

CHAPTER 1

Introduction

Geologic Time Travel in the Great Lakes Region

1.1. Great Lakes Rocks Tell the History of the North American Continent

Great Lakes rocks hold an amazing story that goes back to the dawn of time on Earth, a trail that we will follow in this book. As we work our way back in time, the trail will take us through the history of early human settlement of North America, through periods of mountain building, rifting continents and meteorite impact, to the appearance of life when the continent itself was just beginning to grow.

It might be surprising that the Great Lakes region has such a long and interesting story to tell. For most people today, mention of the Great Lakes region conjures up an image of lakes, shorelines, and little else. But that is not the way native peoples or early European explorers saw it.¹ To them the Great Lakes region was the gateway to central North America. The St. Lawrence River and the Great Lakes provided easy access to the surrounding continent. In this book, we take the same expansive view of the Great Lakes region. As you can see in figure 1.1, it covers the five Great Lakes and extends northward toward James Bay, the southern extension of Hudson Bay; southward toward the Ohio River; and westward to the start of the prairie in Minnesota and Manitoba.

This expanded Great Lakes region includes a wide array of geologic features that built the North American continent and, in fact, the world as we know it. The Great Lakes themselves are the crowning finale in a long series of geologic events that created mountain belts and deep basins, formed continents and ripped them apart, generated vast mineral wealth, and finally scraped it all clean with large glaciers. By reaching out to this enlarged Great

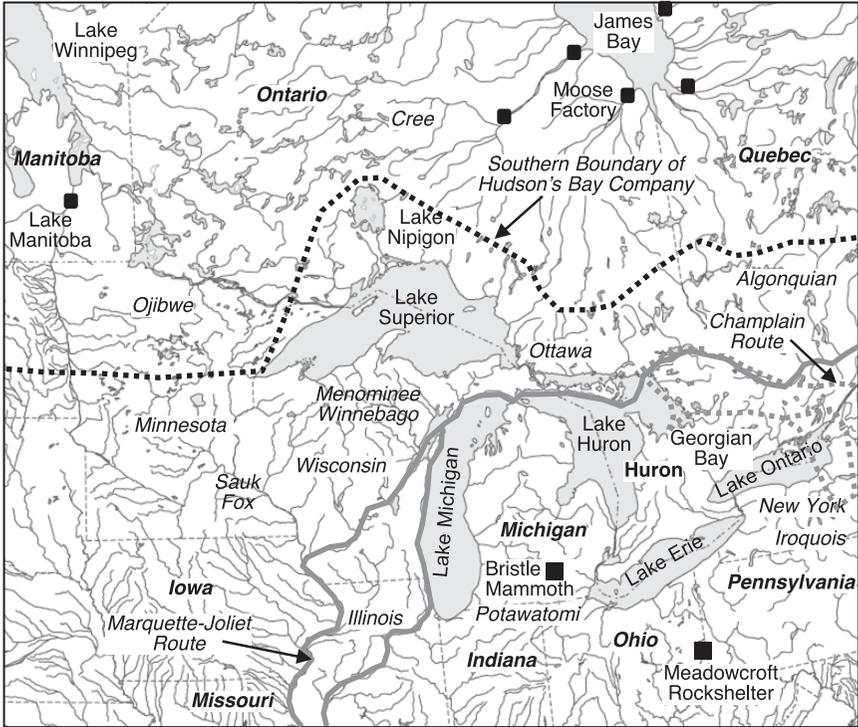


Figure 1.1. The Great Lakes region showing states, provinces, major lakes, and rivers, along with routes taken by early explorers, the southern boundary of Hudson's Bay Company land, the approximate location of Native American and First Nations tribes in about 1600, and the Meadowcroft Rockshelter and Bristle Mammoth sites of early human activity in the region. Squares show the locations of Hudson's Bay Company trading posts, known as factories. (Modified from May 1967.)

Lakes region, we can better understand how geologic processes played a role in drawing people into it.

