University of Minnesota
Minnesota Geological Survey

Minnesota at a Glance

Common Minnesota Rocks

Rocks are made up of minerals. A mineral has a distinct chemical formula and crystal structure. When minerals form in open spaces, their crystal form is apparent (Fig. 1A). However, most minerals occur in an interlocking network with other minerals to form different kinds of rocks (Fig. 1B).

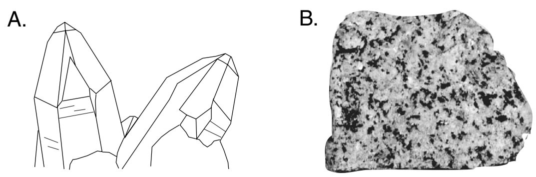

Figure 1. A. Individual crystals with well-developed crystal form. B. Rock made up of many mineral crystals combined.

There are three basic kinds of rocks—igneous, metamorphic and sedimentary. Varieties of all three can be found in Minnesota.

Igneous rocks form from molten liquid called magma. Magma that erupts at the surface is called lava. Lava cools quickly and the resulting rocks are fine-grained basalt or rhyolite depending on their mineral composition (Fig. 2). Basalt contains mostly dark minerals that are compounds of iron (Fe), magnesium (Mg), and silicon (Si). These dark minerals are called Fe-Mg silicates. Rhyolite is a light-colored volcanic rock composed mostly of light-colored silicate minerals that contain potassium (K), sodium (Na), calcium (Ca), and aluminum (Al) along with silicon.

Magma that stays beneath the earth's surface cools more slowly forming coarse-grained intrusive igneous rocks such as gabbro and granite (Fig. 2). Gabbro contains visible crystals of the minerals plagioclase (gray), plus pyroxene and hornblende, both Fe-Mg silicates that are nearly black. The intrusive equivalent of rhyolite is granite, which contains feldspar, quartz, and mica.

Metamorphic rocks form when pre-existing rocks are changed by intense heat and pressure at depth in the Earth's crust. Collision of continents or deep burial provide some of the conditions necessary to partially melt and alter rocks. The minerals in some metamorphic rocks are new, having formed by reactions among the original mineral grains. Minerals in other metamorphic rocks are similar to the minerals present in the original rock, but they have been reorganized. Gneiss, pronounced "nice," is a metamorphic rock in which the elongate or platy mineral grains are reoriented into layers by extreme heat and pressure. Gneiss is derived from granite. Schist and phyllite are other examples of metamorphic rocks that show preferential orientation of grains. Marble, quartzite, and slate are metamorphic rocks derived from sedimentary rocks (limestone, sandstone, and shale, respectively).

Sedimentary rocks form from the accumulated debris of weathered rocks, or by the chemical precipitation of certain elements such as calcium, magnesium, or iron. In clastic sediments—made up of individual particles—the grains, which may be large (coarse) or small (fine), were originally part of

