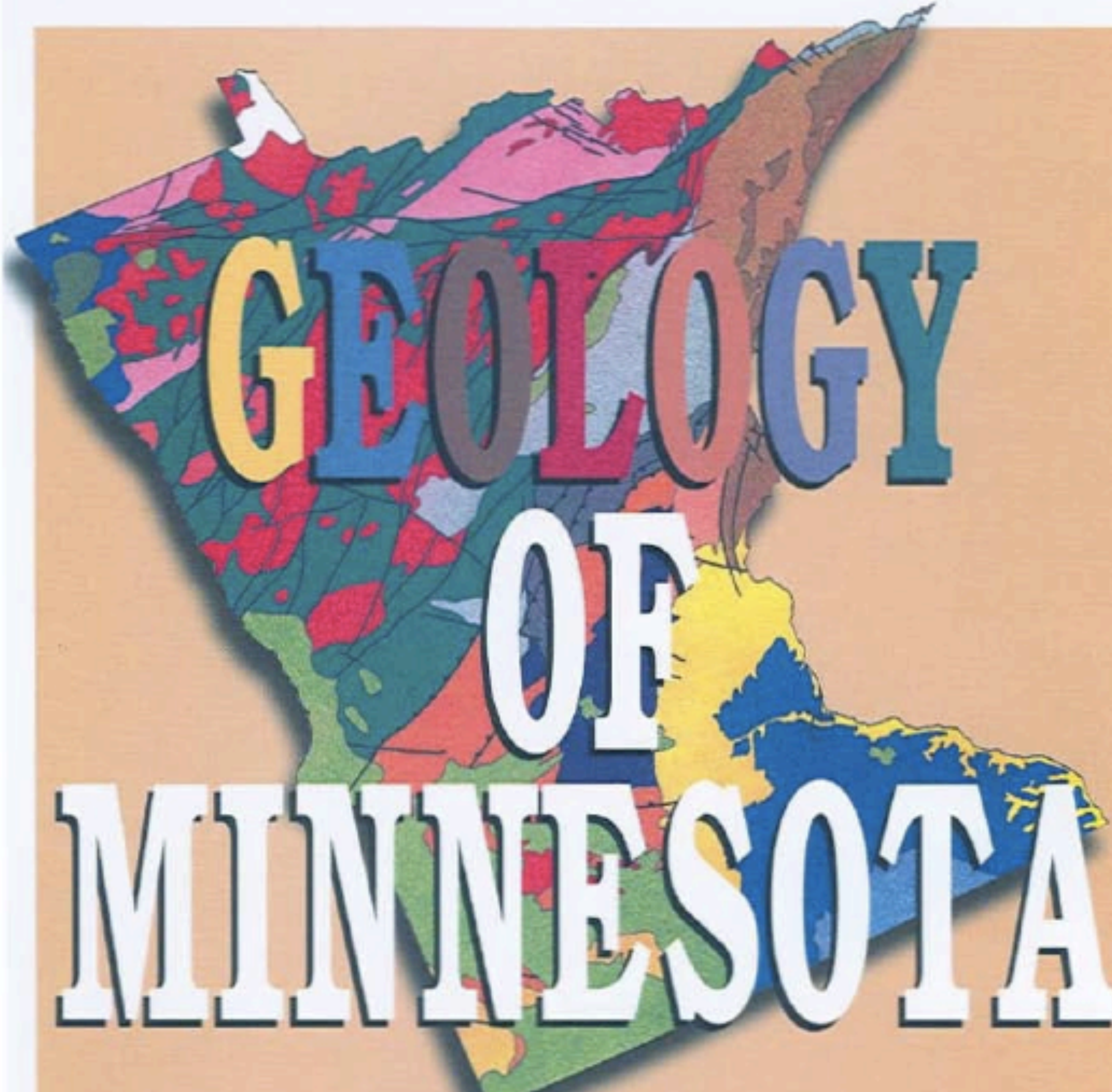
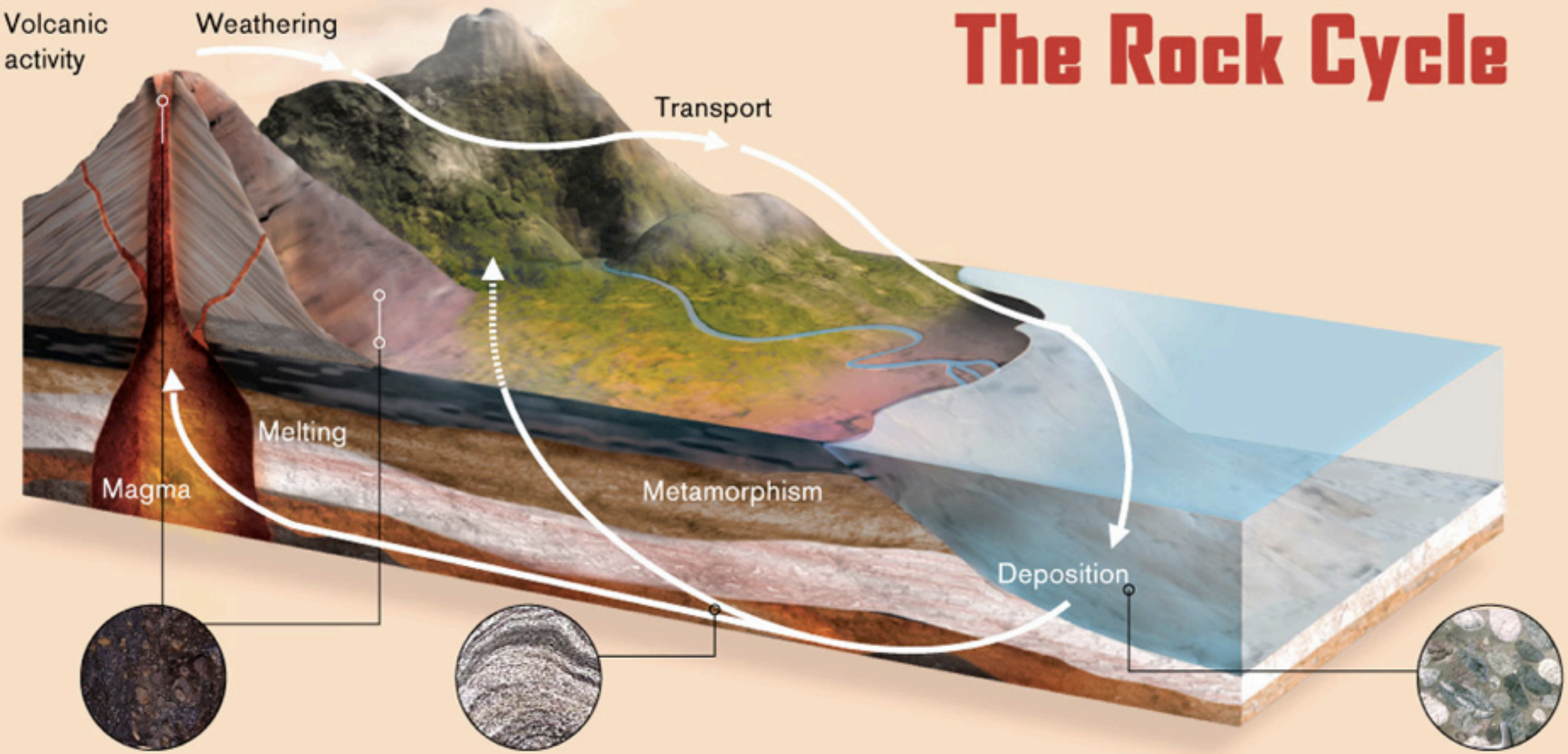
GEOLOGY OF MINNESOTA



??? THREE BASIC ROCK GROUPS ???

The Rock Cycle



Igneous rock

These rocks are formed when magma (molten rock) from the Earth's interior cools and solidifies.

Metamorphic rock

The heat and pressure of the Earth's interior transform igneous and sedimentary rocks into metamorphic rocks.

Sedimentary rock

Atmospheric agents erode and transport igneous rocks to the seabed, where they are compressed and merged with others into sedimentary rocks.

IGNEOUS

INTRUSIVE

COOLS SLOW

LARGE CRYSTALS

GRANITE

MOLTEN MATERIAL
DEEP MAGMA SOURCE
FLUID DYNAMICS

EXTRUSIVE

COOLS FAST

SMALL CRYSTALS

RHYTHM & BLUES

R = RED = RHYOLITE

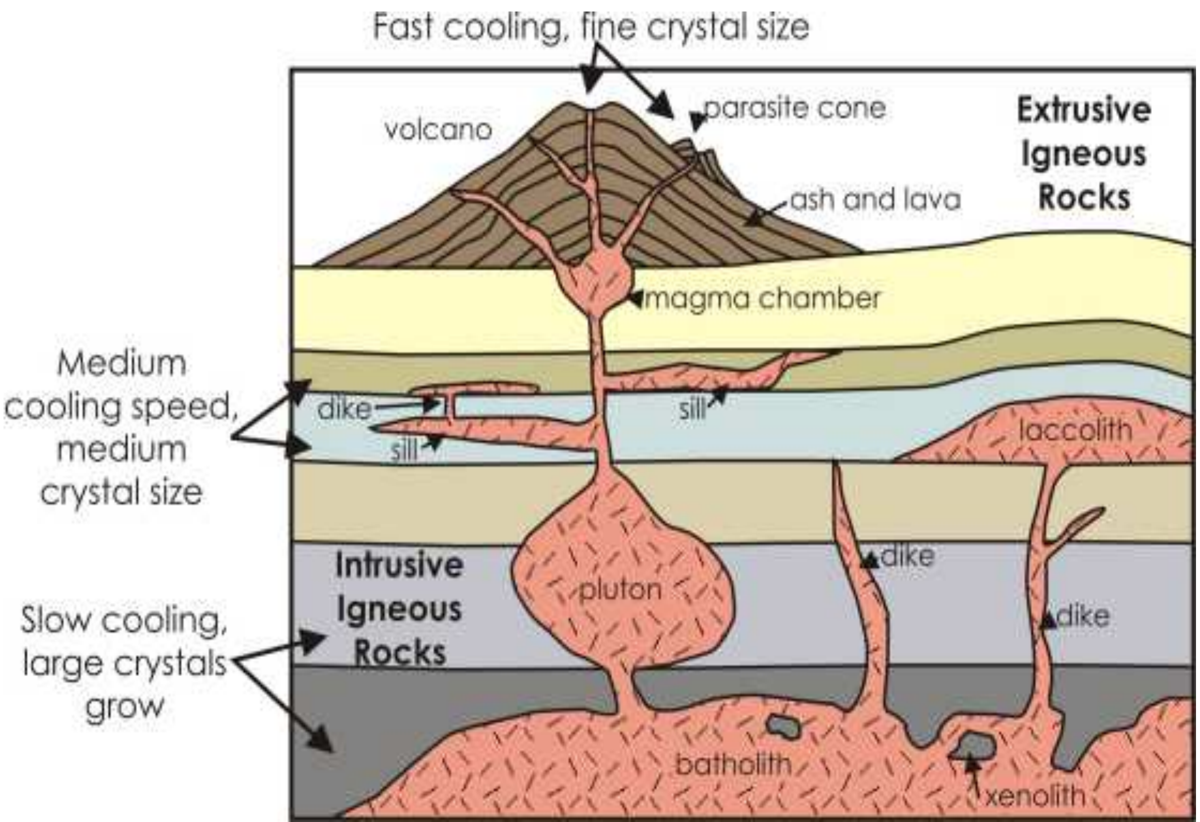
&

B = BLACK = BASALT

&

ANDESITE

(BUFF COLORED)



SECONDARY DEPOSITION

AGATES

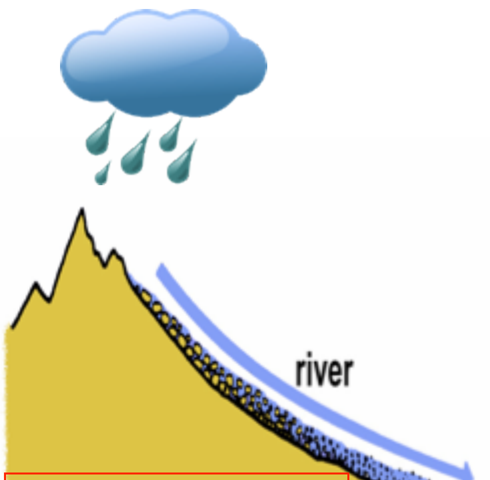


SEDIMENTARY

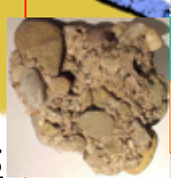
CLASTIC-DETRITAL

PIECES OF ROCK

WEATHERING
-PHYSICAL
-CHEMICAL



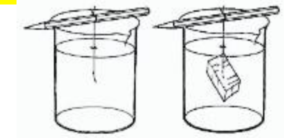
MIXED SIZED MATERIALS → CONGLOMERATES

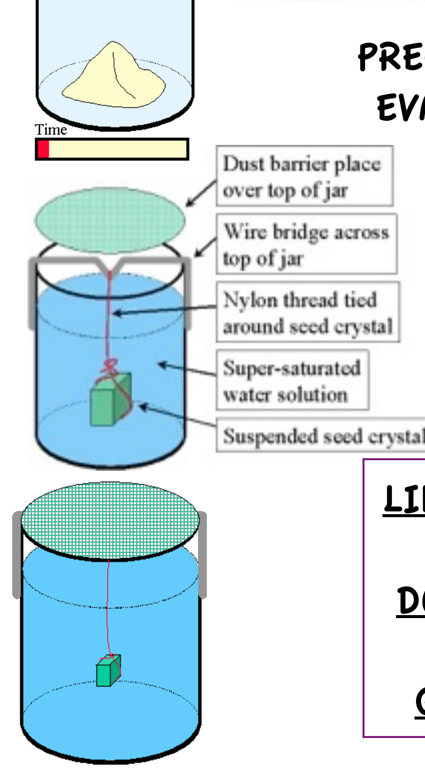


EXISTING ROCKS
REDUCED IN SIZE
TRANSPORTED
SORTED
REDEPOSITED
LAYERS
(STRATIFICATION)