1.2. Our Geological Story Follows the Early Explorers

In our tour through the Great Lakes region, we will be following in the footsteps of early explorers, many of whom left their names on lakes, rivers, and towns. The first explorers were the aboriginal people who came from the far eastern part of Asia during the last retreat of the glaciers (the earliest trace that we see of these immigrants is in the Meadowcroft Rockshelter and Bristle Mammoth site). They and their descendants, along with waves of other

aboriginal immigrants, colonized the Great Lakes region, eventually producing the tribes, councils, and confederations that greeted the European explorers (fig. 1.1).² Their names get pride of place on four of the Great Lakes and Lake Nipigon, as well as many important rivers and towns, including Chicago, Milwaukee, Ottawa, and Toronto. My personal favorite is Wawa, Ontario, at the northeast corner of Lake Superior, named for the Canada goose (see fig. 1.2A).³

Among the first Europeans were the French missionaries and traders, who moved up the St. Lawrence into the Great Lakes region establishing missions and trading posts. Their language graces towns such as Detroit, Eau Claire, La Crosse, and Marquette, and they even captured two Great Lakes wannabes, St. Clair and Champlain. Among the earliest was Samuel de Champlain, known as the “Father of New France,” who explored the eastern part of the Great Lakes system and founded the city of Quebec in 1608. The missionary Jacques Marquette went farther west, establishing missions at Sault Ste. Marie and St. Ignace in what is now Michigan and near Ashland, Wisconsin. In 1673 he and Louis Jolliet headed south into the continent (fig. 1.1). Following directions from Native Americans, they paddled up Green Bay and the Fox River to a two-mile portage that took them into the Wisconsin River and then the Mississippi River at today’s Prairie du Chien. Their return trip, through what is now Chicago, explored one of today’s important connections between the Great Lakes and the Gulf of Mexico.⁴

The English also came into the Great Lakes region, but from the north via Hudson Bay and its southern extension, James Bay. Although English money was involved, leadership was provided by Pierre-Esprit Radisson and Médard Chouart des Groseilliers, residents of New France, whose explorations had extended far north of Lake Superior. By 1670 their group, known then as the “Governor and Company of Adventurers of England Trading into Hudson’s Bay” and today as “The Bay,” had been incorporated in England with a monopoly on trade in an enormous region that covered most of central Canada and extended southward into Minnesota and North Dakota (fig. 1.1).⁵ The company established trading posts, known as factories, throughout the vast region and constructed Prince of Wales fort to protect them (fig. 1.2B).⁶

As more Europeans entered the region, attention shifted to its agricultural potential and mineral resources. Nick Eyles, Peter Newman, and others have pointed out that the rocky, glaciated land north of Lake Superior impeded migration of farmers from the south thus preserving what was to become central Canada. Other migrants were attracted by the possibility of mineral wealth; first by tales of the mysterious Ontonagon cop-

