 1957) due to the lack of accuracy of the base maps that were available to these workers at the time of mapping. To correct these inaccuracies, the maps were redrafted on a township by township basis (a township is normally 36 square miles in area) using lakes, railroads, rivers, roads, and prominent topographic features for additional control.

Once all of the data sources were corrected for scale and plotted on a common base, compilation of the map was begun. In those areas of the state covered by a single source, the data was simply transcribed. As would be expected, the situation is most complex in those areas covered by more than one source. An example of the type of difficulty encountered is shown in figures 2, 3, and 4. Each of these figures is a map of the Lily quadrangle, which includes portions of Langlade and Forest Counties. This area was chosen as representative of the situation that exists in those areas of the state where mapping by more than one individual overlaps. Figure 2 is taken from an unpublished reconnaissance field map prepared by Dr. David Mickelson (1974), Figure 3 is from the map by F.T. Thwaites (1943), and Figure 4 is the air photo interpretation done in conjunction with Project SANGUINE (U.S. Army, 1969). There is obviously a great deal of disagreement between the three investigators as to the glacial geology of the Lily quadrangle.

An additional major source of difficulty lay in the fact that the map units used by the various investigators differed widely. Many of the recent

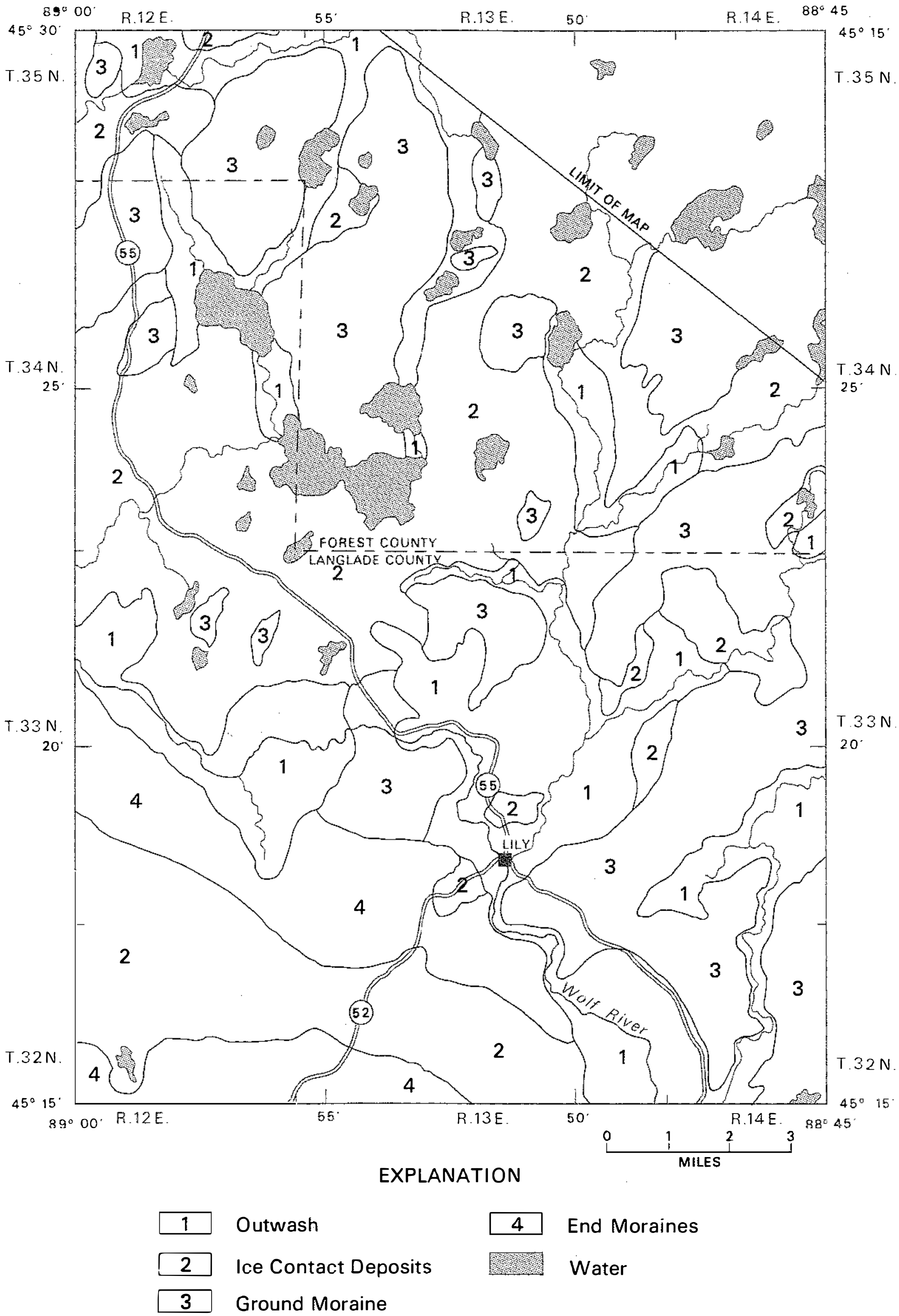
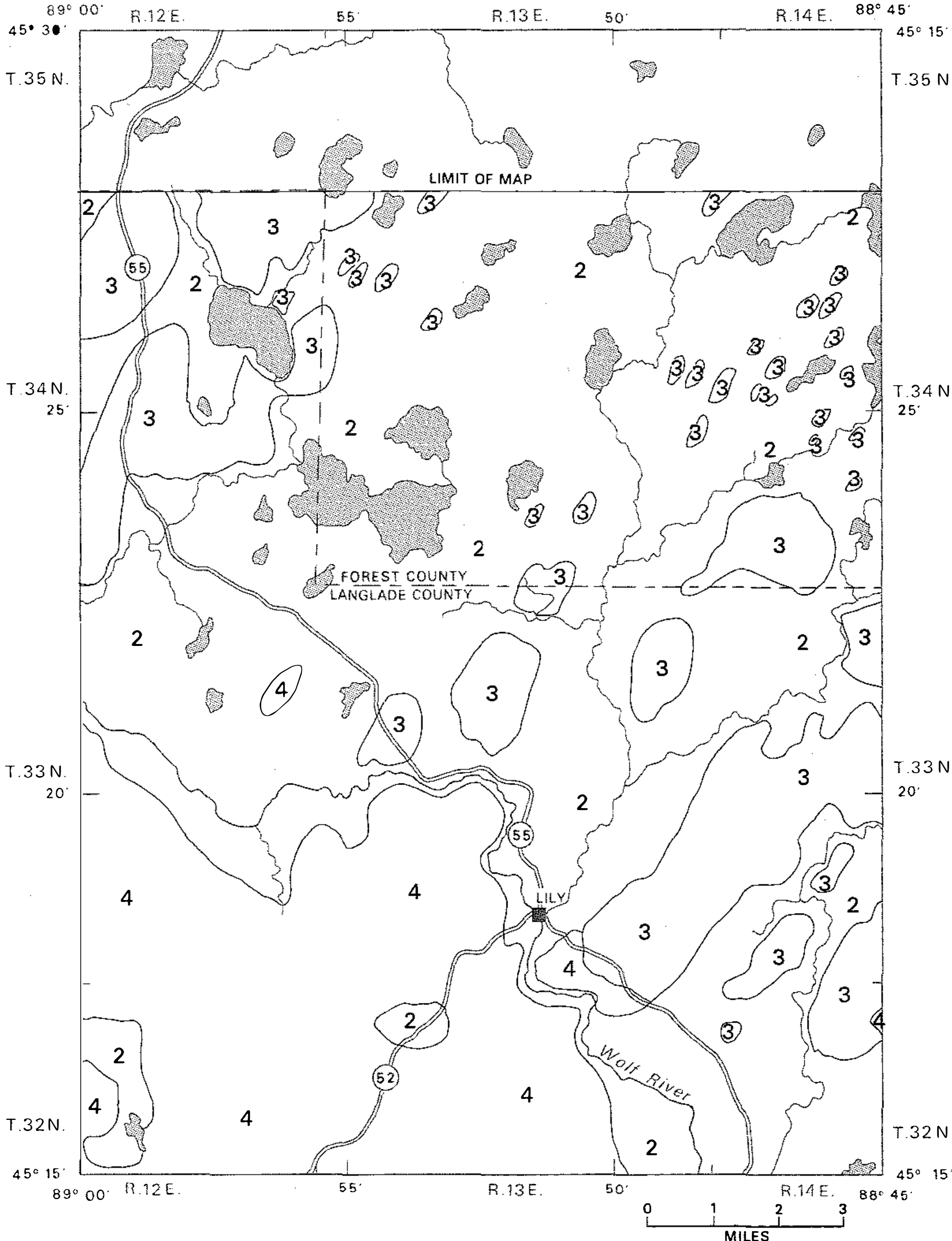


Figure 2. Glacial deposits of the Lily quadrangle, Wisconsin (from Mickelson, 1974).



EXPLANATION

- 1 Outwash
- 2 Ice Contact Deposits
- 3 Ground Moraine
- 4 End Moraines
- Water

Figure 3. Glacial deposits of the Lily quadrangle, Wisconsin (from Thwaites, 1943).