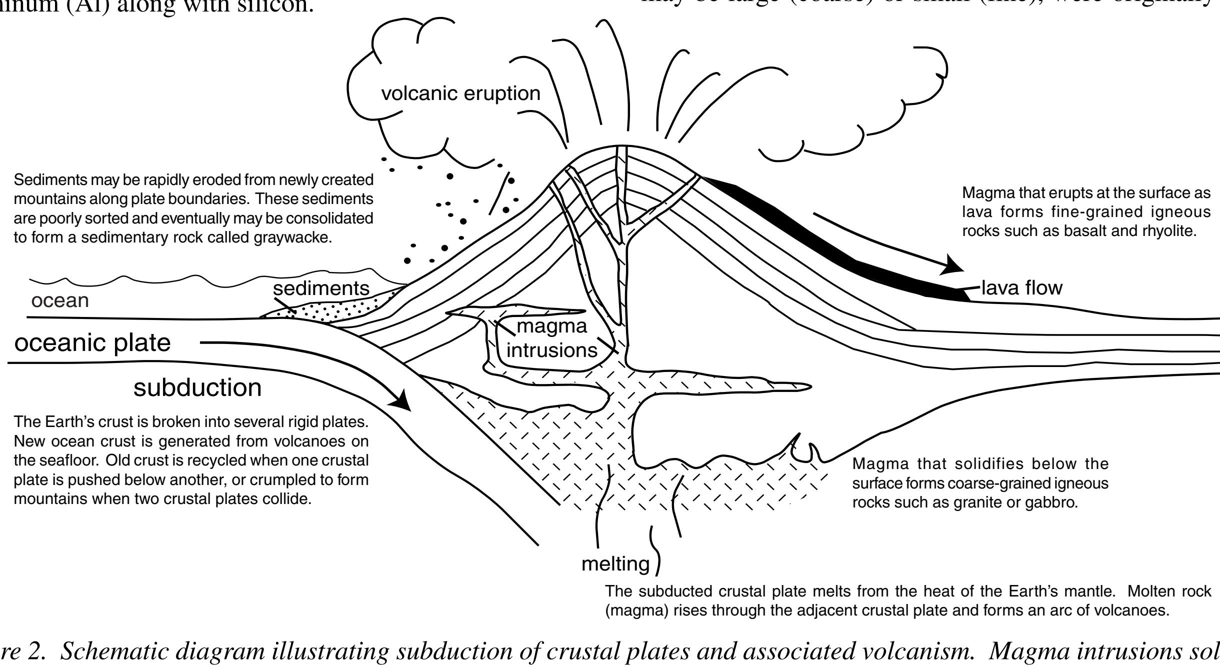

Figure 2. Schematic diagram illustrating subduction of crustal plates and associated volcanism. Magma intrusions solidify to form coarse-grained intrusive igneous rocks (granite or gabbro). Lava flows solidify to form fine-grained extrusive igneous rocks (basalt or rhyolite). Sediments eroded from the highlands eventually form sedimentary rocks such as graywacke.

an older body of rock that was broken down by erosion. The grains were transported by wind and water (sometimes by ice or gravity), deposited, buried, and eventually compacted to form rock.

The size of the grains in a sedimentary rock provides clues about the mechanism by which the grains were transported and deposited. Large grains are heavy and require strong forces such as wind, water, ice, or gravity to move. Finer grained particles may be moved along with the larger grains, but will be blown or washed away by weaker currents after the larger grains have settled. Thus, many sedimentary deposits are said to be sorted—containing grains within a similar size range.

Sandstone, for example, is composed of cemented sand grains. Coarse-grained sandstone typically indicates that the sand was deposited in a high-energy environment, perhaps in a swift-moving stream, or along a wave-washed beach. Shale is composed of finer grained particles of silt and clay that were deposited in the quiet water of maybe a lake or lagoon (Fig. 3).

Chemical sedimentary rocks form when minerals precipitate from water. Limestone is an example of a carbonate sedimentary rock formed where calcium carbonate precipitates from seawater (Fig. 3). "Carbonate" rocks also form when seashells, which contain calcium carbonate, accumulate on the sea floor.

Minnesota Rocks

Throughout geologic time, Minnesota's landscape has undergone many changes. At times, high mountains lined the horizon. Later, vast seas drowned the region. Still later, great sheets of ice covered the land. All of these environments are recorded in the rocks and sediments found around the state.

The following is a summary of the major rock types common in Minnesota. Please note that a specific rock formation (if named) may not be the only example of a particular rock type in the state. See accompanying map insert and geologic time scale to see the distribution and age of rocks throughout Minnesota.

GNEISS

Some of the oldest rocks in the world include the gneiss found in the Minnesota River Valley. The Morton Gneiss, which is 3.6 billion years old, is a coarsely crystalline, foliated metamorphic rock. The texture and mineral assemblage of the Morton Gneiss give clues as to how the rock formed. The fact that it is a crystalline rock with large visible grains indicates that it originated as a granitic igneous rock that cooled slowly beneath the Earth's surface. The foliation, or alignment of the mineral grains, indicates that the original rock was subjected to great heat and pressure deep below the Earth's surface.

Gneiss is quarried for use as building stone and monuments. You can find outcrops of gneiss near Morton (the famous "Rainbow Gneiss"), Redwood Falls, Sacred Heart and Ortonville.

GREENSTONE

Somewhat younger is the greenstone in northern Minnesota. Greenstone is a weakly metamorphosed (altered) basalt that is, as its name suggests, greenish to gray. This type of rock formed about 2.7 billion years ago when the area that is now northern Minnesota was part of a volcanic island arc, much like the islands of Japan are today.

