AN OVERVIEW OF THE GEOLOGY OF THE GREAT LAKES BASIN

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The Great Lakes Basin

The Great Lakes basin, as defined by watersheds that drain into the Great Lakes (Figure 1), includes about 85 % of North America's and 20 % of the world's surface fresh water, a total of about 5,500 cubic miles (23,000 cubic km) of water (1). The basin covers about 94,000 square miles (240,000 square km) including about 10 % of the U.S. population and 30 % of the Canadian population (1). Lake Michigan is the only Great Lake entirely within the United States. The State of Michigan lies at the heart of the Great Lakes basin. Together the Great Lakes are the single largest surface fresh water body on Earth and have an important physical and cultural role in North America.

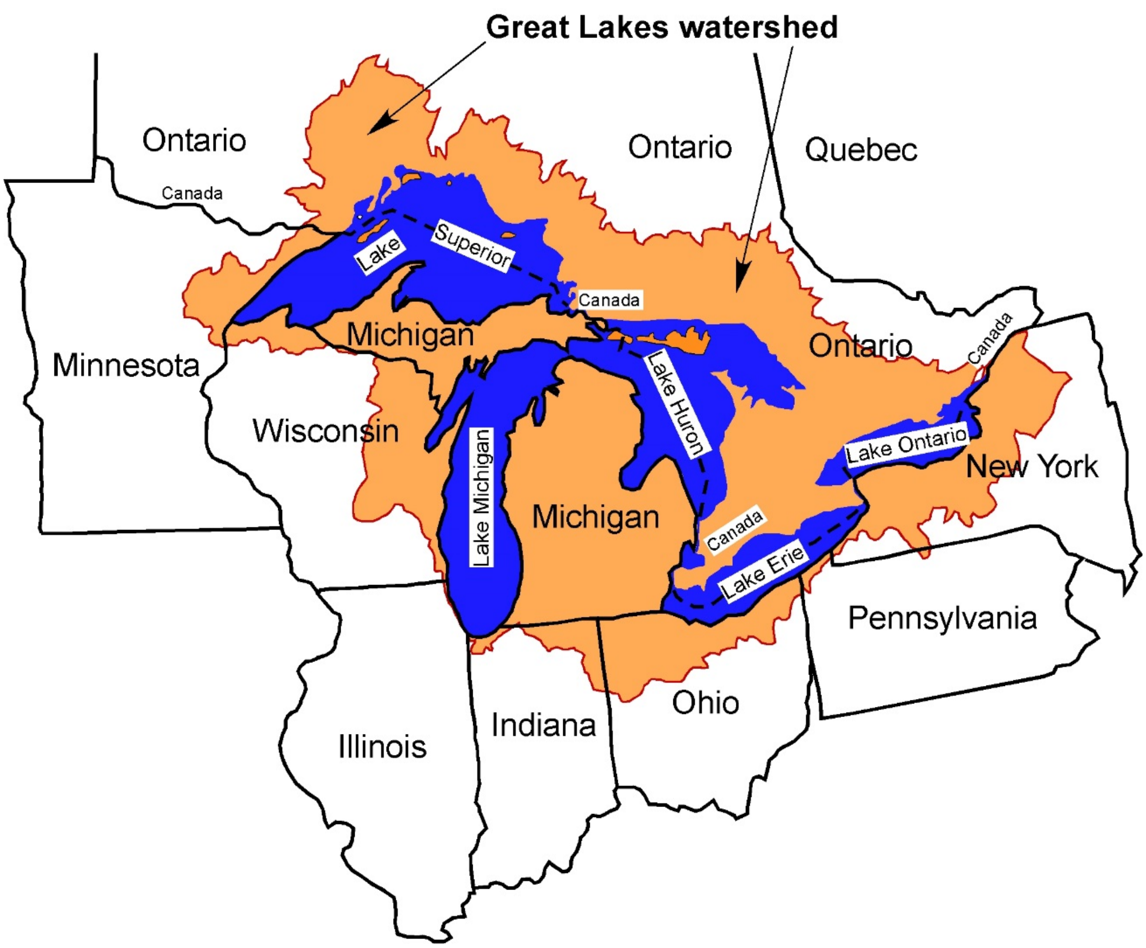

Figure 1: The Great Lakes states and Canadian Provinces and the Great Lakes watershed (brown) (after 1).

