94th Congress, 2d Session } COMMITTEE PRINT

# MINERAL AND WATER RESOURCES OF WISCONSIN

## REPORT

PREPARED BY THE

UNITED STATES GEOLOGICAL SURVEY

IN COLLABORATION WITH THE

WISCONSIN GEOLOGICAL AND NATURAL HISTORY SURVEY

PRINTED AT THE REQUEST OF

HENRY M. JACKSON, *Chairman*

COMMITTEE ON INTERIOR AND INSULAR AFFAIRS

UNITED STATES SENATE

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## MEMORANDUM OF THE CHAIRMAN

*To Members of the Senate Interior and Insular Affairs Committee:*

I am transmitting for your information a report entitled "Mineral and Water Resources of Wisconsin," prepared by the U.S. Geological Survey at the request of our colleague, Senator William Proxmire.

This detailed survey will be particularly helpful to government and business leaders in Wisconsin. It will also be valuable to the Congress and members of this committee as we consider legislation regarding mineral, water, and related energy development.

HENRY M. JACKSON, *Chairman.*

## LETTER OF TRANSMITTAL

U.S. DEPARTMENT OF THE INTERIOR,
GEOLOGICAL SURVEY,
*Reston, Va., September 9, 1976.*

Hon. WILLIAM PROXMIRE,
*U.S. Senate,*
*Washington, D.C.*

DEAR SENATOR PROXMIRE: In response to your letter of June 3, 1974, we are pleased to transmit herewith a report on the "Mineral and Water Resources of Wisconsin," prepared by the U.S. Geological Survey in collaboration with the Wisconsin Geological and Natural History Survey.

The report describes each of the various types of mineral deposits known in Wisconsin. Their relationship to the fundamental geologic framework is discussed in order to indicate how and where other deposits might be found and to provide the information needed for the wise development of the State's mineral resources. The section of the report on water resources describes the broad distribution and availability of surface water and ground water, both geographically and geologically, and discusses the past and future water utilization.

We hope that this report will be helpful to you and your colleagues and also to officials and residents of Wisconsin.

Sincerely yours,

V. E. MCKELVEY,
*Director.*

Enclosure: Report on Mineral and Water Resources of Wisconsin.

## FOREWORD

This report was prepared, at my request, by the U.S. Geological Survey of the Department of the Interior, in cooperation with the Wisconsin Geological and Natural History Survey.

I am confident that the report will prove to be a valuable tool in assisting Federal, State and local decisionmakers in planning ahead for the future of Wisconsin. It contains a wealth of information on the mineral deposits and water resources of the State, information which is required for decisions on the development of Wisconsin's mineral resources and on future water utilization. As the needs and goals of our society have changed, so has the scope of information required to make the decisions to meet these goals. The report on the "Mineral and Water Resources of Wisconsin" will go far toward meeting this requirement as Wisconsin looks to the decades ahead.

I wish to thank the personnel of the Department of the Interior, and the Wisconsin Geological and Natural History Survey for their contributions to this report.

WILLIAM PROXMIRE.

## PREFACE

(By R. A. Weeks, U.S. Geological Survey, Reston, Va.)

In 1971, the Wisconsin Legislature named galena the State mineral of Wisconsin, in recognition of the vital role this mineral played in the early development of settlements within the State. Early French explorers in the mid-17th century recognized this important lead ore mineral among the prized possessions of the Indians, and by the early 18th century established trading posts to acquire galena from them. The beginning of the 19th century saw the first migration into the territory that is now Wisconsin. These first permanent settlers were lead prospectors and miners. The early mines were shallow pits with associated spoil piles that resembled large badger burrows. These mines were responsible for Wisconsin's nickname of the "Badger" State.

From this early beginning, the State has had an active and continuous history of mineral production. The annual value of this industry has been about $114 million in each of the past 3 years (1973–75). While the total value of mineral production over this long history is not fully known, over 1 billion dollars' worth of iron, zinc, and lead ores has been won from the metal mines and an additional 1.3 billion dollars' worth of stone, sand, and gravel has been produced. Known resources and additional favorable areas indicate that present production levels probably can be maintained for these established commodities. Potential resources of peat are large, and increasing use of this material may result in significant growth of the peat industry. Recent discoveries of copper-zinc mineralization indicate that copper may become an important product of the State, and the level of zinc production might be increased.

Water resources are abundant and widely distributed and provide essential support for the agricultural and forestry industries of the State. Ample water of high quality satisfies many other industries, including the brewing industry for which Milwaukee is famous.

This report describes in summary form the mineral and water resources of Wisconsin and the relationship between these resources and the geologic framework of the State. The use, manner of occurrence, distribution, and outlook for all known mineral commodities in the State are described. The treatment of each commodity is necessarily brief, but those who wish to make deeper inquiry will find references to principal sources of detailed information.

The subject material and outline and the selection of authors was worked out jointly by staffs of the U.S. Geological Survey and the Wisconsin Geological and Natural History Survey. Carl E. Dutton of the Geological Survey assembled and edited the report with the close collaboration of Dr. Meredith E. Ostrom, Director and State Geologist.

METRIC-ENGLISH EQUIVALENTS

| Metric unit | | English equivalent |
|---|---|---|
| **Length** | | |
| millimetre (mm) | = 0.03937 | inch (in) |
| metre (m) | = 3.28 | feet (ft) |
| kilometre (km) | = .62 | mile (mi) |
| **Area** | | |
| square metre ($m^2$) | = 10.76 | square feet ($ft^2$) |
| square kilometre ($km^2$) | = .386 | square mile ($mi^2$) |
| hectare (ha) | = 2.47 | acres |
| **Volume** | | |
| cubic centimetre ($cm^3$) | = 0.061 | cubic inch ($in^3$) |
| litre (l) | = 61.03 | cubic inches |
| cubic metre ($m^3$) | = 35.31 | cubic feet ($ft^3$) |
| cubic metre | = .00081 | acre-foot (acre-ft) |
| cubic hectometre ($hm^3$) | =810.7 | acre-feet |
| litre | = 2.113 | pints (pt) |
| litre | = 1.06 | quarts (qt) |
| litre | = .26 | gallon (gal) |
| cubic metre | = .00026 | million gallons (Mgal or $10^6$ gal) |
| cubic metre | = 6.290 | barrels (bbl) (1 bbl=42 gal) |
| **Weight** | | |
| gram (g) | = 0.035 | ounce, avoirdupois (oz avdp) |
| gram | = .0022 | pound, avoirdupois (lb avdp) |
| tonne (t) | = 1.1 | tons, short (2,000 lb) |
| tonne | = .98 | ton, long (2,240 lb) |
| **Specific combinations** | | |
| kilogram per square centimetre ($kg/cm^2$) | = 0.96 | atmosphere (atm) |
| kilogram per square centimetre | = .98 | bar (0.9869 atm) |
| cubic metre per second ($m^3/s$) | = 35.3 | cubic feet per second ($ft^3/s$) |

| Metric unit | | English equivalent |
|---|---|---|
| **Specific combinations—Continued** | | |
| litre per second (l/s) | = .0353 | cubic foot per second |
| cubic metre per second per square kilometre [$(m^3/s)/km^2$] | = 91.47 | cubic feet per second per square mile [$(ft^3/s)/mi^2$] |
| metre per day (m/d) | = 3.28 | feet per day (hydraulic conductivity) (ft/d) |
| metre per kilometre (m/km) | = 5.28 | feet per mile (ft/mi) |
| kilometre per hour (km/h) | = .9113 | foot per second (ft/s) |
| metre per second (m/s) | = 3.28 | feet per second |
| metre squared per day ($m^2/d$) | = 10.764 | feet squared per day ($ft^2/d$) (transmissivity) |
| cubic metre per second ($m^3/s$) | = 22.826 | million gallons per day (Mgal/d) |
| cubic metre per minute ($m^3/min$) | =264.2 | gallons per minute (gal/min) |
| litre per second (l/s) | = 15.85 | gallons per minute |
| litre per second per metre [(l/s)/m] | = 4.83 | gallons per minute per foot [(gal/min)/ft] |
| kilometre per hour (km/h) | = .62 | mile per hour (mi/h) |
| metre per second (m/s) | = 2.237 | miles per hour |
| gram per cubic centimetre ($g/cm^3$) | = 62.43 | pounds per cubic foot ($lb/ft^3$) |
| gram per square centimetre ($g/cm^2$) | = 2.048 | pounds per square foot ($lb/ft^2$) |
| gram per square centimetre | = .0142 | pound per square inch ($lb/in^2$) |
| **Temperature** | | |
| degree Celsius (°C) | = 1.8 | degrees Fahrenheit (°F) |
| degrees Celsius (temperature) | =[(1.8×°C)+32] | degrees Fahrenheit |

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FIGURE

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# MINERAL AND WATER RESOURCES OF WISCONSIN

## INTRODUCTION

(By Carl E. Dutton, U.S. Geological Survey, Madison, Wis.)

This report summarizes and interprets information on the mineral and water resources of Wisconsin. Its main purpose is to help the people of the State and their elected or appointed officials understand and better appraise the present status of their mineral and water resources.

Wisconsin has had a long history of mining activity, dating from the early French explorers obtaining lead ore from the Indian inhabitants. Metallic ores of lead and zinc in southwestern Wisconsin and iron ore in the Gogebic and Florence areas have added significantly to the economic growth in those areas. Construction materials such as sand, gravel, and crushed stone, and other nonmetallic rock products such as silica sand, have been of equal importance in sustained economic development and in the long run are of potentially greater value.

Preparation of this report is particularly timely, in that recent exploration for potential mineral resources has been successful in identifying three significant deposits containing copper and zinc in north-central Wisconsin. Interest in these discoveries has stimulated increased exploration activities. Plans for the development of the three deposits are being prepared and discussed extensively to insure that all potential effects on the environment are considered and that if and when mining is conducted, any adverse effects are minimal and acceptable.

In this report, the fundamentals of the geology of the State are discussed in the detail necessary as a background for resource appraisals. The resources themselves are then treated in some detail to identify the areas in which they are known to occur, and to identify areas in which additional useful materials can be found. The final section of the report reviews the abundant water resources. The selected references to the thousands of pages of publications and the many maps of various kinds supply further guidance to the interested readers and will be helpful to geologists and others needing more detailed information about the geology and the mineral and water resources.

Although the data summarized in this report are extensive, the events that shaped the geologic framework of Wisconsin are still only known in broad outline. Much remains to be learned in future investigations. Maps summarizing the distribution of soils (fig. 3) and glacial deposits (fig. 1) indicate the nature of largely unconsolidated earth materials seen at the surface of much of the State. The map of bedrock geology (fig. 2) shows the known and inferred extent of the consolidated rocks that form the surface beneath the surficial cover. Because surficial materials conceal the nature of the bedrock from direct observation over so much of the State, surface studies are augmented by instrumental surveys that portray magnetic intensity of the underlying rocks (fig. 4) and variation in gravity (fig. 5), both of which help to define the distribution of different types of rocks in the subsurface. Other geophysical surveys have been made in selected areas including radiometric studies, seismic studies of shock-wave transmission, and a variety of studies of electrical and electromagnetic fields and electrical transmission. Each of these defines specific characteristics that are needed to correlate between rock types and structures known in widely scattered exposures of bedrock and the relatively few drill holes and excavations. Several of the geophysical methods are particularly useful in identifying potential resource accumulation, or in the case of magnetic surveys, to identify iron ore accumulation and electromagnetic surveys, to trace strata associated with copper-zinc mineralization. Studies of mineral and rock samples to measure their geochronologic age based on decay rates of natural radioactivity are providing powerful impetus to regional correlations of major events.

Much work remains to be accomplished in the continuing effort to identify Wisconsin's resources and to plan for their wise and orderly use.

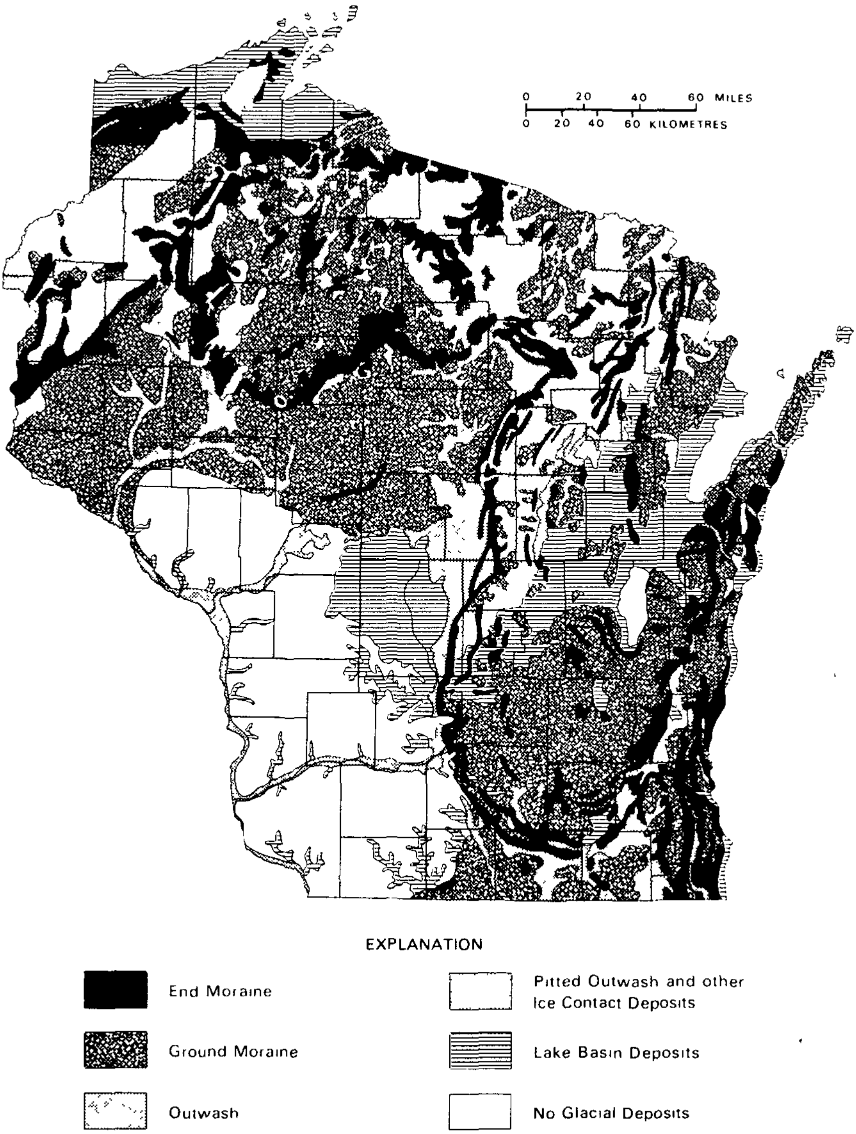



**FIGURE 1.—Map of distribution and types of glacial deposits in Wisconsin.**

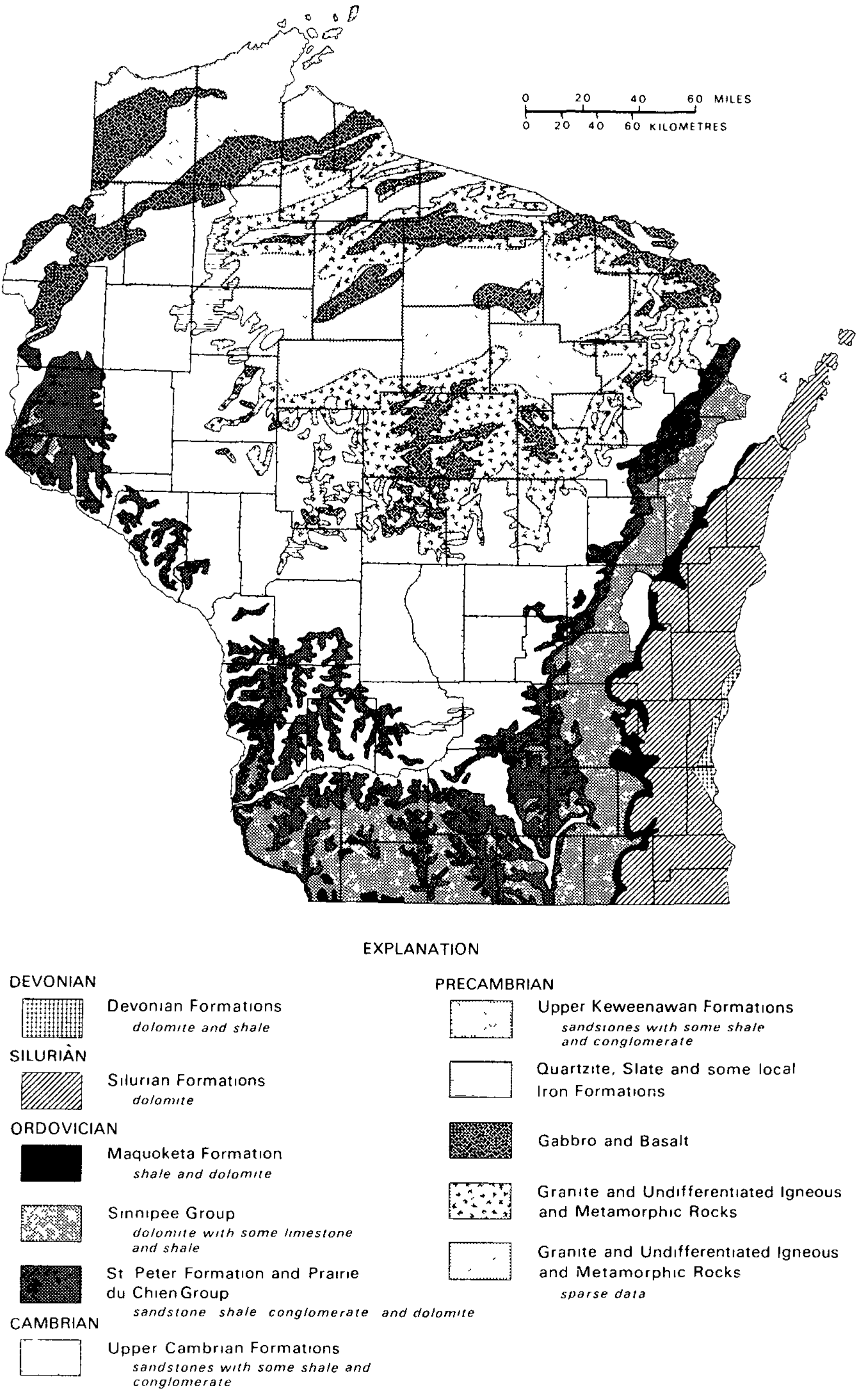



**FIGURE 2.**—Distribution, age, and types of bedrock in Wisconsin; relative ages of Precambrian igneous rocks not shown.

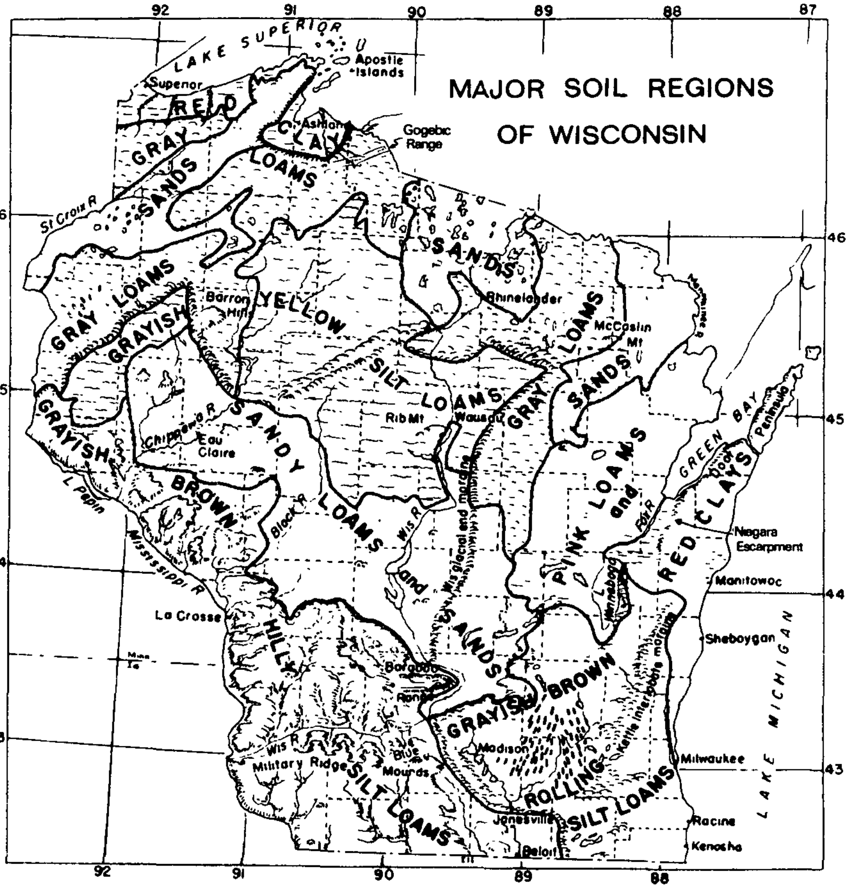
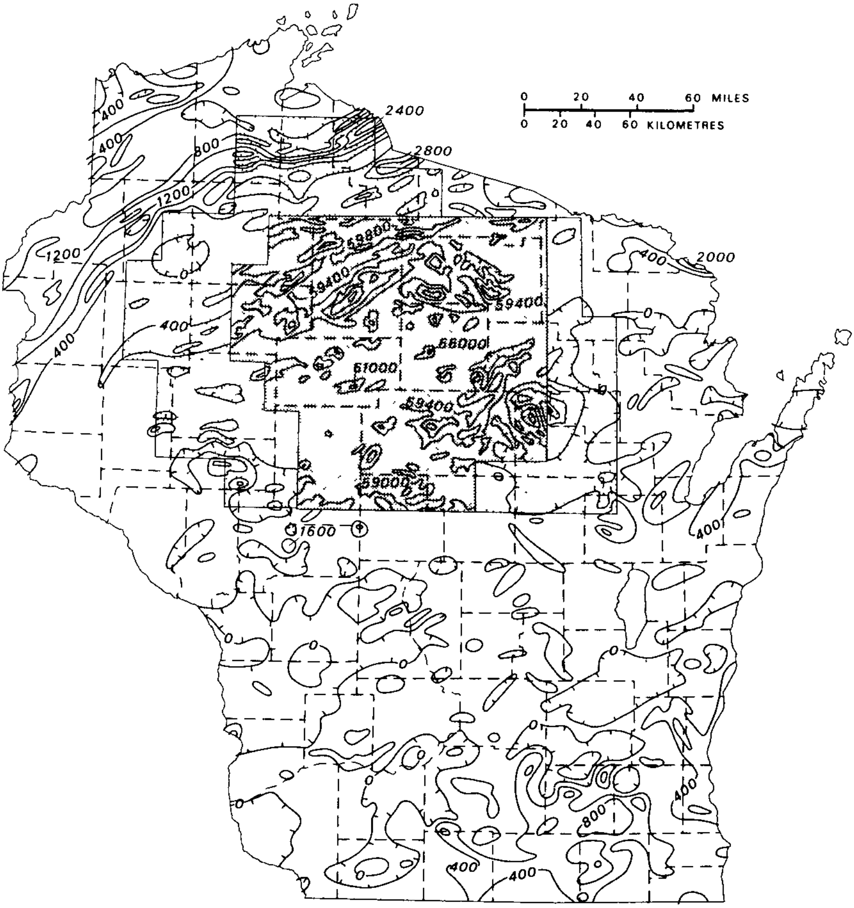



**Figure 3.**—Map of major soil regions of Wisconsin.




EXPLANATION

Wisconsin Aeromagnetic Survey, J H Karl and J C Friedel, 1974
*Aeromagnetic contour interval 400 gammas*

Wisconsin Aeromagnetic Survey, J H Karl and J C Friedel, 1975
*Aeromagnetic contours are from R W Patenaude, 1964*

Aeromagnetic Survey, R W Patenaude, 1964
*Aeromagnetic contour interval 400 gammas shown relative to approximate average magnetic value of 59200 gammas for the State, except for 1974 survey*

FIGURE 4.—Aeromagnetic map of Wisconsin.

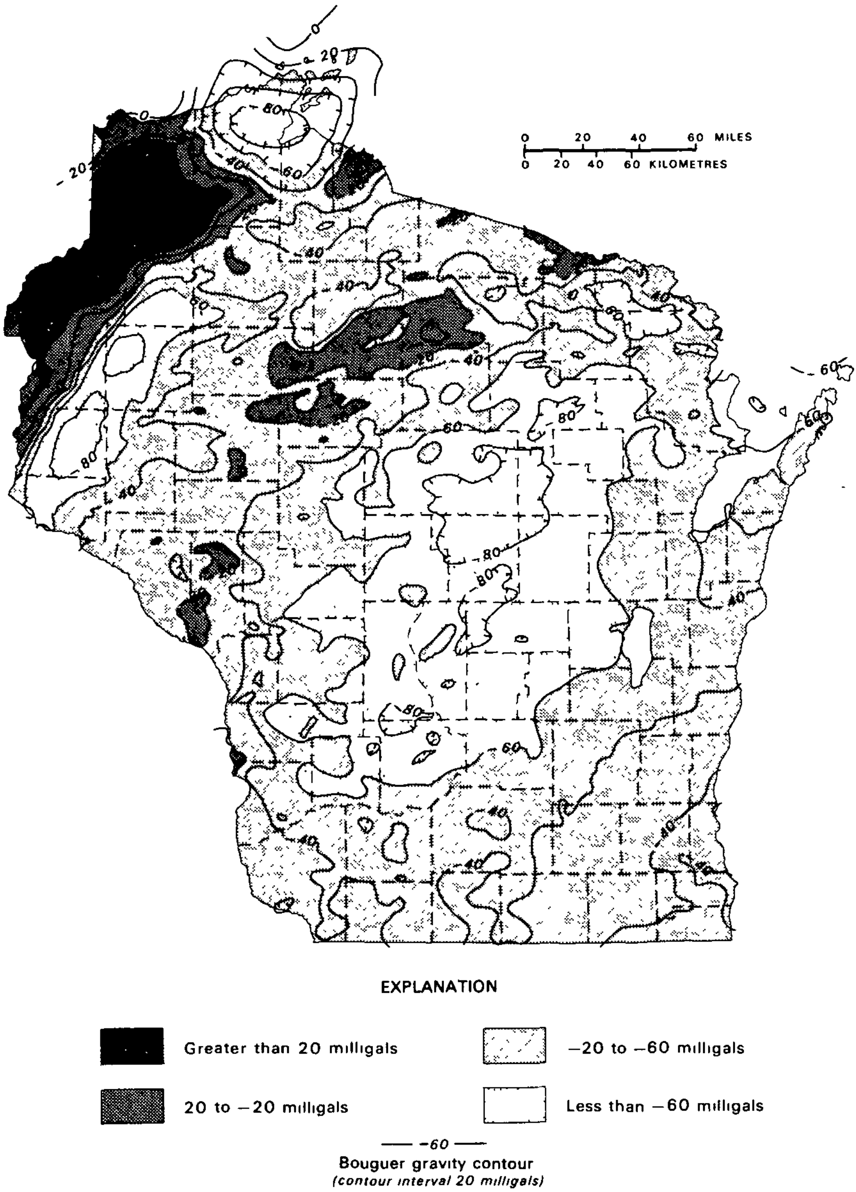



FIGURE 5.—Bouguer gravity map of Wisconsin.

# GEOLOGY OF WISCONSIN

## INTRODUCTION

(By C. E. Dutton, U.S. Geological Survey, Madison, Wis.)

The geology of Wisconsin can be divided broadly into three parts, based on three quite different kinds of deposits formed at different times and by different sequences of events. Unconsolidated debris formed in association with the advance and retreat of Pleistocene continental glaciation mantles the surface in all but the southwestern part of the State. Beneath this mantle in the southern part of the State is a sequence of layered marine sedimentary rocks that were formed in relatively shallow seas that covered this area in Paleozoic time. The oldest group of deposits are of Precambrian age and underlie all of the State. They are at or near the surface in the northern part of the State. These older rocks include complex associations of sedimentary and volcanic deposits intruded by a variety of igneous rocks, all of which have been folded to some degree and subjected to varying amounts of metamorphism. The sequence of geologic events in which these three kinds of deposits formed is summarized in table 1. The distribution of glacial deposits is shown in figure 1 and the distribution of various kinds of bedrock is shown in figure 2.

TABLE 1.—SUMMARY OF GEOLOGIC EVENTS IN WISCONSIN

| Time intervals | Geologic intervals | Geologic processes | |
|---|---|---|---|
| Present to about 10,000 years ago | Post-Pleistocene | 10 | Postglacial erosion and deposition of modern stream sediments. |
| About 10,000 years to 2,000,000 to 3,000,000 years. | Pleistocene | 9 | Erosion and deposition of rock debris during series of glacial advances and retreats. |
| | | 8 | Emergence and erosion. |
| About 400,000,000 to 600,000,000 years. | Paleozoic[1] | 7 | Successive floods by sea water and deposition of rock layers. Erosion occurred between periods of flooding. |
| | | 6 | Emergence and erosion. |
| About 900,000,000 to more than 2,700,000,000 years. | Precambrian | 5 | Folding, faulting, and recrystallization of rocks, an l intrusion of molten material. |
| | | 4 | Accumulation of layered sediments (marine and nonmarine) and lavas. |
| Prior to 2,700,000,000 years | | 3 | Erosion. |
| | | 2 | Rocks deformed, transformed, and intruded by molten rock. |
| | | 1 | Accumulation of sediments and lavas. |

[1] In order of increasing geologic age, the subdivisions are the Devonian, Silurian, Ordovician, and Cambrian periods.

Older rocks of Precambrian age are exposed in many parts of northern and north-central Wisconsin where they form the bedrock beneath the mantle of glacial materials. In places to the south they project upward to form isolated exposures that mark islands around which younger sediments were deposited. These rocks record a complex and still not well-known sequence of geologic events that span the very long time period prior to 600 million years ago. Events as old as 2,700 million years ago are recorded in some of these rocks, and others are similar to rocks in Minnesota that are more than 3,000 million years old. Younger Precambrian lava flows and interlayered sediments in northwestern Wisconsin unconformably overlie older metamorphosed volcanic and intrusive rocks, and are cut by younger intrusions. Sedimentary rock sequences that include sandstones, shales, and iron-formation occur in the Gogebic Range and near Florence and represent basins of deposition that developed in Middle Precambrian time on the older Precambrian basement rock. Elsewhere to the south, volcanic rocks and related intrusive rocks of Middle Precambrian age were emplaced, and subsequently metamorphosed. Description of these Precambrian events is given on pages 11–27.

The sequence of marine sedimentary rocks of Paleozoic age includes layers of limestone, dolomite, sandstone and shale. They are nearly flat-lying to slightly inclined to the southeast, south, or southwest, dipping gently away from the up-warped arch of older rocks on which they were deposited. Detailed studies of these rocks and the fossils present in many layers show that during the period from about 600 to 400 million years ago, shallow seas occupied the region to varying depths at different times. The sequence of layers record the migration of ancient shorelines across the area. Erosional intervals indicate retreat of the sea, and clastic sediments that are now sandstone and shale record advances of the sea. The carbonate rock layers indicate periods of greater water depths or development of reefs in areas further from shorelines. The sequence of Paleozoic strata is well exposed in the unglaciated area of southwestern Wisconsin. Elsewhere to the north and east it is exposed only along streams and in quarries and road cuts. The maximum thickness of Paleozoic rocks is about 2,750 feet in southeast Wisconsin. The Paleozoic deposits are described and interpreted on pages 23–37.

Glacial deposits in Wisconsin are mainly the result of the last three of four major advances and retreats of ice during a period that began about 1 million years ago and ended less than 11,000 years before the present. Except in southwestern Wisconsin, earth materials at the surface in most of the State are mainly mixtures of clay, sand, gravel, and locally consist of many small to large pieces of rocks; all were deposited from glacial ice or from water produced by melting. The rock fragments are similar in composition to bedrock that occurs in areas of central and northern Wisconsin, the adjacent part of Michigan, and south-central Canada. The variety in size and composition of rock fragments, the marked abruptness of the contact of the deposit with the bedrock surface, and the high degree of probability that they came from other than local sources are characteristic of deposits formed directly from melting glacial ice. Unsorted glacier-borne rock debris (moraine) was widely deposited over much of the State (fig. 1); related water-borne clay, sand, and gravel (outwash) were deposited along paths of meltwater drainage from the glacial ice. The deposits left by glacial ice and by water from melting ice accumulated during a period from about 1 million years to about 10,000 years ago (table 1). Glacial deposits are further described and interpreted on pages 38–55.

Each of the three types of deposits contains mineral resources of importance. The Precambrian rocks include resources of iron, copper, and zinc. The Paleozoic strata include abundant supplies of limestone and dolomite to furnish crushed stone and dimension stone, as well as serving as host rocks for ores of lead and zinc. The glacial deposits include ample resources of sand and gravel.

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## PRECAMBRIAN GEOLOGY

(By C. E. Dutton, U.S. Geological Survey, Madison, Wis.)

### *Introduction*

The presence of major iron, copper, and zinc resources in rocks of Precambrian age has stimulated continuing studies of the various kinds of rocks, their extent, and age relationships with other rocks. These rocks are a part of the southern margin of the Canadian shield, a great low-lying region of Precambrian rocks that is the exposed part of the North American craton. Away from this craton, the Precambrian rocks are overlapped by strata of Paleozoic and younger age, which form a thin platform cover of relatively undisturbed rocks that thicken generally southward and westward. Glacial deposits of irregular thickness, soils, and stream deposits cover the bedrock over much of the region so that while much is known in the relatively few areas of bedrock exposures, throughout the broad intervening areas knowledge is limited to inference and regional correlations, supplemented by drill hole data and instrumental surveys that provide magnetic patterns and gravity gradients.

Interest in the copper and iron deposits in northern Michigan and the probable existence of rocks containing similar deposits in northern Wisconsin led to many geological investigations beginning about 1850. Basic concepts concerning distribution, origin, classification, and arrangement of Precambrian rocks in Wisconsin and their relations to adjacent areas were presented by Weidman (1907), Van Hise and Leith (1911), Allen and Barrett (1915). Hotchkiss and others (1915), and Hotchkiss and others (1929). Leith, Lund, and Leith (1935) correlated the known geology and summarized the results of 50 years of work by geologists of the U.S. Geological Survey in the Lake Superior area. Dutton and Bradley (1970) compiled and interpreted geologic, magnetic, and gravity data for Wisconsin from published reports and unpublished data of the Wisconsin Geological and Natural History Survey and the U.S. Geological Survey in a series of six maps and a summary report with a companion bibliography (Dutton and Bradley, 1971).

There is much interest in the developing knowledge of the complex geological history of the Precambrian rocks of Wisconsin. Since 1970, the Wisconsin Geological and Natural History Survey has initiated a detailed low-altitude aeromagnetic survey of the State (fig. 4) and has compiled a regional gravity map of Wisconsin (fig. 5). Only about 1,200 square miles (about 6 percent) of the area where rocks of Precambrian age form the bedrock in Wisconsin have been mapped geologically at a scale of 1:24,000, the scale that is generally needed for appraisal of mineral resource potential (fig. 6).

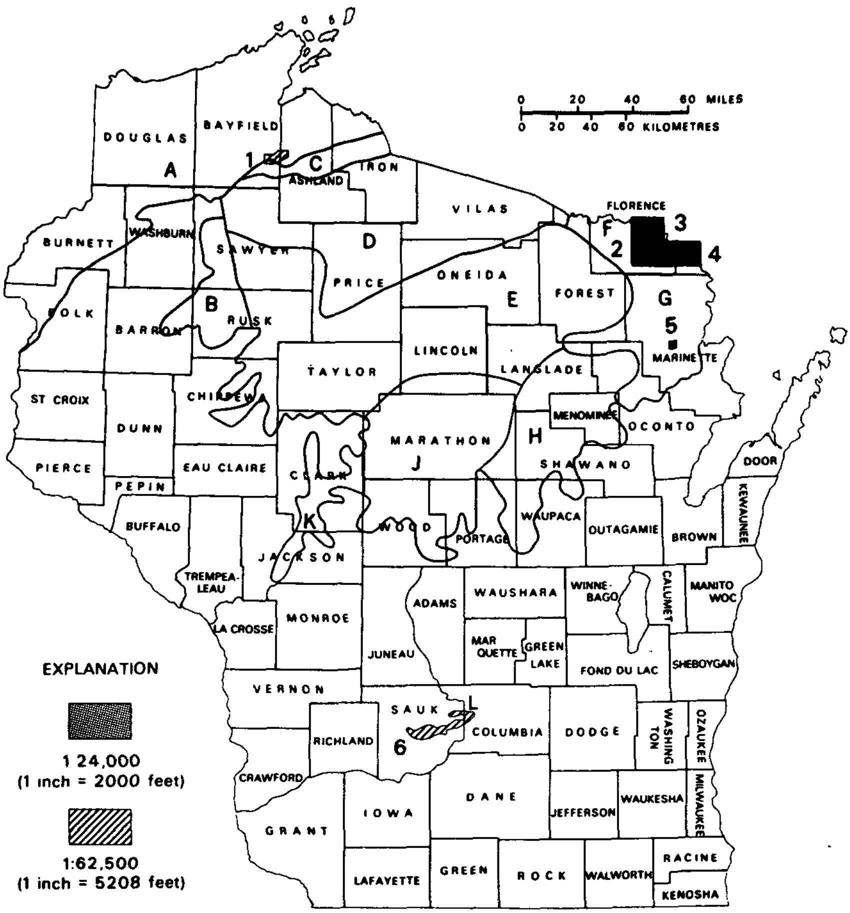
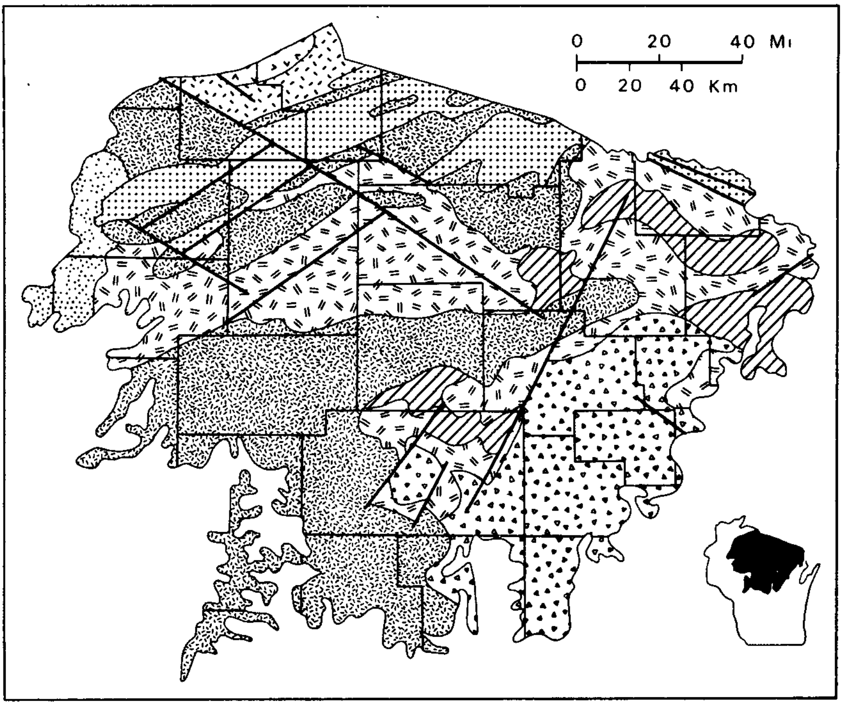



FIGURE 6.—Index of published large scale geologic maps and major areas of Precambrian bedrock outcrops in Wisconsin. Publications containing these maps by numbered areas are: (1) Leighton, 1954, (2) Van Hise and Leith, 1911, (3) Dutton, 1971, (4) Bayley, Dutton, and Lamey, 1966, (5) Fisher, 1957, (6) Dalziel and Dott, 1970. Lettered areas discussed in text are: (A) Keweenawan, (B) Barron, (C) Gogebic, (D) Butternut-Conover, (E) Ladysmith-Rhinelander, (F) Florence, (G) Pembine-Amberg, (H) Southeastern, (J) Wausau-Wisconsin Rapids, (K) Black River Falls_Neillsville, (L) Baraboo.

Two studies published recently provided a regional framework to correlate the detailed studies in widely scattered areas. Van Schmus (1976) bases his interpretation on radiometric age determinations from many areas. Sims (1976) establishes his framework on regional correlation of known and inferred geologic relationships throughout the Lake Superior district, supported by age determinations (fig. 7).

*Regional summary*

The following summary combines the observations and interpretations of Dutton and Bradley (1970), Van Schmus (1976), and Sims (1976). Major events are listed in table 2, as is the distribution of different rocks that resulted from these events. The lithology of the Precambrian rocks is shown in figure 2. More detail is given on relative ages and regional relations in figure 7 for Early and Middle Precambrian rocks, and in figure 33 for Late Precambrian rocks. Areas in which detailed mapping at a scale of 1:24,000 has been published are shown on figure 6, which also provides a location index to specific areas discussed below.




EXPLANATION

LATE PRECAMBRIAN (800-1600 m y )

Rapakivi-type intrusives and anorthosite

Quartzite

MIDDLE PRECAMBRIAN (1600-2500 m y )

Granitic rocks

Dominantly metasedimentary rocks

Dominantly metavolcanic rocks

EARLY PRECAMBRIAN (>2500 m y )

Granitic rocks

Metavolcanic and metasedimentary rocks, mainly greenschist facies

Orthogneiss and paragneiss, granulite and amphibolite facies Includes granitic rocks, probably of both Precambrian early and middle ages, and local bedded rocks of middle Precambrian age

Known or inferred fault

*Modified from P K Sims, 1976*

FIGURE 7.—Map of Precambrian rocks in north-central Wisconsin (modified from Sims, 1976).

TABLE 2.—GENERALIZED SEQUENCE OF PRECAMBRIAN EVENTS IN WISCONSIN (COMPILED FROM SIMS, 1976, VAN SCHMUS 1976, AND DUTTON AND BRADLEY, 1970)

| Approximate age in million years (m.y.) | | | | | Events | Types of rocks and location |
|---|---|---|---|---|---|---|
| Precambrian | Late | Z | 600–800 | | Sedimentation | Sandstones, nearly flat-lying, in area south of Lake Superior (may not be present in Wisconsin). |
| | | Y | 800–1,600 | 1,100 | Sedimentation, volcanism, intrusion, faulting | Basalt flows and related volcanic and clastic sedimentary rocks, gabbroic intrusions emplaced in major rift faults in Keweenawan area. |
| | | | | 1,500 | Erosion, intrusion | Wolf River Batholith. |
| | Middle | X | 1,600–2,500 | 1,650–1,700 | Mild metamorphism and folding | Warping of Baraboo area. |
| | | | | 1,500–1,800 | Sedimentation | Quartzites in Baraboo, Wausau, and Barron areas. |
| | | | | 1,750–1,800 | Volcanism, intrusion | Rhyclite and granite in Baraboo area and small areas to north and east. |
| | | | | 1,800–1,900 | Penokean orogeny with widespread intrusion, folding and strong metamorphism. | Granite intrusions south and west of Florence, and Wausau area, area-wide folding and metamorphism. |
| | | | | 1,900–2,100 | Sedimentation and volcanism | Iron-formation, quartzite, and graywacke-shale in Florence and Gogebic areas; associated mafic volcanics in Florence area. |
| | | | | 2100 | Mild warping | Development of sedimentary basins. |
| | | | | 2,100–2,600 | Erosion | |
| | Early | W | 2,500– | 2,700 | Algoman Orogeny with strong metamorphism, folding intrusion. | Orthogneiss and paragneiss dominantly of granulite and amphibolite facies in north-central areas, granite intrusive into metavolcanic and metasedimentary rocks south of Gogebic area. |

*Lower Precambrian*

The Lower Precambrian rocks of Wisconsin include two different sequences, which Sims (1976) designates as an older gneiss terrain underlying the southern part of the area shown in figure 8 and a younger greenstone terrain that occurs south of the Gogebic Range in Wisconsin and more extensively to the north in the Lake Superior region. The gneiss terrain includes several types of gneisses, granite, and other rocks that have undergone intense metamorphism. The greenstone terrain consists of steeply dipping volcanic rocks and minor interbedded sedimentary rocks that have been folded and subjected to low or moderate grade metamorphism and intruded by granitic rocks. The volcanic rocks are dominantly subaqueous basalt flows, with lesser amounts of more felsic volcaniclastic rocks. The granitic plutons in the greenstone terrain were intruded concurrently with the folding during the Algoman orogeny about 2.7 billion years ago. The age of the gneissic terrain has not yet been established by geochronometric dating in Wisconsin, but is inferred to be older than the greenstone terrain. The gneissic rocks are similar to older rocks known in Michigan and Minnesota with ages of about 3.2 billion years.

The recognition by Sims of these two different sequences of older Precambrian rocks represents a significant step forward in unraveling the complex geologic history of Wisconsin, and provides the first regional synthesis of these old events and a model which will be tested and refined by future investigations.

*Middle Precambrian*

A long interval of stability apparently followed the Algoman orogeny, during which time the region was subjected to significant erosion. Beginning about 2.1 billion years ago, mild warping formed one or more basins in which thick sequences of sedimentary rocks were deposited in the Gogebic and Florence areas, including the iron-formation in which important iron ore bodies formed. A thick volcanic unit occurs in the sedimentary sequence in the Florence area. To the south in Wisconsin extensive accumulations of mafic to felsic volcanic rocks were deposited at about the same time. Some of these volcanic rocks are the host rock for massive sulfide deposits containing copper, zinc, and other metal values in sulfide minerals. The depositional cycle was brought to a close by the Penokean orogeny that involved folding and metamorphism of the bedded rocks about 1.8 to 1.9 billion years ago. After culmination of the orogeny, and mainly after its termination, granitic plutons were intruded in the southern part of the area where the intensity of the orogeny was greater. In the time interval from 1.75 to 1.8 billion years ago, granitic intrusives and rhyolitic volcanic rocks were emplaced in the Baraboo area and adjacent areas to the north and east. Subsequently in that area erosion proceeded, and a sequence of clastic sedimentary rocks was deposited. In the time interval from 1.65 to 1.7 billion years ago, these sediments were subjected to mild metamorphism and folded into a gentle syncline. Elsewhere in the Wausau and Barron areas and westward into Minnesota and South Dakota, extensive accumulations of similar platform quartzites were formed at about the same time or slightly later.

### *Upper Precambrian*

Deposition of quartzose sediments similar to those in the Baraboo area probably continued into Upper Precambrian time in the Barron area and elsewhere in the region. About 1.5 billion years ago a large anorogenic plutonic complex, the Wolf River batholith, was intruded in east-central Wisconsin (fig. 7). Several igneous rock units within the batholith have unusual rapikivi textures, indicative of slow-cooling and passive emplacement. Thermal metamorphism of rocks in the surrounding terrain is indicated by geochronometric dates as young as 1.35 billion years. About 1.1 billion years ago, a major continental rift fault developed that extends from Lake Superior southwestward into Kansas, a distance of nearly 1,000 miles (1600 km.). The basin of deposition that formed over this rift contains a thick sequence of basalt flows, interlayered sedimentary rocks, and gabbroic intrusive rocks. Extensive deposits of native copper are found in some of the basaltic flows, and copper sulfide deposits occur in one shale horizon in these strata in the Keweenaw Peninsula in Michigan. Extrusion of the flood basalts and emplacement of the gabbroic intrusives were accompanied by faulting and emplacement of dikes and by development of synclinal folds along the axis of the rift. These folds served as basins of accumulation for a thick sequence of clastic sedimentary rocks, which are the youngest Precambrian rocks in Wisconsin.

## *Description of principal areas*

The following discussions provide a brief description of the principal areas underlain by Precambrian rocks based largely on summary information in Dutton and Bradley (1970) and further references cited in that study.

### *Keweenawan area*

The northwesternmost area of Precambrian rocks in Wisconsin is underlain by a thick sequence of Upper Precambrian volcanic and sedimentary rocks (figs. 2, 33). The Keweenawan area (location shown in fig. 6) contains about 20,000 feet of basaltic lava flows with some andesitic flows. Individual flows are massive, and most exhibit typical flow-top structures. Beds of shale, sandstone and conglomerate are interbedded with the flows. Gabbroic rocks of essentially identical chemical composition to the lavas form numerous dikes and locally more extensive plutons near Mellen.

A sequence of sedimentary rocks at least 17,500 feet thick, referred to locally as the Lake Superior Sandstone, overlies the lavas. The lower portion of the sequence, the Oronto Group, includes the Outer Conglomerate, Nonesuch Formation and Freda Formation; all are clastic rocks similar in composition to sedimentary rocks interlayered with the lava flows. The upper part of the sequence, the Bayfield Group, includes the Orienta, Devil's Island, and Chequamegon Formations. The sandstones in the Devil's Island closely resemble known Cambrian strata in the regions [pp. 31–32]. The Lake Superior Sandstone has been considered Upper Precambrian in age, but may contain strata of younger age.

The sedimentary and volcanic sequences are folded into a large northeasterly plunging syncline in Douglas and Bayfield Counties.

The outer limits of the syncline are faults of general northeasterly trend along which the volcanic rocks to the south have been raised relative to the adjacent sedimentary rocks. Many transverse faults of general northerly trend are also present (Dutton and Bradley, 1970, sheet 3; also p. 5 and 7).

Native copper deposits in the lava flows and copper sulfide deposits in the Nonesuch shale have been extensively mined in the Keweenaw Peninsula in Michigan. In Wisconsin, the lavas and interlayered sedimentary rocks contain widely scattered occurrences of copper and copper sulfides, and the Nonesuch shale is known to contain copper mineralization, although minable concentrations have not yet been found (see copper chapter, pp. 107–117).

Reports by Irving (1883), Butler, Burbank and others (1929), and White and Wright (1954) concern the geology and copper deposits of the Lake Superior area. General geology is discussed by Grant (1901) and Van Hise and Leith (1911); Grant also discusses the copper deposits in Wisconsin. The upper sedimentary unit of the Keweenawan is discussed by Thwaites (1912b) and Hite (1968).

### *Gogebic area*

The Gogebic Range lies immediately south of the Keweenawan area (figs. 2, 6), and is underlain by Middle Precambrian sedimentary rocks resting unconformably on Early Precambrian greenstones and granites. The sedimentary sequence includes 450 to 550 feet of Palms Quartzite, about 650 feet of Ironwood Iron-formation and about 10,000 feet of Tyler Formation at the top. Locally, the Palms is underlain in small areas by the Bad River Dolomite. The iron-formation is a layered sequence of various ratios of chert and iron oxide, iron carbonate, and iron silicate minerals. The Tyler Formation is an interbedded sequence of fine- to medium-grained clastic sediments that are now dominantly slates.

The Early Precambrian greenstones that underlie the sediments in the Gogebic area are metamorphosed basalt flows, volcaniclastic rocks, and gabbro. At the west end of the Gogebic Range, the sediments are underlain by granite which is intrusive into the greenstone. The granite has been dated as at least 2.7 billion years old a short distance to the east in Michigan (Sims and others, 1976).

The sedimentary sequence has been folded, and the rocks dip steeply to the northwest and have been displaced along steep faults parallel to the trend of the beds or at right angles to the trend. Dikes and sills of Middle and Late Precambrian age locally have invaded the iron-formation.

Significant amounts of iron ore were mined from ore bodies that developed within the iron-formation. These ore bodies formed where dikes intruded or faults offset the iron-formation and produced downward inclined troughs along which descending ground water was directed. Chemical action by the water locally (1) changed the abundant originally soluble iron-bearing minerals into residual and insoluble ones and (2) removed varying amounts of chert.

### *Butternut-Conover and Rhinelander area*

The Butternut-Conover area (figs. 2, 6, 7) extends southward and eastward from the Gogebic Range. Glacial deposits from 25 to 235 feet thick blanket most of the area, and bedrock outcrops are generally small and widely scattered. Most of the geologic data is based on drill hole information, test sites and geophysical surveys (Dutton and Bradley, 1970, pls. 1 and 3).

Sims (1976) describes this area as having an Early Precambrian basement of gnessic rocks in which basins developed in Middle Precambrian time. The basins became the sites of deposition of extensive accumulations of volcanic rocks of dominantly mafic composition and lesser amounts of clastic sedimentary rocks and iron-formation. Subsequently, all of these formations were folded, metamorphosed and intruded by granites. The proportion of volcanic rocks, mainly greenstones, increases to the south. The basins were apparently less extensive than basins in the Gogebic and Florence areas so that regional correlation of units is very conjectural.

Allen and Barrett (1915) interpreted the geology near Conover on the basis of geologic data, magnetic data, and the results of drill core from 50 holes. Exploration at several sites of above normal magnetic values penetrated steeply inclined iron-formation that is commonly interbedded hematite, magnetite, and chert in a wide range of proportions. The segments of iron-formation are steeply dipping limbs of folds or are fault segments of one or more iron-rich layers. The iron-formation did not contain iron ore in mineable concentrations. Associated rocks are chloritic and sericitic phillites or schists and local graphitic slates. Some schists are garnetiferous and locally kyanitic. Greenstone and mafic intrusives are present locally.

Iron-formation was penetrated in a number of drill holes at Butternut. The iron-formation has been intruded by granite. Fine-grained chalcopyrite is sparse in the iron-formation but more common in biotite schists adjacent to the iron-formation on the south (Dutton, 1975).

Geologic data in the Butternut-Conover area are generally too few and scattered to determine the stratigraphic sequences and geologic structures except as generalizations. However, it is likely that the sequence including iron-formation near Pine Lake at the north edge of the area is bounded on the north by a fault, and adjacent rock to the north is probably of Precambrian W age. The south limit of the layered rocks near Butternut in Ashland County is kyanitic schist 1,720 million years old by K/Ar ratio (Goldich and others, 1961, p. 105, and 178) present locally at an intrusive granite of unknown extent; magnetic data in part of the south side of the area suggest the presence of mafic rock of characteristics as indicated on sheet 1 of Dutton and Bradley (1970) and by Hotchkiss and others (1929). Part of the layered sequence near Conover in the eastern part of the area is intruded and flanked by granite (Allen and Barrett, 1915, p. 123).

Data from exploratory drilling (Hotchkiss and others, 1929, pp. 116–145) indicate that strata of the Butternut-Conover area probably extend westward to and presumably under quartzite near Barron.

*Ladysmith-Rhinelander area*

The greenstone sequences in the Ladysmith-Rhinelander areas and adjacent drift-covered areas have been the sites of intensive exploration, and three ore bodies containing copper- and zinc-sulfide minerals have been found recently near Ladysmith-Rhinelander, and Crandon.

Precambrian rocks of special significance occur near Ladysmith in a poorly exposed area west of the Butternut-Conover area. Field notes of 1910 and subsequent publication (Hotchkiss and others, 1915, p. 169) report that volcanic material, "mashed prophyry," from a dug well and that from several shallow test pits near Ladysmith contained copper and silver mineralization. Exploration in T. 33 N., R. 6W., south of Ladysmith, Rusk County, in 1968, penetrated schists and phyllites derived from volcanic and volcaniclastic rocks and containing copper mineralization of commercial significance (Dutton, 1971), the first discovery of ore in rock of this type in Wisconsin.

A somewhat similarly interesting area east of Rhinelander was cited by Dutton and Bradley (1970, p. 8, item 8), and recent successful exploration in the vicinity was reported in 1975. Discovery of copper sulfide with associated zinc sulfide and lesser amounts of gold, silver, and lead sulfide, near Crandon, was announced in May 1976. Exploration in the northwestern part of Marinette County penetrated low-grade copper and zinc mineralization.

Rhyolite was also reported to have been penetrated by one hole in Sec. 10, T. 35N. R. 8W., 14 miles northwest of Ladysmith (Hotchkiss and others, 1915, p. 180) and by five holes in T. 33N., R. 8W., southwest of Ladysmith (Hotchkiss and others, 1929, p. 116–117). This last source also reports that two holes were in granite in section 23 of the same township.

*Florence area*

The Florence area is in the Menominee iron-bearing district in the southeastern part of a triangular basin that extends north and northwest to Crystal Falls and Iron River, Mich.

Argillite and associated graywacke are the most abundant sedimentary rocks. In the northern part of the area, they are above and below the Riverton Iron-formation that is composed of interbedded siderite and chert and is about 600 feet thick (Dutton, 1971). The argillite and graywacke unit below the iron-formation is underlain by Badwater Greenstone and the Michigamme Slate, an argillite-graywacke unit. These rocks are all of Middle Precambrian age. The principal structure is a northwesterly plunging syncline with part of the southwestern limb missing because of uplift by faulting and subsequent erosion. A smaller syncline to the southwest is doubly plunging and is similarly truncated by a fault. Iron ore formed by action of percolating water changing iron carbonate to insoluble iron oxide that concentrated in favorable structural traps along axes of downward flexures of strata or along faults. Chert was locally removed or significantly decreased by solution.

Bedrock in the southern half of the area consists mainly of metamorphosed mafic lava flows, now greenstone, showing pillow structures, and smaller amounts of metafelsic rock. The mafic lavas are older than the metafelsic rock. Both are probably of Middle Pre-

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cambrian age as they are similar to rocks in the Pembine-Amberg area to the southeast that have an age of approximately 1,900 million years (Banks and Rebello, 1969). A fault separates the metafelsic rock from an argillite-graywacke unit adjacent to the north that is interpreted to be correlative with the Michigamme Slate in the northern half of the Florence area. The greenstone unit is intruded by gabbro and by granite.

*Pembine-Amberg area*

The Pembine-Amberg area extends southward from the east end of the Florence area for about 30 miles (figs. 2, 6, 7). According to Jenkins (1973) rocks in the northern part of the area in sequence of probable decreasing age are metabasalt, metaandesite, basalt agglomerate, rhyolite, rhyodacite flows, and a few interbedded sediments. The rocks have been folded and intruded by granite, granodiorite, quartz diorite, and ultramafics. U–Pb ratios in zircons from the volcanics are about 1,905 million years old (Banks and Rebello, 1969) and the granite is 1,890±15 million years old (Banks and Cain, 1969). Some greenstone and rhyolite in the area was examined by geophysical surveys and was explored by drilling. Minor copper and zinc mineralization is present, but interest has waned.

Rocks in the southern part of the area are mainly quartz monzonites about 1,860±15 million years old (Banks and Cain, 1969) and 1,800±30 million years old (Van Schmus, unpublished data). No age data are known for the lesser metavolcanic and metasedimentary rocks, mainly quartzite, that they intrude.

*Southeastern area*

The southeastern area extends over most of Shawano and Waupaca Counties. It includes the Tigerton area of anorthosite (Weis, 1965; Dutton and Bradley, 1970, sheet 3 and p. 11) and a much larger surrounding area of units that comprise the Wolf River batholith (Van Schmus and others, 1975, p. 907–914). Granite and quartz monzonite constitute 51 percent of the Wolf River batholith; porphyritic quartz monzonite is about 21 percent, and quartz monzonite about 10 percent; other units are rhyolite, syenite, and additional varieties of granite.

The rocks of the batholith formed about 1,500±50 million years ago (Van Schmus, 1976, figure 2).

*Wausau-Wisconsin Rapids area*

The Wausau-Wisconsin Rapids area is the south-central part of the Precambrian bedrock at the surface in Wisconsin (fig. 2). It is the largest area of numerous exposures in the State (Dutton and Bradley, 1970, sheet 3, pp. 11–12) but only the area in the vicinity of Wausau has been mapped in detail. Mapping and geologic study of the area began in 1969 and is continuing. Open-file reports and maps are available from Wisconsin Geological and Natural History Survey.

The most common rocks in the Wausau-Wisconsin Rapids area are felsic and mafic varieties of igneous intrusives and extrusives, mainly of Precambrian Y age and locally of Precambrian X age (Sims, 1976). Several areas of quartzite are near Wausau. Exposures of gneisses of Precambrian W age (Sims, 1976) are common along the Wisconsin River and some tributaries south and west of Wausau.

LaBerge and Myers (1976) described the general structure of the Wausau area as ". . . an extensive complex of volcanic and cogenetic intrusive rocks . . ." The distribution of rock types suggests plutons, roof pendants, and contamination zones in the apex of a batholith in the western part of Marathon County. Several major structural trends intersect in the county and ". . . coincide with zones of intense cataclasis . . . before, during, and after batholith emplacement."

The principal rocks in the Stevens Point-Wisconsin Rapids area, which is south of the Wausau area, are granitic and mafic intrusives and gneisses that have been examined in detail in only a few parts of the area. Rocks are locally well exposed along the Wisconsin River where the sequence is, from old to young: banded granitic gneisses and amphibolite, medium-grained tonalite (quartz diorite containing mica and hornblende) fine-grained tonalite dikes, which become less mafic with decreasing age of intrusion, mafic dikes, and diabase sills. All except diabase have been recrystallized under middle grades of metamorphism (Maass and others, 1976).

Whole-rock analyses of Rb-Sr and U-Pb analyses of zircons from the older gneisses at Stevens Point indicate an origin about 2,800 m. y. ago (Van Schmus and Anderson, 1976). Deformation and intrusion during the Penokean orogeny of Precambrian X age took place 1,500 to 1,900 m.y. ago. (Van Schmus and others, 1975). The gneisses formed in Precambrian W time but were modified by Penokean events.

Gneisses are also exposed locally along the rivers in Eau Claire and Chippewa Counties. Cummings (1975) reports that the rocks at Big Falls east of the city of Eau Claire are mainly amphibolite, hornblende gneiss, and banded amphibolite gneiss that have been sheared along major and minor converging and diverging planes.

### *Black River Falls-Neillsville area*

The Black River Falls-Neillsville area (figs. 2, 6) contains the most southwestern exposures of Precambrian rocks in Wisconsin. They are along the course of the Black River and its tributaries west of the Wausau-Wisconsin Rapids area where stream erosion has removed overlying Paleozoic rocks.

The common rocks are mainly gneisses and schists of probable Precambrian W age, but Van Schmus (1976, p. 617) reports an age of 1,900 million years for unspecified rocks in this area. Felsic and mafic intrusives and several areas of iron-formation composed mainly of magnetite, hematite, and quartz are also present. The iron-formation is probably of Precambrian X age.

### *Barron area*

The Barron area (figs. 2, 6) is in the west-central part of the Precambrian area. The rocks there are dominantly quartzite and minor sandstone. They are mainly fine grained, but are locally coarser grained. Some rocks contain quartz pebbles (Hotchkiss and others, 1915, p. 35–45). The basal part of the quartzite contains decomposed fragments of schist and slate. A minor phase is pipestone in which Indians made a shallow quarry.