Greenstone and other associated volcanic and related rocks have in the past been prospected for deposits of economic metals such as gold, copper, zinc, lead, and iron. Iron mines at Ely and Soudan are now closed. As yet, no other significant metal deposits have been found.

IRON-FORMATION and TACONITE

Thin layers of iron-formation occur within the approximately 2.7 billion year old greenstone lava of northern Minnesota. The term is a contraction of "iron-bearing formation," which is precisely what it is—a rock having in places as much as 30 percent iron. Iron-formation formed as iron-rich particles precipitated and settled to the sea floor during quiet periods in volcanic activity. The iron-formation we see today consists of thinly layered red, white, and black minerals. The red layers are jasper; the white—chert (mostly quartz); and the black are iron-bearing minerals—mostly magnetite (magnetic) and hematite (nonmagnetic). An example of this type of rock can be seen at the Soudan Mine State Park. A similar, but much younger formation (only 1.9 billion years old) occurs along the Mesabi Iron Range that extends from Grand Rapids to Babbitt. This iron-formation formed by the same process, but its deposition also involved interplay among sea water, surface rain water, volcanic activity, and some of the world's oldest life forms (cyanobacteria). When upgraded in iron content by industrial processing, rocks of the Mesabi range yield an important ore called taconite.

GRAYWACKE

Graywacke is a poorly sorted sedimentary rock derived from sediments that were transported a relatively short distance before being deposited (Fig. 2). Short transport and quick burial does not allow for the finer material to get removed. Thus, graywacke is a "dirty" coarse-grained rock in which the large grains are surrounded by a matrix of finer grained sediment.

Graywacke is found associated with greenstone in northern Minnesota, with the younger iron-formation of the Mesabi range, and southwest of Duluth near Cloquet and Thomson.

GRANITE

Granite is found throughout northern and central Minnesota. It varies in age from 2.6 billion years in the Minnesota River Valley and northern Minnesota to about 1.7 billion years near St. Cloud. Minnesota granites are composed predominantly of the minerals feldspar, quartz, mica, and hornblende. These rocks formed deep below the surface in the

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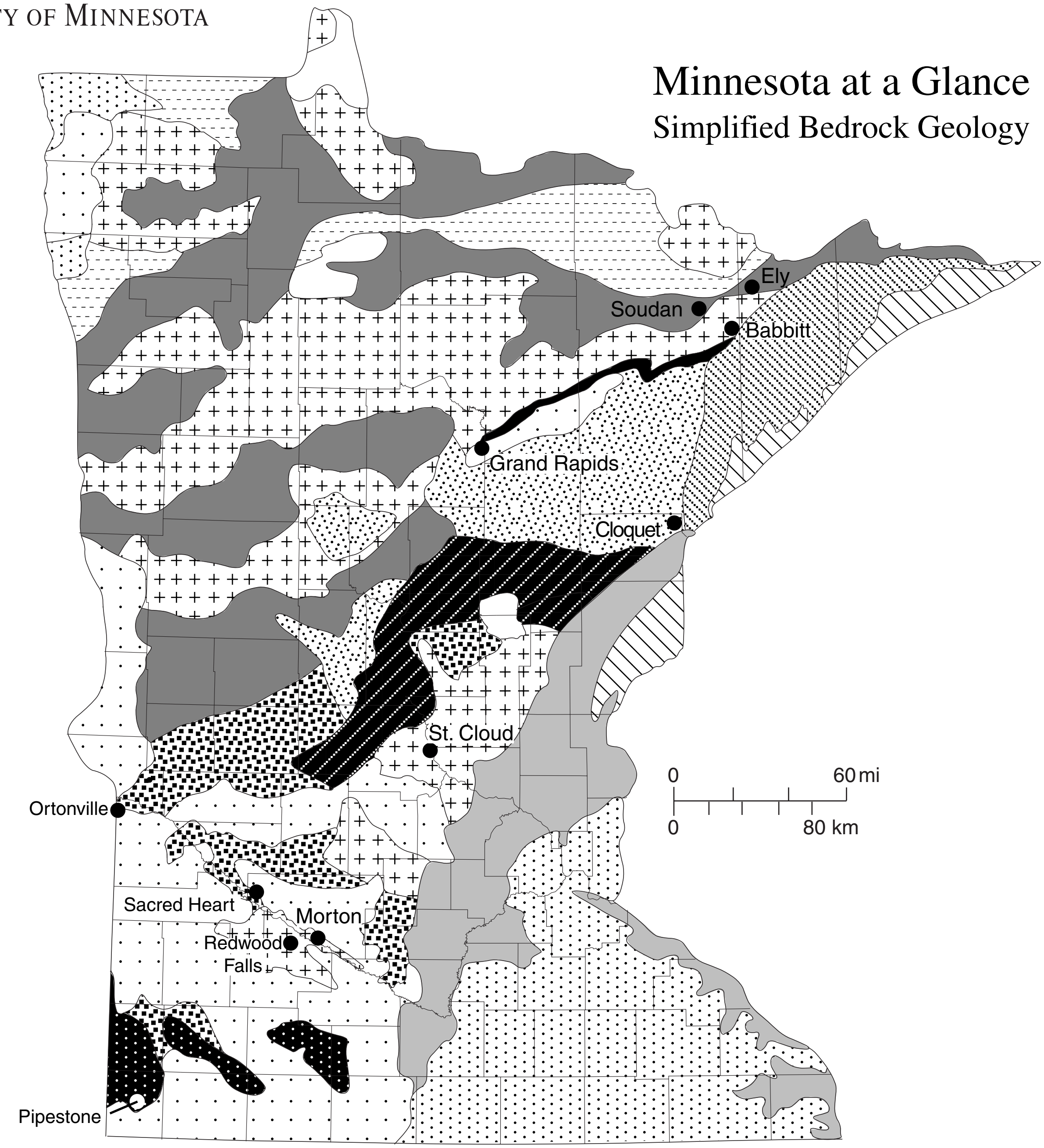
Minnesota at a Glance

