PHYSICAL ENVIRONMENT SUPPORTING LAKE STATES FORESTS

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There are many common features in the physical environment of the three Lake States, as well as many differences that make each unique. This is true of the nature and age of the bedrock, in the degree and effects of Pleistocene glaciation, in soils, and in past and present climate. While we can refer to these states as one unit, it is essential that we recognize that there are also differences.

The northern portion of the Lake States lies on the ancient rocks of the Canadian Shield. These rocks, ranging in age from 3.8 to 0.6 billion years, include both igneous and metamorphic rocks such as granite, gabbro, gneis, lavas, and quartzite. Many have been altered and deformed during periods of mountain building when violent crustal movement, igneous intrusions, and intensive volcanic activity were interrupted with periods of erosion and sedimentation. The remains of these ancient mountains, now leveled, are complex and extensively faulted and only the most resistant rocks form conspicuous surface features such as Rib Mountain in Wisconsin. These PreCambrian rocks are exposed or covered only with glacial deposits in northeastern Minnesota, the northern third of Wisconsin, and the western end of Michigan's Upper Peninsula. About 1.2 billion years ago, a split or rift began to develop running from Lake Superior southwestward across eastern Minnesota and western Iowa into Nebraska and Kansas. In the process, great quantities of basalt were extruded and gabbro, granite, and other molten rocks were intruded and copper deposits were formed.

Some of these PreCambrian igneous and metamorphic rocks include mineral deposits of great value including iron, copper, and zinc ores with small amounts of uranium, silver, and gold. Many deposits have been mined, others are being explored. To the south and east, the ancient rocks are overlain by layers of sediments deposited during the past 600 million years when, from time to time, prehistoric seas covered much of the Midwest.

The sedimentary rock strata, primarily sandstone, shale, and limestone, vary in thickness, from a few to hundreds of feet. These rocks were deposited on relatively level surfaces as shallow seas invaded and then retreated from the central portion of the continent. The oldest of these, Cambrian sandstones, are overlain by progressively younger limestones, dolomites, shales, and sandstones. Unconformities between many of these layers indicate periods of erosion. During the Late Precambrian and continuing through the Paleozoic, major areas remained elevated (e.g., the Wisconsin Arch and the Transcontinental Arch) while others (the Michigan Basin and the Williston Basin) were gradually depressed. The youngest sedimentary rocks in the region are found in the Michigan Basin that holds about 14,000 feet of these Paleozoic deposits. The upper strata of Carboniferous age (i.e., 280-350 million years old) contain some oil deposits. In the driftless areas of southern Wisconsin and Minnesota not influenced by recent glaciation, the

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heavily eroded sedimentary rocks form striking topographic features and a distinctive drainage pattern.

In northeastern Minnesota, ancient PreCambrian rock is close to the surface where it may be completely exposed or covered by a thin cover of glacial material. In the western portion of the State, Mid and Late PreCambrian rock form the bedrock, now covered by deep glacial deposits. Paleozoic sedimentary deposits occur primarily in southeastern and extreme northwestern Minnesota. Only the older portion of the Paleozoic period is represented, Late Cambrian through Devoian. Later strata may have been deposited and then eroded. Massive lava formations of Late PreCambrian age are conspicuous features along the shore of Lake Superior from Duluth to Grand Portage. A major intrusion, called the Duluth Complex, forms a sill beneath the lava. The complex of older rock north and west contained rich deposits of iron and other minerals. The Mesabi Range was discovered in 1890 and within two years ore was being shipped east.