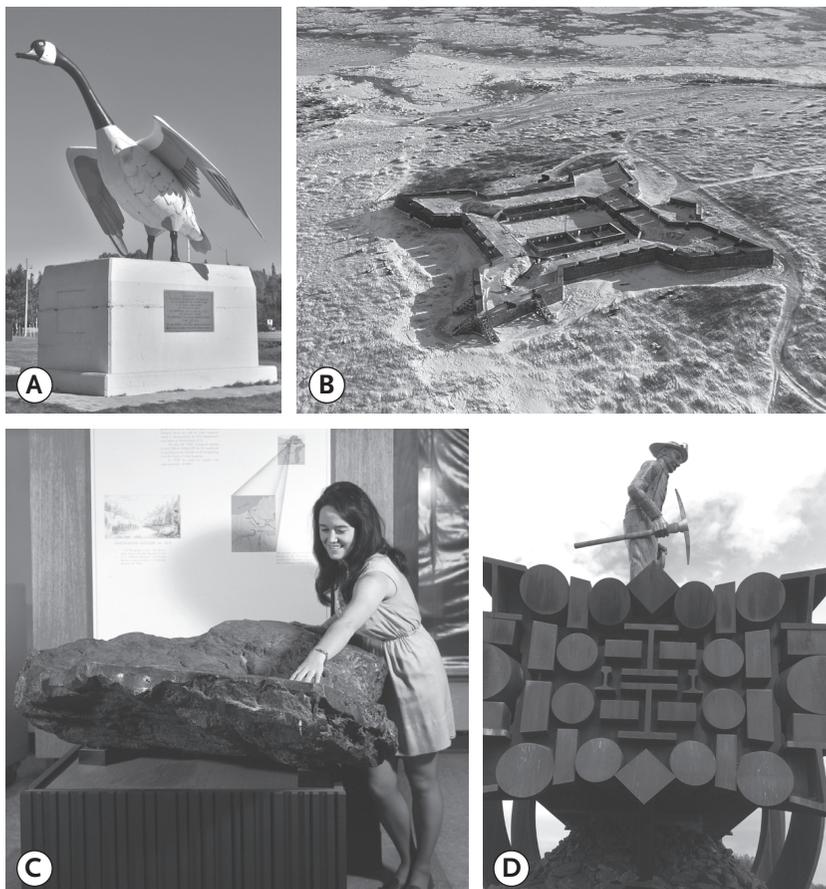


Figure 1.2. (A) Giant statue of a Canada goose at Wawa, Ontario; (B) Prince of Wales Fort near Churchill, Manitoba (photo by Peter Fitzgerald, 2012); (C) boulder of pure copper found along the Ontonagon River in Michigan (SIA ACC. 11-009, Smithsonian Institution); (D) statue of a giant 10 meter high iron miner, Mesabi Iron Range, Chisholm, Minnesota.

per boulder (fig. 1.2C) and later by the huge Mesabi and other iron ranges (fig. 1.2D).

The geologic history that controlled European settlement of the Great Lakes region stretches back in time for almost 4 billion years. Two processes that dominate this geologic history, both past and future, are global climate change and plate tectonics. So, before starting our journey through Great Lakes geologic time, we need to review just how much time we are dealing with and the role of these two processes in geologic history.

1.3. Great Lakes Rocks Span Most of Geologic Time

Although the Great Lakes formed only a few thousand years ago, they are the result of much older processes. In fact the geologic history of the Great Lakes region covers almost the entire 4540-million-year (Ma) span of time since the Earth formed (box 1.1).⁷ Some of the oldest rocks in the world, aged 3800 to 3400 Ma, are found in the Minnesota River valley and in the Watersmeet and Carney Lake areas in the Upper Peninsula of Michigan, and even older rocks are found along the shore of Hudson Bay in Quebec. At the other end of the scale, most of the glacial ridges, valleys, and lake beds that form our present landscape are only a few thousand years old, and the Great Lakes shorelines are evolving today.

BOX 1.1. HOW OLD IS EARTH?

Just when did Earth form? Was it when planetesimal debris first coalesced into a protoplanet Earth or when the protoplanet separated into a core and mantle? Or should we say that Earth really formed only after the giant collision that formed the Moon? How long did a magma ocean last before a solid crust formed and was that really the birth of our planet? Finally, even if we can agree on which of these events represents the beginning of Earth, how can we measure its age? One way would be to measure parent-daughter relations in some isotope system, but what isotope system should we use and what material should we analyze? Another way would be to construct and test theoretical models based on the physics of coalescing planetesimals, but what size should they be and over what period of time did they collect? Although progress is being made on many fronts, these questions continue to fascinate cosmologists, physicists, astronomers, and geologists. At this point, the accumulation of planetesimals to form Earth is thought to have started at 4568 Ma, based on Pb isotope measurements on meteorites, and to have taken only a few million years to form planets. The next big event, the impact that formed the Moon, took place sometime between 4530 and 4520 Ma, based on the Hf-W isotope system. A more widely reported age of 4540 Ma, which averages the ages obtained by several isotope systems, is commonly cited as the age of Earth (<https://pubs.usgs.gov/gip/geotime/age.html>). As we will see in chapter 8, the formation of Earth's earliest crust happened sometime between 4440 and 4430 Ma.⁸

This enormous span of time can be put into perspective with the geologic time scale (fig. 1.3), which is divided into four large periods known as eons—the Hadean, Archean, Proterozoic, and Phanerozoic. Where rocks fit in the time scale is determined by fossil evidence and geologic relations, including the laws of superposition and cross-cutting relations (fig. 1.4A,B,C in color section).⁹ These give us relative ages, such as the obvious fact that beach deposits along the Great Lakes must be younger than the ancient hard rock on which they rest, and that basalts¹⁰ of the Midcontinent Rift are younger than the granites that they cut across. We can also use isotopic analyses,¹¹ which give us absolute ages based on the decay of radioactive elements such as uranium (fig. 1.4D in color section). It is isotopic age measurements that provide the 3800 to 3400 Ma ages of the Minnesota River valley and Carney Lake rocks.

