Chapter 3

Geology of the Great Lakes Basin

The Great Lakes ecosystem exists today within a large region with a complex geological record. For billions of years this basin has undergone a myriad of geological events and changes which resulted in the five Great Lakes and their watersheds. Each of those events built upon previous events and was shaped and affected by those events. The basin as we know it today was different only a few thousand years ago, and it will change in the future.

The Time of Volcanoes

The oldest rocks found in the basin are estimated to be approximately 3.5 billion years old. The time during which those rocks were formed was a period of widespread volcanic activity. Masses of molten lava from volcanoes spread out over the land surface and hardened. Geologists speculate that there may have been an even older rock surface on which these volcanic rocks were deposited, however no evidence of that older rock layer has been found in the basin. Huge deposits of those volcanic rocks built up and, as time passed, natural processes associated with weathering caused the mountains to wear down and sediments to accumulate in valleys. Rocks that had been exposed were buried and underwent metamorphosis to become schists, quartzite and greenstones. Over the next approximately 600,000 years activity continued and resulted in production of granite and gneiss. These are often found as intrusions in the earlier schists and metamorphosed volcanic rocks. Toward the end of that period (Early Precambrian), the land underwent a period of subsidence. The land surface gradually sank, water entered forming shallow seas, and since the minerals of the region contained large amounts of salt, the water of these ancient seas was saline. A marine ecosystem existed in what is now the Great Lakes Basin. Metamorphosis of rocks due to heat and pressure continued. Sediments accumulated on the bottoms of the shallow seas ultimately forming sedimentary rocks. Of course the earth did not subside evenly but rather settled in some areas more so than in others, and it rose in still other areas. The end of the Early Precambrian was marked by a long period of uplift. The land rose up in a series of folding and faulting events that produced an uneven land surface composed of mountains and valleys.

A second period of subsidence occurred with the beginning of the Middle Precambrian. Again shallow seas formed, sediments accumulated and sedimentary rocks formed. These included sandstone deposits and limestones which underwent metamorphosis to become dolomites. Fossils of algae that lived in those seas have been found in these sedimentary rocks. Included in the rocks formed at this time were the iron-bearing formations of the Upper Peninsula of Michigan. During the Middle Precambrian there followed a series of uplifting and then subsidence events. Uplifts resulted in mountain building and tilting of pre-existing rock formations leading to deformation of those existing layers. New layers of sedimentary rocks were laid down during the periods of subsidence. Erosion continued during all of these times, of course. Thus the mountains were worn down and the eroded materials accumulated in the lower elevations.

The Late Precambrian was ushered in my a burst of volcanic activity that once again released lava which flowed over the surface and intruded in subsurface locations. In some locations the weight of these new lava deposits caused the land beneath to tilt from the horizontal. It was during this time that copper and other mineral-bearing deposits were formed. Volcanic rocks of Precambrian origin cover a large part of eastern and central Canada from Lake Superior northward. This large area in known as the *Canadian Shield.*

The Time of Sedimentation and Reforming

The end of the time of great volcanic activity signaled the end of the Precambrian and the beginning of the Cambrian Period, approximately 600 million years ago. Some uplifting continued with resulting erosion of the tilted slopes. However, the violent periods of volcanic activity that had punctuated the previous 2.9 billion years were now quieted.

The Cambrian Period ushered in a time of subsidence. The land surface in the area that is now south of Lake Superior slowly began to sink. As it did, shallow salty seas flooded the region. By the end of the Cambrian Period (500 million years ago) these seas covered much of what is now the Lower Peninsula of Michigan and eastern Wisconsin. By the Middle Ordovician Period (about 465 million years ago) all of the present-day Great Lakes Basin, but what is now Lake Superior, northwestern Wisconsin and northeastern Minnesota, were covered. Seas continued to exist in the Great Lakes region south and east of Lake Superior through the Silurian Period (425 to 405 million years ago) and Devonian Period (which ended about 345 million years ago).