Precambrian Bedrock Geology

The bedrock geology of the Great Lakes basin can be subdivided into rocks of Precambrian and Phanerozoic (Figure 2). The Precambrian of the Great Lakes basin is the result of three major episodes with each followed by a long period of erosion (2, 3).

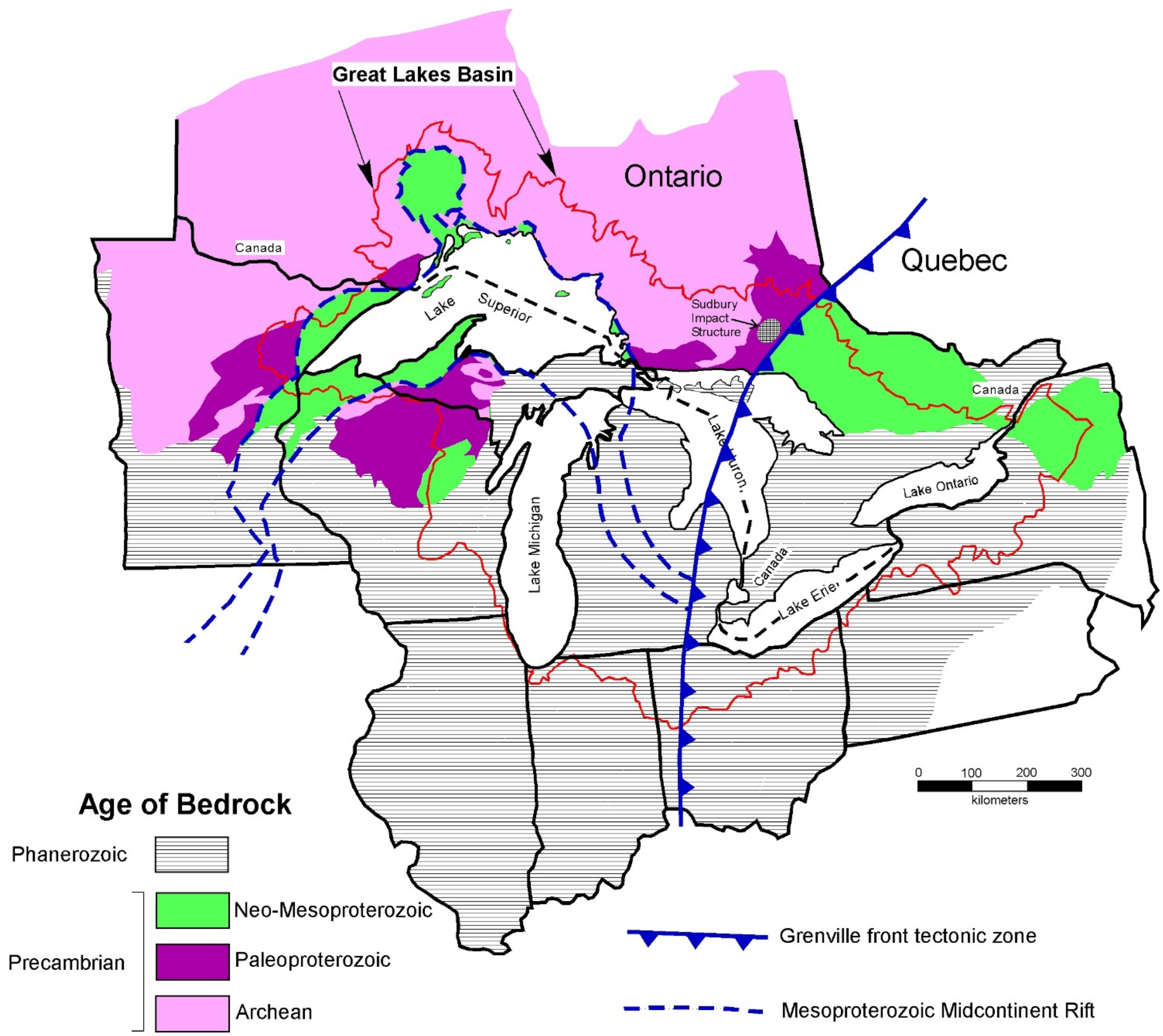

Figure 2: Generalized Precambrian bedrock geologic map of the Great Lakes basin.