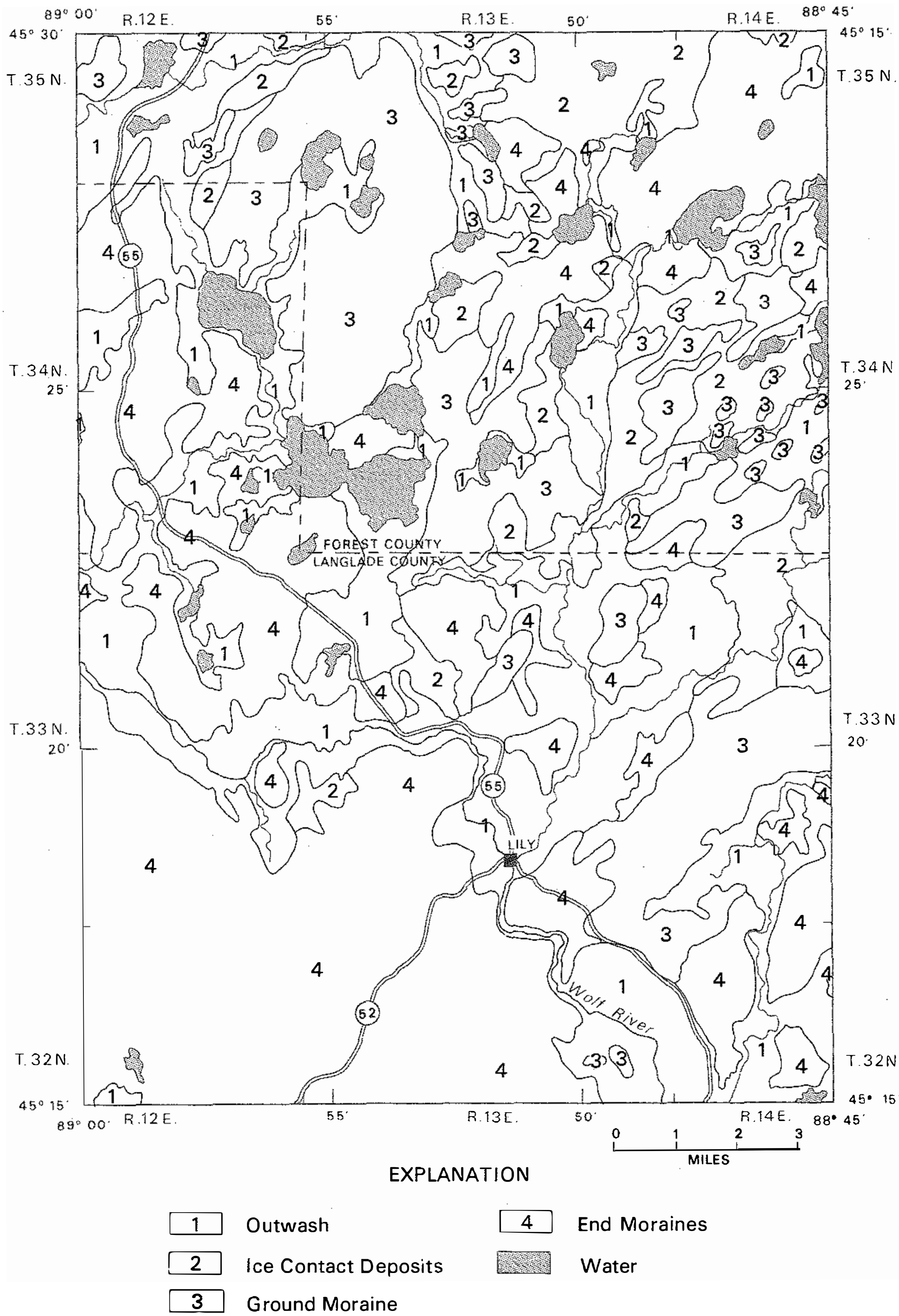


Figure 4. Glacial deposits of the Lily quadrangle, Wisconsin (from Project SANGUINE).

maps, for example, rather than being maps of the glacial geology, are largely derived from soils maps and show only the parent materials from which the soils were believed to have been formed. A great deal of interpretation, therefore, was necessary to convert the data shown on the different maps to a single mapping system so that the various data sources could be compared directly and evaluated. The map units chosen for use in the summary map are discussed in a later section.

A general procedure was established for choosing between conflicting data in the compilation of the summary map. In this procedure the early published studies of Alden (1918) in the southeastern portion of the state and of Thwaites (1943) and Thwaites and Bertrand (1957) in the northeastern portions were considered to be the primary data sources. Where the data shown on these maps had been reinterpreted by Thwaites in his summary compilation of 1956, this interpretation was usually given precedence.

In most cases, the data shown in the U.S. Geological Survey Water Supply Papers were found to be largely based upon the earlier mapping. In these cases, the additional detail shown on the more recent maps was incorporated. Where differences in interpretation did arise, the work of Alden (1918) and Thwaites (1943) and Thwaites and Bertrand (1957) was once again usually given precedence.

As was mentioned earlier, the maps of Waukesha (Olmstead, 1973), Walworth (Hadley, 1974), and Dane (Olcott, 1973) Counties are maps of the surface materials rather than true geological maps. In these cases, the materials information was used primarily to refine the geological boundaries shown on the earlier maps, and to add fine detail. Some alteration of the earlier mapping was made in Walworth County on the basis of ongoing field studies by the author.