During the Devonian Period, the Appalachian Mountains rose, bringing about major changes in drainage patterns along the eastern borders of the present-day Great Lakes region. The inland seas began to shrink in extent. The uplifting continued into the Mississippian Period (345 to 310 million years ago) and the seas covered less area. The higher upland regions north and west, and the newly-formed Appalachian Mountains were slowly eroded down with the resulting sand, silt and clay being transported through rivers into the seas. In addition, growing in the seas were extensive communities of algae along with a variety of invertebrates. These living organisms contributed calcium carbonate to the sediments. There were massive coral reefs in parts of these seas. The skeletons of those animals remained and became fossilized. These processes of erosion and deposition led to thick layers of accumulated sediments. Gradually, over time, those underwent metamorphosis. Thick layers of sand became sandstone and deposits of silt and clay became shale. Remains of shells and skeletons of marine invertebrates and certain kinds of algae became limestone. Massive deposits of salt and gypsum accumulated in the sediments forming the basis for the salt and gypsum mines of modern-day Michigan. The combination of uplift and deposition of sediments led to the seas becoming even shallower. By the middle Pennsylvanian Period (about 295 million years ago), the seas were gone from the region of the present-day Great Lakes. Marshes were found in the central part of the Lower Peninsula of Michigan and along the southern border of the Great Lakes region in Indiana, Ohio, Pennsylvania, and western New York. Sediments in those formed the Pennsylvanian-aged sandstones.

As each new era progressed in the Great Lakes basin, beginning 3.5 billion years ago, new rock layers were laid down on top of existing layers. Thus you would expect the oldest rocks to be on the bottom with newer layers built up on top like layers in a cake. Uplift, mountain-building, folding and other activities, however, led to re-configuring of the land surface and the rock layers. Erosion wore away layers of rock, especially on steeper slopes, re-exposing older rock formations. In some locations in the basin, one could core downward and successively pass through time from the youngest to the oldest rocks. In other locations, as one cores downward, there are missing layers where erosion carried away a rock layer before the next layer was laid down.

Today in the Great Lakes basin, the oldest rocks may be found exposed in the region of Lake Superior and north, where there are granites, gneiss, greenstones and other Precambrian-aged rocks. These form the bottom of the lake and are exposed in the western half of the Upper Peninsula of Michigan and in northern Wisconsin. They extend eastward in Ontario along the north shore of Lake Huron and are cut through by the St. Lawrence River east of Lake Ontario. In the rest of the basin those Precambrian-aged rocks were covered by hundreds or even thousands of feet of sedimentary rocks from the inland seas. Because of tectonic activity, and differences in hardness, some are eroded away while others still exist.

One very interesting outcropping of sedimentary rocks found is a band of Silurian-aged dolostone, which formed from limestone by the later addition of magnesium. This particular dolostone is very hard and thus resistant to erosion. It can be found forming an arc beginning in Wisconsin along the western shore of Lake Michigan, curving across the southern edge of the Upper Peninsula of Michigan, then downward across and under Lake Huron. The Mackinac Bridge is anchored in this dolostone. It re-emerges in Ontario and extends eastward into New York. Here it forms the cap of the Niagara escarpment which is a distinct and very visible cliff running parallel to the south shore of Lake Ontario. At Niagara Falls the Niagara river flows over this rock formation. Because that particular layer of dolostone (Lockport dolostone) is so hard, Niagara falls is a high, abrupt falls rather a long set of rapids.

Perhaps one can imagine the ancient inland sea as being a shallow depression in which sediments built up in layers along its concave bottom and in the shallow waters at its shores. Thus the youngest rocks are found in the center of the depression with progressively older sedimentary rocks appearing in concentric rings as one moves outward. Since each younger layer of rock is nested inside of the next older layer, as one goes downward you pass through each layer. Nearest the surface in the center of the depression, which happens to be the center of the Lower Peninsula of Michigan, are found the youngest of all the rocks in the Great Lakes basin. These rocks are nowhere exposed, but are found under the glacial till that was left behind in more recent years. These final sedimentary rocks were formed during the latter part of the Jurassic Period, which ended about 140 million years ago.

Up to this point we have described a series of geological events which occurred over a period of 3.5 billion years and which resulted in the bedrock which underlies the Great Lakes basin. The Paleozoic Era began with the Cambrian Period and ended with the Permian Period, about 248 million years ago. It is often referred to as the period of sedimentation rock-forming. The Mesozoic Era, which began with the Jurassic Period, lasted from about 248 million years ago to 65 million years ago. The Mesozoic and Cenozoic, which began 65 million years ago and continues today, were and are times of geological modification in the Great Lakes Basin. Land masses have uplifted and the forces of wind and water have carved and shaped the land. During the Mesozoic and Cenozoic the region of the present Great Lakes was cut down by a system of rivers that are thought to have drained generally in a northward or northeastward direction carrying sediments into the ocean to the east of the region.