The Precambrian begins with the formation of the Earth at about 4500 Ma (million years ago) and ends at the beginning of the Phanerozoic, at 542 Ma as life on Earth rapidly expanded (Figure 3). The Archean Eon begins about 4000 Ma when early continents and oceans appeared on Earth and the Earth's atmosphere was much hotter than today and lacked oxygen to sustain aerobic life. While the Earth's continental crust (crust being the outermost solid sphere of the Earth made of aggregates of minerals and rocks) was established by about 4000 Ma, the oldest known rocks of the Great Lakes basin are about 3600 Ma and these rocks are from the Watersmeet area in Michigan's Upper Peninsula (2).

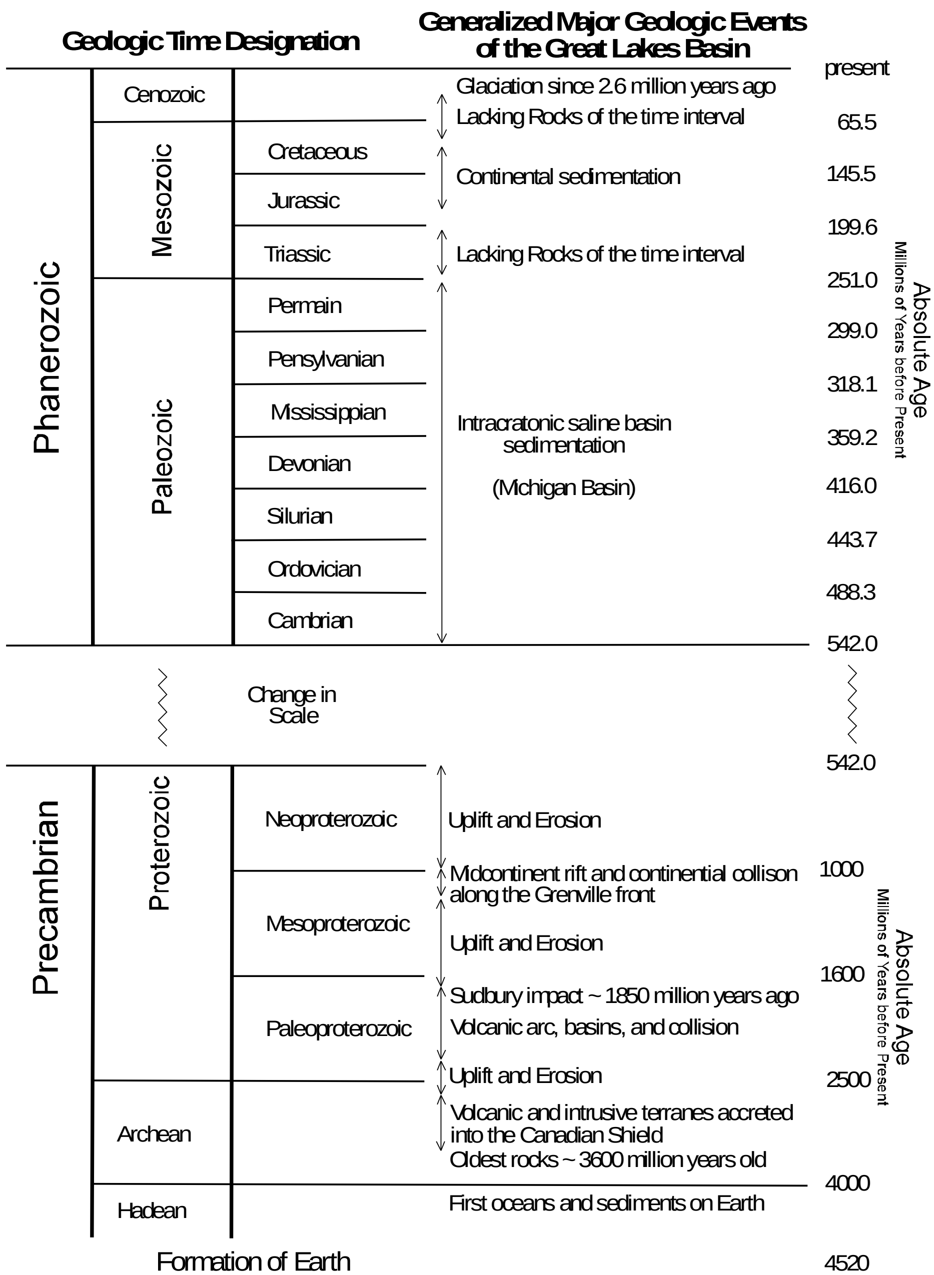

Figure 3: Geologic time scale showing significant geologic events of the Great Lakes basin. Modified from (2).