The Canadian Shield underlies most of the northern half of Wisconsin. However, in the western counties the bedrock is primarily Cambrian sandstone. In the far northwestern counties the glacial deposits are underlain by PreCambrian sandstones and lava flows. The ancient rock in the north central area is greatly altered and includes rocks formed during the Proterozoic and Archean Periods, some at least 2 billion years old. Cambrian sandstones border the Canadian Shield on the west and south with a narrow band to the east. Younger Paleozoic strata parallel the Lake Michigan shoreline and extend westward and southward into Illinois. The harder limestones and dolomites form ridges with weaker strata forming the valleys. The most prominent of these resistant layers is the Niagara dolomite that provides the backbone of Door County and rims the Michigan Basin. The Palezoic strata slope eastward into the Michigan Basin and southward into the Illinois Basin. The Unglaciated Area is extensively dissected with the St. Peter Sandstone or the underlying dolomite of the Prairie du Chien group forming the ridges while the earlier Cambrian sandstones and recent alluvium fill the valleys. As in Minnesota and Michigan's Upper Peninsula, the Cambrian sandstone was derived in part from weathering of the old rocks of the Canadian Shield and in part from sandstones of the Superior Basin. A mass of quartzite, the Baraboo Hills, protrudes above the Cambrian sandstones in south central Wisconsin and a second, Rib Mountain, remains above the eroded PreCambrian surface in north central Wisconsin.

The western portion of the Upper Peninsula is underlain almost entirely of the hard rocks of the Canadian Shield with a relatively thin cover of glacial material. On the Keweenaw Peninsula, resistant strata dip steeply into the Lake Superior syncline. Lava flows are a prominent part of the bed rock. Approximately 1.1 billion years ago volcanic activity ceased and about that time copper was deposited in pockets in the lava and associated rocks. In Late PreCambrian time major faults developed both here and in northwestern Wisconsin. Slippage along these faults dragged the older lava beds over more recent deposits. In contrast, the eastern half of the Upper Peninsula is relatively level with bed rock of Cambrian sandstone and overlying strata of limestone and dolomite, now partially covered by glacial and glacial lacustrine deposits. Michigan's Lower Peninsula is underlain entirely by sedimentary Paleozoic strata. These rocks fill the Michigan Basin with at least 14,000 feet of Paleozoic sediments. The youngest, Carboniferous rocks cover much of the State resting on earlier strata that are near the surface

only in the northern tip and in the extreme southeastern and southwestern corners. The Michigan Basin is bordered on the west by the Wisconsin Arch, on the south by the Kankakee Arch and on the east by the Findlay Arch.

Glacial Geology of the Lake States

During Pleistocene time, beginning perhaps 2.4 million years ago, several glacial advances covered much or all of the Lake States. Interglacial periods between these events permitted erosion and probably revegetation. The last major glacial stage, the Wisconsonian, covered most of the region and little evidence of earlier stages remains in the Lake States. The Wisconsin stage, beginning about 70,000 years ago, involved several major advances and retreats, as well as numerous minor ones, and was responsible for the complex pattern of substrates and land forms on which the forests and soils developed. The sources of ice included the Hudson upland and areas to the west in Canada. While the timing of major advances was similar throughout the region, there were numerous fluctuations that varied from State to State. All of the ice did not originate in the same source area resulting in differences in the nature of the till deposits. Variation in glacial activity accounts for most of the differences in surface features among the States. The Driftless area of southeastern Minnesota and southwestern Wisconsin was apparently lightly, if ever, glaciated resulting in rough topography with prominent ridges and valleys produced by differential erosion of the sedimentary rocks. Much of west central Wisconsin was not glaciated during the Wisconsin epoch.

Ice movement south and westward was influenced by topography with separate lobes following lowlands such as the Lake Michigan Basin or the Superior-Minneapolis Lowland. The peak advance of the Wisconsin ice began about 22,000 years ago. The ice fronts fluctuated considerably and by about 12,000 years ago had retreated sufficiently to permit establishment of forest communities in eastern Wisconsin. These were later overridden by re-advance of the ice. The several moraine systems (Plate 1) indicate the position of various glacial lobes. The weight of the ice, often hundreds of meters thick, depressed the earth's surface that continues to rebound especially in the North. As various lobes of ice shifted and changed direction, outlets to the Great Lakes were either blocked or created. Melting during early periods of retreat resulted in glacial lakes that covered large land areas. Eventually these lakes were drained as barriers were breached or melting of ice created new outlets. Most ice had melted by 9,500 to 11,00 years ago and the Great Lakes began to approximate their present form.