The general structure of the area is a gently northwesterly plunging syncline; minor faults are also present. The geologic age of the quartzite is uncertain due to its isolation and lack of any known relationship to rocks of determined or generally accepted age, but it is generally believed to be Precambrian Y in age.

*Baraboo area*

The Baraboo area is about 75 miles south of the south limit of the Wausau-Wisconsin Rapids area (figs. 2, 6) and is underlain by a sequence of sedimentary rocks. The lowest unit is a resistant quartzite; overlying units are iron-formation and slate.

The Baraboo area has been of special interest to structural geologists as summarized by Dalziel and Dott (1970); "The very existence of an inlier of metamorphic and igneous rocks in the region probably would have attracted much attention from geologists. However, the work of C. R. Van Hise, C. K. Leith, and W. J. Mead . . . in the latter part of the nineteenth and early part of the twentieth centuries, has made the beautifully displayed structures in the deformed metasediments at Baraboo famous to structural geologists throughout the world . . . It is generally accepted that Van Hise was the first to appreciate fully the structural configuration of the quartzite on the basis of bedding/cleavage relations." Concepts developed in this pioneering work on rock cleavage are still among the primary tools used for detailed structural analysis around the world.

The iron-formation in this rock succession contained ore that was mined. The strata are probably of Precambrian Y age. Dott and Dalziel (1972) report a Rb-Sr age for rhyolite below the quartzite as about 1,640 million years.

*Other areas*

Precambrian rocks are present in numerous small areas beyond the limits shown on figure 4, where erosion has locally removed overlying Paleozoic strata. Details of these areas are summarized in Dutton and Bradley (1970, sheets 3, 5) and briefly tabulated here:

| *Location* | *Lithology* |
|---|---|
| Middle Mound, 18 miles west-southwest of Wisconsin Rapids | Quartzite. |
| Necedah Mound, 30 miles south of Wisconsin Rapids | Do. |
| Hamilton Mound, 18 miles southeast of Wisconsin Rapids | Do. |
| Waterloo, 30 miles northeast of Madison | Quartzite and granite. |
| Waushara County | Granite. |
| Green Lake County | Granite and rhyolite. |
| Marquette County | Do. |
| Near Baraboo, Columbia, and Sauk Counties | Do. |

Dating of muscovite from granite that intrudes quartzite in the Waterloo area yields ages of 1,410 million years by K-Ar and 1,440 by Rb-Sr (Dott and Dalziel, 1972, p. 559). Rhyolite in the Fox River Valley has been dated as 1,800 ±30 million years by U-Pb data (Van Schmus, Thurman, and Peterman, 1975, p. 1,262, table 2).

The areas of granite and rhyolite have been investigated by Smith, (1976). Most of the rocks represent one of three chemical groups based on amounts of CaO, $TiO_2$, and Rb-Sr. Rhyolites and granites are probably from the same source.

## PALEOZOIC ROCKS

(By M. E. Ostrom, Wisconsin Geological and Natural History Survey, Madison, Wis.)

### *Introduction*

Sedimentary rocks of Lower Paleozoic age overlie Precambrian rocks in the west, south, and east areas of the State (fig. 2). They consist of a sequence of alternating clastic and carbonate rocks ranging in age from Late Cambrian to Late Devonian (fig. 8). The clastic

| System | Series | Group | Formation | Member |
|---|---|---|---|---|
| Devonian | Upper | | Kenwood (55') | |
| | Middle | | Milwaukee (80') | |
| | | | Thiensville (65') | |
| | | | Lake Church (35') | |
| Silurian | Cayugan | | Waubakee (30') | |
| | Niagaran | | Racine (100') | |
| | | | Manistique (150') | |
| | | | Hendricks } (110')<br>Byron } | |
| | Alexandrian | | Mayville (175') | |
| Ordovician | Cincinnatian | | Neda (55') | |
| | | | Maquoketa (240') | |
| | Champlainian | Sinnipee | Galena (230') | |
| | | | Decorah (25') | |
| | | | Platteville (100') | |
| | | | St. Peter | Glenwood (13') |
| | | | | Tonti } (332')<br>Readstown } |
| | Canadian | Prairie du Chien | Shakopee | Willow River (50') |
| | | | | New Richmond (25') |
| | | | Oneota (200') | |
| Cambrian | St. Croixan | Trempealeau | Jordan | Sunset Point |
| | | | | Van Oser } (60')<br>Norwalk } |
| | | | St. Lawrence (50') | Lodi < Black Earth |
| | | Tunnel City (200') | Lone Rock<br>Mazomanie | Reno |
| | | | | Tomah |
| | | | | Birkmose |
| | | Elk Mound | Wonewoc (100') | Ironton (40')<br>Galesville |
| | | | Bonneterre (20') | |
| | | | Eau Claire (250') | |
| | | | Mt. Simon (500') | |

FIGURE 8.—*Geologic column of Paleozoic rocks in Wisconsin*

rocks are predominantly quartzose sandstone with shale in some areas. A notable exception is the Maquoketa Formation which is mainly shale with some beds of carbonate. The carbonate rocks are mainly dolomite; locally some may consist of dolomitic limestone and limestone.

Paleozoic rocks are well exposed in the Driftless Area of southwestern Wisconsin, but are covered by glacial deposits over most of the remainder of the State (fig. 1). In the Driftless Area, the character of the exposed rocks is well known. Rocks too deep to be exposed in this area, and mostly covered by glacial deposits elsewhere in the State, are known primarily from sparse outcrops and from studies of rock samples collected from the drilling of water wells. Because the outcrops and wells are not evenly distributed, the character of Paleozoic bedrock for many areas of the State is not known.

Paleozoic rocks are the source of both metallic and nonmetallic minerals as well as the host for the State's primary ground water supply. Metallic minerals that have been produced from these rocks include zinc, lead, iron, silver, and very minor copper. Principal nonmetallic mineral products include crushed and dimension stone, lime, silica sand, and shale. In addition, an estimated 48 percent of all water used for industrial, municipal, and private supplies and 55 percent of all ground water used in Wisconsin are obtained from these rocks.

*Depositional pattern*

The Paleozoic rocks of Wisconsin exhibit a distinctive stratigraphic sequence of alternating clastic and carbonate rocks which is interpreted to reflect an equally distinctive depositional history. The pattern is especially well developed in the Upper Cambrian and Lower and Middle Ordovician rocks and persists in modified form in both Silurian and Devonian rocks.

Upper Cambrian and Lower and Middle Ordovician rocks in Wisconsin are a recurring sequence of four rock types. Each sequence is referred to as a cycle of sediments. Characteristics of the cycles are summarized in figure 9.

| CYCLES | ROCK TYPES | DEPOSITIONAL ZONES | GEOLOGIC UNITS | | |
|---|---|---|---|---|---|
| V | Carbonate | Biogenic | Sinnipee Group | | |
| | Shaly sandstone and/or shale | Depositional shelf | | Glenwood Fm. | Harmony Hill Mbr. |
| | Reworked quartz sandstone | Nondepositional shelf | | | Nokomis Mbr. |
| | Quartz sandstone | Shallow marine littoral | | St. Peter Fm. | |
| IV | Carbonate | Biogenic | Prairie du Chien Group | Shakopee Fm. | Willow River Mbr. |
| | Shaly sandstone and/or shale | Depositional shelf | | | New Richmond Mbr. |
| | Reworked quartz sandstone | Nondepositional shelf | | | |
| | Quartz sandstone | Shallow marine littoral | | | |
| III | Carbonate | Biogenic | | Oneota Fm. | |
| | Shaly sandstone and/or shale | Depositional shelf | | Jordan Fm. | Sunset Point Mbr. |
| | Reworked quartz sandstone | Nondepositional shelf | | | |
| | Quartz sandstone | Shallow marine littoral | | | Van Oser Mbr.<br>Norwalk Mbr. |
| II | Carbonate | Biogenic | St. Lawrence Fm. | Lodi Mbr. | Black Earth Mbr. |
| | Shaly sandstone and/or shale | Depositional shelf | Tunnel City Group | Mazomanie Fm. | Lone Rock Fm. |
| | Reworked quartz sandstone | Nondepositional shelf | Wonewoc Fm. | Ironton Mbr. | |
| | Quartz sandstone | Shallow marine littoral | | Galesville Mbr. | |
| I | Carbonate | Biogenic | Bonneterre Fm. | | |
| | Shaly sandstone and/or shale | Depositional shelf | Eau Claire Fm. | | |
| | Reworked quartz sandstone | Nondepositional shelf | Mt. Simon Fm. | | |
| | Quartz sandstone | Shallow marine littoral | | | |

FIGURE 9.—Cycles of sedimentation in Upper Cambrian and Lower and Middle Ordovician in Wisconsin.

The four rock types that comprise a cycle are: (1) quartz sandstone, (2) reworked quartz sandstone, (3) shaly and/or clayey sandstone or shale, and (4) carbonate. Each type is believed to have formed in a different sedimentation zone located on a marine continental shelf and oriented approximately parallel with the shoreline. In a seaward direction the four zones and the four rock types are: (1) the high energy, shallow, marine nearshore zone of sands; (2) the nondepositional shelf zone or slow depositional shelf zone of reworked alternating beds of well-sorted medium and coarse sands and poorly sorted silty and clayey sands which locally contain burrows; (3) the depositional shelf zone of predominantly fine-grained clastics including clay, silt, and very fine to fine sand with glauconite; and (4) the biogenic zone of calcareous carbonate reefs.

A cycle of sediments is formed during a single episode of advance and retreat by the sea. As the sea advances, the land is slowly submerged; and the four sediment zones shift landward. Sediments deposited in zones located near to and roughly parallel with the shore become buried as those previously deposited in zones farther from shore advance shoreward. In this manner, layers of sediment representing different sediment zones are laid on top of the others and always in the same order.

During retreat of the sea it might be expected that deposits would be formed in reverse order. In some cases this is true; but for the majority, at least in Wisconsin, these deposits have been wholly or partly removed by erosion during the retreat phase of a cycle. Maximum retreat of the sea at the close of each cycle is approximately the seaward or southernmost limit of deposits of quartzose sandstone as shown in figure 10.

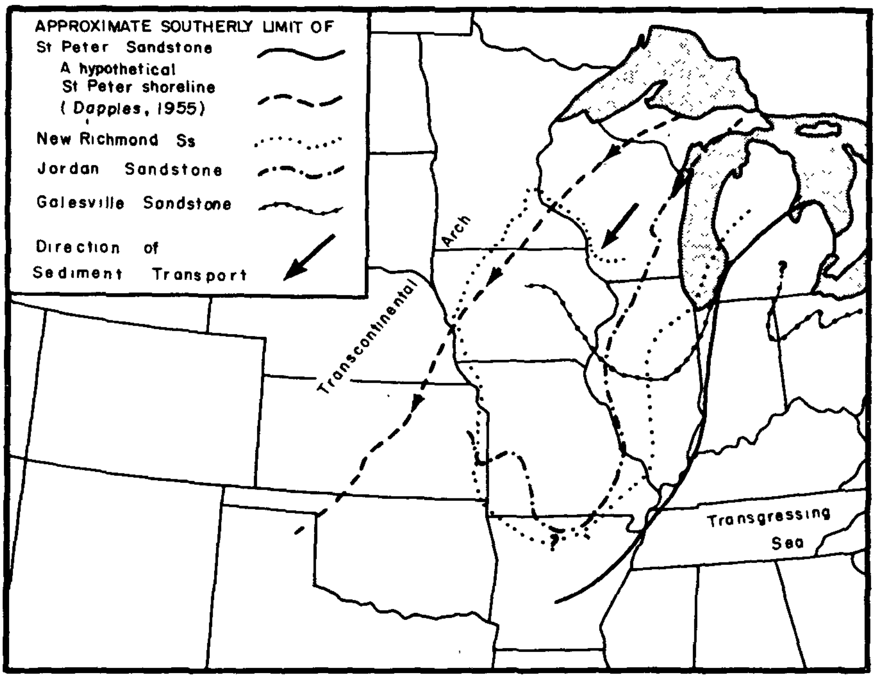


**Figure 10.—Map of approximate southern limit of occurrence of quartzose sandstones.**

Variations in cycles may occur where a particular sediment zone was not present due to differences in sediment source, sediment supply, energy conditions, suitability of receiving area, or distribution pattern of currents and other sediment dispersing agents. Variations may also occur in the last phase of a cycle where one of the normal deposits was removed when the sea retreated and the land was exposed to erosion by streams and wind. A cycle ends with maximum retreat of the sea. In some cases the erosion surface produced during retreat may have a relief of up to 350 feet. However, in most cases relief is small, on the order of several feet, and may be difficult or impossible to detect.

Five sedimentary cycles, indicating five successive episodes of advance and retreat by the sea, occur in the Upper Cambrian and Lower and Middle Ordovician rocks of Wisconsin. The rock strata comprising each cycle and their relationships are shown in figure 9.

Upper Ordovician rocks are primarily shale with some thin units of dolomite. They are widespread in eastern Wisconsin and in a few scattered outcrops in southwestern Wisconsin. On the basis of this distribution pattern, it is believed they formerly had a greater extent and likely covered at least most of southern and eastern Wisconsin. Although these shales are considered to represent clastic deposits of a succeeding cycle, their relationship to the underlying Middle Ordovician carbonates and their environment of deposition are not precisely known. There is, however, some evidence to indicate an erosion surface separating the shale from underlying carbonates. In addition, the presence of chlorite-type clay minerals in the shale and their absence in older rocks suggest a different source area such as possibly the then youthful northern Appalachian Mountains. An extensive delta developed westward from the northern Appalachians in Middle and Late Ordovician time, and the shale may be a deposit from that event.

The Maquoketa Shale, which is above the sediments of the fifth cycle, is locally overlain by a bed of oolitic iron-rich shale that may be up to 20 feet or more in thickness. The age of this shale is not positively determined although it has been assigned to the Upper Ordovician on the basis of fossils. However, the possibility exists that it may be Silurian in age and that the fossils were derived from reworking of the underlying shales.

The Silurian rocks of Wisconsin are predominantly dolomite that accumulated as reefs and related deposits in a shallow marine environment, are almost devoid of clay and sand, and cover most of the Lake Michigan and upper Mississippi Valley regions. Silurian rocks are in a wide belt in eastern Wisconsin, extending from the tip of the Door Peninsula southward to the Illinois border, and are at the tops of the highest hills scattered in southern and southwestern Wisconsin. They are also known from numerous subsurface well samples.

Devonian rocks are confined to a narrow belt along the Lake Michigan coastline extending from approximately Milwaukee northward to Sheboygan. They consist primarily of carbonate rocks, but the upper unit is a shale. These rocks are not well known due to very few subsurface well records and to sparse outcrops.

*Depositional setting*

Deposition of Lower Paleozoic sediments in the upper Mississippi Valley was on a submerged craton (a large relatively immobile area of the Earth's crust) in which there were active intracratonic basins and scattered arches and domes. A study of dispersal centers of Paleozoic and later clastic sediments of this and adjacent areas indicated to Potter and Pryor (1961) that the southward direction of sediment movement and slope of the craton have persisted through the Paleozoic to the present. They believe that (p. 1229–30):

> "Such uniformity over so long a time and over such a wide area can reflect only major tectonic control. The behavior of basement rocks of the craton provides that control. This underlying tectonic control is the immediate cause of persistent paleoslopes, of recycling, and of the location and orientation of major clastic deposits ultimately derived from distant tectonic lands."

Direction of sediment transport in the upper Mississippi Valley area is interpreted to have been to the southwest—that is, parallel to the shoreline, approximately parallel to the continental margin, and perpendicular to the paleoslope, a relationship demonstrated for the St. Peter Sandstone by Dapples (1955). The continental margin lay toward the Appalachian Geosyncline to the southeast and south.

During Lower Paleozoic time, high areas existed in the upper Mississipi Valley and are referred to as the Wisconsin Dome, the North Huron Dome, and a connecting link between these two domes called the Northern Michigan Highland, and the Canadian Shield (fig. 11).

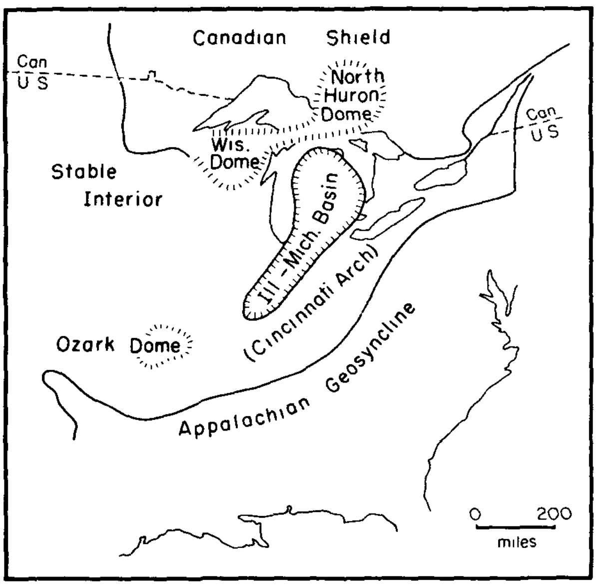


**Figure 11.—Map of eastern North America indicating areas of Pre-Cincinnatian Paleozoic orogenic activity (adapted in part from Eardley, 1951; King, 1959).**

The major intracratonic basin of this time was the Illinois-Michigan Basin. The Ozark area is considered to have subsided during pre-St. Peter time and to have risen before the end of the Upper Ordovician (Cincinnatian) time (Eardley, 1951; Lee, 1943). Deformation during this interval is believed to have resulted in the development of many arches and other structural features on the craton including the

Kankakee Arch, which separated the Michigan Basin from the Illinois Basin (Ekblaw, 1938), and the Findlay and Waverly Arches which bordered these basins along their southeastern margin (Woodward, 1961).

*Geologic history*

*Late Precambrian*

Sandstones referred to as the Lake Superior Sandstone (of local usage) that occur in northwest Wisconsin are of uncertain age. They have alternately been assigned by different authors to the Precambrian or Cambrian. The Lake Superior Sandstone is included in the upper Keewenawan Formation shown on figure 2. In their lower part they are interbedded with confirmed Precambrian rocks. However, the youngest formations are similar if not identical to younger Cambrian sandstones. Unfortunately they do not occur in direct association with Cambrian rocks so that their interrelationships are not known precisely.

The Lake Superior Sandstone is subdivided into two groups on the basis of rock and mineral composition. The lower or Oronto Group consists in ascending order of the Outer Conglomerate, Nonesuch Formation, and Freda Formation. All of these formations contain abundant feldspar and closely resemble older sediments interbedded with known Precambrian rocks. The Oronto Group has an estimated total thickness of 22,000 feet. The upper or Bayfield Group consists in ascending order of the Orienta Formation, Devil's Island Formation, and Chequamegon Formation. The Orienta Formation is very similar to the Freda Formation. However, the Devil's Island is a sandstone and closely resembles the Galesville Sandstone of the Cambrian System in composition, texture, and lithologic characteristics. Chequamegon has a lithology similar to the Orienta. The Bayfield Group has an estimated thickness of 4,300 feet.

The Lake Superior Sandstone was used as a source of building stone only in the late 1800's.

*Cambrian*

The oldest confirmed Paleozoic rocks in Wisconsin are considered to be of Late Cambrian age. They were deposited on the uneven eroded surface at the top of the Precambrian rocks. Upper Cambrian rocks have the widest distribution of all Paleozoic deposits in Wisconsin.

During the Late Cambrian there were at least three episodes of advance and retreat by the sea which produced three cycles of sediments (fig. 9). The first cycle consists of the Mount Simon, Eau Claire and Bonneterre Formations; these are interpreted to indicate submergence of the Precambrian surface and advance of the sea.

The Mount Simon Formation is predominantly a medium- and coarse-grained, moderately sorted, quartzose sandstone with some layers of finer or coarser grains that range from 5 to 40 percent feldspar. It is thick-bedded and cross-bedded. Locally it contains thin shale layers. The Mount Simon is absent in northeastern Wisconsin but ranges to over 800 feet thick in southeastern Wisconsin. Only the upper aproximately 40 feet is fossiliferous; it contains numerous vertical burrows, sparse phosphatic brachiopods, and is moderately to poorly sorted. Sand grains have minute disseminated pyrite crystals on their surfaces, and the upper 6 inches to 1 foot of the formation tends to be iron-enriched.

The overlying Eau Claire Formation, which is in sharp conformable contact with the Mount Simon, is a predominantly fine- and very fine-grained, silty, micaceous sandstone and sandy shale. This unit is thin- to medium-bedded, cross-bedded, and contains abundant sedimentary structures such as ripple marks and load casts. Glauconite is abundant in some beds as are trilobite and brachiopod fossils. Morrison (1968) identified five subdivisions of the Eau Claire that are laterally persistent and characterized by their relative content of sand versus clay. Two of the five units are predominantly shale and calcareous sandy shale. The Eau Claire is locally absent as, for example, in northeastern Wisconsin, but ranges to slightly more than 100 feet in western Wisconsin. In the vicinity of Beloit, the Eau Claire Formation is overlain by a dolomite unit that is tentatively correlated with the Bonneterre Dolomite of Illinois and Missouri. The Bonneterre is well exposed in Missouri and can be traced through Illinois to Wisconsin where it is known only from drill cuttings from water wells.

The upper surface of the Eau Claire Formation shows clear indication of erosion in western Wisconsin. It is postulated (Ostrom, 1964 and 1970) that this erosion occurred during the retreat and emergence phase of the first cycle and represents the close of that cycle of deposition. It may also explain the very limited extent of the Bonneterre Formation.

The Eau Claire Formation is unconformably overlain by the Wonewoc Sandstone Formation. This sandstone is the first unit deposited in the second cycle of sediments and is interpreted to indicate a re-advance of the sea and submergence of the erosion surface developed on the Eau Claire Formation. The second cycle consists in ascending order of the Wonewoc, Lone Rock, and St. Lawrence Formations.

The Wonewoc Formation is widespread over western, southern, and eastern Wisconsin. It ranges in thickness from less than 20 feet to over 100 feet and consists of the Galesville and overlying Ironton Members. The Galesville Sandstone is predominantly medium and fine, well-rounded, quartz grains; it is thick-bedded and cross-bedded. The Ironton Sandstone is characterized by alternating beds of well-sorted predominantly coarse- and medium-grained sandstone and poorly sorted, reworked, and burrowed beds of silt and sand ranging up to granule size. Beds are normally about 2 feet thick. The contact of the Ironton with the Galesville is most commonly transitional. The Ironton ranges from less than 6 inches thick in south-central Wisconsin near the village of Lone Rock and on the crest of the Wisconsin Arch to more than 40 feet to the west in the Mississippi River bluffs. Its precise character and thickness are poorly known in eastern Wisconsin due to being deeply buried. However, well samples suggest its character here is similar to that in western Wisconsin and that its thickness is up to 40 feet.

The Wonewoc Formation is a source of silica sand used for foundry purposes and locally, dimension stone. It is also a major source of ground water.

The overlying Tunnel City Group, which consists of the Lone Rock and the Mazomanie Formations that intertongue, is in sharp contact with the Wonewoc Formation.

The Lone Rock Formation is especially well developed in southwestern, southern, and eastern Wisconsin. It is subdivided into the Birkmose, Tomah, and Reno Members. The characteristic variable lithologies are (1) fine-grained glauconitic sandstone, (2) silty, sandy, and calcareous shale, (3) thin 2- to 12-inch beds of rip-up pebbles (intraclasts), and (4) sandy, glauconitic, and shaly dolomite with rip-ups in its lower part.

The Mazomanie Formation is best developed in the vicinity of the Wisconsin Arch in south-central Wisconsin extending southward to the vicinity of Madison. The Mazomanie is a fine-grained, moderately sorted, thin- to medium-bedded, cross-bedded and locally burrowed sandstone. It is a tongue in the Lone Rock Formation, thins southward, and disappears in southern Wisconsin (Ostrom, 1964 and 1970).

The Tunnel City Group is overlain by the St. Lawrence Formation; the contact may be sharp or transitional. The St. Lawrence is over 50 feet thick in southwestern Wisconsin and may be absent or as much as 40 feet thick in eastern Wisconsin. It gradually thins and ends northward. The St. Lawrence is comprised of the Black Earth and Lodi Members. In reverse of the relationship to the southward-thinning tongue of Mazomanie in Lone Rock, the St. Lawrence Formation has a northward-thinning wedge of Black Earth Dolomite Member in the Lodi Siltstone Member (Nelson, 1956). In southern areas of the State, the Tunnel City may be overlain by the Black Earth. Toward the north, the Black Earth wedge thins and is confined within the Lodi.

The Black Earth Member may be a silty, thin-bedded dolomite or a medium-bedded algal dolomite. It is believed to have formed in the shelf biogenic zone of carbonate development. The Lodi Member is primarily a thin-bedded dolomite, sandy siltstone, and silty and dolomitic fine-grained sandstone.

The Black Earth Dolomite is locally used for dimension stone due to its attractive color, durability, and availability. It is also a minor source of crushed stone.

The St. Lawrence Formation is overlain by the Jordan Sandstone which is the upper unit of the Cambrian System of rocks. The contact may be either unconformable or transitional. It is unconformable in western Dane County (Ostrom, 1970), northeastern Crawford County (Wegrzvn, 1973), and in Winnebago County (fig. 6; Ostrom, 1970). The unconformable relationship is interpreted as a retreat of the sea and erosion of the St. Lawrence Formation followed by advance of the sea and deposition of the Jordan Sandstone (fig. 12). This episode of cyclic deposition extended from the close of Cambrian time into

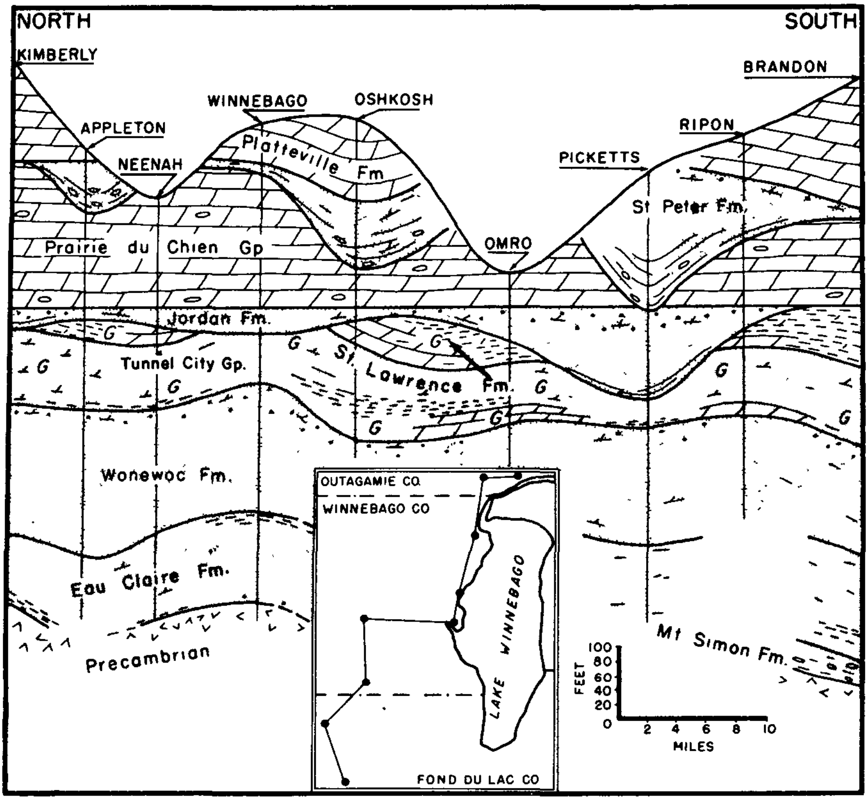


**FIGURE 12.—Cross-section of sub-Maquoketa Shale Paleozoic strata from Kimberly to Brandon.**

Lower Ordovician time. The Jordan is absent in some areas of eastern Wisconsin but is more than 80 feet thick in areas of the southwest.

The Jordan Sandstone consists of the Norwalk, Van Oser, and Sunset Point Members. The Norwalk is a fine- and very fine-grained, medium- to thin-bedded, cross-bedded quartzose sandstone. Locally it is extensively burrowed. In many areas, only lack of carbonate distinguishes it from the underlying Lodi Member. The Norwalk is believed to lap onto the Wisconsin Arch and to be overlapped by the Van Oser Member.

The Van Oser Member is predominantly a coarse-grained, thick-bedded, cross-bedded quartz sandstone. It is in sharp and even contact with the Norwalk. Where it overlaps the Norwalk and rests directly on the underlying St. Lawrence, the contact may be locally unconformable with more than 20 feet of relief.

The Norwalk and Van Oser Members are sources of silica sand used for foundry and abrasive purposes and to increase production from oil wells.

The Sunset Point Member has transitional beds that are predominantly sandstone with beds of (1) sandy dolomite and dolomitic sandstone, (2) sandy blue-green shale, and (3) sandstone with sandy dolomite rip-up pebbles. Its contact with the Van Oser Member may be sharp or locally indistinguishable but generally appears to be transitional.

The Sunset Point Member is the uppermost unit of Cambrian rocks in Wisconsin on the basis of trilobite fossils identified by G. O. Raasch (1935) and of the indefinite character of the basal Ordovician strata. However, recent study of *conodonts* (believed to be mouth parts of worms or dermal structures of fish) from the Sunset Point and overlying Ordovician dolomite rocks of the Oneota Formation suggest that the "Sunset Point Sandstone in western Wisconsin may be Lower Ordovician and not Upper Cambrian as presently thought" (D. L. Clark, 1967, personal communication). Davis (1970) assigned the Sunset Point to the Oneota Dolomite on the basis of (1) McGee's original description (1891), (2) the character of the basal Oneota in northeastern Iowa, and (3) what he described as the closer genetic and environmental relationship of the Sunset Point to the overlying pure dolomites of the Oneota. However, the contact of the Sunset Point with the underlying Van Oser Member is regarded by some (Kraft, 1956; Heller, 1956; Melby, 1967; Ostrom, 1970) as at least as indefinite and unclear as its upper contact with the Oneota.

The Sunset Point was an important source of dimension stone used in the construction of many of the early buildings in south-central Wisconsin. Today it is sometimes used as a source of crushed stone.

A bed of blue-green shale or sandy shale or shaly sandstone is at the top of the Sunset Point member in some areas of western and eastern Wisconsin. This bed tends to be less than 1 foot thick but may locally be up to 3 feet thick. In Minnesota, in the Minnesota River Valley, it is more than 3 feet thick and is blue-green clay and clayey siltstone. This bed is interpreted as representative of the shelf depositional zone.

*Ordovician*

The oldest Ordovician formations in Wisconsin belong to the Prairie du Chien Group of predominantly carbonate rocks which consist of the Oneota and Shakopee Formations.

The Oneota Dolomite, similar to the Black Earth Dolomite, is interpreted to have developed in a biogenic zone of calcareous carbonate reefs. It may locally be up to 300 feet thick. The lower, or sandy, portion contains "floating" sand grains and beds of quartz sandstone, chert, and glauconite. The upper, or non-sandy, portion is mainly pure dolomite with minor chert, shale, and secondary calcite; sand is rare. It is thick-bedded, poorly sorted, and weathers to a rough surface.

The Oneota is a major source of crushed stone products in Wisconsin.

It is believed that after deposition of the Oneota Dolomite the sea once more retreated, at least partly, and that an erosion surface was developed on its top. This surface is especially well displayed in Crawford and Grant Counties in southwestern Wisconsin and southeastern Minnesota and northeastern Iowa.

The next cycle of deposition began with development of the New Richmond Sandstone Member of the Shakopee Formation. The New Richmond is very thin in south-central Wisconsin, on the order of 5 feet thick. It thickens westward to about 20 feet in southwestern Wisconsin, to 50 or more feet in Iowa and Minnesota and to more than 150 feet southward into Illinois.

In south-central Wisconsin, the New Richmond is medium-bedded and interbedded sandy dolomite, quartz sandstone, and shale with some thin beds of oolites and algal stromatolites. To the west, the content of quartz sand increases and carbonate content decreases. In northwestern Iowa, the New Richmond is quartzose sandstone. The New Richmond characteristically has a thin bed of green shale or shaly sandstone at its top and in some areas at its base.

The New Richmond Member was deposited in an advancing sea. It is postulated that the change in rock type within the New Richmond indicates a change in the environment of deposition such that the quartz sandstone phase represents deposits formed in a shallow marine zone and the mixed rock type phase represents a combination or overlapping of the non-depositional zone with the depositional zone. The thin blue-green shale bed at its top is assigned to the depositional zone.

The Willow River Dolomite Member overlies the New Richmond Sandstone along a sharp and even contact. The Willow River is described (Davis, 1970) as sandy and intraclastic dolomite, algal stromatolites, and oolitic dolomite with minor amounts of gray-green shale and quartz sandstone. Exposures are rare in Wisconsin and are limited to the south and west.

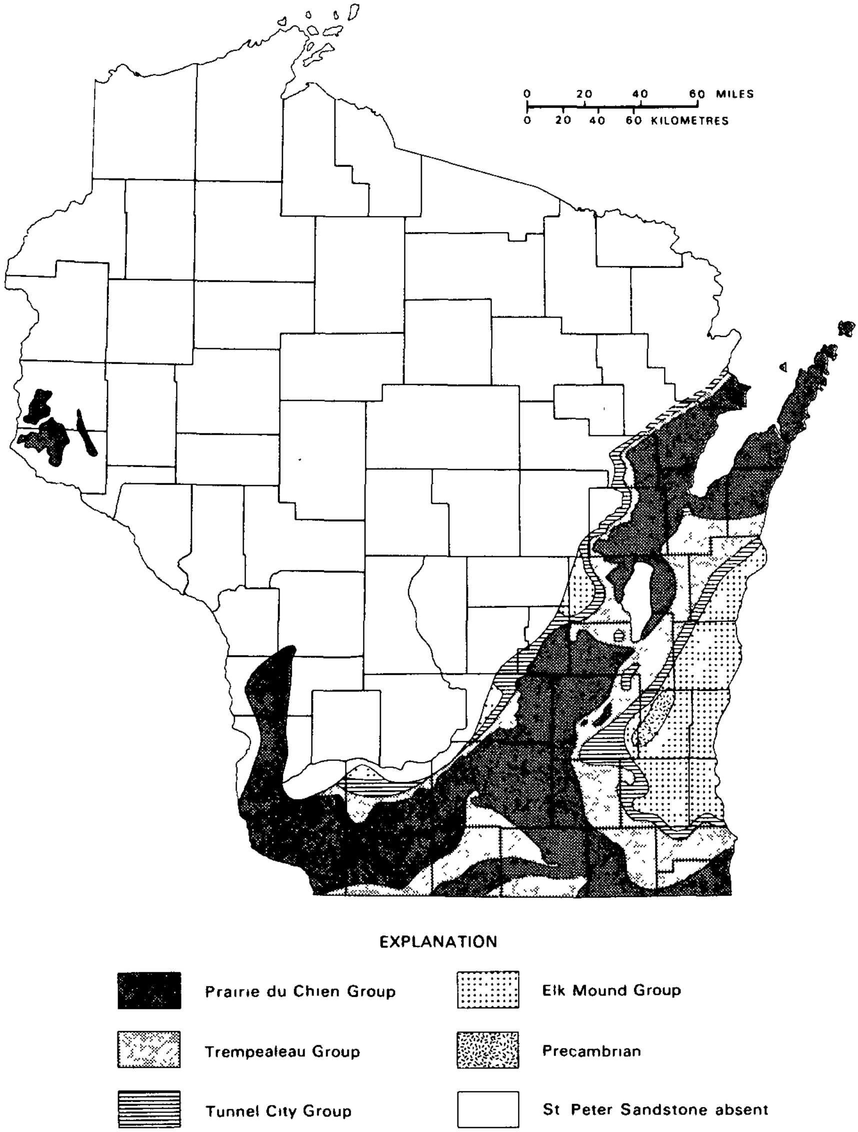


**FIGURE 13.—Generalized geology of projected St. Peter erosion surface in southern and eastern Wisconsin.**

Following deposition of the Willow River Dolomite, the sea retreated once more. The approximate limit of this retreat coincides with the approximate southern limit of occurrence of the St. Peter Sandstone as shown in figure 2. An extensive erosion surface that cut deeply, all the way down to the Eau Claire Formation in some areas of eastern Wisconsin, developed during this retreat.

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The St. Peter Sandstone was deposited in the nearshore shallow marine environment during readvance of the sea over the erosion surface which included an exposed Precambrian high in eastern Wisconsin. The thickness of the St. Peter Sandstone is highly variable over short distances of several hundred yards; it may be more than 350 feet thick or may be absent. It is thickest in areas of deepest erosions which occurred in the vicinity of Milwaukee and along what are believed to have been stream channels leading to the west and southwest. The amount of pre-St. Peter erosion is reflected in figure 13 which indicates formations exposed on the erosion surface.

The St. Peter Sandstone consists of the Readstown, Tonti, and Glenwood Members. The Readstown is primarily a shaly conglomerate which occurs locally in the base of the St. Peter. The Tonti is a thick-bedded, cross-bedded, predominantly medium- and fine-grained, well sorted quartz sandstone. Beds of green shale and/or poorly sorted silty and clayey sandstone occur at its top. These beds, referred to as the Glenwood Member, are absent in south-central Wisconsin, but are more than 13 feet thick in southwestern Wisconsin. They represent non-depositional and depositional environments.

The St. Peter is a source of silica sand used for foundry, glass manufacture, and other purposes. It is also an aquifer in some areas.

The St. Peter is overlain by the Sinnipee Group of predominantly carbonate rocks with some shale. The Sinnipee was deposited in the biogenic zone of carbonate formation and consists of thin- to thick-bedded dolomite, shaly dolomite, and shale. It is subdivided into the Platteville, Decorah, and Galena Formations which have an aggregate thickness of 250 feet to over 350 feet. The Sinnipee is present in eastern, southern, and western Wisconsin. It is a major source of crushed stone and is the host rock of the metallic ores of zinc and lead mined in southwestern Wisconsin. Additional details of the lithology of this group are shown in figure 36.

Following deposition of the Sinnipee Group there was a major change in depositional pattern which is recorded in the Maquoketa Shale Formation. The Maquoketa consists predominantly of calcareous dark gray and brown shale with local beds of carbonate. It contains the clay mineral chlorite which is interpreted to indicate a change in sediment source area to the northern Appalachian Mountains which were in process of forming at about the same time as the Maquoketa. Sediment derived from erosion of the forming mountains was carried westward to become part of a huge delta system referred to as the Queenston Delta.

The Maquoketa Shale is mined for clay used in the manufacture of brick and tile. Tests indicate in some areas it has potential for manufacture of expanded lightweight aggregate.

Locally, above the Maquoketa Shale, there is a reddish and iron-rich oolitic shale called the Neda Formation. Its contact with the Brainard Member of the Maquoketa Shale is described as conformable in eastern Iowa (Brown and Whitlow, 1960, p. 30; Whitlow and Brown, 1963b).

The Neda has been alternately assigned to the Ordovician and Silurian by different authors. Its content of Ordovician fossils is cited as reason for assignment to the Ordovician.

The Neda was mined during the period 1849–1928 as an ore of iron. Mines were developed in Dodge County near Mayville and Iron Ridge. However, its undesirable phosphorous content, limited quantity, and erratic distribution have discouraged use.

*Silurian*

Rocks of the Silurian System, including the Alexandrian, Niagaran, and Cayugan Series, are dolomites deposited as a part of the major shallow marine reef complex which occupied much of the Lower Great Lakes and Upper Mississippi Valley area. Outcrops are sparse due to a cover of glacial deposits. The dolomites range from thin- to thick-bedded and are a composite of reef and inter-reef deposits. In Wisconsin the Silurian rocks occur in a wide band along the eastern coastline extending from the Door Peninsula southward to the Illinois border. They are also present at the top of certain of the highest hills in southwest Wisconsin such as Blue Mounds and Platte Mound.

Silurian rocks are a major source of crushed and dimension stone and of lime. They are also a local supplier of ground water.

*Devonian*

Devonian rocks are dolomite, shaly limestone, and shale. They are poorly exposed in Wisconsin and are known only from a few outcrops and a City of Milwaukee tunnel excavation. Former quarries in Devonian carbonate rocks produced crushed aggregate and lime.

*Status of mapping*

Approximately two-thirds of Wisconsin's land area or 36,470 square miles is underlain by Paleozoic rocks (fig. 2). Less than 2,000 square miles of this area, or only 6%, have been mapped at modern geologic standards at a scale of 1:24,000 (1 inch=2,000 feet) which is considered minimal for mineral resource investigations and for other earth resource and environmental management purposes and problem solving (fig. 14).

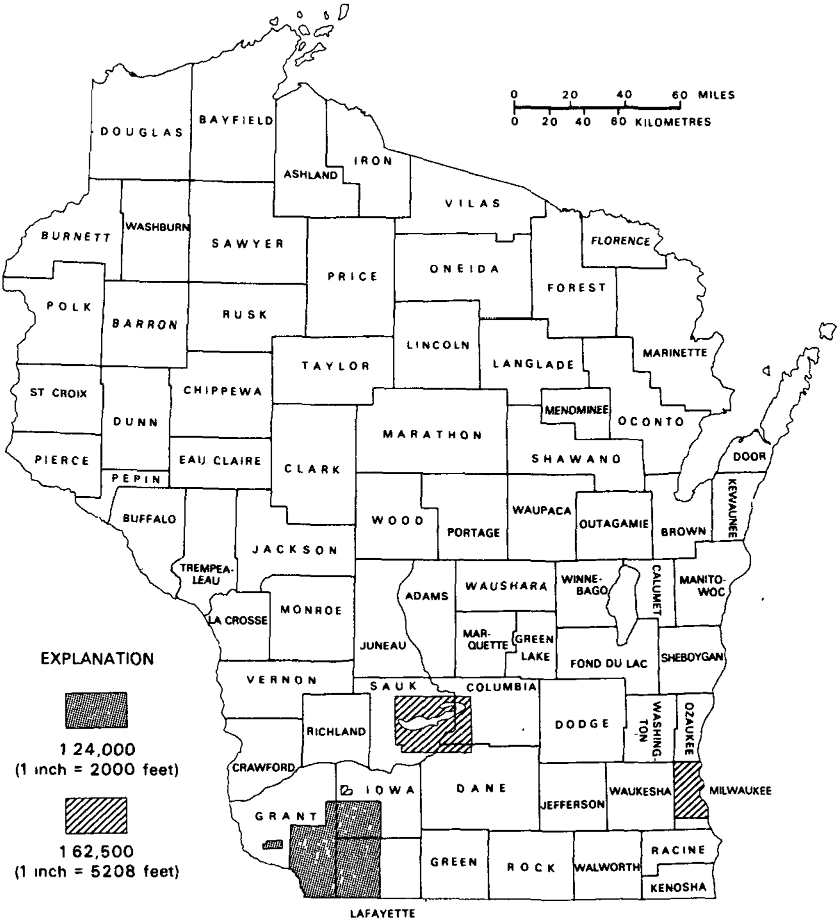


FIGURE 14.—Index of published geologic maps of Paleozoic rocks at scales of 1:24,000 and 1:62,500.

## GLACIAL GEOLOGY

(By D. W. Hadley, Wisconsin Geological and Natural History Survey, Madison, Wis.)

*Origin and distribution of glacial deposits*

Approximately 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". The rate of snow accumulation at centers in Canada began to exceed the rate at which the snow melted. Snow continued to accumulate, and pressures deep in the mass changed the snow to ice. These vast accumulations of ice are believed to have reached thicknesses of almost 2 miles. The great pressure at the base of the ice from such thickness caused it to spread laterally and to move as a "glacier". When the climate moderated, melting once again exceeded the rate of accumulation, and the glacial front receded (melted back) to the north.

Study of the glacial deposits of North America has shown that there were four major advances and retreats of the ice. It is now believed that glacial deposits representing three of these advances are exposed in Wisconsin. The deposits from the early advances are, however, of quite limited areal extent. The great majority of the glacial deposits at the surface of the State were formed by the last of the four advances. The time during which the deposits of the last advance were laid down is known as the Wisconsin Age because deposits of that advance are well preserved in the State and were studied here in detail.

Although glacial deposits dating from the first three glacial advances may well be widespread in Wisconsin, the great thicknesses of glacial materials that were deposited by the last glacial advance blankets most of the State, making the identification and study of the buried older deposits extremely difficult.

During the fourth advance, differences in the rate of ice accumulation in the source areas, coupled with differences in topography, caused the ice front to split into a series of tongue-like lobes. Four major lobes of ice entered Wisconsin and each lobe tended to follow pre-existing low areas of the Earth's surface. One moved along and beyond the present Lake Michigan basin; a second was similarly related to the Green Bay area; the third was similarly related to the Lake Superior area and extended into the extreme northwest corner of the State; and a fourth lobe moved southwestward across that part of the northern peninsula of Michigan south of the Keweenaw Peninsula.

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

Many of the glacial deposits consist of "till," an unsorted and unstratified heterogeneous mixture of clay, silt, sand, and boulders. Till is deposited directly by and under a glacier, either during glaciation or at the time of glacial melting, without being subsequently reworked by the water that is released as the glacier melts.

Till is normally deposited in the form of moraines, which are mounds, ridges, or other accumulations deposited chiefly by the direct deposition from glacial ice. Moraines can be divided into two main classes, namely ground moraine and end moraines. Ground moraine is a thin layer of till which generally has a gently rolling surface and which is formed from the rock debris that was dragged along, in, or under the glacial ice. End moraines are normally ridge-like deposits, often showing considerable relief, that form by the piling up of till at the leading edge of an actively flowing glacier during the periods when the position of the ice front was essentially stationary. There are a number of types of moraines that are lumped under the heading of end moraines. One of the more important of these is the terminal moraine which forms at or near a more or less stationary edge marking the limit of an important glacial advance. Another type of end moraine is the recessional moraine. These form during temporary but significant pauses in the final retreat of a glacial front or during minor readvances of the ice front in a period of general recession. Finally there is interlobate moraine, which forms where the margins of adjacent glacial lobes come together. Figure 15 is a generalized map showing the distribution of end moraines in Wisconsin.

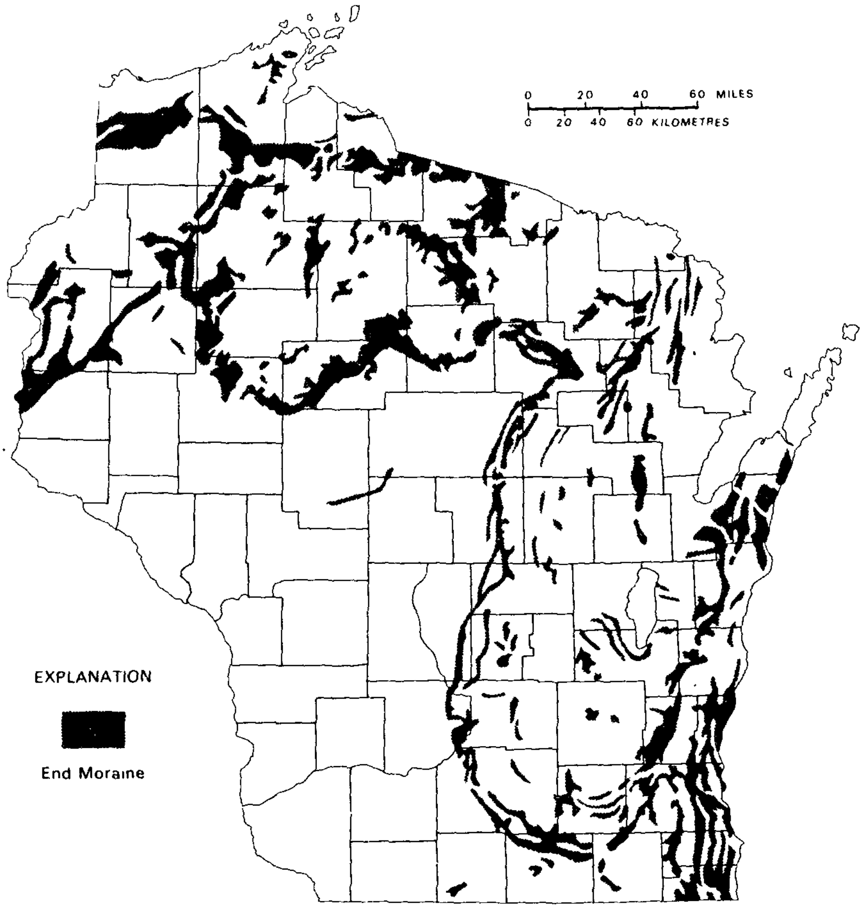


FIGURE 15.—General distribution of end moraines.

Rock and soil debris released from the melting glacier was carried by streams of meltwater and deposited at or near the ice front. These deposits normally consist of sorted and stratified materials, chiefly sand and gravel, and are called outwash. When the meltwater streams flowed out from the glacier across the terminal moraine, they deposited accumulations of sand and gravel called outwash fans. In many cases these fans coalesced forming broad sheets of outwash called outwash plains. Large bodies of outwash were also deposited along the valleys of the major streams that flowed from the glaciers. Outwash deposits confined to the valleys of the major streams are called valley trains. Valley train deposits dissected during erosion by later streams are preserved as bench-like deposits called outwash terraces. Figure 16 is a generalized map showing the distribution of the major deposits of outwash in the State.

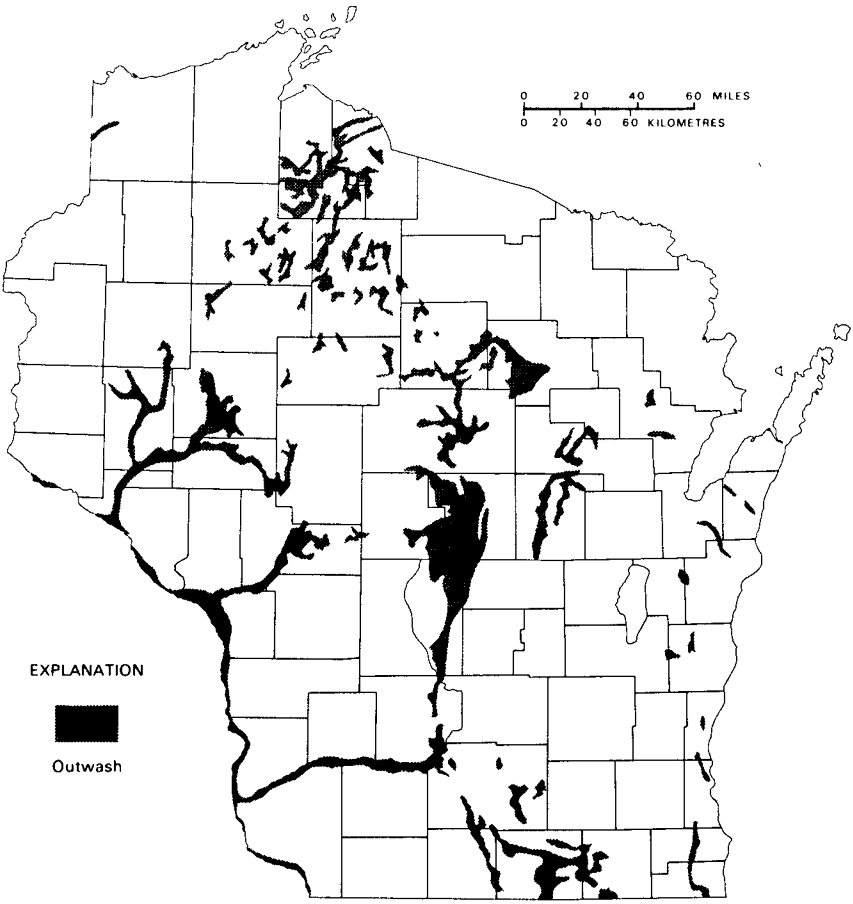


**FIGURE 16.—Generalized distribution of outwash.**

As the glaciers retreated, large bodies of ice often became detached from the main mass. Over large areas of Wisconsin, these masses of stagnant ice were buried under later outwash deposits. When the buried ice melted, the overlying outwash collapsed, leaving pit-like depressions of various shapes and depths. These depressions are called "kettles", and are usually basin- or bowl-shaped with steep sides and often contain lakes or swamps. Outwash plains marked by large numbers of kettles are called pitted outwash plains. The generalized distribution of pitted outwash is shown in figure 17.

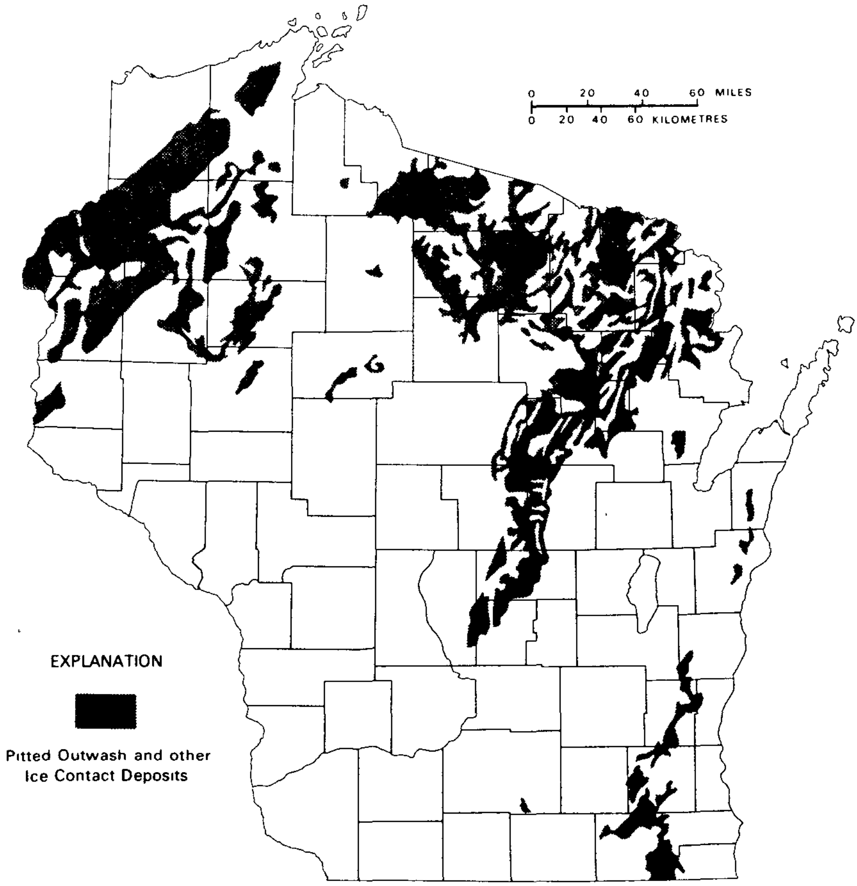


**FIGURE 17.—Generalized distribution of pitted outwash.**

Large areas of the State are covered by sediments deposited in extensive glacial lakes that formed where earlier drainage patterns were blocked by the ice, or by materials deposited from the ice. Large areas were also flooded by the waters of the ancestral Great Lakes when these lakes were at levels appreciably higher than now. Fine-grained sediments that were deposited in glacial lakes are called glaciolacustrine deposits. The more important deposits of this type are shown in figure 18.

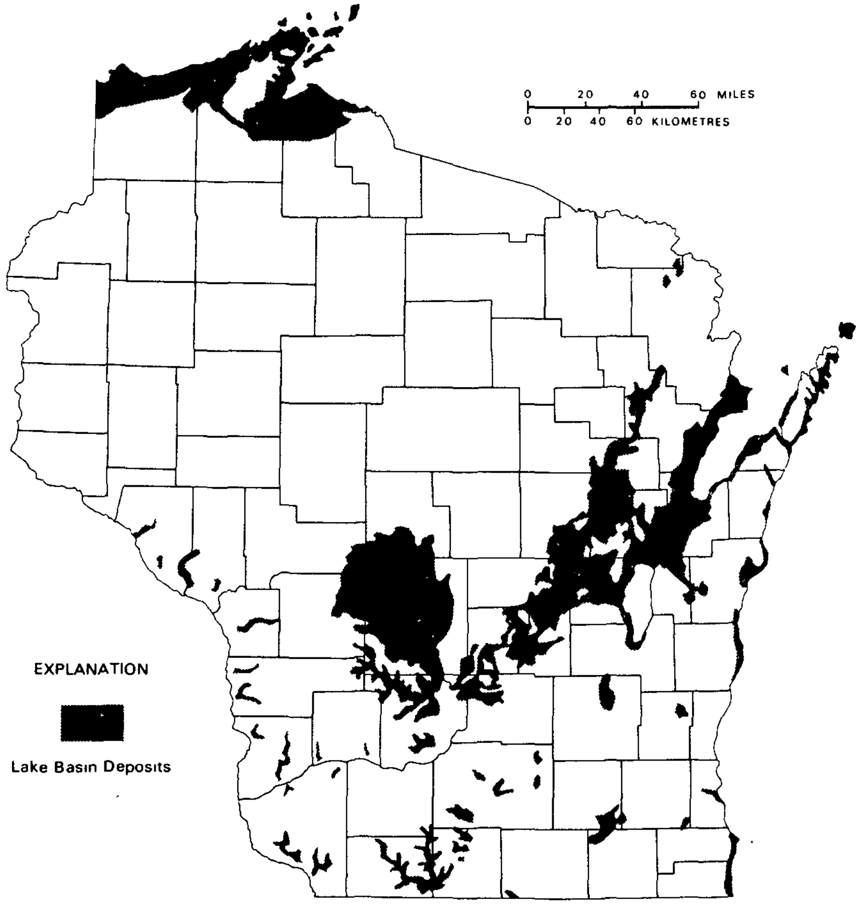


FIGURE 18.—Generalized distribution of glaciolacustrine deposits.

When the glacial fronts retreated, the newly deposited materials were highly vulnerable to erosion. Vast quantities of fine-grained material, primarily silt, were picked up by the wind and redeposited elsewhere as a blanket on the surface. This wind-deposited, or aeolian, material is termed loess. In some areas of the State, fine sand was also wind-carried away from its original sites of deposition to form sand dunes. The distribution and thickness of the aeolian deposits of Wisconsin are shown on figure 19.

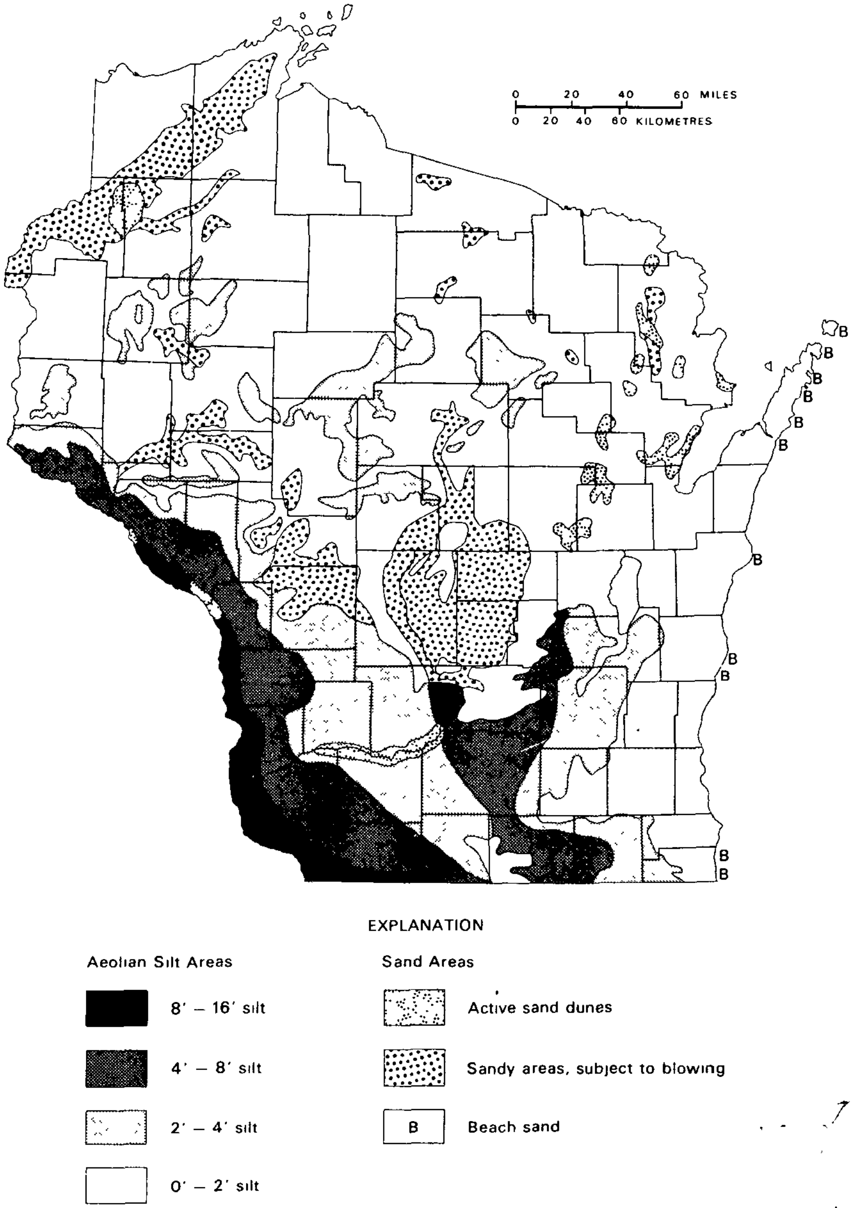


FIGURE 19.—Distribution of aeolian deposits in Wisconsin.

In addition to the major types of glacial deposits already discussed, glacial features too small to show at the scale of the map used in this report are of significant interest. These features are—

(1) *Drumlin.*—A low smoothly sloping, elongated, or oval hill, mound, or ridge of compacted till, built under the glacier and

shaped by it, or carved out of an older moraine by advancing ice. The long axis is parallel to the direction from which the ice approached and has a more gentle slope tapering in the other direction.

(2) *Drumlin field.*—A landscape characterized by swarms of closely spaced drumlins, separated by small marshy tracts. Wisconsin is noted for its drumlin fields. Major fields occur in southeastern Wisconsin, primarily in Jefferson, Columbia, Dodge, Fond du Lac, and Sheboygan Counties, and in northern Wisconsin in Rusk, Sawyer, Price, Oneida, Forest, Florence, Martinette, and Door Counties.

(3) *Kame.*—A steep-sided hill, mound, knob, hummock, or short, irregular ridge, composed of poorly sorted and stratified sand and gravel.

(4) *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 retreating glacier and was left behind when the ice melted.

(5) *Crevasse filling.*—A short, straight, ridge of stratified sand and gravel, believed to have been deposited in a crevasse in a melting glacier and left standing after the ice melted.