The Archean Eon (4000 to 2500 Ma) in the Great Lakes basin consists of a complex succession of volcanic, intrusive, and sedimentary rocks. Fragments of microcontinents and intervening oceanic crust were accreted together to form the Superior Province by about 2,600 Ma (3). Archean greenstone belts are composed of metamorphosed volcanic and sedimentary rocks which are variably folded, and faulted. Within the Archean rocks there are notable occurrences of minerals including those associated with volcanogenic massive sulfide and iron deposits, gold deposits, pegmatites, and more. This Archean bedrock was subjected to erosion for 150 million years from about 2600 Ma until about 2450 Ma (Figure 3).

Beginning about 2450 Ma in Ontario (4) and by about 2300 Ma in Michigan, Wisconsin, and Minnesota (2), there was deposition of a thick sequence of Paleoproterozoic sedimentary and interbedded volcanic rocks in shallow sea rift basins on top of the older Archean rocks (2, 4; Figure 2). The Superior-type banded iron formations of the Lake Superior region were deposited during this episode. While these sedimentary rocks were deposited in northern Minnesota and Michigan's Upper Peninsula, to the south in Wisconsin a volcanic arc was forming and would later be sutured to the sedimentary rocks by collision (2). Among the Paleoproterozoic rocks of the Great Lakes basin there is a layer that has been interpreted as distal ejecta from the large impact of a meteorite at about 1850 Ma in the Sudbury area of Ontario, northwest of Lake Huron (5; Figure 2). The Paleoproterozoic volcanic, intrusive, and sedimentary rocks were metamorphosed, folded, and faulted as well as intruded by granites during the Penokean orogeny at the end of the Paleoproterozoic. Beginning about 1750 Ma the bedrock of the Great Lakes basin was above sea level and subjected to a very long period of erosion lasting about 650 million years. This period of erosion left a peneplaned barren platform of rocks as complex life only began much later. A variety of minerals are associated with the Paleoproterozoic rocks but most notable are occurrences of minerals associated with Superior-type banded iron deposits (the iron deposit are notable for secondary minerals formed during the Mesoproterozoic), volcanogenic massive sulfide deposits, and gold deposits.

The barren peneplaned continental platform of Archean and Paleoproterozoic rocks began to undergo rifting at about 1100 Ma forming the Midcontinent Rift System of North America (2, 6; Figure 2). The rift was initially filled with a great thickness of up to 25 km of Mesoproterozoic basalt-dominated volcanic rocks with minor interbedded sedimentary rocks. Intrusions of basaltic magma formed dikes, sills, and a large layered complex intrusive body and are notable hosting for nickel, copper, and platinum-group elements deposits. Active Midcontinent rifting and its associated volcanism was followed by continued downwarping of the rift basin as it was filled with up to 8 km of clastic sedimentary rocks (6). Sedimentary rock-hosted stratiform copper deposits at White Pine and Copperwood formed at about 1080 Ma while the muds were being converted to shale (rock). The last phase of the Mesoproterozoic Midcontinent rift was compressive faulting at about 1060 Ma related to continental collision along the Grenville front tectonic zone (7; Figure 2). The hydrothermally-deposited native copper deposits of the Keweenaw Peninsula with many associated minerals were formed during the Grenville compressive event. At about 1000 Ma the Grenville tectonic zone is believed to have been a large mountain range and plateau analogous to the Himalaya region today (3). Except for localized faulting within the Great Lakes basin at about 590 Ma, the remainder of the Precambrian was period of tectonic stability and no recorded emplacement of rocks (2, 3; Figure 3). By the end of the Precambrian, the Great Lakes basin was once again turned into a barren peneplaned bedrock surface devoid of life except for bacteria and algae.