THIRD GROUP NOT IN MN
CARBONATES

PRECIPITATES



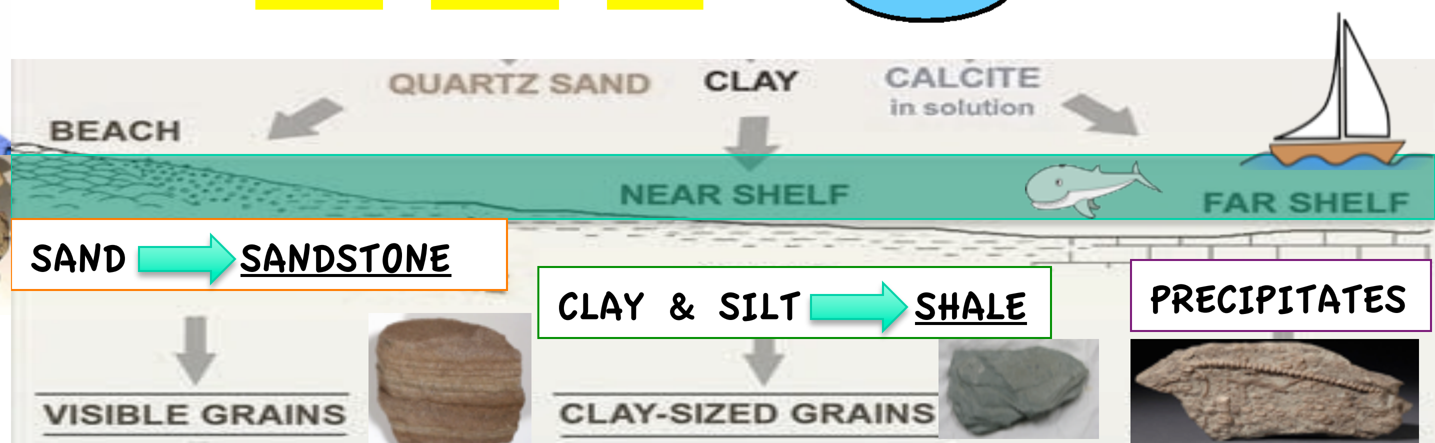


PRECIPITATES
EVAPORITES

LIMESTONE

DOLOMITE

GYPSUM



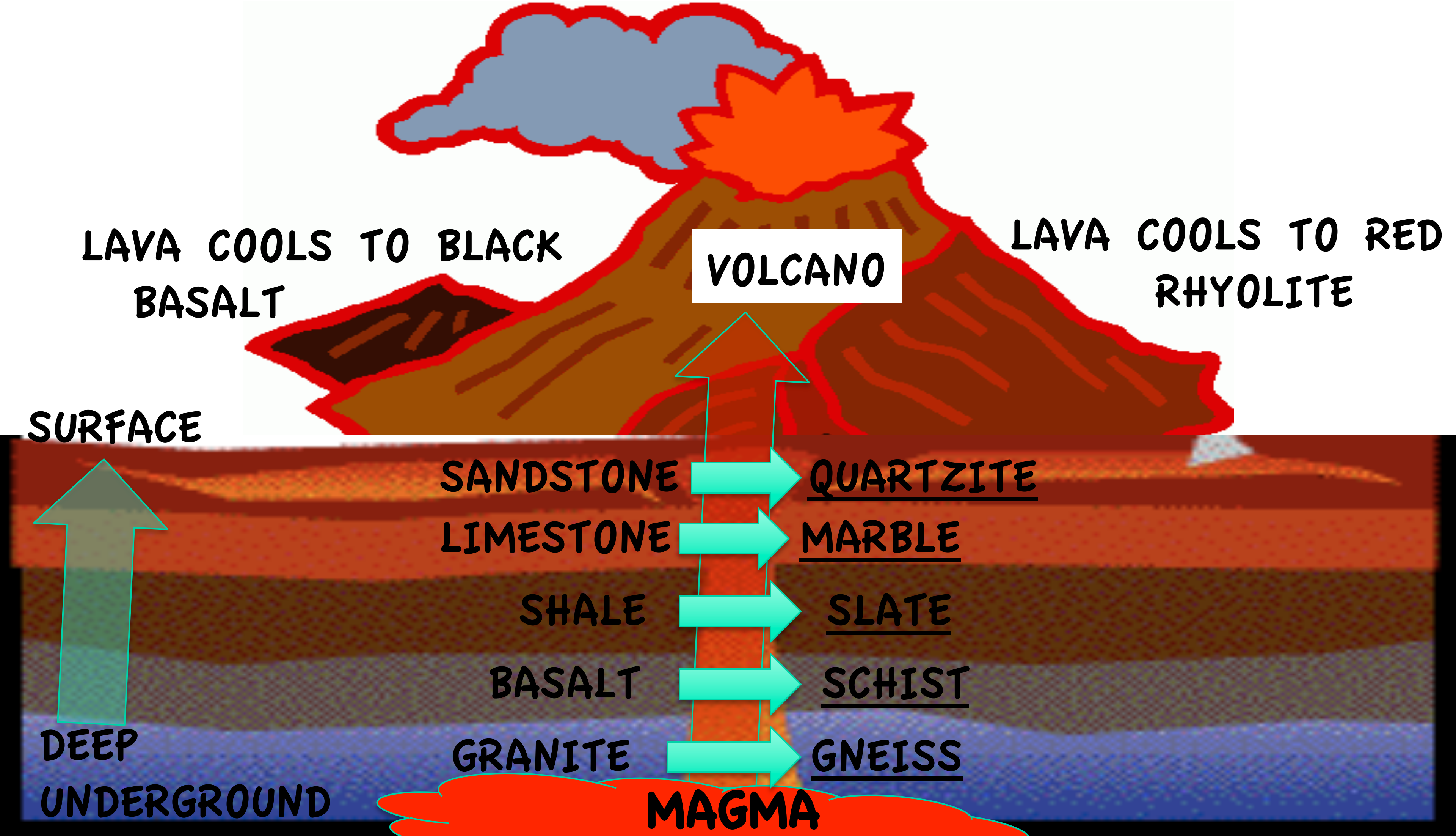
SAND → SANDSTONE

CLAY & SILT → SHALE

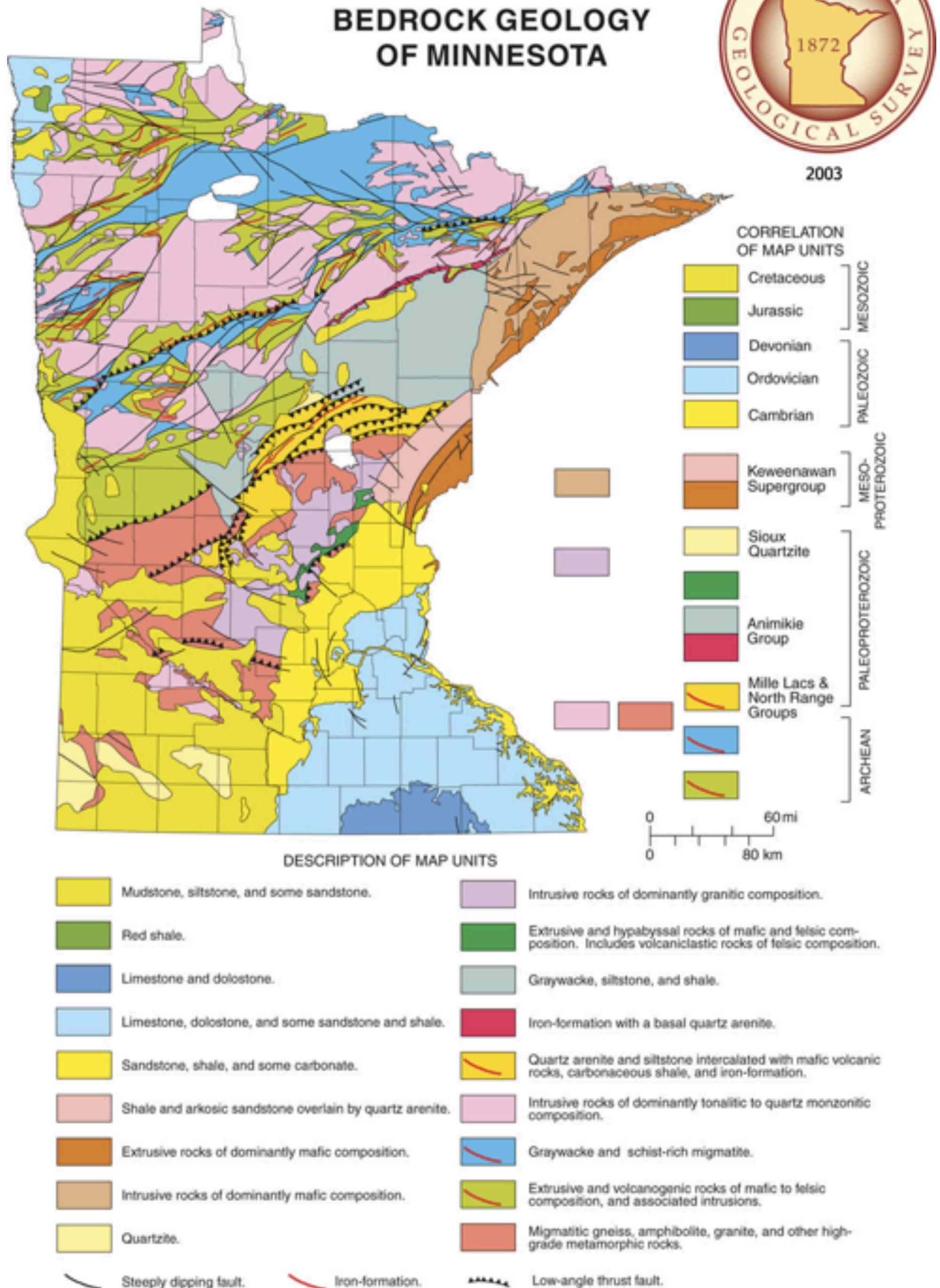
PRECIPITATES

METAMORPHIC

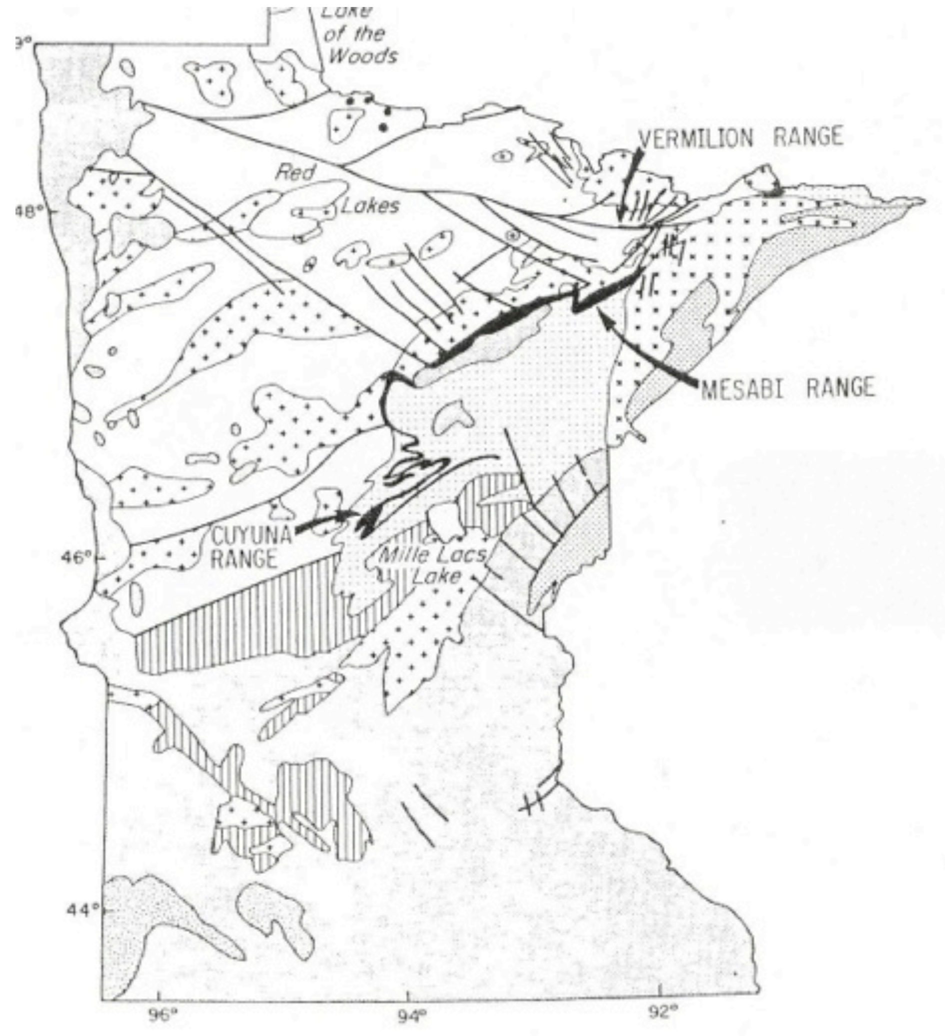
EXISTING ROCKS
ALTERED BY HEAT AND PRESSURE