A highly generalized map of glacial deposits of Wisconsin (fig. 1), indicates that a portion of southwestern Wisconsin has only valley train deposits and the deposits laid down in glacial lakes that formed when tributary valleys were dammed by the great volume of outwash deposited along the floors of the main valley. This region is referred to as the Driftless Area. Most geologists familiar with the area believe that it was not glaciated during the Pleistocene epoch, but some investigators have taken the opposite view.

*Glacial stratigraphy*

Stratigraphy is the study of the individual units of material at and below the surface of the Earth and of their relationships to one another. Stratigraphic studies have long been a basic part of the study of igneous, metamorphic, and sedimentary rocks, but the use of stratigraphic principles in the study of glacial deposits has become widespread only within approximately the past 15 years. Wisconsin, unfortunately, lags far behind some neighboring States in this area of study, and much of what is known is the result of work that has been done in those areas.

Although a detailed description of the glacial stratigraphy of Wisconsin is beyond the scope of this report, it is possible to summarize the basic principles involved and to show the fundamental system of classification being used in the study of glacial deposits.

As described, four major glacial advances came into Wisconsin. Each advance was followed by a general absence of ice and a period of moderated climate during which extensive soil development took place. Within each of the major ice advances there were minor advances and retreats of the ice. The advances are marked by the deposits; and the ice-free periods are marked by soil development, loess deposits, and in many cases the remains of vegetation. Minor advances of the ice may be inferred from changes in the composition of the deposits formed; the ice moved across different terrains, and the resulting sediments are different. The presence of loess or of overridden outwash between successive till sheets can also be used to differentiate the various drift units.

There are two major systems of stratigraphic nomenclature utilized by geologists studying the glacial deposits of Wisconsin. These are time stratigraphy and rock stratigraphy. Time stratigraphy is the sequence and correlation of rock units according to inferred or actual age, whereas rock stratigraphy is the sequence and correlation of rock units based on the physical characteristics of the rocks. Both systems take into account the relative position of one unit with respect to the others.

The period of time during the glaciation of North America is called the Pleistocene Epoch. The rocks deposited during the Pleistocene Epoch belong to the Pleistocene Series of rocks. An Epoch is a unit of geologic time, whereas a Series is a time stratigraphic term that refers to the materials that were deposited during that same time. The term Pleistocene can, therefore, refer either to the time segment or to the body of rocks.

The Pleistocene Series is subdivided into seven stages (stage being a time-stratigraphic term). Each stage is composed of deposits formed either during one of the four major ice advances or during one of the three interglacial periods. The stages are further subdivided into substages which indicate smaller advances and retreats of the ice. The Pleistocene time-stratigraphic nomenclature used in Wisconsin is summarized in table 3.

Although the system of time stratigraphy is well suited for the mapping of large areas, it does not take into consideration variations in physical characteristics relating to rock type. When dealing with problems such as mineral resource investigations, waste management, powerplant siting, utility routing, or water supply management, the physical characteristics of the glacial deposits are the most important consideration. For these applications, as for almost all other aspects of applied or environmental geology, a system of rock stratigraphy is used. In this system, sequences of deposits are divided on the basis of physical characteristics, and thus are recognized and defined by observable physical features rather than by age or geologic history. The fundamental unit of this classification is the formation, which is often subdivided into members.

TABLE 3.—CLASSIFICATION OF PLEISTOCENE TIME-STRATIGRAPHIC UNITS MAPPED IN WISCONSIN (AFTER WILLMAN AND FRYE, 1970)

| $C^{14}$ age (years B.P.) | Stage | Substage |
|---|---|---|
| | Holocene | |
| 7,000<br>11,000<br>12,500<br>22,000<br>28,000±<br>75,000± | Wisconsinan | Valderan (Greatlakean [1]).<br>Twocreekan.<br>Woodfordian.<br>Farmdalian.<br>Altonian. |
| | Sangamonian | |
| | Illinoian | |
| | Yarmouthian | |
| | Kansan | |

[1] Revision proposed by Evenson et al. (1975).

No comprehensive system of Pleistocene rock stratigraphy has yet been developed for Wisconsin, due to the lack of adequate field study and mapping.

*Geologic history*

Before the onset of glaciation, the surface of Wisconsin had been deeply dissected by streams. Although no statewide map of the preglacial topography of the bedrock surface is available, a good approximation of its configuration can be obtained by reference to figure 20

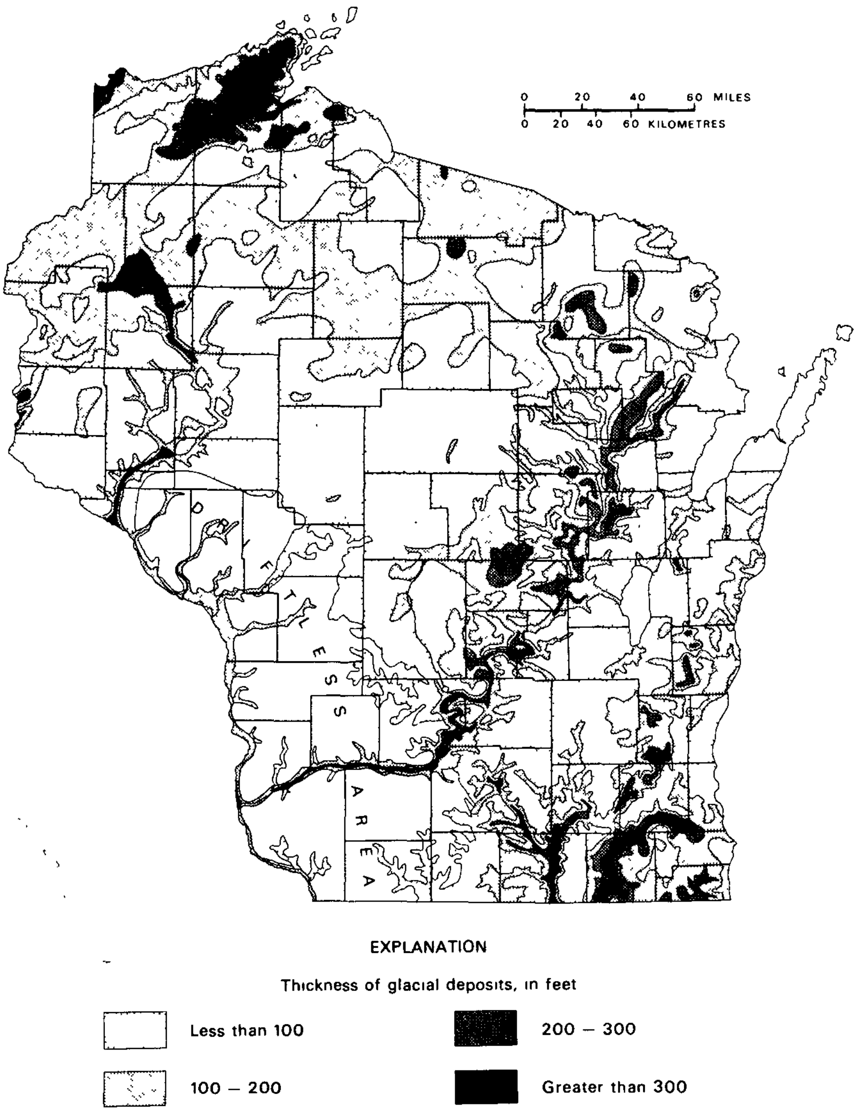


FIGURE 20.—Generalized thickness of glacial deposits in Wisconsin.

which is a map of the thickness of the glacial drift. Bedrock valleys are inferred from areas of thick drift.

Pre-Wisconsin glaciation: The distribution of Pleistocene time stratigraphic units is shown by figure 21. No glacial deposits of

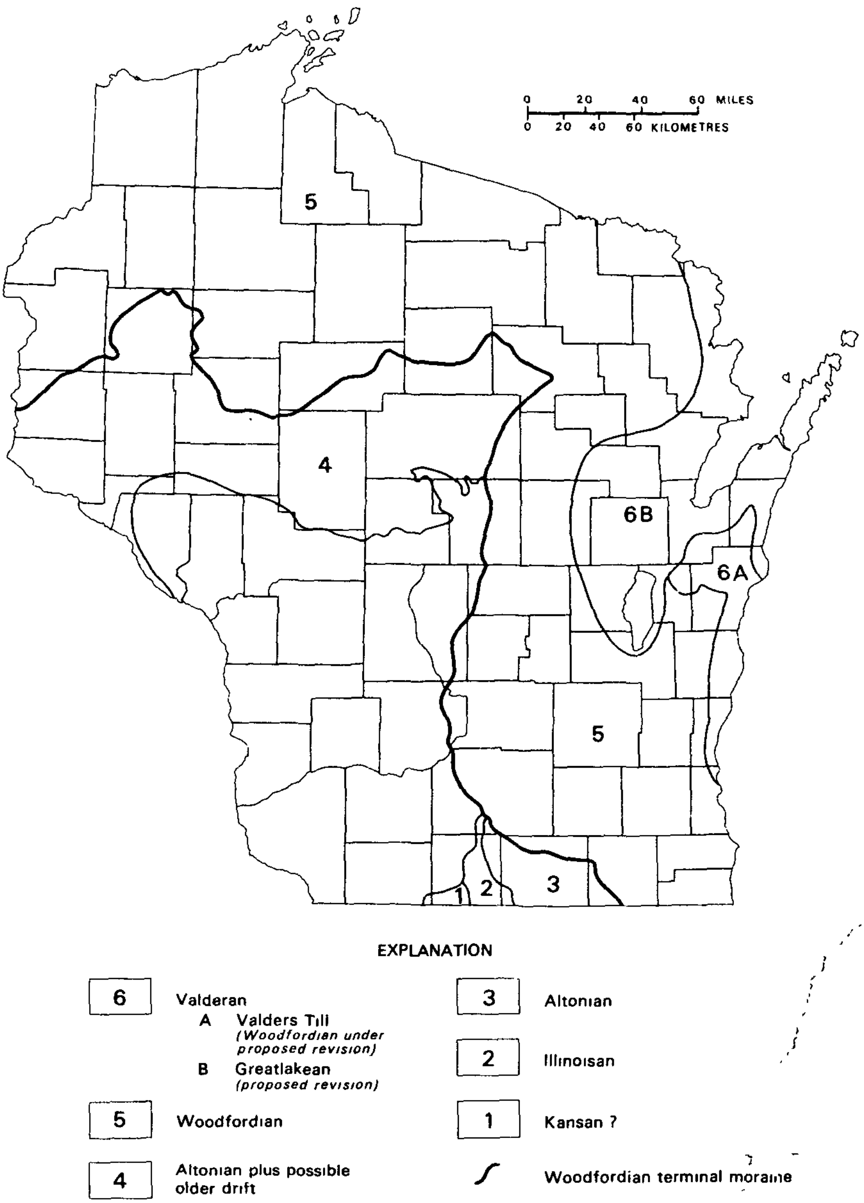


FIGURE 21.—Areal distribution of glacial time-stratigraphic units.

Nebraskan age have been identified in Wisconsin, although it is possible that the State was traversed by Nebraskan ice and the deposits lie buried under younger deposits.

The oldest known glacial deposits in Wisconsin are now thought to be a sequence of till, overlain in part by outwash and possibly ice-contact sand and gravel deposits, found in the area bordering Illinois in portions of Green and Lafayette Counties (Bleuer, 1970). The approximate limits of exposures of these deposits are shown as Area 1 on figure 21. Bleuer considered these deposits to be of Kansan age. To the east of these deposits, in Area 2, the surficial material is thought to be a till of Illinoian age. Isolated crevasse fills and kames that lie to the west of the mapped deposits may have been let down by the stagnant ice of one or more additional Illinoian ice sheets which left no other recognizable evidence. The Illinoian ice is thought to have entered the area from the East. A thick relict soil has been identified by Bleuer on the till surface in several areas, and probably represents weathering during the Sangamonian interglacial stage. As far as is now known, the deposits within Areas 1 and 2 are the only pre-Wisconsin deposits exposed in the State.

Altonian glaciation: Area 3, which lies immediately to the east of the Illinoian deposits, is made up of deposits of the Altonian substage of the Wisconsin stage. During the Altonian, three different ice sheets, bearing materials of distinctly different composition, entered the area from the East. The surfaces of the deposits laid down by the second of these advances show minor soil development and spruce twigs in silts (Bleuer, op. cit.).

Another area thought to be covered by deposits of Altonian age is shown as Area 4 (Mickelson, Nelson, and Stewart, 1970). Recent studies have indicated that at least two ice masses moved into that area. The oldest deposits were laid down by ice moving almost directly from the west. Deposits from the second ice advance show a flow direction from the north-northwest. Radiocarbon dates were obtained for material from bog deposits on the surface of the younger till. The material was dated at 40,800 years Before Present (B.P.), indicating that the younger drift must be at least Altonian in age. Since the older drift shows very extensive weathering, these materials may be early Altonian or older.

The retreat of the Altonian ice marked the beginning of the Farmdalian Substage. During this substage, there was substantial erosion of the previously deposited glacial materials, deposition of windblown silt over broad areas, and some soil development.

Woodfordian glaciation: About 6,000 years after the Altonian ice retreated, ice of the Woodfordian Substage moved across Wisconsin, and an unusually well developed terminal moraine formed. This moraine can be traced continuously from Minnesota to Illinois and is one of the most conspicuous glacial features in Wisconsin. The location of the Woodfordian limit is shown by the heavy line on figure 21 to emphasize the fact that this line separates the often spotty and more deeply weathered drift to the south and west from extremely fresh deposits to the north and east.

Figure 15 indicates the distribution of end moraines and shows, that rather than being a continuous deposit, the Woodfordian terminal moraine is made up of a number of discontinuous segments. These segments are interpreted as indicating that the Woodfordian ice underwent a number of minor retreats and readvances while at or near its terminal position. This oscillating ice front produced a large number of till units, making the interpretation of the Woodfordian deposits extremely complex.

Working out the detailed glacial history and stratigraphy of the Woodfordian deposits is further complicated by the fact that the Woodfordian ice was made up of a number of lobes and sublobes that moved across the State from a number of different directions and at slightly different times. This had the effect of adding to the number of discreet and mappable units of drift. It also led to the formation of a number of extremely complex interlobate areas, the best known example of which is the Kettle Moraine, which formed roughly parallel to the Lake Michigan shoreline at the junction of the Lake Michigan and Green Bay lobes.

The retreat of the Woodfordian ice was interrupted by a series of minor readvances and the attendant formation of a succession of recessional moraines.

During recession, large areas of stagnant ice were common, and large areas of pitted outwash and other ice contact features were formed. The unusually large areas of pitted outwash and other ice stagnation features, the large drumlin fields, most of which are of Woodfordian age, and the many well developed interlobate areas, especially the Kettle Moraine, have made Wisconsin renowned as a site for the study of glacial deposits.

The Woodfordian was also the time of origin of the great majority of glacial lakes in Wisconsin, including ancestral Lake Michigan, known as Lake Chicago, which formed as the Woodfordian ice front retreated northward in the basin in which Lake Michigan now lies.

The Twocreekan Substage: The Twocreekan Substage was named for the very significant forest beds exposed near Two Creeks in Manitowoc County. The Twocreeks deposits, which are exposed in the bluffs of Lake Michigan, are made up of about 10 feet of lake clay overlain locally by silt and sand upon which can be seen the in-place remains of a spruce forest that grew on the deposits formed in the lake and on the beach. Radiocarbon dates for tree remains in the forest bed show them to have grown about 11,800 years ago (Black, 1974).

Valderan (Greatlakean) glaciation: At the end of Twocreekan time, ice moved down the Lake Michigan basin as far south as Milwaukee and down the Green Bay lowland to about the southern end of modern Lake Winnebago. The extent of this glaciation is shown as Areas 6A and 6B (fig. 21).

The Valderan Substage was named after Valders Till exposed in a quarry near the town of Valders in Manitowoc County. Deposits of the Valderan Substage are described as being the youngest glacial deposits in Wisconsin and are typified by the presence of a characteristic red till. Recent studies, however, indicate that the Valders Till actually lies under the Two Creeks forest bed (Mickelson and Evenson, 1975). They show that the Valders Till occurs in Area 6A and indicates that it is a Woodfordian unit. The deposits which lie above the forest bed at Two Creeks are found within Area 6B. It has recently been proposed (Evenson, et al., 1975) that the term Valderan be replaced by the term Greatlakean Substage, which would embrace deposits younger than the Two Creeks forest bed.

The Valderan ice had probably retreated from Wisconsin by about 9,500 years ago, thus closing the Pleistocene glaciation of Wisconsin.

*Status of mapping*

Figure 1 is a modified reduction of a recently compiled map of the glacial deposits of Wisconsin at the scale of 1 : 500,000 and summarizes all of the available published and unpublished glacial mapping. Figure 22 is an index map of the sources used in preparing the map of the

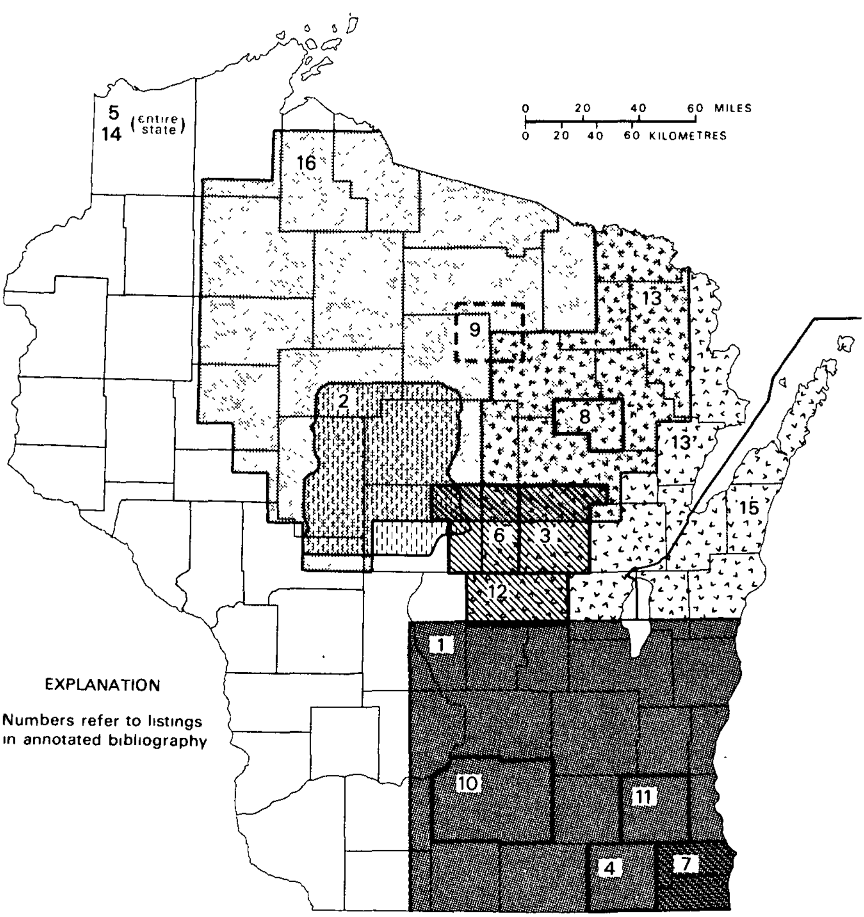


FIGURE. 22.—Index to glacial mapping.

glacial deposits of Wisconsin. The annotated bibliography of glacial mapping in Wisconsin identifies the areas shown, and indicates the kinds of information to be found in each study.

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As shown by figure 1, the surficial deposits over most of Wisconsin are of glacial origin. Thus, they exert an extremely strong influence on many of the principal factors that make up the physical environment. For example, the kinds and distribution of Wisconsin's soils as shown in figure 3 have been determined to a large degree by the nature of the glacial parent materials from which they 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 related to the physical nature of and distribution pattern of the glacial sediments. The abundant deposits of sand and gravel that constitute Wisconsin's most important mineral resource owe their existence 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. The 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. Finally, the kind and distribution of land forms as well as rivers and lakes in the glaciated areas of the State are products of the Pleistocene ice age.

Because of the control exerted by glacial geology on so many facets of our environment, there is a large and diverse group of agencies and individuals that can and do make good use of the geologic data as they become available. This group includes soil scientists, engineers, ecologists, hydrologists, geologists, foresters, planners, administrators, and many others. Existing geologic maps of the glacial deposits of Wisconsin are, for the most part, not adequate to meet these needs. For example, 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 map 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 (No. 16, annotated bibliography). The accuracy of this data is not known, and extensive field checking will be necessary for confirmation. Because of this deficiency of information on the glacial deposits of Wisconsin an intensified program for mapping them is needed.

An additional, and perhaps even more cogent, reason for an accelerated program of glacial mapping in Wisconsin lies in the progress that has been made in the field of glacial geology. Field study in Walworth County by the author has, for example, shown that through careful study it is possible to differentiate at least five distinct units of glacial till exposed at the surface. Units such as these often have physical and chemical characteristics that remain essentially constant within relatively large areas. Inasmuch as 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 will greatly increase the utility of the map.

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 in order to provide the necessary detail for most practical applications.

In summary, in spite of the critical needs for maps to show the distribution and characteristics of glacial deposits, much of Wisconsin has never been mapped in adequate detail. Even where mapping has been at a relatively large scale, considerable doubt remains as to the accuracy of much of the information. Furthermore, 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*

(Location of areas shown on figure 22)

1. Alden, William C., 1918. Quaternary geology of southeastern Wisconsin: U.S. Geol. Survey Prof. Paper 106, 356 pages, 3 plates.
   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, D. 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.
   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: Semi-detailed field check shows the map to be largely accurate.
5. Hadley, D. W., and Pelham, J. W., 1975, Glacial deposits of Wisconsin: Wis. Geol. and Nat. Hist. Survey, map, in press.
   Scale: 1:500,000
   Units mapped: End moraines, ground moraine, outwash, pitted outwash and other ice contact deposits, glaciolacustrine deposits.
   Comments: Summary of previous references.
6. 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.

7. 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.

8. 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.

9. 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.

10. 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. Not field checked in detail.

11. 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.

12. 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.

13. 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.

14. 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 a widely distributed page-size map.

15. 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.

16. 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.

## SOILS

Although not usually regarded as a mineral resource, the approximately 300 billion tons ($272 \times 10^9$ metric tons) of soil in Wisconsin (to a rooting depth of 4 to 5 feet or 1.3m) constitute an important resource that provides the nutrients required for life by plants, animals and human beings, and that serves as an indicator of subsurface geology and hydrology. Sandy and gravelly soils may be indicative of the presence of geologic deposits of sand and gravel, and bodies of organic soils (peats and mucks) may be managed as extractable resources. Some plants take up heavy metals, such as lead, from soil and may be used as indicators of the presence of ore bodies.

Prominent bedrock features designated on the soil map (fig. 3) are the Gogebic and Baraboo Ranges, Barron Hills, Rib and McCaslin Mountains, also Silurian "Niagara" escarpment in the east, Blue Mounds, and the dolomite escarpment that forms Military Ridge in the southwest. Bedrock affects mineral composition of soils locally and the eight major soil regions of Wisconsin relate closely to land forms and geologic materials.

Red clay is present in the lowland near Lake Superior in northwestern Wisconsin; pink loams and red clays are in the lowlands extending from the Green Bay area. Two large areas of pitted sand near McCaslin Mountain and Rhinelander are related to sorting of glacial outwash by meltwater; the northwest area of sands is related to outwash and the underlying Bayfield Sandstone. Three areas of gray loams are derived from lime-deficient glacial till and outwash. Two areas of grayish yellow silt loams formed from thin loess over glacial drift, both lime deficient. Sandy loams and sands between Eau Claire and Madison overlie sandstone and coarse textured glacial drift. Grayish brown hilly silt loams developed extensively in moderately thick loess over limestone and sandstone in upland areas and in outwash deposits along major valleys. Grayish brown rolling silt loams formed from thin loess over limy glacial drift.

Prominent glacial landforms shown are the Wisconsin glacial end moraine, the Kettle Moraine, and an area of drumlins (elongate ice-sculptured hills) indicated on the map by short lines just east of Madison.

Organic matter produced by the vegetative cover darkens soil in proportion to the wetness of the site and fineness of soil texture. Migration and precipitation of iron compounds in irregular color patterns in the soils have been influenced by movement of soil water and decomposition of organic matter. Soil patterns and properties in landscapes therefore record certain hydrologic conditions, such as magnitude and duration of fluctuations of the water table. Wetland soils occupy about 8% of the area of the State, and bordering footslope soils with impeded drainage are nearly as extensive. Soils filter percolating water on its way to the water table and change their hydraulic conductivity from rapid in sands (2.45 gal/ft.$^2$/day or 100 cm/cm$^2$/day at 20 mb tension) to very slow in clay (0.4 gal or 0.2 cm/day at the same degree of saturation).

The definition of hundreds of soil species by profile characteristics (fig. 23) and the delineation of soil bodies on maps have been at an increasing rate in the State since 1882 when T. C. Chamberlin pub-

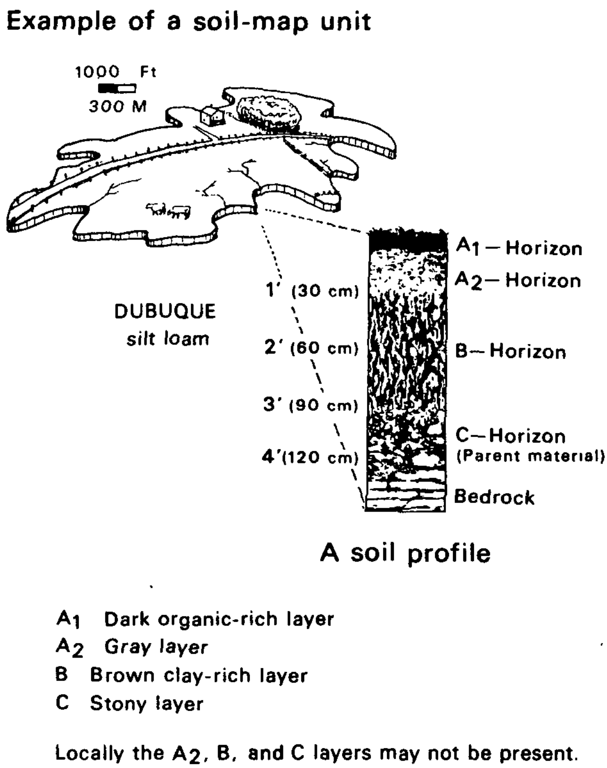


FIGURE 23.—A soil profile.

lished the first State soil map. Although detailed soil maps are not yet available for much of the Northern Highland a large volume of soil information has been published (fig. 24) and can serve as a guide to mineral and water resources.

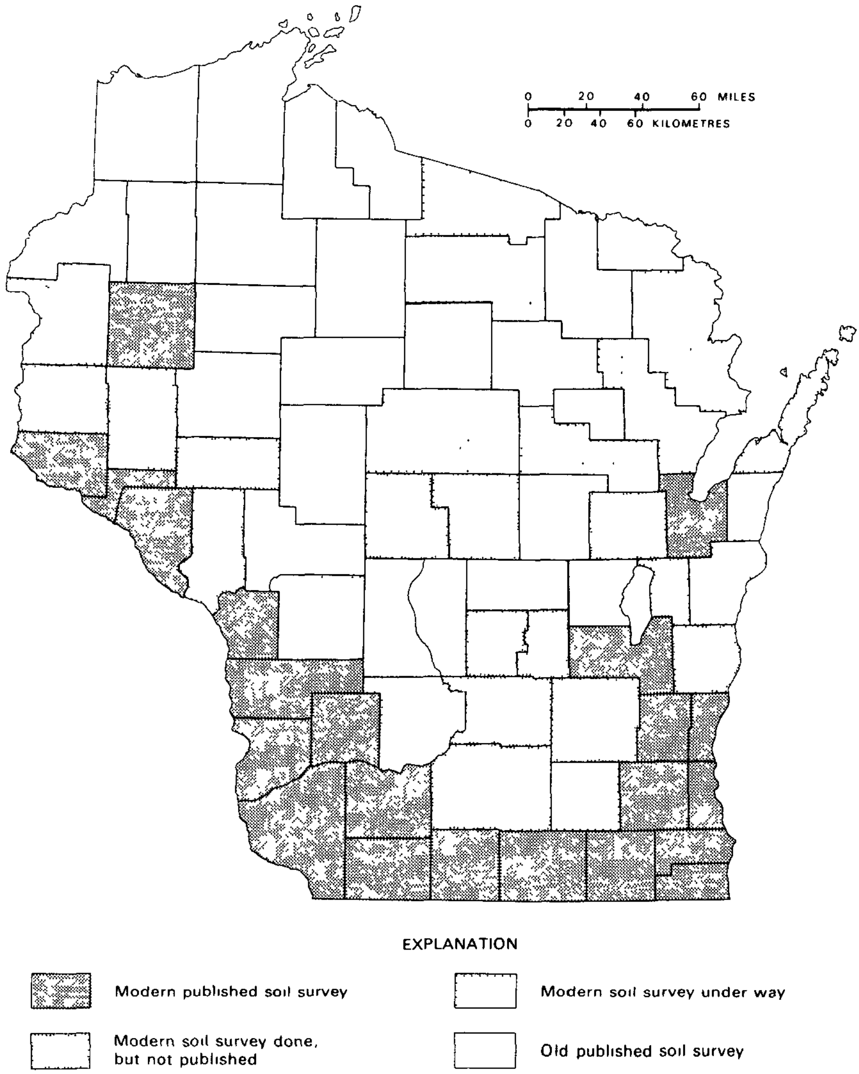


FIGURE 24.—Status of soil surveys, 1975.

## PHYSICAL GEOGRAPHY [1]

[1] Modified by editors from Black, Robert F., 1964, Wisconsin Blue Book, pp. 171–177.

### *Geology*

On the basis of the kinds of rocks and the landforms resulting from them, Wisconsin may be divided into five general geographic regions (fig. 25).

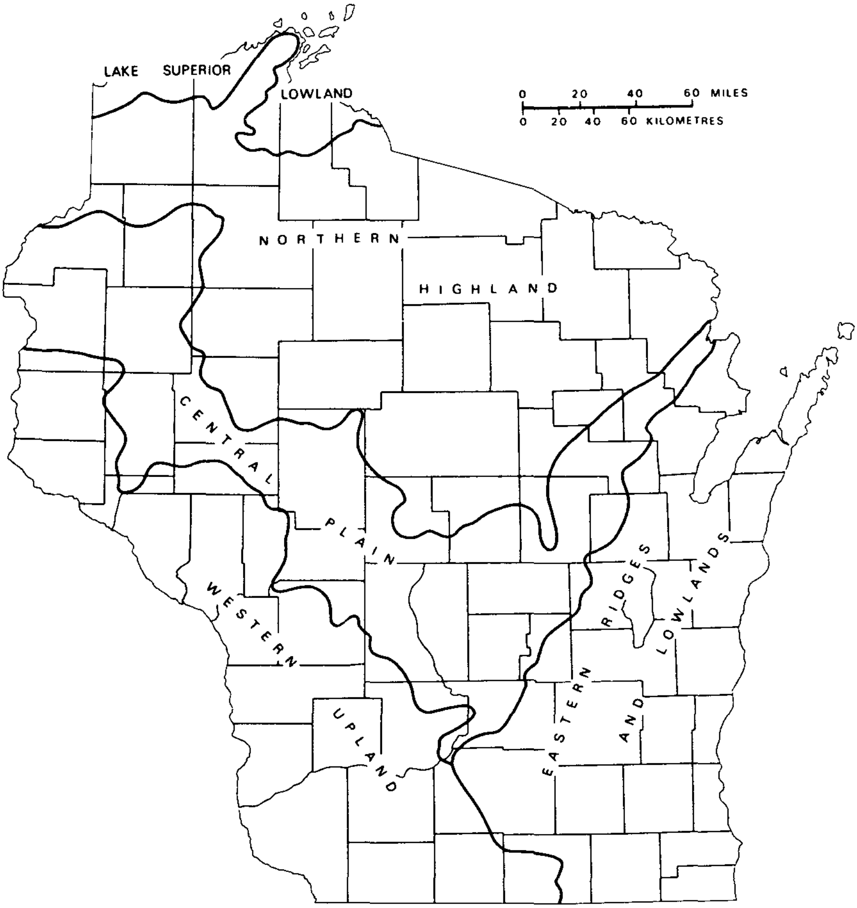


**FIGURE 25.—Geographic regions of Wisconsin modified from Martin, 1932.**

The Lake Superior Lowland is underlain by nearly horizontal rock layers that are principally sandstone and are easily eroded.

The Northern Highland province is underlain by large areas of erosively resistant igneous rocks and generally less extensive rocks formed by metamorphism of igneous and sedimentary rocks. All rocks in the Northern Highland province are more than 600 million years old and thus of Precambrian age.

The other three provinces are part of the Central Plains region that extends southward along the Mississippi River and its tributaries. These provinces are underlain by a gently inclined series of sedimentary rocks—sandstones, shales, and dolomites—lithified from materials laid down in ancient shallow sea water 300 to 600 million years ago. These rocks constitute the Paleozoic section of Wisconsin.

*Topography*

The topography of the Northern Highland province is characterized by local irregularities and low to moderate relief averaging perhaps 200 feet. The general elevation is 1,400 to 1,650 feet. Familiar high points are Rib Mountain at Wausau and Sugarbush Hill near Laona, each about 1,940 feet above sea level. In 1962, the United States Geological Survey established that Tim's Hill, with the Ogema fire tower on top, and nearby Pearson Hill are 1,952.9 and 1,950.4 feet, respectively, the two highest known elevations in the State. The topography of the southern provinces is perhaps more uniform locally than the northern, but differs markedly within the provinces. Because of that variation the units are designated Southwestern Upland, Central Plain, and Eastern Ridges and Lowlands. In the deeply dissected Southwestern Upland the general elevation is 1,000 to 1,250 feet above sea level. The highest points reach 1,450 feet and the lowest valleys, tributary to the Mississippi River, are cut below 700 feet. Relief commonly approaches 500 feet along the steep-sided valleys. Rocky bluffs, castellated spurs, and rock monuments provide some of the most striking scenery in the State. In the Central Plain, as the name implies, flat surfaces or gently rolling surfaces are characteristic. Relief is low except for occasional pinnacles and hills of sandstone. Elevations between 750 and 850 feet are widespread. In the Eastern Ridges and Lowlands, the ridges lack the distinction of being very high but the lowlands along Lake Michigan at 580 feet above sea level are the lowest within the State. Relief on the order of 100 to 250 feet takes in the bulk of this region.

Within the five major provinces of the State many other smaller units than those named will come to the mind of the knowledgeable traveler—the Fox River-Green Bay Lowland, the Rock River Lowland, the Baraboo Range, and so forth—each a descriptive geographic locality. The boundaries of the provinces are determined actually by a complex of bedrock type, topgraphy, soils, vegetation, climate, and land use. Such a complex is not easily defined or applied. Individual boundaries may be moved somewhat according to the weight given any one factor. Obviously bedrock and topography are here weighed most heavily.

*Drainage*

Although the local units named above apply to drainage basins, the major river systems of the State cross the provincial subdivisions. Topography controls the slope down which water can flow. That topography is related ultimately to the bedrock and effects of constructional and destructional processes working on it through geologic time. A complex interrelationship exists. The more resistant Precambrian rocks of the northern province stand higher generally than the overlapping Paleozoic rocks to the south.

The northern province culminating in Vilas County is the source for streams which flow radially outward—north to Lake Superior; east and southeast through the Menominee and Wolf Rivers to Lake Michigan and ultimately to the Atlantic Ocean; west, southwest, and south to the St. Croix, Chippewa, Black, and Wisconsin Rivers to the Mississippi River and ultimately to the Gulf of Mexico.

The ease of access of some drainage basins played an important role in the historical development of Wisconsin. This is especially true for the Lake Michigan, Green Bay, Fox River, and lower Wisconsin River waterway with its original short portage and later canal at the city of Portage, or the Lake Superior-Mississippi River route via the Brule and St. Croix Rivers.

*Resource aspects*

Bedrock significantly determines the mineral and water resources of the State. Besides the direct role of yielding exploitable minerals to supply us with iron, lead, and zinc; of dimensional stone for buildings, tombstones, and the like; or of crushed rock for highway construction and agricultural lime, bedrock has yielded a variety of rock debris to the great glaciers that many times entered the State. Sand and gravel from the glacial drift is still our No. 1 mineral commodity in terms of actual dollar value.

The advances and stagnations of ice in Wisconsin left a generally thick blanket of glacial drift over three-fourths of the State. This drift contains a variety of rocks of different degrees of weathering. In places farming is well-nigh impossible. Elsewhere glaciers left many feet of parent materials that have developed rich soils. Moreover, meltwaters from the stagnating ice created mud flats and bars in the major rivers from which wind picked up silt-sized particles. That dust was deposited in an important blanket of loess in the southwestern upland especially where little drift may be found. This provides a good soil on relatively sterile bedrock surfaces. Our soils owe much of their fertility and variability directly or indirectly to the mixing and transportation of vast quantities of debris by glaciers. In many rural homes and smaller communities, too, the glacial drift provides a source of drinking water, commonly of better quality than that from bedrock. The distribution of bog or forest, of pine or maple, of beaver or opossum, of quail or cottontail, of trout or walleye, among many others, is determined by several factors chief of which is glaciation. The glacial deposits commonly determine topography, soils, and drainage, including ground water and surface runoff, which in turn control the kinds of plants and animals that can use the land. Glacial erosion and deposition and geomorphic processes accompanying and following glaciation also produced all natural lakes and the scenery in many parks.

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## TOPOGRAPHIC MAPPING

(By P. A. Antill, U.S. Geological Survey, Reston, Va.)

The national mapping program of the U.S. Geological Survey provides general purpose topographic mapping and special map products which are essential to the intelligent and efficient inventory, utilization, development and management of the mineral and water resources of Wisconsin.

The Geological Survey began its topographic mapping program in Wisconsin in 1887 in the vicinity of Madison. The program has benefited from a cooperative agreement in which mapping costs for areas of mutual interest are shared equally by the State and the Geological Survey. The initial Wisconsin cooperative program for topographic mapping was with the Wisconsin Geological and Natural History Survey and began in 1915. Except for 1 year, 1918, it continued until 1932. The current cooperative program with the State has been continuous since 1938. At present, the Wisconsin cooperating agencies are the Geological and Natural History Survey, the Department of Transportation, and the Department of Natural Resources.

The status of published topographic mapping in Wisconsin as of June 30, 1975 (fig. 26), is as follows:

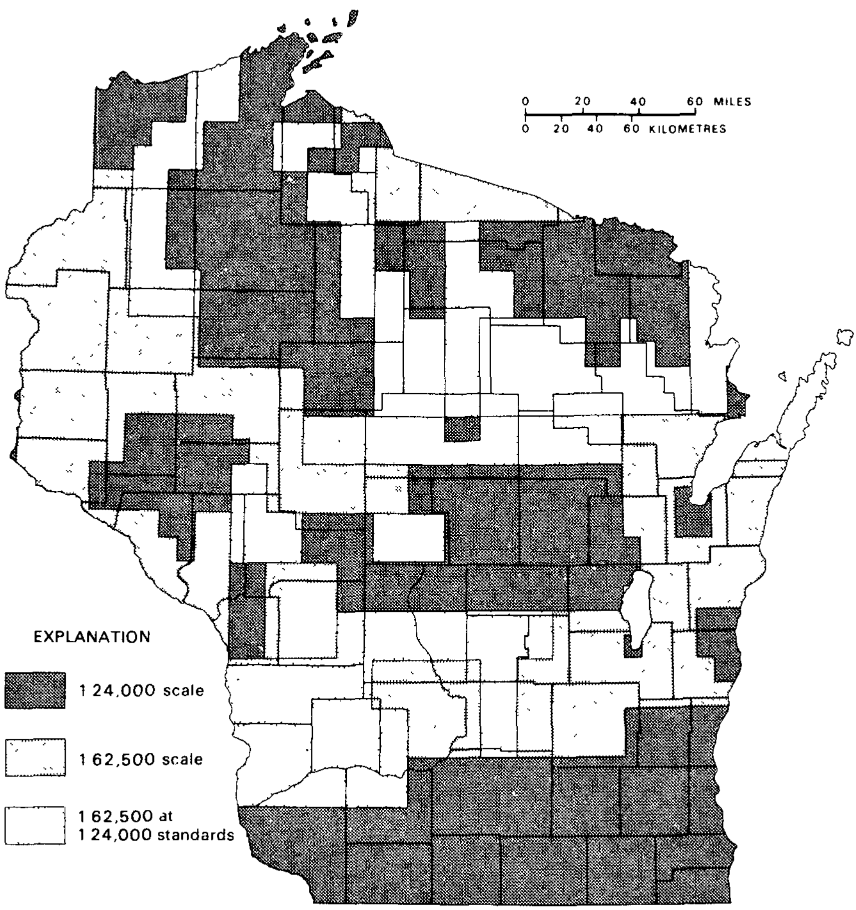


FIGURE 26.—Status of published topographic mapping, June 30, 1975.

| Scale: | Coverage (percent) |
|---|---|
| 1:24,000 [1 inch=2,000 feet] | 44 |
| 1:62,500 at 1:24,000 standards [manuscript copy at 1:24,000 scale is available] | 24 |
| 1:62,500 at 1:62,500 standards [1 inch=approximately 1 mile] | 27 |
| State total | 95 |

About 25 percent of the State is in the present program for 1:24,000 scale mapping; 5 percent is new mapping, and 20 percent is replacement mapping (to replace 1:62,500 scale maps with modern maps at 1:24,000 scale).

The State is also completely covered by published maps at 1:250,000 scale (1 inch=approximately 4 miles) and by State maps (planimetric and topographic) at 1:500,000 scale.

Wisconsin will have complete published coverage at either the 1:24,000 or 1:62,500 scale in 1977. Complete coverage of 1:24,000 scale mapping should occur by the early 1980's at the present rate of funding. To provide a 1:24,000 scale base as soon as possible, the Geological Survey plans to prepare by 1978 orthophotoquads in all areas presently unmapped at 1:24,000 scale.

The orthophotoquad is a black-and-white photo-image map at 1:24,000 scale that contains all of the information appearing on an aerial photograph while having the accuracy of the conventional line map. Distortions due to relief and camera orientation are eliminated through rectification. The orthophotoquad has the additional advantages of relatively low cost and short production time. The orthophotoquad provides an interim substitute until a standard map is available, serves as a companion product to an existing map, and can be used as a means of providing updated information for areas covered by out-of-date maps.

## Mineral Resources

### THE NATURE OF MINERAL RESOURCES

(By W. P. Pratt and J. J. Norton, U.S. Geological Survey, Denver, Colo.)

Mineral resources are naturally formed concentrations of solid, liquid, or gas in the Earth or at its surface, from which profitable extraction of one or more usable commodities is currently or potentially feasible. The commodity being sought may be: (1) an element occurring in its native, uncombined state, such as gold or sulfur; (2) a metal that must be separated from the natural compounds (minerals) that make up its ores, such as lead or zinc or copper from their sulfides, or iron or aluminum from their oxides or hydroxides; (3) a chemical compound for use in its naturally occurring mineral state or for use after conversion to another compound, such as salt (for table and industrial use), fluorspar (for use in steelmaking and in the chemical industry), or phosphate (for use as fertilizer after treating with acid); (4) a mineral used because of its special physical properties, such as diamond (gem and abrasive), asbestos (insulating uses), or barite (used in heavy drilling mud for oil wells); (5) a rock or rock aggregate for use in construction, such as granite, limestone, or gravel; or (6) a substance used in one form or another as a source of energy, such as petroleum, natural gas, coal, or uranium.

Nearly all mineral raw materials used today are taken from natural concentrations of one or more chemical elements or minerals within a mass of rock that is called a mineral deposit. Metallic material rich enough to be mined is called ore.

A mineral deposit may have a regular or very irregular shape and sharp or gradational boundaries, but it is always of relatively small extent compared to the expanse of a continent or a state. A few mineral deposits, such as beds of iron ore, may extend for a few miles; but most mineral deposits are only a few feet or a few tens of feet in at least one dimension and commonly only a few hundreds of feet in their greatest dimension.

Mineral deposits are unique in that they are the products of natural geologic processes that have caused certain chemical constituents to be concentrated in a particular small part of the Earth's crust, rather than dispersed throughout a large part of it. And because most of these geologic processes act very slowly, most mineral deposits were formed over long periods of time—thousands or hundreds of thousands of years; moreover, many such processes take place only at great depths below the surface. Consequently, unlike other natural resources, mineral resources are, with few exceptions, not renewable.

A key question in discussing mineral resources, whether on the scale of an entire nation, a state, or a mining district, is how much more material suitable for use remains in the ground. Stated more exactly, the question becomes: What is known to be present, and what is the expectation for future discoveries, or for development of known deposits that have not yet been mined? The words "reserves" and "resources" are the customary labels for estimates of the amounts likely to be available. Oftentimes such estimates are subdivided according to the completeness of the data on which they are based and the economic feasibility of extraction. The two words sum up a group of complex concepts involving geologic, engineering, and marketing considerations. Put perhaps too simply: "resources are what exists; reserves are what you can get out" (Park, 1975, p. 16). In more precise terms, reserves are what is contained in bodies of earth material whose location, quantity, and quality are known, and from which a usable mineral or energy commodity can be extracted under current technology and at a profit commensurate with the business risks. The word "reserve" is frequently misused or carelessly used by laymen and professionals alike.

Undiscovered ore or energy fuel, even if of great value, is not a reserve until its existence and location become known and its nature can at least be inferred from geologic evidence. Then, as tests of various kinds increase knowledge of (1) the quality of the bodies, (2) their size and shape, (3) the amenability to processing, and (4) the marketability of the product, quantitative estimates proceed through a series of categories until they become what is known as "measured" or "proved" reserve when the material is ready for production. Because such tests are costly, the operators of a mine or wells will tend to maintain proved reserves at a level only large enough to plan the extraction properly and to justify any capital expenditures required, though there is also a necessity to obtain enough information about additional reserves to predict how operations will proceed in the long-term future. Nevertheless, there is little reason to spend money to prove reserves that will not yield a return until many years later. For some commodities there is even a risk that what are considered reserves now will cease to be reserves in the future because better deposits have been discovered elsewhere or technological changes have altered the market.

"Resources" include both reserves and other mineral-bearing or energy-producing materials from which economic extraction of a commodity is potentially feasible. Resources include deposits that are known to exist but are not now recoverable, either because they will not yield a profit or because of legal or political circumstances; such deposits may be extracted when technological, economic, legal, or political conditions change. Resources also include undiscovered deposits. In accordance with known geologic conditions, some undiscovered deposits may reasonably be expected to exist in known mining districts. Others may occur as conventional types of deposits in favorable geologic settings where no discoveries have been made. Still others may occur in as yet unknown types of deposits that remain to be recognized. Some undiscovered deposits would, if found, be minable "as is," though not without the delay of months or years needed for construction of mining, milling, and transportation facilities. Others would become minable only with improvements in mining technology or in other circumstances. Although it is impossible to appraise the magnitude and quality of undiscovered deposits, their importance cannot be overemphasized; finding new deposits is the goal of millions of dollars' worth of exploration each year, and although the successes are relatively few, they include enough major discoveries to prove that the effort is worthwhile.

The world's undiscovered resources of metals and many nonmetals, but probably not the resources of oil, gas, or coal, may be much larger than anyone would dare guess. Vast areas may contain mineral deposits that are too deeply buried to be found at acceptable costs by existing exploration methods, but are shallow enough to be mined if discovered.

The distinction among the categories of resources may be clarified by examples of similarities with personal finances. Reserves—which by definition are known to exist but may take years to be mined out—are analogous to one's cash on hand, bank accounts, other liquid assets, and any reasonably assured future income from salary, pensions, and investments. Known reserves that cannot be mined profitably are like potential income from known skills that are currently unusable owing to strikes or adverse business conditions, and perhaps like pending inventions or products not yet test-marketed. Undiscovered resources are comparable to future income that might be obtained from capital gains, gifts, lottery winnings, unanticipated inheritances, and skills not yet learned or business ventures not yet contemplated.

In estimates of reserves and resources, the quality and quantity of the data and the interpretation of them are more important than mere numerical summaries. Most of the discussions of the various commodities on the following pages will treat resources not primarily in terms of arithmetic calculations, but instead will emphasize the meaning and the shortcomings or strengths of the available information.

MINERAL RESOURCES IN WISCONSIN

*Introduction*

(By M. E. Ostrom, Wisconsin Geological and Natural History Survey, Madison, Wis.)

Minerals, fuels, and also agricultural and forestry products are the primary sources of the material and food requirements of our industrialized civilization. A continuing supply of each is essential to maintain our modern standard of living.

About 40,000 pounds of new mineral materials, including fuels, are required annually for each U.S. citizen (Mining and Minerals Policy, 1975). Wisconsin produces only a very few of the minerals required by its citizens and no fossil fuels. Except for construction materials—such as sand, gravel, crushed and dimension stone, and silica sand—Wisconsin is a net importer of its minerals and fuels requirements.

In 1972, the latest year for which complete records are available, Wisconsin ranked 38th in value of mineral production in the United States. This was 0.28 percent of the U.S. total, and the principal products were sand and gravel, stone, iron ore, and cement. Among the States, Wisconsin is ranked 41st in value of mineral production per square mile ($1,591) and 43rd in dollar value per capita ($20).

Certain commodities of Wisconsin were among the leaders in 1972. For example, Wisconsin contributed 4 percent of the total sand and gravel production in the United States and ranked 6th in quantity and 14th in value of sand and gravel produced.

Mineral commodities are obtained from appropriate earth materials by various mining or drilling operations. An economic mineral deposit is a concentration of one or several useful minerals in sufficient quantity and quality as to be mined, processed, and marketed at a reasonable profit under existing technologic, economic, and ecologic conditions. Mineral reserves are those additional deposits for which location, quantity, and quality are known and from which a commodity can be obtained under existing economic, technologic, and ecologic constraints. Mineral resources are any other materials from which extraction of a mineral commodity is potentially feasible depending on technological, economical, political, and/or ecological circumstances.

Mineral deposits are the product of past geologic events and conditions. Thus, their location, size, purity, and accessibility were predetermined by specific events or combinations of events at various times during the 4.5 billion years since the Earth's crust began to form.

Mineral deposits possess unique characteristics which make them more difficult to identify and to manage than either agricultural or forestry resources. Namely, mineral deposits are nonrenewable, fixed in location, fixed in quantity, fixed in quality, generally rare, and seldom visible at the Earth's surface.

The quantity and value of minerals produced in the State in 10-year intervals from 1910 through 1970 are presented in table 3 (Friz, 1975). Mineral production in 1974, the latest year for which U.S. Bureau of Mines statistics are available, was valued at a record high of $114.8 million.

TABLE 4.—WISCONSIN MINERAL PRODUCTION, 1910–70

| Year | Clay | | Iron ore | | Lead | | Lime | | Peat | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Tons | Dollars | Long tons | Dollars | Tons | Dollars | Tons | Dollars | Tons | Dollars |
| 1910 | (1) | 1,176,883 | 1,149,551 | 3,609,139 | 3,384 | 341,793 | 248,238 | 959,405 | 0 | 0 |
| 1920 | (1) | 1,413,255 | 1,067,159 | 4,333,307 | 2,647 | 423,520 | 144,590 | 1,539,027 | (1) | (1) |
| 1930 | (1) | 2,778,533 | 1,148,277 | 3,179,175 | 1,537 | 153,700 | 64,989 | 598,739 | 0 | 0 |
| 1940 | (1) | 326,000 | 1,277,840 | 3,290,389 | 445 | 44,500 | 65,632 | 542,749 | 0 | 0 |
| 1950 | 80,000 | 70,000 | 1,720,000 | 8,814,000 | 532 | 144,000 | 124,530 | 1,448,000 | 2,293 | 9,000 |
| 1960 | 144,000 | 156,000 | 1,502,000 | [2] 16,222,000 | 1,165 | 273,000 | -------- | (2) | 8,500 | [3] 145,000 |
| 1970 | 8,000 | 14,000 | 806,000 | [3] 10,308,000 | 761 | 238,000 | 247,000 | 4,503,000 | 1,531 | [3] 139,000 |

[1] Not available.
[2] Included under miscellaneous.
[3] Estimate.

Source: U.S. Bureau of Mines Minerals Yearbook, 1906–71.



TABLE 4.—WISCONSIN MINERAL PRODUCTION, 1910–70—Continued

| Year | Sand and gravel | | Stone | | Zinc | | Miscellaneous [1] | | Total dollars |
|---|---|---|---|---|---|---|---|---|---|
| | Tons | Dollars | Tons | Dollars | Tons | Dollars | Tons | Dollars | |
| 1910 | 1,451,758 | 425,563 | (2) | 2,644,518 | 20,952 | 2,133,216 | (2) | 5,249,163 | 12,504,977 |
| 1920 | 2,422,689 | 1,553,622 | 1,564,940 | 3,729,236 | 27,285 | 4,420,170 | (2) | 497,360 | 18,029,039 |
| 1930 | 7,082,063 | 2,801,713 | 3,370,750 | 5,100,266 | 12,558 | 1,205,568 | (2) | 1,890,201 | 17,711,394 |
| 1940 | 6,742,882 | 2,304,197 | 4,330,360 | 5,030,263 | 5,770 | 727,020 | (2) | 734,885 | 13,553,683 |
| 1950 | 19,117,000 | 11,959,000 | 7,000,000 | 14,495,000 | 5,722 | 1,625,000 | (2) | 3,129,000 | 41,693,000 |
| 1960 | 35,681,000 | 25,648,000 | 16,486,000 | 22,302,000 | 18,410 | 4,750,000 | (2) | 7,675,000 | 77,171,000 |
| 1970 | 41,103,000 | 35,107,000 | 17,577,000 | 25,167,000 | 20,634 | 6,322,000 | (2) | 5,871,260 | 87,670,000 |

[1] Includes variously abrasive stones, cement, gem stones.
[2] Not available.

Source: U.S. Bureau of Mines Minerals Yearbook, 1906-71.

Minerals have been an important economic asset to Wisconsin ever since the lead deposits of southwestern Wisconsin first attracted prospectors and miners. Wisconsin's mineral industry has expanded to include production also of iron ore, zinc ore, clays, dimension stone, crushed stone, lime, sand and gravel, peat, and abrasives.

The single most critical characteristic of mineral deposits is nonrenewability—that is once a deposit is mined out it is exhausted as a source of minerals. Thus, if the supply of minerals is to continue, the choices are (1) a new deposit must be found, or (2) technology must be developed to make feasible and profitable the use of deposits with less suitable mineral, or (3) a system of recycling must be established, or (4) a substitute must be found.

The finding of new deposits requires exploration using the most sophisticated geological and geophysical techniques. Exploration is the only method to locate and thus provide for reservation of concentrations of minerals that have the potential for development whether under existing or future technologic and economic conditions. Thus, identification of mineral supplies essential to satisfy the projected needs of society requires geological and geophysical studies to determine mineral resources potential and to delineate reserves.

Although the solid outer part of the Earth is composed of minerals, we must not be lulled to believe the mineral supplies are inexhaustible. Instead, we must consider the availability of minerals under existing and probable future conditions of occurrence, distribution, technology, energy, and ecological requirements. Thus, availability of minerals is limited by how much environmental disturbance and atmospheric degradation we are willing to tolerate, and how much money and energy resources we are willing to expend to obtain and to use the minerals.

As known mineral deposits are mined out, the total number of deposits decreases and the search for new deposits becomes more difficult and more costly. Although new technologies will likely allow the mining of lower grade materials, they will also likely require the use of more energy consumed per unit of mineral produced. Given an unlimited supply of energy, it is conceivable that the supply of minerals would be unlimited. However, the major source of energy used by industry is fossil fuels, and deposits of these fuels have the same problems of nonrenewability, location, size, purity, and accessibility as do mineral deposits.

Recycling is a viable alternative to provide at least a portion of specific critical mineral needs. However, the total supply of a given mineral cannot be recycled because many are combined with other minerals or used in such ways that they cannot be reclaimed at reasonable and acceptable cost. Recycling can and does, however, provide for at least a portion of the demand, which has the effect of extending reserve supplies over a longer period of time. For example, in 1974, approximately 25 percent of U.S. consumption of both iron and copper was from recycled scrap. However, recycling will never be adequate to provide for projected needs; thus, new sources of supply must be found.

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Substitution might be another alternative to the exhaustion or lack of a specific mineral. However, substitution that results from lack of availability of the most suitable material generally leads to use of a less suitable material. Thus, the substitute may not be as effective or desirable. This can ultimately lead to greater overall cost through lost efficiency. On the other hand, research which indicates that greater efficiencies or lower costs or both can be achieved using an alternative mineral that occurs in large supply would be highly desirable. For this reason, minerals and materials research to discover substitutes which will perform at the same or higher efficiency and approximately the same cost levels should be encouraged.

The concept of mineral independence, whether applied to Wisconsin or to the Nation, assumes the existence of domestic supplies adequate to meet foreseeable demands or that substitutes can be found. Although desirable, it is highly unlikely that complete independence in supplies of minerals or fuels can be achieved by a state or nation because events in geologic history that produced mineral deposits also led to their unequal distribution over the Earth's surface. For example, Wisconsin does not produce coal, petroleum or gas, or chromium, aluminum, or salt because, so far as has been determined, the combination of geologic events necessary for their formation and preservation did not occur there. Wisconsin depends on other states and nations for its supply of these and many other critical minerals. In like manner the United States cannot be independent because concentrations of certain minerals in deposits of commercial potential either do not occur within its borders or are few in size and number. Thus, the United States must rely on foreign sources to satisfy most of its demand for mineral commodities such as asbestos, manganese, chromium, aluminum, and tin.

All states in the United States and all nations in the world are dependent on each other for at least a portion of their mineral needs. This condition will not change. Thus, it can be expected that as the worldwide demand for minerals increases there will be a corresponding need for increased interdependence among nations.

Dependence on outside sources for mineral requirements is unavoidable. Such dependence is a problem only when such sources become unreliable. This has been clearly demonstrated on an international scale by the Organization of Petroleum Exporting Countries (OPEC) which has used its control over world petroleum resources for both economic and political benefit. Similar organizations of countries have been formed for purposes of leverage in the world market, notably the International Tin Council (ITC) and the Council of Copper Exporting Countries (CIPEC).

The future will certainly bring increased demand for mineral resources and greater interdependence among nations. The increased demand will require increased supply which can only come from new deposits. This demand will require an increase in both geological and geophysical surveys which are the basis for minerals exploration. It also suggests that increased research to identify substitutes for minerals in short supply is essential.

*Nonmetallic mineral resources*

## Barite

(By D. A. Brobst and A. V. Heyl, U.S. Geological Survey, Reston, Va. and Denver, Colo.)

*Description and use.*—Barite (barium, sulfur, and oxygen—$BaSO_4$) is a relatively soft, generally white to gray, heavy mineral that has a specific gravity of 4.5. This material occurs in many geological environments in sedimentary, igneous, and metamorphic rocks. Barite in ore deposits occurs alone or, more commonly, in association with quartz, chert, jasper, fluorite, celestite, and various carbonate and metallic-sulfide minerals. Three types of deposits can be defined: vein and cavity-filling, residual, and bedded. The geologic features of these types of deposits and some well-known examples of each have been described by Brobst (1973). The major domestic sources of barite in recent years have been the large high-grade bedded deposits of Nevada and Arkansas and the extensive residual deposits of Missouri and the southern Appalachian region.

The properties of softness, chemical inertness, and weight make it valuable for many uses that are nearly hidden among the technical complexities of modern industrial processes and products. About 85 percent of the barite consumed annually in the United States is ground to sizes less than one three hundred twenty-fifths of an inch and added to the fluid used in the rotary drilling of oil and gas wells; the heavy weight thus imparted to the fluid assists in the drilling process and in controlling high oil and gas pressures at depth. The remaining 15 percent is used directly as barite or in the preparation of barium compounds for a variety of uses as fillers and extenders in ink, paper, textiles, rubber goods, asbestos products and linoleum; heavy aggregate for concrete construction material; electronic equipment; ceramics; and flux in glass manufacture. Some barite is still used in the manufacture of lithopone, a white pigment of 70-percent barium sulfate and 30-percent zinc sulfide; but production has declined greatly since the introduction of titanium dioxide pigments.

The quality standards and prices for barite are determined by different uses. Various product specifications and other technical aspects of the barite industry have been discussed by Lewis (1970) and Brobst (1975). Domestic barite had an average value of $16.50 per ton at the mine during 1974, according to the U.S. Bureau of Mines. The Engineering and Mining Journal in September 1975 quoted prices of $21 to $28 per ton for drilling mud-grade barite at gulf ports and $40 to $50 per ton for domestically produced chemical and glass-grade barite.

Statistics in the annual Minerals Yearbook of the U.S. Bureau of Mines indicate that the United States has been the world's largest producer and consumer of barite since World War II. Annual domestic consumption has reached nearly 2 million tons. The annual domestic production is currently more than 1 million tons which was supplemented in 1974 by imports chiefly from Ireland, Peru, and Mexico.

*Occurrences in Wisconsin.*—Wisconsin has produced little barite. According to Heyl and others (1959, p. 80), some production was reported from 1919 to 1930, except for 1923, in the zinc-lead district in the southwestern counties. No precise data are available for most years, but 5,095 tons of barite concentrates were shipped from Lafayette County in 1930. The principal commercial sources of barite were the Raisbeck Mine at Meeker Grove and the two mines of the Porter Mining Company about 2 miles south of Meeker Grove. The Porter mines, also called the Laird by Agnew and others (1954), are the only ones in the district known to have been worked chiefly for barite. In 1929 and 1930, the 1,000 tons of jigged barite concentrates from the Raisbeck mine sold for about $5 per ton which was enough also to cover the cost of mining and producing the galena (combined lead and sulfur) concentrates (Heyl and others, 1959, p. 80). The barite was used in the manufacture of lithopone.

The major barite occurrences in Wisconsin are associated with the commercially valuable deposits of zinc, lead, and other metals that constitute the greater part of the Upper Mississippi Valley zinc-lead district. The most recent comprehensive descriptions of this district (Heyl and others, 1959, and Heyl, 1968) discuss the relation of barite to these deposits and offer some information of value in assessing the potential for future barite production.

The ore deposits containing barite occur chiefly in the rocks of the Decorah Formation and the Galena Dolomite and a few are in the Prairie du Chien Group (all of Ordovician age). Most of the barite is concentrated in the central part of the district where it is abundant in most sulfide deposits. Barite content diminishes toward the margins of the district and is absent at the periphery. The barite occurrences correspond to the central part of the copper zone of Heyl and others (1959, fig. 73, p. 143), but the zone of greatest barite abundance encompassing an area of about 55 square miles trends more southerly. According to Heyl and others (1959, p. 93), "Elsewhere in the district, barite is restricted to small quantities in the zinc-lead deposits. The barite zone contains 90 percent of the localities in which barite is found and includes all of those in which it is abundant."