The SANGUINE (U.S. Army, 1969) mapping was given the lowest priority of all maps utilized in the study primarily because of the almost complete absence of on-the-ground field checks. In those areas in which the SANGUINE data overlapped the work of other investigators, it was found that the data agreed relatively well on a broad regional scale, but that the finer scale interpretations were often apparently poor.

It can be seen from the above that in compiling this map it was necessary to make a number of relatively arbitrary decisions, since neither the time nor the funds were available for the extensive field checking that would be necessary to make an informed choice between the differing views of several investigators. As a general rule, precedence was given to the view of the investigator who, in the opinion of the author, had the greatest overall grasp of the glacial geology of the area, and whose work generally incorporated the greatest amount of field study.

When compilation of the map at a scale of 1:250,000 had been completed on the U.S.G.S. quadrangle base, each quadrangle was reduced to the final mapping scale of 1:500,000 photographically.

An additional major problem lay in the lack of compatability between the 1:250,000 base maps and the state base map at a scale of 1:500,000. When the data as compiled on the 1:250,000 maps was projected on the state base map, it was found to be seriously out of registry with the drainage pattern as shown on the state base.

It was necessary, therefore, to go back to the original geologic maps and pick out the deposits that were closely associated with those lakes and streams shown on the state base map. This data was then replotted on the state map in proper registry. These stream and lake controlled deposits were then used as control points, and the remainder of the data was replotted so as to retain the proper spatial relationships.

Throughout the process of compiling the map, each reduction in scale necessitated generalizing the data as shown on many of the source maps. This was especially true in the final reduction from the compilation scale of 1:250,000 to the final map scale of 1:500,000. In this reduction, all of the data was generalized so as to provide about the same density of information as shown on the maps of Alden (1918), Thwaites (1943), and Thwaites and Bertrand (1957).

Although this generalization was necessary from practical cartographic considerations and to provide better continuity in the finished map, a great deal of valuable information was lost. It was decided, therefore, that in addition to the state glacial map, which is largely synoptic, showing an overview of the glacial deposits and their interrelationships, the Survey would also prepare a set of maps at the compilation scale. When completed, these maps will constitute an Atlas of the Glacial Geology of Wisconsin. The maps will be placed on open file at the Geological and Natural History Survey and transparent overlays for the U.S.G.S. one degree by two degree quadrangle maps will be available for purchase. As glacial mapping within the state progresses, these maps will be continuously revised and updated.

MAP UNITS

The following seven units were used in compiling the summary glacial map of Wisconsin:

1. Outwash
2. Pitted Outwash and Other Ice Contact Deposits
3. Ground Moraine
4. End Moraines
5. Glaciolacustrine Deposits
6. No glacial deposits
7. Water

The types of glacial deposits included with the map units are listed below:

OUTWASH

Outwash plains, terraces, fans, and valley trains. Mainly well sorted and stratified sand and/or sand and gravel.

PITTED OUTWASH AND OTHER ICE CONTACT DEPOSITS

Pitted outwash plains, kames, eskers, crevasse fillings, and related features. Mainly sand and gravel with sorting and stratification locally poor.

GROUND MORAINE

Till plains. Thin drift, mostly till of relatively uniform thickness but discontinuous in some areas of older drift. Includes drumlins.

END MORAINES

Terminal, recessional and interlobate moraines. Mostly till and associated local ice-contact deposits.

GLACIOLACUSTRINE DEPOSITS

Lake sediments, including associated deltas, sand dunes, and organic deposits. Mainly sand, silt and clay.

SAND AND GRAVEL POTENTIAL

Sand and gravel are found primarily in outwash bodies and in ice contact features such as kames and eskers. Thus, the potential for finding sand and gravel in each of the map categories depends upon the inclusion of sand and gravel bodies of these types in the unit. The potential for finding sand and gravel in each of the categories used in this study is summarized below:

Outwash:

Outwash is a primary source of sand and gravel and has the greatest potential for containing high quality commercial deposits. Identification of commercial deposits may be difficult because outwash is normally flat-lying and varies in quality thus much drilling or test pitting may be necessary. Special mining methods may be required where the depth to water is shallow and where rigorous winter ice conditions impose severe limitations.

Pitted Outwash and other Ice Contact Deposits:

Pitted outwash and other ice-contact deposits have a high potential for containing commercial sand and gravel. These deposits tend to be smaller and often less uniform than those found in outwash. However, as most ice contact deposits are steep-sided, the sand and gravel is often exposed by erosion and thus more readily found than are flat-lying outwash plains and alluvial fans. In addition, the sand and gravel is usually well-drained, making special mining methods unnecessary.

Ground Moraine:

Till plains have a low potential for containing deposits of commercial sand and gravel. Production is limited to gravel-cored drumlins and to isolated kames, eskers and similar features which are often superimposed on the ground moraine.

End Moraines:

End moraines have a low potential for containing large deposits of commercial sand and gravel. Outwash fans as well as kames and other local ice-contact deposits are often found in association with end moraines. These associated deposits have a high potential to contain moderate to small deposits of sand and gravel.