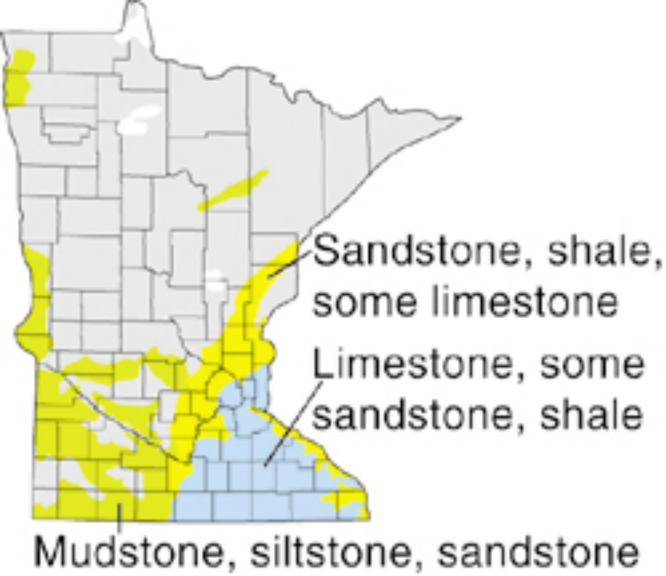
BEDROCK GEOLOGY OF MINNESOTA



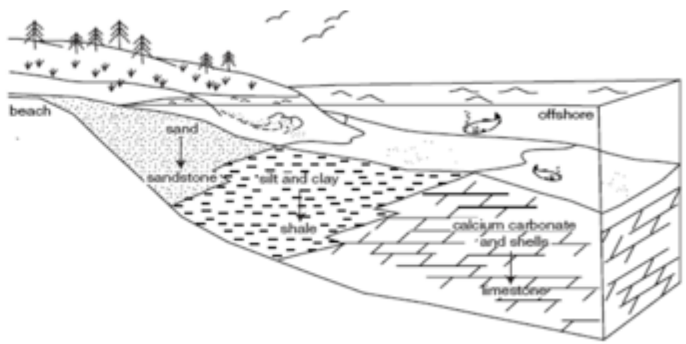
BEDROCK GEOLOGY



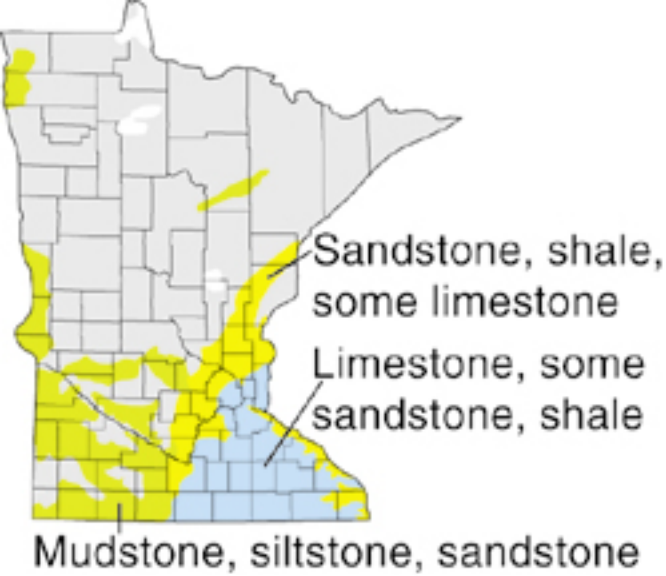
Minnesota DNR – Minnesota Geological Survey - USGS



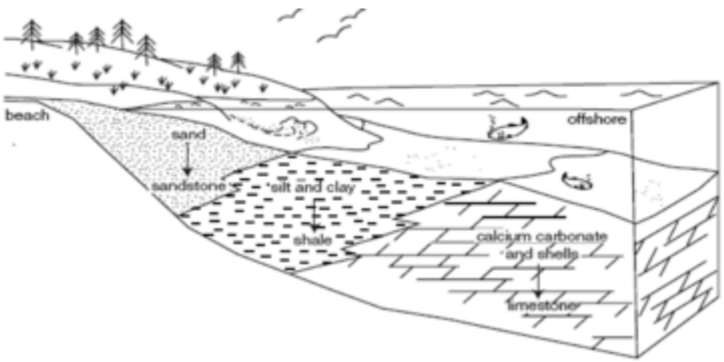
SANDSTONE



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. Sediment eroded from upland areas was transported to the seashore, and the coarser sediment eventually formed the sandstones seen today in southern Minnesota (above). Some of these sandstones are so poorly cemented that the grains can be rubbed off with your finger (below). As the sandstone is eroded, piles of clean quartz sand are formed.



SHALE



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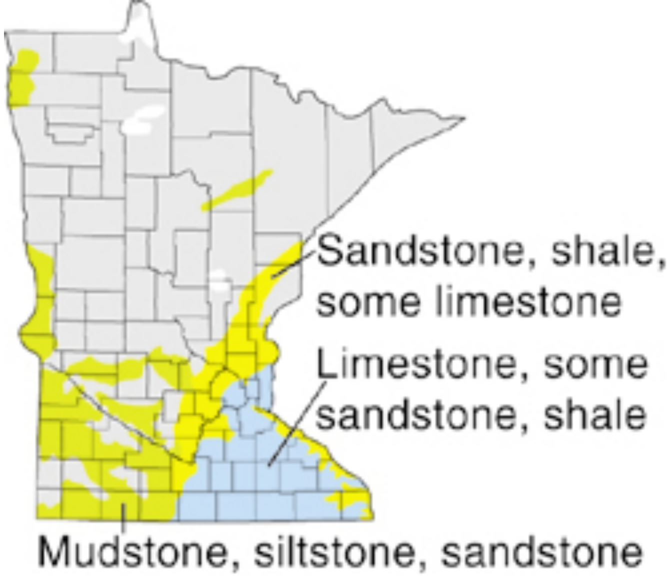
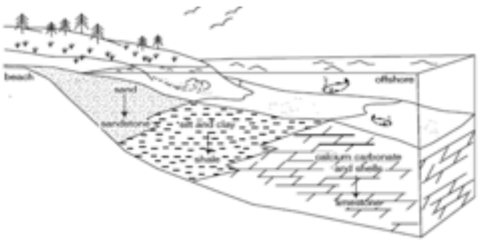
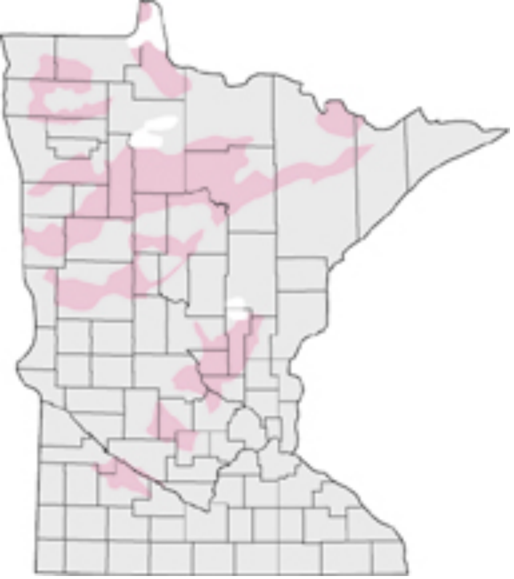


LIMESTONE



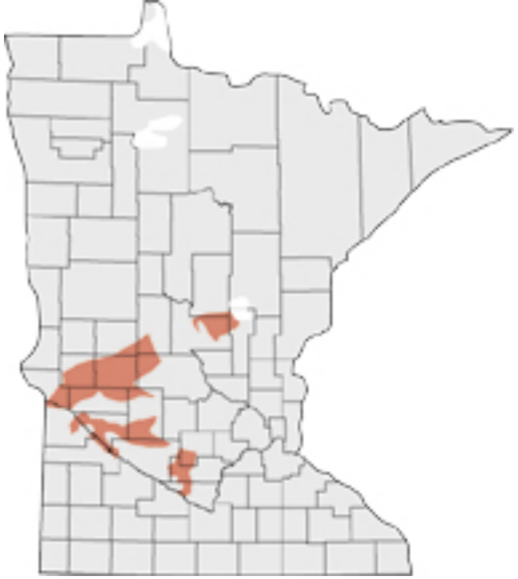
Offshore away from the beach, finer grained sediment accumulated and chemical sediment precipitated to form limestone and a closely related rock called dolostone. In this environment, marine life was abundant. Shells and skeletons of various clams, snails, corals, etc., are preserved in the limestone 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.



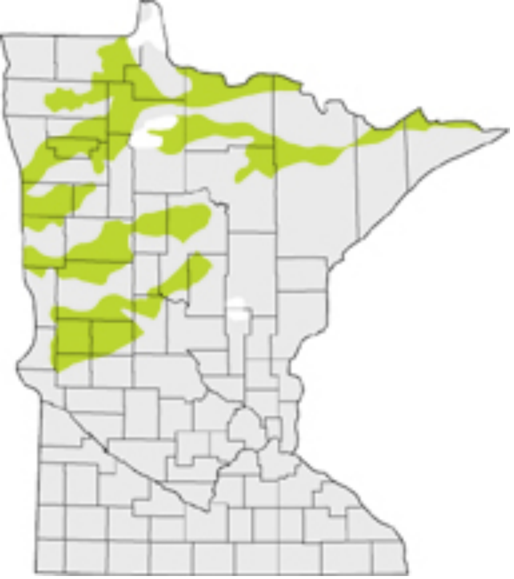
GRANITE

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 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.

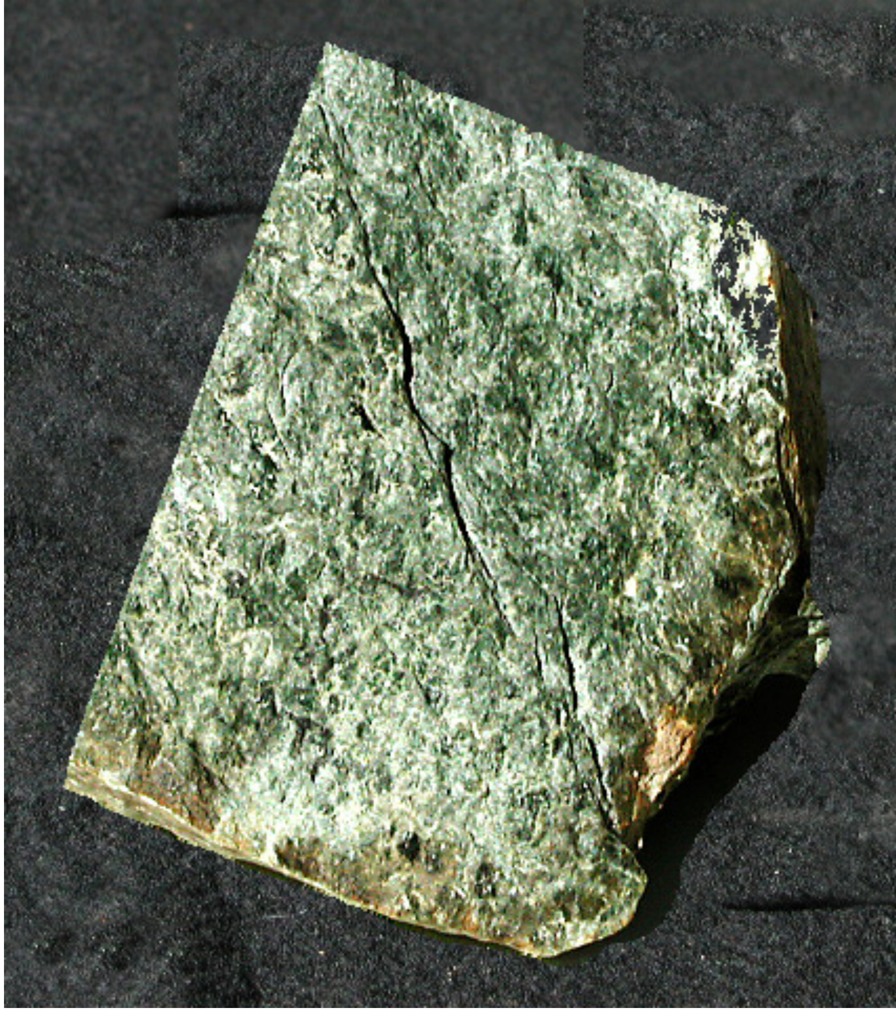


GNEISS

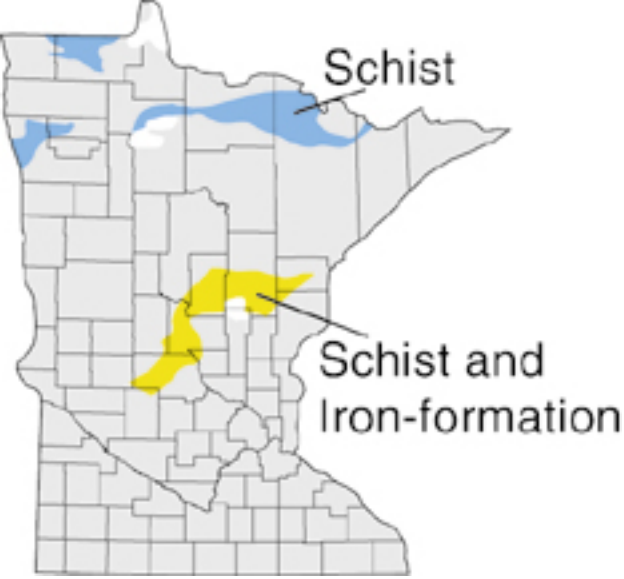
Some of the oldest rocks in the world include the gneiss found in the Minnesota River Valley. The Morton Gneiss, which is 3.6 billion years old, is a coarsely crystalline, foliated metamorphic rock. The texture and mineral assemblage of the Morton Gneiss give clues as to how the rock formed. The fact 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, Redwood Falls, Sacred Heart and Ortonville.