The Time of Glaciation and the Formation of the Great Lakes

About 2 million years ago the climate of the northern hemisphere began to be change dramatically. There were wide swings in temperature from warm to very cold. This period of the Cenozoic Era is referred to as the Pleistocene Epoch. The remains of the first humans are found in geological deposits from early in the Pleistocene. In the region of the Great Lakes, the periods of extreme cold led to the formation of monstrous glaciers that moved from the north across the land slowly toward the south. These glaciers formed as more snow accumulated than melted each year. With glaciers in general, new snow falls over the entire surface of the glacier each winter. However, there is melting in the summer in part of the glacier, in the case of the continental glaciers of the Pleistocene, this melting occurred at the southern edge. However, layers of snow accumulate year after year in the colder parts of the glacier; as long as more snow accumulates than melts each year, the glacier grows. The weight of snow compresses older layers of snow under it. Thus the fluffy, white snow is converted first into denser granular crystals called *firn*. With more compression caused by increased weight of accumulated snow on top of the glacier, the firn is in turn changed into dense ***glacier ice***. The change in density of the ice is quite dramatic as it is converted from snow flakes to glacier ice. Dorr and Eschman (1970) report that flakes have a density in the range of 0.1 to 0.3 (the density of pure water is 1.0), firn has a density greater than 0.55, and glacier ice has a density of between 0.8 and 0.9. During the Pleistocene, snow accumulated in this manner to form glaciers as thick as 2,000 feet in some places.

Glaciers move. The mass of ice and snow in a glacier responds to the pull of gravity to cause it to move downhill. The mechanics of this movement is a complex interaction of deformation of ice crystals, differences in fluidity, and steepness of slope. In general, speed of movement varies with depth. The surface of the glacier moves faster than the lower layers, with the slowest movement being at the base of the glacier where it contacts the rock substrate. Perhaps the most obvious evidence that the surface is moving faster than the base is the presence of crevasses or cracks. The more rapid expansion of the surface causes that layer to split much as dry paint on the surface of a balloon, which is being blown up, splits and cracks. Like the glacier, the surface of the balloon is spreading out, and since the paint like the surface ice is not plastic enough to stretch, it breaks apart. Surfaces of glaciers move at a rate that is generally less than 1 foot per day, but some have been shown to move as fast as 50 feet per day (Zumberge and Nelson, 1972). Dorr and Eschman (1970) suggest an average rate for glacial movement of probably in the order of a few thousand feet per year, with maximum rates of 150 feet per day.

At least four times during the two million years of the Pleistocene, the climate has gotten cold enough and snow has accumulated enough to form continental glaciers in the northern part of eastern North America. Evidence of these four is found as deposits of materials moved by the advancing glaciers. These four glaciers are known as the Nebraskan, which is the oldest, followed in time by the Kansan, Illinoian and Wisconsin glaciers. The time periods associated with them are "ice ages." They are so named because the geological evidence of these was first found in the state for which the ice age is named. The glaciers left behind loose deposits of weathered rock material -- rocks, gravel, sand, silt and clay-- known as *till*. In some places the till was pushed up into ridges and mounds, known as moraines and drumlins. These were formed by piles of till pushed in front of the advancing glacier and then left when it began to melt or were till that had accumulated under the glacier and were re-exposed when the glacier melted from on top of them. In other locations the till was spread out in more or less uniform layers over the surface of the land. All four glaciers moved through the region of the Great Lakes. However, each succeeding glacier picked up till from its predecessors and pushed it in front of its own till. Thus, in localities where the Wisconsin glacier existed, the evidence of the other three is obliterated. The map in Figure 3- shows the extent of the four glaciers in the region of the Great Lakes. It becomes immediately evident from the map that all of the Great Lakes basin was at one time under the Wisconsin glacier. In fact, the present Great Lakes, and the topography and soils of the Great Lakes ecosystem, owe their configuration and makeup to the activities of that glacier.

