UNIVERSITY OF MINNESOTA

Minnesota at a Glance

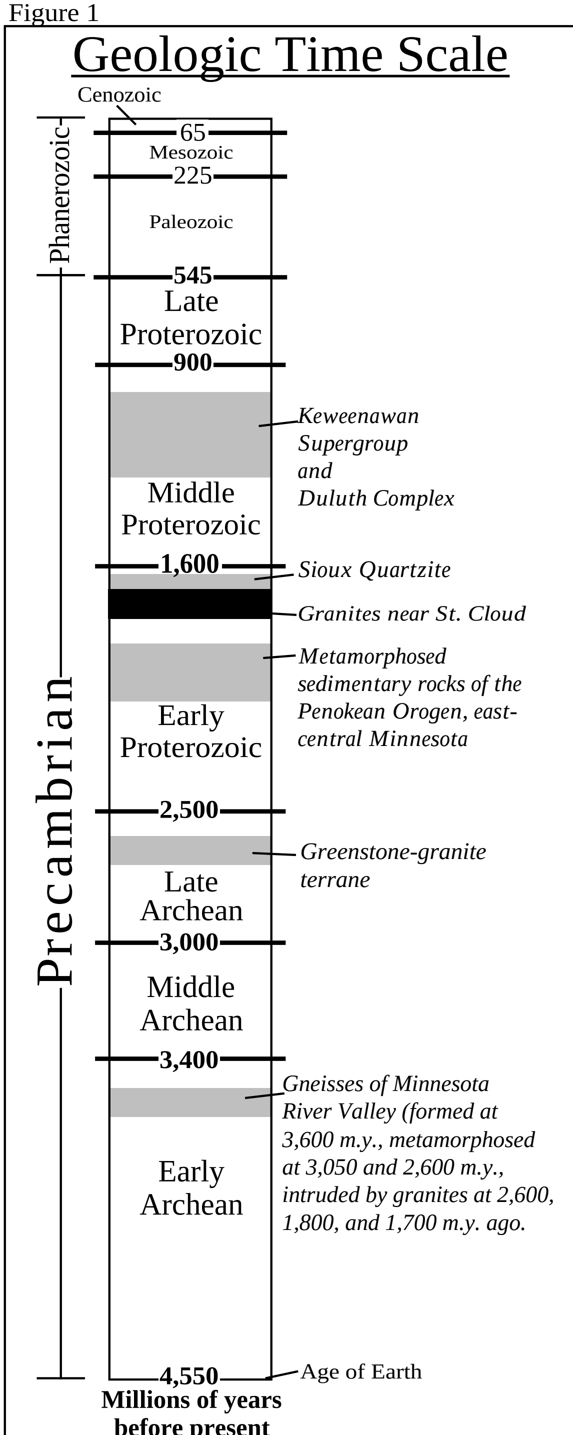
Precambrian Geology

Have you ever admired the cliffs along the North Shore of Lake Superior, fished off a smooth outcrop in the Boundary Waters Canoe Area, overlooked one of the immense iron mines on the Mesabi range, or noticed the abundant knobby outcrops within the Minnesota River Valley? If so, you were looking through windows of younger material into the very old bedrock, commonly referred to as "ledge-rock", that underlies all of Minnesota. Minnesota is situated at the southern edge of the Canadian Shield—the nucleus of the continent of North America that formed during Precambrian time. This period of time encompasses about 85% of earth's history. Geologists consider Precambrian time to have begun with the formation of planet earth about 4,550 million years (m.y.) ago and to have ended about 570 m.y. ago, when organisms with hard parts, such as shells, first appeared. The rocks formed in Minnesota during this enormous span of time record a complicated geologic history that involved volcanoes, ocean islands, mountain chains, and unstable geologic conditions that were very different from the Minnesota of today. Precambrian Minnesota resembled modern-day Indonesia for a while; later, it resembled modern-day California, and still later it resembled parts of the Middle East and eastern Africa.

The mountains and other features of the various Precambrian landscapes were slowly eroded to low relief over many millions of years. Most of the Precambrian rocks now exposed in Minnesota's flat terrain originally were much deeper in the earth; they record processes and conditions that existed beneath landscapes long since removed by erosion. Geologists can reconstruct the conditions that existed within the ancient Precambrian crust of the earth through studies of these formerly deep-seated rocks now exposed at the surface. Presently, these deeply-eroded Precambrian rocks are mostly covered by younger sedimentary rocks, or by a thick blanket of glacially-deposited clay, sand, and gravel. However they do appear at the surface here and there in northeastern, east-central, and southwestern Minnesota.