Many geologic stories begin with old rocks like those in the Minnesota River valley. In this book, however, we start at the present and work our way backward. This allows our time traveler to start with features, like waterfalls, lakes, caves, deltas, and glaciers, that are relatively familiar and to use insights about these familiar features to understand how sedimentary basins, lava-filled rift valleys, and colliding continents behaved farther back in time.

Figure 1.3 shows how the chapters of this book work their way back through time, starting with chapter 2, which concerns current geologic features that formed largely during the Holocene epoch after the last glaciers retreated from the Great Lakes region about 10,000 years ago. Chapter 3 moves back to Pleistocene time, about 10,000 to 2.5 million years (Myr) ago, when glaciers ground down much of North America and left the southern part with thick deposits of sand and gravel. Then, in chapter 4, we jump back to Mesozoic and Paleozoic time, about 145 to 542 Myr ago, when oceans flooded the continents, covering them with sedimentary basins from which we get oil, natural gas, salt, gypsum, and limestone.

The last part of the book deals with Proterozoic and Archean time, which go by the informal designation of Precambrian. Chapter 5 reviews a time, about a thousand million years ago (1000 Ma), when the North American continent began to split apart, forming the Midcontinent Rift and its large copper deposits. Chapter 6 moves farther back in time to the Paleoproterozoic Era, between about 1600 and 2500 Ma, when the edge of the North American continent was located in the Great Lakes region. This was a busy time for Earth. We gained an oxygen-rich atmosphere, vast iron and uranium deposits, and the Penokean mountain range and were struck by the enormous Sudbury meteorite. Chapter 7 goes all the way back to Archean time, before 2500 Ma, and the story of how early continental or craton fragments