In western Minnesota, the Red River lowland served as a channel for several advances of ice from the west and north that created major moraines including till from Saskatchewan and the Dakotas. The Wadena, Rainy, and Superior lobes pushed into the center of the State forming another series of looping moraines. As this ice mass began to disintegrate, streams formed under the ice eroding deep valleys in the Duluth-Minneapolis Lowland. Later the Red River lobe pushed south and eastward and the vigorous Des Moines lobe moved down the Red River-Minnesota River lowland and spread across most of the central and south-central part of the State depositing a till rich in shale and limestone that became the parent material for soils in southern and western Minnesota. Advances of the Superior and Rainy lobes left till that was generally acid and relatively rocky and infertile.

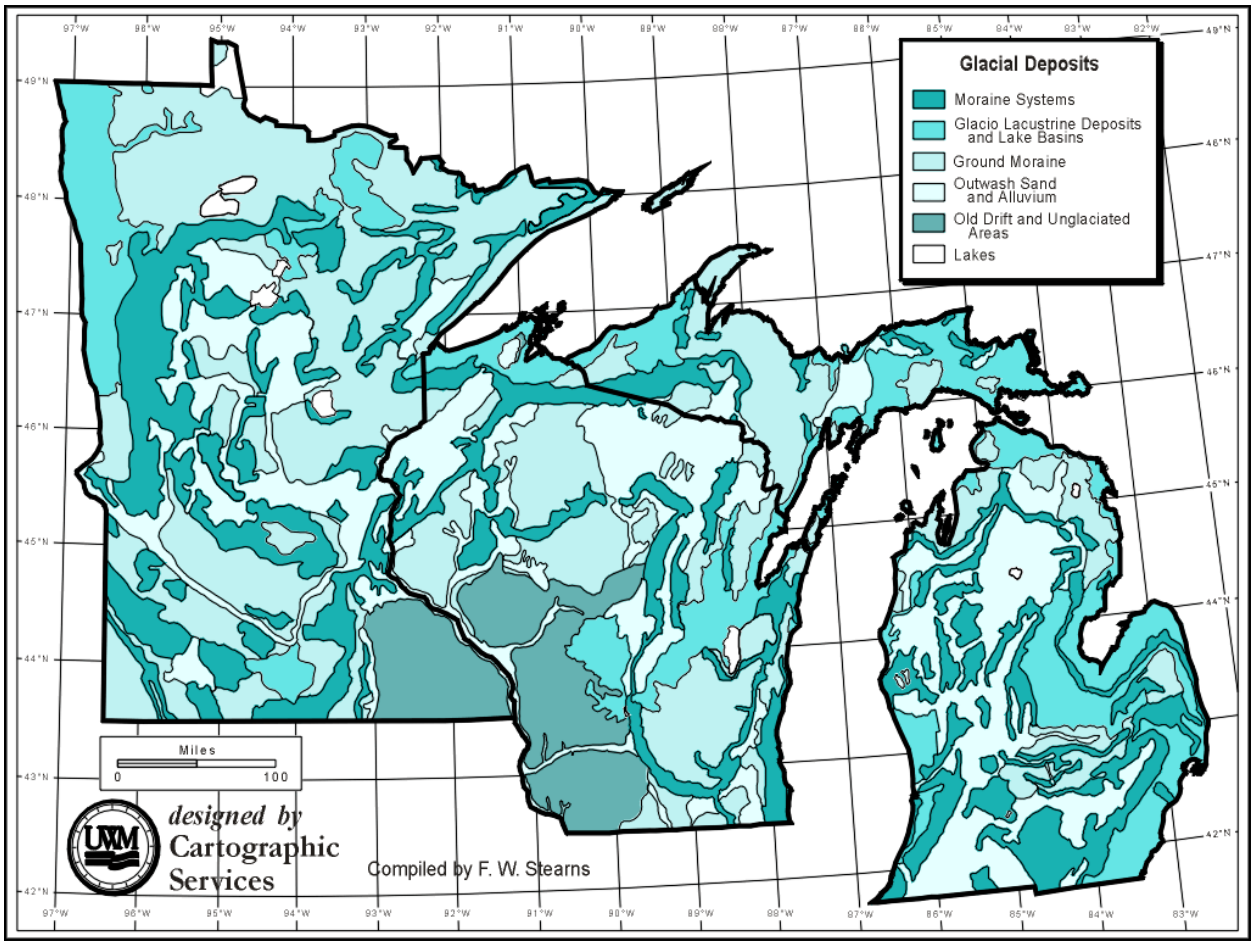

Plate 1.—*Glacial deposits in the Lake States.*

As the ice of the Wisconsinan glaciation retreated, it left behind a variety of deposits of different form and textures mapped here. From about 14,500 to 95,00 years ago, lakes formed when the ice blocked drainages. Lacustrine deposits occurred in many areas. After the ice left, crustal rebound also resulted in changes in drainage water levels. To provide a comprehensive picture of the region, many small details had to be omitted and some similar categories were combined. For example, drumlins, kames, eskers, and weak moraines were omitted. Much greater detail may be found in the various sources listed.

Sources used in the development of the Glacial Deposits map include:

Quaternary Geologic Atlas of the United States Quadrangles: Minneapolis (1983), Des Moines (1991), Chicago (1983), and Lake Superior (1984) from the U.S. Geological Survey Misc. Investigation Series;

Quaternary Geology of Southern and Northern Michigan, W.R. Farrend. 1982. Michigan Department of Natural Resources, Geological Survey Division, two sheets.

Glaciation of Wisconsin, 1992. L.Clayton, J.Attig, D.Mickelson, and M.Johnson, ed. Series 36. Wisconsin Geological and Natural History Survey, University of Wisconsin Extension.

Geologic Map of Minnesota: Quaternary Geology. 1979. J.E. Goebel and M.Walton. State Map Series S-4. Minnesota Department of Natural Resources.