GREENSTONE

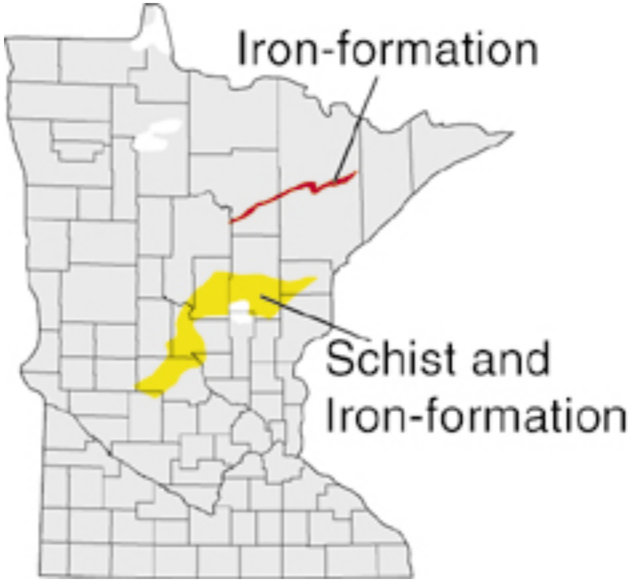


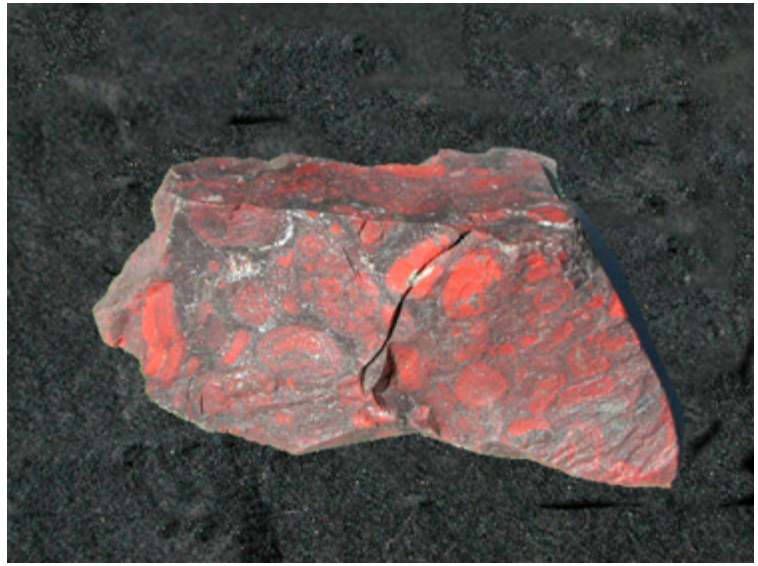
Greenstone in northern Minnesota is somewhat younger than gneiss. Greenstone is a weakly metamorphosed (altered) basalt that is, as its name suggests, greenish to gray. This type of rock formed about 2.7 billion years ago when the area that is now northern Minnesota was part of a volcanic island arc, 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.



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.



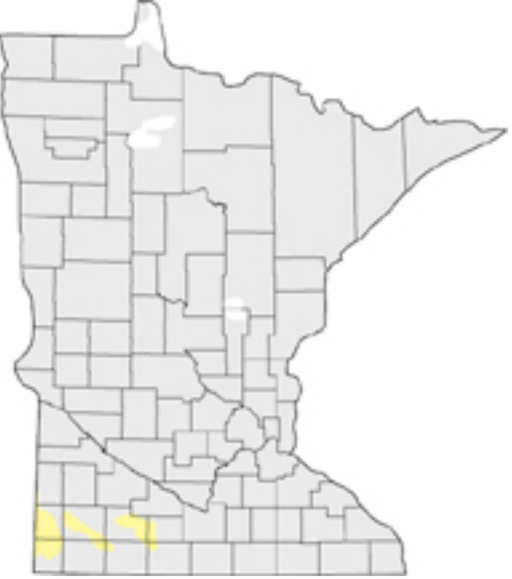


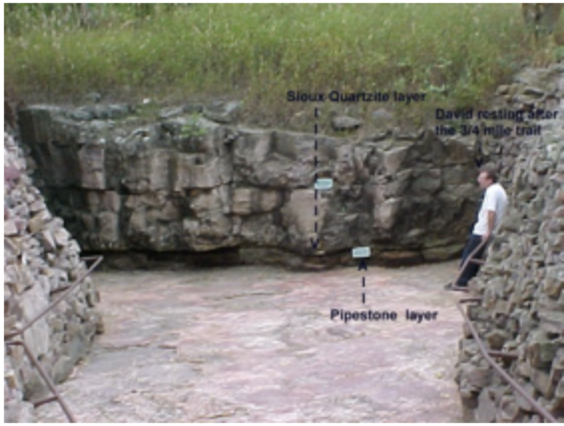
TACONITE ORE

TACONITE PELLETS

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). A much younger iron-formation (only 1.9 billion years old) occurs along the Mesabi Iron Range that extends from Grand Rapids to Babbitt. This iron-formation (above) 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 (below).





QUARTZITE
(CATLINITE)

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 above). 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 (below) is a thin claystone layer that is sandwiched between thick layers of quartzite.

BASALT / RHYOLITE / ANDESITE

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 rhyolitic 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.

Shown here is an example of amygdaloidal andesite. The grey-brown is riddled with vesicles, or holes, created when gas was trapped within the lava flow as it cooled. The cavities have since been filled by minerals to form zeolites or agates (light colored nodules in the above picture).

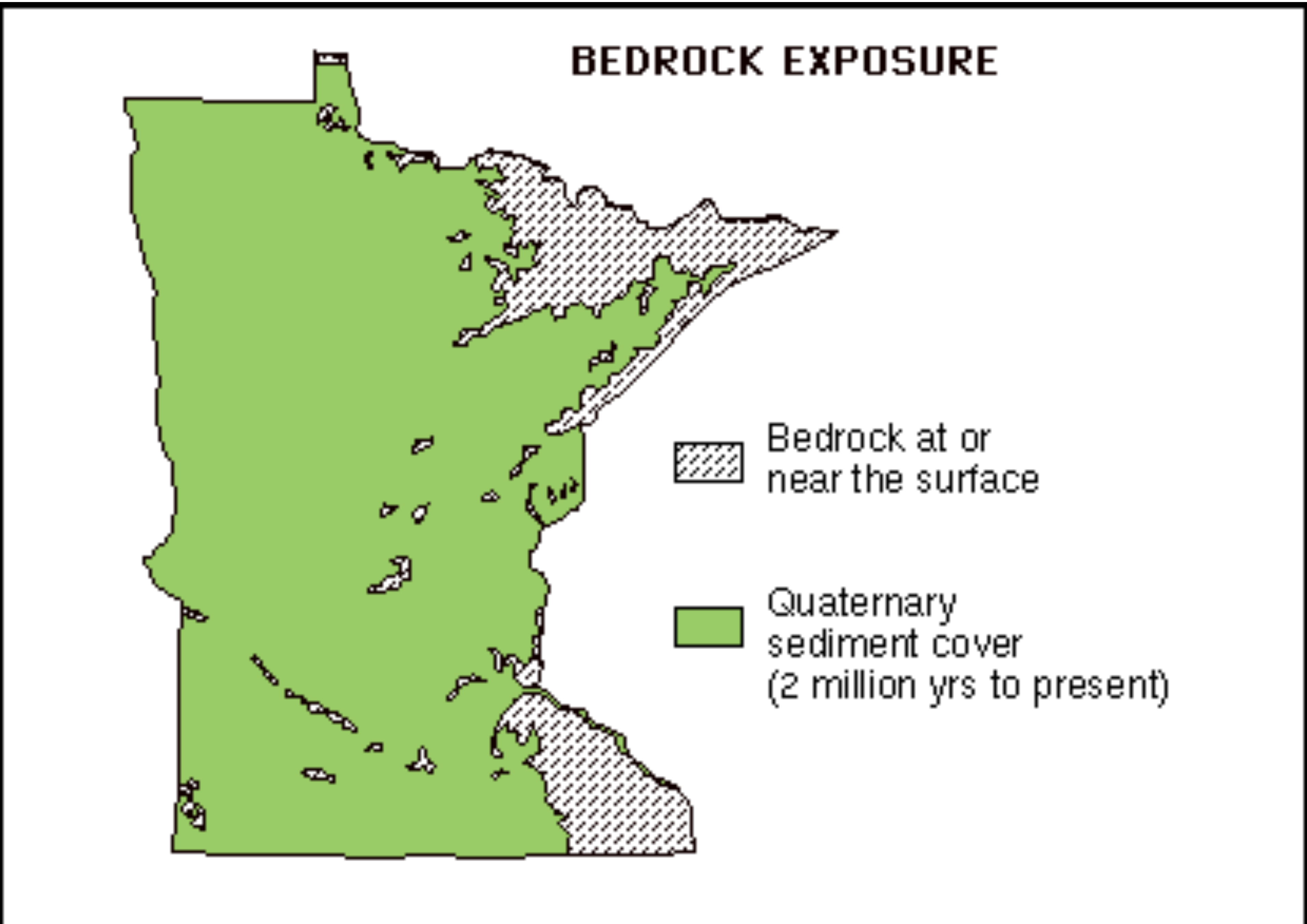
GABBRO

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 rhyolite. As mineral-rich water circulates through the cavities, silica ($SiO2$), 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.

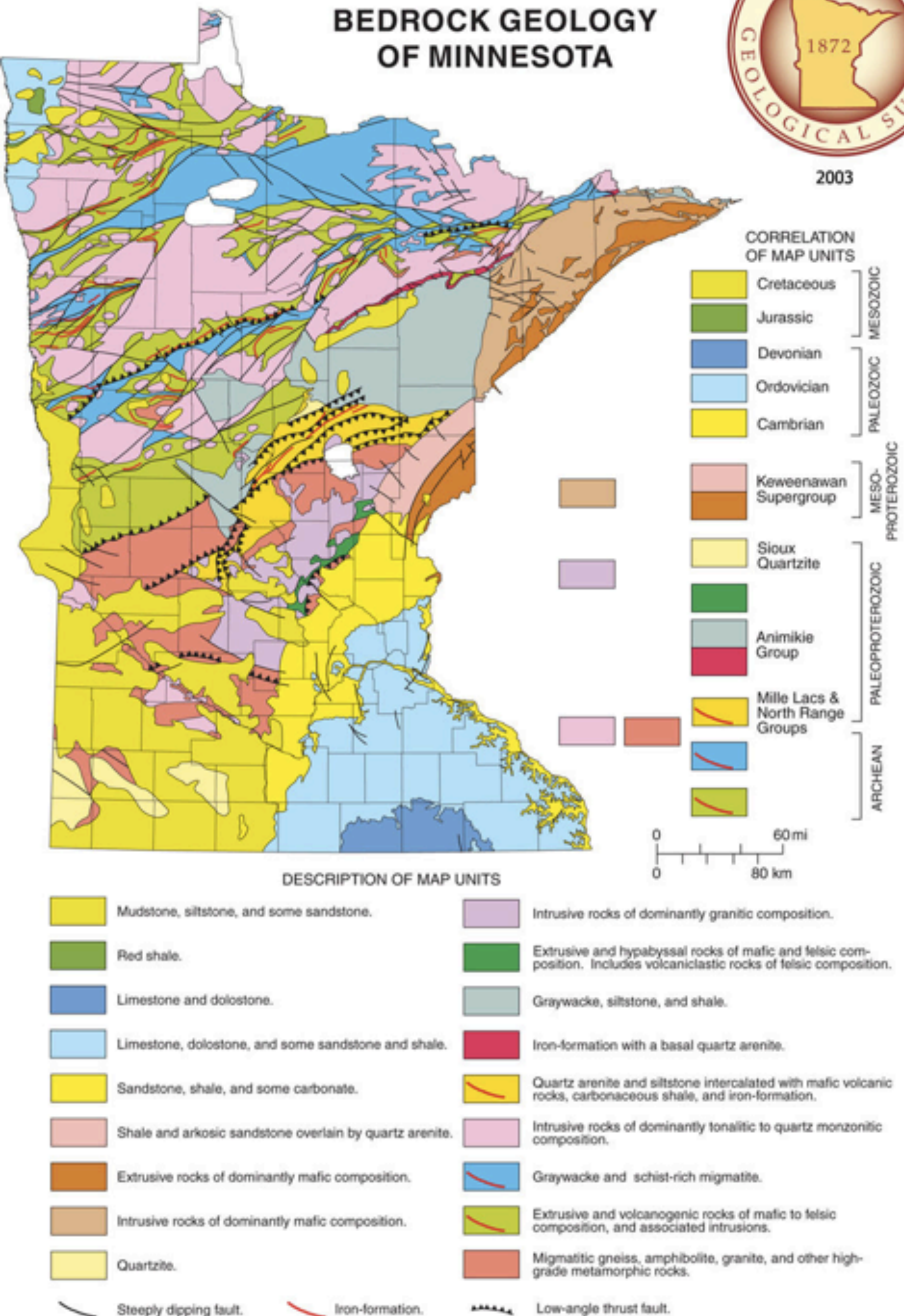
Although agates originated in the rhyolitic rocks along the North Shore, some of the best places to hunt for agates are in gravel pits scattered across the state. Specifically, agates are likely to be found where operators are mining glacial sand and gravel deposits associated with glaciers that advanced into Minnesota from the northeast, bringing agate-bearing gravel into the central and southern parts of the state.