Glaciolacustrine Deposits:

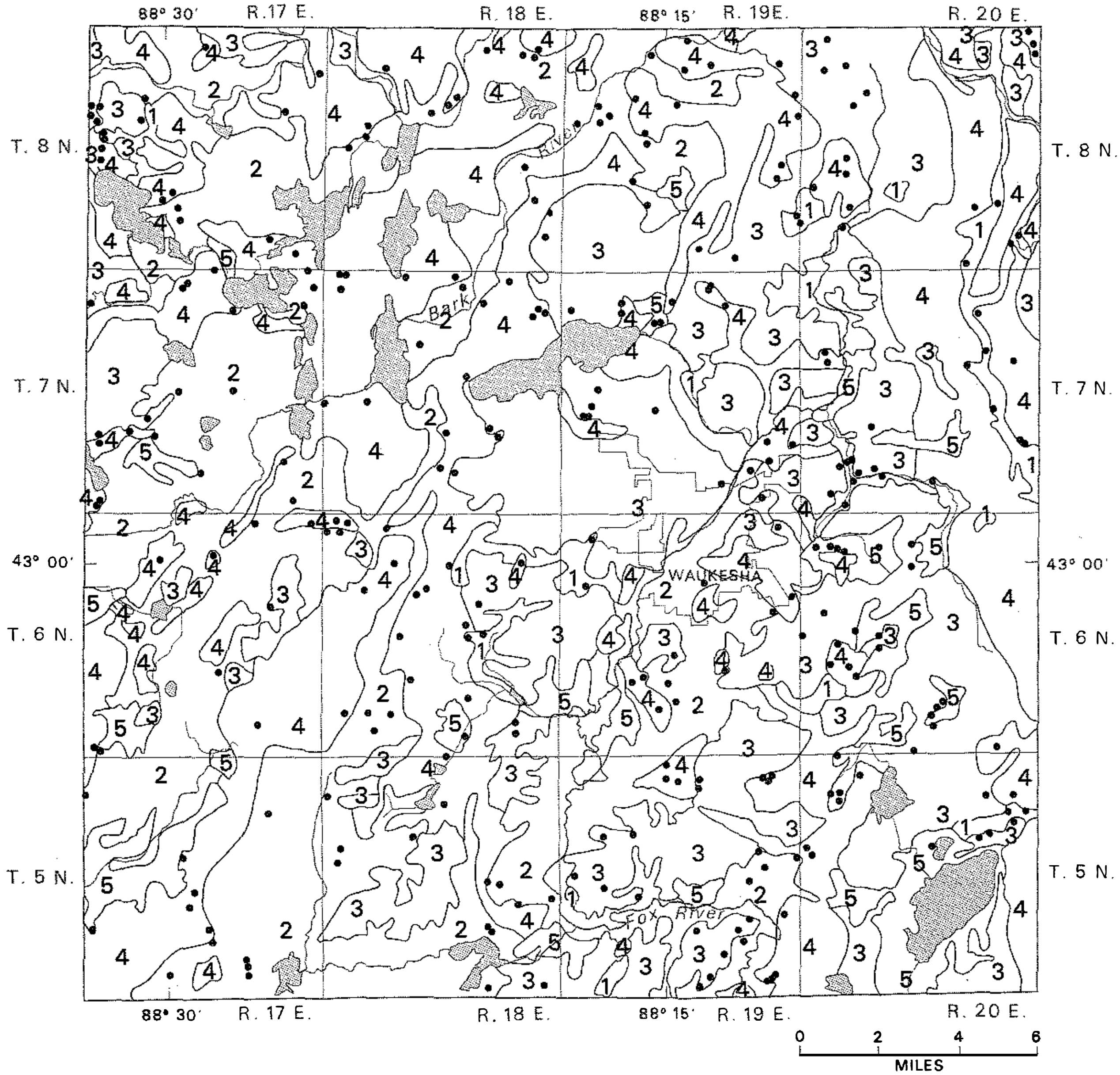
Lake sediments and associated features have the least potential for containing commercial deposits of sand and gravel. Production is limited to deltaic deposits and to sand deposits in beaches, bars, and dune areas.

General Comments: When using the map of the Glacial Deposits of Wisconsin to evaluate the potential of an area for sand and gravel production, it must be remembered that the map shows only the surficial deposits. In many portions of the state, particularly in the highly populous areas of southeastern Wisconsin, a large percentage of the sand and gravel production comes from deposits that are not exposed at the surface. Even though the area may be mapped as ground moraine, and therefore be expected to supply little or no sand and gravel, the area may in fact be underlain at a shallow depth by outwash. Figure 5 is an enlargement of Waukesha County from the Glacial Deposits of Wisconsin map, on which has been plotted the location of the sand and gravel pits in the county. It can be seen that the actual pit locations bear little relation to the areas mapped as deposits having a high potential for sand and gravel production on the basis of the surficial materials, since much of the production is from subsurface units.