Simplified Bedrock Geology



DESCRIPTION OF MAP UNITS

Igneous Rocks

- Volcanic rocks, mostly basalt.
- Intrusive rocks, mostly gabbro and anorthosite.
- Greenstone (also graywacke and slate).
- Granite.

Sedimentary Rocks

- Mudstone, siltstone, and sandstone.
- Limestone and dolostone (some sandstone and shale).
- Sandstone and shale (some limestone and dolostone).
- Graywacke.
- Iron-formation.

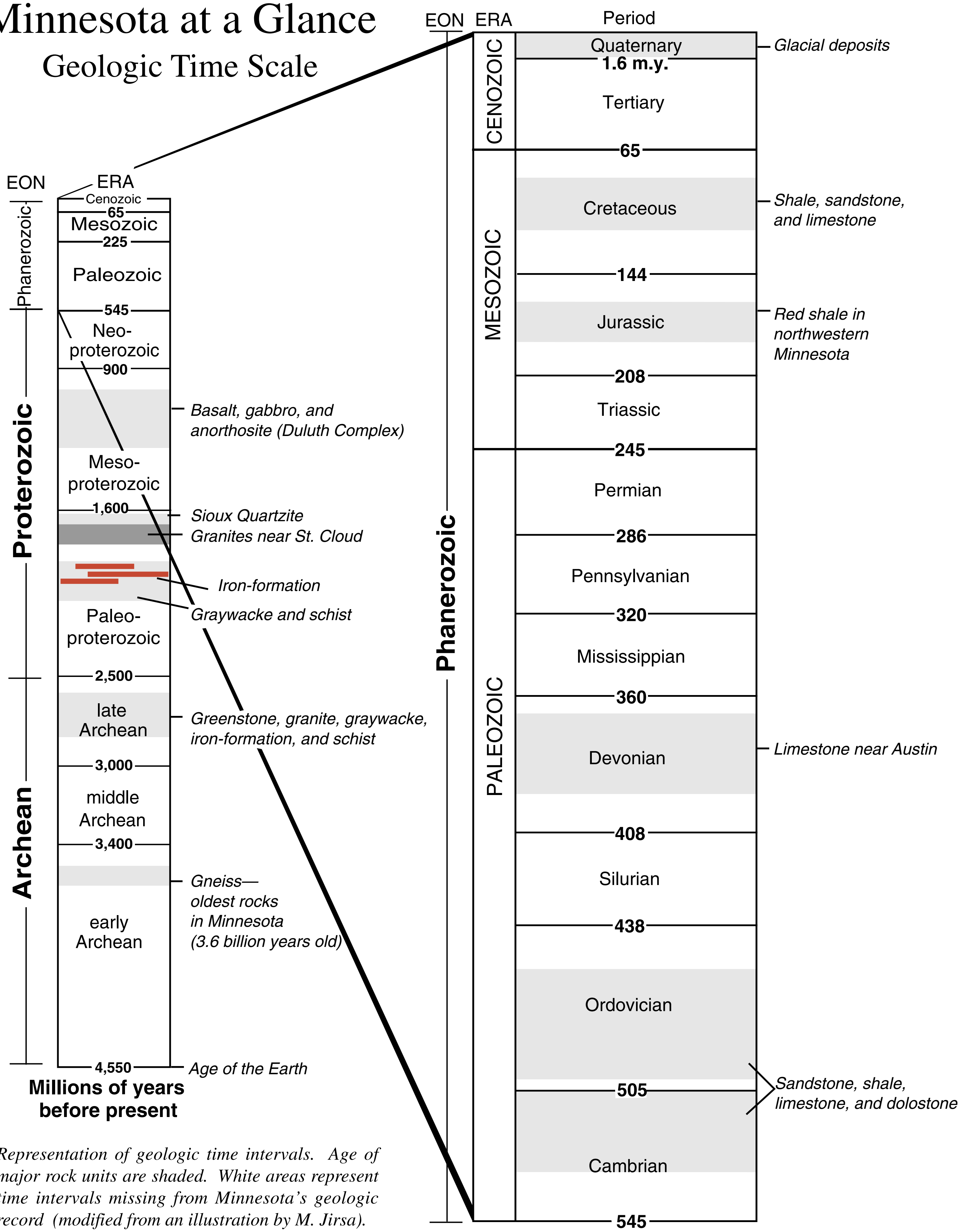
Metamorphic Rocks

- Gneiss and other metamorphic rocks.
- Schist and iron-formation.
- Schist.
- Quartzite.

Simplified from 1996 postcard that was modified from Morey, G.B., compiler, 1996, Geologic map of Minnesota, Bedrock geology: MGS State Map Series S-20.

Minnesota at a Glance

Geologic Time Scale



Representation of geologic time intervals. Age of major rock units are shaded. White areas represent time intervals missing from Minnesota's geologic record (modified from an illustration by M. Jirsa).

roots of major mountain ranges. These once deeply buried rocks are now exposed at or near the surface due to uplift and erosion. Granite is quarried for use as building stone and monuments. You can find outcrops of granite in Stearns, Pine, and Mille Lacs counties, and also in places in northeastern Minnesota, including the Boundary Waters Canoe Area.

MICA SCHIST