Phanerozoic Bedrock Geology

As the Precambrian ends the Phanerozoic begins with the Cambrian at 542 Ma. While the land surface was devoid of much life, the Cambrian the equatorial oceans surrounding the Precambrian bedrock of the Great

Lakes basin were teeming with life (8). Rapid evolution of life occurred during a short 15 million year period of time in the middle Cambrian called the Cambrian Explosion. During the late Cambrian, seas encroached on the Precambrian bedrock of the Great Lakes basin and sand accumulated on the shore and shallow seas formed the sandstones of the Pictured Rocks area of Michigan's Upper Peninsula (8). From about 500 Ma to 300 Ma, the bedrock varied from submerged below shallow seas to dry land and during this time interval up to 14,000 feet (4,300 m) of dominantly sandstone, shale, limestone, dolostone, and salt were deposited in the Michigan Basin (8; Figure 4). Rocks formed from about 300 Ma to about 2.5 Ma ago are missing from the Michigan Basin, termed the "Lost Interval," although they are present in adjacent areas (9). In the west-central part of the Michigan Basin, red sandstones and shales, limestone, and gypsum were deposited on eroded Paleozoic rocks during the Jurassic at about 175 Ma (9). Hydrothermally-deposited minerals, analogous to Mississippi-Valley type deposits, are present in Paleozoic rocks of the Great Lakes basin. Kimberlite pipes, known for containing diamonds and other minerals formed within the Earth's mantle, were emplaced at about 170 Ma in the Great Lakes basin and broader area (9, 10).