Geologic Time Scale

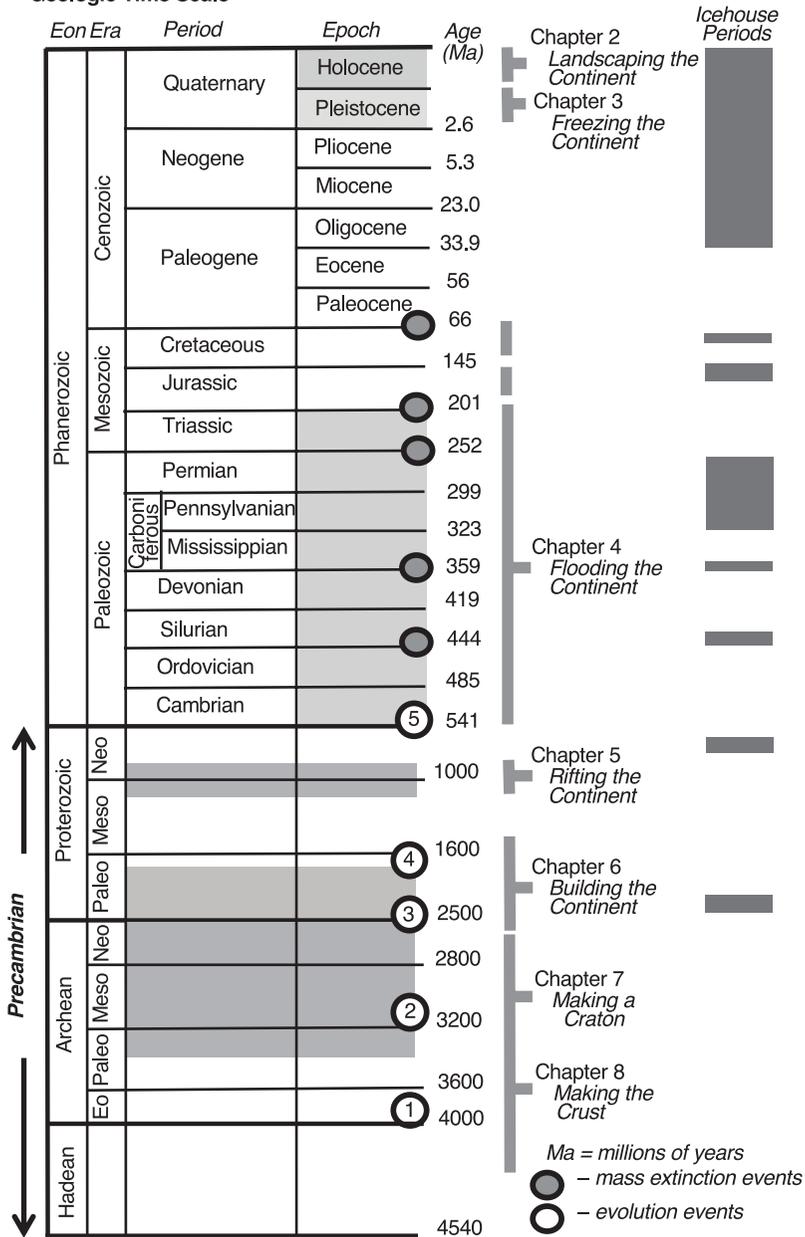


Figure 1.3. Geologic time scale showing time periods discussed in each chapter and their relation to global icehouse periods, mass extinctions, and evolutionary events discussed in the book: (1) earliest life, (2) photosynthesis and cyanobacteria, (3) onset of the Great Oxidation Event, (4) eukaryotes, (5) Cambrian explosion. (Modified from Dyson 1999; Nesbitt et al. 2003; Dalrymple 2004; Cockell 2007; Committee on the Importance of Deep-Time Geologic Records 2011; Lyle 2016.)

like the Minnesota River valley and the Wawa terrane were amalgamated to form larger continents such as our own North America and how they formed the wild array of gold, copper, and zinc deposits that support many northern economies and supply many of our metal needs. Closing out the story, in chapter 8 we try to look through the mists of time to see what was happening in the Great Lakes region during the earliest period of Earth's history, the Hadean Eon.

Finally, in chapter 9 we do an about-face and use these insights about the geology of the area to predict the geologic future of the Great Lakes region and its sustainability as a habitat for humans. Along the way, we will see that events in the Great Lakes region have been and will continue to be strongly affected by global processes such as climate change and plate tectonics.

1.4. Great Lakes Rocks Reflect Global Climate Change and Plate Tectonic Processes

Climate change is a long-term feature of geologic history. Earth has fluctuated between hot and cold climate states, known as greenhouse and icehouse respectively, since at least 2500 Ma.¹² Cooling climates lead to the accumulation of ice on the continents, which causes global sea level to fall, as happened during Pleistocene time. (Earth has had other icehouse intervals, which we will visit briefly, including the period known as “snowball Earth” when ice covered much or maybe even all of the planet.) As climates warm, polar ice melts, oceans expand, and sea level rises, as happened several times in the Great Lakes region during Paleozoic time.

Changes in the amount of greenhouse gases such as CO₂ and CH₄ in the atmosphere, which are part of the carbon cycle (box 1.2), are an important cause of climate change. Many natural processes affect atmospheric gas contents, including plant growth and decay, volcanic emissions, permafrost melting, and the weathering of exposed rocks on Earth's surface. Anthropogenic processes also play a role, including the burning of fossil fuels and leakage of natural gas from landfills and wells. Additional influence on climate comes from variations in solar radiation reaching Earth, snow and ice cover, ocean circulation patterns, and the position of the continents relative to the poles, which leads us back to plate tectonics and continental drift.

Changes in global climates also reflect changes in the deeper Earth. You can see in figure 1.5 that the continents consist of rock up to 4 billion years old whereas the oldest ocean rocks are less than 300 million years old. This huge

BOX 1.2. THE CARBON CYCLE

The carbon cycle is one of the most effective ways that Earth has to control global climate and sea level. It involves the flow of carbon among the planet's four major reservoirs: the atmosphere, hydrosphere, lithosphere, and biosphere. In the atmosphere, most carbon is present as CO_2 , an important greenhouse gas. (CH_4 , also a greenhouse gas, was part of the early Earth atmosphere.) CO_2 is taken out of the atmosphere by plants, which send the carbon back to the atmosphere when they decay or burn or to the lithosphere when they are buried in sediment. Carbon in the atmosphere can also be dissolved in water to form carbonic acid, which is the main agent of rock weathering. Dissolved carbon is taken out of the ocean by plants and animals that form limestone, which accounts for about 80 percent of the carbon in the lithosphere; the other 20 percent is in buried plants and other organic matter. Carbon in the lithosphere returns to the atmosphere and hydrosphere when rocks are metamorphosed or melted to form magmas that release CO_2 .