Melting of the Des Moines lobe served to deepen the Minnesota River valley and a recessional moraine blocked southward drainage and formed Lake Agassiz that soon covered much of northwestern Minnesota as well as huge areas in Canada. As that lake drained northward it left vast expanses of level, poorly drained land that is now covered with peat. In a similar fashion, moraines and ice in the northeast confined Glacial Lake Duluth. That lake drained first into Lake Superior and later into the St. Croix and Mississippi basin.

Glacial ice advanced in Wisconsin with several lobes moving from Lake Superior southward. Major lobes also occupied the Lake Michigan basin and the Green Bay Lowland. Advances were not constant, but alternated with retreats and stagnation. The greatest advances occurred perhaps 20,000 to 16,000 years ago when the Lake Michigan lobe reached northern Illinois and the Green Bay lobe formed a terminal moraine in Rock and Walworth Counties just north of the Illinois border. The Green Bay lobe split with a branch moving northward to meet the southward expanding Langlade lobe. The proximity of the Green Bay and Lake Michigan lobes resulted in a long interlobate strip of outwash and till from both lobes. This strip, called the Kettle Moraine, remains a prominent feature of eastern Wisconsin. Similarly the proximity of the Green Bay and Langlade lobes resulted in a complex of morainic hills and outwash, deposits that with those of the Wisconsin Valley, Chippewa, and Superior lobes form an almost continuous ridge across northern Wisconsin that includes several of the highest points in the State. In the west central part of the State, an extensive area has recently been shown to be covered only by PreWisconson glacial deposits. Another feature is the extensive sandplain that formed the bed of Glacial Lake Wisconsin that developed when flow of the Wisconsin River was blocked. Many advances and retreats of various ice lobes occurred before final retreat of the ice, perhaps 9,500 years ago. The pitted moraine and outwash deposits in northwestern and north central Wisconsin are responsible for the exceptional number of lakes, much more abundant here than in Michigan or Minnesota. As the ice retreated vast quantities of meltwater formed broad valleys that are now occupied by far smaller streams.