The great span of Precambrian time is divided for convenience into two major parts—Archean (4,550-2,500 m.y. ago) and Proterozoic (2,500-570 m.y. ago). Each of these is divided still further (Figures 1 and 2). The ages of rocks are determined by measuring the tiny amounts of certain naturally occurring radioactive isotopes they contain. Before isotopic dating methods were developed in the 1950s, the ages of rocks assigned to the Precambrian were not known. The crystalline rocks beneath the fossil-bearing strata were assigned arbitrarily to the Precambrian, without knowledge of the vast length of time they represented. The fossil-bearing rocks represent the most recent part of earth history, called the Phanerozoic (570 m.y. to present, Figure 1).

Figure 1



Relative times of major geologic intervals. Age of major Precambrian rock units shaded, white areas represent intervals of Precambrian time missing in Minnesota.

Archean

Archean rocks make up the oldest of the Precambrian rocks, and are subdivided into two units or terranes (the word terrane indicates an area of a particular kind of rock) on the basis of their age and metamorphic history (see "A primer on geology" at the end for the definition of metamorphism).

The oldest group of Archean rocks (Early to Middle Archean) crops out in the valley of the Minnesota River between New Ulm and Ortonville, and similar rocks underlie the southwestern quarter of the state. Most of them are different kinds of gneiss (pronounced nice), a family of coarse-grained streaky or banded rocks that formed between about 3,600 and 2,600 m.y. ago, miles below the surface of an Archean continent. This continent or continental fragment is about 900 million years older than the Archean volcanic rocks of northern Minnesota. It may have been joined to the northern volcanic rocks during a period of continental growth about 2,700-2,600 m.y. ago.

The younger Archean rocks (Late Archean) occur mainly in northern Minnesota, and may be seen in Voyageurs National Park, in the western part of the Boundary Waters Canoe Area, and in scattered areas elsewhere between Lake of the Woods and Ely. These originally were parts of volcanic islands similar to those which make up Indonesia or Japan in the western Pacific. Greenstone (a dark greenish-gray, fine-grained, weakly metamorphosed basalt), metadacite (a grayish-white, fine-grained metamorphosed volcanic rock), and graywacke (a layered gray rock made up of sand and mud eroded from volcanic sources) were the main materials in the upper parts of the Archean volcanic islands. Lower parts, revealed by deep erosion, contain large amounts of granite and related coarse-grained rocks that crystallized at depth from the molten state. Much of the granite formed when the volcanic islands were squeezed together by tectonic forces about 2,700 m.y. ago to form an Archean continent. The Late Archean rocks, collectively, are called the greenstone-granite terrane. Perhaps you have heard of Ely greenstone.

Rocks of the gneiss terrane are quarried in the Minnesota River Valley for use as building stone and crushed rock aggregate used for road and railroad construction. Rocks of the greenstone-granite terrane have been explored extensively for various metals including gold, copper, zinc, lead, and iron, but the only deposits found so far that have been large enough and rich enough to mine are the now-closed iron mines near Ely and Soudan. The underground Soudan mine is open for public tours.

Proterozoic

Proterozoic rocks form two belts of very different age and geologic history in the eastern part of Minnesota. The older belt (Early Proterozoic) crops out from St. Cloud to the neighborhood of Moose Lake and Carlton (south of Duluth), north to the Mesabi iron range near Eveleth and Hibbing. The predominant rock types in this older belt consist mainly of metamorphosed slate and graywacke with minor amounts of volcanic rocks and iron-formation, as well as a large proportion of later granitic rocks. These rocks and those like them beneath the ground surface are part of a former mountain belt—the Penokean orogen—that extended from Lake Huron to South Dakota, and perhaps farther, about 2,000 to 1,800 m.y. ago. The eroded remnants of this belt have geologic similarities to modern mountain belts along the west coast of North America, and geologists infer that mountains comparable to those in western California existed long ago in Minnesota.