The flow of carbon among these reservoirs is closely linked to global climate. High flows of CO_2 or CH_4 into the atmosphere lead to global warming, which melts glaciers, causing sea level to rise. Volcanoes are an important source of carbon for the atmosphere, especially large-scale basalt eruptions. Conversely, increased weathering or plant growth consume atmospheric carbon, causing cooling that might lead to glaciation and a lower sea level.

These processes are also linked to the supercontinent cycle, which is discussed below. When continents collide to form supercontinents, the resulting orogenies and mountain belts lead to increased weathering, which draws CO_2 out of the atmosphere. When seafloor spreading breaks up the supercontinents, this can be reversed by the increase in volcanism.

Processes and places that produce carbon are called sources, and the carbon is consumed at sinks. When carbon sources and sinks are in balance, planet Earth cycles gently between cool and warm periods. If the balance is disturbed, climates and sea level can take extreme excursions, possibly including icehouse events and mass extinctions. So far these cycles have been controlled by natural processes, although we are now undertaking an experiment involving anthropogenic transfer of huge amounts of carbon from the lithosphere (fossil fuels) to the atmosphere.¹³

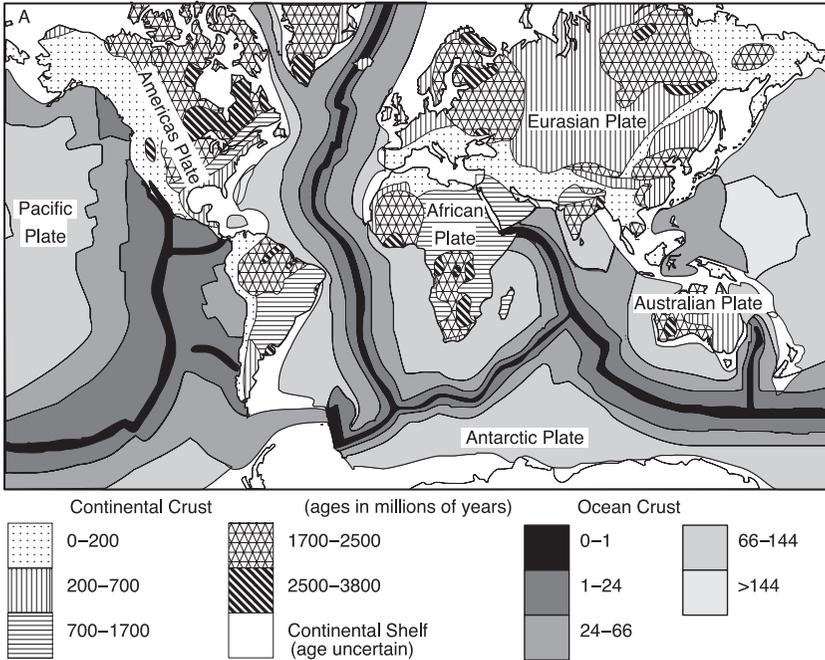


Figure 1.5. Present configuration of the tectonic plates showing zones of seafloor spreading (represented by black strips) in the oceans. Note that most of the ocean crust is less than about 200 million years old, whereas some parts of the continents are up to 4300 million years (Myr) old.

difference exists because new ocean crust is being formed continually at the mid-ocean ridges (the thin black zones in fig. 1.5) and old ocean crust is sinking back into the deeper Earth (the mantle) at deep ocean trenches known as subduction zones. This process, which we call plate tectonics,¹⁴ has operated throughout much of Earth's history, moving continents across the globe.