Glacial deposits in the western Upper Peninsula are generally thinner than in northern Wisconsin and there are few areas of pitted outwash and few lakes. The streams emptying into Lake Superior flow largely over bedrock at a steep gradient. In the eastern Upper Peninsula the relatively weak sedimentary rocks were eroded by the ice, leaving large level and poorly drained areas. An extensive plain slopes south toward Lake Michigan and a shorter one slopes north toward Lake Superior. Major glacial-lacustrine deposits occur along the Lake Superior shoreline west of the Keweenaw Peninsula, while much of the eastern UP is covered with glacial lacustrine deposits. In the Lower Peninsula, lacustrine deposits fringe the tip and occupy low areas along the Lake Michigan coast. Large areas of these deposits border Saginaw Bay including the “Thumb” and often extend inland as far as 30 miles. An extensive band of

lacustrine deposits varying from 10 to 30 miles wide extends south and southwestward to the State boundary and Lake Erie. Looping lateral moraines within the lacustrine deposits indicate earlier ice borders. For a considerable period, the entire Lower Peninsula was covered by the ice of the Michigan lobe and the Saginaw sublobe of the Huron lobe. Movement of these lobes left behind complex moraine systems embedded in ground moraine, outwash sands, and ice contact deposits. Both till and sands are often calcareous originating from dolomite and limestone in the Huron Lobe

Soils of the Lake States

Soil results from the interaction of three factors: climate, parent material, and organisms, both plant and animal. Precipitation and temperature affect evapotranspiration influencing the movement of salts in the soil, the leaching of nutrients as well as the water available for plant growth and for micro-organisms. The size of substrate particles, whether coarse (e.g., sand or gravel), intermediate (e.g., silt), fine (e.g., clay), or a mixture of sizes (e.g., sandy loam) play an important role in retention of water, in nutrient availability, in soil aeration and drainage, etc.. The organisms that become established provide organic matter, larger drainage ways and through translocation of nutrients from roots to leaves influence plant productivity.

Leaves and litter of deciduous trees are generally richer in calcium and other mineral elements and tend to make soil less acid while accumulation of conifer needles may lower the pH of the soil resulting in leaching of organic matter and minerals to form a podzol (leached) layer. Insects, worms, and various arthropods, as well as mammals, mix the soil body improving its structure. Over time, soils develop layers or horizons characteristic of the particular climate, parent material, and vegetation of the region.

For simplicity, soils of the Lake States are grouped into four major categories: light colored soils formed under forest vegetation; dark colored soils that developed under prairie grasses as a result of the accumulation of organic matter under generally dry and neutral or alkaline conditions; other dark soils that resulted when poor drainage prevented the decomposition of organic matter; and lastly, young, poorly developed soils formed on steep slopes or in thin layers of parent material (Plate 2).