In southwestern Minnesota, the Early Proterozoic Sioux Quartzite accumulated as sand deposited by braided streams that flowed within several fault-bounded basins, on an erosional surface developed on older Archean rocks. Later metamorphism has recrystallized the sandstone into the hard quartzite seen today in the bluffs at Blue Mounds State Park. Thin beds of reddish-brown mudstone (catlinite) in the quartzite are still being quarried - and carved - at Pipestone National Monument.

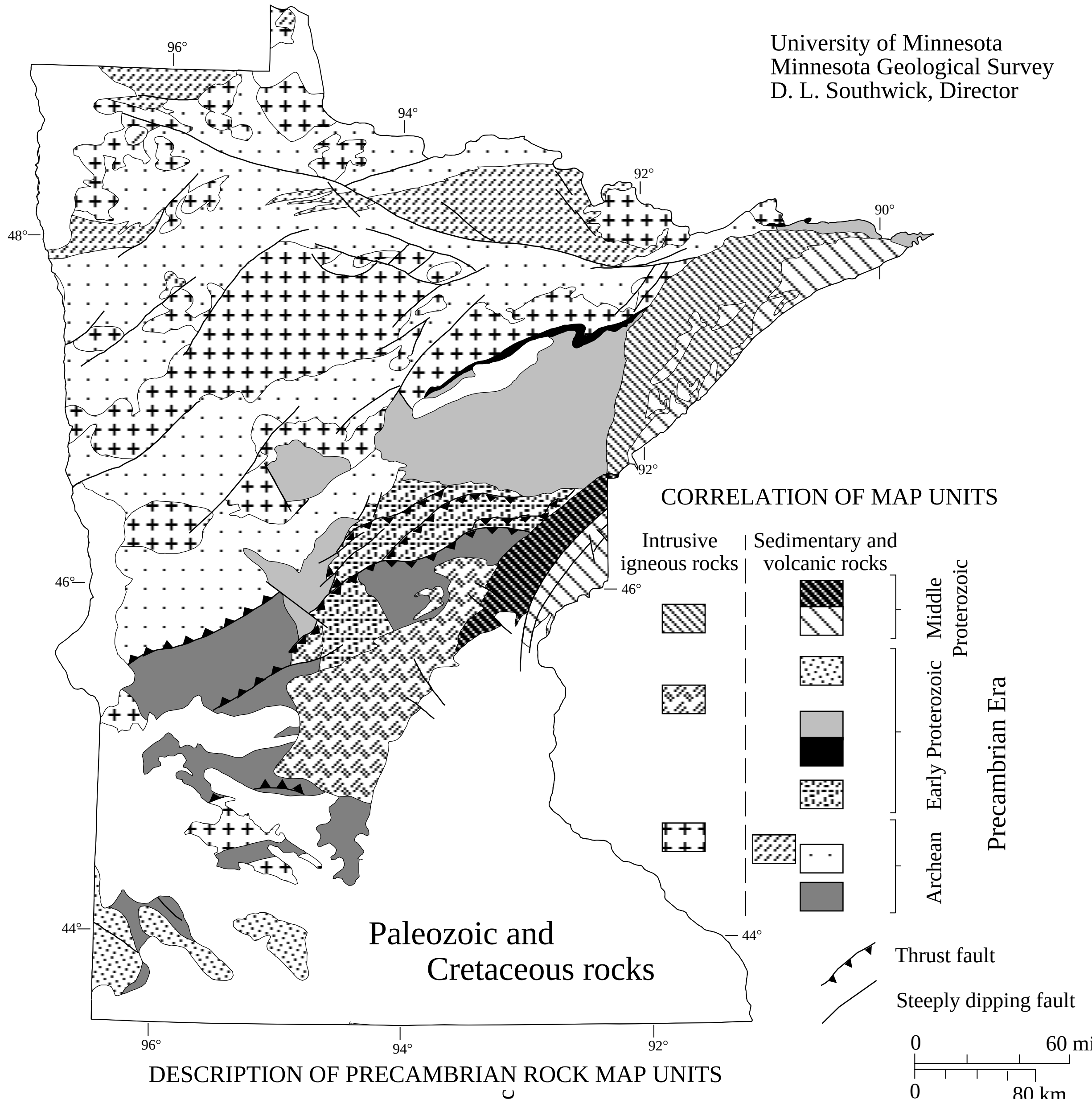
The younger belt (Middle Proterozoic) runs along the North Shore of Lake Superior and continues south along the Minnesota-Wisconsin border all the way to Kansas, beneath younger rocks. This younger belt of rocks consists mainly of gabbro and anorthosite, as well as volcanic rocks such as basalt and rhyolite. These rocks formed around 1,100 m.y. ago along the Midcontinent rift system, a major feature that formed by the spreading apart of older continental crust. Fractures in the thinned crust allowed magmas to work their way to the surface, where they erupted as volcanoes. The lava flows produced by these volcanoes are exposed along Lake Superior, and their well-preserved flow features are the same as those in modern-day volcanic rocks in Hawaii. The Lake Superior agate, for which Minnesota is famous, formed when vesicles (frozen gas bubbles) in these basalts were filled in by thin bands of red and white quartz. The base of the volcanic pile was intruded by coarse-grained gabbro, anorthosite, and granite, some of which may have supplied magmas that were feeding lava flows higher up in the sequence. When volcanism ceased, blankets of sand—now sandstone—were deposited in a basin on top of the volcanic rocks.