It should also be remembered that the rating of the various map units in terms of their potential for containing sand and gravel deposits was done on an average, or overall, basis. Large areas mapped as outwash, for instance, may be made up almost entirely of sand and have, therefore, no potential for gravel production. Similarly, although end moraines are often potentially rich in sand and gravel deposits, the moraines within any particular area may be almost devoid of deposits of this type. Finally, in some areas of the state, especially those areas mapped through the air photo interpretation work for Project SANGUINE (U.S. Army, 1964), areas mapped as outwash may be found to be covered by swamps, lakes, or significant thicknesses of silty recent sediments, making production from these deposits difficult if not impossible.

THE NEED FOR A PROGRAM OF GLACIAL MAPPING

As shown on the map of the Glacial Deposits of Wisconsin that accompanies this report, the surficial deposits over most of the state are of glacial origin. Since these glacial materials are the surficial deposits, they exert an extremely strong influence on many of the principal factors that together make up the physical environment. As an example, the types of soils that have developed since glaciation of the state have been determined to a large degree by the nature of the glacial parent materials upon which they have formed. As a consequence, factors such as the distribution of prime agricultural lands can be closely tied to the glacial geology. Similarly, the distribution and quality of both ground and surface water are closely tied to the nature and pattern of distribution of the glacial sediments. The abundant deposits of sand and gravel that constitute Wisconsin's number one mineral resource owe their existance to glacial action, and as the more readily located deposits near our population centers are exhausted, the need for knowledge of the large-scale glacial geology becomes increasingly important. Finally, the



EXPLANATION

1	Outwash
2	Ice Contact Deposits
3	Ground Moraine
4	End Moraines
5	Lake Basin Deposits
(shaded)	Water
•	Sand and Gravel Pit

Figure 5. Relationship between the location of sand and gravel pits and surficial materials in Waukesha County, Wisconsin.

engineering properties of the surficial deposits throughout the glaciated portions of the state are controlled in large part by the composition and mode of deposition of the deposits and can, therefore, often be correlated directly with the glacial geology.

Because of the control exerted over so many facets of our environment by the glacial geology, there is a large and diverse group of agencies and individuals that can and do make good use of the geologic data as it becomes available. This group includes soil scientists, engineers, ecologists, hydrologists, geologists, foresters, planners, administrators, and many others.

One of the major goals of the study described in this report was to evaluate the existing mapping in terms of how well it met the needs of the contemporary user groups. It was found that the existing geologic mapping of the glacial deposits of Wisconsin was, for the most part, not adequate to meet these needs. Some of the major inadequacies are discussed below.

Over a substantial portion of the state, the only source of information on the distribution of glacial deposits is the rough compilation of Thwaites (1956). This mapping is at a scale of 1:1,000,000 and for the most part the sources of information from which Thwaites compiled his map are unknown.

Over much of north-central Wisconsin, the only source of information is the air photo interpretation work for Project SANGUINE. The accuracy of this data is not known and extensive field checking will be necessary for confirmation.

In those areas of the state that have been more intensively studied, there is significant disagreement over the distribution of mapped units in practically every instance in which the work of two or more investigators overlaps.

An additional, and perhaps even more cogent, reason for an accelerated program of glacial mapping in Wisconsin lies in the advances that have been made in the field of glacial geology. The author's work in Walworth County has, for example, shown that through careful study it is possible to differentiate at least eight distinct units of glacial till. Units such as these often have physical and chemical characteristics that remain essentially constant over relatively large areas. Since many of the factors of interest to soil scientists, geologists, planners, and engineers can be correlated with the various till units, differentiating these units in mapping could greatly increase the utility of the map.

Finally, although maps at a scale of 1:250,000 and smaller are useful for providing an overview of the glacial geology of large areas, maps of a much larger scale are needed for most practical applications in order to provide the needed detail.

In summary, in spite of the critical need for maps to show the distribution of glacial deposits, the glacial geology of much of Wisconsin has never been mapped in detail. Even where relatively large-scale mapping has been carried out, there is considerable doubt about the accuracy of much of the information. Finally, the existing maps are at such a small scale that they are of little use in most practical applications and most are badly outdated in terms of the types of information shown.

ANNOTATED BIBLIOGRAPHY OF GLACIAL MAPPING IN WISCONSIN

Each numbered entry refers to numbered area shown on Figure 6

1. Alden, William C. 1918. Quaternary geology of southeastern Wisconsin: U.S. Geol. Survey Prof, Paper 106, 356 pages, plate 3.

   Scale: 1:250,000
   Units mapped: Terminal moraines, ground moraine, interlobate moraine, outwash, outwash terraces, lake bed deposits, drumlins, eskers, beach and dune deposits, marshes.
   Comments: Deposits are differentiated on the basis of both age and glacial lobe. Very poor base map. This is still the primary reference for the glacial deposits of southeastern Wisconsin.

2. Bell, E. A. and Sherrill, M.G. 1974. Water availability in central Wisconsin-an area of near surface crystalline rock: U.S. Geol. Survey, Water-Supply Paper 2022, 32 pages, plate 2.