The barite generally forms white, tabular, platy masses that are locally common to abundant in the ores of zinc or lead or both. Commonly barite fills the central parts of veins, but it also forms radiating, concentrically banded or fine-grained masses and many replace adjacent rock, especially at the periphery of individual ore bodies. In a few deposits near Shullsburg, barite also was deposited at the outer margin of the veins.

At the Porter mines in the NE¼, NW¼, sec. 34 NE¼, NE¼, sec. 33, T.2N., R.1E., the ore occurs in the lower beds of the Prosser "cherty" and the Ion Members of the Decorah Formation. The larger of the two mines is in an ore body that is probably of the pitch-and-flat-type (Heyl and others, 1959, p. 39) in sec. 34 where the barite occurs in white, crystalline masses that fill fractures and replace wall rocks. The barite contains some galena in coarse euhedral crystals. The smaller mine, in sec. 33, produced similar barite from shallower workings in the Decorah Formation. "Similar barite deposits were noted in the vicinity of these mines, especially in the south toward Leadmine". (Heyl and others, 1959, p. 241).

The Raisbeck mine, sec. 21, T.2N., R.1E., yielded barite and galena concentrate from a pitch-and-flat deposit. In 1959, Heyl and others (p. 237) reported that a large part of the thick barite flat still remains containing scattered crystals of galena in a ratio of 6 tons of barite to 1 ton of galena. The ore body was known for its richness with flats of galena, sphalerite (combined zinc and sulfur) and barite as much as 5 feet thick. Barite veins 3 to 5 feet thick are known. In one place a crosscut drifted 40 feet through a barite vein. The barite in this partly developed and mined ore deposit probably aggregates many thousands of tons.

The Nigger Jim diggings, NE¼, SW¼, Sec. 22, T.4N., R.1E., about 3 miles southeast of Rewey consist of workings less than 50 feet deep that show galena and much barite (Heyl and others, 1959, p. 266). The deposits were drilled by the U.S. Bureau of Mines (Apell, 1949). The ore is in veins, breccia, and wall replacements in the McGregor and Quimbys Mill Members of the Platteville Formation as well as in the so-called "blue beds" and the Guttenberg Member of the Decorah Formation. Indications are that the limits of this ore body can be enlarged by more prospecting. The deposit might produce barite with lead as a major byproduct. Several other little-prospected galena and barite deposits are known in the vicinity.

Barite is abundant enough in several other parts of the district, such as north of Linden, northwest of Mineral Point, between Cuba City and Shullsburg, and in places south of Platteville, to provide a potential byproduct with the lead and zinc ores. Such a barite product is now successfully recovered and sold from somewhat similar deposits in southern Illinois.

*Appraisal and outlook.*—A review of the geologic literature of the Wisconsin zinc-lead district suggests that the potential barite production is considerably greater than indicated by the meager past production. The potential production of barite from many known deposits and their extensions yet to be found by prospecting, plus that found by new exploration and that possibly recoverable by reworking old mine waste, might amount to a significant tonnage should economic conditions warrant such effort. Studies by Wharton (1972) of the potential production of barite from old tailings ponds in the Washington County district, Missouri, suggest that 67 tailings ponds might contain about 1.9 million tons of barite—an amount equal to 17 percent of the district's total production through 1971. Recovery of minerals from tailings ponds and mine dumps perhaps should not be dismissed too quickly in these days of higher energy costs.

Much of the barite in the State would have to be produced as a co-product with the zinc and lead sulfides. Many users of barite have preferred not to depend on co-product recovery for their supply for the obvious reason that the demand for the prime product governs the total production and thus controls the availability of their desired product in the market. As the industrialized world faces possible future shortages of minerals, however, the economics of recovering and depending upon the supply of co-products is likely to become as attractive again as it was one-half century ago when the sale of Wisconsin barite covered the cost of production of the lead. With the expected increase in the amount of oil and gas drilling the world over in the coming years, the demand, and price, for barite also might increase.

Extrapolation of sketchy available data suggests that perhaps as much as several million tons of barite might be geologically available within 250 feet of the surface in southwestern Wisconsin.

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## Clay and shale

(By S. H. Patterson, U.S. Geological Survey, Reston, Va.)

*Description and use.*—Clay and shale consist mainly of extremely fine-grained minerals (clay minerals) and most deposits contain appreciable amounts of nonclay minerals and other impurities. Clay and shale are used in many types of products, because they have many different physical and chemical properties. These differences are caused by variations in clay mineral composition, size and shape of mineral particles, and amounts and type of nonclay minerals and other impurities. The most common use of clays and shale in Wisconsin has been in the manufacture of common brick and title. The properties required for these products include plasticity and fired strength. Much of the clay and shale in Wisconsin is either naturally plastic or becomes sufficiently plastic when worked that it can be shaped into brick and tile and develops sufficient strength when fired. Kaolin is another type of clay that was produced in Wisconsin on a small scale many years ago. It is generally white and plastic, and was used in the manufacture of paper and porcelain.

*Economic importance and development.*—Though Wisconsin has never been a major clay-producing State, 190 brick and tile plants were on record at the turn of the century (Buckley, 1901). The brick and tile industry continued to be moderately active but has declined markedly in the last few decades. According to the records of the Wisconsin Geological and Natural History Survey, only 1,000 tons of clay, valued at $3,000, were produced in 1973. Apparently the only noteworthy kaolin production in Wisconsin was by the Superior China Clay Co. in the early 1900's (Buckley, 1901, p. 234). This company operated a kaolin-washing plant near Hersey, St. Croix County, which had an annual capacity of 5,000 tons.

*Occurrences in Wisconsin.*—The Wisconsin clay and shale used in common brick and tile (Ries, 1906) accumulated in a variety of environments. Many clays are fine-grained materials that were transported by glaciers or water from melting glacial ice or both. These deposits are generally of irregular thickness, commonly contain variable quantities of boulders, and are irregularly distributed over much of Wisconsin. A second type of deposits are water-laid clays located in belts along Lake Michigan, Green Bay, and Lake Superior. A third type of clays are similar to the second type but contain more limy materials that were glacially transported. The third type of clays are located mainly in belts west of the second type of deposits in southeastern and eastern Wisconsin. Loess, which consists of fine-grained, wind-blown material, occurs mainly in the unglaciated region in the southwestern part of the State. Clays formed by decay of crystalline rocks and then protected from erosion by overlying sedimentary formations are mainly in Eau Claire, Jackson, Taylor, Marathon, Wood, and Portage Counties in the central part of the State.

The shale used for brick and tile was dug mainly from the Maquoketa Shale of Ordovician age and irregular deposits in Precambrian rock. The Maquoketa Shale is exposed mainly in a narrow belt extending from Green Bay southward to the Wisconsin-Illinois boundary and in isolated patches in southwestern Wisconsin. The clay formed on Precambrian rock is scattered through several areas in the northern and northwestern part of the State.

The plastic kaolin near Hersey that was mined many years ago is in the form of sedimentary deposits interstratified with sand (Buckley, 1901, pp. 233–234). The age of these deposits is unknown, but some of them are covered with glacial materials. Other sedimentary kaolin deposits are scattered through the eastern part of St. Croix and western part of Dunn Counties. All of these deposits contain abundant quartz and large quantities of waste sand remained when the kaolin was recovered by washing. Residual-type kaolin deposits that formed by weathering in place are in Precambrian schists at several places in the northern part of the State. Most such deposits contain abundant quartz and iron oxide and have little value for use in ceramic products other than brick and tile. Presumably the best residual kaolins are in the Rice Lake and Eau Claire districts (Buckley, 1901, pp. 232, 237).

*Appraisal and outlook.*—The several different types of clay and shale used for brick and tile at many places in Wisconsin in the past indicate that the total resources of these materials must be very large. However, few are as suitable for brick and tile as deposits in neighboring States as noted at the turn of the century by the leading economic geologist specializing in clays (Ries, 1902, p. 272) as follows:

> "It seems doubtful, however, whether Wisconsin can ever become an important clay-producing State, partly on account of the character of the raw materials and partly because competition with neighboring States, such as Ohio, would be nearly impossible."

Not only have Dr. Ries' gloomy doubts about the future of the clay-using industry in Wisconsin proved to be well founded by the virtual end of the brick and tile production in recent years, but also the future of this industry continues to be clouded. The reasons for the condition of the industry are no doubt partly related to the low quality of the raw material, but this factor certainly would be offset by the costs of transporting out-of-state brick and tile to Wisconsin markets. Probably much of the decrease in the Wisconsin industry has been due to the lack of plant modernization and the closing of other plants brought about by environmental requirements of expanding metropolitan areas. The rejuvenation of the brick and tile industry is also hampered by uncertainties of future fuel supplies and increasing costs of plant and mining equipment, labor, et cetera. Nevertheless, sufficient demand for construction brick must exist in Wisconsin to justify at least one new large, modern brick plant.

Samples of a clay from St. Croix County, Wis., were tested as a possible substitute for the western bentonite used in bonding pellets of beneficiated fine-grained iron ore (Tosh, 1973), and the results were negative. Little hope remains that high-quality bonding clay will be found in Wisconsin, because the most efficient clays for this use consist chiefly of sodium-montmorillonite, and large deposits of such clay are virtually unknown in the types of rocks that are in Wisconsin. The St. Croix County deposits consist primarily of calcium-montmorillonite (M. E. Ostrom, written commun., 1975).

Several Wisconsin clay, shale, and other fine-grained rocks have been tested for possible use in making lightweight aggregate (Cole, Hanson, and Westbrook, 1961). According to these preliminary investigations, some of the lower part of the Maquoketa Shale does expand with heat, and deposits of sufficient size to supply a large plant probably could be found. Because a market for lightweight aggregate in Wisconsin is likely to exist now and expand in the foreseeable decades, the future for this type of product seems brighter than for some of the other construction materials made from clay and shale.

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## Crushed stone

**(By D. W. Hadley, Wisconsin Geological and Natural History Survey, Madison, Wis.)**

*Description and use.*—Crushed stone is rock quarried for uses that depend primarily upon its physical properties. This contrasts with most other types of mining, where the mineralogical and chemical properties of the rock are of primary importance. Most crushed stone is used in construction whereas most other mineral production is used for manufacturing or chemical purposes.

Certain rock types, because of their physical properties, and to a lesser degree chemical properties, are ideally suited for use as aggregates, roadstone, road bases, and other similar purposes. Because the natural rock is broken into irregular shapes and various sizes before it is used, the product is known as crushed stone.

The demand for crushed stone is high. As a measure of this demand, the national crushed stone consumption was 8,592 pounds per person in 1970. Preliminary data for 1974 shows a small decline in stone production, reflecting the downturn for the construction industry as a whole during this period. The overall trend is, however, one of increasing demand. Production data for the period 1919 through 1974 are shown in table 5. Although these data include dimension stone, crushed stone now accounts for more than 99 percent of the total stone production.

TABLE 5.—STONE PRODUCTION IN WISCONSIN, 1919-74

[By year]

| Year | Production in thousands of short tons | Value in thousands of dollars | Year | Production in thousands of short tons | Value in thousands of dollars |
|---|---|---|---|---|---|
| 1919 | 1,557 | 3,180 | 1947 | [1] 5,898 | [1] 11,676 |
| 1920 | 1,565 | 3,729 | 1948 | [1] 7,224 | [1] 12,581 |
| 1921 | [1] 1,744 | [1] 3,570 | 1949 | 7,327 | 13,636 |
| 1922 | [1] 1,800 | [1] 3,310 | 1950 | 7,000 | 14,495 |
| 1923 | 2,488 | 4,591 | 1951 | 6,609 | 14,672 |
| 1924 | [1] 2,222 | [1] 4,087 | 1952 | 8,579 | 16,755 |
| 1925 | [1] 2,541 | [1] 4,208 | 1953 | 7,450 | 15,980 |
| 1926 | [1] 2,852 | [1] 4,933 | 1954 | 8,289 | 16,188 |
| 1927 | [1] 3,104 | [1] 5,182 | 1955 | [1] 12,180 | [1] 18,843 |
| 1928 | 3,314 | 5,516 | 1956 | 11,126 | 20,402 |
| 1929 | [1] 4,004 | [1] 6,167 | 1957 | 12,434 | 22,455 |
| 1930 | [1] 3,371 | [1] 5,100 | 1958 | 13,722 | 23,334 |
| 1931 | [1] 2,627 | [1] 4,080 | 1959 | 13,522 | 23,782 |
| 1932 | 1,683 | 3,191 | 1960 | 16,486 | 22,302 |
| 1933 | 1,199 | 1,805 | 1961 | 13,418 | 19,686 |
| 1934 | 2,680 | 3,115 | 1962 | 13,392 | 19,709 |
| 1935 | [1] 2,495 | [1] 3,117 | 1963 | 13,583 | 18,744 |
| 1936 | [1] 3,171 | [1] 3,967 | 1964 | 13,901 | 20,232 |
| 1937 | 3,332 | 4,284 | 1965 | 15,344 | 21,924 |
| 1938 | 3,097 | 3,881 | 1966 | 16,150 | 23,735 |
| 1939 | 3,183 | 3,564 | 1967 | 17,122 | 24,863 |
| 1940 | 4,330 | 5,030 | 1968 | 17,000 | 25,223 |
| 1941 | 4,377 | 5,666 | 1969 | 18,954 | 27,571 |
| 1942 | 4,493 | 6,309 | 1970 | 17,577 | 25,167 |
| 1943 | [1] 4,186 | [1] 6,677 | 1971 | 15,568 | 25,105 |
| 1944 | [1] 4,659 | [1] 7,741 | 1972 | 19,394 | 29,681 |
| 1945 | 4,764 | 8,443 | 1973 | 23,818 | 36,917 |
| 1946 | 6,193 | 11,473 | 1974 | 22,443 | 40,912 |

[1] Some data not included to protect confidential information.

*Economic importance.*—Stone production is, and historically has been, one of the major industries of Wisconsin. Since 1919 a total of 398,886,350 tons of stone, valued at $634,036,072 has been produced. Statistics for 1973 show a production of 23,800,000 tons valued at almost $37 million with Wisconsin ranking 19th among the states in tonnage of stone produced.

In 1973, there were 343 active stone quarries in Wisconsin, with stone being produced in 50 of the State's 72 counties. Stone production by counties is given in table 6.

*Occurrences in Wisconsin.*—A number of different rock types are currently being quarried for use as crushed stone in Wisconsin. The more important ones are listed below and their major uses described.

*Limestone and dolomite.*—Almost all of the rocks commonly referred to as limestone in Wisconsin contain a high percentage of dolomite, a carbonate of calcium and magnesium. Dolomite differs from ordinary limestone in its much higher magnesium content which is a controlling factor in determining potential uses. Dolomite is used as crushed stone and as dimension stone; it is the most important rock type quarried in the State. In 1972 more than 80 percent of the crushed stone produced in Wisconsin was dolomite.

Crushed dolomite is used for many purposes. The largest single user in Wisconsin is the construction industry, which uses crushed dolomite as aggregate in portland cement and bituminous concrete, in macadam, and in the bases for roads and as roadstone. Large amounts of dolomite are used as agricultural limestone. Miscellaneous uses include railroad ballast, flux for metallurgy, raw material for the production of lime, and riprap and jetty stone.

TABLE 6.—STONE SOLD OR USED BY PRODUCERS, BY COUNTY, IN WISCONSIN, 1972–73 [1]

[Thousand short tons and thousand dollars]

| County | 1972 | | | 1973 | | | Kind of stone produced in 1973 [1] |
|---|---|---|---|---|---|---|---|
| | Number of quarries | Quantity | Value | Number of quarries | Quantity | Value [2] | |
| Barron | | | | 1 | 9 | 18 | Limestone.[3] |
| Bayfield | | | | 1 | (4) | (4) | Do. |
| Brown | 10 | 670 | 970 | 9 | 898 | 1,135 | Do. |
| Buffalo | 8 | W | W | 12 | 340 | W | Do. |
| Burnett | 1 | W | W | 1 | W | W | Other stone. |
| Calumet | 3 | W | 155 | 3 | 36 | W | Limestone. |
| Clark | 1 | W | W | 1 | 1 | 1 | Granite. |
| Columbia | 4 | W | W | 5 | 337 | W | Limestone. |
| Crawford | 9 | 252 | 252 | 13 | 404 | 504 | Do. |
| Dane | 23 | 1,255 | 2,036 | 26 | 1,388 | 1,972 | Do. |
| Dodge | 8 | 535 | 723 | 9 | 655 | 940 | Do. |
| Door | 4 | W | W | 3 | 64 | 62 | Do. |
| Douglas | 1 | 3 | W | 1 | 7 | 12 | Traprock. |
| Dunn | 3 | 43 | 58 | 1 | 50 | 44 | Limestone. |
| Fond du Lac | 13 | 347 | 912 | 13 | 580 | 1,360 | Do. |
| Grant | 18 | 714 | 927 | 34 | 980 | 1,177 | Limestone, other stone. |
| Green | 24 | 515 | 521 | 20 | W | W | Limestone. |
| Green Lake | 3 | 25 | 36 | 2 | 54 | 81 | Do. |
| Iowa | 19 | 443 | 418 | 17 | 532 | 494 | Do. |
| Jackson | 1 | W | W | 2 | 45 | W | Do. |
| Jefferson | 1 | W | W | 1 | W | W | Do. |
| Juneau | 2 | W | W | 2 | W | W | Do. |
| Kewaunee | 1 | W | W | | | | |
| La Crosse | 2 | W | W | 7 | 439 | 541 | Do. |
| Lafayette | 20 | 573 | 509 | 19 | 524 | 473 | Do. |
| Manitowoc | 3 | W | 550 | 2 | W | W | Do. |
| Marathon | 16 | 1,767 | 3,560 | 19 | 2,527 | 4,069 | Granite, quartzite, sandstone. |
| Marinette | 1 | W | W | 2 | W | W | Traprock. |
| Marquette | 2 | W | W | 2 | W | W | Granite, limestone. |
| Milwaukee | 2 | W | W | 2 | W | W | Limestone. |
| Monroe | 8 | W | W | 7 | W | W | Do. |
| Oconto | 3 | W | W | 1 | W | W | Do. |
| Outagamie | 3 | W | W | 5 | W | W | Do. |
| Ozaukee | 2 | W | W | 1 | W | W | Do. |
| Pepin | 6 | 146 | 169 | 2 | 39 | W | Do. |
| Pierce | 12 | W | W | 10 | 351 | 440 | Do. |
| Polk | 2 | W | W | 2 | W | W | Limestone, traprock. |
| Portage | | | | 1 | (4) | (4) | Sandstone. |
| Racine | 6 | 1,220 | W | 3 | W | W | Limestone. |
| Richland | 3 | W | W | 9 | 227 | W | Do. |
| Rock | 14 | 489 | 636 | 12 | 319 | 478 | Do. |
| St. Croix | 7 | W | W | 9 | 374 | 476 | Do. |
| Sauk | 9 | 709 | 923 | 12 | W | W | Limestone, quartzite, sandstone. |
| Shawano | 2 | W | 87 | 4 | W | W | Limestone. |
| Sheboygan | 1 | 4 | 25 | 1 | 3 | 24 | Do. |
| Trempealeau | 5 | W | W | 9 | 298 | W | Do. |
| Vernon | 12 | W | W | 27 | W | W | Do. |
| Vilas | | | | 1 | 25 | W | Granite. |
| Walworth | 1 | 24 | W | 3 | W | 62 | Limestone. |
| Washington | 1 | 34 | 33 | 1 | 32 | 36 | Sandstone. |
| Waukesha | 23 | 2,270 | 3,419 | 29 | 2,726 | 4,419 | Limestone. |
| Waupaca | 2 | 21 | 36 | 2 | 38 | 82 | Do. |
| Winnebago | 15 | W | W | 3 | 744 | 1,152 | Do. |
| Wood | 2 | 79 | 117 | 3 | 104 | 143 | Granite, sandstone. |
| Various | 1 | W | W | 28 | W | W | Limestone. |
| Undistributed | | 7,257 | 12,605 | | 8,669 | 16,719 | |
| Total [2] | 343 | 19,394 | 29,681 | 415 | 23,818 | 36,917 | |

W—Withheld to avoid disclosing individual company confidential data, included with "Undistributed".
[1] Includes both crushed and dimension stone. Crushed stone in 1973 accounted for over 90 percent of total value and over 99 percent of total quantity. In 1974 it accounted for approximately 84 percent of total value and 98.5 percent of total volume.
[2] Data may not add to totals shown because of independent rounding.
[3] "Limestone" used generally to include dolomite.
[4] Less than one-half unit.

Source: Data from U.S. Bureau of Mines Minerals Yearbook.

Because of its high magnesium content, dolomite is not suitable for use in manufacture of portland cement, and although cement is produced in Wisconsin, the limestone used in its manufacture is shipped from other states.

*Granite.*—Because it is extremely hard, little or no crushed granite is produced in the State. However, friable and highly weathered granite is found in some areas of the State and is used as roadstone on local roads and for landscape and decorative purposes.

*Basalt*—A limited amount of crushed basalt, which is a dark-colored fine-grained rock, is produced in Wisconsin. The products are used primarily as roofing granules and for concrete aggregate. There were four basalt quarries active in 1972 located in Douglas, Polk, and Marinette Counties.

*Quartzite.*—A rock similar to sandstone but the sand grains are so firmly joined together that fracture takes place through rather than around the grains. Because of its great hardness, quartzite is rarely used for dimension purposes except as flagstone. Its hardness does, however, make quartzite valuable for use as railroad ballast, grinding pebbles, and abrasives. Quartzite is produced from quarries located in Sauk County.

*Gabbro.*—An igneous rock, very similar to basalt but with a larger grain size, like that of granite. Limited quantities of crushed gabbro have been produced in Ashland County. Most gabbro produced in Wisconsin is for use as dimension stone.

*Marble.*—Marble has been quarried in Bayfield County near Grandview. The product is marble chips, used as decorative aggregate and in terrazzo.

*Appraisal and outlook.*—Geological factors control the potential for stone production. Almost all of the stone quarries in Wisconsin are in one of four of the many rock units recognized in the State. These four units are:

1. The dolomite formations of the Silurian System of rocks.
2. The dolomite formations in the Sinnipee Group of the Ordovician System of rocks.
3. The dolomite formations of the Prairie du Chien Group, also of the Ordovician System.
4. The granites, basalts, gabbros, quartzites and associated igneous and metamorphic rocks of the Precambrian.

Although the bedrock geology of less than 10 percent of Wisconsin has been mapped in detail, the broad picture of the areal distribution of the various major rock units is known over much of the State. Figure 2, a geologic map of Wisconsin, shows this distribution and indicates the areas in which each of the four units listed above occurs at the bedrock surface.

The situation is complicated, however, in that the bedrock surface of most of the State is covered by unconsolidated deposits of sand, gravel, and other materials laid down during glaciation (fig. 1). Only in the "Driftless Area" of southwestern Wisconsin, an area which shows no evidence of glaciation, is the bedrock generally exposed. The extent and thickness of the glacial deposits are shown on figure 20. As can be seen from inspection of this figure, a large proportion of the areas where the four rock units containing material suitable for stone production are found is covered by glacial deposits to depths of 300 feet or more. This, of course, makes stone production economically unfeasible over large areas.

A potential exists for stone production primarily in those areas with an overburden thickness of 50 feet or less.

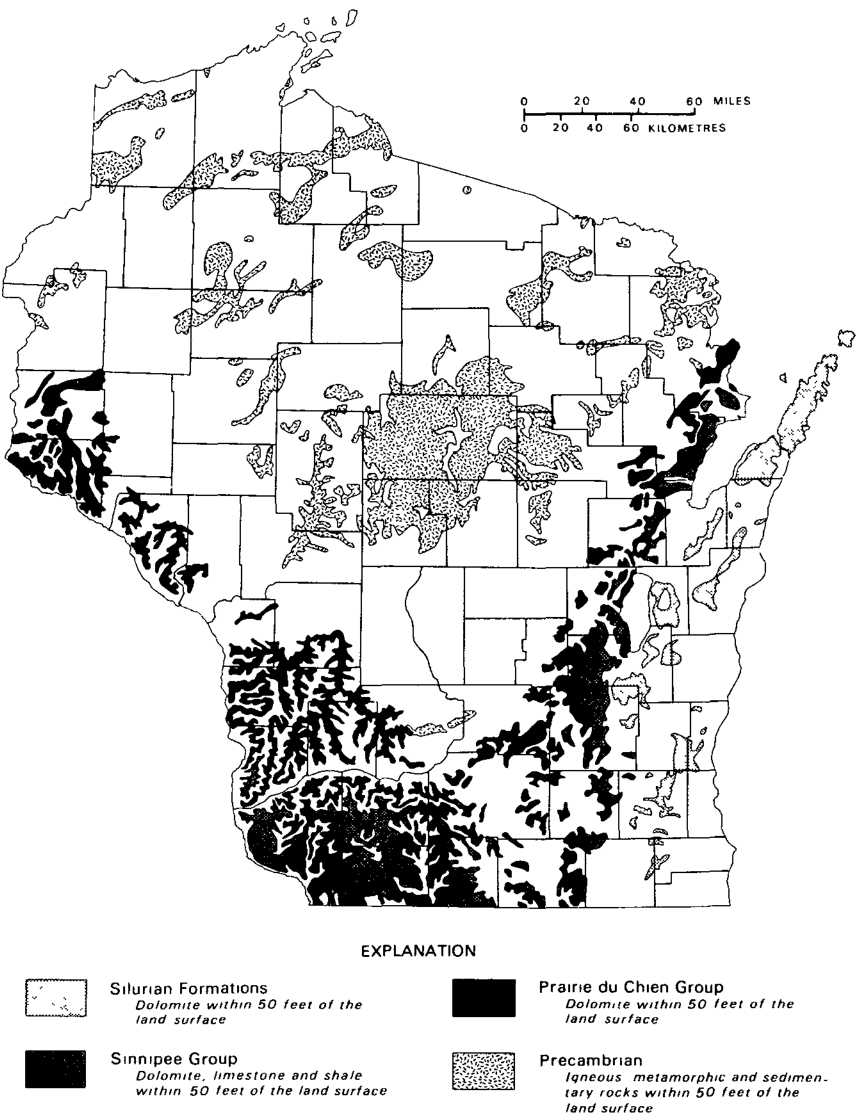


FIGURE 27.—Potential crushed stone production areas in Wisconsin.

Figure 27 is a map of potential stone production areas in Wisconsin and shows those areas which on the basis of existing records are considered to have the greatest potential to contain materials suitable for use as crushed stone and which occur under 50 feet or less of overburden.

Minor quantities of crushed stone are also produced from the St. Lawrence, Eau Claire, and Lone Rock Formations. However, these have only local importance, as the quality of the above formations limits their use potential so they are not included in figure 27.

Use of the map should be conditioned on the following considerations:

1. The map is based on relatively limited data and is of very small scale which makes it unsuitable for evaluation of specific sites.
2. Even though an area is known to be underlain by rocks of one of the four rock units previously mentioned, there is no guarantee that the rock at any given site will be physically or chemically suitable for use. This is especially true of those areas underlain by Precambrian rocks, where knowledge of the bedrock geology is extremely limited.
3. Crushed stone is a large volume, low value product. Production will be economically feasible, therefore, only if the deposit is within reasonable shipping distance of the intended market.

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## Dimension stone

(By R. A. Laurence, U.S. Geological Survey, Knoxville, Tenn.)

*Description and use.*—Stone has been used as a construction material since prehistoric times, and though many other materials now compete with natural stone for building and monumental uses, the value of dimension stone produced in the United States in 1972 was approximately 1 percent of all non-fuel mineral production, and ranked 17th among 59 non-fuel mineral commodities produced in that year. Dimension stone was produced in 43 states in 1972, demonstrating that although many of its former uses have been largely taken over by competing materials, the industry is still alive, active, and competitive.

Dimension stone is defined as "natural building stone that has been selected, trimmed, or cut to specified or indicated shapes or sizes, with or without one or more mechanically dressed surfaces" (American Society for Testing and Materials, 1975, p. 7). It is used principally for building construction, monuments, curbing, and as flagstone. Granite, limestone, dolomite, sandstone, marble, and slate are the principal rock types used as dimension stone; all six are present in Wisconsin but only the first four have been quarried for dimension stone.

The major requirements of rock to be used as dimension stone are durability, absence of closely spaced joints or fractures, a desirable color, and absence of minerals (e.g. sulfides—metal, especially iron, combined with sulfur) that may cause staining or deterioration. More detailed information on this is presented in the several standards for natural building stones of the American Society for Testing and Materials (1975, p. 1–37).

Selection of a quarry site is largely dependent upon depth of overburden and proximity to transportation and markets, especially for the more common varieties of stone.

*Economic importance and development.*—Wisconsin's dimension stone industry began before 1846, with quarrying of limestone in Waukesha County (Friz, 1975, p. 17). By 1880, as reported in the 10th census, Wisconsin production was $227,065, from 46 limestone and 14 sandstone quarries. Granite quarrying began in 1880 (Friz, 1975, p. 18) but was not reported in the 10th census. Production for selected years is given in table 7, and production in 1973 by types of stone in table 8.

*Occurrences in Wisconsin.*—The areas of past and current dimension stone quarrying are shown on figure 28.

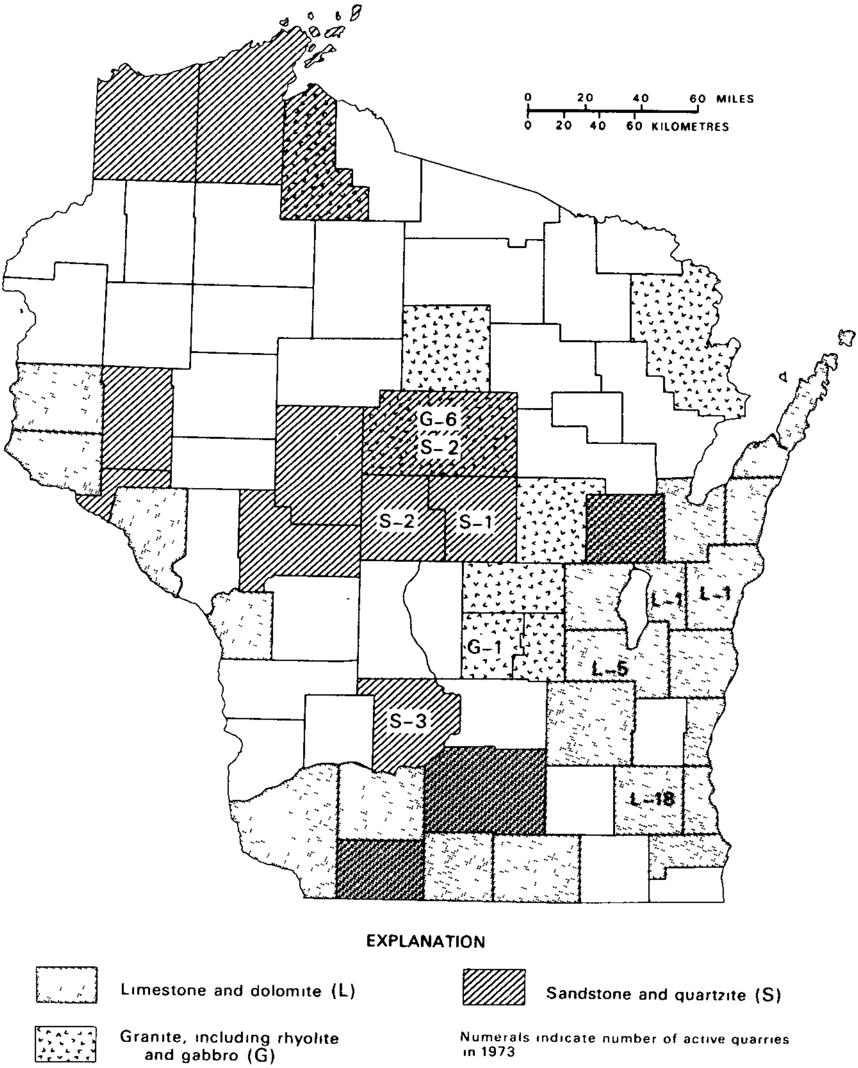


FIGURE 28.—Wisconsin counties that have produced dimension stone.

TABLE 7.—WISCONSIN DIMENSION STONE PRODUCTION IN SELECTED YEARS

| Year | Quantity (short-tons) | Value (dollars) |
|---|---|---|
| 1880 | (1) | 227,065 |
| 1910 | (1) | 1,838,387 |
| 1930 | 78,710 | 1,892,214 |
| 1940 | 77,250 | 1,306,675 |
| 1950 | 79,530 | 2,520,807 |
| 1960 | 118,235 | 3,082,256 |
| 1973 | 72,327 | 3,608,000 |

[1] Not available.

Source: Data from U.S. Geological Survey, Mineral Resources of the United States, 1882 and 1910, and U.S. Bureau of Mines, Minerals Yearbook, 1930–73.

TABLE 8.—DIMENSION STONE PRODUCTION, WISCONSIN, 1973

| Kind of stone | Number of quarries | Quantity (short tons) | Value (dollars) | Rank among States | |
|---|---|---|---|---|---|
| | | | | Quantity | Value |
| Limestone and dolomite | 25 | 62,871 | 1,347,000 | 2 | 2 |
| Granite | 7 | 8,041 | 2,231,000 | 8 | 8 |
| Sandstone | 8 | 1,415 | 30,000 | 9 | 11 |

Source: Data from Drake, 1975, p. 11–12.

The 1973 dimension stone output of Wisconsin was equivalent to:

4.6 percent of the U.S. output of dimension stone in 1973, by quantity.
4.2 percent of the U.S. output of dimension stone, 1973, by value.
0.3 percent of total Wisconsin output of stone in 1973, by quantity.
9.7 percent of total Wisconsin output of stone in 1973, by value.
3.15 percent of all Wisconsin mineral output in 1973, by value.

*Limestone and dolomite.*—Most of the rocks commonly called limestones in Wisconsin, and especially those used as dimension stone, are actually dolomite (Hanson, 1964, p. 207), a variety containing more than 40 percent of the mineral dolomite, a double carbonate of calcium and magnesium.

Limestone and dolomite occur throughout the eastern, southern, and western parts of the State, and have been quarried for dimension stone, at least for local use, in nearly every county in that area. Production in 1973 was from the Silurian dolomites in the east-central area, and especially near Lannon, Waukesha County, and in Fond du Lac County; and a minor amount came from the St. Lawrence Formation in Dane County. The widely known Lannon stone is used principally as house veneer, curbing, and flagstone. The dolomites of the Sinnipee and Prairie du Chien Groups have also been quarried for dimension stone.

The number of active dimension limestone quarries in Wisconsin has declined from 39 in 1970 (Friz, 1975, p. 17) to 25 in 1973 (Drake, 1975, p. 31), but output was down only 4,000 tons, from 67,000 to 63,000, and value increased from $1,263,000 to $1,347,000. This was a better performance than the national production of dimension limestone for the same period.

*Granite.*—Igneous rocks are present in about a third of Wisconsin's area, chiefly in the north-central part, where many varieties of granite occur. Granite is the officially designated State rock. Red and reddish brown varieties are the most abundant, and these are highly desirable for monuments and cut and polished slabs or blocks in building construction. Leading areas of current production are in Marathon County ("Wausau Granite") and Marquette County ("Montello Granite"). Dimension granite has been produced in at least six other counties. Production of the widely known "Wisconsin Black Granite," actually a gabbro, in Ashland County, and a gray granite in Marinette County has not been reported since 1970.

Much of Wisconsin's dimension granite in earlier years was used as paving blocks, especially in Milwaukee and Chicago, but this market has been lost to more modern paving methods.

*Sandstone.*—Sandstones occur chiefly in three geologic units in Wisconsin: in the Precambrian rocks mostly in the northern half of the State; in the several formations of the Upper Cambrian System (called Potsdam in most older reports) occupying a wide belt adjacent to the Precambrian, mainly in the central and western part; and the St. Peter Sandstone, of Ordovician age, mainly in the southern and southwestern part.

Current production of dimension sandstone is entirely from the Upper Cambrian formations, in Wood, Portage, Sauk, and Marathon Counties (fig. 28). It is used as house veneer, cut stone, rough construction, and flagstone.

Formerly, a red Precambrian sandstone, known as "Lake Superior Brownstone," was extensively quarried in Douglas, Bayfield, and Ashland Counties (Thwaites 1912b; Buckley 1898, pp. 167–219), but the demand for this type of stone declined in the 1890's and there has been very little production in the past 60 years.

Sandstone has been produced for local use from the St. Peter Sandstone, chiefly in Lafayette County.

*Other types.*—Marble occurs in the Precambrian sedimentary rocks and has been quarried near Grandview, Bayfield County, but it was crushed and sold as terrazzo chips and not as dimension stone (Gustavson 1961, p. 1133).

Boulders, both granite and limestone, in glacial deposits have been used at many localities as "field stone," for house veneer, stone walls, and fences. This type of stone is widespread, but is, of course, not present in the Driftless Area.

*Resource appraisal and outlook.*—Stone, unlike many of our mineral commodities, is in no danger of exhaustion. However, the quantity of stone in Wisconsin that has acceptable physical and chemical properties is unknown. Barton (1968, p. 28) noted that "Dimension stone of one variety or another is almost always available within reasonable distance. Few large areas are totally devoid of formations that will yield blocks for major construction, though choice of rock types and rock quality may be greatly restricted. Outwash plains, filled valleys, coastal plains, deltas, fans, and similar alluvium-covered areas are about the only places where dimension stone resources may be absent." However, availability of these resources may be restricted by depth of overburden which must be removed in quarrying dimension stone. Figure 27 shows areas in Wisconsin where different types of stone are within 50 feet or less of the surface.

Use of dimension stone as a principal material for load-bearing in building construction has declined since the increase of structural steel construction, but the stone industry has adjusted to this by providing dimension stone in thin veneer slabs or blocks for both exterior and interior uses.

As reserves and resources of dimension stone in Wisconsin are not well known, the major resource problems are identifying suitable deposits and adjusting to the growth of cities, suburbs, and highways so that the quarrying of the more desirable or available stone deposits is not prevented by these conflicting uses of the land. Establishment of mineral reservation and extraction districts is proposed as a solution to the latter problem (Friz, 1975, p. 57).

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## Feldspar

(By F. G. Lesure, U.S. Geological Survey, Reston, Va.)

*Description and use.*—Feldspar is the general name for a group of important rock-forming minerals; they constitute nearly 60 percent of many igneous rocks and are common in some sedimentary and many metamorphic rocks. The feldspars are aluminum silicate minerals that contain varying amounts of potassium, sodium, and calcium.

From 1955 to 1970 about 55 percent of the feldspar in the United States was used in glass, 31 percent in pottery, 4 percent in enamel and 10 percent in soaps, abrasives, mineral fillers, welding rod coatings and other miscellaneous uses. A little more than 110 pounds of feldspar is used in an average ton of glass containers and slightly less than 100 pounds in a ton of flat glass. Feldspar is useful in ceramics as a flux because it lowers the melting temperatures of the other ingredients. The resulting glass cements unmelted particles so that the feldspar imparts strength, toughness, and durability to the finished product. Feldspar makes up 10–35 percent of the body and 30–50 percent of the glaze in many types of ceramics.

*Economic importance and development.*—No feldspar is produced from occurrences in Wisconsin, but nearly 9,000 short tons of ground feldspar were used in the State in 1961, the last year for which figures were published (Wells, 1965, p. 325). This was about 1.5 percent of the total United States consumption of feldspar at that time.

Feldspar was first mined in the United States in 1825 from very coarse-grained granitic bodies called pegmatite in Connecticut and shipped to England for use in ceramics (DuBois, 1940, p. 207). Principal production from 1853 to 1910 was from Connecticut, New York, Maine, Pennsylvania, and Maryland. Feldspar mining began in North Carolina in 1911, and that State has for many years accounted for nearly one-half or more of the annual U.S. production. In recent years California, Connecticut, South Carolina, Georgia, and South Dakota have been our other important feldspar producers.

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Transportation cost is an important element in marketing feldspar for glass because the delivered cost per unit of alumina plus alkalies ($Na_2O+K_2O$) is the basis for determining relative value of competing feldspar products. The ceramic industry is more concerned with a particular feldspar and its effect on the delicate balance of ceramic mix, plant operation, and product quality. In general, one feldspar product cannot be substituted for another in a ceramic mix without extensive tests. A ceramic feldspar is sometimes shipped past another producing plant to a consumer who would rather pay more freight than change suppliers.

The average price of crude feldspar was $16.20 per long ton in 1973 and $9.51 in 1960 (Wells, 1974, p. 1). The average price of ground feldspar per short ton was $18.05 in 1973 and $13.40 in 1960. Prices quoted for ground feldspar for May 1975 were as follows: North Carolina, 20 mesh, flotation $16; 200 mesh, flotation $25.50–$32 (Engineering and Mining Journal, 1975). Details of the mining, beneficiation, and marketing of feldspar are given by Castle and Gillson (1960), Cooper and Wells (1970), Feitler (1967), and Neal (1973).

*General characteristics.*—Commercial deposits of feldspar are found in some pegmatites, many granites and related igneous rocks, and certain beach sands and alluvium. Examples of all three types are found in Wisconsin but have not been evaluated as sources of feldspar.

Most pegmatites are light-colored coarsely crystalline igneous rocks which are found as lenticular or tabular bodies in metamorphic rocks or in large granitic intrusions. Individual mineral grains and crystals may be many feet in length. Pegmatite bodies range in size from small pods and veins to large masses hundreds of feet thick and thousands of feet long. Feldspar, quartz, and mica are the most common minerals present, but many rare and unusual minerals are found in some deposits. In many pegmatites the minerals are somewhat evenly distributed throughout, but in others the minerals are segregated into certain layers or parts of the body called zones (Cameron and others, 1949). These zones can sometimes be selectively mined to recover the desired minerals by hand sorting and are, therefore, important economically.

Granite and related igneous rocks are composed of one or two kinds of alkalic feldspar; quartz; and minor amounts of various other minerals, mainly muscovite, biotite, hornblende, or rarely pyroxene. Feldspar content ranges from 50 to 70 percent, and grain size from less than one-fourth inch to about an inch. Deposits range from small masses measured in feet to very large masses measured in miles. Granitic rocks that contain only small amounts of iron- and magnesium-bearing minerals, can be mined in bulk and a mixture of potassium and sodium feldspar recovered by milling and flotation. Mixtures of feldspar and quartz are also produced as a byproduct of granite quarrying.

Feldspathic beach sands and alluvial (river) deposits formed as the result of erosion of granitic rocks, or pegmatites, may be rich enough to be mined for their feldspar content. Alluvial deposits along the Mississippi, Illinois, Wabash, and Ohio Rivers and dune and beach sands of Pleistocene age in Illinois contain 5 to 25 percent feldspar, 2 to 12 percent feldspathic rock fragments, 60–80 percent quartz, and some flint and heavy minerals. The alluvial sands are in lower river terraces, in present channels and in sand bars (Hunter, 1965). Similar deposits along the Kansas, Arkansas, Little Arkansas, and Republican Rivers in Kansas contain as much as 27 percent feldspar.

In Wisconsin a few small pegmatite bodies have been reported in the area of Precambrian rocks in T.29N., R.6E. in Marathon County (Weidman, 1907, p. 653) and in T.37N., R.18E, in Marinette County (Dutton and Bradley, 1970). These deposits have not been evaluated as to quality or quantity of feldspar present.

Granite and related granitic rocks are widespread in east central Wisconsin, especially in the Wolf River Batholith (Medaris and others, 1973). Broken granite from two quarries near Wausau was examined optically by Hill and others (1969, p. 7) and found to contain too much iron oxides for use as a source of feldspar. Other deposits may contain much less iron and a full evaluation of the feldspar potential of these rocks has not been made.

Much of Wisconsin has a cover of glacial deposits including extensive areas of material deposited by water from melting of the ice. Sand in such deposits should be considered as a potential source of feldspar. No data have been found on the mineralogical content of the sand deposits in Wisconsin and no evaluation of feldspar resources can be made.

*Appraisal and outlook.*—The feldspar resources of Wisconsin have not been adequately studied to permit more than a qualitative appraisal. No reserves are known but hypothetical resources of feldspar in the known areas of granitic rock and speculative resources in areas of glacial sand deposits are probably large.

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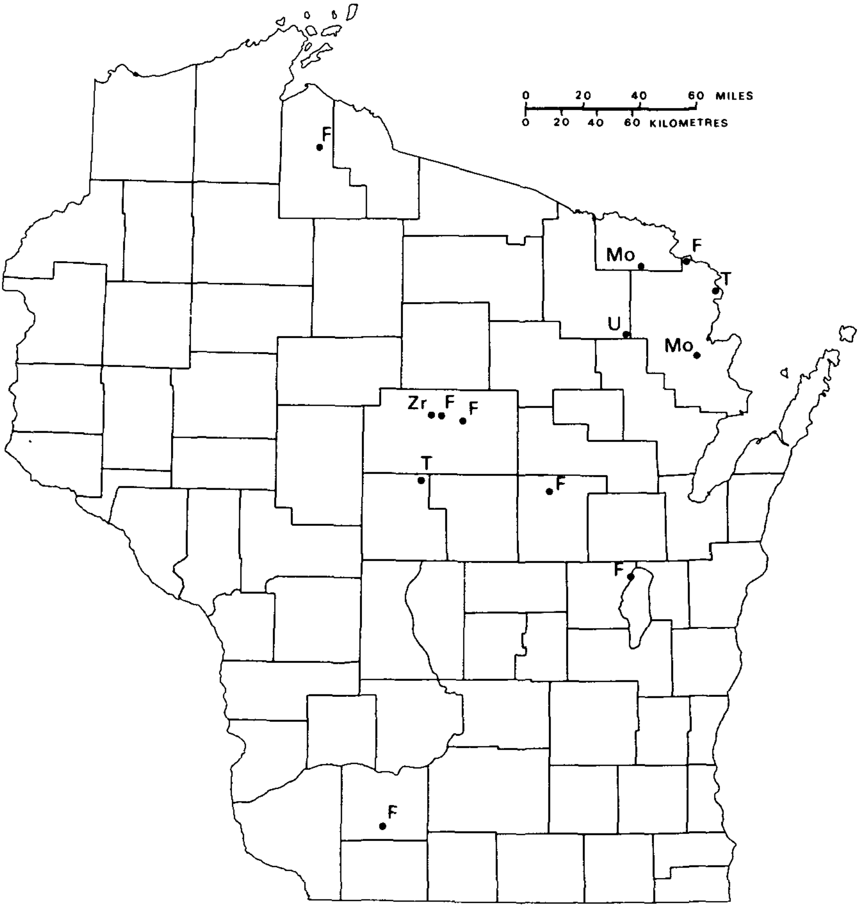
## Fluorite

(By R. E. Van Alstine, U.S. Geological Survey, Reston, Va.)

Fluorite is transparent or nearly so and may have a wide range of generally light colors; it is an industrial mineral that contains calcium and fluorine as $CaF_2$. About one-half the amount used in the United States is for making steel, and an equal amount for making aluminum, uranium, refrigerants, aerosol propellants, resins, drugs, plastics, and other products. About 1 percent is used for opalescent glass and also special enamels as coating on appliances and fixtures.

The annual consumption in the United States is about 1,400,000 tons, of which 90 percent is imported chiefly from Mexico, Spain, and Italy. Mines in Illinois, Kentucky, Nevada, New Mexico, Texas, and Utah produced 167,000 tons in 1974.

Only about 1,000 tons of fluorite are used annually in Wisconsin for fluorine chemicals and the manufacture of aluminum and steel.




EXPLANATION

| | | | |
|---|---|---|---|
| F | Fluorite | U | Uranium - thorium |
| Mo | Molybdenite | Zr | Zircon |
| T | Talc | • | Areas of known occurrence |

FIGURE 29.—Location of selected nonmetallic mineral commodities.

Seven minor occurrences of fluorite in Wisconsin have been reported (fig. 29), and there appears to be small potential for commercial deposits of fluorite in the State. Search for a deposit of significant size and grade, however, probably would be directed most profitably to the localities where fluorite has already been found, especially where granite or syenite intrusive bodies contain fluorite. Other bodies of similar rock could be examined for fluorite deposits.

Occurrences of fluorite have been reported as follows:

| | Latitude | Longitude |
|---|---|---|
| 1. Mellen area, Ashland County. About 0.4 km northeast of Mellen, East half sec. 31, T.45N., R.2W. In granite (Irving, 1880b, p. 172–174; 1883, p. 314) | 46°20′ | 90°40′ |
| 2. Northwest corner of Marinette County, sec. 7, T.38N., R.20E. In granite (Prinz, 1959, p. 100) | 45°47′ | 88°02′ |
| 3. Marathon County. In syenite (Myers, 1973) | 44°59′ | 89°47′ |
| 4. Wausau area, Marathon County. In syenite and pegmatite (Weidman, 1907) | 44°57′ | 89°38′ |
| 5. Big Falls area, Waupaca County. In granite and associated variant (quartz monzonite) (Medaris and others, 1973, p. 9 and 22) | 44°37′ | 89°01′ |
| 6. Neenah quarry, Winnebago County. Associated with calcite, galena, and pyrite in 0.3 meter zone of vein filling and coating on seams and joints in Galena Dolomite (Bagg, 1918) | 44°10′ | 88°28′ |
| 7. Near Mineral Point, Iowa County. Detected in zinc ore in replacement bodies and veins along shears and faults in Galena Dolomite. Grayville mine, sec. 31, T.5N., R.3E. (Brown, 1967, p. 1736) | 42°52′ | 90°11′ |

## Gemstones

(By R. E. Thaden, U.S. Geological Survey, Denver, Colo.)

*Description and use.*—Gemstones historically have included certain mineral species and certain organic materials, in particular, jet, amber, pearl, and coral, which, by virtue of having a desired combination of the qualities of beauty, rarity, and durability, have been coveted by people over the ages for use as items of personal adornment or as small ornamental household objects. These materials are used in their natural state or, more usually, are slabbed, carved, polished en cabochon, or faceted in order to enhance their natural beauty. Those few materials exceptionally endowed with the desired qualities have been, in past times, termed "precious" stones. Ordinarily included were diamond, ruby, sapphire, and emerald. All others were termed "semiprecious" stones. In recent years this rather artificial distinction has been largely abandoned due, for the most part, to changes in taste and availability. Increased use of chrysoberyl, fire opal, turquoise, and aquamarine, for instance, has resulted in skyrocketing prices for these minerals. The use of the family of cryptocrystalline quartz minerals, the flints, cherts, jaspers, agates, and petrified wood and bone, usually thought of as the least expensive and perhaps least desirable of the semiprecious stones, also has increased enormously, but there has been no comparable increase in price because of their greater abundance. In fact, the production of the cryptocrystalline quartz minerals in this country greatly outweighs the production of all other gem materials.

A contemporary definition of gemstones must also accommodate two other types of materials. First, handsome granites, porphyries of various kinds, brightly patterned dolomites and quartzites, and other kinds of rocks are sold in increasing quantities. And, second, rock and mineral specimens are mined and marketed simultaneously and without distinction from the mining, fashioning, and marketing of gemstones, because many specimens adequate in size and quality for the production of jewelry are exactly those materials that can be sold as attractive cabinet pieces. For this reason, the summaries of production and value of the many mineral commodities, which have been published annually for many years by the U.S. Bureau of Mines, do not, and cannot, distinguish between the production of gemstones and the production of rock and mineral specimens.

*Economic importance and development.*—Wisconsin is not well endowed with the so-called precious or semiprecious minerals because the potentially gem-bearing bedrock, except in the southwestern part of the State, is mostly buried under glacial deposits that are as much as several hundred feet thick. Few gemstones, therefore, are produced, and so Wisconsin has become one of about 20 States, mostly those in the Southeast and Great Plains areas of the United States, whose annual production of gemstones, as estimated by the Bureau of Mines, is $1,000 or less. This is in contrast to a few of the Western States, whose annual production ranges from several hundred thousand to more than $1 million.

*Occurrences in Wisconsin.*—Although a State whose potential gemstone deposits are relatively inaccessible and that is relatively unknown as a producer, Wisconsin early became famous because a number of remarkably large specimens of that most exotic of gemstones, diamond, were found in the latter part of the 19th century. Starting with the diamonds and continuing to the present, production of gemstones in Wisconsin, as elsewhere in the country, has derived almost entirely from the activities of individuals, mineral clubs, and operators of small lapidary and rock shops, who tend to specialize in local gemstone products mined by themselves.

Figure 30 shows the distribution of the several kinds of potentially gem-bearing rocks to be found in Wisconsin, as well as the approximate position of selected mineral and gemstone localities mentioned in the text.

*Appraisal and outlook.*—Keweenawan volcanic rocks similar to those in the northern part of the State have yielded an abundance of thompsonite, pumpelleyite, datolite, prehnite, and other gem materials to the east in Michigan. In Wisconsin, these minerals should be looked for, as well as varieties of the rock itself, for instance, varieties showing spherulitic structure—breccias recemented either with calcite or another mineral or with interstitial copper, and rosettes of porphyritic feldspar crystals set in a dark matrix. Specimens of wavellite, pyrophyllite, and a metallic copper and silver may also be found. Precambrian iron formations in the Gogebic and Menominee areas contain splendidly banded taconite and jaspillite, as well as masses of variously colored jasper, crystals of specular hematite, some perhaps of faceting grade, and specimens of intergrown quartz and specularite, needle hematite, and radiating aggregates of goethite. Attractive specimens of layered iron-formation are also present locally near Black River Falls.

Precambrian metamorphic rocks of many compositions and grades are found throughout the northern and north-central parts of the State. They may well contain a variety of gem materials including

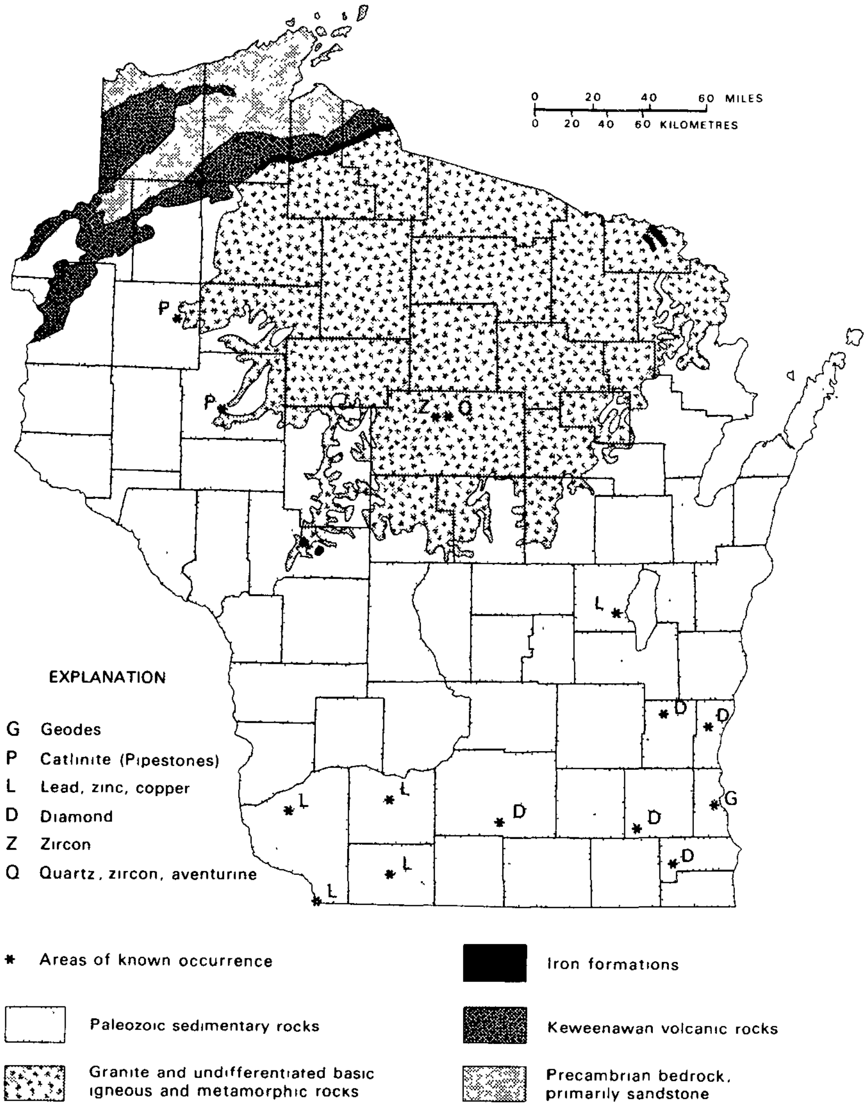



FIGURE 30.—Geologic map of Wisconsin and location of potential gemstone-bearing areas.

garnet, corundum, chrysoberyl, actinolite, topaz, spinel, staurolite, kyanite, and perhaps jade minerals similar to those found as boulders along Rib Creek near Wausau, among many others. The high-grade metamorphic zones near Marathon, near Mercer, and along the trend of the iron-formation near the Gogebic area west of Hurley should be fascinating and perhaps rich in gemstones. Unusual but beautiful material for the lapidary is found among the rocks themselves, for example, cummingtonite and grunerite rocks, which commonly have fibrous structure resembling tiger's eye quartz, and soapstone, marble, and serpentine, which are easily carved.

Precambrian granitic rocks have yielded zircons, quartz crystals, aventurine, and garnet in Wood County and should contain a wide variety of other gemstones, especially in the numerous pegmatites. Some gemstones characteristic of pegmatites are tourmaline, beryl, apatite, spodumene, moonstone, and sphene. Again, the rock itself may furnish material for the lapidary at many places. Graphic granite and other graphic intergrowths, for example, quartz and tourmaline, are common, and a quite ordinary, but very beautiful, granite is quarried commercially at Wausau.

Near Milwaukee, some Paleozoic sedimentary rocks contain millerite-bearing geodes, and deposits of catlinite comparable to those in the Pipestone National Monument in Minnesota occur in Barron and Chippewa Counties in the northwestern part of the State. At the Lutz quarry near Oshkosh, mineral specimens have been found containing covellite, marcasite, sphalerite, calcite, pyrite, smithsonite, galena, cerussite, hemimorphite, bornite, and cuprite. At Mineral Point, in the southwest corner of the State, specimens containing many of these same minerals can be found. In fact, the area of zinc-lead mining in the three southwesternmost counties represents a severely neglected area of beautiful mineral specimens; probably the best specimens available anywhere in the zinc-lead district are to be found in those counties.

The surficial glacial cover also offers something to the gem collector. It contains the so-called Lake Superior agate, which is found in gravel beds and gravel pits in the northern part of the State along the St. Croix and Mississippi Rivers. Large pieces of metallic copper, ripped from the bedrock and carried south by glaciers, have also been found at a number of places in northern Wisconsin. The glacial cover also carried cherts and jaspers and an abundance of beautiful and exotic rocks of all kinds, many from far to the north in Canada. Not least, it contains the diamonds, all but one of which were found before the turn of the century in a small area in the southeastern part of the State in association with moraines. Why others have not been found in recent times is not known, but the six documented and apparently legitimate finds can hardly have exhausted the diamond supply of the moraines.

It remains to mention the highly colored, and in many instances fantastically shaped, freshwater pearls that were produced in some quantity in Wisconsin in past years. Pollution and the construction of dams have caused a decline of the freshwater mussel population, but the clean upper reaches of flowing streams still harbor these shellfish: if interest is not in the pearls, it might be in the mother-of-pearl shell, which supported a thriving button industry in years gone by.

The number of older, retired people with time on their hands is increasing rapidly in this country. Also, changes are taking place in attitudes and lifestyles of all age groups; these changes include a renewed interest in and appreciation for the natural environment, including the rocks and minerals. These trends suggest the likelihood of a continuously, if slowly, expanding production of gemstones and allied materials by individuals in the future, and of an associated increase in those sectors of commerce supportive of this kind of recreational and esthetic pursuit. In particular, the tourist industry is expected to be the principal beneficiary of this activity.

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## Graphite

(By P. L. Weis, U.S. Geological Survey, Reston, Va.)

*Description and use.*—Graphite is pure crystalline carbon, is very soft, and has excellent cleavage. It is flexible and is a very good conductor of heat and electricity. Graphite is unaffected by or extremely resistant to attack by most chemical solvents and reagents. In an oxygen-rich atmosphere at temperatures above 600° C, graphite decomposes slowly to form the gas $CO_2$; but if protected by a nonoxidizing atmosphere or an inactive coating it is stable to 3,500° C, the highest melting point of any element.

No commercial graphite deposits are known in Wisconsin, but possibly some minor graphite is present locally.

Natural graphite occurs in three geologic environments, and the distinctive qualities of the graphite in each give rise to three commercial classes:

(1) Veins—mineral material that fills fractures in rocks—consisting of 75–100 percent graphite are of commercial value but are found only in a few places in the world. The veins occur only in igneous and metamorphic rocks, mostly of Precambrian age.

(2) Flake graphite is the commercial designation for graphite that occurs as flakes scattered through layers of carbon-bearing sedimentary rocks altered by heat or pressure or both. Commercial deposits contain from about 5 to more than 20 percent graphite. The thickness, toughness, density, size, and shape of the flakes vary by the deposit.

(3) Amorphous graphite [2] is a commercial designation for any homogeneous, very fine-grained graphite, most of which comes from thermally altered beds of coal. Deposits of commercial value generally contain at least 80 percent graphite.

Industrial uses of graphite depend upon the characteristics of the three natural graphite types. Fine-grained, relatively low-cost amorphous graphite is used extensively for foundry facings, certain refractories, and as a source of carbon in steelmaking. Flake graphite is prized for high-quality lubricants and for high-quality crucibles and refractory ware. Amorphous lump, or vein graphite, is also used in lubricants and refractory ware but is especially desired for carbon brushes in electric motors. The uses of the graphite consumed in the United States in 1973 have been summarized by Willard (1973, table 1).

The only domestic graphite mine now active, that at Burnet, Tex., produces flake graphite. Deposits of similar material, however, occur

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[2] The term "amorphous" is a misnomer; all graphite is crystalline.

in many other places in the United States, chiefly in Alabama, Alaska, New York, Pennsylvania, and other places in Texas (Weis and Feitler, 1968, p. 304). Deposits of vein graphite occur in Montana and New York, and deposits of amorphous graphite occur in Rhode Island, New Mexico, and Colorado. The inactive deposits are not economically competitive with foreign sources of natural graphite (Weis, 1973, p. 278).