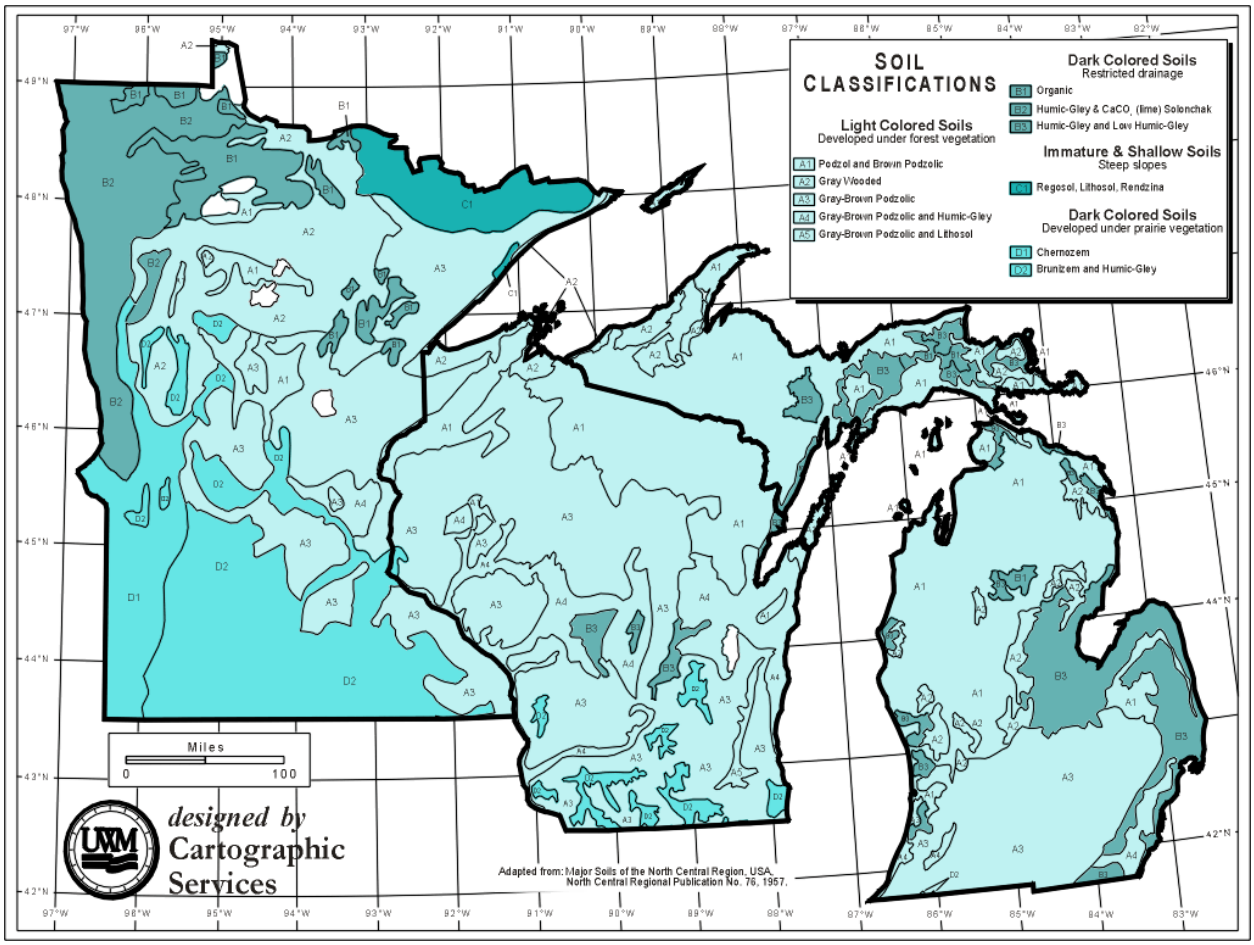

Plate 2.—*Soils of the Lake States.*

This map was adapted from the map of the Soils of the North Central Region in North Central Regional Publication No. 76. 1957 compiled by the Soil Surveys of States of the North Central Region in cooperation with the U.S. Department of Agriculture. Soil classifications have been simplified. Since soils are the product of the interaction of substrate, vegetation, and climate, the map portrays the resulting pattern of these factors for the Lake States region including differences from west to east and north to south.

Lake States soils are young, developing since the retreat of the Wisconsin ice sheets. The complex nature of the glacial parent material makes generalization difficult. For example, outwash sand may have been deposited over lake clay, silty morainic material, or even gravel, while the surface may or may not have been covered with loess.

The forest soils are of special interest and form a continuum from north to south. Those in the colder northern areas generally have a surface organic layer above a well-developed light-colored layer from which iron, aluminum, other minerals, and organic matter have been leached. Those soils often developed under conifers on sandy and loamy material derived largely from

igneous and metamorphic rock. They tend to be acidic and are often strongly podzolised. Southward, soils found under deciduous forests show less leaching and more often develop from calcareous parent material whether till, sand, or clay. In the glaciated landscape, north or south, the surface is often uneven with poorly drained depressions that accumulate organic matter and often become anaerobic resulting in the development of peat or gley soils.