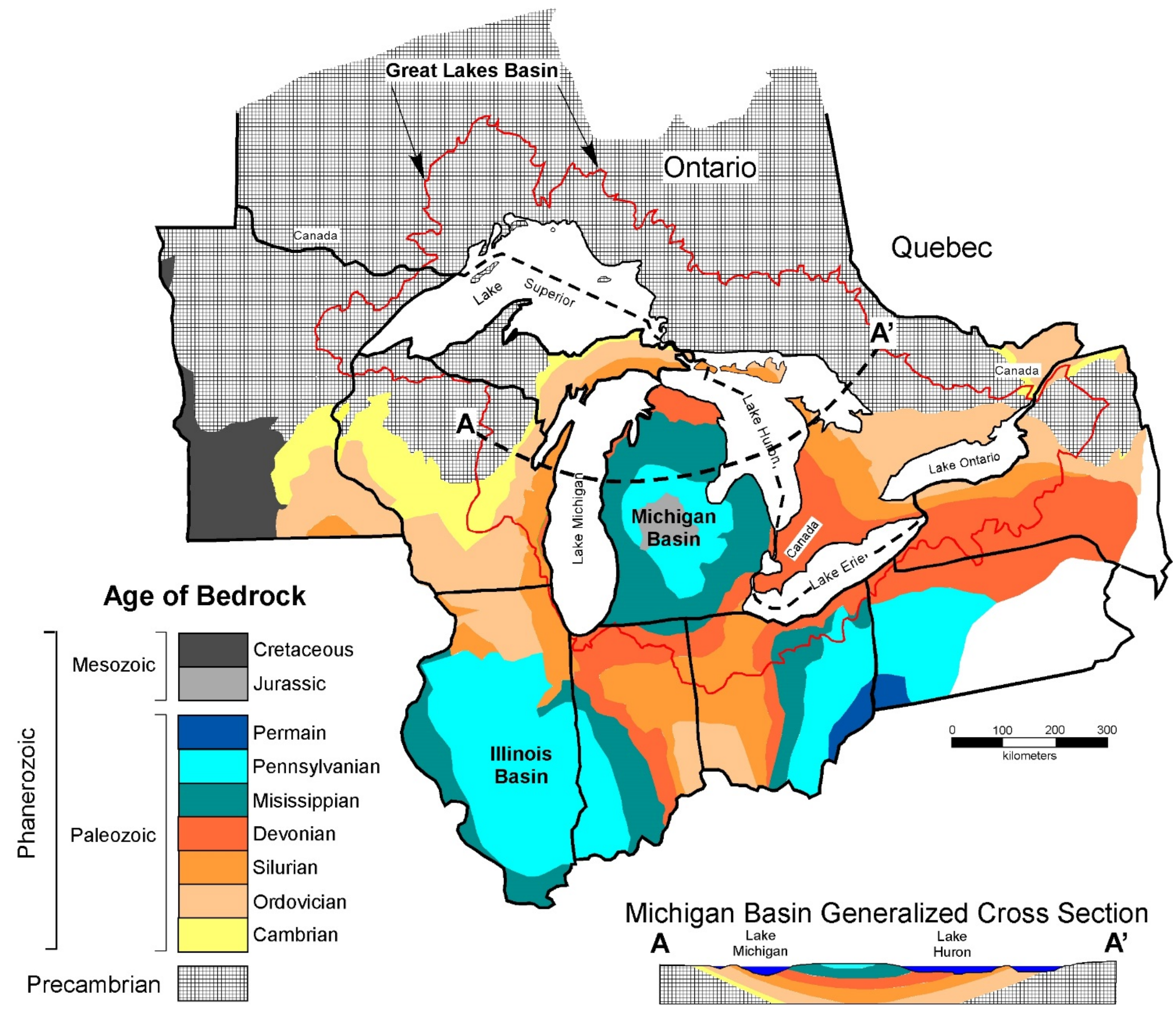

Figure 4: Generalized Phanerozoic bedrock geologic map and geologic cross section of the Great Lakes basin.

Unconsolidated Pleistocene Glacial Deposits

Pleistocene glaciation, beginning about 2.6 million years ago, has shaped the surface topography of the Great Lakes basin. Multiple repeated advances of continental glaciers, up to one mile thick and originating from the north, sculpted the surface of the bedrock. The glaciers carved out the basins that are now occupied by the Great Lakes (11). The less competent rocks tend to be more easily scoured and result in valleys. This is especially true for Lake Superior which mimics the shape of the Midcontinent rift (Figure 2). The center of the rift was filled with less competent sedimentary rocks, such as siltstone and fine-grained sandstone, whereas on the margin are the more competent dipping lava flow or to the north older Archean basement. Thus, by preferentially scouring out the less competent rocks, the glaciers left behind a horseshoe shaped Lake Superior. The driftless area in Wisconsin does not show evidence of being buried under glacial ice (12; Figure 5).

The eroded bedrock was converted to sand, silt, clay, and gravel that was entrained into the glacial ice as it moved generally southward (Figure 5). The advancing glacier transports its load of sediment as the ice moves. Most clasts are only moved a short distance from their place of origin in the bedrock, typically less than about 10 miles or 16 kilometers (13). However, rocks can also be transported great distances of 100s of kilometers. When a glacier retreats it does so by melting and the rocks entrained in it are dropped on to the surface as a blanket of loose unconsolidated debris, filling depressions glacially craved out in the bedrock surface, making ridges when advance and retreat was balanced. The glacial debris also occurs in other forms as it is redistributed by meltwater exiting the glacier. The finest clay-sized material was carried in the meltwater until it settled out in glacial lakes that lie out in front of the retreating glacier; planar topography with thick underlying varved clays characterize these areas today. This unconsolidated glacial debris is an important component in shaping the topography in combination with the undulating surface of the bedrock.

The youngest of the several episodes to have impacted the Great Lakes basin is termed the Wisconsinan episode which lasted from about 55,000 to 10,000 years ago. The maximum advance occurred about 20,000 years ago (Figure 5). During this advance, unconsolidated glacial debris left after retreat of previous glacial episodes was easily eroded and removed, hence little remains in areas north of the maximum. Debris transported a relatively short distance from their source by an initial episode of glaciation are subsequently transported still further from their source by later glaciations. The last glaciers retreated from the Great Lakes basin about 10,000 years ago

Prior to glaciation, Phanerozoic rocks covered the entire Great Lakes basin rather than only being present in the southern part (Figure 4); they were removed from the northern area by glacial action. Rocks of the latest Mesozoic and Cenozoic may have been removed from the Great Lakes basin too. Thus, the glaciers played an important role in determining the bedrock available for exploitation by humans. Besides its role in topography, the unconsolidated debris left behind by retreat of the Wisconsinan glacial episode provided abundant sand and gravel used throughout the region.