The force generated by a glacier as it moves is tremendous. The sheer weight of hundreds or thousands of feet of ice is hard to imagine. But, slowly and surely, that incredibly heavy mass of ice moves slowly along over the rock surface. As it does, the weight pushes vertically downward and that, in combination with the horizontal movement forward, loosens and removes boulders, rocks, gravel and sand from the rock substrate. The loosened rocks, gravel and sand are collectively referred to as *grit*. It is possible to visualize the action of a moving glacier by imagining it being like a giant sheet of sandpaper attached to a block of wood. As one pushes down on sandpaper and moves it across the surface of a piece of wood, the grit on the sandpaper tears tiny pieces of wood out of the surface and carries them away. You can increase the number of pieces of wood torn away from the surface by either pushing down harder on the sand paper, or by using sand paper made with larger-sized particles of grit. Doing both, that is pushing down hard on very coarse sandpaper, gives the greatest removal of wood. Conversely, the least amount of wood removal occurs when using very fine sandpaper and a very light touch. The second part of this analogy is that hard woods, such as oak, are much more resistant to wood removal by sandpaper than are soft woods, such as pine. As the glacier moves forward, the grit that has accumulated under it is pressed into the land surface leveling, grinding and/or smoothing it. Where fractures or wear lines exist in the rock surface, the glacier can pluck or quarry large pieces of rock out of the bedrock. Depending upon the type of land surface, hard rock vs. soft rock for example, and the type or size of the grit, this scouring of the glacier may leave holes, deep grooves or striations or it may polish the surface making it quite smooth.

It was through the scouring activity of the Wisconsin glacier, which began its move about 70,000 years ago, that the beds of the five Great Lakes were scoured out.

The very hard granites of the Precambrian granites in the north of the basin, the so-called *Canadian Shield*, resisted scouring. Loose materials were picked up, and soft rocks were carried out, but the glacier flowed over the hard granites, leaving a relatively smooth surface. However, when the advancing front of the glacier reached the softer sedimentary rocks south of Lake Superior, it scoured, polished and plucked its way. Movement of the glacier was fastest along the river valleys of the pre-existing rivers (referred to above) which had been draining the region towards the northeast. The glacier advanced along these "pathways of least resistance" and thus they directed the direction in which glaciation occurred. The geographic orientation of the Great Lakes resulted, in part, because of the orientation of those earlier river systems. Since the granites of the Canadian Shield resisted plucking, the grit under the glacier moving down those old river valleys was composed of smaller sized particles, rather than boulders. The bedrock of Lakes Michigan, Huron, Erie and Ontario were mostly polished.

Land which was south of the Wisconsin glacier was drained southwestward into the Mississippi River drainage system, since the glacier formed a barrier to the old pattern of drainage to the northeast. In low-lying areas immediately in front of the advancing glacier there were extensive shallow wetlands. About 16,000 years ago, the climate began to warm, resulting in snow no longer accumulating on the top of the glacier. At its southern edge (see Fig. 3- for southern extent of the Wisconsin glacier), ice began to melt away from the glacier faster than new ice was moving southward. The Wisconsin glacier began its retreat. Slowly, the ice melted from the south progressing northward and leaving behind till and a great deal of water. This melting was not an unbroken continuum, but rather was a period of melting, punctuated by periods of colder weather when melting ceased. By 14,000 years ago, the glacier had retreated enough to expose land surfaces which were lower than the surrounding regions. These low regions filled with melt water and became the first post-glacial lakes.

Geologists have named those first post-glacial lakes Lake Chicago and Lake Maumee. As the map in Figure 3- shows, those two lakes drained southwestward into the Mississippi River system and ultimately into the Gulf of Mexico. As the glacier melted further north, new and lower drainage routes opened up. The first of these (at about 10,500 years ago) drained water from Lake Maumee northeastward through the Mohawk and Hudson River systems of what is now New York. At this same time, the ice had retreated enough in the northwestern part of the basin to form a third new lake, Duluth (Fig. 3-). Lake Duluth drained southward into the Mississippi River and the Gulf of Mexico. By about 8,000 years ago, the glacier had retreated to a point north of Lake Ontario, to the north shore of Lake Huron, and about half the way across what is now Lake Superior. Lake Duluth still drained south, but Lake Chicago had expanded to fill present-day Lake Michigan. It extended into present-day Lake Huron and that entire, very large lake has been named Lake Algonquin. Lake Algonquin drained southward into the Mississippi river system and also into early Lake Erie which by this time began to flow over Niagara Falls into a lake known as Lake Iroquois. The St. Lawrence River formed in even lower regions extending east out of the northeast corner of Lake Iroquois and thus water drained from Lakes Algonquin, early Lake Erie and Lake Iroquois out to the Atlantic Ocean (Fig. 3-) So much water drained out through this newly-opened waterway that the levels of Lake Algonquin and early Lake Erie dropped.