Natural graphite now faces competition from synthetic graphite, marketed as artificial graphite. The commercial name is a misnomer insofar as it implies an imitation, because the product is really crystalline graphite, produced in high-temperature furnaces from petroleum coke or other forms of amorphous carbon. This synthetic graphite is a product of high purity, but it tends to be finer grained, less dense, and more expensive than most natural flake graphite. Synthetic graphite can be substituted to some degree in all of the uses of natural graphite though its higher cost makes it noncompetitive for some uses. Synthetic graphite, however, is the only product that is pure enough for use as moderator rods in nuclear reactors. It is also used in electrodes for electrosmelting and in anodes for the electrochemical industry. Total consumption of synthetic graphite has increased steadily over the last 20 years and in 1973 was almost 332,000 tons, about 5½ times the total tonnage of natural graphite consumed (Willard, 1973, p. 2). The use of synthetic graphite in future industrial markets undoubtedly will affect the mining of natural graphite.

*Occurrences in Wisconsin.*—No commercial graphite deposits are known in Wisconsin. Rocks containing amorphous carbon were mined from two properties near Junction City, Portage County, before World War I (Bastin, 1911, p. 1093). The carbonaceous material occurs as lenses in shaly zones in quartzite. It was mined and crushed for use as paint pigment. Although it was marketed as graphite by the producers, tests showed it to be non-graphitic amorphous carbon (Weidman, 1907, pp. 655–657). Both amorphous carbon and graphite can be used to produce suitable black pigment for paints, but graphite-based paints are much more effective protection from corrosive vapors. They are therefore used mostly in chemical plants, smelters, and other industrial uses where they are likely to be exposed to acid fumes.

Graphitic schists are reported from Presque Isle, Vilas County, and from Manitowish, Manitowish County, and in an area northeast of Butternut, Iron County (Dutton and Bradley, 1970). Small vein-like streaks of graphite occur in pegmatite veins cutting quartz syenite near Wausau, Marathon County (Weidman, 1907, p. 307–308). No attempts have been made to exploit any of these occurrences.

*Appraisal and outlook.*—Potential for graphite production from Wisconsin appears small. Many areas in the United States are known to contain significant flake graphite deposits much larger and richer than any known in Wisconsin (Cameron and Weis, 1960). Many are much closer to potential users, yet only one producer in Texas has continued successful operations in the United States since World War II.

It appears highly unlikely that large, high-grade graphite deposits remain undiscovered in Wisconsin. Even if they did exist, discovery would not necessarily lead to successful production. They would be faced with competition from low-cost foreign deposits, domestic deposits closer to markets, and already established domestic producers, and the purchasing habits of a small group of users who are traditionally reluctant to change from tested sources of supply, regardless of prices or salesmanship.

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## Kyanite

(By F. G. Lesure, U.S. Geological Survey, Reston, Va.)

*Description and use.*—Kyanite is an aluminum-rich mineral used to make high-quality heat resistant materials and other ceramic products. Kyanite together with chemically similar sillimanite and andalusite form the kyanite or sillimanite group of minerals, all having the same chemical composition, $Al_2SiO_5$, but different physical properties. Although there has been some production of all these minerals in the United States in the past, only kyanite is produced in quantity today (Espenshade, 1973), and only kyanite is known to occur in quantity in Wisconsin.

When kyanite-group minerals are heated to high temperatures, the resulting product (mullite) retains its strength and chemical stability at high temperatures for long periods of time and is, therefore, used to make bricks and other shaped objects for furnaces in the metallurgical and glass industries. One of the earliest uses for mullite was in automobile sparkplugs. Synthetic mullite is also made from mixtures of materials containing alumina ($Al_2O_3$) and silica ($SiO_2$), and can substitute for kyanite in most uses.

The United States is a leading producer and exporter of kyanite and synthetic mullite. Most of the current production of kyanite is from Georgia and Virginia. Prices for kyanite in June 1975 were listed as: Georgia, raw bagged, 35 mesh, $63 a short ton; 325 mesh $118 (Engineering and Mining Journal, 1975). Excellent reviews of properties, treatment, and uses of these minerals and the geology of the deposits are given by Espenshade and Potter (1960), Klinefelter and Cooper (1961), Varley (1965), and Cooper (1970).

*Occurrences in Wisconsin.*—Kyanite occurs in a belt of rocks that extends for 15 miles (25 km) along part of the Flambeau River in Ashland and Iron Counties south and southwest of Mercer, Wis. Outcrops of kyanite-bearing schist have been reported in T.41N., R.1 and 2E. and T.42N., R.1, 4, and 5E. (King, 1882, p. 585–615; Allen and Barrett, 1915, p. 111–121). The kyanite forms 6 to 7 percent of some layers of the schist and occurs in crystals as much as several centimeters long associated with the minerals quartz, feldspar, biotite, and garnet. The kyanite crystals contain inclusions of other minerals and crushing to less than 60 mesh is needed to get a good concentration (Fries, 1939). Similar kyanite-bearing schist or gneiss is also present in T.42N., R.10E., Vilas County, about 40 miles (66 km) east of Mercer (Allen and Barrett, 1915, p. 120).

Other areas of kyanite-grade metamorphism are in Lincoln, Marathon, and Taylor Counties (Dutton and Bradley, 1970, sheet 6). Sillimanite is locally present, but no occurrences of kyanite are known.

*Appraisal and outlook.*—Although large tonnages of kyanite-bearing schist are probably present, a complete study of the poorly exposed occurrences, and milling tests of large samples are needed in order to evaluate the resource potential. Hypothetical resources of kyanite in the schist and gneiss are probably large. The quality of the kyanite may be low because of inclusions of other minerals and the outlook for exploitation is not good.

## Magnesite

(By A. J. Bodenlos, U.S. Geological Survey, Reston, Va.)

According to information contained in private company reports, several small outcrops of magnesite (composed of magnesium, carbon, and oxygen) are near Pembine (Sec. 21, T.37N., R.21E.). Although the area is largely covered, the outcrops may represent a mineralized belt more than 1,000 feet long; the magnesite, however, is contaminated by large amounts of talc and quartz and also contains too much iron to be usable in industry. The magnesite evidently resulted from the alteration of a belt of serpentine (a magnesium silicate mineral), that produced magnesium carbonate, quartz (silicon dioxide), and talc (another variety of magnesium silicate).

Similar deposits, very large in size, are in Vermont, Canada and other parts of the world, but none are being mined because they too contain large amounts of similar impurities (Bodenlos and Thayer, 1973, p. 381).

## Peat

(By C. C. Cameron, U.S. Geological Survey, Reston, Va.)

*Description and use.*—Peat, which is partly decomposed vegetable matter that accumulated under water or in a water-saturated environment, has a wide range of physical and chemical properties. For statistical purposes, the U.S. Bureau of Mines classifies peat in three general types. Material from decomposed Sphagnum, Hypnum, and other moss groups is classified as moss peat, whereas that from reed-sedge, shrub, and tree groups is classified as reed-sedge peat. Peat humus is material so decomposed that its botanical identity is obscured and further oxidation of the material has been impeded. The Bureau of Mines classification, however, does not adequately identify peat according to properties important to the modern industry. Chief among these properties are water-holding capacity, ash, and fiber contents. Water-holding capacity, which is measured in percentage by weight, depends upon botanical character, the degree of decomposition, and the degree of drying to which the peat has been subjected. Ash content, also measured in percentage, consists of the solids remaining after dry peat has been heated at 550° C. Ash content is, therefore, the reciprocal of organic content valuable to peat use. Accordingly, the American Society for Testing and Materials accepted in 1969 a modification of the Bureau of Mines classification which states that all commercial quality peat must have an ash content not exceeding 25 percent. Fiber content refers to the proportion of stem, leaf, and other plant fragments between the sizes of 0.5 mm and 12.7 mm. Percentages of fiber are based on oven-dried weight at 105° C. Sphagnum moss peat must contain a minimum of 33⅓ percent fiber, of which at least half is Hypnum moss fibers. Reed-sedge peat also must contain a minimum of 33⅓ percent fiber, of which reed-sedge and other nonmoss fibers comprise more than 50 percent. All other forms of peat with ash content not exceeding 25 percent are classed as other peat in ASTM designation: D 2607–69.

Soper and Osbon (1922, pp. 11–12) recognize three general types of peat deposits. These include: (1) the filled basin, in which peat accumulates in marshes, ponds, and lakes; (2) the built-up deposit and its corollary, the climbing bog, in which peat forms on flat or gently sloping moist areas not covered with water; and (3) the composite deposit consisting of built-up peat underlain by peat of the filled-basin type.

As the formation of peat deposits depends on many factors, the rate of its accumulation varies widely from place to place and from year to year. If climate, topography and vegetation are favorable, peat forms rapidly as in a few sphagnum bogs along the coasts of Maine and Alaska; but if one of these features is relatively unfavorable, the rate of accumulation is retarded, or brought to a stop, or destruction of the deposit may set in. Estimates of the growth rate of peat in Minnesota show an average production of about 2 tons per acre per year (dry basis) or about 0.2 centimeter annual increase in thickness per year.

Although the present physical property requirements of marketable peat are largely based on agricultural uses, the same properties account for the increasing use of peat in environmental control. For example, moss peat, because of its high water-holding capacity, has been used in large quantities in combating pollution caused by oil spills from offshore drilling and from freighters and barges. Extensive research by the department of chemical engineering of the University of Sherbrooke, Quebec, Canada, revealed the high efficiency of moss peat in the filtration of pigments and dyes in wastes from textile plants, and of mercury and other metals in wastes from other industrial plants—moss peat is 20 to 30 times cheaper than activated charcoal presently employed as a filtering agent. Moss peat also can be used for the manufacture of activated carbon, as a binder for pelletizing iron ore concentrate, and for manufacture of concretes used as lightweight thermal and sound insulators. Preliminary laboratory studies in the United States using natural peat cores have shown good results in reducing nitrates in waste water effluent below acceptable levels. Denitrifying organisms were shown to be present in all of the peat material used and no additional carbon source was necessary to initiate the biochemical process. Peat is also used for phosphate removal in the treatment of waste water. Thus, peat-over-sand mound systems became operational in 1974 in a number of U.S. Forest Service lake campgrounds in Wisconsin, Minnesota, and Michigan. Studies are being initiated at a number of State agencies and universities (Minnesota, for example), in the use of peat as an alternate energy source and as a source of chemicals for fertilizers and industrial uses. The U.S. demand for peat by the year 2000 is forecast by Decarlo (1970) as 1,200,000 to 2,400,000 short tons.

*Economic importance and development.*—All peat humus, reed-sedge, and some moss peat production is from surface pits, and most operations use conventional excavating and earth-moving machinery including bulldozers, draglines, and front-end loaders in drained bogs, and clam shell and dredges for submerged bogs. In 1973, 68 percent of the peat was shredded before sale; the remainder was sold without prior processing, or in some instances shredded and kiln-dried.

The production of peat in the United States for soil conditioning and horticultural purposes began about 1904 when 12 companies produced a few thousand tons annually. By 1973 peat production climbed to 635,000 short tons, an increase of 10 percent over the production reported in 1972. Peat was produced at 98 operations in 22 States. Fifty-three percent of the total production was reed-sedge peat valued at $11.29 per ton; 24 percent was moss peat valued at $13.92 per ton, and the remaining 23 percent was humus peat valued at $12.44 per ton (Sheridan, 1974a).

Before 1955, most domestic peat was sold locally in bulk, but since then large quantities have been distributed to all parts of the United States. Prices of domestic peat vary greatly, but in general the sales value depends chiefly on type of peat, the degree of processing, and whether the peat is sold in bulk or package. In 1973, 58 percent of the peat was sold in packaged form at $14.26 per ton, and 42 percent was sold in bulk at $8.84 per ton (Sheridan, 1974a). Although fourth in world production after the U.S.S.R., Ireland, and West Germany, the United States produces only 0.6 percent of the world total.

The peat industry in the United States is based on use of peat as a soil conditioner and horticultural material. Commercial sales of peat for 1973 totaled 634,503 short tons for $7.547,000, averaging $12.16 per ton (Sheridan, 1974a). In addition 323,501 short tons valued at $18,762,000 were imported chiefly from Canada and West Germany. The largest single market is the individual homeowner who uses peat as a soil conditioner in preparing and maintaining lawns, shrubs, and gardens. The second largest market is for use by landscape contractors and municipal, State and Federal Governments in preparing public parks, golf courses, and strips along public highways in urban areas. Eighty-seven percent of the total peat marketed by producers in 1973 was sold for general soil-improvement purposes. Most of the remaining 13 percent used as a material for packing flowers and shrubs, and as an ingredient for potting soils, and as a filler for mixed fertilizers.

The utilization of peat in Wisconsin began with the settlement by emigrants from Ireland, Germany, and Scandinavia where peat had been used as a fuel for centuries. As far back as 1868 an attempt was made to market it as a fuel. Its use in combination with fertilizers dates from the beginning of this century. However, the early attempts at development of Wisconsin peat were mainly along the lines of utilizing it for fuel, gasifying it, and manufacturing it into paper. By 1911, peat and muck marshes were being drained and converted into valuable agricultural land for raising cranberries, corn, and other crops. But it was not until recent development of the modern industry based on agricultural and horticultural usage that a market was found. Today the peat industry in Wisconsin is represented by two operations (Sheridan, 1974b). The Demilco, Inc., mine from which humus peat is excavated is located in Waukesha County near the town of Wales in the southeastern part of the State. The moss and peat humus mine belonging to Superior Brand Peats is located in Lincoln County near Tomahawk. The combined production in 1973 of the two operations amounted to 2,261 short tons air-dried of which 1,959 tons were sold in bulk and package for $208,000 at an average of $106.15 per ton, by far the highest average price per ton of any peat sold in the United States in 1973 (Sheridan, 1974a). A third operation, that of Certified Peat and Sod, Inc., located near New Berlin, Waukesha County, and producing bulk and packaged moss peat, was reported active in 1975 (Mickelson, 1975b).

*Occurrences in Wisconsin.*—Peat is found in many parts of Wisconsin on the poorly drained surface of glacial drift within the generalized area shown in figure 31. Peat deposits surveyed in 1903 and in 1908

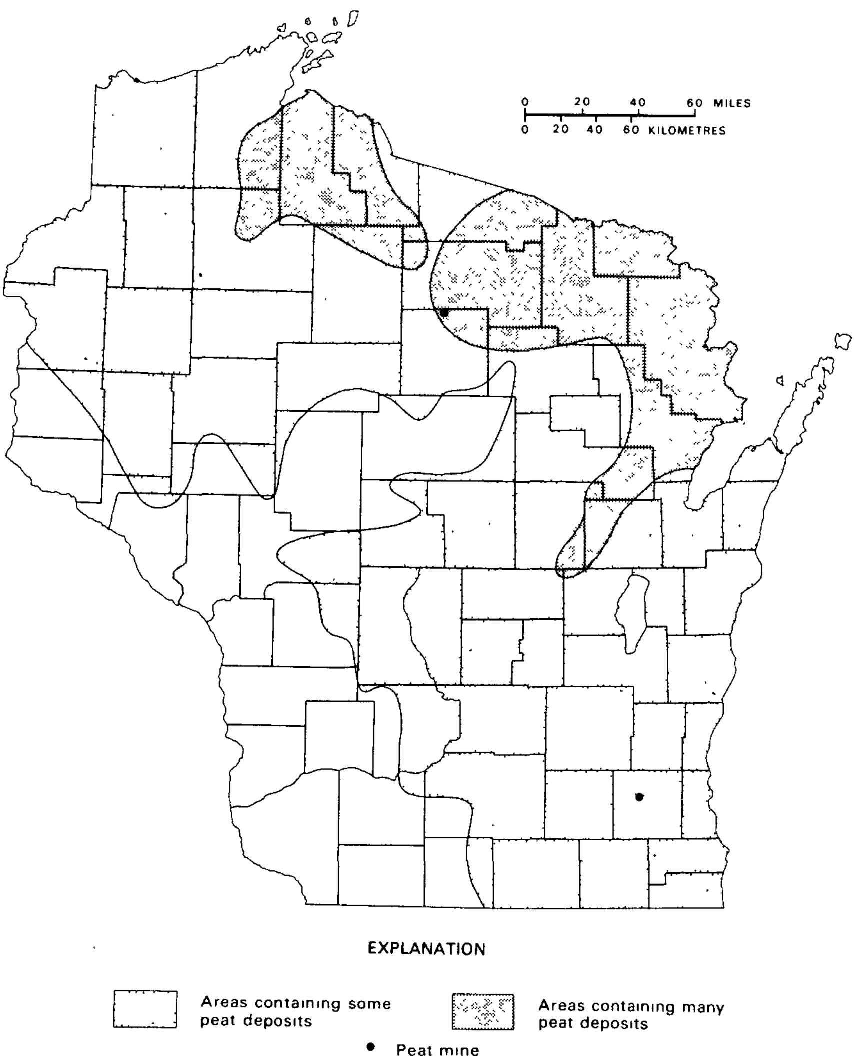


**FIGURE 31.—Location of peat mine operations in 1974 in Wisconsin and generalized areas containing swamps and marshes suitable for peat prospecting.**

are described in a comprehensive report on the peat resources published in 1915 (Huels. 1915). Fifty deposits scattered throughout the State in the area delineated were found to range from 1 or 2 feet to over 20 feet in depth and to cover from 10 to more than 30,000 acres in area. In the southeast deposits, peat near the surface is in an imperfect state of decomposition and is light, spongy, fibrous and of yellow or light reddish brown color. The lowest layers are almost black in color, pitchy and slippery and almost fiberless in structure. These deposits are representatives of many more that occupy depressions formed by glacial action during the Wisconsin stage of glaciation. They are found in some but not all spruce-sphagnum and tamarack-sphagnum bogs and swamps that predominate in the northern part of the State and in many grass-sedge meadows and marshes that occur in the southern part.

*Appraisal and outlook.*—Soper and Osbon (1922) estimated that a little more than 1 million acres of peat land in Wisconsin is capable of yielding 2.500 million short tons of air-dried peat based on the production of 200 tons air-dried peat per acre-foot. This figure should be revised by additional studies which take into account changes that have come into effect since 1922, such as (1) reduction in peat lands by drainage for crops and urban features; (2) addition of previously unmapped swamps and marshes; (3) destruction of peat deposits by forest fires and by oxidation brought about by lowering the water table within the deposits; and (4) the limitations on quality of peat for the modern industry listed in American Society for Testing and Materials D 2607–69, standard classification of peats, mosses, humus, and related products.

The outlook for increased development of the peat industry appears favorable in the light of expanded markets owing to predicted food shortages throughout the world. However, utilization of peat lands for the production of peat products must be balanced against utilization as crop lands based on suitability studies. The growing shortage of fossil fuel already has directed a hard look at peat as an alternate source of energy (Farnham, 1974) in areas such as Minnesota with large peat resources. Because peat mining is a stripping operation, the effect of large-scale exploitation in the midst of Wisconsin's recreational areas would have to be considered.

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## Sand and gravel

(By D. W. Hadley, Wisconsin Geological and Natural History Survey, Madison, Wis.)

*Description and use.*—Deposits of sand and gravel were formed by the physical and chemical destruction of bedrock, and subsequent reworking and deposition by water, wind, and glacial action.

With few exceptions, the sand and gravel deposits of Wisconsin were formed in conjunction with the glaciation of the State. As the great ice masses of the continental glaciers moved down from Canada, they incorporated vast amounts of rock and soil. When the glacial ice melted, these materials were released mainly as glacial outwash, which is the primary source of sand and gravel in Wisconsin.

In many areas of Wisconsin, bodies of stagnant ice were largely buried, and pits formed in the surface as the ice blocks melted. These pitted plains are also prime sources of sand and gravel, although such deposits are often smaller and less uniform than are the large outwash bodies.

Figure 1 shows the distribution of surficial glacial deposits at the surface in Wisconsin from which the approximate distribution of areas of potential sand and gravel deposits can be determined. Five mapping units are used. Two of these, namely outwash and pitted outwash, have already been indicated as major sources of sand and gravel. The remaining three map units, and their potential for useful deposits of sand and gravel, are described briefly below.

Ground moraine is rock debris carried forward in, on, or beneath a glacier or ice sheet and finally deposited from its under surface. It normally has a surface of low relief. The potential for sand and gravel production from ground moraine is relatively small.

End moraines are mounds, ridges, or other accumulations of unsorted glacial material, mostly till, deposited at the front of an actively moving glacier. End moraines have a relatively high potential to contain moderate to small deposits of sand and gravel.

Lake deposits were laid down in lakes formed either by the blocking of preglacial drainage or by the flooding of depressions in the surface of the glacial deposits. The potential for sand and gravel in these deposits is extremely low.

*Economic importance and development.*—The largest single use of sand and gravel is as concrete aggregate. A vast amount of concrete is used every year in Wisconsin in the construction of homes, factories, farm buildings, roads, bridges, and for a multitude of other purposes. Because at least three quarters of concrete consists of aggregate, cheap and abundant gravel is extremely important to the construction industry. Other principal uses of sand and gravel include material for fill, for the paving and maintenance of road systems, and for use as railway ballast.

Wisconsin's need for sand and gravel is great. In 1970, for example, consumption was well in excess of 18,000 pounds per person, which is more than twice the national average. The deposits in Wisconsin are widespread and, in 1972, of the State's 72 counties, only Iowa and Menominee Counties had no operating pits.

Sand and gravel has been produced in Wisconsin since the early days of settlement, when the major use was as a surfacing material for roads. The U.S. Bureau of Mines has maintained statistical data on sand and gravel production since 1911. These data, which include both the tonnages produced and the market value, are shown in table 9. Preliminary data for 1974 show sand and gravel to be the principal mineral commodity produced in Wisconsin, constituting 41.6 percent of the total value for mineral production in the State. In 1973, the last year for which data are available, Wisconsin ranked fifth in quantity and seventh in the value of sand and gravel produced among the States, and contributed 3 percent of the Nation's total sand and gravel production. In 1972 there were 368 operating gravel pits in the State. Counties with production of more than 1 million tons of sand and gravel were, in descending order of quantity: Waukesha, Washington, Rock, and Dane Counties.

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*Appraisal and outlook.*—The map of glacial deposits of Wisconsin shows only the surficial deposits. In many portions of the State, particularly in the highly populous areas of southeastern Wisconsin, a large proportion of production comes from deposits that are not exposed at the surface. The rating of the various map units in terms of their potential for sand and gravel production is based on general character of surface deposits. Large areas mapped as outwash, for example, may be made up almost entirely of sand, and therefore have no potential for gravel production. Similarly, although end moraines are often rich in sand and gravel, the moraines within any particular part of the State may be almost devoid of such water-borne deposits.

TABLE 9.—SAND AND GRAVEL PRODUCTION IN WISCONSIN, 1911–74

| Year | Thousands of short tons produced | Value (thousands) | Year | Thousands of short tons produced | Value (thousands) |
|---|---|---|---|---|---|
| 1911 | 3,677 | $732 | 1943 | 6,223 | 2,596 |
| 1912 | 3,052 | 664 | 1944 | 8,634 | 4,128 |
| 1913 | 4,045 | 772 | 1945 | 8,384 | 4,111 |
| 1914 | 3,594 | 769 | 1946 | 14,829 | 6,803 |
| 1915 | 2,862 | 690 | 1947 | 16,335 | 9,939 |
| 1916 | 3,545 | 894 | 1948 | 18,613 | 11,370 |
| 1917 | 3,610 | 1,081 | 1949 | 17,023 | 10,456 |
| 1918 | 2,170 | 810 | 1950 | 19,117 | 11,959 |
| 1919 | 2,763 | 1,543 | 1951 | 19,392 | 12,392 |
| 1920 | 2,423 | 1,554 | 1952 | 24,896 | 16,938 |
| 1921 | 2,900 | 1,783 | 1953 | 23,656 | 16,173 |
| 1922 | 3,434 | 1,958 | 1954 | 23,979 | 17,396 |
| 1923 | 5,022 | 2,794 | 1955 | 27,978 | 19,958 |
| 1924 | 5,714 | 2,703 | 1956 | 27,715 | 19,097 |
| 1925 | 6,181 | 2,064 | 1957 | 29,394 | 18,693 |
| 1926 | 7,977 | 3,264 | 1958 | 39,383 | 25,845 |
| 1927 | 9,020 | 3,190 | 1959 | 41,999 | 27,535 |
| 1928 | 10,104 | 3,680 | 1960 | 35,681 | 25,648 |
| 1929 | 10,728 | 4,574 | 1961 | 39,978 | 28,457 |
| 1930 | 7,082 | 2,802 | 1962 | 33,649 | 24,408 |
| 1931 | 5,152 | 1,961 | 1963 | 35,363 | 24,863 |
| 1932 | 3,621 | 1,307 | 1964 | 34,348 | 24,695 |
| 1933 | 3,369 | 1,377 | 1965 | 38,751 | 27,707 |
| 1934 | 4,773 | 1,837 | 1966 | 41,523 | 30,713 |
| 1935 | 4,777 | 2,067 | 1967 | 42,542 | 32,955 |
| 1936 | 8,192 | 3,514 | 1968 | 39,807 | 30,903 |
| 1937 | 7,531 | 3,292 | 1969 | 42,815 | 35,414 |
| 1938 | 6,273 | 2,800 | 1970 | 41,103 | 35,107 |
| 1939 | 7,025 | 2,616 | 1971 | 38,561 | 32,748 |
| 1940 | 6,743 | 2,304 | 1972 | 36,430 | 31,324 |
| 1941 | 9,263 | 3,398 | 1973 | 40,250 | 43,647 |
| 1942 | 9,266 | 3,497 | 1974 (preliminary) | 36,225 | 51,077 |

The glacial map indicates that a large portion of southwestern Wisconsin is largely devoid of glacial deposits. This region, which is known as the "Driftless Area", is thought by most geologists to be unglaciated, and sand and gravel production is limited to valley train deposits along major valleys together with some recent stream deposits.

Sand and gravel are high volume, low value commodities, and transportation costs between the source and market areas often make up a large share of the costs to the user. As the haulage distance increases, the delivered price also increases, adding to the costs of construction. Thus, although the sand and gravel resources of the State as a whole are enormous, there is already a shortage of suitable deposits within reasonable haulage distances of a number of communities in Wisconsin. This is partly due to the unavoidable depletion or "mining out" of deposits, but many very valuable deposits of sand and gravel are being lost through the spread of the communities that such deposits might well have served. When homes and shopping centers are built over the deposits, or when mining is prevented by zoning restrictions, the deposits are for all practical purposes lost.

In several parts of the country, far-sighted administrators and planners have not only initiated programs to identify sand and gravel deposits that are near population centers, but also have taken steps to insure that sufficient reserves will be available to meet the future needs of the expanding communities. Many of these plans incorporate the idea of multiple sequential land use. These plans protect the sand and gravel resources until they are needed and call for the rehabilitation and restoration of the land when mineral extraction is completed. In many cases, the restored land has been found to be significantly more valuable as a site for development after mining and restoration than it was in its initial state. It is to be hoped that similar programs will be undertaken in Wisconsin in the near future to insure the continued availability of high quality, low cost sand and gravel to the citizens of the State.

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## Silica sand

(By K. B. Ketner, U.S. Geological Survey, Denver, Colo.)

*Description and uses.*—In a geologic sense, sand refers to particles of earth materials in the size range between 1/16 and 2 mm. The particles, or grains, may have similar properties or may differ greatly in shape, color, and hardness depending on the combination of chemical constituents of which they are composed. As resource materials, silica sands have a very high content of clear grains of the mineral quartz, and one important use of silica sand is as the main constituent used to make glass.

Silica sand is the product of especially long continued or often-repeated cycles of weathering, abrasion, and winnowing. The hardness and chemical inertness of quartz favor development of concentrated quartz sand deposits because almost all other minerals tend to decompose or disintegrate and be carried away. The most extensive and purest silica sands formed in shallow seas. Less extensive and generally less pure deposits formed as dunes along the shores of lakes and the sea, as dunes of desert regions, and as channel and flood plain deposits along streams.

The principal uses of silica sand are listed below:

*Abrasives*

Blasting sand is of uniform grain size. The grains are propelled at high velocity by air, water, or centrifugal force for removing tarnish, rust, or paint from metal surfaces or for renovating stone veneer.

Glass-grinding sand is clean, fine- to medium-grained, and is used for rough or semifinal grinding of plate glass.

Stone-carving and rubbing sand is relatively pure, well-sorted, angular, and coarse grained; it is used for sawing and rough grinding dimension stone.

*Glass*

High-quality glass sand must be more than 99 percent $SiO_2$ and have an extremely low content of alumina and iron. Moreover, the sand must be very well sorted in order to promote even melting.

*Refractories*

Furnace bottom sand (also fire sand) is used for lining and patching open hearth and electric steel furnaces. The sand should contain enough clay to provide cohesiveness and enough fines and iron oxide to promote rapid fusion.

Ganister mix (also semi-silica or cupola daub) is a mixture of sand and fine clay used for lining and patching metal vessels and certain types of furnaces. It may be a naturally occurring mixture or may be prepared by mixing silica sand with plastic fire clay.

Molding sand or core sand is washed and graded silica sand in combination with appropriate bonding agents. It is used for cores and molds in ferrous and nonferrous foundry practice.

Runner sand is coarse-grained, moderately high in natural clay, and is used to line runners and dams on the casting floor of blast furnaces. Runner sand is also used in the casting of pig iron.

*Miscellaneous*

Filter sand is washed and graded silica sand used for filtering suspended impurities and bacteria from water-supply systems.

Hydraulic-fracturing sand is very closely graded in size. Mixed with a suitable carrier, it is pumped at great pressure into rock formations to increase oil, gas, or water production by preventing feeder fractures from closing.

Standard testing sand is prepared to exact size and shape specifications for use in research or testing work involving a comparison of methods or materials.

Traction sand (also called engine sand) is well-sorted, free flowing, medium-grained, and has a minimum of soft rock fragments; it is used to increase the friction of locomotive wheels on slippery rails.

*Economic importance.*—Ten companies were producing high-silica sands in Wisconsin in 1970 (Ostrom, 1970b). The total State production of high-silica sands cannot be determined from published figures because of incomplete reporting and because figures for some categories of high-silica sands are lumped with those for common sands. However, the bulk of high-silica sands produced in Wisconsin is used as molding sand, and in the decade ending in 1971, the last year for which figures are available, the average yearly production for that use was 822,000 short tons worth $2,258,000. Total annual U.S. production of high-silica sands at present is about 30 million short tons.

*Occurrences in Wisconsin.*—High-silica sand in Wisconsin is obtained chiefly from the Wonewoc, Jordan, and St. Peter Formations. These formations are layers of sand and weakly coherent sandstone interlayered with limestone, dolomite, shale, and impure sandstone. The entire layered sequence of rocks seems to lie flat locally but, on a regional scale, it slopes gently to the east, south, and west from the north-central part of the State. The effect of erosion on these gently sloping strata has been to expose the edges of the beds in an arc that encompasses most of the State, as shown on figure 2. The high-silica sand deposits were never formed or were completely eroded from the northern counties, and, although they are beneath the surface in the counties that border Lake Michigan, they are completely covered by thick layers of dolomite and shale.

The Wonewoc Formation is the high-silica formation lowest in the sequence of rock strata and is the most widely exposed. It forms most of the bluffs in and at the edge of the sand plains area in the central part of the State. The sands of the Wonewoc are of medium grain and are moderately high in silica content. The Wonewoc ranges from about 60 to more than 100 feet in thickness, except where erosion has stripped away part of it.

The Jordan Sandstone lies about 250 feet above the Wonewoc in the sequence of rock strata. The sand grains in this formation tend to be finer than those of the Wonewoc but are of similar purity. The Jordan ranges from about 20 feet to more than 60 feet in thickness.

The St. Peter Sandstone, about 250 feet above the Jordan, is a weakly coherent medium-grained sandstone like the Wonewoc but is much more pure and, on the average, is much thicker, but ranges from 9 to 350 feet.

Selection of a silica sand quarry site involves locating areas in which high-silica formations crop out and then locating parts of the outcrops that are free from deleterious mineral matter, are easily disaggregated, and are close to transportation and markets.

The places where high-silica formations may crop out can be determined approximately from the State geologic map, and more specifically from geologic maps of the various counties of the State, geologic quadrangle maps, and miscellaneous maps of small areas. These maps can be found in certain University of Wisconsin theses and in various publications of the U.S. Geological Survey and the Wisconsin Geological and Natural History Survey. Assistance in locating the most complete maps of particular areas can be obtained from personnel of the Wisconsin Geological and Natural History Survey. The names of St. Peter, Jordan, and Wonewoc may not appear on some maps of areas in which these formations crop out. If not, the assistance of a geologist familiar with stratigraphic names may be required.

*Appraisal and outlook.*—The resources of high-silica sand in Wisconsin are ample for the foreseeable future. Even if production were to increase greatly, there is no apparent possibility that the deposits would be exhausted soon. However, a large proportion of the most favorably located deposits may be precluded from exploitation by shortsighted practices. When residential developments are allowed to spread over valuable sand deposits and when land-use laws are invoked to prohibit exploitation of known deposits in urban areas, costs will increase as a result of having to confine mining to areas remote from industrial users and the ultimate consumers.

Sand and sandstone deposits capable of yielding high-quality silica sand should be identified and precisely delineated on geologic maps. Geologic maps exist for some areas, and workable silica sand deposits are specifically designated on only a few of these. Precise location of all deposits would permit orderly planning for the most beneficial multiple use of land underlain by silica sand deposits.

Much of the popular opposition to mining in urban areas lies in the unsightly, dangerous, and useless condition of mined-out areas. Methods for restoring abandoned pits to esthetically acceptable appearance and productive or recreational use should be developed. Some abandoned pits become partly filled with water. If the banks are sloped and suitably planted and maintained, these ponds can be converted at moderate cost to parks or recreational and wildlife areas.

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## Talc and soapstone

(By C. Ervin Brown, U.S. Geological Survey, Reston, Va.)

*Description and use.*—The term "talc," as used industrially and in this report refers to rocks composed mainly of hydrous magnesium- and calcium-rich silicate minerals and having the mineral talc, which contains no calcium, as an important constituent. Soapstone is a general term for massive impure fine-grained talc rock that is sawed into shapes for various purposes. Use of a well-known mineral name, talc, for an industrial raw material of mixed mineralogy leads to confusion as also does the fact that many people associate that mineral with talcum powder, which is only a minor use.

Minerals other than talc that are most commonly present in industrial talc and soapstone are tremolite, anthophyllite, serpentine, chlorite, and diopside. Quartz and carbonates of calcium, magnesium, and iron are less commonly present.

The mineral constituents of industrial talc differ widely in physical properties ranging from talc, that is extremely soft and slippery, to tremolite that is hard, hackly, and breaks in sharp prismatic grains. Consequently, the physical properties of rocks composed of these minerals vary according to the ratio of constituents and usually reflect the properties of the dominant minerals.

Industrial talc is used where certain combinations of the following properties are desired: Extreme whiteness when powdered or fired, softness or smoothness, fibrous or flaky particle shape, various degrees of oil absorption, chemical inertness, high fusion point, low water absorption and shrinkage when fired as a ceramic body, low electrical and thermal conductivity, good retention as fillers, and ease of grinding to extreme fineness (Industrial Minerals, 1968).

Talc is used as a base material for manufacture of ceramic wall and floor tile; as a filler by the plastic, paper, roofing, and rubber industries; as a paint extender, and as a diluent or carrier for insecticides. Other special uses are diverse, ranging from a polish for rice, wood turnings, nails, and white shoes to a dusting powder for rubber products and salami. The massive form, soapstone, is cut for laboratory tabletops and sinks, steel-marking crayons, and blocks for art carvings. High-frequency ceramic insulator shapes are machined and fired from another massive pure talc variety known as block steatite, and block talc is machined and fired for burner nozzles. Cosmetic talc for talcum requires very pure, white, mineral talc of which little occurs in the United States. The United States also is deficient in reserves of block steatite; however, the United States has vast resources of talc for the numerous other uses (Brown, 1973).

*Economic importance.*—About 1 million short tons of talc is consumed annually in the United States. Of this, 86 percent is produced by five States: New York, Texas, Vermont, California, and Montana. None is produced close to the manufacturing industries of the central part of the United States. Wisconsin is ideally located to supply this important industrial commodity to these industries and has the type of rocks that might contain talc deposits.

*Development and exploitation.*—Talc and soapstone were produced briefly in Wisconsin from deposits in Wood County. These deposits were first noted in the early 1920's and were mined by the American Talc Co. from 1929 to 1931 when 9,011 tons valued at $29,383 were sold (Bowles and Stoddard, 1932a, 1932b, 1933). The rock was used mainly for filler and also for roof coating and foundry facing. The deposits were later explored and tested by several companies and in 1963 the Marathon Mining and Manufacturing Co. applied for an Office of Minerals Exploration loan to explore for block steatite and chrysotile asbestos. Laboratory tests performed by the Bureau of Mines found that only another fibrous mineral (amphibole) and not chrysotile asbestos occurred there and that although the massive soapstone machined well it cracked when fired. Also, the reflectance and fired color were poor because of a high iron content, but the rock would serve well for filler uses where color was not important.[3] Because of these test results, the loan application was denied. Apparently no further work has been done on the deposits since 1963.

*Occurrences in Wisconsin.*—The deposits in Wood County occur in a northeast-southwest trending zone about 1 mile wide and 3 miles long. The material appears to be altered mafic (magnesium- and iron-rich) volcanic rock. The predominant rocks in this area are mainly chloritic and biotitic schists, which are metamorphosed mafic volcanics. One type of talcose rock occurs as lensy, coarse, white seams up to 4 feet wide that transect schists and soapstone. The soapstone is a fine-grained grayish talc-tremolite rock.

One worker[4] attributed the development of talc in Wood County to alteration of an iron- and magnesium-rich rock by heat and solutions from the surrounding very ancient granitic material that was molten and far below the earth's surface. The occurrence of the soapstone close to its contact with the granite and accompanying aplite (related very fine-grained rock) appears to support this theory (fig. 32).

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[3] Unpublished report from U.S. Archives. Grosh, W. A., and Sweeney, J. W., 1963, Evaluation of Marathon Mining and Manufacturing Co.'s Application, OME-6301: U.S. Archives.

[4] Shaw, Chester, W., 1942, The talc deposits near Milladore, Wis., unpublished research report, University of Wisconsin.

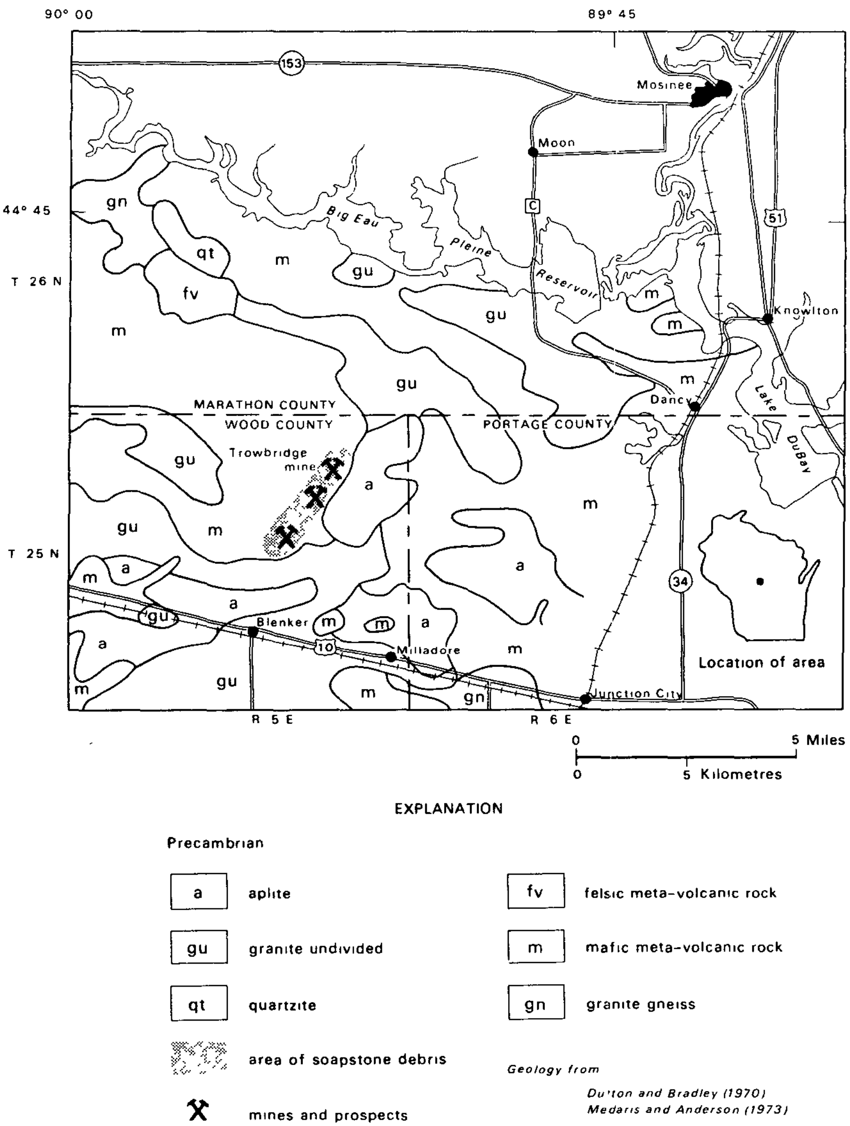


FIGURE 32.—Geologic map and soapstone occurrence in Wood County.

A second occurrence of talc-rich rock is in Marinette County in the SE¼, NW¼, section 21, T. 37 N., R. 21 E. (fig. 29). Here talc is associated with the mineral magnesite ($MgCO_3$) and both were formed from the alteration of serpentinite (rock chemically similar to talc) by hot aqueous carbon dioxide-rich solutions. The serpentinite has accessory chromite (mineral composed of iron, chromium, and oxygen), which is evidence of its origin as an ultramafic (magnesium and iron rich) igneous intrusion (report in Wisconsin Geological Survey files). Much of the talc mined in Vermont is from similar rocks. Other serpentinite areas containing asbestos are nearby in section 21, T. 38 N., R. 21 E. (Prinz, 1959) and N½, SE¼, section 24, T. 36 N., R. 21 E. Talc was not reported associated with these serpentinite bodies.

*Appraisal and outlook.*—The paint, paper, rubber, ceramic tile, and insecticide industries in the midcontinent area do not have a nearby producing source of an inert mineral filler such as talc. Other deposits of talc in the United States formed in areas of metamorphic and igneous rocks similar to those in northcentral Wisconsin. The soapstone and talc zone in northeastern Wood County probably is not unique in Wisconsin because the geologic situation that possibly produced the deposit is a common rock association throughout the northcentral part of the State.

The talc-magnesite alteration product of serpentine in Marinette County is similar to the large talc deposits mined in Vermont (Chidester, 1962). More of this type deposit probably also occurs in Wisconsin.

Rock containing talc is soft and would have been severely eroded by glaciation. This perhaps explains the rarity of outcrops of talc-bearing rock in Wisconsin. More may be found as exploration for mineral deposits in the glaciated areas of Wisconsin progresses.

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*Metallic mineral resources*

## Copper

(By W. S. White, U.S. Geological Survey, Reston, Va. and C. E. Dutton, U.S. Geological Survey, Madison, Wis.)

*Description and use.*—Copper has a unique combination of physical and chemical properties that make it essential to an industrial society. These properties include high electrical and thermal conductivities; good ductility and malleability that make it easily worked and shaped; strength; good corrosion resistance as, for example, in pipes and roofing; and lack of magnetism. It can be readily combined with many other metals to form useful alloys, notably the brasses and bronzes. Copper is an essential ingredient in many fungicides. About half (53 percent) of the copper used domestically in 1970 was for electrical applications, followed by 16 percent in construction, 12 percent in industrial machinery, 8 percent in transportation, 6 percent in ordnance, and 5 percent in other uses (Brobst and Pratt, 1973, p. 164). Among the other uses are jewelry, coins, and computers.

*Economic importance and development.*—Copper has not, heretofore, been a resource of any consequence to Wisconsin, but this situation appears to be changing rapidly.

Heyl and others (1959) have estimated that a few small copper mines on the margin of southwest Wisconsin's zinc-lead district produced about 10,000 tons of ore (copper combined with sulfur) containing 15–20 percent copper between 1837 and 1949. Although these deposits account for the only recorded production of copper in the State, they are characteristically small, scattered, and are not likely to make important contributions to the mineral wealth of the State.

The similarity of certain rocks in the vicinity of Mellen, Wis., to those in which some concentrations of copper-nickel ore have been found in northeastern Minnesota has encouraged some prospecting for similar deposits in Wisconsin. During the period 1955–58, Bear Creek Mining Co. put down about 30 diamond drill holes as part of one such effort. This exploration did not lead to any mining activity, and the results were not published.

Three other types of deposits have greater potential as major sources of copper. These are: (1) Native copper in the ancient basaltic lavas that cross the northwestern corner of the State; (2) copper in the form of copper sulfide at the base of a thick bed of shale known to lie above these lavas over a considerable area east, southwest, and south of Ashland; and (3) copper, again combined with sulfur, but associated with zinc and other metals in massive sulfide deposits in greenstone belts of north-central Wisconsin. The first two types of deposits have been of major importance in Michigan, and their successful exploitation in that State was a principal encouragement to exploration in the similar rocks of northwestern Wisconsin. Although results of these explorations in Wisconsin have not been encouraging, the possibilities for discovery of native copper deposits, at least, are far from exhausted.

The targets of exploration in the greenstone belts of north-central Wisconsin are deposits of a type that is common in those parts of Canada underlain by ancient metamorphic rocks, the so-called Canadian Shield. The rocks of north-central Wisconsin may, in fact, be regarded as an extension of the Canadian Shield, with the intervening area covered by younger rock in the Lake Superior region. Exploration in this part of Wisconsin, beginning about 10 years ago, has been extraordinarily active, and is being rewarded by important discoveries, as will be discussed below. It is safe to predict that deposits in this area will make Wisconsin a significant producer of copper within a relatively few years.

*Copper deposits of the Lake Superior type*

*Occurrences in Wisconsin.*—The Lake Superior region has long been famous for a distinctive type of copper deposit. The copper occurs chiefly as the native metal, whereas in all the other major districts of the world, most of the copper is chemically combined with sulfur.

Three forms of this type of deposit are recognized. In the commonest and quantitatively most important type, the copper fills holes and pockets in what were originally the frothy or broken-up tops of ancient lava flows. In a second type of deposit, almost as important in terms of total production, the copper is found in the spaces between pebbles in beds of conglomerate, a rock formed by consolidation of gravel. A third type of copper deposit is in fissures that cut across the lava flows and conglomerate beds. Such fissure deposits locally contain spectacular masses of native copper and were the first type of deposit to be exploited in the Lake Superior region. Total production from fissures has, however, been less than 2 percent of the total for all types in Michigan.

If one were to drill a hole 3 or 4 miles deep through the sequence of rocks that contain the above described forms of deposits, he might expect to make the following observations on the drill core obtained. Most of the rock would be basaltic lava; a geologist would be able to identify individual lava flows by noting places where the frothy top of one flow was overlain by massive rock at the base of the next higher lava flow. The 3 to 4 miles of drill hole would probably have passed through 300 to 400 individual lava flows. The frothy top makes up, on the average, about 15 percent of the thickness of each flow, or about 7 to 8 feet for a flow of average thickness (50 feet).

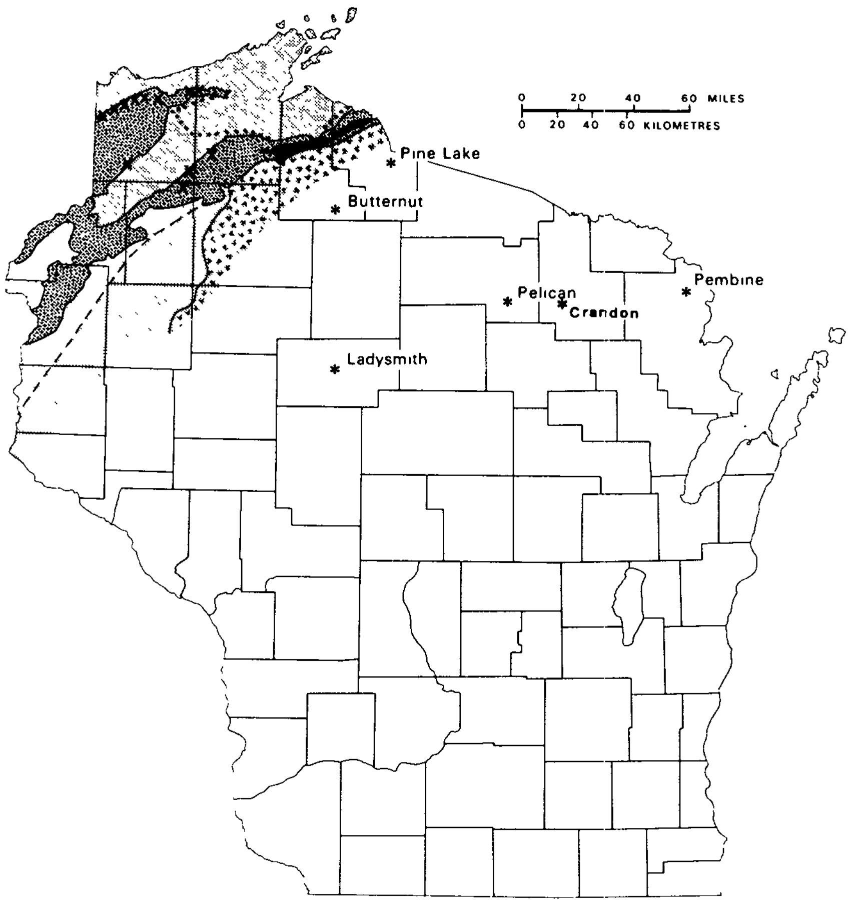
A few pairs of lava flows in this drill hole would be separated by beds of conglomerate or sandstone, the conglomerate acting, in a sense, like the filling and the lava flows like the bread in a sandwich. Individual beds of conglomerate range in thickness from less than an inch to as much as 100 feet, and conglomerate might make up anywhere from 1 to 10 percent of all the rock sampled by the drill hole—the proportions of conglomerate and basalt differ from place to place. There would probably be 20–30 separate beds of conglomerate and sandstone in the 3 to 4 miles of drill core; and on the average they would be separated, one from another, by 500–2,000 feet of basaltic lava flows.

In all this core, perhaps 20–30 percent of the individual frothy tops of the lava flows would be found to contain at least a few specks of copper, and one or two of the tops might contain as much as would be found in the average rock of a commercial deposit. This does not mean that a commercial deposit would actually have been intersected, because small scattered shows of copper are hundreds to thousands of times more numerous than major deposits, but the occurrence of much visible copper would encourage further attention to the layer that contained it. One or two of the conglomerate beds intersected might also show traces of copper, though such occurrences would be much less common than traces of copper in lavas.

*History of exploration.*—Indians mined native copper in northwestern Wisconsin in prehistoric times (Sweet, 1880, p. 358), though on a more modest scale than in Michigan. The earliest recorded explorations, in 1846–47, were contemporaneous with the beginning of serious exploration throughout the Lake Superior region. But this and later recorded flurries of exploration activity in Wisconsin (1855–57, 1863–65, 1890–91, and 1898–1902) did not lead to development of any mines or copper production other than copper yielded by mill tests. Individual prospects consist, for the most part, of trenches, test pits, and, at some, one or several shafts a few tens of feet deep. By far the most ambitious exploration in Wisconsin was at the Weyerhaeuser prospect in easternmost Douglas County, 12 miles east of Gordon. The work done here from 1906–13 included 19,374 feet of diamond drilling and 1,950 feet of underground workings, but the results did not encourage further investment.

The search for native copper deposits in Wisconsin since 1913 has been desultory. Minor explorations were recorded in 1916 and 1924. The U.S. Bureau of Mines unwatered and sampled the most promising underground workings of the Weyerhaeuser prospect (A lode) in 1944–45 (Smith, 1947) and of the Chippewa prospect (14 miles southeast of Superior) in 1953 (Holliday, 1955); 157 tons of bulk sample from the Weyerhaeuser contained an average of 0.25 percent copper. Further drilling at the Weyerhaeuser property in 1959 by a mining company was designed to test two other promising copper-bearing layers, but the average copper contents were found to be less than 0.10 percent (Wisconsin Geol. & Nat. History Survey files).

*Resource appraisal and outlook.*—The types of rock in which these deposits occur—basaltic lava flows and the conglomerate beds found between some pairs of flows—underlie a very large area around the western half of Lake Superior in Michigan, Wisconsin, and Minnesota. The area underlain by these rocks in Wisconsin is shown in figure 33.




EXPLANATION

- Mostly sandstone, some shale and conglomerate. These rocks are slightly younger than lavas
- Ancient lava flows roughly 1 billion years old
- Ancient lava flows deeply buried below much younger sandstone
- Rocks older than ancient lava flows
- Rocks older than ancient lava flows deeply buried below younger sandstone
- Rocks of basaltic composition that were injected in a molten condition into the rocks that now surround them. Similar rocks in Minnesota contain copper-nickel deposits that may prove to be commercial
- Line along which copper-bearing shale is at the surface or covered only by glacial deposits
- X Native copper prospects in areas underlain by ancient lava flows (after Grant, 1901)
- * Explorations containing copper sulphides

**FIGURE 33.—Bedrock geology of northwest Wisconsin, showing location of copper prospects.**

Of the native copper produced in the Lake Superior region, 97 percent has come from about 1 percent of the total area in which these lava flows form the principal bedrock, and all the individual deposits that have produced significant amounts of copper are in Michigan. The belt containing these rocks in Michigan is 3–7 miles wide and extends almost 150 miles from Keweenaw Point to the Wisconsin border. All the known major copper deposits lie within a 28-mile segment of this belt, and, except for a small amount from Isle Royale, all the recorded production, including a significant amount from unsuccessful mines and explorations, has come from a 90-mile segment that ends about 40 miles east of the Wisconsin border.

The geologic basis for this remarkable concentration of the rich deposits is only partially understood, but the geologic setting and certain characteristics of the rocks that contain copper deposits in Michigan are sufficiently like those of the rocks in Wisconsin to permit the hope that workable deposits can be found in Wisconsin. The following attributes of the lavas and associated conglomerate beds in Wisconsin are favorable: (1) Visible traces of copper are common; this is also the situation in Michigan, where a few copper stains can be seen in almost every large roadcut in the lavas, but it is not true of the lavas exposed in many other parts of the Lake Superior region or of lavas of similar composition elsewhere in the world. (2) The minerals associated with the copper in the numerous explorations in Wisconsin are the same as those associated with the copper in the Michigan deposits. One goal of future geologic study of the rocks in Wisconsin should be a map showing the distribution of these associated minerals. On such a map of the Michigan district, it can be seen that different combinations of minerals are characteristic of different areas, and that most of the major copper deposits lie close to the boundary separating two such areas. Search for a similar line in Wisconsin could be productive. (3) Without more diamond drilling than has been done in Wisconsin, it is not possible to be sure that the abundance of conglomerate beds and of thick rubbly tops of lava flows is comparable to their abundance in Michigan, but the results of such exploration as has been done certainly do not rule out the possibility. (4) The copper-bearing lavas of Wisconsin are parts of a thick sequence of lavas that once was nearly horizontal. This sheet was later deformed in such a way that it now forms a trough that can be followed southwest from the vicinity of Ashland to Minneapolis-St. Paul. In the northern belt of lava flows shown in figure 33, the individual flows slope southeastward toward the axis of the trough. If it were possible to tunnel down toward the southeast along a single lava flow, the tunnel would go down with gradually decreasing steepness until, at a distance of 10 to 20 miles from the tunnel mouth, and a vertical depth of 2 to 5 miles, the tunnel would be flat. It would then start to rise, and would reach the surface somewhere along the southern belt of lava flows shown in figure 33. It appears to be an important geologic characteristic of the productive district in Michigan that such a tunnel would have an inclination of 25° or more near the surface and would flatten out many miles away and many thousands of feet below the surface. The configuration and dimensions of the trough in Wisconsin suggest that the depths and distances to which individual flow tops may extend are comparable to those that exist in Michigan.

The chief obstacle to exploration in Wisconsin is the size of areas that are deeply and completely covered by glacial deposits. In a few areas, outcrops of bedrock are fairly common, and shows of copper have encouraged prospecting, but these areas have not so far proved to contain commercial deposits. Literally nothing is known, however, of the potential of more than 90 percent of the area underlain by rocks that could conceivably be copper bearing. Geophysical techniques have yet to be found useful in direct surface or airborne detection of native-copper deposits, but can be helpful in establishing the trend of individual lava flows across these areas. Beyond this, however, it is difficult to see how geologic investigation of these large drift-covered areas can be effective without drilling of some sort. A large proportion of the regional geologic information available for the copper-bearing rocks of Michigan comes from drill holes; for 90 miles southwest from Keweenaw Point, very few sections [1 square mile] in which the bedrock is lava flows have less than one drill hole, and some have more than 20.

*Copper in shale*

*Occurrences in Wisconsin*—Copper chemically combined with sulfur occurs in the bottom-most beds of a gray shale formation, 200–700 feet thick, over a large area in Michigan and northwestern Wisconsin. This shale has been named the Nonesuch Shale. If one were to put down a deep vertical diamond-drill hole 20–25 miles west of Ashland, he would expect the hole to pass, successively, through the following materials: (1) 200–400 feet of unconsolidated glacial material, mostly sand; (2) 6,000–8,000 feet of reddish sandstone; (3) 200–300 feet of Nonesuch Shale, possibly with traces of copper in the bottom few inches or few feet; (4) 1,000–2,000 feet of reddish conglomerate; and (5) a series of lava flows, belonging to the group described in connection with the native copper occurrences. If it were possible to follow the Nonesuch Shale sideways away from the point at which it was cut by the drill hole, one would expect it to become deeper and deeper below the surface eastward, and to become shallower northward, westward, and southward. It would reach the surface just beneath the glacial deposits (i.e. 200 feet or more below the land surface) along the dotted line of figure 33. There is no place west of Mellen, Wis., where the Nonesuch Shale can be examined at the surface—it is everywhere covered by glacial deposits along the dotted line where it should reach the surface—but its position is known or can be at least roughly predicted as a consequence of the exploration drilling by the Bear Creek Mining Co. East of Mellen, the shale can be seen at several places where major streams like the Bad, Potato, and Montreal rivers cross the location of the dotted line of figure 33. Throughout the fishhook-shaped area partially enclosed by the dotted line, the Nonesuch Shale is present at depths ranging from near zero to several thousands of feet. Nothing is known about its possible presence in depth north of a line connecting Ashland and the point of the fishhook, but if the shale is present there, geophysical evidence suggests that it is likely to be 10,000 to 20,000 feet below the surface. South and west of the fishhook, all the rocks are older than the Nonesuch Shale, and if the shale was ever present as a blanket overlying these older rocks, it has long since been eroded away.

Copper chemically combined with sulfur, primarily in the mineral chalcocite (a common ore mineral), is generally present at the very base of the Nonesuch Shale. At most places in Michigan and Wisconsin, the copper-bearing layer is less than a foot thick, and places where it is an inch or less in thickness are common. The total amount of copper present is typically very small; at very few places is it equivalent to the amount in a layer 1 foot thick with 1 percent copper. In the vicinity of White Pine, Ontonagon County, Mich., however, the copper-bearing zone ranges up to 50 feet in thickness, and a number of beds in the lowermost 20 feet contain 1 to 4 percent copper. The White Pine deposit is one of the Nation's major copper ore bodies. The hope of discovering similar concentrations of copper elsewhere has prompted drilling programs in both Michigan and Wisconsin.

*Resource appraisal and outlook.*—During the period 1955–1960, the Bear Creek Mining Co. made a thorough search, particularly in the area south and southwest of Ashland, for copper deposits in shale, of the type now being actively mined at White Pine, Ontonagon County, Mich. The locations of 45 diamond drill holes put down during the course of this exploration are shown on map 3 of the series by Dutton and Bradley (1970). This exploration did not lead to any mining activity, but did establish the continuity of certain strata from Michigan westward into Wisconsin.

A little copper stain is visible in the bottom inch or so of the Nonesuch Shale in outcrops northeast of Mellen. The shale contains far more sand than is typical of areas in which the copper-bearing zone is thicker and richer in copper. The shale is steeply inclined, which means that even if the thickness and copper content of the copper-bearing layer increased northward at rates comparable to those found near White Pine, the amount of ore available above, say, a depth of 5,000 feet would be very small indeed.

The detailed results of the drilling by Bear Creek Mining Co. farther west have not been published. The geologist in charge of the exploration did state, in a paper presented orally at a meeting of the Institute on Lake Superior Geology in 1963, that of the 1-foot intervals assayed, the richest found anywhere contained less than 1 percent copper, and the second richest contained less than 0.2 percent copper. The drill core from this program was given to the U.S. Bureau of Mines for storage in its facility at Fort Snelling, Minn., and a number of these cores were examined microscopically by the U.S. Geological Survey. The shales of the Wisconsin area lack certain features that are closely related to copper content in the White Pine deposit. The beds that are rich in copper at White Pine are dark-gray, and the copper minerals are conspicuous; similar dark-gray beds above the copper-bearing zone contain conspicuous iron pyrite. In Wisconsin, the shale is light-gray, and neither copper minerals or iron pyrite are conspicuous in any beds.

The density of drilling in Wisconisin is adequate to establish that no deposit anything like the one at White Pine exists in the explored area. The White Pine deposit is at least 8 miles long and up to 5 miles wide, and if the area of submarginal copper concentration around it is included, it is very much larger still—a very large target indeed. The only area where a large deposit of this type might remain concealed in Wisconsin is east and north of the drilled area, in east-central Bayfield County and northernmost Ashland County; in this region, the Nonesuch Shale lies at depths ranging from 2,000 feet to perhaps as much as 10,000 feet.

*Copper in greenstone belts*

*Occurrences in Wisconsin.*—Other areas in Wisconsin underlain by Precambrian rocks have been of recent interest in regard to exploration for copper-bearing deposits (Dutton and Bradley, 1970; Dutton, 1972). The favorable rocks are layered sequences of light-colored, explosively ejected, mainly fine- to some medium-grained fragmental material; associated rocks are commonly sequences of dark-colored lava flows. The light-colored rocks are generally similar to those that contain significant amounts of copper, lead, zinc, and silver in Ontario and Quebec, Canada.