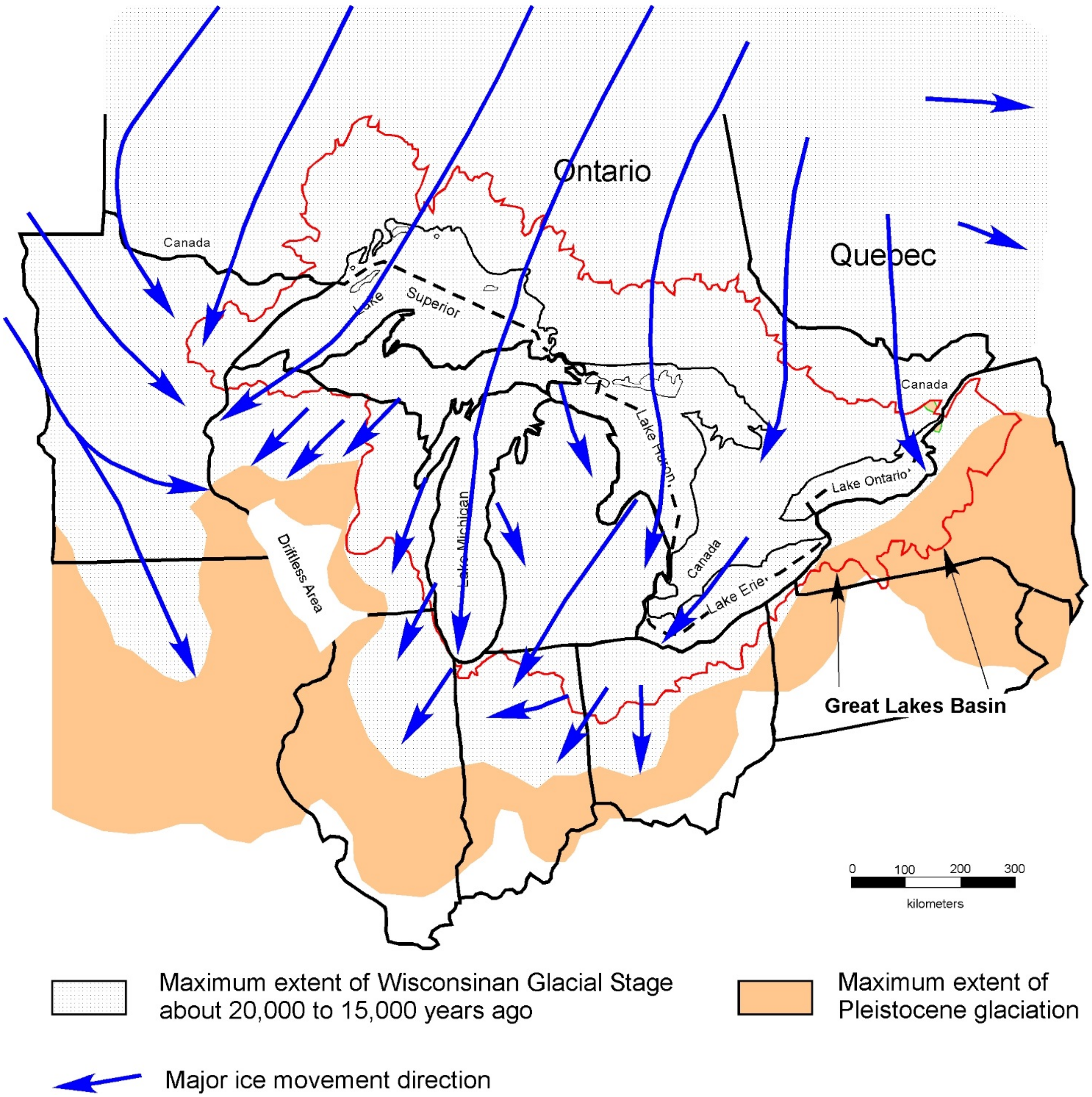

Figure 5: Generalized map showing Pleistocene glaciation. Ice movement direction compiled from multiple sources.

The Great Lakes basin has a long and complex geologic history. You can learn more by searching on the web e.g., publications available on the Institute on Lake Superior Geology web site. The Museum online gift shop sells an excellent summary of the "Geology of the Lake Superior region" by Gene LaBerge. The rocks of the basin host 100s of mineral species and some specimens of minerals from the Great Lakes basin are notable for being among the best for their species especially native copper from Michigan's Keweenaw Peninsula, a strength of the A. E. Seaman Mineral Museum. The Museum online gift shop sells the book "Mineralogy of Michigan" by George Robinson which describes a large number of the species present in the Great Lakes basin.

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