The iron mines on the Mesabi range, near Hibbing and Virginia, are developed in Early Proterozoic rocks. The Mesabi Iron Range is one of the largest mining districts in the world, and in 1992 accounted for 74 percent of the total iron ore production in the United States. Several quarries developed in Early Proterozoic granite are in operation near St. Cloud. These quarries provide building stone used not only in Minnesota but around the world, as well as crushed rock aggregate used for railroad and highway construction. The Sioux Quartzite also is quarried for aggregate.

Rocks similar to the Middle Proterozoic North Shore volcanic rocks are mined extensively for copper in Michigan. In Minnesota, a large reserve of copper, nickel, and associated platinum and gold exists at the base of the Duluth Complex, along the northwest edge of the Middle Proterozoic system. The sandstones that overlie the volcanic rocks have been quarried in the past for building and paving stone.

GENERALIZED GEOLOGIC MAP OF MINNESOTA

University of Minnesota
Minnesota Geological Survey
D. L. Southwick, Director



DESCRIPTION OF PRECAMBRIAN ROCK MAP UNITS

Middle Proterozoic

- Sandstone.
- Volcanic rocks, dominantly basalt.
- Intrusive rocks, dominantly gabbro and anorthosite.

Early Proterozoic

- Sioux Quartzite.
- Intrusive rocks of dominantly granitic composition.
- Graywacke, siltstone, shale.
- Iron-formation with a basal quartz arenite.
- Metamorphosed sedimentary rocks, minor volcanic rocks, and iron-formation.

Late Archean

- Intrusive rocks of generally granitic composition.
- Schist (metamorphosed graywacke).
- Greenstone belts, volcanic rocks and associated graywacke.

Early to Middle Archean

- Granitic gneiss, amphibolite and other high-grade metamorphic rocks.

Figure 2. This simplified schematic geologic map shows the general distribution of Precambrian rock types underlying Minnesota. The colorless areas are places where Precambrian rocks are covered by Phanerozoic sedimentary rocks. The map incorporates new geologic ideas developed by scientists during the past decade. Modified from Morey, 1993.

A Primer on Geology

The three basic rock groups are igneous, sedimentary, and metamorphic. Igneous rocks, which include volcanic and plutonic rocks, have formed from the cooling of molten rock, or magma, that has risen up from the earth's mantle. Plutonic rocks such as gabbro and granite form when magma ponds in chambers deep in the earth's crust and cools very slowly, allowing time for large crystals to form. Volcanoes form when magma from these deep chambers finds its way to the surface along fractures in the earth's crust. Volcanic rocks are fine-grained because they cool very quickly.

Sedimentary rocks form from eroded material such as sand and mud. Graywacke is a sedimentary rock especially abundant in Minnesota that is made up of sand and mud eroded from volcanic sources.

Metamorphic rocks such as slate, schist, and gneiss form when a rock is recrystallized as a result of high temperature and pressure conditions found deep in the earth's crust. The protolith, or composition of a metamorphic rock prior to recrystallization, can often be determined by the types of metamorphic minerals present.