   Scale: 1:125,000
   Units mapped: Alluvium and peat, outwash, and till.
   Comments: Interpretation difficult because of the small number of map units.

3. Berkstresser, C.F., Jr. 1964. Ground-water resources of Waupaca County, Wisconsin: U.S. Geol. Survey, Water-Supply Paper 1669-U, 38 pages, plate 3.

   Scale: 1:62,500
   Units mapped: Alluvium, dune sand, peat and marl, glaciolacustrine deposits, till, glaciofluvial deposits, undifferentiated till, and glaciofluvial deposits.
   Comments: Combined units make interpretation difficult.

4. Hadley, D.W. 1974. Surficial deposits of Walworth County, Wisconsin: Wis. Geol. and Nat. Hist. Survey, open-file map.

   Scale: 1:62,500
   Units mapped: Till, outwash, peat and muck, glaciolacustrine deposits, silty alluvium and colluvium, ice contact deposits.
   Comments: Derived from soils mapping. Semi-detailed field check shows the soils mapping to be in error in several areas.

5. Holt, C.L.R., Jr. 1965. Geology and water resources of Portage County, Wisconsin: U.S. Geol. Survey, Water-Supply Paper 1796, 77 pages, plate 1.

   Scale: 1:62,500
   Units mapped: Moraine deposits, ground moraine, outwash, undifferentiated outwash and till, alluvium, and marsh deposits.
   Comments: In some cases, combined units make interpretation difficult.

6. Hutchinson, R.D. 1970. Water resources of Racine and Kenosha Counties, southeastern Wisconsin: U.S. Geol. Survey, Water-Supply Paper 1878, 63 pages, plate 2.

Scale:	1:125,000
Units mapped:	Outwash, ice contact deposits, sandy till, silty clay till, lake deposits, dunes and alluvium, organic deposits.
Comments:	Primarily a map of surficial materials.

7. Milfred, C.J.; Olson, G.W.; Hole, F.D. 1967. Soil resources and forest ecology of Menominee County, Wisconsin: Wis. Geol. and Nat. Hist. Survey, Bull. 85, Soil Series No. 60, 203 pages, map.

Scale:	1:63,360
Units mapped:	Till, outwash, drumlins, eskers, ice contact deposits.
Comments:	Deposits are further broken down on the basis of color and topography. Although map units are tied to the regional geology in the text, the classification scheme used on the map is not.

8. Nelson, A.R. 1973. Age relationships of the deposits of the Wisconsin Valley and Langlade glacial lobes of north-central Wisconsin: unpublished M.S. thesis, Univ. Wis.-Madison, plate 1.

Scale:	Approx. 1:140,000
Units mapped:	Till, lake sediments, outwash, ice contact features, complex undifferentiated drift, drumlins, eskers, moraines.
Comments:	Differentiates four tills and three moraines.

9. Olcott, P.G. 1973. Surficial materials of Dane County, Wisconsin: Wis. Geol. and Nat. Hist. Survey, open-file map.

Scale:	1:62,500
Units mapped:	Till, outwash, glaciolacustrine, alluvium, marsh and made land.
Comments:	Derived from soils mapping. Detailed field check of a representative township has disclosed many errors in the soils mapping.

10. Olmstead, R.J. 1973. Surficial materials of Waukesha County, Wisconsin: Wis. Geol. and Nat. Hist. Survey, open-file map.

Scale:	1:62,500
Units mapped:	Till, ice contact deposits, outwash, alluvium, marsh, glaciolacustrine deposits, eolian deposits, and altered land.
Comments:	Derived from soils mapping. Not field checked.

11. Summers, W.K. 1965. Geology and ground-water resources of Waushara County, Wisconsin: U.S. Geol. Survey, Water-Supply Paper 1809-B, 32 pages, plate 3.

Scale:	1:62,500
Units mapped:	Alluvium, outwash, morainal deposits, undifferentiated outwash and till, glaciolacustrine deposits.
Comments:	Much combining of units. For example, drumlins and ice contact forms are mapped as morainal deposits.

12. Thwaites, F.T. 1943. Pleistocene of part of northeastern Wisconsin: Geol. Soc. Amer. Bull., v.54, pp. 87-144, plate 10.

Scale: 1:250,000
Units mapped: Terminal moraines, ground moraine, outwash and outwash terraces, deltas, sand dunes, drumlins, and eskers.
Comments: Deposits of three different ages are differentiated, and the areas that were submerged by various glacial lakes are delineated. Very poor base map.

13. Thwaites, F.T. 1956. Glacial features of Wisconsin: Wis. Geol. and Nat. Hist. Survey, open-file map.

Scale: 1:1,000,000
Units mapped: End moraines, ground moraine, outwash-pitted, outwash-unpitted, lake basins.
Comments: Map was compiled from unspecified published and unpublished sources, and served as the basis for the widely distributed page-size map included as Figure 1 in this report.