The earliest known record and collected specimens of copper-bearing material in such rocks in Wisconsin was in 1914 by a Wisconsin Geological Survey party engaged in geologic and magnetic investigations. Specimens of quartzose sericitic rock collected from the bottom of a 50-foot well that was dug 10 feet into bedrock in the SE¼, SE¼, sec. 16, T. 33 N., R. 6 W., contain small amounts of scattered malachite. Two samples from the well were reported (Hotchkiss and others, 1915, p. 169) to contain 1 oz. of silver per ton, and one sample contained 0.75 percent copper but the other had none. An occurrence of similar rock with less evidence of copper was reported to be in a pit 15 feet deep in the northeast corner of the SE¼, sec. 16. A third occurrence is mentioned in the field notes of May 15, 1910, as " 'schistose granite mineralized with copper sulphides and carbonate' from a pit 12 feet deep in the SW¼, NW¼, sec. 15, T. 33 N., R. 6 W." (Dutton, 1971, p. 100). However, recent exploration in T. 33 N., R. 6 W. was not successful in finding commercially valuable amounts of copper mineralization.

All of the areas known to be underlain by the sequences of volcanic rocks have too few exposures to permit determination of the location or even the appraisal of the possible presence of ore. Consequently, additional data are sought by means of airplanes equipped to detect and record variations in the natural and/or artificially generated electrical currents produced in materials possibly associated with copper-bearing minerals in the earth under and adjacent to the flight paths over the areas of interest.

The progressively favorable sequence of—(1) initial geologic appraisal of an area of interest if sufficient data are available, (2) subsequent confirmation by aerosurvey data, (3) negotiations for lease or purchase of desired areas for drilling exploration and possible subsequent mining, (4) results of exploration, (5) estimated costs of mining and recovery of metallic copper, and (6) reasonable assurance of economic feasibility—have led to three discoveries being announced and considered for development. These are the Flambeau deposit near Ladysmith, the Pelican deposit near Rhinelander, and an as yet unnamed deposit near Crandon (fig. 33).

The following information is from the Preliminary Environmental Report for the proposed Flambeau Mining Corp. Copper Mine, Rusk County, Wis., 161 pages, prepared by the State of Wisconsin, Department of Natural Resources, 1975.

Kennecott Copper Corp., through its exploration subsidiary Bear Creek Mining Co., has discovered a minable copper deposit southwest of Ladysmith in Rusk County. The Flambeau Mining Corp., a wholly-owned subsidiary of Kennecott, would be responsible for the mining phase of the project. The company proposes to mine by open pit methods for a period of approximately 11 years which would possibly be followed by an 11-year phase of underground shaft mining. The copper-bearing sulfide ore would be concentrated at the project site. The copper concentrate would be transported out of Wisconsin to be smelted. The open pit would be rehabilitated as a 50-acre lake, and the 186-acre waste containment area (tailings pond) would be revegetated and would form a terraced, flat-topped hill.

The mine site is located in Rusk County in northwestern Wisconsin. The center of the ore deposit is located south of Ladysmith 1.6 miles and 0.2 miles west of Highway "27." The 2,750 acres under control are located in sections 9, 10, 16, 17, 20, 21, and 22, T. 34 N., R. 6 W.

The Precambrian bedrock consists of a complex interfingering suite of volcanic and volcaniclastic rocks now metamorphosed and altered to schists and phyllites. These rocks were probably volcanic flows, ash beds, pumice deposits and volcanic-derived sediments of Middle Precambrian age. Within this complex volcanic pile is a distinctive rock type, a quartz-sericite schist, termed the ore horizon, since it contains the copper ore body. The ore horizon pinches and swells along strike for 15,000 feet and varies in width from 25 to 200 feet. Only the one ore horizon containing the single known ore body has been found.

The ore horizon, because it contains more quartz than the adjoining rocks, has resisted erosion to form a gentle broad northeast-trending ridge in the Precambrian bedrock surface. This bedrock ridge is of great significance to the development and operation of the open pit mine, for it acts as a natural impermeable barrier between the river and the pit located some 300 feet to the east. The buried ridge rises beneath the east bank of the river to reach a subsurface elevation of 1,095 feet under the west pit perimeter. This elevation is approximately 10 feet higher than the average river level.

The Flambeau ore body lies conformably within a quartz-sericite schist and is intimately associated with lenses of metachert. The ore body strikes north 45° east and dips approximtely 70° to the northwest. Diamond drilling has outlined a tabular-shaped massive sulfide deposit 2,400 feet long, averaging 50 feet in width, and extending to 800 feet beneath the surface. Deeper drilling has not intersected economical mineralization. Massive sulfide mineralization, greater than 50 percent sulfide, grades at depth into semimassive sulfides which vary from 20 to 50 percent sulfide. An envelope of disseminated sulfides, predominantly pyrite with minor amounts of chalcopyrite, encloses the ore body and is found along strike within the ore horizon. The width of this pyrite halo averages 110 feet to the north of the ore body but only 55 feet to the south. Contacts between the massive-semimassive ore body and the enclosing rock vary from knife-edge sharp to gradational over 15 to 20 feet. Therefore any improvements in mining technology or higher copper prices would not have an appreciable effect in increasing ore reserves.

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Pyrite is the predominant sulfide mineral. The chief copper mineral is chalcopyrite which is found scattered throughout the pyrite. In the upper or north wall of the ore body the sulfides are crudely banded; however, the character of the mineralogy changes across the ore body as well as with depth. Sphalerite, a zinc sulfide, increases noticeably toward the lower contact of the ore body, imparting a well-banded appearance to the ore body when mixed with pyrite and chalcopyrite. At depth, pyrite decreases, sphalerite is reduced to minor amounts, and the chalcopyrite grains coalesce to form irregular masses. The uppermost 50 to 150 feet of the ore body were enriched in copper during the ancient weathering interval which produced the clay saprolite. Chalcocite is the predominant copper mineral in the upper portion of the enriched zone, whereas bornite predominates in the lower half. The disseminated pyrite halo has been enriched on either side of the massive sulfide vein. Zinc minerals are virtually absent in the enriched zone.

Copper with trace amounts of gold and silver would be produced from the Flambeau ore body. Although small amounts of zinc are found in the lower wall and in satellite lenses beneath the vein, the company reports insufficient tonnage to warrant recovery under present economic conditions.

Relatively little specific information has been published as yet about the massive sulfide deposit discovered near Rhinelander. The following information appeared in a September 1975 issue of the Wisconsin State Journal (Madison). Noranda Exploration Co. notified the Department of Natural Resources of plans to begin copper and zinc open pit mining near Rhinelander. The firm, a subsidiary of Noranda Mines Ltd., of Toronto, found copper and zinc ore in April 1975 in exploratory drilling on land owned by Consolidated Papers, Inc., 8 miles southeast of Rhinelander in Pelican Township. According to Consolidated Chairman George W. Mead II, the start of operations would depend upon environmental and other governmental approval and could take as long as 5 to 7 years. Consolidated would be paid royalties. The area is expected to produce 1,000 tons of ore a day for 10 to 14 years. From other news accounts, this deposit is generally similar to the Flambeau deposit except that the zinc content is significant and recoverable.

In May 1976, the Exxon Corp. announced the discovery of a major massive sulfide ore body 6 miles south of Crandon, Forest County. The announcement reported that zinc-copper ore had been intersected at depths ranging from 417 to 1,387 feet beneath the surface in 10 to 11 drill holes over a length of about 5,000 feet, and may contain around 30 million tons of ore. This estimate would place the deposit among the 10 largest massive sulfide deposits in the United States.

*Outlook.*—The ore-bearing potential of areas known or inferred to be underlain by comparable volcanic host rocks is being examined and tested by a significant number of mining interests. The outlook for additional discoveries appears quite promising.

*Other occurrences in Wisconsin*

Copper mineralization is also present in another geologic setting (Dutton, 1975). Occurrences of predominantly fine-grained chalcopyrite in rocks associated with magnetic cherty iron formation in northern Wisconsin are near Butternut (T. 41 N., R. 1 W.). Twenty-eight drill holes in an area slightly more than 1 mile long and about 800 feet wide penetrated widths of 300 to 700 feet of bedrock. Cores from 16 of 20 drill holes that entered the rocks south of the iron formation for 10 to 200 feet and a median distance of 40 feet contain chalcopyrite. The approximate amount of this mineral in 24 representative core pieces of 2- to 4-inch length ranges from more than 25 grains in 1 specimen from each of four holes, and 5 to 20 grains in 13 specimens in three of above holes and eight additional holes, to less than 5 grains in two of above holes and in four more holes. Only in core from 1 of 12 drilled cross-sections was chalcopyrite not seen.

Chalcopyrite with or without associated pyrite is most commonly present in calcite that occurs as lenses, irregular areas, and fracture fillings in biotite schist that may or may not also contain quartz and locally small garnets.

Semiquantitative spectrographic analyses of 12 pieces of core from eight drill holes in the Butternut area had a range of copper content in parts per million as follows: 2 at 700, 1 at 150, 3 at 100, and 1 each at 70, 20, 15, and 7.

Steeply northward inclined masses of pink granitic rocks that were penetrated by 17 drill holes in 11 of 13 cross-sections, ranged from 10 to 160 feet thick. Traces of chalcopyrite occur on fine chloritic or biotitic seams in the granite. Sparse very fine chalcopyrite is also in recrystallized chert in iron formation from a hole about 2 miles north of Butternut.

The association of sulfides and rock minerals at Butternut are believed to indicate clearly that the constituents of the sulfides were mobile, but no evidence was seen as to whether they were transferred within the host rocks, were partly or mainly derived from the granite, or came from other sources.

A few very fine grains of chalcopyrite are in cores from an iron formation in Iron County near Pine Lake (T. 44 N., R. 3 E.), about 18 miles northeast of Butternut. The rock is chloritic phyllite that has thin layers and lenses of fine-grained quartz or calcite or both. The cores from this exploration have not been examined for the amount, distribution, and geologic relation of the mineralization. Spectrographic analyses of two pieces of core from different holes indicated 100 parts per million of copper.

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## Gold and silver

(By C. E. Dutton, U.S. Geological Survey, Madison, Wis., and W. C. Prinz, U.S. Geological Survey, Reston, Va.)

Gold and silver occur in three distinct geologic terrains in Wisconsin: (1) Precambrian rocks in the vicinity of the Gogebic iron-mining district, (2) ore from the upper Mississippi Valley zinc-lead district, and (3) copper deposits in greenstone belts in the northcentral part of the State. There has been no gold and only a small amount of silver produced in Wisconsin, but significant production of these two metals can be expected in the future as recently-discovered copper deposits in greenstone belts are put into production.

Several areas in and near the Gogebic district were explored for gold and silver in the late 1800's according to sketchy old accounts, mainly the Ashland Press newspaper. Ore from the Northern Belle mine in the W½SW¼ sec. 22, T. 45 N., R. 4 W. was reported to have assayed $90.50 in gold and silver per ton. A mine in sec. 32, T. 45 N., R. 2 E. was reported to have produced 200 pounds of ore containing $164 worth of silver per ton. Samples from the southwest part of sec. 2 and the northwest part of sec. 11, T. 44 N., R. 6 W. contained 0.433 to 0.59 percent copper, 0.36 to 1.74 ounces of silver per ton, and from a trace to 0.004 ounce of gold. Other areas in which exploration activity for gold and silver were reported are in sec. 6, T. 44 N., R. 5 W., and secs. 15, 22, 23 and 34, T. 45 N., R. 4 W., but no assay data were given for these areas. These explorations do not appear to have resulted in any significant discoveries or production.

Lead concentrates and galena from the upper Mississippi Valley zinc-lead district in southwestern Wisconsin contain trace amounts of gold and trace amounts to 3.0 ounces per ton of silver (Heyl and others 1959, p. 95–96). Some silver has been produced as a smelter byproduct during the refining of lead ores from the district, but published production statistics are incomplete and the total amount produced is unknown. There has been no recorded production of gold from the district.

Three copper-zinc deposits have recently been discovered in metamorphosed volcanic rocks or greenstone belts, in northcentral Wisconsin (see Copper and Zinc-lead chapters); similar deposits elsewhere generally contain gold and silver that are recoverable as byproducts of the copper mining. Two of the Wisconsin deposits, the Flambeau deposit near Ladysmith and the deposit near Crandon, are known to contain gold and silver. The other deposit, which is near Rhinelander, probably does also. As these deposits are put into production, Wisconsin can be expected to produce, for the first time, significant amounts of gold and silver.

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## Iron

(By H. Klemic, U.S. Geological Survey, Reston, Va., and C. E. Dutton, U.S. Geological Survey, Madison, Wis.)

*Description and use.*—Iron is one of the widely distributed elements in the earth's crust. The average iron content of the crustal rocks is about 5 percent, and some large rock units contain more than 50 percent iron. Common sedimentary rocks contain 2 to 3 percent iron, and some common igneous rocks contain almost 9 percent. Iron ore, rock mined principally for iron, generally contains from 20 to 69 percent iron. Large quantities of iron ore containing less than 40 percent iron are mined. These require beneficiation (separation of ore minerals from associated minerals) to increase iron content and be economically suitable for recovery of iron metal. The average iron content of ores shipped in the United States in 1970 was 60.64 percent (American Iron Ore Association, 1971).

The extent to which iron ores can be beneficiated at reasonable costs is dependent primarily upon the types and relative amounts of iron-rich minerals present. Iron occurs in a great number of different types of minerals, but three of them—all oxides of iron and containing 60 percent or more iron—are the most important iron ore minerals.

Magnetite ($Fe_3O_4$—3 parts iron and 4 parts oxygen) is the iron-ore mineral having the highest percentage of iron—up to 72.4 percent. It is hard, black, strongly magnetic, and is slightly more than five times as heavy as water. Its magnetic properties make it possible to separate magnetite from associated nonmagnetic iron-poor minerals.

Hematite ($Fe_2O_3$), in pure form, contains 70 percent iron and is black to red, depending upon grain size, or steel-gray if in the crystalline form of specularite. It is hard and dense, being 4.2 to 5 times as heavy as water. Hematite is virtually nonmagnetic relative to magnetite. Some hematite ores are rich enough to be used directly. Differences in density and differences in behavior in liquids used in flotation processes make possible the separation and concentration of hematite from low-grade ores containing iron-poor waste minerals.

Goethite ($Fe_2O_3 \cdot H_2O$) contains up to about 60 percent iron, is yellow to dark brown, hard to soft and earthy, 3.6 to 4 times as heavy as water, and nonmagnetic. The earthy and impure form is called limonite and generally contains lower percentages of iron. Some goethite ores are beneficiated by washing out impurities having lower density. Others are direct-shipping ores.

Impurities in iron ores can be considered to include all undesirable constituents other than iron. For this reason iron ores that have the highest iron content are preferred, but other iron-bearing rocks in which most of the impurities can be separated from the iron-rich minerals form the major part of the ores mined in the United States. Impurities that are major constituents of iron ores are minerals containing silicon, magnesium, aluminum, calcium, and titanium. Undesirable impurities that are minor, but very significant, constituents are minerals of phosphorus, sulfur, zinc, and arsenic. Those of phosphorus and sulfur are the most common.

Beneficiation of iron ores generally involves (1) the separation and removal of valueless minerals with a resulting concentration of the iron-rich minerals and (2) agglomeration of the iron concentrates into briquettes or pellets of suitable size for smelting. Some ore concentrates are sintered into porous agglomerates for furnace feed.

The ratio of some crude ore to iron concentrates is as much as 3 to 1, and the concentrates contain more than 60 percent iron. Pellets made from such concentrates thus have the desirable characteristics of high iron content, low amounts of impurities, and favorable particle size for efficient smelting. For example, pellets produced near Black River Falls, Wis., by the Jackson County Iron Mining Co. in 1970 contained in dry form 63.41 percent iron, 0.016 percent phosphorus, 8.08 percent silica ($SiO_2$), 0.05 percent manganese, 0.29 percent alumina ($Al_2O_3$), 0.33 percent lime ($CaO$) and 0.28 percent magnesia ($MgO$). (American Iron Ore Association, 1971, p. 72.)

Iron deposits of economic value generally form by one of three major geologic processes: (1) magmatic activities involving segregation of molten materials or precipitation from hydrothermal solutions, (2) sedimentary accumulations by chemical precipitation or by deposition of grains of iron-rich minerals, and (3) residual concentrations resulting from the chemical breakdown of iron-bearing minerals and removal of iron-poor constituents, by near-surface-weathering processes or by leaching in the subsurface by permeating solutions. Some deposits form or are enriched as the result of two or more of these processes, and some deposits are changed in mineralogic character and in shape after their initial concentration as a result of later geologic conditions involving changes in one or more conditions of temperature, pressure, physical deformation, and chemical stability.

The iron deposits of economic significance in Wisconsin are principally those formed by sedimentary processes. Some of the deposits have been residually enriched by redistribution of iron or by leaching of impurities, and some have been metamorphosed. For the most part, these changes involve movement of iron or recrystallization of iron minerals within the original beds or layers of iron-rich sedimentary rock.

The locations of iron resource districts and areas in Wisconsin are shown in figure 34.

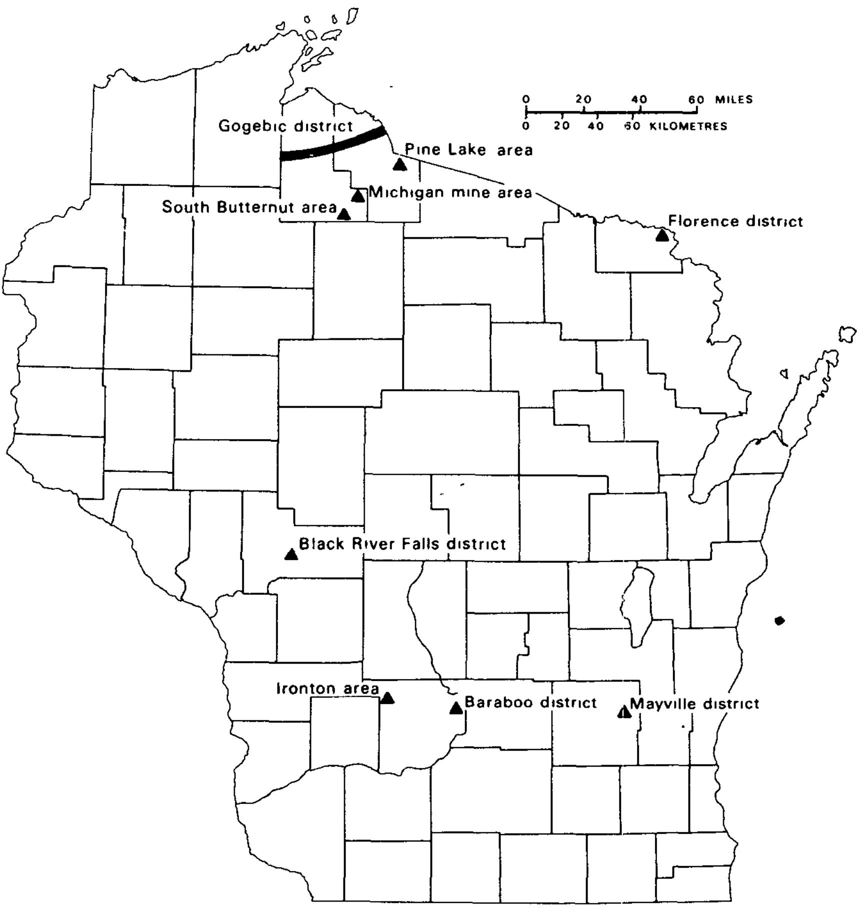


FIGURE 34.—Iron-ore resource areas of Wisconsin.

Most of the large iron deposits are in the sedimentary iron-formations of Precambrian age and were deposited more than 1 billion years ago. Deposits of that origin and age in Wisconsin are in the Gogebic Range, the Florence area, the Baraboo Range, and the Black River Falls area in Jackson County. Other known deposits of Precambrian age have not been brought into production. Some deposits in sedimentary strata of Paleozoic age were formed in the Ordovician Period about 450 million years ago, but those in Wisconsin are not large or of present economic importance.

Iron is the principal metal employed in modern industrial civilization, and more than 99 percent of the iron produced is alloyed with other elements to form steel. Steel is used in a great variety of structural forms, tools, machinery, transportation equipment, containers, and other items for both industrial and consumer needs. There are no practical substitutes for steel in many of its applications.

Vast quantities of steel are produced. Estimated world production of raw steel in 1974 was about 700 million metric tons or slightly more than 771 million short tons. (U.S. Bur. Mines, 1975a, p. 83). U.S. production of about 132 million metric tons (145 million short tons) was 18.8 percent of world production and was second to that of the Soviet Union which produced about 136.3 million metric tons (153 million short tons) or 19.4 percent of world production. (Skillings Mining Review, 1975, Iron and Steel, February 1975, vol. 64, no. 8, p. 22).

World iron ore production in 1974 was nearly 877 million long tons (891 million metric tons). U.S. production of 85 million long tons (86 million metric tons) was about 9.6 percent of world production.

In addition to domestic and imported iron ores, considerable amounts of iron and steel scrap are used in steelmaking. About 49 million metric tons of purchased scrap (54 million short tons) were consumed by the U.S. steel industry in 1974 (U.S. Bur. Mines, 1975a, p. 84). There is a competitive economic relationship between domestic and imported ores and scrap metal.

*Economic importance and development.*—Wisconsin has had continuing iron ore production for about 100 years except for a few years in the 1960's (table 10). The 67 million long tons (68 million metric tons) produced since 1910 was 1.4 percent of the U.S. total production of that period. In recent years, however, production from Wisconsin has been only about 1 percent of domestic production, averaging 900,000 long tons (914,000 metric tons) per year.

Recent and continuing expansion of mining and iron ore pelletizing facilities in the Lake Superior region will increase the amount of domestic production from that area and will increase total U.S. production.

In 1974, 84.5 percent of U.S. iron ore production was from the Lake Superior region, mostly from Minnesota and Michigan (U.S. Bur. Mines, 1976). Iron ore production in Wisconsin in 1974 was nearly 879,000 metric tons (865,000 long tons) of pellets, or slightly more than 1 percent of U.S. production of usable iron ore (U.S. Bur. Mines, 1974). Production was from the open pit taconite mine and pellet plant of the Jackson County Iron Mining Co. near Black River Falls, in Jackson County.

**TABLE 10.**—*Production or shipments of iron ore in Wisconsin*

[Data from reports of U.S. Bureau of Mines, U.S. Mineral Resources, Wisconsin Geological Survey reports, and Lake Superior Iron Ore Association] [1]

| Year | Long tons [2] | Year | Long tons [2] |
|---|---|---|---|
| Prior to 1880 | 372,000 | 1928 | 1,396,000 |
| 1880 | 37,000 | 1929 | 1,792,000 |
| 1881 | 198,000 | 1930 | 1,149,000 |
| 1882 | 276,000 | 1931 | 630,000 |
| 1883 | 62,000 | 1932 | 360,000 |
| 1884 | 35,000 | 1933 | 613,000 |
| 1885 | 48,000 | 1934 | 596,000 |
| 1886 | 152,000 | 1935 | 722,000 |
| 1887 | 389,000 | 1936 | 919,000 |
| 1888 | 337,000 | 1937 | 1,421,000 |
| 1889 | 837,000 | 1938 | 625,000 |
| 1890 | 949,000 | 1939 | 1,174,000 |
| 1891 | 589,000 | 1940 | 1,229,000 |
| 1892 | 790,000 | 1941 | 1,487,000 |
| 1893 | 439,000 | 1942 | 1,548,000 |
| 1894 | 318,000 | 1943 | 1,392,000 |
| 1895 | 664,000 | 1944 | 1,537,000 |
| 1896 | 482,000 | 1945 | 1,296,000 |
| 1897 | 491,000 | 1946 | 1,097,000 |
| 1898 | 677,000 | 1947 | 1,543,000 |
| 1899 | 476,000 | 1948 | 1,469,000 |
| 1900 | 746,000 | 1949 | 1,406,000 |
| 1901 | 739,000 | 1950 | 1,702,000 |
| 1902 | 784,000 | 1951 | 1,745,000 |
| 1903 | 675,000 | 1952 | 1,486,000 |
| 1904 | 483,000 | 1953 | 1,655,000 |
| 1905 | 1,719,000 | 1954 | 1,429,000 |
| 1906 | 2,033,000 | 1955 | 1,886,000 |
| 1907 | 839,000 | 1956 | 1,488,000 |
| 1908 | 734,000 | 1957 | 1,576,000 |
| 1909 | 1,067,000 | 1958 | 867,000 |
| 1910 | 1,150,000 | 1959 | 701,000 |
| 1911 | 560,000 | 1960 | 1,502,000 |
| 1912 | 1,152,000 | 1961 | 1,122,000 |
| 1913 | 896,000 | 1962 | 1,045,000 |
| 1914 | 592,000 | 1963 | 938,000 |
| 1915 | 1,125,000 | 1964 | 524,000 |
| 1916 | 1,529,000 | 1965 | 141,000 |
| 1917 | 1,180,000 | 1966 | ---------- |
| 1918 | 1,168,000 | 1967 | ---------- |
| 1919 | 882,000 | 1968 | ---------- |
| 1920 | 1,067,000 | 1969 [3] | 36,000 |
| 1921 | 118,000 | 1970 | 806,000 |
| 1922 | 795,000 | 1971 | 824,000 |
| 1923 | 831,000 | 1972 | 887,000 |
| 1924 | 786,000 | 1973 | 956,000 |
| 1925 | 935,000 | 1974 | 865,000 |
| 1926 | 1,241,000 | | |
| 1927 | 940,000 | Total | 84,966,000 |

[1] Statistics concerning production and shipments differ in some reports—larger figures used in such cases.
[2] Figures rounded.
[3] Pellets.

Iron ore reserves in the United States are estimated to be more than 9,000 million tons, and identified resources, including both reserves and potential ores total more than 100,000 million tons (Klemic and others, 1973a). Of these resources, about 78 percent are in the Lake Superior region, in the States of Minnesota, Michigan, and Wisconsin. Most of the iron ore resources of the United States are in low-grade material that requires both beneficiation and agglomeration to be usable.

The United States has imported about one-third of the iron ore it has consumed in recent years (about 48 million long tons or 49 million metric tons in 1974). Iron ore production in Wisconsin in recent years has been equivalent to only about 2 percent of the amount of iron ore imported.

The selection of specific deposits or parts of deposits for more detailed evaluation or for development for production is based upon the relative advantages to be gained in each case. Not only must the quantity and quality of the ore in the deposits be determined, but their physical setting and geographic location relative to transportation systems and markets must be considered. Only those parts of the total resources that are chosen for development and production are considered to be reserves. That is, reserves are known, identified deposits of mineral-bearing rock from which the mineral or minerals can be extracted profitably with existing technology and under present economic conditions (Klemic and others, 1973a, p. 2). The remainder of the identified resources is only potential ore.

The classification of iron resources as reserves or as potential ores is not a static matter. As economic considerations change, or as the technological developments in steelmaking result in changed specifications for iron ores, some mines may be closed and mine plants dismantled, even though their resources have not been exhausted. Such resources are reclassified to the status of potential ores and are no longer reserves. Other deposits which previously had not been competitive and were only potential ores may be reevaluated and developed for production and reclassified as reserves.

*Occurrences in Wisconsin.*—Gogebic district: The Gogebic iron-mining district, extending southeastward for about 50 miles along the outcrop zone of the Ironwood Iron-formation from 6 miles west of Mellen, Wis., to 6 miles west of Lake Gogebic in Michigan is one of the major iron-bearing districts of the Lake Superior region. The part of the district in Wisconsin extending west from the State border at Hurley is about 30 miles long and about 0.2 mile wide. The Ironwood Iron-formation, the ore-bearing sequence, ranges in thickness from about 400 to 1,000 feet. It is steeply inclined, dipping about 60 degrees to the north, and in places has been offset by transverse and longitudinal faults and intruded by mafic dikes and sills (Dutton, 1955).

The Palms Formation, a metasedimentary unit 400 to 500 feet thick, consistingly mainly of greenish gray silty argillite, underlies the iron-formation. Overlying the iron-formation is the Tyler Formation, a light to dark gray metasedimentary sequence that is mainly clayey siltstone, but which includes sandstone and hardened clay or silt, and has a basal iron-rich zone that has locally been mined for iron ore (Schmidt, Robert G., 1975, written communication). The thickness of the Tyler Formation in Wisconsin is as much as 9,500 feet.

The Ironwood Iron-formation was formed principally by chemical sedimentation, but some fragmental sediments and material of organic origin are also present (Schmidt, Robert G., 1975, written communication). The Ironwood Iron-formation is of Precambrian X age (1,600 to 2,500 million years) and is probably correlative with the Negaunee Iron-formation of the Marquette district and the Vulcan Iron-formation of the Menominee district (James, 1966).

Five distinctive members of the formation, characterized by the predominance of either thick, wavy-bedded cherty iron formation or thin straight-bedded iron-formation were recognized by Hotchkiss (1919). Chert or fine-grained quartz, siderite, hematite, magnetite, chamosite, and stilpnomelane are the principal minerals in the unmetamorphosed and low-grade metamorphosed zones in the formation (Schmidt, 1975). Iron silicates including stilpnomelane, minnesotaite, grunerite-cummingtonite, and iron pyroxenes are present in the more metamorphosed parts of the formation near the western end of the district near intrusive mafic bodies. The iron content of various parts of the formation ranges from about 26 to 33 percent. High-grade iron deposits within the formation resulted from oxidization and leaching of iron-rich carbonates and silicates by deeply circulating waters principally in structurally controlled zones along the intersections of mafic dikes and iron formation. The ore bodies formed mostly above the crosscutting dikes, but some occur elsewhere in the iron formation. Ore was found at the surface in some areas and some ore has been mined at depths as great as 3,500 feet (Dutton, 1955). Large quantities of hematite ores from such ore bodies averaged more than 52 percent in iron.

Iron ore shipments from the Gogebic district in Michigan and Wisconsin from the start of mining in 1884 through 1967 totaled 320 million long tons of which about 65 million long tons (66 million metric tons) was from the part of the district that is in Wisconsin.

In the Wisconsin part of the Gogebic district, most of the productive ore bodies were in Iron County; but some ore was also mined near Mellen in Ashland County. The principal mines, the Montreal and Cary, were in Iron County, and produced roughly 30- and 15-million long tons, respectively, of usable ore. Other important mines were the Ottawa, Atlantic, Iron Belt, Germania, and Pence mines. The Ottawa mine yielded nearly 4-million long tons and the others less than 2-million tons each. Most of the smaller mines were closed by 1913, but the Montreal and Cary mines were in production up to the mid-1960's.

Some high-grade ore remains in the district, but the greatest amount of potential ore is in lower grade partly oxidized but unleached iron formation.

Only a limited amount of information is available concerning the potential iron ore resources that exist in low-grade material in the iron formation. Investigations were made by the U.S. Bureau of Mines (Zinner and Holmberg, 1947) of the character and amenability for beneficiation of some of the iron formation in Iron County, Wis. The results of their investigations indicated that material from certain parts of the iron formation could yield iron ore concentrates, but that the concentrates were somewhat higher in impurities than was generally acceptable. More than 100 million tons of such iron-bearing material that could be mined by opencut methods were reported to be present in the 2-mile length of the district that was in the area of their studies. Extrapolation of their results to include the entire length of the district in Wisconsin would suggest that there are more than 2,000 million tons of low-grade material.

It is likely that the potential resources are considerably larger because the iron formation in the western part of the district contains a greater percentage of the iron in the form of magnetite, and because of advances made in the technology of mineral beneficiation in the past two decades. Potential ore in the Gogebic district has been estimated at 7,750 million tons (Roberts and Crago, 1948), but this included both the Wisconsin and Michigan parts of the district.

The area of potential magnetic iron resources remaining in the Gogebic district extends for about 18 miles southwest of Upson, and the approximate width is about 300 feet. However, about 20 percent of that material would not be recoverable because of associated waste rock such as (1) interbedded slate, (2) masses of intrusive rock, (3) excessively broken rock produced during displacement of rock segments, and (4) material in which percolation of water has altered the iron formation and destroyed magnetism. Furthermore, the inclination of the iron formation locally steepens, and the minable width correspondingly decreases. Additionally, the fineness of grinding of the rock needed for liberation of the magnetic material and the percent of recovery are not known.

Butternut—Pine Lake area: Discontinuous elongate segments of Precambrian age iron-formation trend northeasterly from Pine Lake in Iron County and from near Butternut in Ashland County, Wisconsin (Dutton and Bradley, 1970). The northern area, called the Marenisco Range, and the southern one, the Turtle Range (Allen and Barrett, 1915), are characterized by magnetic anomalies present locally in zones extending to near Marenisco in Gogebic County, Mich. Most of these parts of Wisconsin and Michigan are covered by glacially deposited sediments and the presence of the iron-formation was determined mainly by exploratory drilling at the sites of the magnetic anomalies. At one site, a shaft was sunk into the iron-formation and in other places iron-formation was found in outcrop and in loose boulders.

Early exploration in the area, before 1915, was in search for deposits of high-grade ores, but no such material was found. In the period from 1955 to 1966, exploratory drilling based on data from magnetometer surveys was to appraise the quality and quantity of iron-formation suitable for concentration into marketable ores. Iron-formation containing magnetite as the principal iron-rich mineral was present at several localities, and magnetite-hematite iron formation, hematite-siderite iron formation, and ferruginous slates were also found (Dutton and Bradley, 1970, p. 9).

The rock types most commonly associated with the iron-formation are micaceous and chloritic schists; and locally phyllites, black slate, quartzite, and greenstone are present. Granite and diabase cut some of the iron-formation. Ages of 1.72 billion years for a schist unit and 1.66 billion years for a granite have been reported (Goldich and others, 1961, p. 105). Some of the iron-formation may be in remnants of synclinal folds, or in fault segments, but other parts may be lenses or locally magnetic parts of larger rock units.

In the south Butternut area a magnetic anomaly about 2 miles long trends southwesterly from the town of Butternut in T. 41 N., R. 1 W., in Ashland County. Diamond drilling in the area extended for 5,700 feet along the anomaly, and bedrock was penetrated for a width of as much as 630 feet (Dutton and Bradley, 1970). Overburden in the area averages 125 feet in thickness. The area tested is largely underlain by steeply southeastward dipping iron-formation bounded on the north and south sides by schists and granites. The iron-formation contains fine-grained hematite and specular hematite in association with chert or jasper. Quartz-garnet-biotite schists occur between some areas of iron-formation, and some masses of granite penetrate the iron-formation.

Data concerning the quantity and magnetic iron content of the iron-formation are not available, but if an average width of 300 feet is assumed for a length of 1 mile, to a depth of 500 feet from the surface, the area would contain an estimated 50 million tons of iron-formation. This amount of minable iron-formation might be expected to yield more than 15 million tons of magnetic concentrates.

The Michigan mine area, which is in T. 42 N., R. 1 E., about 10 miles northeast of the town of Butternut in Ashland County, includes the site of the former Broomhandle and Michigan mine explorations; the latter was reexamined by private interests in the period from 1953 to 1958 (Dutton and Bradley, 1970). Diamond drilling was in an easterly trending area about 13,500 feet long and up to 1,200 feet wide, to an average depth of about 350 feet, lying east of the old Michigan mine shaft. Steeply dipping to vertical iron-formation ranging in width from about 23 feet to more than 1,100 feet was penetrated along a length of about 2 miles. Glacial till in the area averages about 30 feet in thickness. Phyllites, schists, and greenstone porphyry adjoin the iron-formation to the north and chlorite schists with calcite beds and marble and greenstone occur to the south.

The iron-formation in outcrop, at the old mine shaft and test pits, sampled by drilling, and on dumps of a pit excavated to get material for metallurgical testing, consists of chert, magnetite, and specular hematite distributed in an alternation of ferruginous and cherty layers that differ greatly in thickness and in relative proportions of the various minerals. The total iron present in crude iron-formation commonly was 25 to 30 percent, but the magnetic iron represented only 15 to 25 percent of the iron-formation. The estimated tonnage of iron-formation to a depth of 400 to 500 feet is more than 200 million tons, and the amount of iron ore pellets containing more than 62 percent iron that possibly could be produced from the crude ore is estimated to be about 70 million tons (Skillings Mining Review, 1957).

The Pine Lake area is about 12,000 feet long and up to 800 feet wide in T. 44 N., R. 3 E. It is just east of Pine Lake and about 15 miles south of the Gogebic district, and was explored in the period 1954 to 1963 by diamond drilling. Schist and iron-formation are beneath a cover of 35 to 100 feet of glacial overburden. The iron-formation contains magnetite, hematite, siderite, iron-rich silicates, and chert. Analyses of drill core from the upper part of the iron-formation show values of 23 to 33 percent soluble iron but commonly had only 20 to 25 percent of magnetic iron. Concentrates of finely ground material averaged about 62 to 66 percent iron and about 8 to 12 percent silica. Drill cores from oxide-carbonate-silicate iron-formation zones contained 22 to 26 percent of soluble iron, but only 11 to 15 percent of magnetic iron, and locally as little as 1.35 percent magnetic iron. The total thickness of the iron-formation is not known, but one section is about 1,900 feet thick. How much of this thickness is caused by folding or faulting is not known.

The quantity of iron-formation present to depths reasonable for open-pit mining is estimated to be in hundreds of millions of tons, but information concerning the amount of ore that would be economically amenable for beneficiation to a usable product is not available.

Florence district: This district, extending southeastward for about 25 miles along the north side of Florence County, Wis., is at the southeastern end of a roughly triangular-shaped basin of metamorphosed and complexly folded sedimentary rocks of Precambrian age. The Iron River-Crystal Falls district to the northwest in Michigan is in the much larger part of the basin.

The Riverton Iron-formation, the principal iron-rich unit in the Florence area, is about 600-feet thick and consists mainly of interbedded chert and siderite (Dutton, 1971). It also contains local zones of chert, hematite, and magnetite (Pettijohn and Clark, 1946). Unoxidized parts of the iron-formation contain 20- to 30-percent iron. Enriched ore bodies formed by oxidation and leaching of the iron-formation were in plunging synclines and along the flanks of those structures. Ore was found to depths of 825 feet in the Florence district. The oxidized ore bodies tend to occur in low swampy areas, whereas the unoxidized iron-formation crops out at the surface in some areas. However, much of the iron-formation is not exposed in outcrop.

The Riverton Iron-formation is underlain by the Dunn Creek Slate; it is a sequence of phyllite, graphitic slate and breccia, and graywacke about 2,500 feet thick. It also includes some layers of slaty sideritic iron-formation and immediately beneath the iron-formation is about 30 feet of pyritic graphitic slate that typically contains 30- to 40-percent pyrite (James, 1958).

The Iron River Iron-formation is overlain by the Hiawatha Graywacke that is a clastic rock unit consisting of about 100 feet or less of graywacke and slate in the Florence district in the eastern part of the basin. The Stambaugh Formation overlies the Hiawatha Graywacke and is mainly iron-rich rocks that range from chloritic mudstone and slate to laminated chert-siderite-magnetite rock (James, 1958). In the Florence district, the Stambaugh Formation is about 200-feet thick (Dutton, 1971). The overlying Fortune Lake Slate is the youngest unit in the area; it contains minor iron-rich rocks in Michigan, but none are known in Wisconsin.

Mining in the Florence district began in 1880 and continued with some interruptions to 1932. A small quantity of ore was shipped from the district in 1937 (Lake Superior Iron Ore Association, 1938), and the Davidson mine in the Commonwealth area was worked from 1952 to 1960. Total shipments from the district through 1937 were 7,274,000 long tons; the natural ores contained 48- to 50-percent iron. Production was from the Commonwealth, Ernst, and Florence mines—all in T. 40 N., R. 18 W. The ores were high phosphorus non-Bessemer grade (more than 0.18-percent phosphorus). Production from the individual mines or groups, in long tons, was Commonwealth group—2,923,010, Ernst mine—670,183, Florence mine—3,680,601.

Exploration by drilling and sinking test pits in areas along strike from the previously productive mines has not been successful. The potentialities for discovery of additional large bodies of high-grade ore or large resources of low-grade ore amenable to beneficiation by present methods do not appear to be favorable (Dutton, 1971).

Black River Falls district: This iron mining district is in Jackson County, in T. 21 and 22 N., R. 3 and 4 W., and is within the Hatfield and Black River Falls 15-minute quadrangles. The Jackson County Iron Co. mine, which is currently in operation, is located about 5 miles east of the town of Black River Falls.

The rock formations in the area include an underlying complex of steeply dipping granitic gneisses, schists and greenstones, and intrusive mafic dikes and bodies of granite of Precambrian age (Chamberlin, 1877). The surface of the Precambrian rocks has been eroded to a broad regional plain that locally has hills or monadnocks having relief of 100 feet or more. A pronounced unconformity separates the Precambrian rocks and the overlying sequence of flat-lying sandstone beds of Late Cambrian age.

The iron deposit being mined is metamorphosed siliceous magnetite-hematite iron-formation, or taconite, of Precambrian age that formerly cropped out in an elongate mound extending about 100 feet above the surrounding plain. Sandstone of the Mount Simon Formation of Late Cambrian age covered most of the mound and underlies the surrounding area to depths up to about 100 feet. The iron-formation is as much as 500 feet wide, and has a length of more than 2,000 feet, and has been drilled to depths of several hundred feet. Siliceous micaceous schists occur on both flanks of the iron-formation and thin lenses of schist containing actinolite, garnet, and talc are interbedded with the iron-formation. The content of magnetic iron in the deposit ranges from 15 to 35 percent and averages about 25 percent (Ohlson, 1973).

Five other mounds of Precambrian iron-formation crop out in the district, and iron-formation is known to occur beneath the Cambrian sandstone in other places where magnetically anomalous areas have been drilled. The iron-formation may be in remnants of tightly folded structures or in fault segments of such folds. Granite which intrudes the metamorphosed Precambrian rocks in the area has been dated as being about 1.69 billion years old (Klemic and Peterman, 1972) but may be somewhat older. Granite intruding iron-formation has been found near one of the mounds, so the iron-formation can be considered to be older than the granite, but its actual age is not known. Unmetamorphosed diabase dikes also cut the iron-formation and associated Precambrian rocks.

The iron deposits of the Black River Falls district were discovered in 1839, were worked briefly in 1856 and 1857, and between 1880 and 1890 (Skillings, 1970), with only limited success. In 1939 the Inland Steel Co. purchased the Jackson County Iron Co. Exploration and testing of the deposits were in the 1940's and 1960's, and construction of the mine and beneficiation plan facilities was begun in 1967. Production of iron ore pellets began in 1969 and is continuing. Initial plans were announced for the production of 750,000 tons of pellets for a period of 20 years, but production in recent years has averaged about 900,000 long tons (914,000 metric tons) per year. The iron ore concentrates produced average about 68-percent iron and 5.5-percent silica (Ohlson, 1973), and the pellets contain about 63.5-percent iron (Skillings, 1970). Reserves in the district at the start of production are estimated to have been about 45 million tons of crude taconite and about 30 million tons remain. Some of this reserve is in deposits that are not adjacent to the beneficiation and pelletizing plant, and the economics of future operations may affect how much of the ore can be mined.

Baraboo district: The Baraboo district is in Sauk and Columbia Counties about 31 miles northwest of Madison. It is within a 28-mile-long synclinal basin of metamorphosed Precambrian sedimentary rocks that trends easterly (Dalziel and Dott, 1970). The iron-bearing unit, the Freedom Formation, is within a basin that is about 22 miles long and as much as 6 miles wide. The area underlain by the Freedom Formation is within T. 11 N., R. 5, 6, 7, and 8 E., but most of the exploration and all of the mining was within T. 11 N., R. 5 and 6 E. (Weidman, 1904; Schmidt, 1951, unpublished thesis). Most of the interior of the basin and all of the area underlain by the Freedom Formation are covered by relatively flat-lying Paleozoic sedimentary rocks and Pleistocene sediments to depths of as much as 700 feet (Schmidt, 1951).

The Freedom Formation is a dolomitic unit that includes interbedded slate and chert and contains iron-bearing dolomite and manganese- and iron-bearing dolomite near the base. Iron silicates and magnetite formed in the basal part of the formation by metamorphism, and later oxidation resulted in the development of rock very similar to the oxidized iron-formations of the Lake Superior region (Schmidt, 1951). Some parts of the iron-formation have been oxidized, leached, and formed ore bodies that yielded ores containing 47 to 54 percent iron (Lake Superior Iron Ore Association, 1938).

The Seeley Slate, consisting of about 370 feet of chloritic slate and some lenses of quartzite, underlies the Freedom Formation and overlies the Baraboo Quartzite which is a few thousand feet thick. A quartzitic unit as much as 214 feet thick and a sericitic slaty unit up to 149 feet thick were reported to overlie the Freedom Formation (Leith, 1935) in some places, but elsewhere the Freedom Formation is overlain by Paleozoic sedimentary rocks.

Iron-formation was discovered in the Baraboo district in 1887; iron ore was discovered in 1900. Mine development began shortly afterward; and, with some interruptions, ore shipments were made in the period from 1904 to 1925. Shipments from the Illinois mine in the period 1904 to 1908 and in 1916, totaled 315,350 long tons (320,000 metric tons), and those from the Cahoon mine in the period 1916 to 1925 were 327,683 long tons (337,000 metric tons). Data on shipments from the Sauk mine opened in 1903 are not available, but the total amount of ore shipped from the Baraboo district may have been 1 million tons (Schmidt, 1951). The ores contained 47 to 54 percent iron and included low phosphorus and non-Bessemer ores. Some of the ore bodies may not have been totally depleted, but excessive amounts of water in the mines may have stopped operations.

The possibility exists that more ore bodies of the same type are present in the district, but no estimate of the amounts can be made. On the basis of thickness and extent of the iron-formation, there may be at least 50 million tons to a depth of 100 feet beneath the cover of Paleozoic sediments in the western part of the district (Van Hise and Leith, 1911) but much of this may not be amenable to beneficiation. The potential resources of low-grade iron-formation in the central and eastern parts of the district may be comparable.

Mayville district: The Mayville iron-bearing district is in Dodge County; and the formerly productive mines were near the towns of Mayville. Iron Ridge, and Neda, in T.11 N., R.16 E. The iron-bearing unit, the Neda Formation, crops out sparsely in Dodge, Brown, and Door Counties. and is known to be present locally in the subsurface in Kenosha, Racine, Waukesha, Washington, Fond du Lac, Calumet, Brown, and Manitowoc Counties (Thwaites, 1912).

The Neda Formation is of Ordovician age. It is above the Maquoketa Shale and beneath the Mayville Dolomite of Silurian age, and is in a sequence of sedimentary strata that dip very gently to the east. The iron-rich beds of the Neda Formation occur in broad lenses having areas measured in square miles and range in thickness from a few feet to as much as 55 feet (Thwaites, 1912; Percival, 1855b; Chamberlin, 1877). They crop out at the foot of a bluff of dolomite near Iron Ridge.

The ore zones consist of hematite-rich oolitic or flaxseed textured rock having a hematite matrix. The oolites are composed of a large variety of minerals that are in concentric layers around nuclei of fossil material, rock and mineral fragments, or fragments of oolites. The oolites are composed of goethite, hematite, phosphatic minerals, clay minerals, and carbonates (Hawley and Beavan, 1934). The iron ores contain 40 to 47 percent iron; iron-rich strata in some other places contain about 34 percent iron and are high phosphorus ores (Thwaites, 1912; Lake Superior Iron Ore Association, 1938).

Mining in the Mayville district began as early as 1849, when ore from deposits that cropped out at the foot of a bluff of dolomite was removed from an open cut to supply a furnace at Mayville (Chamberlin, 1877). Later mining extended into the subsurface. In the period 1869 to 1874, about 305,000 tons were produced. The Iron Ridge mine was inactive from 1892 to 1902. From 1902 to 1914 production was about 236,000 tons. Total production from the Iron Ridge mine was more than 540.000 tons.

The Mayville mine, an underground operation that was opened in 1892 and worked continuously until 1928, shipped about 2,144,000 tons of ore (Lake Superior Iron Ore Association, 1938). Ore from the Iron Ridge mine in 1914 contained about 41 percent iron and 1.22 percent phosphorus, and that from the Mayville mine in 1928 contained about 39.5 percent iron and 1.3 percent phosphorus.

Potential resources of iron in the Neda Formation in eastern Wisconsin are not known, but it is likely that some lenses of ore in the subsurface contain millions of tons in minable thicknesses. The ores, however, would have to be mined by underground methods; and it is unlikely that beneficiation to the grades acceptable at present would be possible.

Ironton area: A small deposit of iron ore was worked in the vicinity of Ironton in Sauk County in the period between 1850 and 1873 (Chamberlin, 1882) but is now only of historic interest. The deposit was on the side and base of a hill underlain by Paleozoic sedimentary rocks in T.12 N., R.3 E. The ore was hematite in botryoidal and stalactitic shapes intermingled with a rubble of sandstone and sand. The hematite probably formed from iron that was released by the decomposition of pyrite and transported by solution to sites of deposition in fractures in Cambrian sandstone.

The deposit yielded about 25,000 tons of ore which supplied a furnace at Ironton that produced about 11,000 tons of iron.

Similar iron deposits in Richland, Crawford, Pierce, and Vernon Counties are of no economic importance. No estimate is made for amounts of potential resources in deposits of this type.

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## Molybdenum

(By C. E. Dutton, U.S. Geological Survey, Madison, Wis.)

Molybdenum is a metal of silver-gray color and is obtained from minerals in which it is combined with sulfur or with iron and oxygen. Molybdenum is used mainly for the manufacture of stainless steel, high-speed steel, and construction steel. The principal molybdenum-bearing deposits of the world are associated with intrusive rocks much younger than any rocks in Wisconsin.

Molybdenite, the combination of molybdenum with sulfur, occurs in very small amounts in Wisconsin; furthermore, the geologic occurrences are not similar to those at the principal known sources of molybdenite. The following information is from an open-file report prepared by D. Jerome Fisher for the U.S. Geological Survey and released June 26, 1957; a copy is in the files of the Wisconsin Geological and Natural History Survey.

A small area of granite exposures near the middle of sec. 18, T.33 N., R.20 E. is about 4 miles northwest of the small community of Middle Inlet in Marinette County (fig. 29). Scattered grains and small clusters of grains of molybdenite are in quartz veins and locally in adjacent altered granite. Ten prospect shaft openings were made in 1939–42, and about 2,000 tons of rock were removed. The resulting molybdenite concentrate weighed 6,094 pounds and contained 47.82 percent molybdenum and 0.04 percent copper.

Another occurrence of molybdenite is in the north-central part of sec. 33, T.38 N., R.18 E. (fig. 29), which is about 4 miles south of Aurora, in Florence County. Six test pits were in granite exposures in an area about 700 feet long and from 100 to 400 feet wide. The rock exposed is mainly mica schist and locally gneiss; white feldspar crystals about one-half by 1 inch are irregularly distributed and constitute about 50 percent of the rock. Most pegmatites (coarse-grained granitic vein-like units) are parallel to layering in the schist and gneiss and cut across pegmatities of other directions. Some flakes of molybdenite are in the mineral quartz at the pits but are less common at the other exposures.

## Uranium-thorium

(By R. W. Schnabel, U.S. Geological Survey, Denver, Colo.)

Uranium is a heavy, silvery metal that has few uses except as a source of energy. Some minor uses are in various laboratory applications, in the photographic industry, and in coloring glass a fluorescent yellowgreen.

The only known occurrence of uranium in Wisconsin is in one fragment of a quartz pebble conglomerate found near Mt. McCaslin (fig. 29) (secs. 35 and 36, T.34 N., R.16 E.) in the northeastern part of the State, but further investigations in that area have not found similar material. The fragment was reported to contain 0.44 percent equivalent uranium and 0.75 percent uranium. The rock containing the uranium is similar to that in a uranium deposit in an area of Canada just north of Lake Huron.

Geologic conditions comparable to those bearing important uranium deposits elsewhere in (1) sandstone lenses in shales, (2) conglomerates, and (3) filling of fractures in rocks are not known at the surface in Wisconsin. However, large areas of north Wisconsin are underlain by some rocks similar to those bearing uranium in Canada.

Like uranium, thorium is a heavy, silver-gray metal, is a source of radioactive products, is a possible nuclear fuel, and is more common and widely distributed than uranium. The present industrial value of thorium is combining with other metals to permit them to be drawn into wires and threads. Thorium-bearing rocks in Wisconsin are of igneous or sedimentary origin; none are of commercial interest at present.

Granite near Big Falls (T.25 N., R.12 E.) has local radioactivity along zones of more than normal amounts of dark colored minerals. Scattered pits and drill holes contained 0.01 to 0.02 percent $U_3O_8$, and the best sample was 0.08 percent $U_3O_8$. The average of two composite samples in the vicinity of the pits and drill holes averaged 77.2 ppm (parts per million) $eThO_2$ (equivalent thorium plus oxygen) and 65.7 $eU_3O_8$ as determined by spectrometric assay (Malan and Sterling, 1969, p. 11). Large areas of central and northern Wisconsin are underlain by rocks similar to those at Big Falls but are covered by glacially transported debris. Present methods of detecting covered deposits of radioactive minerals are not practical.

In unglaciated southwestern Wisconsin, several radioactive anomalies in Monroe County were investigated. Analyses of 11 samples from the Tunnel City group of strata indicated 1 to 6 ppm U and 40 ppm eU that probably resulted from $K^{40}$. Another sample contained 5.3 ppm $ThO_2$, 1.5 ppm $U_3O_8$, and 7.6 percent K by gamma spectrometric assay (Malan and Sterling, 1969, p. 14).

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## Zinc and lead

(By W. S. West, U.S. Geological Survey, Platteville, Wis., and R. A. Weeks, U.S. Geological Survey, Reston, Va.)

The zinc and lead mines of southwestern Wisconsin are part of the oldest continuously producing lead-zinc mining district in the United

States, the upper Mississippi Valley district. The largest and most productive parts of this district (fig. 35) extend across five Wisconsin counties and into small areas in Illinois and Iowa, and widely scattered minor deposits extend the area of known mineralization in all directions far beyond the limit of the mining district, suggesting that the total area of mineralization is much larger than the mining district. This widespread mineralization plus the fact that there has been limited exploratory prospecting for mineral deposits by drilling or other means within and beyond the boundary of the main mining district gives every reason to believe that new ore bodies and important unmined extensions of ore deposits will be discovered, thus assuring a future for zinc-lead mining in southwestern Wisconsin. In addition, recent discoveries of copper-zinc mineralization in north-central Wisconsin suggest that the State's zinc production may increase significantly in the next few years.

As shown in table 11, over 1.2 million tons of zinc and nearly 100,000 tons of lead have been recovered from the Wisconsin portion of the Upper Mississippi Valley district from 1910 to 1974, with a combined value in excess of $267 million. Value and tonnage of the early produc-

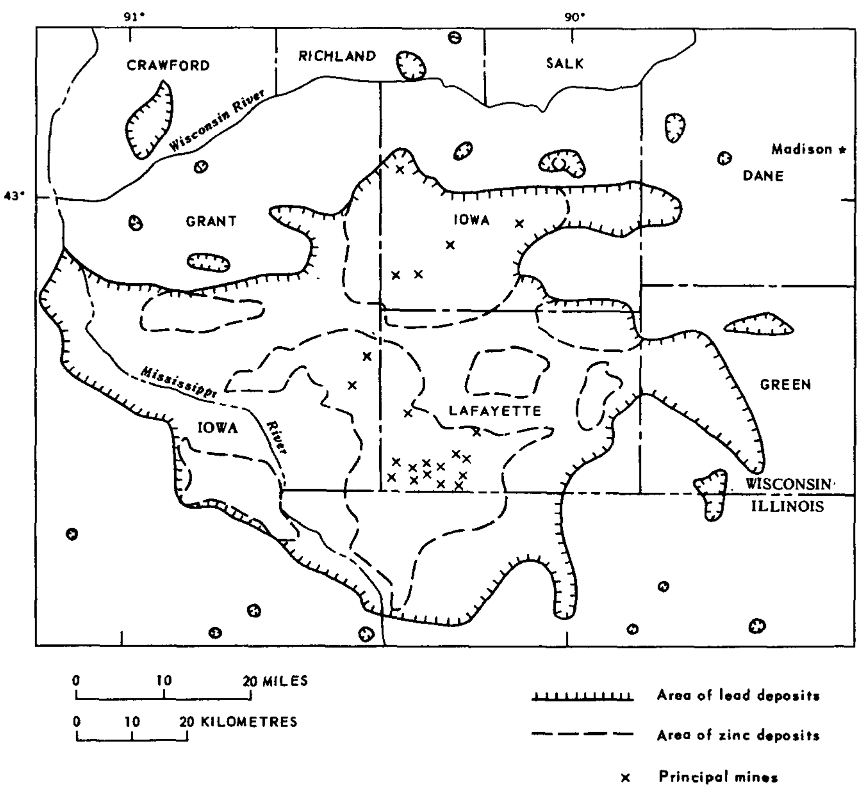


**Figure 35.—Map of main part of Upper Mississippi Valley zinc-lead district in Wisconsin and adjacent States. Modified from Heyl and others, 1959, fig. 73, and Heyl and others, 1955, pl. 1.**

tion are not known accurately but estimated production given by Heyl (1959, table 1) suggests an additional 250,000 tons of zinc and 350,000 to 400,000 tons of lead were produced in the Wisconsin part of the district in the period following 1800.

Lead is one of the metals earliest known to man, largely because of the ease with which it can be won from its ores by smelting. Its softness and workability, high specific gravity, extreme resistance to corrosion, and a combination of low-melting and high-boiling point make it most useful. About 10 percent of its uses are based on its weight, some 30 percent is based on its softness, malleability, and resistance to corrosion, about 25 percent is attributed to its alloying properties while the remainder of its uses are related to specific properties of its chemical compounds. Nearly three-fourths of its use is in metallic form, alone or in lead-based alloys. Two major uses are in storage batteries and antiknock additives for gasoline, so that consumption is directly related to automotive transportation. Other significant uses include pigments, cable sheathing, construction materials, ammunition, and chemical compounds.

TABLE 11.—ANNUAL TONNAGE AND VALUE OF ZINC AND LEAD METAL PRODUCTION IN WISCONSIN, 1910-74

| | Zinc | | Lead | |
|---|---|---|---|---|
| | Short tons | Value | Short tons | Valu |
| Year: | | | | |
| 1910 | 25,927 | $2,800,000 | 4,325 | $381,000 |
| 1911 | 29,720 | 3,388,000 | 3,286 | 296,000 |
| 1912 | 33,050 | 4,561,000 | 2,529 | 228,000 |
| 1913 | 30,110 | 3,372,000 | 1,829 | 161,000 |
| 1914 | 31,113 | 3,174,000 | 1,464 | 114,000 |
| 1915 | 41,403 | 10,268,000 | 2,276 | 214,000 |
| 1916 | 56,803 | 15,223,000 | 2,982 | 412,000 |
| 1917 | 59,742 | 12,187,000 | 4,056 | 698,000 |
| 1918 | 50,014 | 9,103,000 | 4,442 | 631,000 |
| 1919 | 40,765 | 5,952,000 | 4,130 | 438,000 |
| 1920 | 27,285 | 4,420,000 | 2,594 | 415,000 |
| 1921 | 3,390 | 339,000 | 972 | 87,000 |
| 1922 | 10,952 | 1,249,000 | 691 | 76,000 |
| 1923 | 13,211 | 1,797,000 | 734 | 103,000 |
| 1924 | 14,027 | 1,824,000 | 1,254 | 201,000 |
| 1925 | 20,230 | 3,075,000 | 1,877 | 327,000 |
| 1926 | 26,800 | 4,020,000 | 1,546 | 247,000 |
| 1927 | 32,841 | 4,204,000 | 2,069 | 261,000 |
| 1928 | 18,417 | 2,247,000 | 1,698 | 197,000 |
| 1929 | 16,986 | 2,242,000 | 1,536 | 194,000 |
| 1930 | 12,558 | 1,206,000 | 1,537 | 154,000 |
| 1931 | 10,088 | 767,000 | 952 | 70,000 |
| 1932 | 7,522 | 451,000 | 910 | 55,000 |
| 1933 | 7,800 | 655,000 | 540 | 40,000 |
| 1934 | 9,807 | 843,000 | 234 | 17,000 |
| 1935 | 8,923 | 785,000 | 286 | 23,000 |
| 1936 | 8,126 | 813,000 | 904 | 83,000 |
| 1937 | 6,938 | 902,000 | 1,091 | 129,000 |
| 1938 | 2,073 | 199,000 | 320 | 29,000 |
| 1939 | 5,904 | 614,000 | 388 | 36,000 |
| 1940 | 5,700 | 727,000 | 445 | 44,000 |
| 1941 | 6,238 | 936,000 | 1,225 | 140,000 |
| 1942 | 9,426 | 1,753,000 | 775 | 104,000 |
| 1943 | 14,387 | 3,108,000 | 920 | 138,000 |
| 1944 | 15,549 | 3,545,000 | 1,415 | 226,000 |
| 1945 | 15,561 | 3,579,000 | 1,776 | 305,000 |
| 1946 | 14,276 | 3,483,000 | 1,588 | 346,000 |
| 1947 | 12,224 | 2,958,000 | 1,166 | 336,000 |
| 1948 | 7,864 | 2,092,000 | 861 | 308,000 |
| 1949 | 5,295 | 1,313,000 | 857 | 271,000 |
| 1950 | 5,722 | 1,625,000 | 532 | 144,000 |
| 1951 | 15,754 | 5,734,000 | 1,391 | 481,000 |
| 1952 | 20,588 | 6,835,000 | 2,000 | 644,000 |
| 1953 | 16,830 | 3,871,000 | 2,094 | 549,000 |
| 1954 | 15,534 | 3,355,000 | 1,261 | 346,000 |
| 1955 | 18,326 | 4,508,000 | 1,948 | 581,000 |
| 1956 | 23,890 | 6,546,000 | 2,582 | 811,000 |

TABLE 11.—ANNUAL TONNAGE AND VALUE OF ZINC AND LEAD METAL PRODUCTION IN WISCONSIN, 1910–74—Con.

| | Zinc | | Lead | |
|---|---|---|---|---|
| | Short tons | Value | Short tons | Value |
| 1957 | 21,575 | 5,006,000 | 1,900 | 543,000 |
| 1958 | 12,140 | 2,477,000 | 800 | 187,000 |
| 1959 | 11,635 | 2,676,000 | 745 | 171,000 |
| 1960 | 18,410 | 4,750,000 | 1,165 | 273,000 |
| 1961 | 13,865 | 3,189,000 | 680 | 140,000 |
| 1962 | 13,292 | 3,057,000 | 1,394 | 256,000 |
| 1963 | 15,114 | 3,476,000 | 1,116 | 241,000 |
| 1964 | 26,278 | 7,148,000 | 1,742 | 456,000 |
| 1965 | 26,993 | 7,882,000 | 1,645 | 513,000 |
| 1966 | 24,775 | 7,185,000 | 1,694 | 512,000 |
| 1967 | 28,953 | 8,016,000 | 1,596 | 447,000 |
| 1968 | 25,711 | 6,942,000 | 1,126 | 298,000 |
| 1969 | 22,901 | 6,687,000 | 1,102 | 328,000 |
| 1970 | 20,634 | 6,322,000 | 761 | 238,000 |
| 1971 | 10,645 | 3,428,000 | 752 | 207,000 |
| 1972 | 6,873 | 2,440,000 | 757 | 228,000 |
| 1973 | 8,672 | 3,583,000 | 844 | 275,000 |
| 1974 | 8,675 | 6,229,000 | 1,235 | 556,000 |

Zinc as a component of the alloy brass has been in use for several thousand years, although metallic zinc was not known until much later. Major quantities of zinc are now consumed in four widely divergent applications: (1) zinc metal, both as castings and in rolled forms, (2) as major ingredients in brass and other alloys, (3) as a protective coating against corrosion on a wide variety of steel products, and (4) as a chemical compound and pigment, zinc oxide, in rubber products and paints. The usage of zinc has grown so that it is now fourth, following iron, aluminum, and copper in the amounts of metals used.