The present arrangement of continents and tectonic plates at Earth's surface is just the latest in a sequence of arrangements that Earth has gone through for billions of years. Occasionally this has brought the continents together into clusters called supercontinents. The assembly of supercontinents takes tens of millions of years and involves continent-scale collisions (orogenies) in which rocks are pushed up to form mountains, which erode and shed sediments into the ocean. The accumulation of heat beneath the supercontinents eventually causes them to break apart through rifting, forming new ocean basins that grow by seafloor spreading at mid-ocean ridges. The

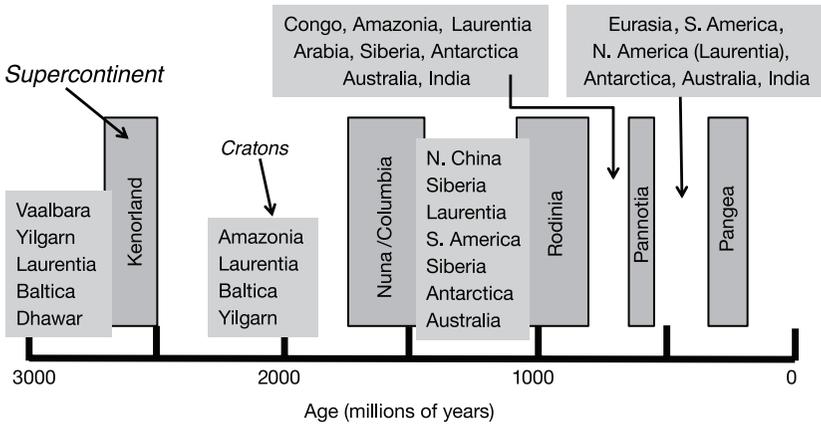


Figure 1.6. Supercontinent cycle showing the major supercontinents and, between them, names of the continental fragments (cratons) that assembled to form them. (Modified from Nield 2007; Murphy and Nance 2013; Li et al. 2016).

increased number of spreading ridges during the breakup of supercontinents leaves less room in the ocean for seawater, causing it to flood the continents. If the supercontinents are close to the poles, ice might accumulate, leading to global glaciation and a decrease in sea level. If the continental fragments are close to the equator, shallow seas might evaporate to form evaporite deposits consisting of salt and other minerals (discussed further in chapter 4).

The repeated joining and breaking up of supercontinents, known as the supercontinent cycle (fig. 1.6), has had a strong impact on the geologic history of the Great Lakes region. This cycle is so repetitive that we can see ancient processes in today's events. For instance, Africa and India are pushing against Eurasia from the south today, trying to create a new supercontinent and forming high mountain ranges like the Alps and Himalayas. In chapters 5 and 6, we will see that similar processes during the Rodinia-Pannotia supercontinent cycle formed the Midcontinent Rift and the Grenville Mountains in the Great Lakes region.

1.5. Great Lakes Fossils and Rocks Record the Evolution of Life

While the continents were forming and jostling for position, life began to evolve, and the Great Lakes region preserves some of the fossils that record

this long history. Life required an ocean, which probably formed during the Great Rain when Earth cooled enough to condense water from the atmosphere, as discussed in chapter 8. Early life, once it started, went through several important evolutionary steps, one of which was development of eukaryotes, probably aided by the Great Oxidation Event when oxygen showed up in the atmosphere. Once life was well under way, in Paleozoic time, there were several important global extinction events that are mentioned in chapter 4. Older extinction events probably occurred as well, although they are much harder to detect. For instance, the Late Heavy Bombardment, from about 4100 to 3800 Ma, included numerous large impacts on Earth that would have created conditions very difficult for life. Life might have persisted, perhaps protected by ocean water, or maybe it was extinguished and developed again. What we know about this long-term history of life is discussed at the end of each chapter.

Now that we have outlined the “big picture” it is time to see how Great Lakes rocks have helped us understand the story. Keep in mind as we go along that everything we discuss, every rock and mineral and fossil, had to be found by someone walking along the ground. And then their significance to the larger story had to be outlined and interpreted. Each new rock exposure adds some information and helps clarify the story. So, after reading this, step outside and see what you find.

Notes

1. The term *native peoples* is used here to refer to Native American, First Nations, and other indigenous peoples. The Great Lakes region does not extend far enough north to include Inuit peoples.