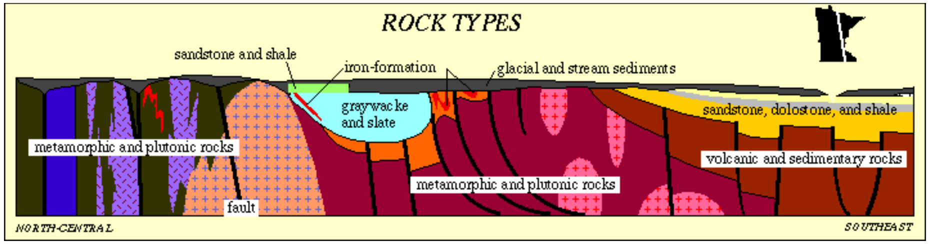

BEDROCK EXPOSURE
Bedrock at or near the surface
Quaternary sediment cover (2 million yrs to present)

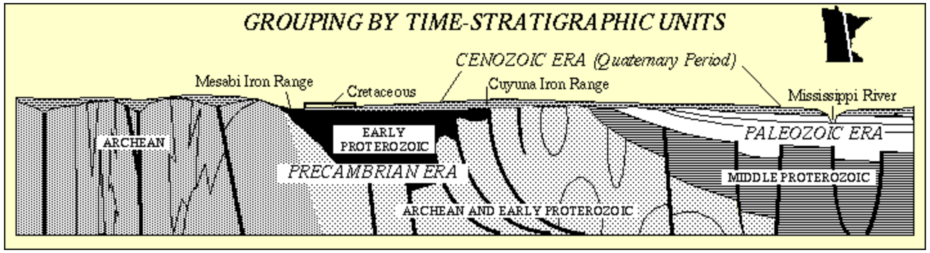
Stratigraphic Column

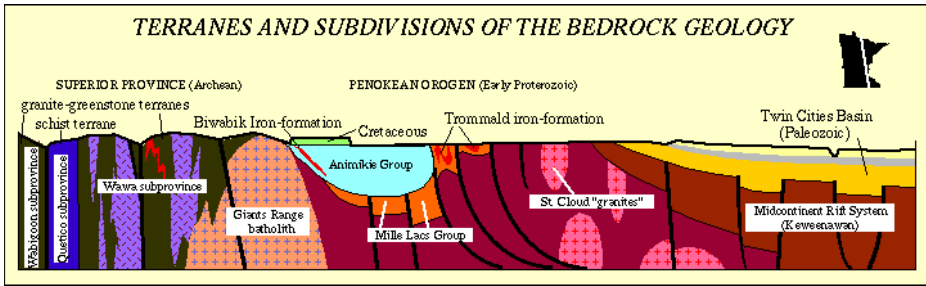
Geologic Era

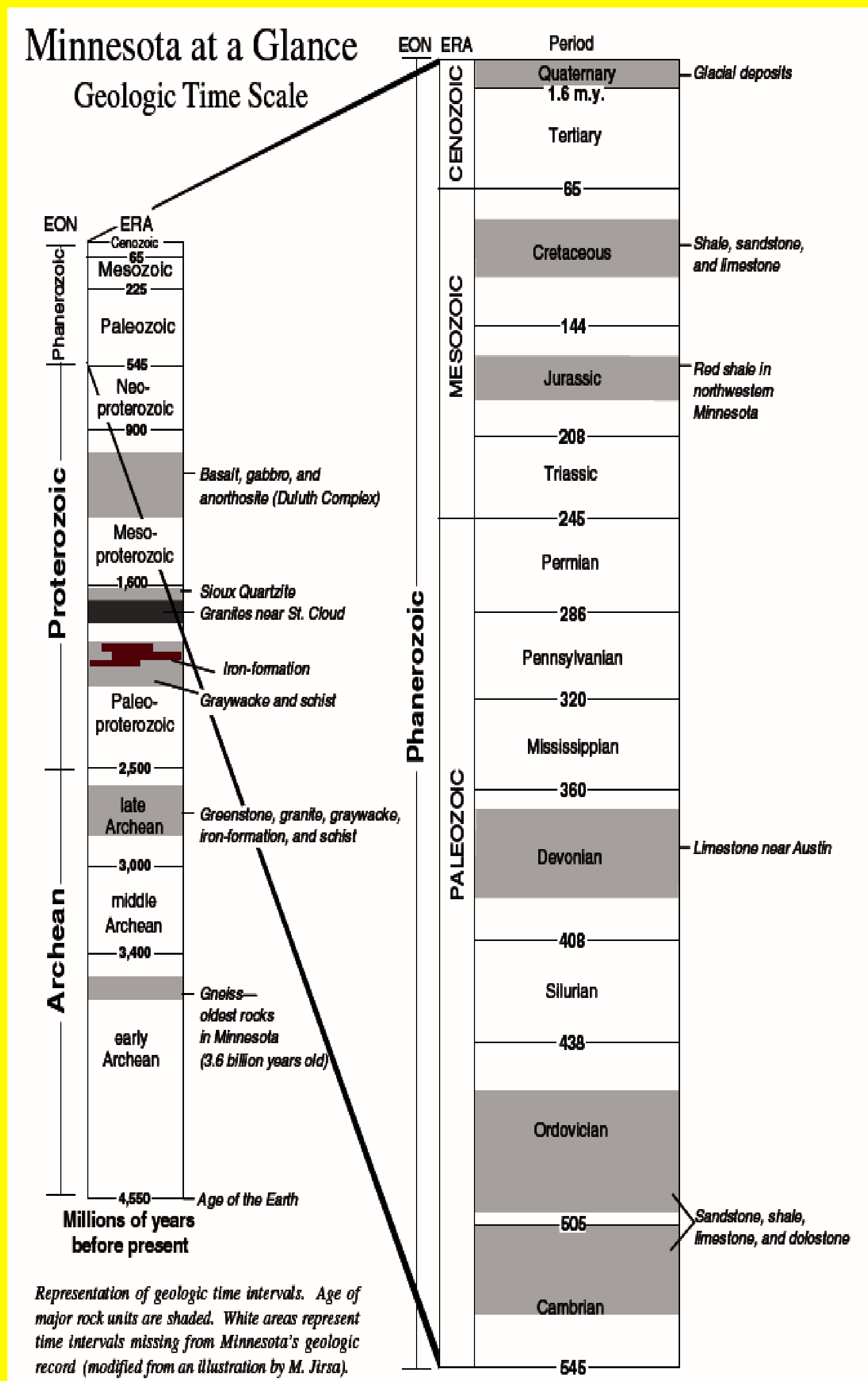
Geologic Cross-section



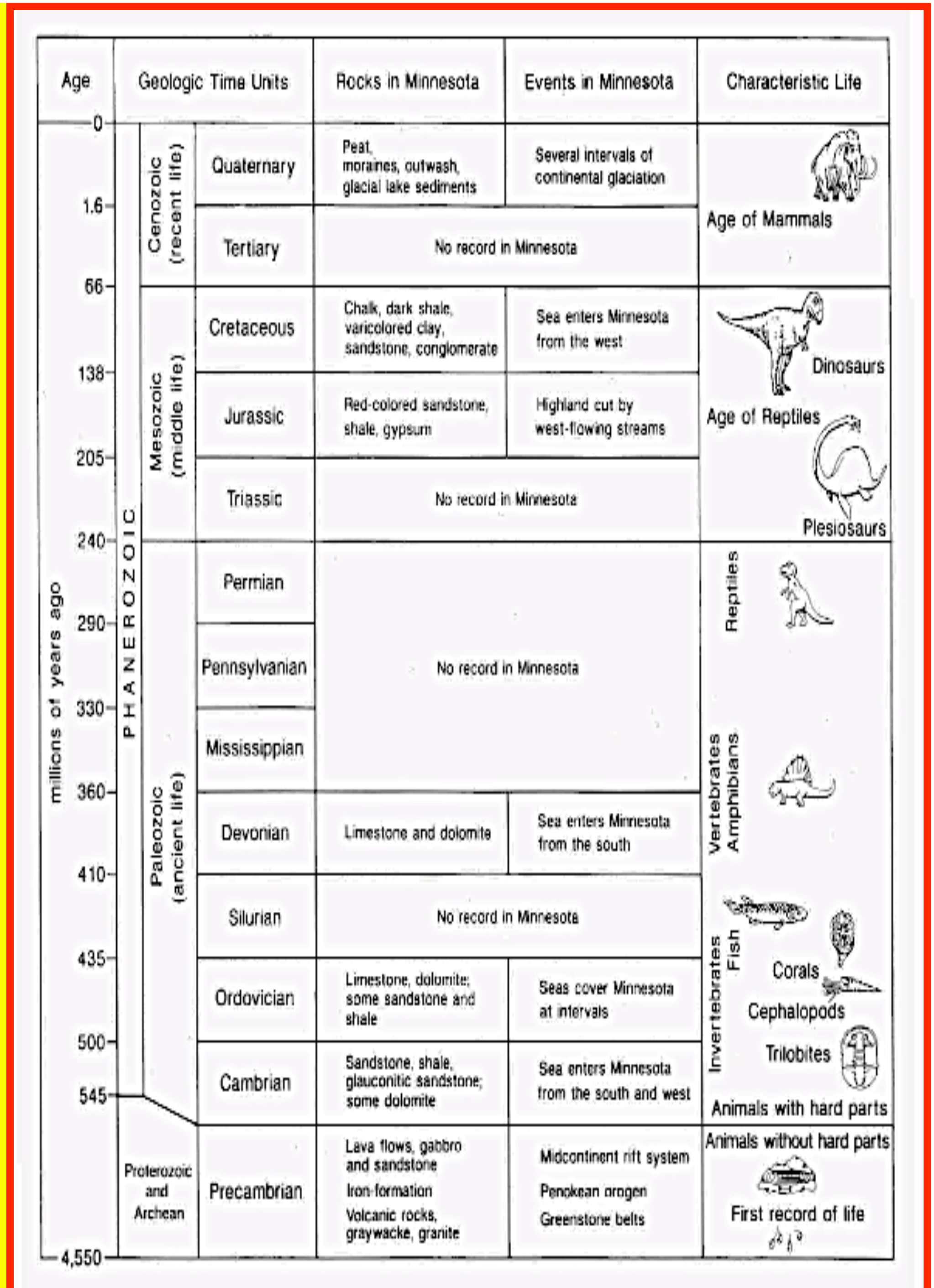






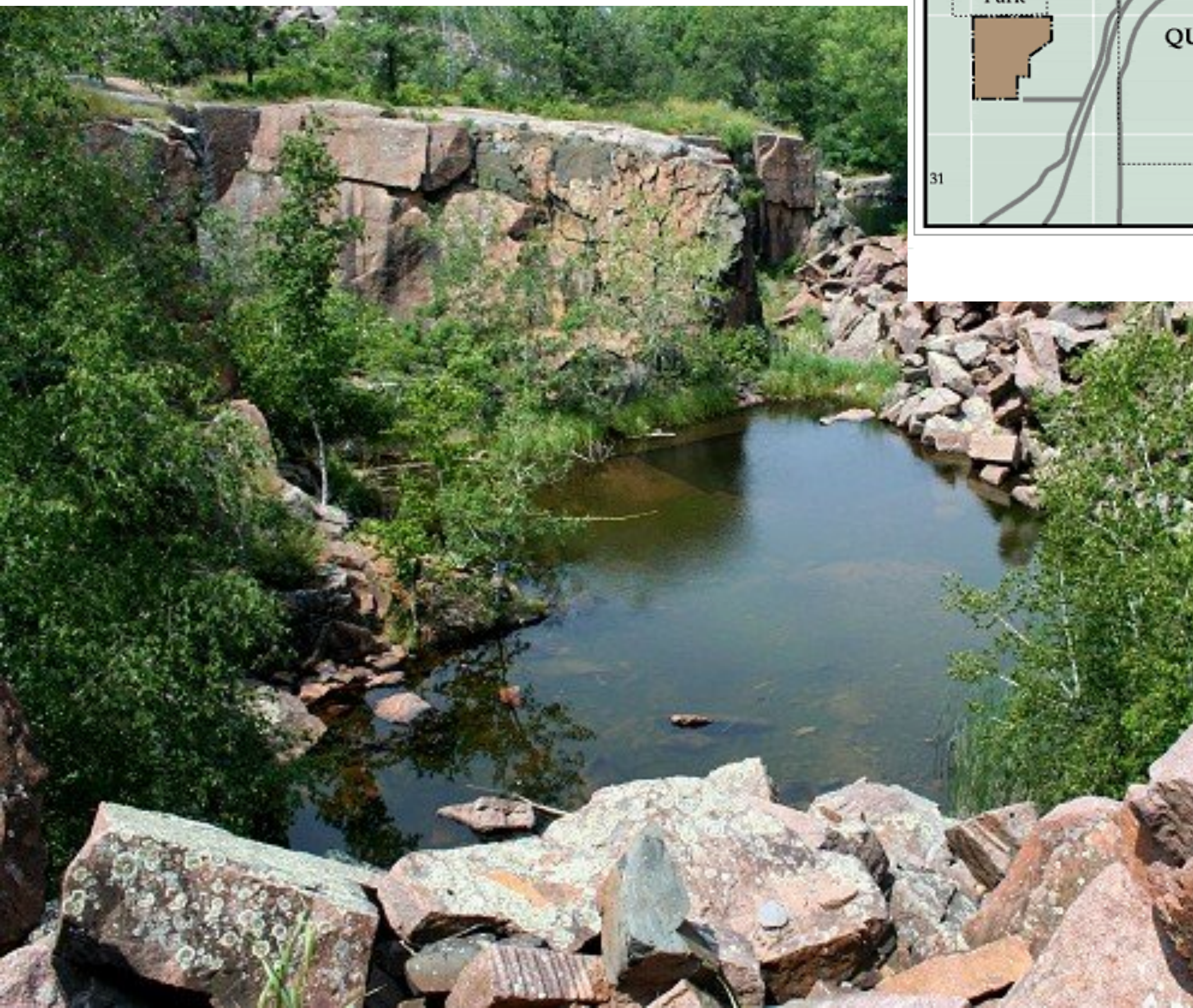


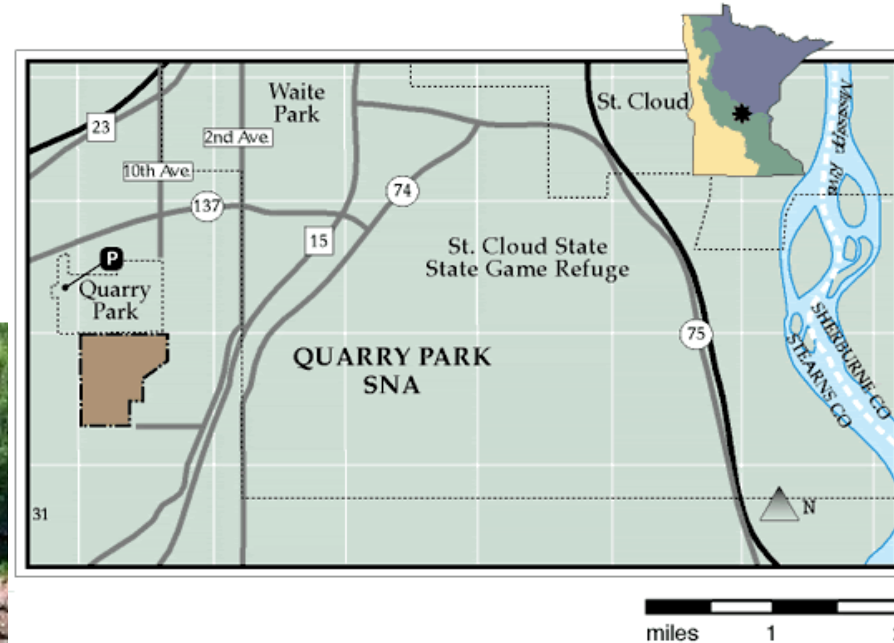
Representation of geologic time intervals. Age of major rock units are shaded. White areas represent time intervals missing from Minnesota's geologic record (modified from an illustration by M. Jirsa).

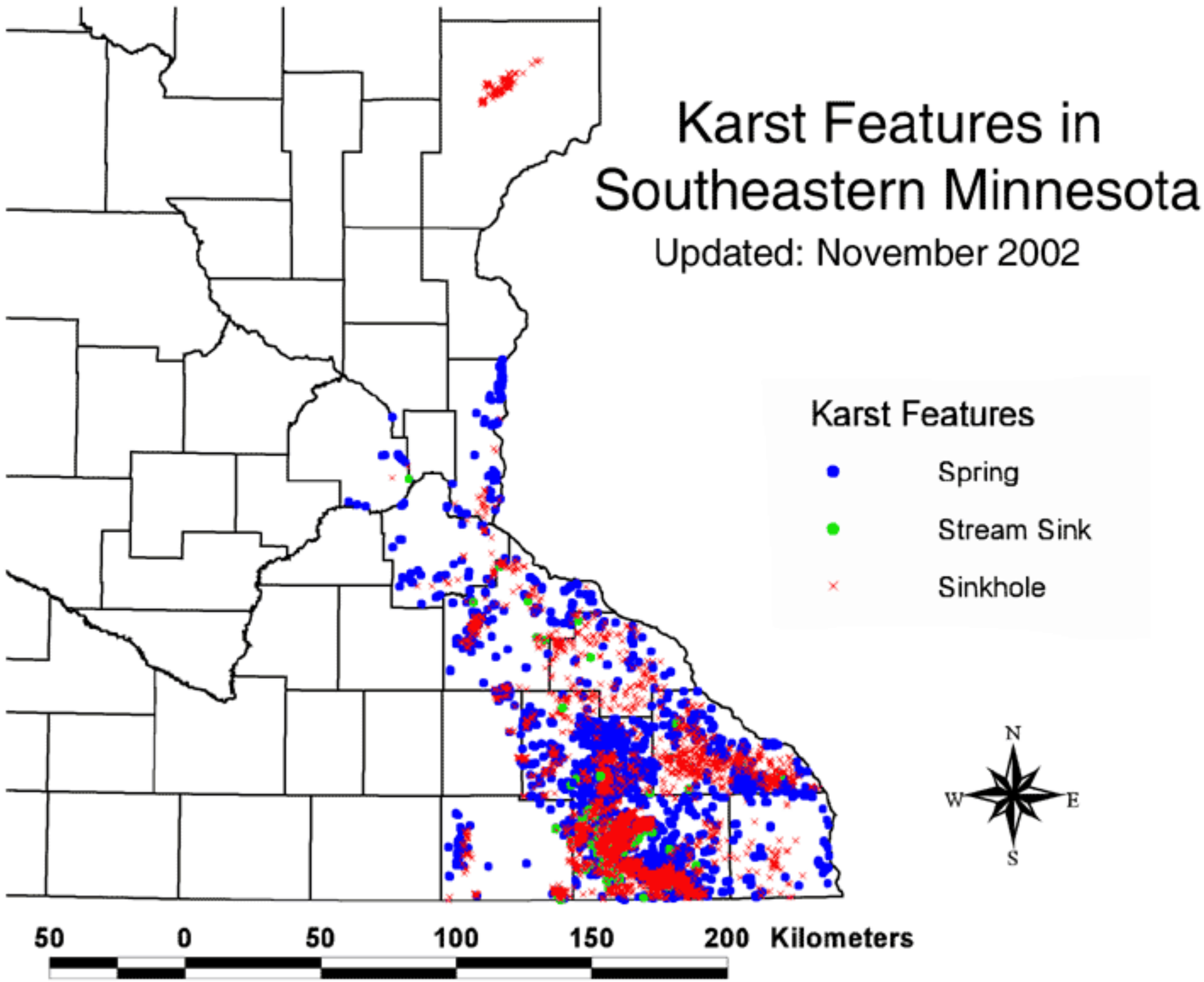


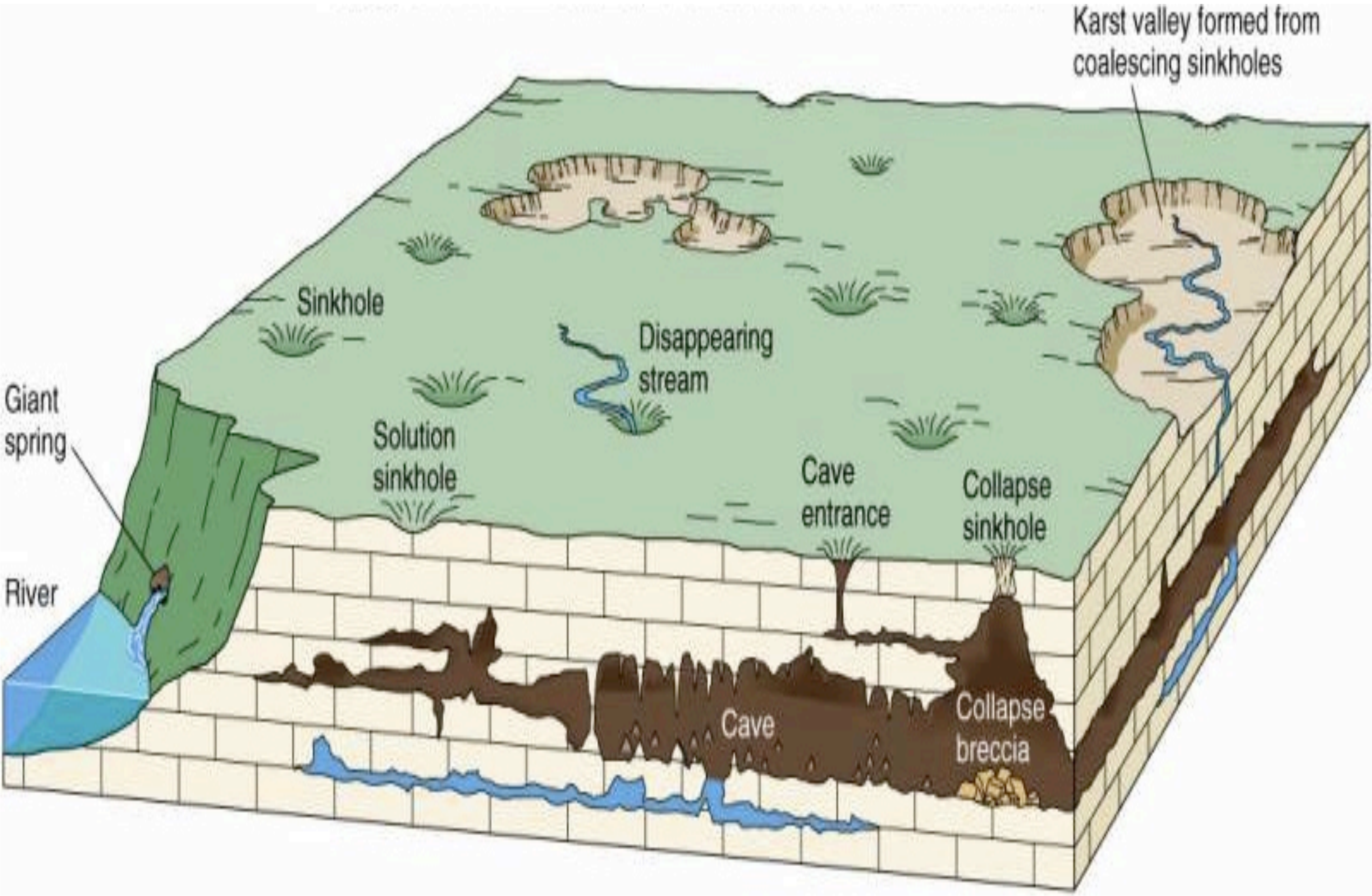
Age (millions of years ago)	Eon	Era	Period	Rocks in Minnesota	Events in Minnesota	Characteristic Life
0–1.6	PHANEROZOIC	Cenozoic (recent life)	Quaternary	Peat, moraines, outwash, glacial lake sediments	Several intervals of continental glaciation	Age of Mammals
1.6–66			Tertiary	No record in Minnesota		
66–138		Mesozoic (middle life)	Cretaceous	Chalk, dark shale, varicolored clay, sandstone, conglomerate	Sea enters Minnesota from the west	Dinosaurs
138–205			Jurassic	Red-colored sandstone, shale, gypsum	Highland cut by west-flowing streams	Age of Reptiles
205–240			Triassic	No record in Minnesota		Plesiosaurs
240–290		Paleozoic (ancient life)	Permian	No record in Minnesota		Vertebrates: Reptiles
290–330			Pennsylvanian			
330–360			Mississippian			
360–410			Devonian	Limestone and dolomite	Sea enters Minnesota from the south	Amphibians
410–435			Silurian	No record in Minnesota		Fish
435–500			Ordovician	Limestone, dolomite; some sandstone and shale	Seas cover Minnesota at intervals	Invertebrates: Corals, Cephalopods
500–545			Cambrian	Sandstone, shale, glauconitic sandstone; some dolomite	Sea enters Minnesota from the south and west	Trilobites; Animals with hard parts
545–4,550	Proterozoic and Archean		Precambrian	Lava flows, gabbro and sandstone; Iron-formation; Volcanic rocks, graywacke, granite	Midcontinent rift system; Penokean orogen; Greenstone belts	Animals without hard parts; First record of life