- Podzolic and Brown podzolic soils commonly originate in outwash sands and are often acidic and excessively drained.
- Gray wooded soils (the northern equivalent of the Gray-Brown podzolic soils) are usually moderately well drained and often originate on a glacial lake plain.
- Grey Brown podzolic soils often form in a well drained silty sediment lying over acid sandy loam on brown till.
- Grey Brown podzolic with humic gley soils include low poorly drained pockets of humic gley that have a thick dark colored surface horizon and grey-gleyed subsoil.
- The dark prairie Brunizem soil is well drained save in depressions where humic gley occurs. It tends to have a thick, dark, surface horizon and develops in acid sands and also in loess.
- Chernozem, a prairie soil with a deep highly organic surface layer, forms over calcareous loamy sand or till and develops a calcareous horizon as calcium is moved upward by evapotranspiration.
- Solonchak, a dark poorly drained soil also forms over a calcareous substrate.

Soils in Minnesota differ considerably from those in Wisconsin and Michigan. Much of southwestern Minnesota has dark colored prairie soils, Chernozems and Brunizems, while much of the northwest supports organic and CaCo-Solonochak soils with restricted drainage. The northeastern border of the State has extensive areas of immature and shallow soil and the remainder of Minnesota developed forest soils ranging from Pozols through Gray Wooded and Gray Brown Podzolics. Humic Gley soils are present throughout.

Light-colored forest soils predominate throughout Wisconsin ranging from Podzols and Brown Podzolic and Gray-Brown Podzolic soils in the north to variants of Gray-Brown Podzolic in the central and southern areas. Several large areas of Humic-Gley soils occur in the central sandplain while areas of dark Humic-Gley and Solonochek soils are scattered across the southern fourth of the State. Smaller patches of peat and humic gley are widespread. Patches of prairie Brunizem soils occur in southern Wisconsin, but no Chernozem soils are present.

The western half of Michigan's Upper Peninsula is similar to northern Wisconsin with primarily Podzol, Brown Podzolic, and Gray Wooded soils, while the eastern UP has extensive areas of Organic and Humic-Gley soils. Small areas of poorly drained soils are found along the tip of the Lower Peninsula and along Lake Michigan while extensive areas are found in eastern central Michigan, on the "Thumb," and along the southeastern side of the State. The remainder of the Lower Peninsula soils range from Podzols and Brown-Podzols in the north, and small areas of

Grey-Wooded soil in the central area to predominately Grey-Brown Podzolic forest soils in the south

Climate of the Lake States

The northern Lake States lie between the boreal and the cold temperature regions with strong north-to-south and west-to-east temperature and moisture gradients. The climate of the western portion is similar to that of the Great Plains, while eastward precipitation increases and extremes of temperature are moderated. A pronounced snow belt is present along the shores of the Great Lakes.

A climatic transition zone between colder and warmer temperature regimes trends from northwest to southeast from north central Minnesota to southeastern Wisconsin and then east across lower Michigan. This zone is defined not only by temperature and frontal movement, but also by changes in vegetation; the zone includes plants and animals of both northern and southern affinities. A gradual transition is evident from the continental climate of western Minnesota to the maritime climate east of Michigan. The Lake States are located in latitudes between those that receive a surplus of radiation energy (maximum in the tropics) and those that receive less than average amounts (minimum in the arctic). This difference results from the angle at which the solar rays reach the earth and contributes to considerable energy exchange modified by the influence of the rotation of the earth and by the presence of the Great Lakes. The Lakes greatly alter air flows and act as huge heat sinks, absorbing heat in the summer and autumn and thus cooling the land near the shore while releasing heat during autumn and winter, warming the land near shore. There is considerable difference from winter to summer in the amount of energy available for warming the land surface, a difference that is increased in winter by reflection of energy from the snow-covered surface. The large area of the Great Lakes results in a steep temperature gradient from north to south especially in the winter

Most of the region lies in the humid, continental, cool summer climatic zone, but there is considerable variation. Minnesota tends to be more continental in climate with hotter summers and cooler winters than Wisconsin and Michigan. Precipitation also varies increasing from northwest to southeast. The region as a whole may be characterized as one with snowy, cold winters and mild to warm summers during which precipitation is fairly evenly distributed. The jet stream is frequently overhead or south of the region in winter and north in Canada during the summer. Highs and lows move rapidly across from west to east resulting in an active climate. Differences between seasons are well defined and change between seasons is often rapid and dramatic especially in spring and fall.