Just as today, the erosion of ancient rocks produced sediment. These sediments, fine-grained sand and mud, were later deformed by the same forces that caused the uplift of mountains in northern Minnesota. The resulting high temperatures and pressures formed metamorphic rocks called schist. Schist is composed predominantly of mica minerals, which impart a platy or layered texture to the rock. Schist is common in central Minnesota and across northern Minnesota.

QUARTZITE

Not long after mountains were uplifted across central Minnesota, sand began to accumulate in braided streams in southwestern Minnesota. These stream deposits of reddish quartz sand grains were eventually consolidated and slightly altered into a very hard rock called quartzite.

The reddish to purple Sioux Quartzite is at the surface near Blue Mound State Park and the Jeffers Petroglyphs in southwestern Minnesota. At the Pipestone National Monument, the soft, red pipestone (catlinite) the Indians favored for carving is a thin claystone layer that is sandwiched between thick layers of quartzite.

BASALT

About 1.1 billion years ago, the continent that had been building for billions of years began to split apart across what is now Minnesota. The "Midcontinent rift," as it is called, is where the crust began to separate to form a new ocean basin. The same process is currently underway between Africa and Saudi Arabia. The rifting process stopped short of producing a new ocean basin in central North America, but the abundant dark red-brown basaltic rocks now exposed along Lake Superior's north shore are a testament to the massive outpouring of lava through fractures or cracks along the rift. Gooseberry Falls State Park is an ideal place to explore these ancient lava flows.