Metamorphism typically accompanies rock deformation (folding and faulting). Rock deformation is mainly the result of a process known as plate tectonics. The hard crust of the earth (the "plate") is actually quite thin relative to the earth as a whole, and the earth has several of these plates that slowly drift and move relative to one another. As these plates collide, they produce some of the geologic events that we see today, such as the faults and associated earthquakes in California and the chains of volcanoes along the west coast of South America, U.S., and Canada. Although the details of plate tectonics during Precambrian time may have differed slightly from those at present, the overall processes are believed to be similar. Through careful rock analysis geologists are able to figure out the folding and faulting history preserved in the Precambrian rocks. You can see several faults on the geologic map of Minnesota; however these are ancient faults that are no longer active.

Suggested Readings

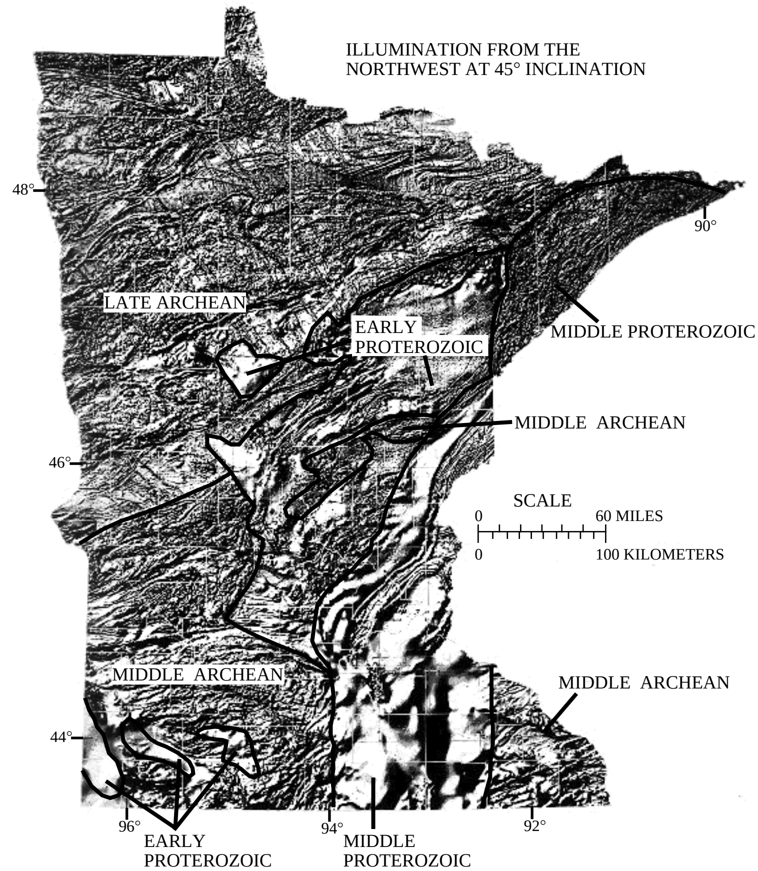
Ojakangas, R.W., and Matsch, C.L., 1982, Minnesota's geology: Minneapolis, University of Minnesota Press, 255 p.

Morey, G.B., 1983, Geologic map of Minnesota: Bedrock geology: Minnesota Geological Survey State Map S-19, scale 1:3,000,000.

Minnesota at a Glance is produced by the
Minnesota Geological Survey
University of Minnesota
2642 University Avenue
St. Paul, MN 55114

T. Boerboom, 1994

Aeromagnetic Image of Minnesota



Shaded-relief aeromagnetic image of Minnesota. This artificial computer-generated image, created from data collected in an airborne magnetic survey, shows the variable magnetic character of the rocks beneath the state. This map has no relation to ground topography. The peaks (white areas) correspond to areas where the bedrock is more magnetic and the valleys to areas less magnetic.

Data such as these help geologists to interpret the nature of the Precambrian basement, as the cover of younger sedimentary rocks and glacial drift is not thick enough or magnetic enough to mask the aeromagnetic signature of the Precambrian rocks. This can be seen in the southeast where the aeromagnetic signature of the Precambrian basement shows through Paleozoic sedimentary rocks.

The major Precambrian terranes of Minnesota are shown, separated by heavy black lines. Compare this image to the bedrock geologic map of Minnesota. Not shown on the geologic map but shown clearly on this map are the multitude of northwest-trending dikes (narrow, vertical bodies of fine-grained gabbro), in the northwest one-third of the state. These dikes less than 300 feet thick, but show up well because they are strongly magnetic. Although they crop out only locally, they can be traced for miles through the use of geophysical maps such as this.