Granite Quarry
Quarry Park SNA
St. Cloud, MN

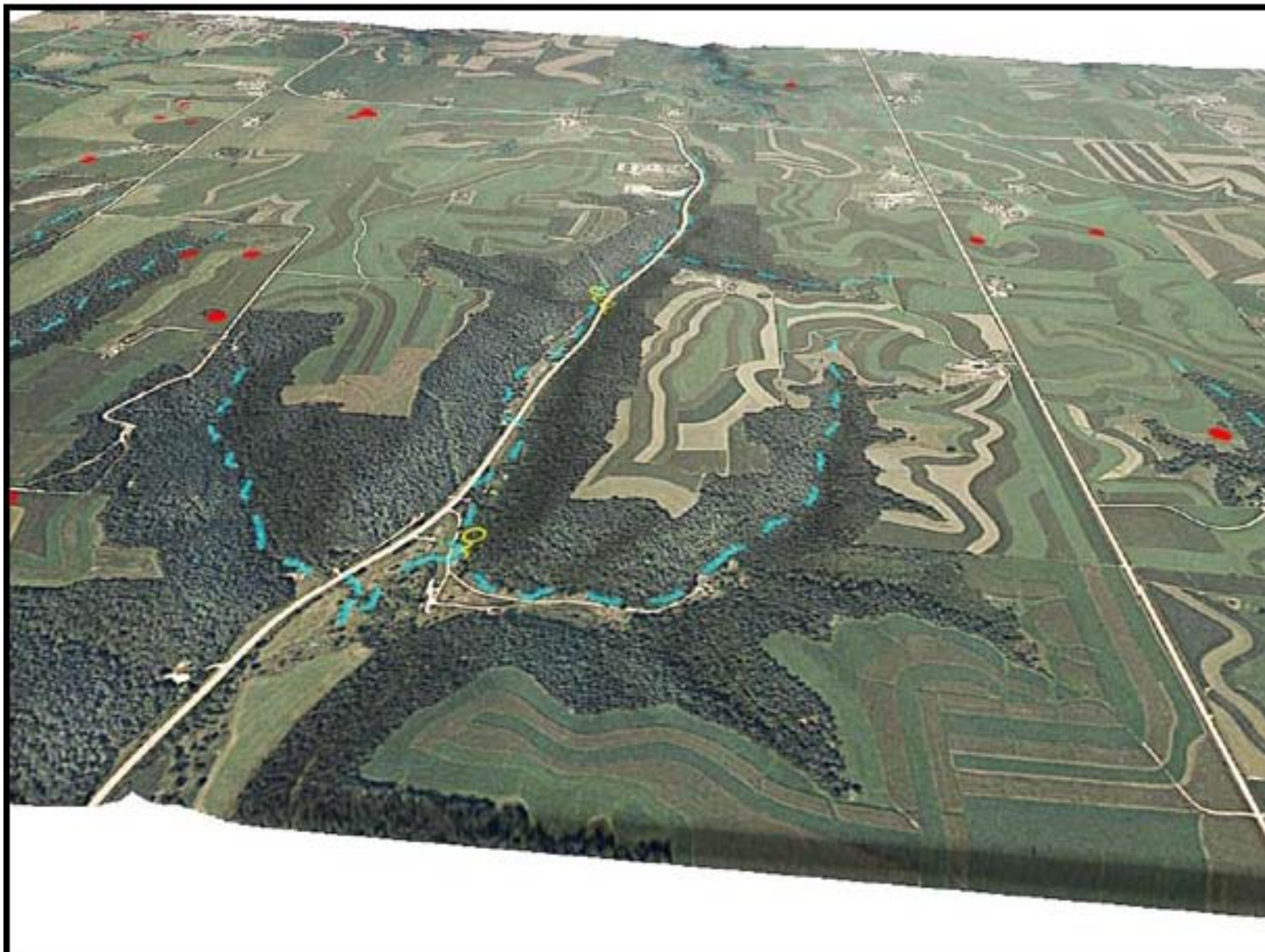





Karst Features in
Southeastern Minnesota
Updated: November 2002
Karst Features
Spring
Stream Sink
Sinkhole
N
W
E
S
50
0
50
100
150
200
Kilometers


Karst valley formed from coalescing sinkholes
Sinkhole
Disappearing stream
Giant spring
Solution sinkhole
Cave entrance
Collapse sinkhole
River
Cave
Collapse breccia

The figure below is a three-dimensional aerial view from Winona County, showing the landscape position of sinkholes (red) relative to intermittent streams (blue dashes) and springs (yellow circles).



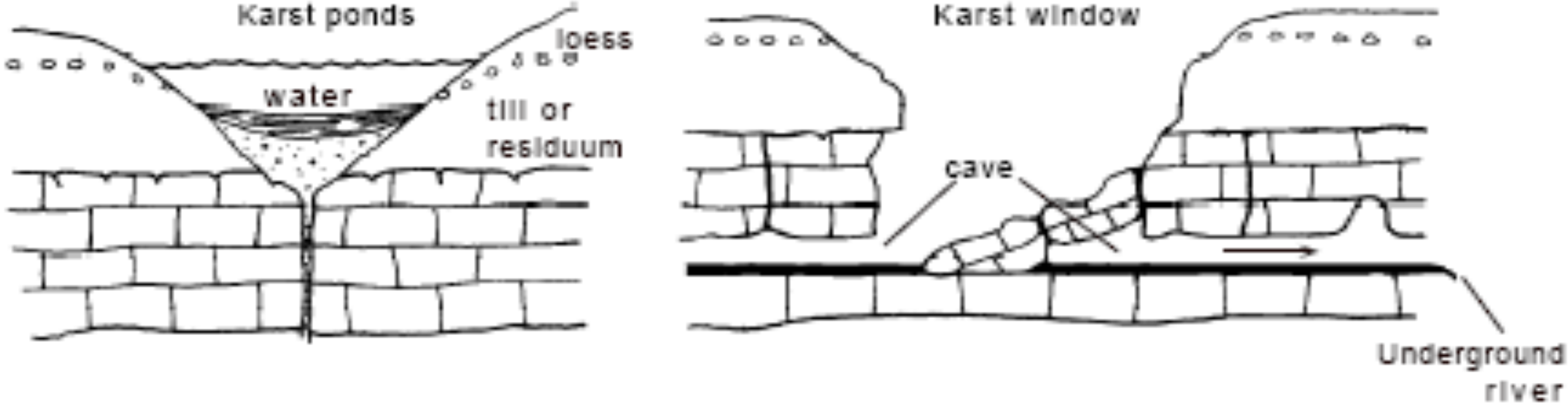


Figure 4. Development and evolution of sinkholes beneath glacial drift. Drawn by E.C. Alexander, Jr., 1995).

KARST
TOPOGRAPHY

JUST WEST
OF KARST
UNIQUE
FEATURE
IN ATLAS

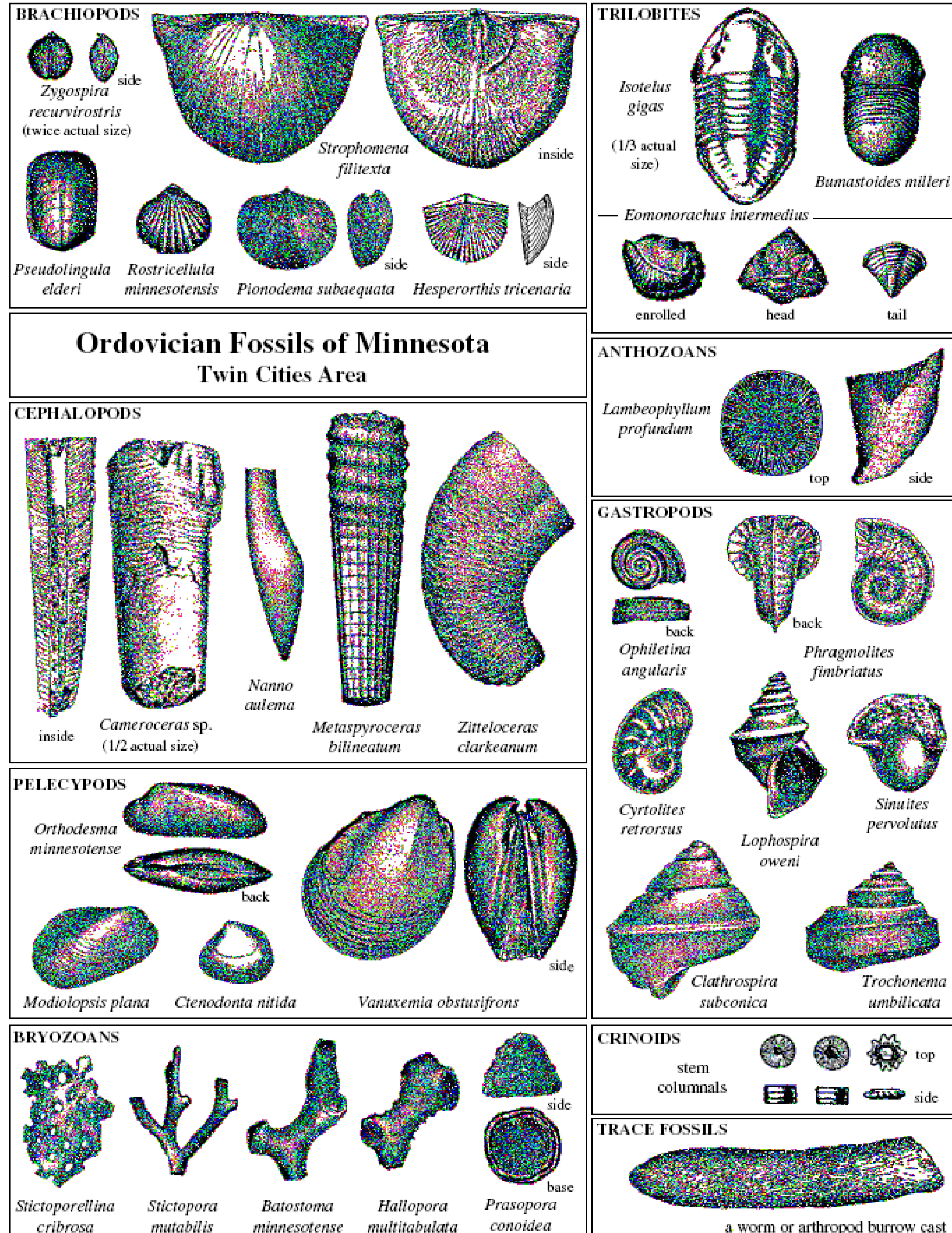
26 – D2

UNIVERSITY OF MINNESOTA

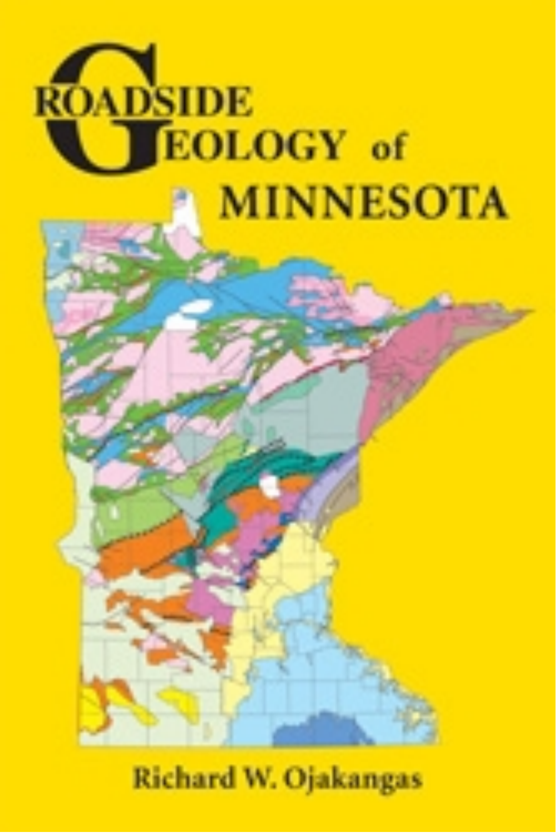
Minnesota Geological Survey

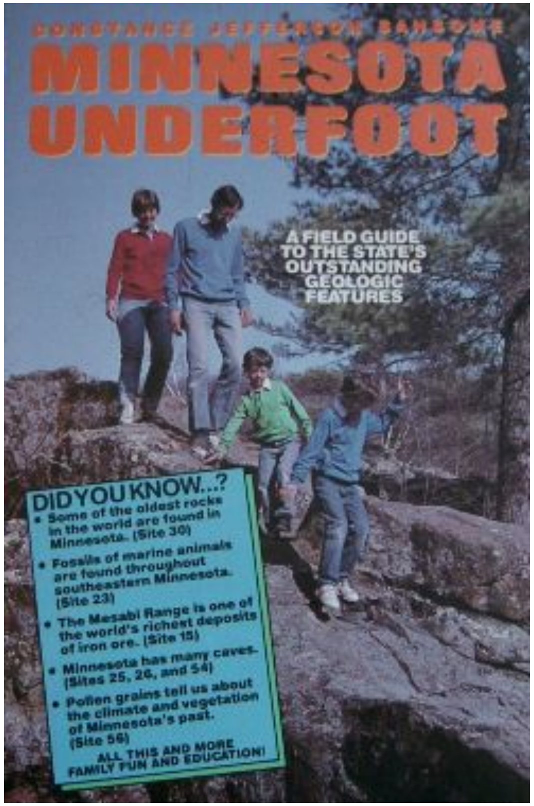
Minnesota at a Glance

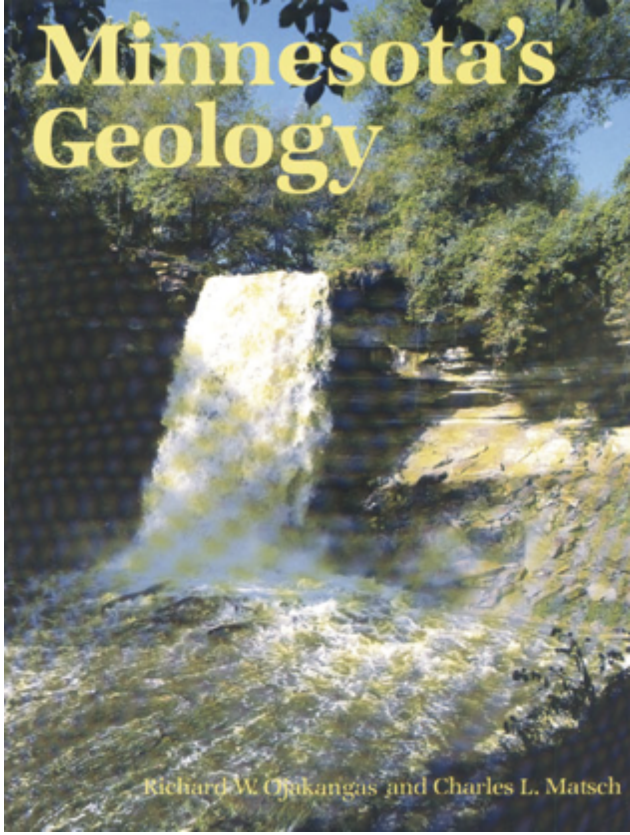
Fossil Collecting in the Twin Cities Area