2. Some of the tribes shown in figure 1.1 moved into the Great Lakes region from the east, first driven by internal efforts to expand, then by conflict with other tribes, and finally by pressure from European immigrants (Clifton and Porter 1987; Warren 2009; Schmitt 2016).

3. Although *wawa* is widely said to be the Ojibwe name for the Canada goose, *nika* is the name given in the *Ojibwe People's Dictionary*.

4. See Chmielewski (2017), Harkins (2009), and Skinner (2008) for further information on French activities in the Great Lakes region.

5. According to Peter Newman (2005), the Hudson's Bay Company is the oldest continuous commercial enterprise in the world. A few other organizations, including the Storra Koppaberg copper mine in Sweden (1288), the Löwenbrau brewery in Munich (1383), and the Banco di Napoli (1539), were formed earlier, but they have not operated continuously or in the same business. The English royal charter that established the Hudson's Bay Company did not consider either the aboriginal or other European claims to the land. French attempts to enter the area, which stimulated construction of Prince of Wales fort, were unsuccessful and ceded at the Treaty of Utrecht in 1713. In 1870, the

Hudson's Bay Company ceded its land control to Canada but continued its fur and trading activities.

6. See Elle (2009) and Newman (2005) for histories of the Hudson's Bay Company, and Maurice (2004) for an entertaining account of one of the last company traders.

7. The abbreviation Ma (mega-annum) is used throughout the book to indicate ages in units of millions of years.

8. If you want to read more about the age of Earth, try the summary by Rubie et al. (2015) and chapter 10 in Condie (2016).

9. The two main geologic laws governing relative geologic ages are the laws of superposition and cross-cutting relations. The law of superposition, which applies to layered sedimentary and volcanic deposits, indicates that the layer on top is youngest. The law of crosscutting relations, which applies to intrusive igneous rocks, indicates that older rocks are crosscut by younger ones.

10. Basalt is a volcanic (extrusive) igneous rock with a mafic composition (enriched in iron and magnesium). It makes up most of the ocean crust. Continental crust consists largely of granite, a felsic intrusive igneous rock (enriched in sodium and potassium) and andesite, a volcanic rock with a composition intermediate between basalt and granite (see also chapter 5 note 4).

11. In simple terms, isotopic ages (also known somewhat inaccurately as radiometric ages) are determined by measuring the abundance of a radioactive parent isotope and a daughter isotope in a sample. If all of the daughter isotope was derived from decay of the parent, as in the case of the decay of K^{40} to Ar^{40} , the age can be determined by the parent-daughter ratio and the half-life of the parent isotope. If some of the daughter isotope in the sample was not derived from decay of the parent (i.e., it was already present when the rock formed), it is necessary to analyze several samples and determine the age by means of the isochron method. For more insight into these and other isotopic age methods, see (<https://pubs.usgs.gov/gip/geotime/radiometric.html>).

12. See Nesbitt et al. (2003) and National Academies Press (2011) for more information on the global climate story.

13. For more information on the carbon cycle, see the summary on the National Atmospheric and Space Administration (NASA) web page (<https://earthobservatory.nasa.gov/Features/CarbonCycle/>) and Committee on the Importance of Deep-Time Geologic Records (2011).

14. Plate tectonics (fig. 1.7) involves 15 to 200 km thick, relatively rigid plates made up of crust and uppermost mantle, which slide over the underlying deeper mantle. (Two types of crust [ocean and continental, see note 10] overlie the mantle, which consists of ultramafic rocks, and the central core, which consists largely of iron.) Convective heat loss and resulting flow in the mantle drives plate tectonics. At the mid-ocean ridges, release of pressure on upward flowing mantle rocks causes partial melting to form basalt magma, creating new ocean crust. The new ocean crust and uppermost mantle migrate away from the mid-ocean ridges, and eventually sink into the mantle at subduction zones. During subduction, partial melting in the presence of water forms intermediate and felsic magmas that make up volcanic arcs consisting of andesite and granite. Volcanic arcs and sediments shed from them collect together to form continents. Because the continents are buoyant, they move about Earth's surface, colliding and rifting in the supercontinent cycle (fig. 1.6).