GABBRO

Gabbro is an intrusive rock formed when molten rock is trapped beneath the land surface and cools into a hard, coarsely crystalline mass. It is the intrusive equivalent to basalt. Minnesota's best examples of gabbro are in the part of the 1.1 billion year old Midcontinent rift exposed in the large hills at Duluth, known as the Duluth Complex.

The rock is dense, dark-colored and contains varied percentages of the minerals plagioclase, pyroxene, and olivine. The Duluth Complex contains extensive, but relatively low-grade deposits of copper, nickel, and platinum group elements. None are currently being mined.

AGATE

Minnesota's state rock is the Lake Superior agate—so named because it is found predominantly along the coast of Lake Superior. Agates form in cavities in basalt. As mineral-rich water circulates through the cavities, silica (SiO_2), or quartz, is deposited in layers along cavity walls. Eventually, the cavities completely fill with this banded variety of quartz. The color variations are due to slight mineral impurities in the water. Iron, for example, causes much of the red and orange color seen in Lake Superior agates.

Although agates originated in the basaltic rocks along the North Shore, some of the best places to hunt for agates are in

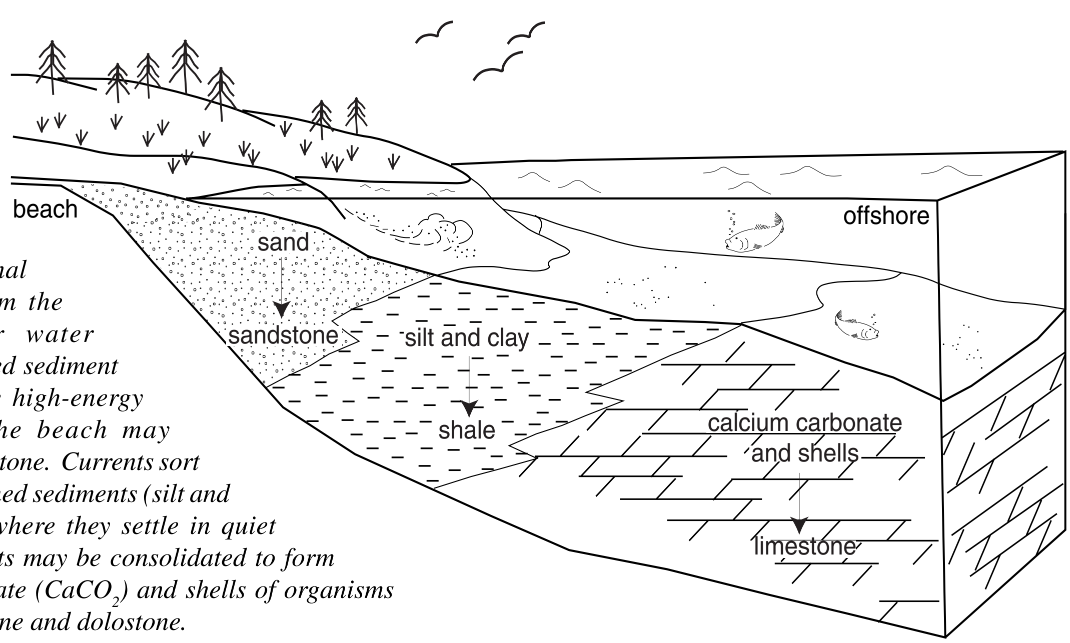


Figure 3. Cross-sectional view of the ocean from the shoreline to quieter water offshore. Coarse-grained sediment (sand) deposited in the high-energy environment along the beach may eventually become sandstone. Currents sort and transport finer grained sediments (silt and clay) farther offshore where they settle in quiet water. These sediments may be consolidated to form shale. Calcium carbonate ($CaCO_2$) and shells of organisms combine to form limestone and dolostone.

gravel pits scattered across the state. Specifically, agates are likely to be found where operators are mining glacial sand and gravel deposits associated with glaciers that advanced into Minnesota from the northeast, bringing agate-bearing gravel into the central and southern parts of the state.