After the lakes had shrunk, another landscape-shaping event occurred. The climate cooled and a lobe of the glacier made a new advance covering all of Lake Duluth and the north part of Lake Algonquin; this period is known as the Valders advance (Fig. 3-). That lobe eventually retreated re-exposing the basins of all the present-day Great Lakes. The lake occupying the basin of present-day Lake Huron was called Lake Stanley, and it drained outward through what is now the region of the Ottawa River directly into the St. Lawrence River (Fig. 3-).

In addition to the retreat of the glacier as the climate warmed, another set of geological events was occurring also. With the melting of the glacier, the tremendous weight of the ice was released from the land surface and the earth's crust rebounded upward. There was a slow increase in elevation of the land in the northern part of the basin. Eventually the level of Lake Stanley, and Lake Chippewa, as Lake Michigan was them known, rose enough that water cut out the St. Clair and Detroit Rivers. For a while drainage occurred through the Chicago River channel, the Ottawa River channel and also into Lake Erie, but with more rebounding in the north and the rapid cutting down of the St. Clair and Detroit Rivers, the Ottawa River connection was too high and all the water soon drained into Lake Erie (Fig. 3-). Geologists refer to this as the Algoma postglacial lake stage. The present Great Lakes where completed, and their outlines were very similar to today. The present lake levels and outlines have remained pretty much unchanged for the past 2,500 years.

The processes of erosion and deposition go on, of course, with uplands slowly wearing down and sediments slowly accumulating. When we look at the changes that occurred in the 13,500 years after the glacier began to melt, the past 2,500 years seems to have been rather calm. However, when we consider those 2,500 years in terms of the changes that have occurred to this part of the earth in the past 3.5 billion years, it's much too soon to make a judgment about whether this calm is a momentary event or if it will continue for some time to come.

Minerals and Mining

In Chapter Two it was pointed out that the presence of minerals in the rocks of the Great Lakes basin attracted many people to come to the region, and in the first part of this chapter, reference was made to iron and copper deposits which formed during the Precambrian. Mining of those minerals has had an important impact upon the Great Lakes ecosystem including the history of the people of the basin, the economic development of the basin and the ecological conditions found there. Large deposits of iron-containing minerals were found in the rocks of the Canadian Shield in the western Upper Peninsula of Michigan, in northeastern Minnesota and in Ontario northwest and northeast of Lake Superior. Equally important deposits of copper, some nearly pure, were located in the Keweenaw Peninsula at the western end of Lake Superior. At Sudbury, Ontario, some of the world's largest deposits of nickel-containing rocks were found.

South of the Canadian Shield, in the sedimentary rocks of the Continental Interior, are found other minerals important to the economy of the region. The world's largest limestone quarry (Dorr and Eschman, 1970) is located near Rogers City, Michigan, in the northeastern part of the Lower Peninsula. Limestone from here and other quarries located in Michigan and northern Ohio is used to produce a large part of the cement used in construction. Limestone is also used directly as a construction material. Large deposits of salts, including common table salt (NaCl) and salts of other elements such as calcium chloride, magnesium chloride and potash occur in Gratiot, Lapeer, Mason, Manistee, Midland, Muskegon, St. Clair and Wayne Counties in Michigan. These have been mined for many years. According to Dorr and Eschman (1970), Michigan supplies 20 - 25% of the United States' output of common table salt. Large deposits of gypsum occur near Grand Rapids, the Saginaw Bay area and near Detroit in Michigan and in Ontario near the Detroit River. Gypsum is used to make plaster wallboard, plaster of Paris and lath. Ground up it is used as a soil conditioner to improve clayey soils.

Mining puts many demands upon the ecosystem. As referred to earlier, the spoils from mining were often dumped into Lake Superior causing water pollution. Runoff from mines leached toxic substances into the waters of the ecosystem. The nickel smelter at Sudbury is one of the largest air polluters in North America. Materials mined at one location had to be transported elsewhere. That required construction and sailing of ever-larger ships. One major outgrowth of the shipping need was the construction of the navigational locks at Sault Ste. Marie which enabled ships to move into and out of Lake Superior. A serious negative impact of the enlargement of the navigational locks of the Welland Canal, needed to handle large ore carriers, was that sea lampreys got around Niagara Falls from Lake Ontario and into the four other Great Lakes. Harbors had to be built and enlarged, reducing naturally occurring wetlands. Spawning grounds of fish were covered with sediments or dredged to make shipping channels. The net effect, is an altered ecosystem.

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