14. Thwaites, F.T. and Bertrand, K. 1957. Pleistocene geology of the Door Peninsula, Wisconsin: Geol. Soc. Amer. Bull., v. 68, pp. 831-880, plate 8.

Scale: 1:250,000
Units mapped: Terminal moraines, ground moraine, outwash, sand dunes, drumlins, and eskers.
Comments: Deposits of two ages are differentiated, and areas submerged by various glacial lakes are indicated. Shows geology of the shallow subsurface under thin surficial deposits. Poor base map.

15. U.S. Army Cold Regions Research and Engineering Laboratory, 1969, An airphoto analysis of a portion of Wisconsin and Michigan for Project SANGUINE: 125 pages, 5 appendices, 99 maps.

Scale: 1:48,000
Units mapped: Moraines, ground moraine, drumlins, outwash, eskers, kames, lake bed deposits, beach ridges, alluvium, sand dunes, loess.
Comments: An excellent airphoto study, but contains many inaccuracies due to lack of adequate field checking. Many areas mapped as moraine may be ice contact deposits. Fails to show thin drift in many areas.

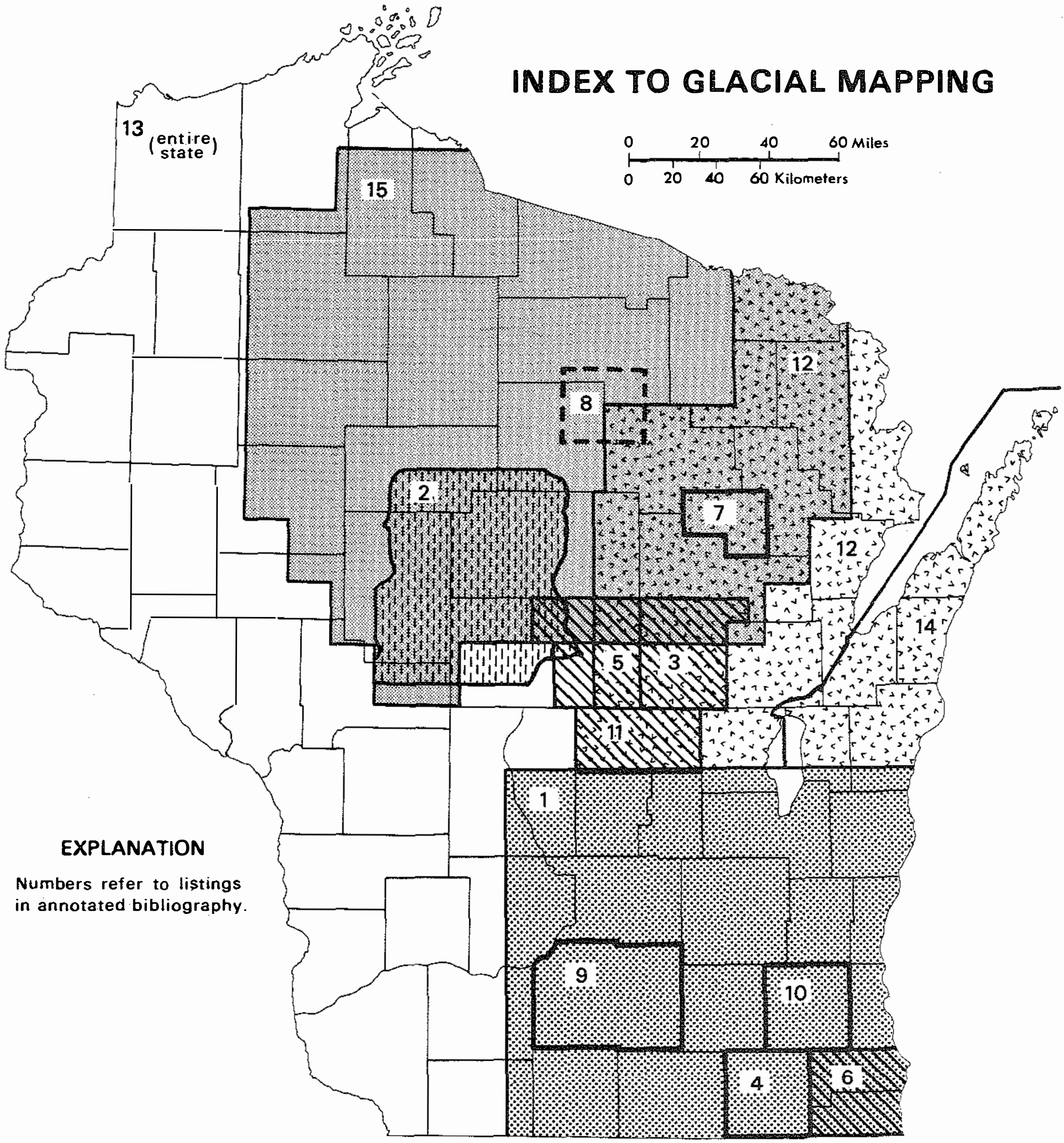


Figure 6. Index to glacial mapping in Wisconsin.