ANORTHOSITE

Similar in composition to rocks on the moon, anorthosite is a coarse-grained intrusive igneous rock composed almost entirely of a single mineral—plagioclase feldspar.

In Minnesota, anorthosite was intruded into the lowermost lava flows that formed during the opening of the Midcontinent rift. Anorthosite is part of the Duluth Complex and the closely related Beaver Bay Complex exposed along the North Shore of Lake Superior. Split Rock Lighthouse sits atop an outcrop of anorthosite.

SANDSTONE

A major time period when sandstone along with other sedimentary rocks in Minnesota were deposited was during the early Paleozoic era (about 500 million years ago). At that time, Minnesota was near the equator, and shallow seas covered most of the state (Fig. 3). Sediment eroded from upland areas was transported to the seashore, and the coarser sediment eventually formed the sandstones seen today in southern Minnesota. Some of these sandstones are so poorly cemented that the grains can be rubbed off with your finger. As the sandstone is eroded, piles of clean quartz sand are formed.

SHALE and MUDSTONE

We know from observation along modern coastal zones that fine-grained silt and clay is deposited in quieter water, away from the high-energy shoreline (Fig. 3). The same situation existed along ancient coastlines. These muddy sediments eventually form shale and mudstone. The Paleozoic shale layers in southeastern Minnesota are thin and inconspicuous. The rock is soft, gray to greenish gray, splits into ragged chips, and converts easily back to mud when soaked in water. Shale of Cretaceous age (about 80 million years old) is used to make bricks and tiles near Springfield, Minnesota.

LIMESTONE and DOLOSTONE

Farther offshore away from the beach, finer grained sediment accumulated and chemical sediment precipitated to form limestone and a closely related rock called dolostone (Fig. 3). In this environment, marine life was abundant. Shells and skeletons of various clams, snails, corals, etc., are preserved in the limestone of southern Minnesota. Limestone is typically tan to gray. It may be massive or bedded in layers with sandstone and shale. In places fossils may readily be found (see Minnesota at a Glance: Fossil collecting in the Twin Cities area).

Many quarries in southern Minnesota mine and crush limestone for aggregate. Coarsely crushed limestone and dolostone are used for road ballast and making concrete; finer grained aggregate can be used for landscaping; powdered limestone is used on farm fields.

GLACIAL TILL

Glacial sediments were deposited relatively recently, within the last 2 million years, when ice repeatedly covered the state (see Minnesota at a Glance: Quaternary Glacial Geology). Glaciers passed over all the various rocks described here and ground them up (Fig. 4). Those rocks, now particles of sand, silt, clay, and even boulders, are distributed in a thick blanket that covers most of Minnesota's underlying bedrock. When you pick up a rock almost anywhere in the state, the chances are good that it has been transported from somewhere else by glaciers.

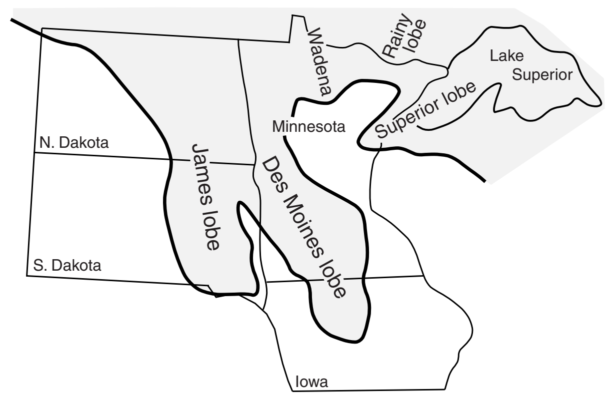


Figure 4. Simplified map showing position of ice lobes (shaded area) about 14,000 years ago (modified from Lusardi B.A., 1994, Minnesota at a Glance: Quaternary Glacial Geology).

Although not technically a rock, the glacial debris that covers much of the state may eventually become consolidated into a rock called diamictite. The process will probably take hundreds of thousands of years, and during that time, the processes of weathering will continue to erode and modify the surface that we see today.

Minnesota at a Glance is produced by the Minnesota Geological Survey—University of Minnesota, 2642 University Avenue, St. Paul, MN 55114; (612) 627-4780; www.geo.umn.edu/mgs

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B.A. Lusardi, 2000