Galena, the principal lead ore mineral, was known and prized by the Indian inhabitants of the region, although it apparently was valued for its attractive appearance and/or great weight, since there is no evidence that they smelted it to produce metallic objects. Early French explorers recorded the presence of lead ores in the region as early as the middle of the 17th century, and easily exploited deposits of lead ore at or near the surface of the ground were responsible for the establishment of a trading post in the region about 1690. Later, at the beginning of migration into the territory that is now Wisconsin, the first permanent settlers were lead prospectors and miners. In 1971, galena was named the State mineral of Wisconsin, in recognition of its unique place in the State's early history. Additionally, the State derives its nickname as the "Badger" State in large part because of the numerous shallow pits and spoil piles that resemble badger burrows and result from the search for and mining of shallow deposits of residual lead ores. The importance of lead in the early history of the State was nationally significant. From about 1830 to 1871, the region was the most important lead-producing district in the Nation.

Zinc ores, although known to be present as early as 1840, were not mined until 1859, because until then there was no market for the ores. With the establishment of the first zinc smelter in the United States at LaSalle, Ill., in 1860, the zinc industry of Wisconsin began in earnest, and has been continuous since then with the possible exception of 1862. The early zinc mining exploited the weathered surface ores made up of smithsonite (zinc carbonate) and hemimorphite (hydrous zinc silicate), but the zinc sulfide mineral sphalerite has become the principal ore mineral.

*History*

The prehistoric residents of Wisconsin evidently gathered cubes of galena, inasmuch as the mineral is found at old village sites and in burials. There is no authentic evidence that the Indians actually practiced mining or smelting of lead sulfide before they were taught by early French explorers.

The first written record that lead was known in the district was in 1658–59 when Radisson and Groseillers "heard of lead mines among the Boeuf Sioux, apparently in the vicinity of Dubuque, Iowa," (Thwaites, 1895). Perhaps the first extensive mining of lead ore by French and Indians was associated with the establishment of a trading post by Nicholas Perrot about 1690 at or near the present location of East Dubuque, Ill., for obtaining lead (Bain, 1906).

In 1699, Pierre Charles Le Sueur conducted the first significant mining exploration in the area and visited many Indian lead mines including Snake Cave which is very likely the oldest lead mine in Wisconsin. The site was later called St. John's mine and is now a tourist attraction in Potosi, Wis.

Settlement by lead miners in the territory that is now Wisconsin followed the congressional act of 1807 that acquired the mineral lands and the treaty with the Sac and Fox Indians in 1815 that gave the United States title to the lands in the lead region. Settlement began in 1819 with the arrival of Jesse W. Shull at Gratiot's Grove south of Shullsburg (Bain, 1906). By 1820, lead deposits had been found at sites near the present towns of Fairplay, Potosi, Blue Mounds, and perhaps Beetown (Forsyth, 1872). In 1824 the mining towns of Hazel Green and New Diggings were first settled following discovery of rich deposits.

The early mining was strictly a pick and shovel operation, aimed at recovering float ore, that is, concentrations of galena in the residual soil formed as the host rocks weathered away from around mineralized joints and crevices. The miners dug relatively shallow pits called digs and since the output of each dig was small, they had to make many pits to obtain much ore. The pock-marked hillsides resembled a battlefield after an artillery bombardment, and are still to be seen where they have not been obliterated by plow or bulldozer.

The heyday of lead mining extended from the late 1820's to 1848 when the easily mined deposits were becoming depleted and the discovery of gold in California attracted many lead miners away from this area. From about 1830 to 1871 the region was the Nation's most important lead-producing district.

Zinc mining increased in importance from its early days. About 1882 a zinc oxide furnace first converted smithsonite ores to white zinc oxide. Eventually this smelter also treated zinc sulfide ores and operated successfully until 1928. Other successful plants used zinc ores to produce sulfuric acid at Mineral Point from 1899 to 1930 and a similar plant operated at Cuba City from about 1910 to 1949. The first flotation mill in the district was established at Linden in 1929, and most ores are now treated in such mills which lower the cost of treatment of the zinc concentrates by eliminating much waste material and by separating large quantities of barite from the ores.

Most of the mill concentrates of zinc ore are made into metallic slab zinc at smelters located outside Wisconsin, and some concentrates are converted directly to zinc oxide.

Production of sphalerite ore overtook that of smithsonite after 1873, and practically no smithsonite has been produced since 1929 except for a few carloads in the 1930's and again about 1949. Zinc production first equaled lead production in 1873, and the two metals were produced in about equal amounts for the next 20 years. Since 1893, the zinc produced has exceeded lead ranging from 5 to 20 times as much, and presently averages about 10 times as much. The average ore grade differs from mine to mine and from area to area within a given mine. Within the past 10 years, the ores mined by highly mechanized methods have averaged between 3 and 4 percent zinc, with most companies trying to maintain mill feed at about 3 percent ore to prolong the life of their deposits and maximize the recovery of metal from their mines by blending in as much lower grade material as possible.

Although zinc and lead ores have been the most important product mined in southwestern Wisconsin, small tonnages of high-grade copper ores and barite also have been produced; iron sulfides have been mined for the manufacture of sulfuric acid; limonite and hematite were mined as iron ore north of the main mining area; and waste rock from the zinc-lead mines and mills has been widely used for road metal, blacktop, agricultural lime, and railroad ballast. Wisconsin continues as an important producer of both zinc and lead.

*Deposits*

The zinc-lead deposits of southwestern Wisconsin are frequently cited in the geologic literature as examples of a class of deposits called stratabound. Such deposits occur selectively in certain strata within a generally favorable sequence of rocks that typically include the carbonate rocks, limestone and dolomite. The localization of ore deposits within the beds tends to be controlled by the presence of through-going fractures or by subtle changes in porosity, permeability, or chemical reactivity of the host carbonate rocks.

Although some zinc and lead deposits occur in most of the stratigraphic units exposed in the district, all important ore bodies found thus far have been in the Platteville, Decorah, and Galena Formations with some smaller but intriguing occurrences in the Prairie du Chien Group. Practically all production to date has been from the first three of these formations. The details of these formations are shown on figure 36 and a regional stratigraphic summary is shown in figure 37.

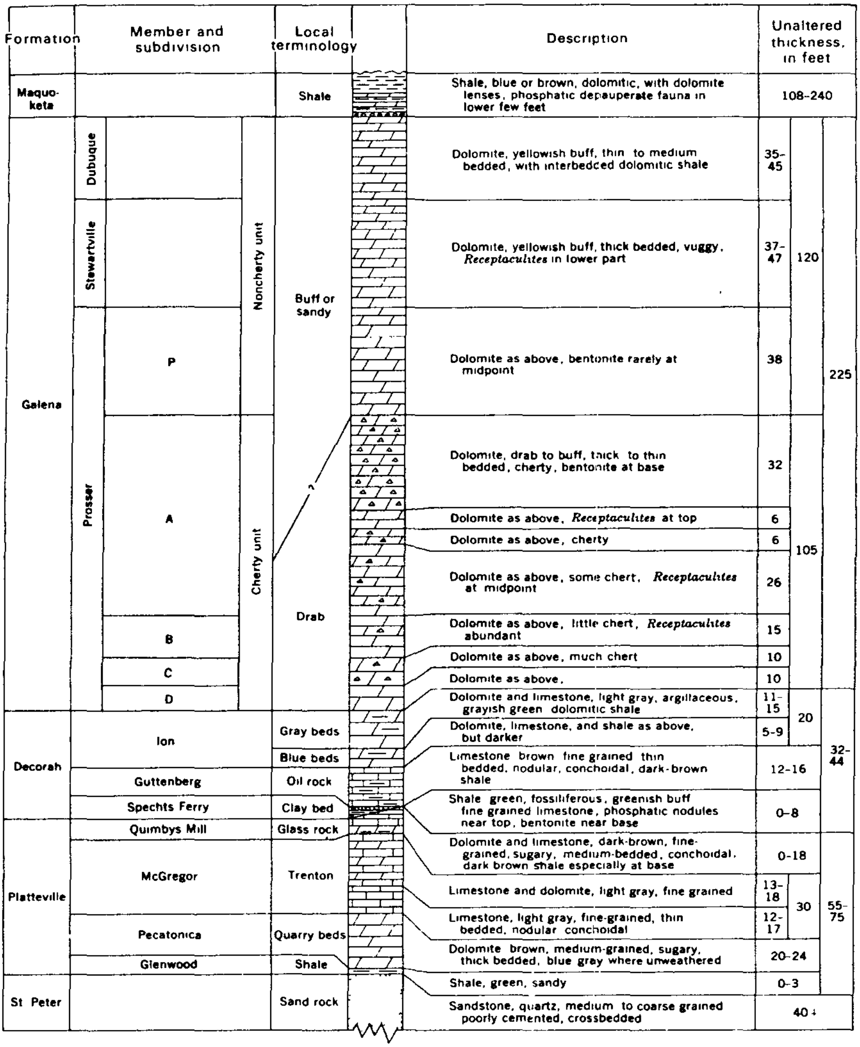


**Figure 36.—Detailed stratigraphic column of Platteville, Decorah, and Galena Formations in zinc-lead district. From Heyl and others, 1950, figure 3.**

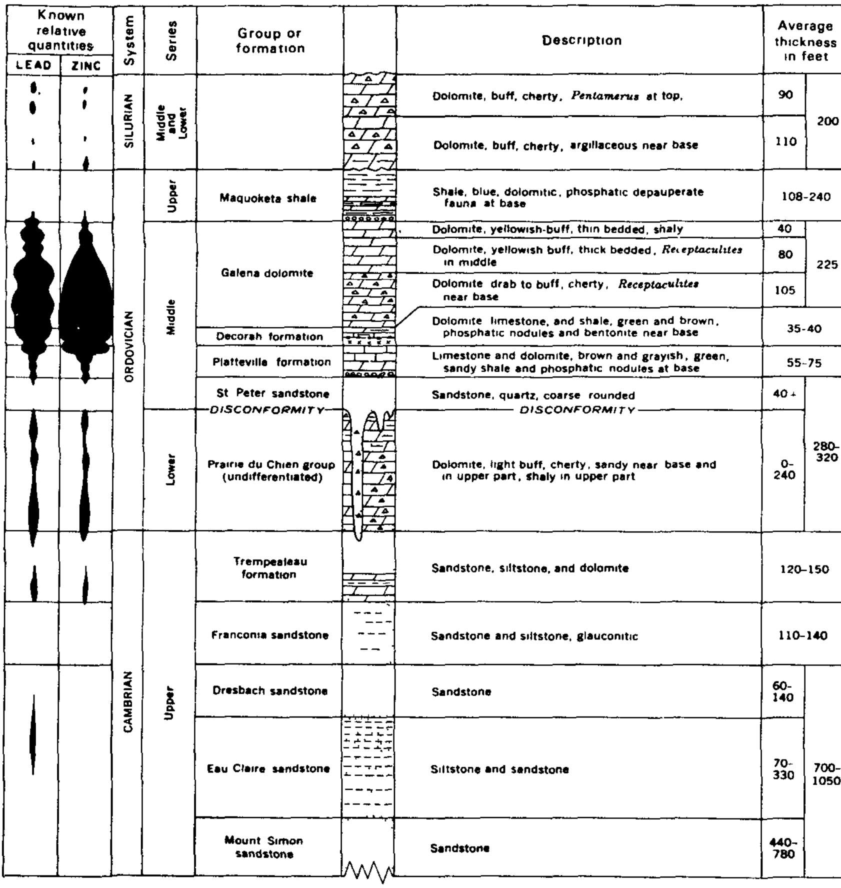


FIGURE 37.—Simplified stratigraphic column showing relative quantitative stratigraphic distribution of zinc and lead in Wisconsin district. From Heyl and others, 1959, figure 2, with addition of relative quantities of zinc and lead from Heyl and others, 1970, figure 8.

Most of the zinc deposits are in the lower part of the Galena, Decorah, and the upper two-thirds of the Platteville Formations (fig. 37). The principal lead deposits are in the Galena Formation. Small lead, zinc, and copper deposits have been found locally in the northern part of the district in the Prairie du Chien Group, and in the Trempealeau and Franconia Formations. In places, the St. Peter Sandstone is pyritized, and it is most heavily pyritized where it directly underlies zinc deposits.

The more common types of mineral deposits are: (1) those associated with vertical or steeply inclined joints or fractures, called crevice deposits; (2) those associated with inclined and horizontal fractures, called pitch-and-flat deposits; (3) those consisting of fine lead sulfide and zinc sulfide particles or crystals scattered through the country rock, called disseminated deposits; and (4) those made up of angular rock fragments cemented together by ore and associated minerals, called brecciated deposits. The crevice and pitch-and-flat deposits are most abundant, and both types are stratigraphically and structurally controlled.

Early mining recovered lead ore and minor zinc ore from crevice or crevice-related deposits, principally from discontinuous veins, called gash-veins, in crevices or fractures and from ore deposited in solution-widened openings along fractures at certain stratigraphic intervals. Crevice deposits are mainly restricted to the Galena Dolomite although a few have been mined from the Decorah and Platteville Formations. A large proportion of the production for about the past 70 years has come from pitch-and-flat deposits (veins along inclined joints or fractures being the "pitches" and the horizontal veins the "flats"). These deposits are usually found on the limbs (slopes) and ends of synclines in the Decorah Formation and the cherty lower part of the Galena Dolomite. Veins of zinc and lead sulfide that form flats along bedding at or near the base of the Quimby's Mill Member of the Platteville Formation are also quite common.

The most abundant minerals with the ore minerals are calcite, pyrite, marcasite, barite, and more rarely chalcopyrite. Some of the frequently seen minerals that formed later are smithsonite, limonite, cerussite, hematite, malachite, and azurite. These and a large number of other minerals from this district are described by Heyl and others (1959).

The structural setting of the zinc-lead district has been shown to be closely related to the distribution of ore deposits. Regionally, the district is on the western slope of the north-trending Wisconsin Arch, and on the south slope of the Wisconsin Dome, a structural high that exposes Precambrian rocks to the north. Within the district, the strata have a gentle regional dip of about 18 feet per mile (less than 1°) to the south-southwest. Locally, the rocks have been broadly warped into anticlinal arches and synclinal troughs trending generally eastward, with some domes and basins. The folds are very gentle, but extend from 20 to 30 miles in length and are 3 to 6 miles across, and have amplitudes of 100 to 200 feet.

The deformational stresses that produced these gentle folds produced a number of faults (fractures that show displacement of the rock layers) and joints (fractures without apparent displacement other than separation across the joints). Some of the faults with minor displacement and many of the inclined joints are thought to have resulted from collapse of rocks through removal of support as underlying strata were solution-thinned and leached.

All the stratigraphic units exposed in the area have well-developed joints, both vertical and inclined. The vertical joints are most numerous, and some are traceable for as much as 2 miles horizontally and up to 300 feet vertically. Regional trends of the vertical joints are mostly N. 77° W., N. 13° W., and N. 25° E., with the N. 77° W. trending joints generally being more open than the others.

The ore deposits show both vertical and regional zoning. Copper, barium, nickel, and arsenic are quite abundant in the east-central part of the district along a northwest-trending zone. The distribution of zinc deposits within the broader distribution of lead deposits is shown on figure 35. Vertically, lead is in greater concentration in the higher part of the mineralized zone whereas zinc, iron sulfides, nickel, silica, and dolomite are in greater abundance in the deeper deposits. Part of the apparent vertical zoning may be the result of compositional differences in the several stratigraphic units.

### *Outlook*

The district is very large, covering some 4,000 square miles, and has many small- to moderate-sized deposits of good grade. A significantly large part of it is unexplored by modern physical and chemical exploration techniques. Potential resources of zinc and lead are large, and the district will be an important source of these metals for many years. Byproduct production of copper, barite, and pyrite may become more important locally. Future exploration will certainly search for major extensions of the district to the south and west in Illinois and Iowa, but many older mining areas in the central and northern parts of the district may again become productive, as will such little-known outlying areas near Potosi, and Beetown to the west and Yellowstone and Wiota to the east.

Following World War II, several large mining companies started major prospecting programs using some of the new techniques for locating ore bodies and other information developed from studies of the mining area by the U.S. Geological Survey in cooperation with the Wisconsin Geological and Natural History Survey and the U.S. Bureau of Mines. These prospecting programs had built up the known mineable ore reserves from 1 million tons in 1942 to more than 10 million tons in 1950. Ore found by exploration since 1950 has kept pace with ore removed by mining. Consequently, the ore reserves at the present time are still about 10 million tons.

Relatively recent discovery and development of one new ore body in the northern part of the main Wisconsin mining district, four new ore bodies in the central part, and two new ore bodies in the western part prove that undiscovered commercially valuable mineral deposits are to be found by using modern prospecting methods in unexplored areas between old mines. Unexplored and scarcely prospected areas are present in the district. Additionally, several mines are being, or recently have been, profitably operated in partly mined out ore bodies in and near old mine workings. Great numbers of this type of potential resources are available for future investigation and recovery in the main mining area (fig. 36) as indicated by the numerous widely scattered diggings, mine shafts, and geological signs of mineralization.

Large resources of oxidized and mixed oxidized-sulfide zinc-lead ores that generally occur at shallow depths are in many parts of the district. These deposits will no doubt be mined when smelting methods are developed to handle this type of ore.

Some interest has developed in the Prairie du Chien Group, from which minor amounts of both zinc and lead ores were produced, and in the more calcareous parts of the Upper Cambrian units underlying the mining district; these must be considered as potentially producing zones. Even the relatively small intense magnetic anomalies so far discovered within the district are generating some interest in the Precambrian rocks as a possible mineral source.

Geologic studies of the district suggest that there probably is as much ore still in the ground as has been mined in the past. In any event the potential resources of both zinc and lead are very large, and the district will certainly continue to be an important source of these metals for many years to come.

During the past 290 years of more or less continuous mining in this area, the Wisconsin zinc-lead district along with the rest of the Upper Mississippi Valley base metal district has had its ups and downs in production. The more productive years have been primarily the result of technological advances in mining, milling, and smelting, and were also periods of emergency and high metal prices.

As described in the copper section of this report, much recent exploration in northcentral Wisconsin has been directed toward the discovery and evaluation of massive sulfide deposits associated with so-called greenstone belts of metamorphosed volcanic rocks. Three significant deposits have been identified thus far, and plans to mine them are being developed. All three deposits are reported to contain zinc in association with copper, although the zinc content of the Flambeau deposit near Ladysmith in Burk County is apparently too low to warrant recovery. The deposit near Rhinelander in Oneida County contains zinc in sufficient amounts to be recovered economically, and the zinc content of the ores near Crandon, Forest County, is reported to be greater than the associated copper.

No specific description of the Noranda Exploration Co. deposit located about 8 miles southeast of Rhinelander in Pelican Township has been published, but the company has indicated the deposit is capable of supporting a 1,000 ton per day operation for a period of 10 to 14 years. Presumably, this deposit is similar to the Flambeau deposit, which has been described as containing pyrite, chalcopyrite, and sphalerite in a single ore horizon associated with a quartz-sericite schist. In that deposit, the ore horizon pinches and swells, varying from 25 to 200 feet and averaging about 50 feet in thickness. The ore body comprises massive and disseminated sulfides, dominantly pyrite, with minor chalcopyrite and some sphalerite which forms distinct bands and some lenses.

Published details on the deposit near Crandon are meager but indicate that the Exxon Corp. has discovered a major massive sulfide deposit, containing an estimated 30 million tons of zinc-copper ore with associated minor values in silver, gold, and lead.

Although the extent of zinc resources in northcentral Wisconsin is still largely unknown, the recent discoveries suggest that further resources may be found and that production of zinc in this region can be expected.

*Annotations and selected references*

The first geologic study in the Wisconsin zinc-lead district and perhaps the first significant geological study made by the U.S. Government in the entire country was in 1839 by D. D. Owen, John Locke, and 139 assistants (Owen, 1840). They mapped the locations of the lead mines and described the general geology for Owen's evaluation of the mineral-bearing Government land which is now Wisconsin, Illinois, and Iowa. Edward Daniels (1864) and J. G. Percival (1855a, 1856) recognized the main stratigraphic features and the alinement of lead-producing areas. J. D. Whitney (1862, 1866) produced the first detailed reports covering the entire district and described the lead-bearing crevices. Moses Strong (1877) and T. C. Chamberlin (1882) gave detailed descriptions of the mines and geology as well as advancing some theories on the processes by which the ore may have been deposited.

As zinc mining became increasingly important, studies of the origin and deposition of the zinc ore as well as the relation of deposition to stratigraphy and structure were made by W. P. Blake (1893), Arthur Winslow (1893 a, b, c), W. P. Jenny (1894), C. R. Van Hise (1901), C. R. Van Hise and H. F. Bain (1902), U. S. Grant (1903, 1905 a, b, 1906), Grant and E. F. Burchard (1907), G. H. Cox (1909, 1911, 1912), and W. O. Hotchkiss and Edward Steidtmann (1909).

Some other noteworthy contributors to our knowledge of the southwestern Wisconsin ore deposits and their origin prior to World War II were H. C. George (1918), W. F. Boericke and T. H. Garnett (1919), J. E. Spurr (1924), G. M. Kay (1935 a, b, c, 1939), G. M. Kay and G. I. Atwater (1935), W. H. Emmons (1929, 1940), C. K. Leith (1932), W. H. Newhouse (1933), L. C. Graton and G. A. Harcourt (1935), C. H. Behre, Jr. (1935), C. H. Behre, Jr., E. R. Scott, and A. F. Banfield (1937), and E. S. Bastin, C. H. Behre, Jr., and G. M. Kay (1939).

Although geologic information sporadically influenced mining company personnel as early as 1853 with periods of more frequent application between 1890 and 1925, much of the so-called geologic work was actually mining engineering. Since 1946 most mining companies have employed geologists who have successfully used geologic techniques in the search for ore (Agnew, 1955).

In October 1942 the U.S. Geological Survey began a detailed restudy of the geology and ore deposits of the upper Mississippi Valley zinc-lead district in the hope that a systematic investigation would help increase production of lead and zinc which were then in extremely short supply and badly needed. This geologic investigation has continued with important benefits to the State of Wisconsin as well as to both the State and Federal geological surveys. Since July 1945, work in the Wisconsin part of the zinc-lead district has been also partly financed and supported by the Wisconsin Geological and Natural History Survey under the successive directorships of State geologists E. F. Bean, G. F. Hanson, and M. E. Ostrom.

From 1942 to 1950 the rock units were studied and the stratigraphic nomenclature (formal names for each rock unit) to be used for the area was established; accessible mines were mapped to determine the ore-emplacement controls; and detailed geologic maps of some highly mineralized localities were made to determine the distinctive characteristics of favorable ore-bearing structures (Agnew and Heyl, 1943; Agnew, 1944, 1946; Agnew, and others, 1954, 1956; Allingham, and others, 1955; Heyl and Agnew, 1945; Heyl, and others, 1945, 1948, 1952, 1955, 1959). In addition, underground mine mapping also helped locate some extensions of ore deposits being mined as well as new ore bodies, and the limited geologic mapping at the surface led to the discovery of previously unknown mineralized areas.

In the late 1940's the U.S. Geological Survey conducted experimental geochemical prospecting studies in the area (Kennedy, 1956). This work indicated that geochemical methods of prospecting, based on results from soil, rock, and water samples, show definite promise as a tool in searching for ore deposits in southwestern Wisconsin. High zinc content of spring water samples verified and helped locate at least one rich zinc-lead ore body which was mined.

Drilling projects from 1942 to 1956 by the U.S. Geological Survey and cooperatively by the U.S. Geological Survey and the U.S. Bureau of Mines were to test possible ore-bearing structures, mainly in the Platteville, Decorah, and Galena Formations but also to a limited extent in the Prairie du Chien Group, and for obtaining stratigraphic information (Agnew, and others, 1953; Heyl, 1951; Carlson, 1956). Several productive zinc-lead ore bodies including the largest single ore body to date in the upper Mississippi Valley base metal district and some potentially productive ore deposits were thus found. The drilling for stratigraphic information by the U.S. Geological Survey proved very helpful in the geologic mapping of 7½-minute quadrangles.

Geologic mapping of 7½-minute quadrangles began in September 1951 and is continuing primarily for making detailed studies of geologic features related to mineralized areas in order to aid in finding other localities that are possibly favorable for zinc and lead deposits and other commercially valuable materials. To date 18 quadrangles, each covering about 54 square miles, in the Wisconsin zinc-lead region have been published in U.S. Geological Survey bulletins or geologic quadrangle maps (Carlson, 1961; Whitlow and Brown, 1963b; Allingham, 1963; Agnew, 1963; Taylor, 1964; Klemic and West, 1964; Mullens, 1964; Whitlow and West, 1966a, 1966b, 1966c; West and Blacet, 1971; and West and others, 1971).

The cooperative detailed geologic mapping already has helped and will continue to help develop Wisconsin's mineral industry as these maps and related reports serve to stimulate and guide the development of metallic and nonmetallic mineral resource-based industries. The mapping has located numerous structures possibly favorable for containing zinc-lead deposits and also located many areas of rock alteration and mineralization, some of which very likely contain subsurface zinc and lead ore bodies. Within the area mapped geologically, several new zinc-lead deposits have been and are being mined; some old mines reopened; quite an extensive amount of prospecting and exploration work by drilling and other methods has recently been done; and many acres of land have been leased during the past few years by various mining and exploration companies. The royalties and lease rentals paid to the farmers and other landowners who have the mineral rights have been and are benefiting Wisconsin's agricultural industry. The geologic maps and reports have been and will continue to be very valuable to individuals and companies interested in sources of sand and gravel, agricultural lime, road material, road ballast, concrete aggregate, dimension stone, and foundry and glass sand. Water well drillers use the maps and reports for locating domestic and stock wells and as an aid in making out their well log reports to the State and the landowners. Government agencies, universities, libraries, research geologists, geological societies, and collectors of rocks, minerals, and fossils are frequent users of the geologic publications on the Wisconsin zinc-lead district.

In September 1972 the Federal and State geological surveys cooperatively initiated a geochemical exploration program in southwestern Wisconsin to accompany geologic mapping (West and Wedow, 1972). The purpose of this program was to encourage additional interest in mining and to increase mineral production in Wisconsin by use of another geological tool to locate new ore deposits and determine the approximate extent of both new and known ore bodies, not only within the limits of the main mining district but also in the adjoining areas to the north and east. From the data thus far obtained, geochemical testing of soil and stream sediments appears to be giving excellent results in locating and delimiting the approximate extent of new areas that warrant additional prospecting as well as indicating belts of mineralization (West, 1973, 1974).

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## Zircon

(By Harry Klemic, U.S. Geological Survey, Reston, Va.)

*Description and use.*—The principal primary occurrence of zircon is as an accessory mineral (a minor component) of igneous rocks. It also is present in metamorphic and sedimentary rocks and in unconsolidated sediments derived from zircon-bearing rocks. Zircon is heavier (specific gravity 4.7) and more resistant to decomposition than most of the major rock-forming minerals. Consequently, it accumulates in sandy sediments and is commonly found in beach sands and stream sediments as placer concentrations formed by wave or stream action. Most of the zircon deposits of present commercial importance are in unconsolidated sands from which a few heavy mineral products are obtained (Klemic, 1975). Ancient placer deposits also are present in sandstone formations, but mining and extracting zircon from unconsolidated sand are less expensive than mining and milling hard rock.

Identified zircon resources in the United States are mainly in sands of coastal areas from Florida to New Jersey, along and inland from the Gulf of Mexico, and in California.

Zircon is used as the source of the corrosive-resistant metallic elements zirconium and hafnium for alloys and coatings in the chemical and nuclear reactor industries. Zircon is mainly used in heat-resistant molds for metallic foundry and glass industries.

*Occurrences in Wisconsin.*—Although quantities of commercial significance have not been found, zircon in greater than the normal low amounts is known to occur locally in a complex of syenitic rock (differs from granite by lacking the glassy mineral quartz) of Precambrian age near Wausau, Marathon County (Weidman, 1907; Youngman, 1931; Emmons and Snyder, 1944; Vickers, 1956). Another zirconium-bearing mineral (eucolite) has also been found (Geisse, 1951). The area of syenitic rocks is within Townships 29 and 39 N., Ranges 6 and 7 E. figs. 29 and 30). It extends westward for about 8 miles from the city of Wausau and northward from Wisconsin Highway 20 for about 5 miles. In the southwestern part of the area, coarse-grained granitic masses cut the syenitic rocks, which are intrusive into an older sequence of greenstones (altered basalt) and metasedimentary rocks (Weis and LaBerge, 1969). The zircon-bearing granite and some of the syenite are radioactive, mainly due to minerals that contain thorium, (Vickers, 1956).

Some of the Paleozoic sandstone formations in Wisconsin and adjoining areas consist largely of quartz (Ostrom, 1971) but also contain zircon and other heavy resistate minerals (Thiel, 1935). Glacial sediments in the area are also known to contain zircon (Dreimanis and others, 1957; Fanning and Jackson, 1967), particularly in the coarse silt-size component. The heavy minerals in zones measuring tens of feet in thickness in the St. Peter Sandstone total considerably less than 1 percent, and contain zircon as practically the only heavy mineral of commercial interest that is more than 15 percent of the heavy mineral fraction (Thiel, 1935). Some glacial sediments in the Lake Superior region contain from 3 to 24 percent heavy minerals but less than 1 percent zircon (Dreimanis and others, 1957). Coarse silt from glacial sediments and soils in Wisconsin contain about 0.06 percent zirconium (Fanning and Jackson, 1967), equivalent to about 0.1 percent zircon.

*Appraisal and outlook.*—Attempts were made to exploit loose surficial material from the Wausau deposit for zircon in the 1920's and a small amount of zircon-bearing rock was mined from shallow open pits for beneficiation studies during the 1940's. In 1946 the U.S. Bureau of Mines conducted geophysical studies and did sampling by diamond drilling, trenching, and soil sampling. Some of the surficial material contained 25 percent zircon, but no zircon-bearing rock of comparable grade was found in the sampling. No estimate of potential resources of zirconium and hafnium in the Wausau area can be made using the limited data available from shallow sampling. However, the fact that commercial quantities of zircon and associated co-products have been found in syenite complexes in other parts of the world and that some zircon-rich rock has been found here makes this area worthy of further study.

Unconsolidated sands containing about 3 percent of heavy minerals consisting mostly of salable co-products such as ilmenite, leucoxene, rutile, zircon, monazite, and staurolite are about the lower limit for profitable mining in the southeastern United States (Mertie, 1958). Such sands generally contained zircon in amounts of 10 to 15 percent of the heavy minerals or 0.4 to 0.6 percent of the bulk sand. The mineable thicknesses were generally greater than 8 feet over areas measuring from less than 10 acres to a few square miles.

From this comparison it would appear unlikely that mineable concentrations of heavy minerals will be found in the Paleozoic sandstones or in the glacial silt and soils of Wisconsin. However, it is possible that heavy mineral concentrations of economic value may occur in glacial sands and in fine fractions washed from sand and gravel operations in loose sediments derived from some Paleozoic sandstones. Detailed studies of specific deposits of glacial material or of washings from sand and gravel operations would be required before any estimates could be made of potential zircon resources in such material.

## Water Resources in Wisconsin

### INTRODUCTION

Wisconsin has abundant water of good quality. Large supplies that are stored in rocks below the Earth's surface are available for man's use. The State also is crossed by 33,000 miles (53,000 km) of streams, and more than 30,000 lakes dot the landscape. Unlike mineral resources, our water resources are continually being replenished.

Wise management of our water resources becomes more important as man's use of the resource increases. In Wisconsin, there are numerous water-management programs in operation to help officials make these decisions.

The State of Wisconsin has set water-quality standards, exercises flood-plain and shoreland management, regulates well construction for public and private water supplies, and controls surface-water-irrigation pumpage and waste effluent discharge.

Eight multicounty planning commissions and numerous county and local planning commissions are involved with questions concerning water management. State ground-water policy is now under review. Water and related land resource use is being considered in river-basin planning by the U.S. Department of Agriculture; U.S. Army Corps of Engineers; Bureau of Outdoor Recreation, U.S. Department of the Interior; and the Great Lakes and Upper Mississippi River Basin Commissions.

*What rocks contain water*

In Wisconsin, all of the rocks below the water table contain some water. The water table is the top of the saturated zone and is commonly within 50 feet (20 m) of the land surface, although in places it is greater than 200 feet (60 m.) This means that there is a zone of rock, saturated with water, underlying the State. This zone is the ground-water reservoir.

The rocks making up the ground-water reservoir differ throughout the State. In the southeast, they include sandstone, dolomite, shale, and permeable glacial deposits totaling more than 1,000 feet (300 m) in thickness. In central Wisconsin they may be very thin, or missing, but commonly consist of 50 to 150 feet (20 to 50 m) of permeable glacial deposits.

## WATER BUDGET

Precipitation on the land and water surfaces starts the pattern of circulation called the water cycle (fig. 38). Some of the water runs rapidly off the land surface (overland flow) into nearby streams and lakes to become surface runoff; some water evaporates immediately from the surface soil and plants (evaporation); some returns to the air by plants (transpiration); and some seeps down through soil and rocks, reaching subsurface reservoirs (ground-water recharge) that eventuaally contribute base flow to streams and lakes (ground-water discharge).

An average yearly water budget calculated for the State of Wisconsin is based on averages for the 30-year period, 1931–60.

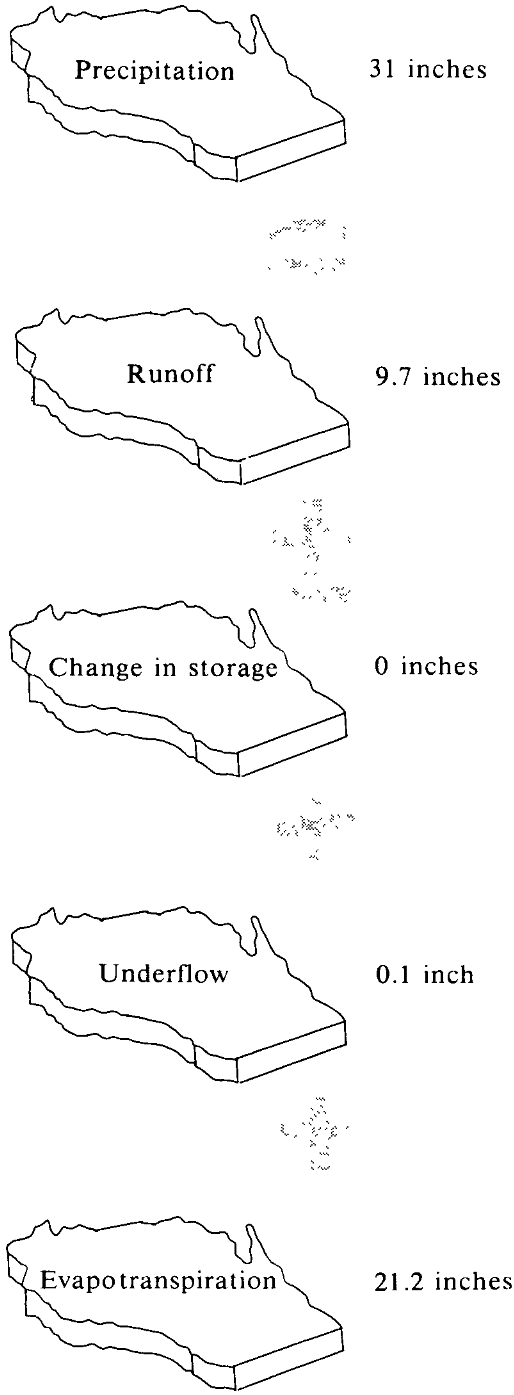



FIGURE 38.—Water budget for Wisconsin.

*Precipitation*

The average precipitation, based on U.S. Weather Bureau figures for the 30-year period, 1931–60, is 31.0 inches (790 mm). It is greatest in the southwest and north-central parts of the State.

*Runoff*

The average yearly streamflow or runoff leaving the State during this same period is equal to 9.7 inches (250 mm). This is equal to 26 billion gallons (98 billion liters) per day, or enough water to fill Lake Winnebago 1,200 times in 1 year.

Although this water is measured in stream channels, its source is overland flow of precipitation and ground-water discharge into the lakes and stream channels. Nearly two-thirds of the streamflow in Wisconsin is contributed by ground-water bodies.

*Change in storage*

A large amount of water is temporarily stored in lakes and surface reservoirs, in the subsurface ground-water reservoirs, and as soil moisture. More than 1,000 inches (25,000 mm) is stored in the ground-water reservoirs and more than 3 inches (80 mm) in the lakes and streams. The exact amount in storage changes from year to year, but during the 30-year budget period, increases and decreases balance out and the net change is zero.

*Underflow*

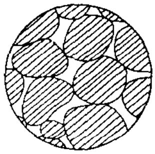
Not all of the ground-water discharge to lakes and streams is measured in streams leaving the State. Some is discharged directly to Lake Superior and Lake Michigan, and some moves across the State line to Illinois. The total quantity is about 0.1 inch (2 mm), which is a very small part of the budget.

*Evapotranspiration*

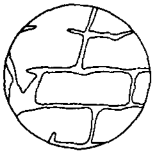
Evapotranspiration is the return of water to the atmosphere by a combination of evaporation from open water, foliage surfaces, and the land surface, and transpiration from plants. More than two-thirds of the water that enters Wisconsin from precipitation leaves by evapotranspiration.

## GROUND-WATER RESOURCES

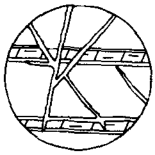
The water supply in ground-water reservoirs is replenished by the downward percolation of water from melting snow and ice and from rainfall. The amount of replenishment, or ground-water recharge, through the soil and rocks, depends on the connected pore space and fractures in the rocks. These factors also control how much water the rock will yield to wells drilled into it (fig. 39).



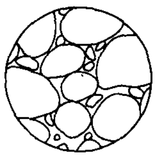
Sand and gravel yield water from interconnected pore spaces between the grains



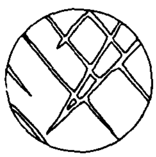
Dolomite and limestone yield water from fractures that may be enlarged by solution



Shale may yield some water to wells from fractures



Sandstone yields water from small interconnected pore spaces between the grains. Part of the pore spaces are filled by cementing material. Some water commonly comes from fractures



Crystalline rocks may yield some water from small fractures

FIGURE 39.—Types of rock openings.

*How much ground water is available*

Rocks that are capable of yielding water to wells in usable quantities are called aquifers. The four principal aquifers in Wisconsin are the sandstone, the Galena-Platteville, the Niagara, and the glacial sand and gravel.

The sandstone aquifer is largely sandstone but includes beds of dolomite and siltstone. It includes all the rocks above the Precambrian and below the Galena-Platteville unit discussed below. Its permeability is not nearly as great as the sand and gravel, but more than 1,000 gallons per minute can be obtained from wells in this aquifer in southern and eastern Wisconsin because of its great thickness. Well depths range from about 50 feet (15 m) to more than 2,000 feet (600 m) in extreme southeast Wisconsin (fig. 40).

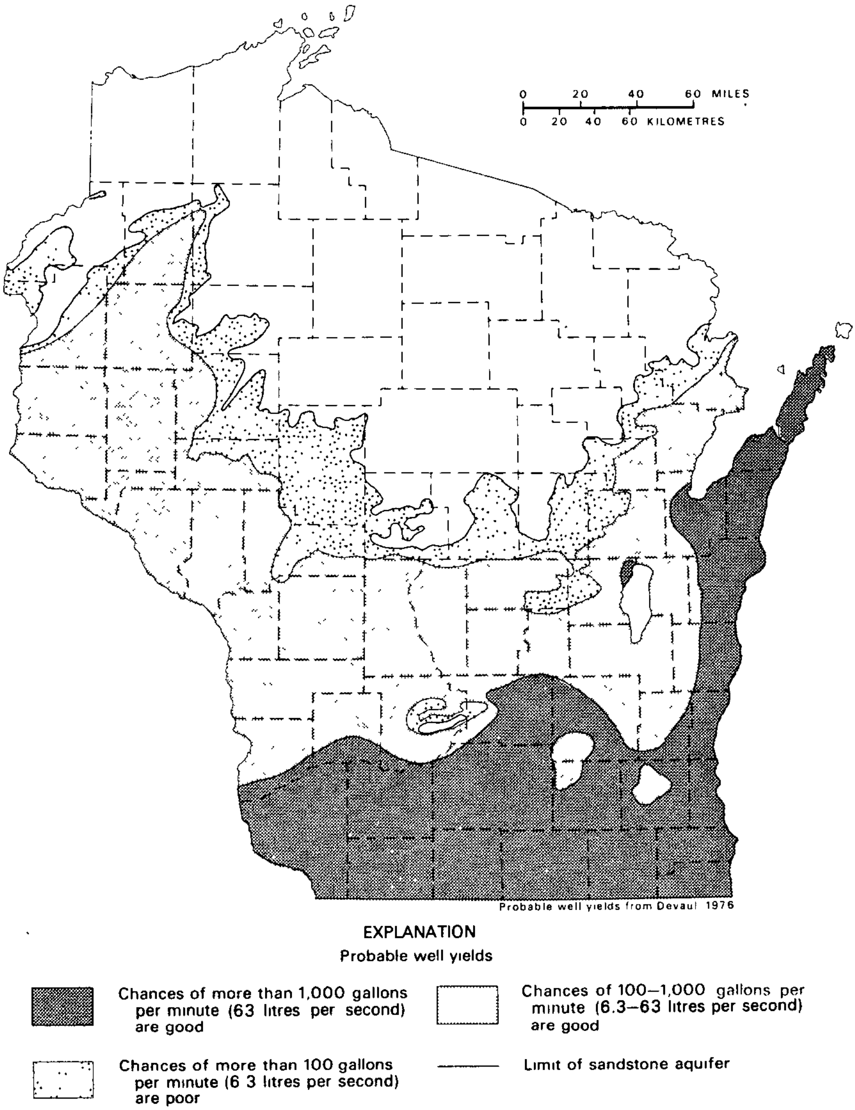



FIGURE 40.—Probable yields of wells in the sandstone aquifer.

The Galena-Platteville aquifer is a dolomite that yields water to numerous wells where it is the uppermost bedrock unit in the southern part of the State (fig. 41). Where it is overlain by the Maquoketa Shale (along the eastern part of the State) it has a low permeability and yields very little water. Aquifer thickness ranges from zero to more than 300 feet (90 m). Well depths are as much as 475 feet (145 m) but are commonly less than 250 feet (76 m).

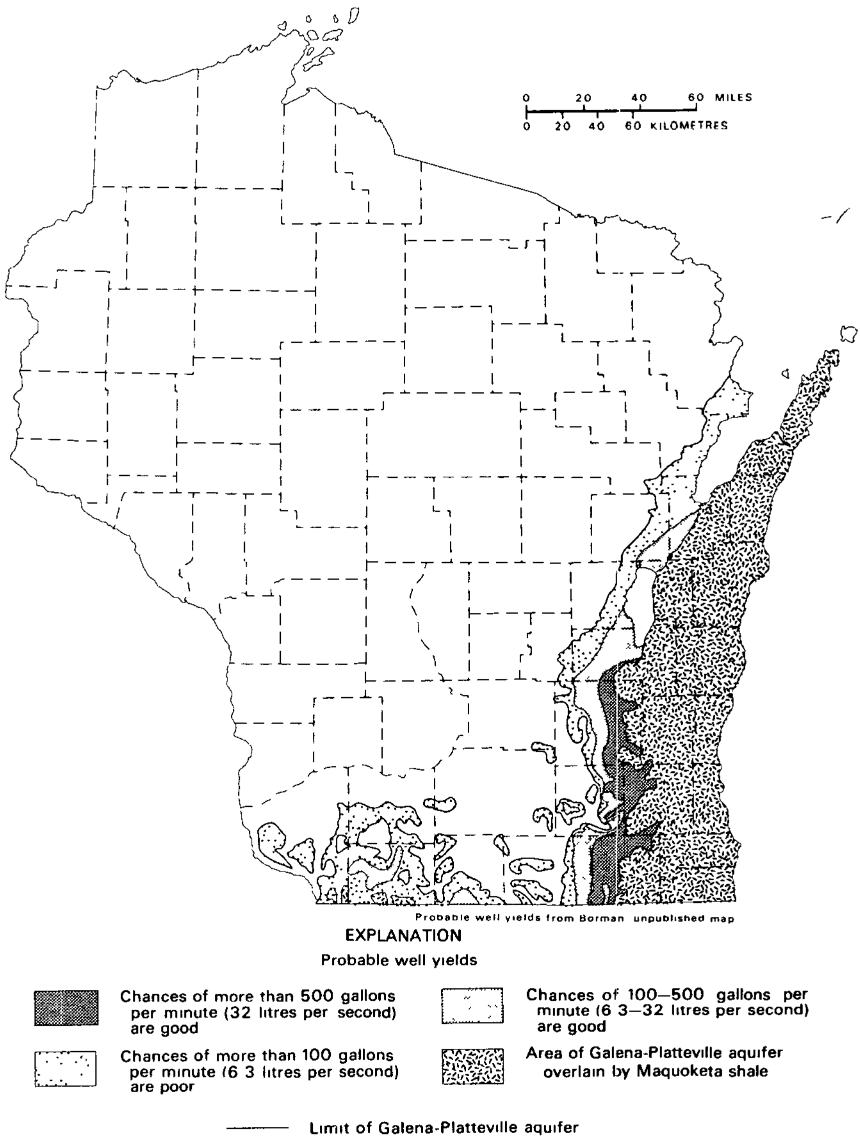



**FIGURE 41.—Probable yields of wells in the Galena-Platteville aquifer.**

The Niagara aquifer also is a dolomite. It is present only along Wisconsin's east shore (fig. 42), where it is extensively used for water supplies. It is the uppermost bedrock unit in most of this area and is up to 700 feet (200 m) thick. Well depths range from about 50 feet (15 m) to about 600 feet (200 m); most are from 100 to 150 feet (30 to 46 m) deep.


FIGURE 42.—Probable yields of wells in the Niagara aquifer.

The sand and gravel aquifer is not a continuous rock layer but is made up of numerous layers, lenses, terraces, and valley fillings of permeable sand and gravel that are part of the glacial and alluvial deposits covering most of Wisconsin (fig. 43). It is not well mapped but is known to be as thick as 300 feet (100 m). Wells in this unit are generally not deep; depths of less than 100 feet (30 m) are common. However, because of the extremely high permeability of some sand and gravel beds, well yields of more than 1,000 gallons per minute are possible.

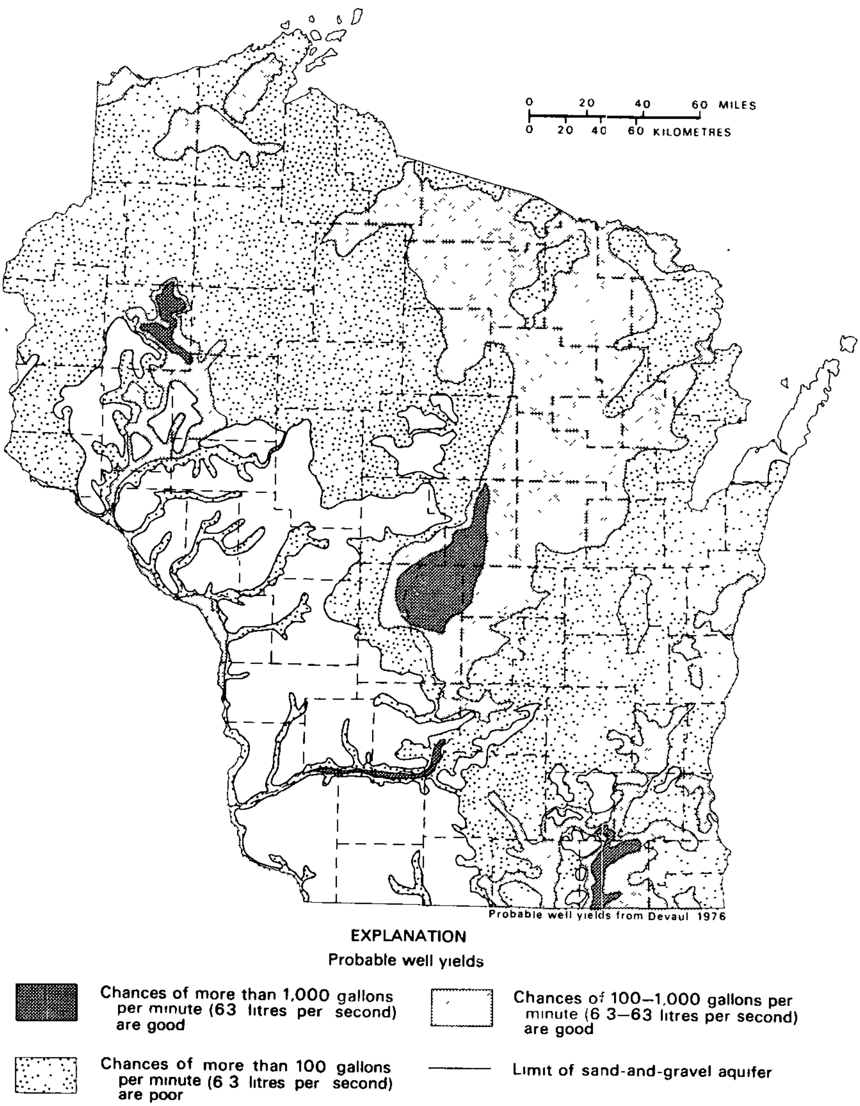



FIGURE 43.—Probable yields of wells in the sand and gravel aquifer.

Lakes and streams are replenished by precipitation on their surfaces, by overland flow, and by ground water discharging into them. The rate of streamflow depends largely on the size of each stream's drainage basin, which controls the amount of precipitation it can capture. The constancy of streamflow is controlled by many factors, including the number of lakes and wetlands, channel gradient, amount and type of vegetation, variations in geology and soil cover, the size of the ground-water contribution, and man's regulation of surface reservoirs.

*Where the surface water is located*

*Rivers and streams*

Based on average streamflow, the 10 largest streams bordering and within the State are, in descending order, the Mississippi, Wisconsin, Chippewa, St. Croix, Fox, Menominee, Wolf, Rock, Flambeau, and

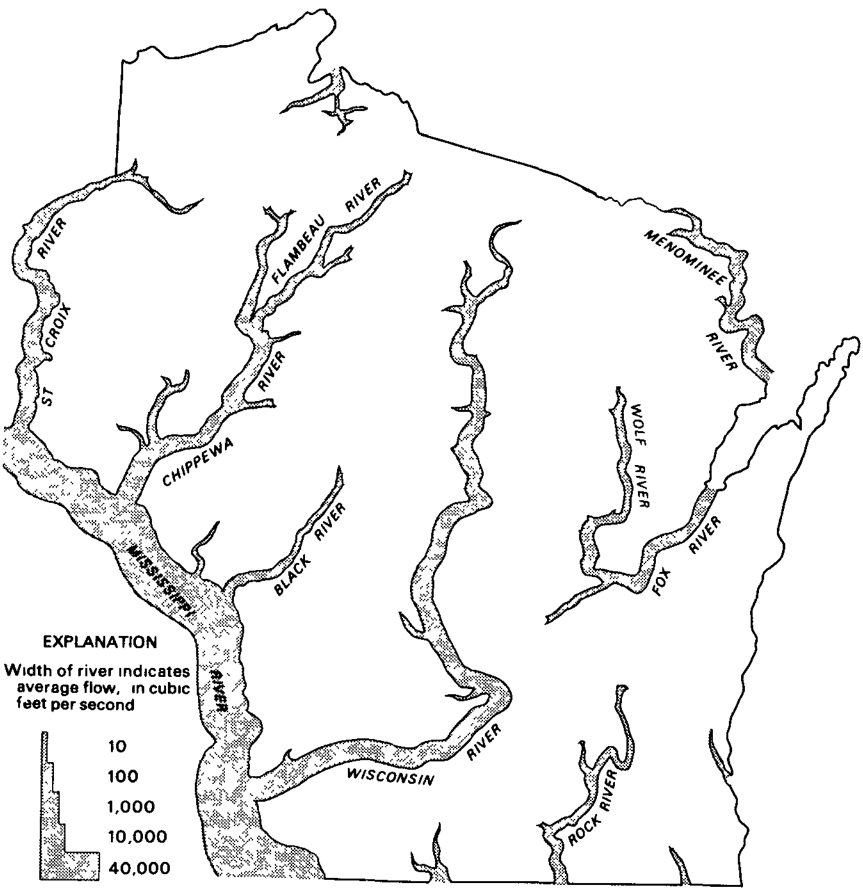


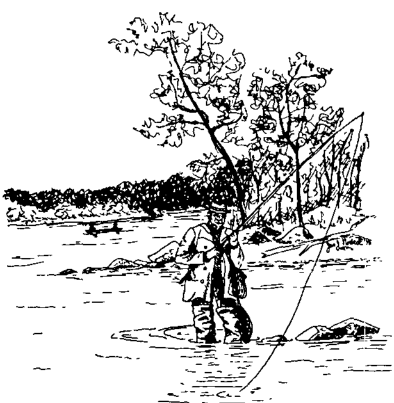

FIGURE 44.—Average flow of principal rivers.

Black Rivers (fig. 44). All have average discharges of more than 1,500 cubic feet of water per second (30,000 l/s).

Small tributaries to the large rivers account for most of the drainage mileage in Wisconsin.

*Lakes*

Wisconsin's landscape is dotted with lakes. The Wisconsin Department of Natural Resources has described about 31,000 of them. They range in size from Lake Superior to 2-acre (0.008-km²) spring ponds. Some are deep, some shallow; most are natural, some manmade. They fit into the water cycle in different ways. Some are no more than a wide spot in a stream. Others occupy depressions in the land surface formed by glacial ice. These kettle lakes are fed by ground-water discharging as seeps or springs.



*Wetlands*

Wetlands can be defined as areas that are flooded or saturated for a month or more during the year. Many of these result from the natural process of aging of lakes (fig. 45). Wetlands are an obvious part of our surface water but actually hold little of Wisconsin's total water in storage.

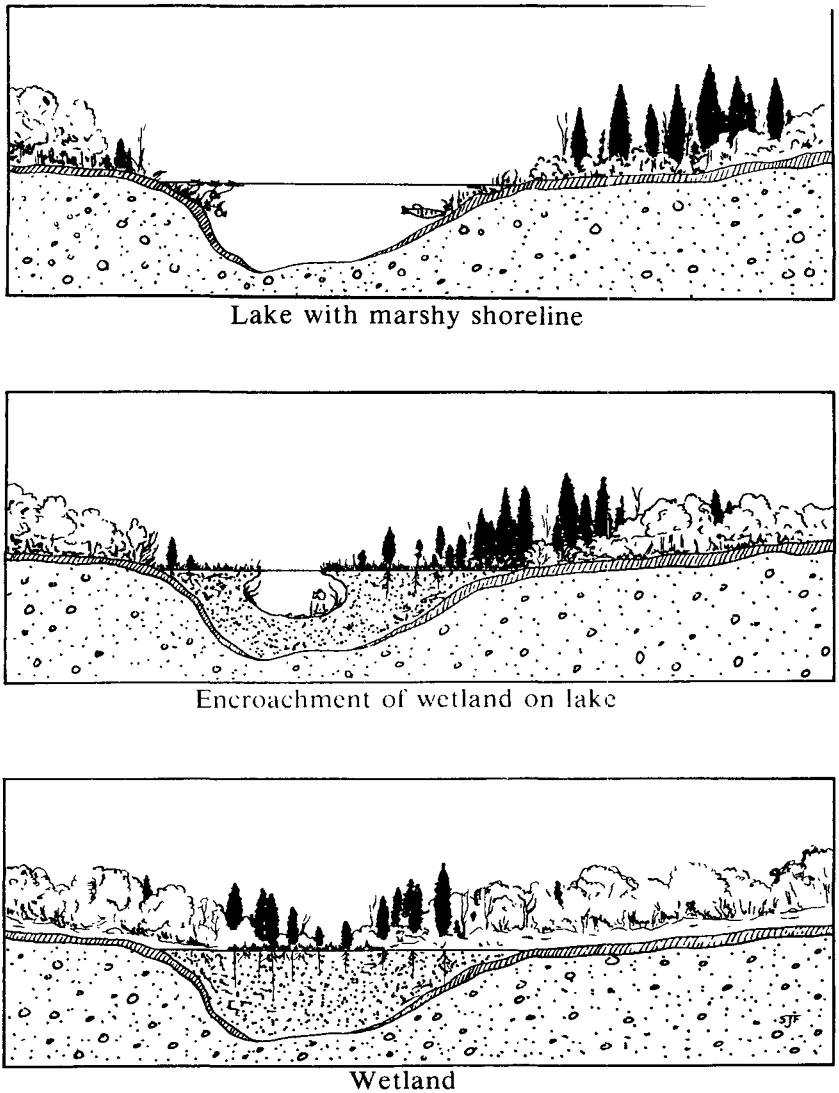



**FIGURE 45.—Natural succession of lake filling.**

*How streamflows vary*

*Low flow*

Streamflow is generally highest after snowmelt and heavy rainfall. Between periods of rainfall, there is no overland flow, and streamflow is sustained by natural release of water from lakes or from the groundwater reservoir, or by controlled release from impoundments. The low-flow discharge of a stream depends on how much water is released from storage during these periods of no rainfall.

In the basin of the east branch of the Milwaukee River there is very little natural storage, either of ground water or surface water, and no artificial storage in impoundments (fig. 46). The stream occasionally dries up. In 1971, flows were below the average annual streamflow 73 percent of the time. Sixty percent of the time, flows were more than 10 cubic feet per second (300 l/s) below the average streamflow.

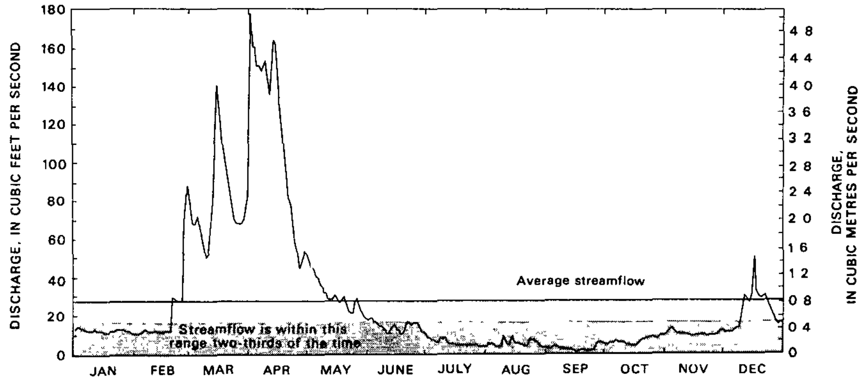



FIGURE 46.—Streamflow graph for East Branch Milwaukee River near New Fane in 1971.

In contrast, much of the basin of Black Earth Creek is underlain by permeable sand and gravel. These sediments are readily recharged by rainfall and store large quantities of water, releasing it slowly to the creek. Although the average streamflow was similar to East Branch Milwaukee River in 1971, discharges in Black Earth Creek did not drop below 19 cubic feet per second (540 l/s). The flow maintained by ground-water discharge was more than 10 cubic feet per second (300 l/s) below the average streamflow only 1 percent of the time (fig. 47).

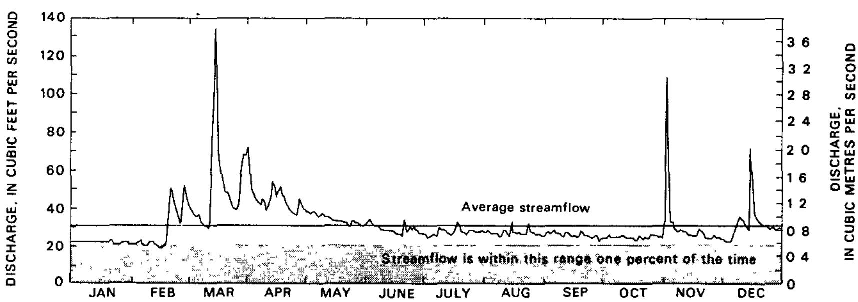



FIGURE 47.—Streamflow graph for Black Earth Creek at Black Earth in 1971.

Because of its high frequency of low flows, East Branch Milwaukee River would require additional storage to be a dependable source of water.

*Floods*

Floods can result from rapid snowmelt while the ground is frozen, heavy spring rains, a combination of the two, or heavy summer rainfall. Local flooding can result from backwater created by damming of a stream by ice or debris. Dams or other control structures can be built to protect against floods of a given magnitude.

A common unit used to assess flood magnitude is the 100-year flood, a flood that would be expected, on the average, once every 100 years. This can be calculated, and for the Chippewa River at Durand it is 172,000 cubic feet per second (4,870,000 l/s) (about 23 times the average flow). Small streams tend to be flashier than large streams. For instance, the Eau Galle River at Spring Valley, with a drainage area of only 65 square miles (170 $km^2$), has an estimated 100-year flood of 25,000 cubic feet per second (710,000 l/s), about 860 times its average.

## WATER USE

*Withdrawal use*

A total of 3.1 billion gallons (12 billion liters) of water—about 12 percent of the average daily flow of all streams flowing from Wisconsin—is withdrawn daily from lakes, streams, and the ground-water reservoir to meet the needs of Wisconsin's homes, factories, and farms (table 12). This does not include the 55 billion gallons (210 billion liters) of water used each day for generating hydroelectric power (fig. 48). Fortunately, most of the water withdrawn for use returns to streams and lakes for possible reuse.