Minnesota Geological Survey, 1995







USGS

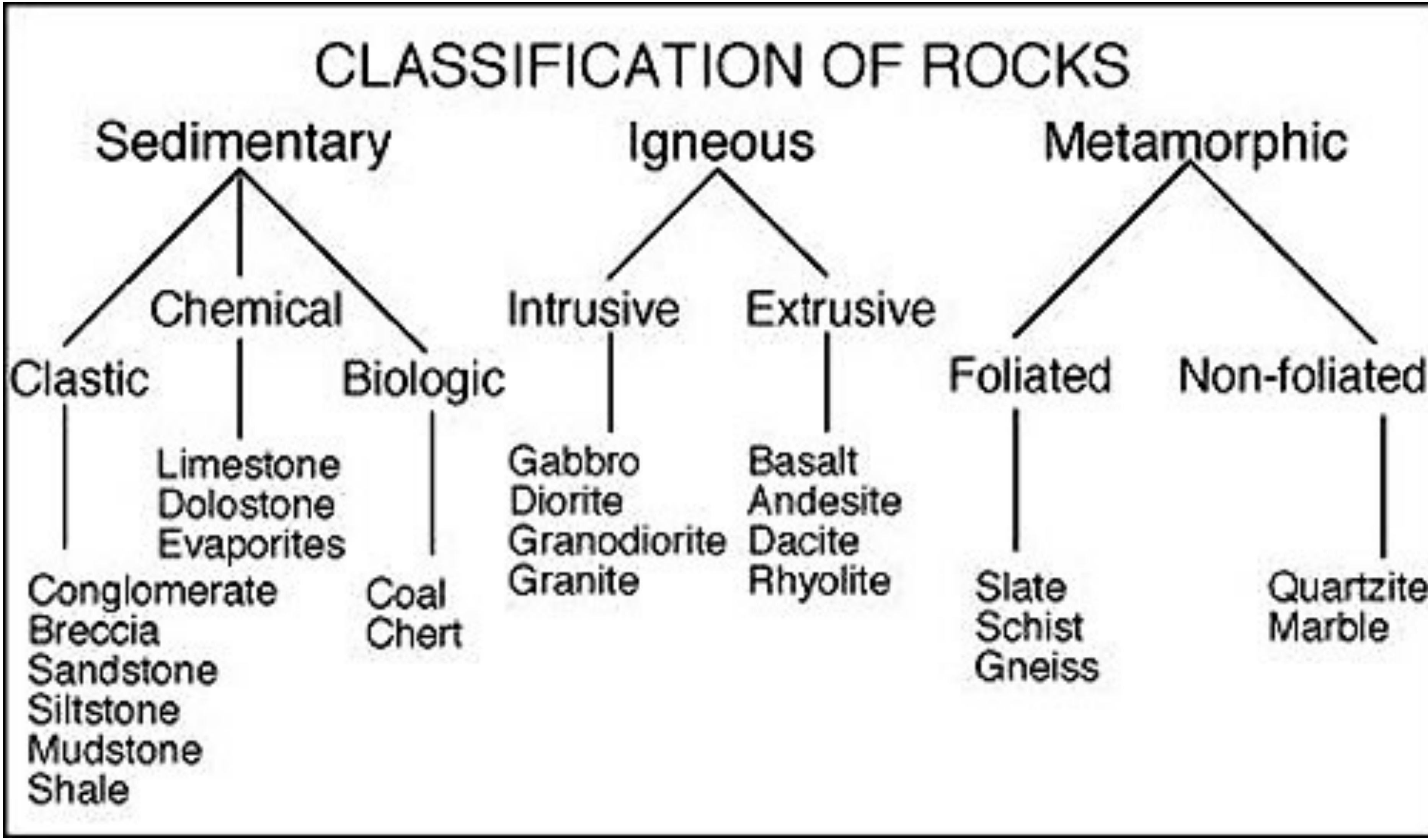
MINNESOTA GEOLOGICAL SURVEY 1872

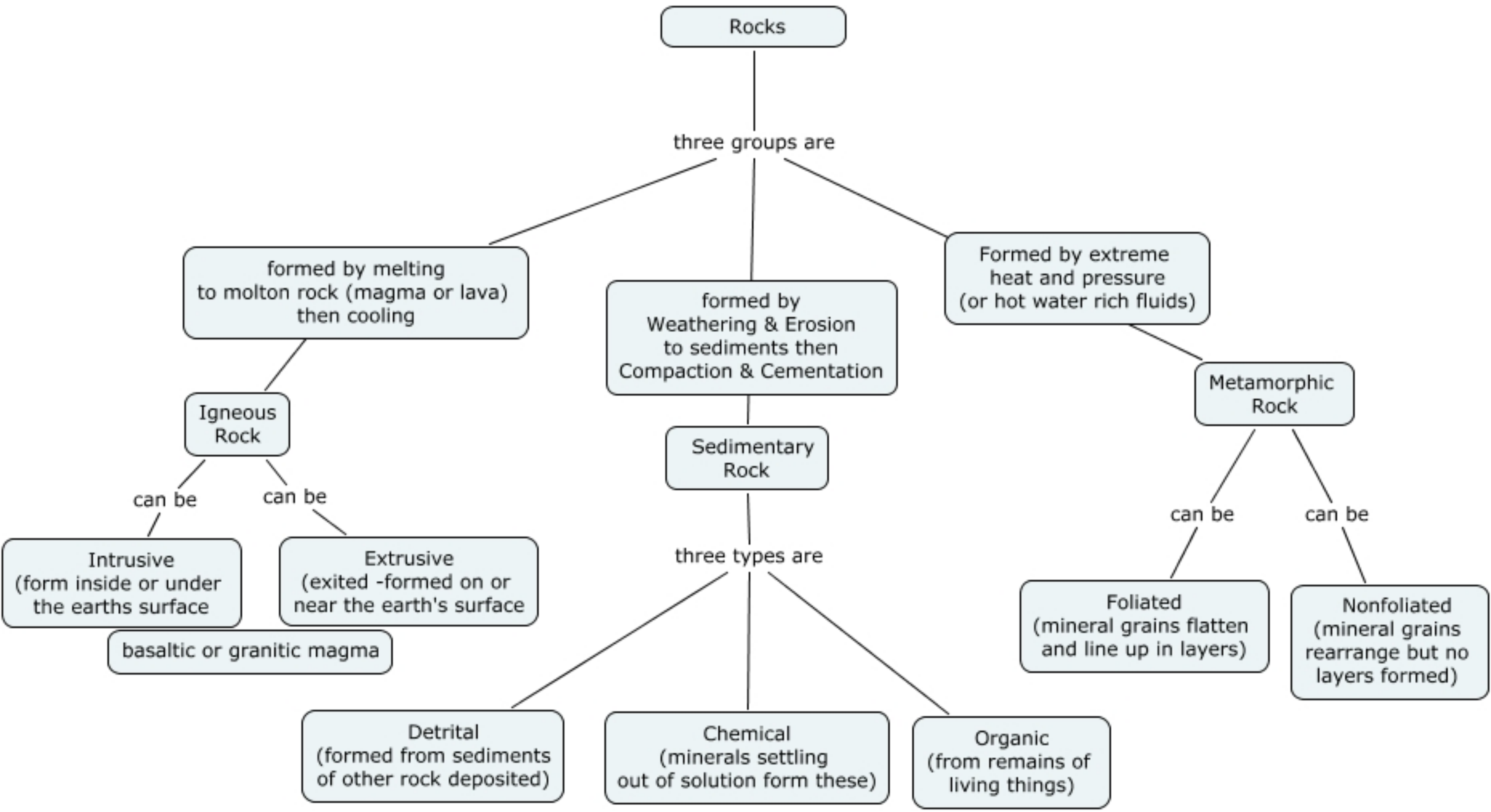
MINNESOTA DNR

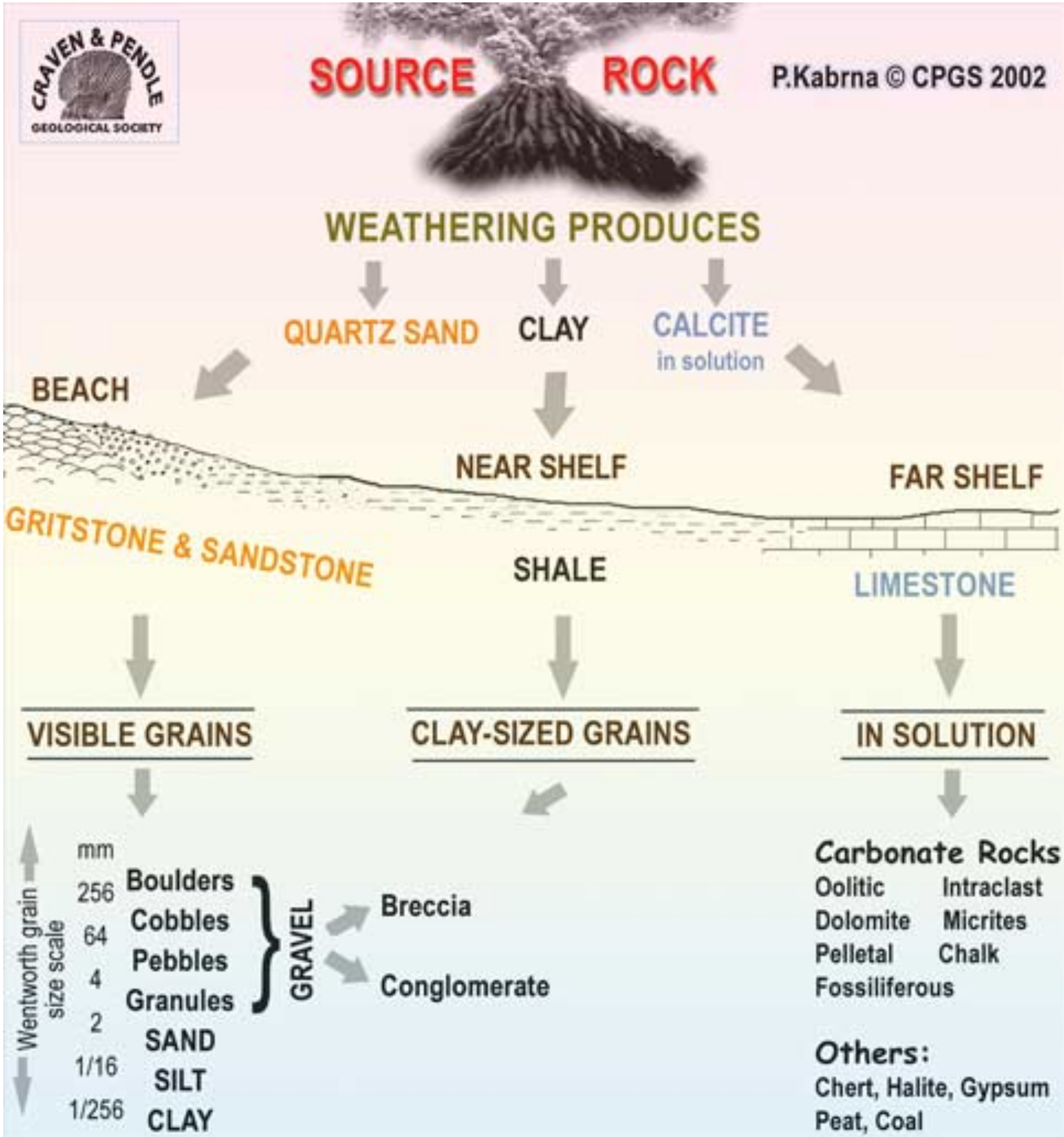
http://www.mngs.umn.edu/index.html

http://tapestry.usgs.gov/states/minnesota.html

http://www.dnr.state.mn.us/snas/naturalhistory.html


CLASSIFICATION OF ROCKS
Sedimentary
Igneous
Metamorphic
Chemical
Clastic
Biologic
Intrusive
Extrusive
Foliated
Non-foliated
Limestone
Dolostone
Evaporites
Conglomerate
Breccia
Sandstone
Siltstone
Mudstone
Shale
Coal
Chert
Gabbro
Diorite
Granodiorite
Granite
Basalt
Andesite
Dacite
Rhyolite
Slate
Schist
Gneiss
Quartzite
Marble


Rocks
three groups are
formed by melting to molton rock (magma or lava) then cooling
formed by Weathering & Erosion to sediments then Compaction & Cementation
Formed by extreme heat and pressure (or hot water rich fluids)
Igneous Rock
Sedimentary Rock
Metamorphic Rock
can be
can be
Intrusive (form inside or under the earths surface
Extrusive (exited -formed on or near the earth's surface
basaltic or granitic magma
three types are
Detrital (formed from sediments of other rock deposited)
Chemical (minerals settling out of solution form these)
Organic (from remains of living things)
can be
can be
Foliated (mineral grains flatten and line up in layers)
Nonfoliated (mineral grains rearrange but no layers formed)



CRAVEN & PENDLE
GEOLOGICAL SOCIETY
SOURCE ROCK
P.Kabrna © CPGS 2002
WEATHERING PRODUCES
QUARTZ SAND
CLAY
CALCITE
in solution
BEACH
NEAR SHELF
FAR SHELF
GRITSTONE & SANDSTONE
SHALE
LIMESTONE
VISIBLE GRAINS
CLAY-SIZED GRAINS
IN SOLUTION
Wentworth grain size scale
mm
256 Boulders
64 Cobbles
4 Pebbles
2 Granules
1/16 SAND
1/256 SILT
CLAY
GRAVEL
Breccia
Conglomerate
Carbonate Rocks
Oolitic
Intraclast
Dolomite
Micrites
Pelletal
Chalk
Fossiliferous
Others:
Chert, Halite, Gypsum
Peat, Coal