The jet stream develops wavelike patterns, a southward wave may bring up warm, moist air masses from the Gulf of Mexico while a northward wave may bring down cold dry arctic air. When the jet stream lacks the wave pattern, it may bring in air masses from the Pacific that gradually lose moisture and often reach the Great Lakes as dry and mild air. Replacement of a warm air mass with a cold one or vice versa involves frontal development with strong temperature differences between the contrasting air masses. Differences in barometric pressure between the air masses often produce strong winds as air moves from areas of high to low pressure.

Shifts of the jet stream, rotation of the earth, and movement of air masses combine to produce anti-cyclones and cyclones--air masses rotating respectively either clockwise or counter-clockwise and moving in an eastward direction. The Great Lakes themselves alter the amount of precipitation whether snow in winter or rain in summer as well as the cyclonic activity. The region is one with considerable storminess in autumn with unexpected wind shifts and strong winds. It may also occasionally be impacted by severe droughts such as those in 1871, 1891, the mid-1930's and the late 1980's. Extreme precipitation may also occur as in 1993.

Thunderstorms are a frequent summer occurrence in the Lake States and provide much of the summer moisture. Tornadoes are most common in the southern and western portions of these States but may occur in the northern forested areas. The less frequent downbursts that accompany passage of very strong thunderstorm fronts are most evident in the northern areas. The snow belts that receive massive amounts of winter precipitation, the lake breezes that affect fog formation, and their contribution to stabilizing climate during the summer and autumn are among the characteristics of the lake environments.

For Minnesota, the Great Lakes have relatively little effect, both temperature and precipitation are typical of a continental climate that is influenced by the rain shadow of the western mountains. Moisture in the maritime air flowing from the west is lost as the air rises over the mountains. Precipitation, both winter and summer, is relatively low and is concentrated during the summer while summer evapotranspiration is high. Temperatures are higher in summer and lower in winter and drought is more frequent than in either Wisconsin or Michigan. Thunder storms are more frequent in the southern counties than in the north.

The Great Lakes have considerable influence on Wisconsin's climate. Temperatures along Lake Michigan are cooler in summer and warmer in autumn and winter than to the west, accounting for the southward bend of the climatic and vegetational transition zone (and for successful cherry culture on the Door Peninsula). Lake effects are also evident along the Lake Superior shoreline, an area that experiences heavy winter snows. Temperatures are higher and rainfall lower along the western side of the State than to the east. Mean annual precipitation varies from 28-34 inches in the north and west to about 32 inches in the southeast. Estimated evaportranspiration varies from 18 inches in the north and east to 24 inches in the southwest and extreme southeast where growing season water shortages are frequent. Mean January temperatures range from 10-14F in the north to about 20F in the south, while mean July temperatures vary from 66-68F in the north to 72-74 in the south. The number of frost-free days increases from 100 in the northeast to 160 in the south.

The Great Lakes are also a major influence on Michigan's climate in both the Upper and Lower Peninsula, where proximity to Lakes Superior, Michigan, and Huron result in heavy snowfall in winter and rainfall in summer. Despite being between Lakes Superior and Michigan, the average frost-free period inland from the lakes varies from only 60 days in the western Upper Peninsula to about 100 days in the eastern portion. However, the tip of the Lower Peninsula has 20-40 fewer frost-free days than do similar latitudes in northern Wisconsin. January and July mean daily temperatures are similar to those at an equivalent latitude in Wisconsin, although the eastern UP is several degrees warmer in winter

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