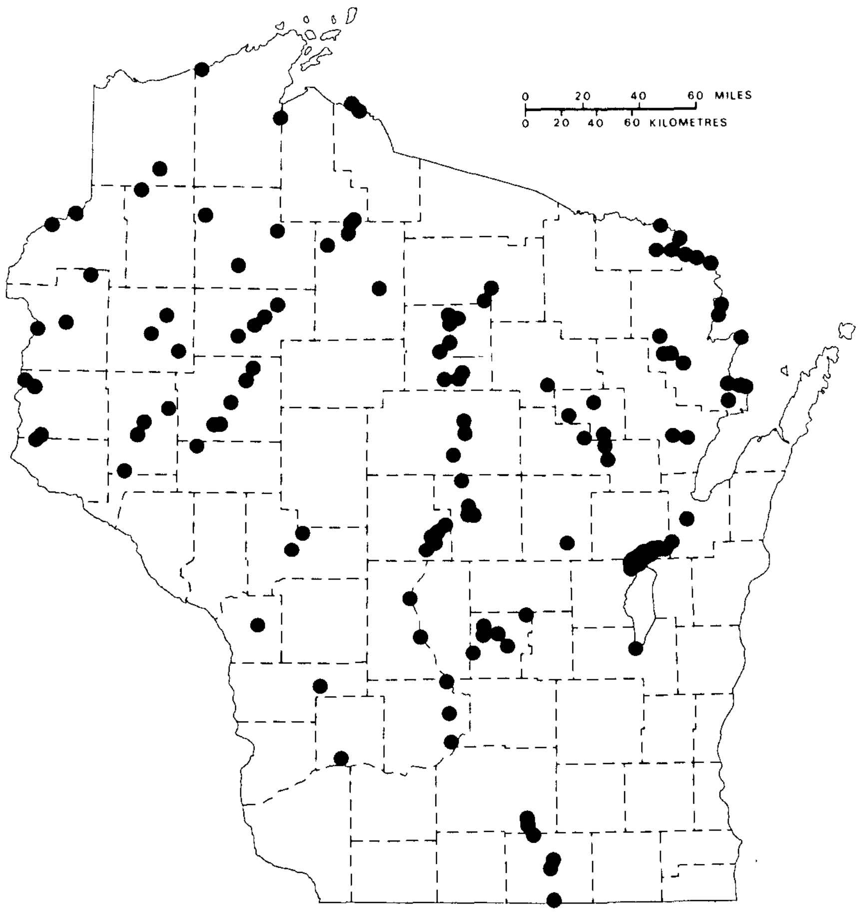



FIGURE 48.—Location of hydroelectric generating plants.

*Nonwithdrawal use*

Nonwithdrawal uses of water have great social and economic importance in our society. The most important of these uses are: fish and wildlife habitat, recreation, hydroelectric power generation, navigation and transportation, and waste transport and disposal.

In Wisconsin the management of fish and wildlife habitat and recreation are extremely important because the State derives great economic gain from tourism. Wisconsin's 31,000 lakes and 4,400 square miles (12,000 km$^2$) of wetlands are extremely important game habitat.

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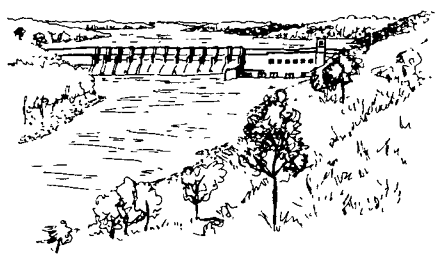
TABLE 12.—WITHDRAWAL USE OF WATER IN WISCONSIN

[In millions of gallons per day]

| Use | Source and type of supply | | | | |
|---|---|---|---|---|---|
| | Ground water | | | Surface water | |
| | Public supply | | Private supply | Public supply (municipal) | Private supply |
| | Municipal | Other | | | |
| Domestic | 62.1 | 4.1 | 70.3 | 71.7 | 0 |
| Industrial and commercial [1] | 91.0 | 1.3 | 92.5 | 124.5 | 217.1 |
| Thermal-electric cooling | 0 | 0 | 0 | 0 | 2,158.0 |
| Irrigation | 1.8 | 0 | 32.5 | 2.6 | 19.7 |
| Stock | 0 | 0 | 54.9 | 0 | 15.6 |
| Other | 41.8 | 2.8 | 11.2 | 55.7 | 1.3 |
| Subtotal | 196.7 | 8.2 | 261.4 | 254.5 | 2,412.0 |
| Total | | 466.3 | | 2,666.5 | |

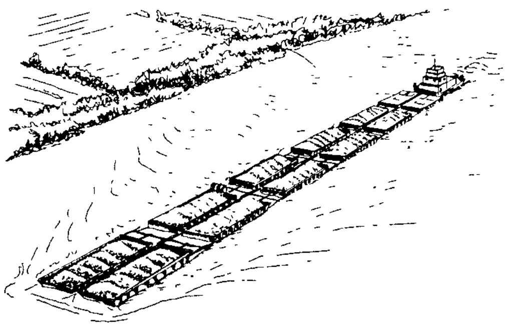
[1] Excluding thermal-electric cooling.

About 55,000 million gallons per day (2,400 $m^3/s$) of Wisconsin's river water passes through turbines to generate about 1.6 billion kwh of hydroelectric power. Most of this is generated on the Wisconsin, Chippewa, Menominee, St. Croix, and Fox Rivers. More than half of this power is generated by the Wisconsin and Chippewa Rivers.



Water navigation and transportation are limited to the Mississippi River and to the Great Lakes. Ports on Lake Superior and Lake

Michigan handle 54 million short tons (49 million tonnes) annually, including grain, fuel oil, coal, gypsum, food, lumber, limestone, and iron ore. Barge traffic on the Mississippi River in Wisconsin handles about 17 million short tons (15 million tonnes).



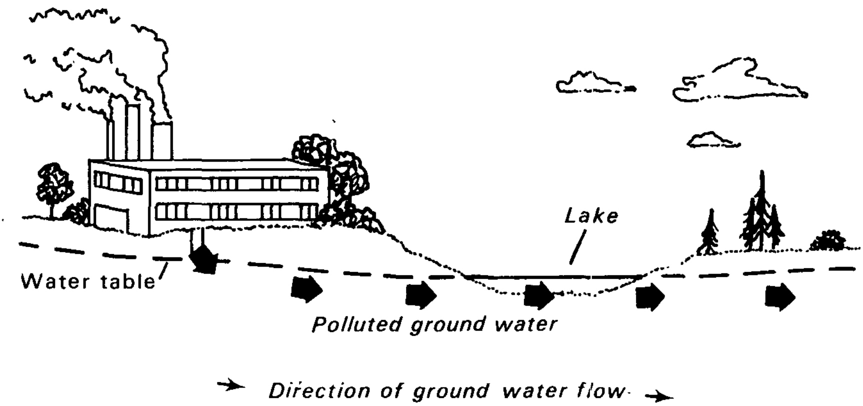
## WATER QUALITY

### *Natural quality*

The chemical quality of Wisconsin's water generally is very good. Most is unpolluted and suitable for many purposes. However, all natural water contains some dissolved solids. Rain picks up dissolved solids as it falls, as it infiltrates through the soil, and as it percolates through the rocks. In Wisconsin, much water contains considerable calcium and magnesium, which cause hardness. These elements are derived largely from limestone and dolomite composed of calcium and magnesium carbonates.

#### *Ground water*

Wisconsin's ground water contains small amounts of sulfate, nitrate, chloride, fluoride, silica, iron, manganese, and potassium, but more than 80 percent of its dissolved solids is calcium, magnesium, and bicarbonate. Natural ground-water quality changes very little from month to month or year to year.




Lakes can be polluted by nutrients from the septic systems of lakeshore cottages or by industrial and municipal waste discharges. Lakes also may be polluted from the streams flowing into them.

Streams are easily polluted. Common pollution sources are municipalities and industries (treated and partly treated wastes), power-generating plants (heated water), and farms and unsewered homes (agricultural and untreated animal and domestic wastes).

Overloading a stream with inadequately treated wastes may result in fish kill, unsightly appearance, odor, and a resultant decrease in the value of the resource (fig. 52). The reduction of oxygen by chemical or biological wastes discharged into the streams lowers the amount of dissolved oxygen in the streams and limits animal life to species tolerant of oxygen-poor water. This demand for oxygen is measured as biochemical oxygen demand (BOD).

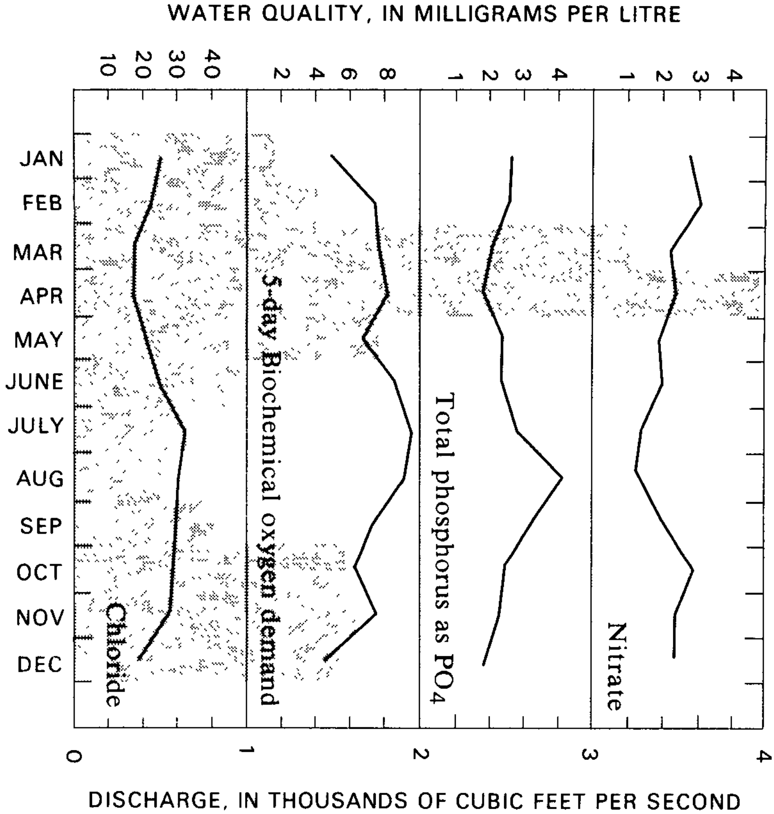



**FIGURE 52.—Seasonal changes in water quality characteristics of the Rock River near Afton.**

In the example above, chloride and phosphorus concentrations increase when streamflow decreases. Because they are introduced in sewage and industrial wastes, the concentrations are determined by the amount of water available for dilution.

Nitrate concentrations show no trend that can be related to flow. The concentration is generally dependent upon the discharge from sewage-treatment plants and upon agricultural fertilization.

## REFERENCES CITED


Agnew, A. F., and Heyl, A. V., Jr., 1943, Potosi lead-zinc area, Grant County, Wis.: U.S. Geol. Survey Prelim. Rept., 3 p., 1 map.

Agnew, A. F., 1944, Zinc deposits of the Mifflin-Cokerville area of the Wisconsin lead-zinc district: US. Geol. Survey Strategic Minerals Inv. Prelim. Rept. 3–134, 5 p., 1 map.

———, 1946, Quimbys Mill, new member of Platteville Formation, Upper Mississippi Valley: Am. Assoc. Petroleum Geologists Bull., v. 30, p. 1585–1587, 1 fig.

Agnew, A. F., Flint, A. E., and Allingham, J. W., 1953, Exploratory drilling program of U.S. Geological Survey for lead-zinc in Iowa and Wisconsin, 1950–51: U.S. Geol. Survey Circ. 231.

Agnew, A. F., Flint, A. E., and Crumpton, R. P., 1954, Geology and zinc-lead-barite deposits in an area in Lafayette County east of Cuba City, Wis.: U.S. Geol. Survey Mineral Inv. Field Studies, Map MF–15, 1 map.

Agnew, A.F., 1955, Application to the discovery of zinc-lead ores in the Wisconsin-Illinois-Iowa district: Mining Eng., v. 7, no. 8, p. 781–795: Am. Inst. Mining Metall. Engineers Trans., 1955, v. 202.

Agnew, A. F., Heyl, A. V., Jr., Behre, C. H., Jr., and Lyons, E. J., 1956, Stratigraphy of Middle Ordovidian rocks in the zinc-lead district of Wisconsin, Illinois, and Iowa: U.S. Geol. Survey Prof. Paper 274–K, p. 251–311.

Agnew, A. F., 1963, Geology of the Platteville Quadrangle, Wisconsin: U.S. Geol. Survey Bull. 1123–E, p. 245–278, 5 figs., 1 pl., 1 table.

Aldrich, H. R., 1923, Magnetic surveying on copper-bearing rocks in Wisconsin: Econ. Geology, v. 18, p. 562–574.

———, 1929, Geology, of the Gogebic iron range of Wisconsin: Wisconsin Geol. and Nat. History Survey Bull. 71, 279 p.

Aldrich, L. T., Wetherill, G. W., Bass, M. N., Compston, W., Davis, G. L., and Tilton, G. R., 1959, Mineral age measurements, *in* Annual Report of the Director of the Department of Terrestrial Magnetism: Carnegie Inst. Washington Year Book 58, 1958–1959, p. 244–247.

Aldrich, L. T., Wetherill, G. W., Bass, M. N., Tilton, G. R., and Davis, G. L., 1960, Mineral age measurements and earth history: *in* Annual Report of the Director of the Department of Terrestrial Magnetism: Carnegie Inst. Washington Year Book 59, 1959–1960, p. 209–213.

Aldrich, L. T., Davis, G. L., and James, H. L., 1965, Ages of minerals from metamorphic and igneous rocks near Iron Mountain, Michigan: Jour. Petrology, v. 6, pt. 3, p. 445–472.

Allen, R. C., 1909, The occurrence and origin of the brown ores of Spring Valley, Wisconsin: Mich. Acad., Sci., 11th Rept., p. 95–103.

Allen, R. C., and Barrett, L. P., 1915, Contributions to the Precambrian geology of northern Michigan and Wisconsin: Michigan Geol. and Biol. Survey Pub. 18, Geol. Ser. 15, p. 65–129.

Allingham, J. W., Flint, A. E., Agnew, A. F., 1955, Zinc and lead deposits of the Sinsinawa River area, Grant County, Wis.: U.S. Geol. Survey Mineral Inv. Field Studies Map MF–40.

Allingham, J. W., and Bates, R. G., 1961, Use of geophysical data to interpret geology in Precambrian rocks of central Wisconsin: U.S. Geol. Survey Prof. Paper 424–D. p. 292–296.

Allingham, J. W., 1963, Geology of the Dodgeville and Mineral Point quadrangles, Wisconsin: U.S. Geol. Survey Bull. 1123–D, p. 169–244.

American Foundry Society, 1952, Foundry sand handbook: American Foundry Society, Inc., 6th ed., 265 p.

American Geophysical Union and U.S. Geological Survey, 1964, Bouguer gravity anomaly map of the United States (exclusive of Alaska and Hawaii): Washington, D.C., U.S. Geological Survey, 2 sheets.

American Iron Ore Association, 1971. Iron ore–1970, (grade names and analyses section, and grade classification average analyses section) p. 72–85.
American Society for Testing and Materials, 1969, D 2607–69, Standard classification of peats, mosses, humus, and related products: 1916 Race Street, Philadelphia, Pa. 19103, 1 p.
———, 1975, 1975 Annual book of ASTM standards, pt. 19: 476 p.
Apell, G. A., 1949, Investigations of the Nigger Jim lead diggings, Lafayette County, Wisconsin: U.S. Bur. Mines Rept. Inv. 4372.
Asquith, G. B., 1964, Origin of the Precambrian rhyolites: Jour. Geology, v. 72, p. 835–847.
Atwater, G. I., 1935, The Keweenawan-Upper Cambrian unconformity in the upper Mississippi Valley: Kansas Geol. Soc. Guidebook 9th Ann. Field Conf., p. 316–319.
Bagg, R. M., 1918, Fluorspar in the Ordovician limestone of Wisconsin: Geol. Soc. America Bull. 29, p. 393–398.
Bain, A. F., 1906, Zinc and lead deposits of the Upper Mississippi Valley: U.S. Geol. Survey Bull. 294, 155 p., 45 figs., 15 pls.
Banks, P. O., and Rebello, D. P., 1969, Zircon age of a Precambrian rhyolite, northeastern Wisconsin: Geol. Soc. America Bull., v. 80, no. 5, p. 907–910.
Banks, P. O., and Cain, J. A., 1969, Zircon ages of Precambrian granitic rocks, northeast Wisconsin: Jour. Geology, v. 77, p. 208–220.
Barton, W. R., 1968, Dimension stone: U.S. Bur. Mines Inf. Circ. 8391, 147 p.
Bastin, E. S., 1911, Graphite, *in* Nonmetals, pt. 2 *of* Mineral Resources of the United States, 1911: U.S. Geol. Survey, p. 1079–1112.
Bastin, E. S., Behre, C. H., Jr., and Kay, G. M., 1939, Contributions to a knowledge of the lead and zinc deposits of the Mississippi Valley Region: Geol. Soc. America Special Paper 24, 156 p., 4 pls., 27 figs.
Bayley, R. W., Dutton, C. E., and Lamey, C. A., 1966, Geology of the Menominee iron-bearing district Dickinson County, Michigan, and Florence and Marinette Counties, Wisconsin: U.S. Geol. Survey Prof. Paper 513, 96 p.
Behre, C. H., Jr., 1935, The geology and development of the Wisconsin-Illinois lead-zinc district: Kansas Geol. Soc. Guidebook 9th Ann. Field Conf., p. 377–382, 3 figs.
Behre, C. H., Jr., Scott, E. R., and Banfield, A. F., 1937, The Wisconsin lead-zinc district, preliminary paper: Econ. Geology, v. 32, no. 6, p. 783–809, 14 figs.
Black, R. F., 1974, Geology of Ice Age National Scientific Reserve of Wisconsin: National Park Service Scientific Monograph Series No. 2, 234 p.
Blake, W. P., 1893a, The mineral deposits of southwest Wisconsin: Am. Geologist, v. 12, p. 237–248; Am. Inst. Min. Eng. Trans., v. 22, p. 558–568, 1894.
———, 1893b, The progress of geological surveys in the State of Wisconsin: a review and bibliography (abstract)): Wisconsin Acad. Sci. Trans., v. 9, p. 225–231.
———, 1893c, Wisconsin lead and zinc deposits (with discussion by J. F. Kemp and T. C. Chamberlin): Geol. Soc. American Bull., v. 5, p. 25–32.
Bleuer, N. K., 1970. Glacial stratigraphy of south-central Wisconsin: Wisconsin Geol. and Nat. History Survey Inf. Circ. No. 15, 35 p.
Bodenlos, A. J., and Thayer, T. P., 1973, Magnesian refractories, *in* United States mineral resources, Brobst, D. A., and Pratt, W. P., editors: U.S. Geol. Survey Prof. Paper 820, p. 379–384.
Boericke, W. F., and Garnett, T. H., 1919, The Wisconsin zinc district: Am. Inst. Min. Met. Eng. Trans., v. 152, p. 1213–1235, 5 figs., 2 tables.
Borst, R. L., 1958. The granites of Big Falls, Wisconsin: Madison, Wisconsin Univ., M. Sc. thesis, 61 p.
Bowles, Oliver, and Stoddard, B. H., 1932a, Talc and soapstone, *in* Mineral Resources of the United States, 1929, pt. 11, p. 219–227.
———, 1932b, Talc and soapstone, *in* Mineral Resources of the United States, 1930, pt. 11, p. 303–313.
———, 1933, Talc and soapstone, *in* Mineral Resources of the United States, 1931, pt. 11, p. 99–110.
Bowles, Oliver, 1939, The stone industries (2d. ed.): New York, McGraw-Hill Book Co., 519 p.
Brobst, D. A., 1973, Barite, *in* Brobst, D. A. and Pratt, W. P., eds., United States Mineral Resources: U.S. Geol. Survey Prof. Paper 820, p. 75–84.

Brobst, D. A., and Pratt, W. P., 1973, eds., United States Mineral Resources: U.S. Geol. Survey Prof. Paper 820.
———, 1975. Barium minerals *in* Lefond, S. H., ed., Industrial Minerals and Rocks, 4th ed., N.Y. Am. Inst. Mining Metall. and Petroleum Engineers, p. 427–442.
Broderick. G. N., 1974, The Mineral Industry of Wisconsin, *in* U.S. Bureau of Mines, 1973 Minerals Yearbook.
Brown, C. E., 1966, Phosphate deposits in the basal beds of the Maquoketa Shale near Dubuque, Iowa: U.S. Geol. Survey Prof. Paper 550–B, p. B152–B158.
———, 1967, Fluorite in crystal-lined vugs in the Maquoketa Shale at Volga, Clayton County, Iowa: Amer. Mineralogist, v. 52, p. 1735–1750.
———, 1973, Talc and soapstone, *in* Mineral Resources of the United States: U.S. Geol. Survey Prof. Paper 820, p. 619–626.
———, 1974, Phosphatic zone in the lower part of the Maquoketa Shale in northeastern Iowa: U.S. Geol. Survey Jour. Research, v. 2, no. 2, p. 219–232.
Brown, C. E., and Whitlow, J. W., 1960. Geology of the Dubuque South quadrangle, Iowa-Illinois: U.S. Geol. Survey Bull. 1123–A, p. 1–93.
Buckley, E. R., 1898, On the building and ornamental stones of Wisconsin: Wisconsin Geol. and Nat. History Survey, Bull. 4, 544 p.
———, 1901, Clays and clay industries of Wisconsin: Wisconsin Geol. and Nat. History Survey Bull. 7 (Part 1), Econ. Ser. 1, 304 p.
Butler, B. S., Burbank, W. S., and others, 1929, The copper deposits of Michigan· U.S. Geol. Survey Prof. Paper 144, 237 p.
Cain, J. A., 1961, Geology of the Pembine area, Marinette County, Wisconsin: Evanston, Ill., Northwestern Univ., M.S. thesis, 105 p.
———, 1963, Some problems of the Precambrian geology of northeastern Wisconsin—A review: Ohio Jour. Sci., v. 63, no. 1., p. 7–14.
———, 1964, Precambrian geology of the Pembine area, northeastern Wisconsin: Mich. Acad. Sci., Arts, and Letters Papers, v. 49, p. 81–103.
Cain, J. A., and Beckman, W. A., Jr., 1964, Preliminary report on the Precambrian geology of the Athelstane area, northeastern Wisconsin: Ohio Jour. Sci., v. 64, no. 1, p. 57–60.
Calvin, Samuel, and Bain, H. F., 1900, Geology of Dubuque County, Iowa: Iowa Geol. Survey Ann. Rept. (1889), v. 10, p. 379–622, 58 figs., 8 pls.
Cameron, E. N., Jahns, R. H., McNair, A. H., and Page, L. R., 1949, Internal structure of granitic pegmatites: Econ. Geology Mon. 2, 115 p.
Cameron, E. N., and Weis, P. L., 1960, Strategic graphite—a survey: U.S. Geol. Survey Bull. 1082–E, p. 201–321.
Carlson, J. E., 1956, Drilling data in the Montfort, Rewey, Mifflin, Belmont, and Calamine quadrangles, Wisconsin zinc-lead district: U.S. Geol. Survey open-file report.
———, 1961, Geology of the Montfort and Linden quadrangles, Wisconsin: U.S. Geol. Survey Bull. 1123–B, p. 94–138.
Castle, J. E., and Gillson, J. L., 1960, Feldspar, nepheline syenite, and aplite, *in* Industrial Minerals and Rocks, 3d ed.; New York, Am. Inst. Mining, Metall. and Petroleum Engineers, p. 339–362.
Chamberlin, T. C., 1877, Geology of Wisconsin, Survey of 1873–1877: Wisconsin Geol. Survey, v. 2, pp. 327–335.
———, 1882, Geology of Wisconsin, Survey of 1873–1879: Wisconsin Geol. Survey, v. 4.
Chidester, A. H., 1962, Petrology and geochemistry of selected talc-bearing ultramafic rocks and adjacent country rocks in northcentral Vermont: U.S. Geol. Survey Prof. Paper 345, 207 p.
Chidester, A. H., Engel, A. E. J., and Wright, L. A., 1964, Talc resources of the United States: U.S. Geol. Survey Bull. 1167, 61 p.
Cole, W. A., Hanson, G. F., and Westbrook, W. T., 1961, Lightweight aggregates: expansion properties of clays, shales, and Precambrian rocks of Wisconsin: U.S. Bur. Mines Rept. Inv. 5906, 26 p.
Coons, R. L., 1966, Precambrian basement geology and Paleozoic structure of mid-continent gravity high: Madison, Wisconsin Univ. Ph.D. thesis, 296 p.
Cooper, J. D., 1970, Kyanite and related minerals, *in* Mineral facts and problems: U.S. Bur. Mines Bull. 650, p. 1059–1072.
Cooper, J. D., and Wells, J. R., 1970, Feldspar, *in* Mineral facts and problems, 1970 ed.: U.S. Bur. Mines, Bull. 650, p. 977–988.

Cox, G. H., 1909, Copper in southwestern Wisconsin: Min. and Sci. Press, v. 99, p. 592.
———, 1911, Origin of the lead and zinc ore in the Upper Mississippi Valley district: Econ. Geology, v. 6, p. 427–448, 582–603.
———, 1912, New type of Wisconsin zinc deposit; Eng. and Min. Jour., v. 94, p. 1040–1041.
———, 1914, Lead and zinc deposits of northwestern Illinois: Illinois Geol. Survey Bull. 21, 120 p.
Craddock, Campbell, Thiel, C. C., and Gross, Barton, 1963, A gravity investigation of the Precambrian of southeastern Minnesota and western Wisconsin: Jour. Geophys. Research, v. 68, no. 21, p. 6015–6032.
Cummings, M. L., 1975, Structure and petrology of Precambrian amphibolite, Big Falls County, Wisconsin: (abs.) Twenty-first Ann. Inst. Lake Sup. Geol., 5 p.
Dalziel, I. W. D., and Dott, R. H., Jr., 1970, Geology of the Baraboo district Wisconsin: Wis. Geol. and Nat. History Survey, Inf. Cir. no. 14, 91 p., maps.
Daniels, Edward, 1854, First annual report of the geological survey of the State of Wisconsin: Wisconsin Geol. Survey, Madison, Wis., 84 p.
Dapples, E. C., 1955, General lithofacies relationships of St. Peter Sandstone and Simpson Group: Am. Assoc. Petroleum Geologists Bull., v. 39, p. 444–467.
Davis, R. A., Jr., 1970, Prairie du Chien Group in the Upper Mississippi Valley: Wisconsin Geol. and Nat. History Survey Info. Circ. No. 11, p. 35–44.
Decarlo, J. A., 1970, Peat, *in* Mineral facts and problems: U.S. Bur. Mines Bull. 650, p. 137–146.
Dott, R. H., and Dalziel, I. W. D., 1972, Age and correlation of Baraboo Quartzite of Wisconsin, Jour. of Geology, p. 557, 559.
Drake, H. J., 1975, Stone: U.S. Bur. Mines, preprint from 1973 Bureau of Mines Minerals Yearbook, 19 p.
Dreimanis, A., Reavely, G. H., Cook, R. J. B., Knox, K. S., and Moretti, F. J., 1957. Heavy mineral studies in tills of Ontario and adjacent areas: Journal of Sed. Petrology, v. 27, n. 2, p. 148–161.
DuBois, H. B., 1940, Development and growth of the feldspar industry: Am. Ceramic Soc. Bull., v. 19, no. 6, p. 206–213.
Dugdale, R. I., 1900, Lead and zinc in southwestern Wisconsin: Southwestern Wisconsin Miner's Assoc., Platteville, Wis., 60 p.
Durrie, D. S. 1872, Johnathon Carver and "Carver's Grants": Wisconsin Hist. Coll., v. 6, p. 225.
Dutton, C E., 1955, Iron ore deposits of North America and the West Lndies, *in* United Nations, 1955, Survey of world iron ore resources, p. 191.
Dutton, C. E., and Linebaugh, R. E., 1967, Precambrian geology of the Menominee iron-bearing district and vicinity, Michigan and Wisconsin: U.S. Geol. Survey Misc. Geol. Inv. Map I–466.
Dutton, C. E., and Bradley, R. E., 1970, Lithologic, geophysical, and mineral commodity maps of Precambrian rocks in Wisconsin: U.S. Geol. Survey Misc. Geologic Investigations Map I–631, 15 p., 6 maps.
Dutton, C. E., 1971, Geology of the Florence area, Wisconsin and Michigan: U.S. Geol. Survey Prof. Paper 633, 54 p., maps.
Dutton, C. E., and Bradley, R. E., 1971, Bibliography of Precambrian geology of Wisconsin 1778–1968: Wisconsin Geol. and Nat. History Survey open-file rept., 28 p.
Dutton, C. E., 1972, Volcanic-sedimentary belts and sulfide occurrences in Wisconsin: U.S. Geol. Survey Prof. Paper 750–B, p. B96–B100.
———, 1975, Chalcopyrite associated with magnetic iron-formation in Wisconsin: U.S. Geol. Survey, open-file report no. 75–7, 1974.
Eardley, A. J., 1951, Structural geology of North America: Harper and Bros., New York, 624 p.
Eblaw, G. E., 1938, Kankakee Arch in Illinois: Geol. Soc. America Bull., v. 49, p. 1425–1430.
Emmons, R. C., 1953, Selected petrogenic relationships of plagioclase: Geol. Soc. America Mem. 52, p. 71–87.
Emmons, R. C., and Snyder, F. G., 1944, A structural study of the Wausau area: Wis. Geol. Survey file rept., Madison, Wis.
Emmons, W. H., 1929, The origin of the sulfide ores of the Mississippi Valley: Econ. Geology, v. 24, no. 3, p. 221–271, 14 figs.

———, 1940, The principles of economic geology: 2nd. ed., New York and London, McGraw-Hill Book Co., Inc., p. 117, 394.

Emrich, G. H., 1966, Ironton and Galesville (Cambrian) sandstones in Illinois and adjacent areas: Illinois Geol. Survey Cir. 403, 55 p.

Engel, A. E. J., and Wright, L. A., 1960, Talc and soapstone, *in* Industrial Minerals and Rocks (3d ed.) : New York, Am. Inst. Mining Metall., and Petroleum Engineers, p. 835–850.

Ervin, C. P., and Hammer, S., 1974, Bouguer anomaly gravity map of Wisconsin: Wisconsin Geol. and Nat. History Survey, 2 sheets, 13 p.

Espenshade, G. H., and Potter, D. B., 1960, Kyanite, sillimanite, and andalusite deposits of the Southeastern States: U.S. Geol. Survey Prof. Paper 336, 121 p.

Espenshade, G. H., 1973, Kyanite and related minerals, *in* United States Mineral Resources, Brobst, D. A. and Pratt, W.P., eds.: U.S. Geol. Survey Prof. Paper 820, p. 307–311.

Evenson, E. B., Farrand, W. R., Mickelson, D. M., Eschman, D. F., and Maher, L. D., 1975, Greatlakean Substage: A replacement for Valderan in the Lake Michigan Basin: submitted to *Quaternary Research.*

Fanning, D. S., and Jackson, M. L., 1967, Zirconium content of coarse silt from some Wisconsin soils and sediments: Soil Science, c. 103, n. 4, p. 253–260.

Farnham, R. S., 1974, Peat, an alternate source of energy?: Earth Journal, v. IV, no. 3, p. 15–17.

Feitler, S. A., 1967, Feldspar, resources and marketing in eastern United States: U.S. Bur. Mines, Inf. Circ. IC 8310, 41 p.

Fisher, D. J., 1957, Report on molybdenite in northeastern Wisconsin: U.S. Geol. Survey open-file rept., 13 p.

Forsyth, Thomas, 1872, Journal of a voyage from St. Louis to the Falls of St. Anthony in 1819: Wisconsin Hist. Coll., v. 6, p. 194–195.

Fries, Carl, Jr., 1939, Petrogeny of a kyanite deposit (near Powell, Iron County, Wis.) : Master of Arts thesis, Wisconsin Univ. Library, 40 p.

Friz, T. O., 1975, Mineral resources, mining and land-use planning in Wisconsin: Wisconsin Geol. and Nat. History Survey, Inf. Circ. 26, 61 p.

Gay, T. E., Jr., 1957, Specialty sands, *in* Mineral commodities of California: California Div. Mines Bull. 176, p. 547–564.

Geisse, Elaine, 1951, The petrography of the syenites and related rocks of Wausau, Wis. (unpublished Master of Science thesis in files of Smith College Library, Northampton, Mass.)

George, H. C., 1918, Wisconsin zinc district: Am. Inst. Mining Eng. Trans., v. 59, p. 117–150.

Goldich, S. S., and others, 1961, The Precambrian geology and geochronology of Minnesota: Minnesota Geol. Survey Bull. 41, 193 p.

Goldich, S. S., Lidiak, E. G., Hedge, C. E., and Walthall, F. G., 1966, Geochronology of the Midcontinent region, United States: Jour. Geophys. Research, v. 71, no. 22, p. 5389–5404.

Grant, U. S., 1901, Preliminary report on the copper-bearing rocks of Douglas County, Wisconsin: Wisconsin Geol. and Nat. History Survey Bull. 6, 55 p.

———, 1903, Preliminary report on the lead and zinc deposits of southwestern Wisconsin: Wisconsin Geol. and Nat. History Survey Bull. 9, Econ. ser. 5, 103 p., 8 figs., 4 pls.

———, 1905a, Structural relations of the Wisconsin zinc and lead deposits: Econ. Geology, v. 1, p. 233–242.

———, 1905b, Zinc and lead deposits of southwestern Wisconsin: U.S. Geol. Survey Bull. 260, p. 304–310.

———, 1906, Report on the lead and zinc deposits of Wisconsin, with an atlas of detailed maps: Wisconsin Geol. and Nat. History Survey Bull. 14, Econ. ser. 9, 100 p., 10 figs., 26 pls.

Grant, U.S., and Burchard, E. F., 1907, U.S. Geol. Survey Geol. Atlas, Lancaster and Mineral Point folio (No. 145), 14 p., 11 figs., 2 maps.

Graton, L C., and Harcourt, G. A., 1935, Spectrographic evidence on origin of ores of Mississippi Valley type: Econ. Geology, v. 30, no. 7, p. 800–824, 1 fig.

Gustavson, S. A., 1961, The mineral industry of Wisconsin, *in* U.S. Bur. Mines, 1960 Minerals Yearbook, vol. II. p. 1131–1148.

Hansell, J. M., 1926, A cross-section in the Keweenawan of Wisconsin: Madison, Wisconsin Univ., M.S. thesis, 80 p.

Hanson, G. F., 1964, The mineral resources of Wisconsin, *in* 1964 Wisconsin Blue Book, p. 199–211.

———, 1967, The natural resources of Wisconsin: Natural resources committee of State agencies, Madison, Wis., p. 133–145.
Hawley, J. E., and Beavan, A. P., 1934, Mineralogy and genesis of the Mayville iron ore of Wisconsin: American Mineralogist, v. 19, no. 11, p. 493–514.
Heindl, R. A., 1970B, Zinc, *in* Mineral facts and problems; U.S. Bur. Mines Bull. 650, p. 805–824.
Heller, R. L., 1956, Status of Prairie du Chien problem: Guidebook for field trips, Minneapolis, Geol. Soc. America, Field Trip No. 2, p. 29–40.
Henderson, J. R., Tyson, N. S., and Paige, J. R., 1963, Aeromagnetic map of the Wausau area, Wisconsin: U.S. Geol. Survey Geophys. Inv. Map GP–401.
Heyl, A. V., Jr., and Agnew, A. F., 1945, The structural relations of the Upper Mississippi Valley zinc-lead district (abstracts): Econ. Geology, v. 40, no. 1, p. 87: no. 8, p. 594-595, 1945; Geol. Soc. America Bull.. v. 56, no. 12, pt. 2, p. 1166, December 1945.
Heyl, A. V. Jr., Agnew, A. F., and Behre, C. H., Jr., 1945. Zinc deposits of the Meekers Grove (Jenkinsville) area of the Wisconsin zinc-lead district: U.S. Geol. Survey Strategic Minerals Inv. Prelim. Rept. 3–161, 6 p., map.
Heyl, A. V., Jr., Lyons, E. J., and Agnew, A. F., 1948. Geologic structure map of the Potosi area, Grant County, Wis.: U.S. Geol. Survey Strategic Minerals Inv. Prelim. Map 3–221, 1 map.
Heyl, A. V., Jr., Agnew, A. F., Behre, C. H., Jr., and Lyons, E. J., 1948. Zinc-lead deposits of the Hazel Green-Shullsburg area, Lafayette and Grant Counties, Wis.: U.S. Geol. Survey Strategic Minerals Inv. Prelim. Rept. 3–216, 11 p.
Heyl, A. V., Jr., Lyons, E. J., Theiler, J. J., 1952, Geologic structure map of the Beetown lead-zinc area, Grant County, Wis.: U.S. Geol. Survey Mineral Inv. Field Studies Map MF–3, 1 map.
Heyl, A. V., Jr., 1951, Exploratory drilling in the Prairie du Chien Group of the Wisconsin zinc-lead district by the U.S. Geological Survey in 1949–1950: U.S. Geol. Survey Circ. 131, 35 p.
Heyl, A. V., Jr., Lyons, E. J., Agnew, A. F., and Behre, C. H., Jr., 1955, General geologic relations and lead, zinc, and copper resources in the Upper Mississippi Valley district: U.S. Geol. Survey Bull. 1015–G, p. 227–245, 2 pls., 2 figs.
Heyl, A. V., Jr., Agnew, A. F., Lyons, E. J., and Behre, C. H., Jr., 1959, The geology of the Upper Mississippi Valley zinc-lead district: U.S. Geol. Survey Prof. Paper 309, 310 p.
Heyl, A. V., 1968, The Upper Mississippi Valley base-metal district, *in* v. 1 of Ridge, J.D., ed., Ore deposits of the United States, 1933–1967—the Graton-Sales Volume: New York Am. Inst. Mining Metall. and Petroleum Engineers.
Heyl, A. V., Jr., Broughton, W. A., and West, W. S., 1970, Guidebook to the Upper Mississippi Valley base metal district: Wisconsin Geol. and Nat. History Survey Information Circ. no. 16; 49 p., 15 figs., 1 table.
Hill, T. E., Jr., Kenworthy, H., Ritchey, R. A., and Gerard, J. A., 1969, Separation of feldspar, quartz, and mica from granite: U.S. Bur. Mines Rept. Inv., R.I. 7245, 25 p.
Hite, D. M., 1968, Sedimentology of the Upper Keweenawan sequence of northern Wisconsin and adjacent Michigan: Madison, Wisconsin Univ., Ph.D. thesis, 217 p.
Holliday, R. W., 1955, Investigation of Chippewa copper-nickel prospect near Rockmont, Douglas County, Wisconsin: U.S. Bur. Mines Rept. Inv. 5114, 11 p.
Hotchkiss, W. O., and Steidtman, Edward, 1909, Geological maps of the Wisconsin lead and zinc district: Wisconsin Geol. and Nat. History Survey, Supp. to Bull. 14, Econ. Ser. no. 9, 6 maps.
Hotchkiss, W. O., and others, 1915, Mineral land classification: Wisconsin Geol. and Nat. History Survey Bull. 44, 367 p.
Hotchkiss, W. O., 1919, Geology of the Gogebic Range and its relation to recent mining developments: Engineer and Mining Journal, p. 3–30.
Hotchkiss, and others, 1929. Mineral lands of part of northern Wisconsin: Wisconsin Geol. and Nat. History Survey Bull. 46, 200 p.
Huels, F. W., 1915. The peat resources of Wisconsin: Wisconsin Geol. and Nat. History Survey Bulletin 45, Economic Series no. 20, 274 p.
Hunter, R. E., 1965, Feldspar in Illinois sands: a further study: Illinois State Geol. Survey, Circ. 391, 19 p.
Industrial Minerals, 1968, Talc—Mineral with multitude of uses: Indus. Min. (London), no. 5, Feb. p. 9–16.

Irving, R. D., 1877, Geology of central Wisconsin, *in* Geology of Wisconsin 1873–77: Wisconsin Geol. Survey, v. 2, p. 409–524.

———, 1880a, The geological structure of northern Wisconsin, *in* Geology of Wisconsin 1873–79: Wisconsin Geol. Survey, v. 3, p. 1–25.

———, 1880b, Geology of the eastern Lake Superior district, *in* Geology of Wisconsin 1873–79: Wisconsin Geol. Survey, v. 3, p. 53–238.

———, 1883, Copper-bearing rocks of Lake Superior: U.S. Geol. Survey Mon. 5, 464 p.

———, 1883, Iron ores: *in* Chamberlin, T. C., 1877, Geology of Wisconsin: Survey of 1873–1877, v. 2, p. 327–335, atlas.

———, 1883, Minerals of Wisconsin, *in* Geology of Wisconsin, Survey of 1873–1879: Wisconsin Geol. Survey, v. 1, pt. 2, p. 309–339.

Irving, R. D., and Van Hise, C. R., 1882, Crystalline rocks of the Wisconsin Valley, *in* Geology of Wisconsin 1873–79: Wisconsin Geol. Survey, v. 4, p. 627–714.

———, 1892, Penokee iron-bearing series of Michigan and Wisconsin: U.S. Geol. Survey Mon. 19, 534 p.

Jahns, R. H., 1955, The study of pegmatites: Econ. Geology 50th Anniversary Volume, pt. 2, p. 1025–1130.

———, 1960, Gem stones and allied materials, *in* Industrial minerals and rocks, 3d ed.: American Institute of Mining, Metallurgical, and Petroleum Engineers, New York, p. 383–441.

James, H. L., 1954, Sedimentary facies of iron formation: Econ. Geol. v. 49, no. 3, p. 235–292.

———, 1955, Zones of regional metamorphism in the Precambrian of northern Michigan: Geol. Soc. America Bull., v. 66, p. 1455–1487.

———, 1958, Stratigraphy of pre-Keweenawan rocks in parts of northern Michigan: U.S. Geol. Survey Prof. Paper 314–C, p. 27–44.

James, H. L., Dutton, C. E., Pettijohn, F. J., and Wier, K. L., 1959, Geologic map of the Iron River-Crystal Falls district, Iron County, Mich.: U.S. Geol. Survey Mineral Inv. Field Studies Map MF–225, 3 sheets.

James, H. L., 1966, Chemistry of the iron-rich sedimentary rocks: U.S. Geol. Survey Prof. Paper 440–W, p. W34.

Jaster, M. C., 1957, Selected annotated bibliography of high-grade silica of the United States and Canada, through December 1954; U.S. Geol. Survey Bull. 1019–H, p. 609–673.

Jenkins, R. A., 1973, Geology of Beecher and Pembine Townships, Marinette County, Wisconsin (abs.): 19th Ann. Inst. on Lake Superior Geol., Madison, Wisc., p. 15.

Jenney, W. P., 1894, Lead and zinc deposits in the Mississippi Valley: Am. Inst. Min. Eng. Trans., v. 22, p. 171–225, 642–646.

Karl, J. H., and Friedel, J. C., 1974, Wisconsin aeromagnetic survey maps: Wisconsin Geol. and Nat. History Survey.

Kay, G. M., 1935a, Distribution of Ordovician altered volcanic materials and related clays: Geol. Soc. America Bull., v. 46, no. 2, p. 225–244, pls. 20–22, 14 figs.

———, 1935b, Ordovician Stewartville-Dubuque problems: Jour. Geology, v. 43, no. 6, p. 561–590, 8 figs.

———, 1935c, Ordovician system in the Upper Mississippi Valley: Kansas Geol. Soc. Guidebook 9th Ann. Field Conf., p. 281–295, 1 fig.

———, 1939, Stratigraphic setting, Wisconsin-Illinois district, in Bastin, E.S., and others, Contributions to a knowledge of the lead and zinc deposits of the Mississippi Valley region: Geol. Soc. America Special Paper 24, p. 26–28.

Kay, G. M., and Atwater, G. I., 1935, Basal relation of the Galena Dolomite in the Upper Mississippi Valley lead and zinc district: Am. Jour. Sci., 5th ser., v. 29, no. 170, p. 98–111, 4 figs.

Kennedy, V. C., 1956, Geochemical studies in southwestern Wisconsin lead-zinc area: U.S. Geol. Survey Bull. 1000–E, p. 187–223.

King, E. R., Henderson, J. R., and Vargo, J. L., 1966, Aeromagnetic map of Florence-Goodman area, Florence, Forest, and Marinette Counties, Wisconsin: U.S. Geol. Survey Geophys. Inv. Map GP–576.

King, F. H., 1882, Geology of the upper Flambeau Valley, *in* Geology of Wisconsin, Survey of 1873–1879, vol. IV: Wis. Geol. Survey, Madison, Wis., p. 685–615.

King, P. B., 1959, The evolution of North America: Princeton Univ. Press, Princeton, New Jersey, 190 p.

Kirby, J. R., and Petty, A. J., 1966, Regional aeromagnetic map of western Lake Superior and adjacent parts of Minnesota, Michigan, and Wisconsin: U.S. Geol. Survey Geophys. Inv. Map GP–556.

Kirkemo, Harold, Anderson, C. A., and Creasey, S. C., 1965, Investigations of molybdenite deposits in conterminous United States 1942–60: U.S. Geol. Survey Bull. 1182–E, p. E85–E88.

Klemic, Harry, and West, W. S., 1964, Geology of the Belmont and Calamine quadrangles, Wisconsin: U.S. Geol. Survey Bull. 1123–G, p. 361–436, 4 figs.

Klemic, Harry, and Peterman, Z. E., 1972, Iron formation in Jackson County, Wisconsin, *in* Geological Survey Research 1972, Chapter A, U.S. Geol. Survey Prof. Paper 800–A, p. A3.

Klemic, Harry, Gottfried, D., Cooper, M., and Marsh, S. P., 1973, Zirconium and hafnium: U.S. Geol. Survey Prof. Paper 820, p. 713–722.

Klemic, Harry, James, H. L., and Eberlein, G. D., 1973a, Iron, *in* United States mineral resources: U.S. Geol. Survey Prof. Paper 820, p. 825.

Klemic, Harry, 1975, Zirconium and hafnium minerals: *in* Society of Mining Engineers of AIME, 1975, Industrial minerals and rocks, 4th edition, in preparation.

Klinefelter, T. A., and Cooper, J. D., 1961, Kyanite—A materials survey: U.S. Bur. Mines Inf. Circ. 8040, 55 p.

Kraft, J. C., 1956, A petrographic study of the Oneota-Jordan contact zone: Guidebook for field trips, Minneapolis, Geol. Soc. America, Field Trip No. 2, p. 24–28.

LaBerge, G. L., 1970, Preliminary report on the geology of the northern part of the Wausau East quadrangle: Wisconsin Geol. and Nat. History Survey, 13 p.

———, 1971, Progress report on mapping of Precambrian geology in Marathon County, Wisconsin, 1970: Wisconsin Geol. and Nat. History Survey, 27 p.

LaBerge, G. L., and Myers, P. E., 1972, Progress report on mapping of Precambrian geology of Marathon County, Wisconsin, 1971: Wisconsin Geol. and Nat. History Survey, 27 p.

Lake Superior Iron Ore Association, 1938, Lake Superior iron ores, Cleveland, Ohio, 362 p., appendix.

———, 1952, Lake Superior iron ores: Cleveland, Ohio, Lake Superior Iron Ore Association, p. 231.

Lee, Wallace, 1943, The stratigraphic and structural development of the Forest City Basin: Kansas Geol. Survey Bull. 51, 142 p.

Leighton, M. W., 1954, Petrogenesis of a gabbro-granophyre complex in northern Wisconsin: Geol. Soc. America Bull., v. 65, p. 401–442.

Leith, Andrew, 1935, The Precambrian of the Lake Superior region, the Baraboo district and other isolated areas in the upper Mississippi Valley, Kansas Geol. Soc. Guidebook, Ninth Ann. Field Conf., p. 320–322.

Leith, C. K., 1897, Pre-Cambrian volcanics of the Fox River valley: Madison, Wisconsin Univ. B. Sc. thesis, 149 p.

———, 1932, Structures of the Wisconsin and Tri-state lead and zinc deposits: Econ. Geology, v. 27, no. 5, p. 405–418.

Leith, C. K., Lund, R. J., and Leith, Andrew, 1935, Precambrian rocks of the Lake Superior region—A review of newly discovered geologic features with a revised geologic map: U.S. Geol. Survey Prof. Paper 184, 34 p.

Leitner, J. C., 1956, Midwest gem trails: Mineralogist Publishing Company, Portland, Oregon, 64 p.

Lewis, R. W., 1970, Barium, *in* Mineral facts and problems, 1970: U.S. Bur. Mines Bull. 650, p. 865–877.

Lyons, E. J., 1947, Mafic and porphyritic rocks from the Niagara area, Wisconsin: Madison, Wisconsin Univ. B. Sc. thesis, 58 p.

Maass, R. S., Medaris, L. G., Jr., and Van Schmus, W. R., 1976, Penokean structures and plutonic rocks in Portage and Wood Counties, Wisconsin (abs.): 22d Annual Inst. on Lake Superior Geol., St. Paul, Minn., p. 38.

Mack, J. W., 1957, A regional gravity study of crustal structure in Wisconsin: Madison, Wisconsin Univ., M. Sc. thesis, 79 p.

Malan, R. D., and Sterling, D. A., 1969, Geologic study of uranium sources in Precambrian rocks of western United States: U.S. Atomic Energy Commission Rept. AEC–RD–10, 25 p.

Mancuso, J. J., 1957, Geology and mineralization of the Mountain area, Wisconsin: Madison, Wisconsin Univ., M. Sc. thesis, 32 p.
———, 1960, The stratigraphy and structure of the McCaslin district, Wisconsin: East Lansing, Michigan State Univ., Ph. D. thesis.
Martin, Lawrence, 1932, The physical geography of Wisconsin: Wisconsin Geol. and Nat. History Survey Bull. 36, 609 p.
McDowell, J. S., and Rochow, W. F., 1950, Modern refractory practice: Pittsburgh, Pa., Harbison-Walker Refractories Co., 439 p.
McGee, W. J., 1891, The Pleistocene history of northeast Iowa: U.S. Geol. Survey, 11th Annual Report, p. 187–577.
Medaris, L. G., Anderson, J. L., and Myles, J. R., 1973, The Wolf River Batholith—a late Precambrian Rapakivi massif in Northeastern Wisconsin, *in* Guidebook to the Precambrian Geology of northeastern and northcentral Wisconsin, 19th Annual Inst. on Lake Superior Geol.: Wisconsin Geol. and Nat. Hist. Survey, Madison, Wisconsin, 86 p.
Medaris, L. G., Jr., and Anderson, J. L., 1973, Preliminary geologic map of Green Bay sheet, *in* Guidebook to the Precambrian geology of northeastern and northcentral Wisconsin, 19th Annual Inst. on Lake Superior Geology.
Meeker, Moses, 1872, Early history of the lead region: Wisconsin Hist. Coll., v. 6, p. 271–296.
Melby, J. H., 1967, The stratigraphy of the Sunset Point Sandstone in Western Wisconsin: Unpub. master's thesis, Wisconsin Univ., 95 p.
Mertie, J. B., Jr., 1958, Zirconium and hafnium in the southeastern Atlantic States: U.S. Geol. Survey Bull. 1082–A, 28 p.
Mickelson, D. M., Nelson, A. R., and Stewart, M. T., 1974, Glacial events in north-central Wisconsin, *in* Later Quaternary environments of Wisconsin, J. S. Knox and D. M. Mickelson, eds.: Wisconsin Geol. and Nat. History Survey publication, 19 p.
Mickelson, D. M., and Evenson, E. B., 1975, Pre-Twocreekan age of the type Valders Till: submitted to *Geology*.
Mickelson, D. P., 1975, Peat producers annual: U.S. Bureau of Mines, Washington, D.C., U.S. Government Printing Office, 11 p.
Mining and Minerals Policy, 1975, Annual report of the Secretary of the Interior under the Mining and Minerals Policy Act of 1970, 63 p.
Morrison, B. C., 1968, Stratigraphy of the Eau Claire Formation of west-central Wisconsin: Unpub. master's thesis, Wisconsin Univ., 41 p.
Mullens, T. E., 1964, Geology of the Cuba City, New Diggings, and Shullsburg quadrangles, Wisconsin and Illinois: U.S. Geol. Survey Bull. 1123–H, p. 437–532.
Murphy, T. D., 1960, Silica sand and pebble, *in* Gillson, J. L., ed., Industrial minerals and rocks: Am. Inst. Mining, Metallurgical, and Petroleum Engineers, p. 763–772.
Myers, P. E., 1973, Stettin syenite pluton, *in* Guidebook to the Precambrian geology of northeastern and northcentral Wisconsin: 19th Ann. Institute on Lake Superior geology, p. 75–78.
Neal, J. P., 1973, The feldspar story in our leading feldspar state: evaluations and comparisons: Soc. Min. Eng. of AIME, preprint, 73–H–19, p. 33.
Nelson, C. A., 1956, Upper Croixan stratigraphy: Geol. Soc. America Bull., v. 67, p. 165–184.
Newhouse, W. H., 1933, The temperature of formation of the Mississippi Valley lead-zinc deposits: Econ. Geology, v. 28, no. 8, p. 744–750.
Ohlson, J. M., 1973, The iron ore deposits at Black River Falls, Wisconsin; geology and operation, 19th Annual Institute on Lake Superior geology unpublished report, 7 p.
Ostrom, M. E., and Hanson, G. F., 1961, Mineral and rock collecting in Wisconsin: Wisconsin Geol. and Nat. History Survey, University of Wisconsin, Madison. Wisconsin, 12 p.
Ostrom, M. E., 1964, Pre-Cincinnatian Paleozoic cyclic sediments in the Upper Mississippi Valley: a discussion: Kansas Geol. Survev Bull. 169, v. II, p. 381–398.
———, 1967, Paleozoic stratigraphic nomenclature for Wisconsin: Wisconsin Geol. and Nat. History Survey Inf. Circ. no. 8, 1 sheet.
———, 1970, Directory of Wisconsin mineral producers, 1968: Wisconsin Geol. and Nat. History Survey, Univ. Wisconsin Extension, Inf. Circ. 12.

———, 1974, Mineral industry surveys: The mineral industry of Wisconsin in 1974, 2 p.
———, 1975a, Commodity data summaries (iron ore and iron and steel sections) p. 80–83.
———, 1975, Mineral industry surveys, Iron ore monthly: Iron ore in December 1974, 6 p.
———, 1975b, Mineral industry surveys, Iron ore monthly: Iron ore in February, 1975, p. 6.
U.S. Geological Survey, 1883–1923, Mineral resources of the United States: sections on iron ore production (by various authors).
U.S. Geological Survey and American Association Petroleum Geologists, 1962: Tectonic map of the United States (exclusive of Alaska and Hawaii) : 2 sheets, scale 1:2,500,000.
Van Hise, C. R., 1901. Some principles controlling the deposition of the ores: Am. Inst. Mining Metall. Eng. Trans., v. 30, p. 27–177.
Van Hise, C. R., and Bain, H. F., 1902, Lead and zinc deposits of the Mississippi Valley, U.S.A.: Inst. Min. Eng. Trans., v. 23, p. 376–434
Van Hise, C.R., and Leith, C.K., 1911, The geology of the Lake Superior region: U.S. Geol. Survey Mon. 52, p. 359–364.
Van Schmus, W.R., 1976, Early and Middle Proterozoic history of the Great Lakes area, North America: Phil. Trans. R. Soc. London, vol. 280A, pp. 605–628.
Van Schumus, W. R., and Anderson, J. L., 1976, Gneiss and migmatite of Archean age in the Precambrian basement of Central Wisconsin, U.S.A. (abs.) : Twenty Second Annual Inst. on Lake Superior Geology, St. Paul, Minn., p. 67.
Van Schmus, W.R., Medaris, L.G., Jr., and Banks, P.O., 1975, Geology and age of the Wolf River batholith, Wisconsin: Geol. Soc. America Bull., v. 86, p. 907–914.
Van Schmus, W.R., Thurman, E.M., and Peterman, Z.E., 1975, Geology and Rb-Sr chronology of Middle Precambrian rocks in eastern and central Wisconsin: Geol. Soc. America Bull., v. 86, p. 1255–1265.
Varley, E.R., 1965, Sillimanite-andalusite, kyanite, sillimanite: London, Overseas Geol. Surveys, Mineral Resources Div., 165 p.
Vickers, R.C., 1956, Airborne and ground reconnaissance of part of the syenite complex near Wausau, Wisconsin: U.S. Geol. Survey Bull. 1042–B, p. 25–44.
Warner, J.H., 1904. The Waterloo quartzite area of Wisconsin: Madison, Wisconsin Univ., B.A. thesis, 33 p.
Wegrzyn, R. S., 1973, Sedimentary petrology of the Jordan Formation: Unpub. master's thesis, Northern Illinois University, 148 p.
Weidman, Samuel, 1898, Precambrian rocks of the Fox River valley, Wisconsin: Wisconsin Geol. and Nat. History Survey Bull. 3, 63 p.
———, 1904, The Baraboo iron-bearing district of Wisconsin: Wisconsin Geol. and Nat. History Survey Bull. 13, 190 p.
———, 1907, The geology of north-central Wisconsin: Wisconsin Geol. and Nat. History Survey Bull. 16, 697 p.
Weis, L.W., 1965, Origin of the Tigerton anorthosite: Madison, Wisconsin Univ., Ph.D. thesis, 65 p.
Weis, L.W., and LaBerge, G.L., 1969, Central Wisconsin volcanic belt: Guidebook for 15th Annual Inst. on Lake Superior geology, prepared with the collaboration of C.E. Dutton, 30 p., maps.
Weis, P. L., 1963, Graphite, *in* United States Mineral Resources, U.S. Geol. Survey Prof. Paper 820, p. 277–283.
Weis, P.L., and Feitler, S.A., 1968, Graphite, *in* Mineral resources of the Appalachian region: U.S. Geol. Survey Prof. Paper 580, p. 303–307.
Wells, J.R., 1965, Feldspar, *in* Mineral Facts and Problems, 1965 Edition; U.S. Bur. Mines Bull. 630, p. 321–327.
———, 1974, Feldspar, nepheline syenite and aplite, *in* Minerals Yearbook, v. 1, Metals minerals and fuels: U.S. Bur. Mines, 8 p. (preprint).
West, W.S., and Blacet, P.M., 1971, Geologic map of the Lancaster quadrangle, Grant County, Wisconsin: U.S. Geol. Survey Geol. Quad. Map, GQ–949.
West, W.S., Whitlow, J.W., Brown, C.E., and Heyl, A.V., Jr., 1971, Geologic map of the Ellenboro quadrangle, Grant County, Wisconsin: U.S. Geol. Survey Geol. Quad. Map, GQ–959.

West, W.S., and Wedow, Helmuth, Jr., 1972, Geochemical sampling in Wisconsin: U.S. Geol. Survey Prof. Paper 800–A, p. A2.

West, W.S., 1973, Geochemical sampling in the Hurricane quadrangle, Wisconsin: U.S. Geol. Survey Prof. Paper 850, p. 5.

———, 1974, Geochemically selected target area for zinc in southwestern Wisconsin: U.S. Geol. Survey Prof. Paper 900, p. 3.

Westrick, E.W., and Parsons, G.E., 1957, Integrated exploration finds columbium deposits in Chewett and Collins townships, Ontario, *in* Canadian Inst. Mining and Metallurgy, Comm. Geophysicists, Methods and case histories in mining geophysics, p. 184–195.

Wharton, H. M., 1972. Barite ore potential of four tailings ponds, Washington County barite district, Missouri: Report of Investigations 53, Missouri Geological Survey and Water Resources, 91 p.

White, W. S., 1966a. Tectonics of the Keweenawan basin, western Lake Superior region: U.S. Geol. Survey Prof. Paper 524–E, 23 p.

———, 1966b, Geologic evidence for crustal structure in the western Lake Superior basin, *in* Steinhart, J. S., and Smith, T. J., eds., The earth beneath the continents: Am. Geophys. Union Geophys. Mon. Ser. 10, p. 28–41.

White, W. S., and Wright, J. C., 1954. The White Pine copper deposit, Ontonagon County, Michigan: Econ. Geology, v. 49, no. 7, p. 675–716.

Whitlow, J. W., and Brown, C. E., 1963a. The Ordovician-Silurian contact in Dubuque County, Iowa: U.S. Geological Survey Prof. Paper 475–C, p. 11–13.

———, 1963b, Geology of the Dubuque North quadrangle, Iowa-Wisconsin-Illinois: U.S. Geol. Survey Bull. 1123–C, p. 139–168, 3 figs.

Whitlow, J. W., and West, W. S. 1966a, Geology of the Potosi quadrangle, Grant County, Wisconsin, and Dubuque County, Iowa: U.S. Geol. Survey Bull. 1123–I, p. 533-571.

———, 1966b, Geologic map of the Kieler quadrangle, Grant County, Wisconsin, and Jo Davies County, Illinois: U.S. Geol. Survey Geol. Quad. Map, GQ–487.

———, 1966c, Geologic map of the Dickeyville quadrangle, Grant County, Wisconsin: U.S. Geol. Survey Geol. Quad. Map, GQ–488.

Whitney, J. D., 1862. Report of a geological survey of the Upper Mississippi Valley lead region: Albany, N.Y., p. 74–455.

Willard, D. G., 1973, Graphite: U.S. Bur. Mines Minerals Yearbook (preprint) 9 p.

Willman, H. B., and Frye, J. C., 1970. Pleistocene stratigraphy of Illinois: Illinois Geol. Survey, Bull. 94, 204 p.

Winslow, Arthur, 1893, Notes on the lead and zinc deposits of the Mississippi Valley and the origin of the ores: Jour. Geology, v. 1, p. 612–619.

Wisconsin Geological and Natural History Survey, 1974, Publications of the Wisconsin Geol. and Nat. History Survey, 29 p.

Woodward, H. P., 1961. Preliminary subsurface study of southeastern Appalachian Interior Plateau: Am. Assoc. Petroleum Geologists Bull., v. 45, p. 1634-1655.

Workman, L. E., and Bell, A. H., 1948. Deep drilling and deeper oil possibilities in Illinois: Am. Assoc. Petroleum Geologists Bull., v. 32, p. 2041–2062.

Wright, C. E., 1880. Huronian series west of Penokee Gap, *in* Geology of Wisconsin 1873–1879: Wisconsin Geol. Survey, v. 4, p. 241–301.

Youngman, E. P., 1931. Zirconium; part II, Domestic and foreign deposits: U.S. Bur. Mines Inf. Circ. I.C. 6456, p. 25–27.

Zinner, Paul, and Holmberg, C. L., 1947, Investigation of the iron-bearing formation of the western Gogebic Range, Iron County, Wis.: U.S. Bur. Mines Rept. Inv. 4155, Dec. 1947, 48 p.

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