Karst and water pollution

Demonstrations, inquiry activities, and fun games to teach about geology and water in southeast Minnesota.

Aligned with 2019 K-12 Science Standards, Commissioner Approved Draft

May 2025

MINNESOTA POLLUTION CONTROL AGENCY

www.pca.state.mn.us/education

CLEAN WATER LAND & LEGACY AMENDMENT

Contents

About

These lessons were created by the Minnesota Pollution Control Agency, with review and content provided by the Minnesota Departments of Natural Resources and Agriculture in 2020. These lessons provide an overview of karst geology starting with Minnesota's basic geological history and processes and ending with student projects that explore best practices for protecting groundwater in karst regions.

These lessons encourage place-based learning for students in southeast Minnesota. But why this topic and why now?

The unique karst geology of southeastern Minnesota poses unique challenges for keeping our groundwater clean. Here, the bedrock is dissolvable by water. Cracks and openings have formed over millions of years. With soil thin to non-existent in this area of southeast Minnesota, water moves into these conduits, fractures, and pore spaces nearly everywhere across the watershed.

Contaminants like nitrate-nitrogen, bacteria, and pesticides dissolve or are transported by water and move quickly into karst bedrock where they move at varying rates and distances. They ultimately find their way into drinking water wells and streams. Little or no soil filtration occurs, which might have otherwise removed some of these contaminants.

Groundwater pollution is a problem. In southeast Minnesota, bedrock layers close to the surface commonly contain water-soluble contaminants such as nitrate-nitrogen. Communities are working hard to protect groundwater, but many residential and farm wells are at or above the health risk limit for nitrates, which is 10 milligrams per liter.

These lessons provide activities that explore how we work together to ensure safe drinking water for all Minnesotans. They are tailored for a 6th through 8th grade audience and meet many of the 6th grade earth science standards in Minnesota's 2019 K-12 Science Standards. The four lessons take 45 to 90 minutes each, depending on the activities selected. Some lessons provide advanced content or extra resources that provide teachers with more background on the topics.

The materials for the lessons are common household items. We also have a few things available to supplement the lessons—this includes a Plexiglas 3D model, DVD, and books. Those items are called out in each lesson and are available through the Minnesota Pollution Control Agency in a portable kit. Visit www.pca.state.mn.us/education for more details and contact us to request the kit.

Funding for this project was provided from the Clean Water Fund to protect, enhance, and restore water quality in lakes, rivers, and streams and to protect groundwater and drinking water from degradation.

Lesson one: Rocks tell stories

I. Overview

This lesson introduces igneous, sedimentary, and metamorphic rocks and the idea that rocks tell stories about what was here long ago. The sedimentary rocks of southeast Minnesota tell the story of an ancient sea.

MN State Science Standards:

6E 3.1.1.2
6E 3.2.1.1

Learning targets

1. Students will identify the three basic types of rocks: igneous, sedimentary, and metamorphic.
2. Students will recognize that southeast Minnesota was once covered by a sea that formed the rocks we see today.
3. Students can describe the process of constant change that rocks undergo from their creation millions of years ago to the weathering processes of today.

Materials

*An asterisk means the item is available in the lesson kit, see the “about” section for information.

Introduction
*Optional children’s’ books (ages 7+)

Rocks tell stories: Southeast Minnesota’s geologic history
Gravel, sand, soil or clay, crushed white chalk, containers, shell fragments (optional), plaster, water, spoons
*Sedimentary rock

Fossil boxes
Shoe boxes in varied shapes and sizes
Sand box sand (local hardware store)
Copies of the student worksheets and ID guides

Minnesota rock assessment
*Minnesota Rocks and Minerals: A Field Guide to the Land of 10,000 Lakes
SE Minnesota rock identification handout

Vocabulary

Familiarize yourself with the following terms:

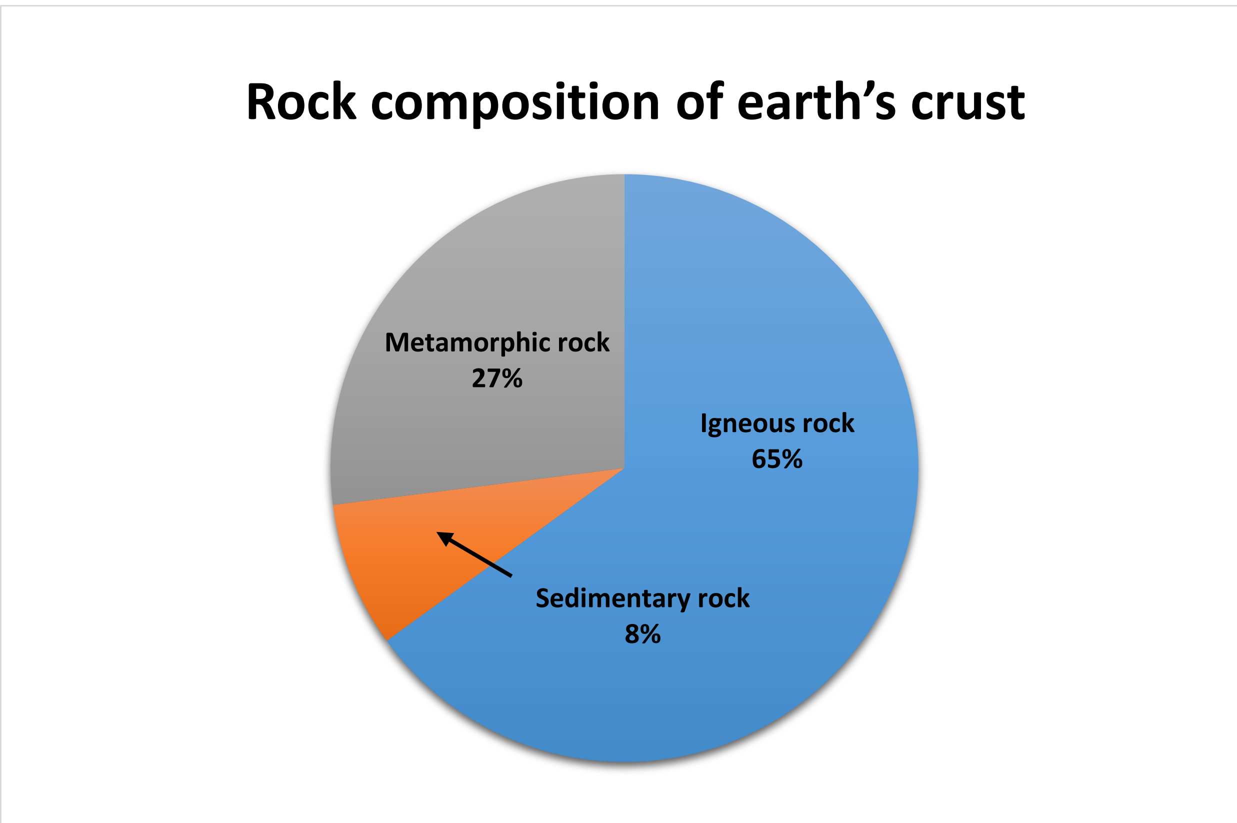
Weathering, tectonic plates, sandstone, shale, limestone, dolostone, carbonate

II. Activities

A. Introduction to the rock cycle (10-20 minutes)

The Earth is divided into four main parts: the inner core, outer core, mantle, and crust. We spend our lives living on the solid crust. The crust formed as a result of millions of years of small but constant changes, like weathering and the movement of tectonic plates under the continents. There are three basic types of rocks found on the surface of the earth.

Igneous rock forms from the cooling of melted rock and makes up most (65%) of the surface of the earth. Sedimentary rock (8%) forms when small pieces of other rocks or organic material are compressed together like a sandwich forming layers. Metamorphic rock (27%) starts as igneous, sedimentary, or even other types of metamorphic rock, but changes into a new rock as a result of intense heat and pressure. Minnesota has all three types of rocks, and they tell all kinds of stories about the history of the state.



For younger audiences, consider these fun books: The Rock Factory: The Story About the Rocky Cycle, by Jacqui Bailey (ages 7+), The Pebble in My Pocket, by Meredith Hooper (ages 7+), and The Street Beneath My Feet (ages 5-8). These are available in the learning kit.

After playing a fun game about the rock cycle, we are going to learn about the rocks in southeast Minnesota and the special story they tell about this place.

B. Rock-rock-rock game (15 minutes)

These quick games familiarize your students with the vocabulary of rock types.

Option 1: Students will play a game in the style of the hand game rock-paper-scissors, but as a group and using their new vocabulary: igneous, sedimentary, and metamorphic rock.

As a large group, choose a full-body pose that will signify each rock type (e.g., igneous – jumping with arms up like an exploding volcano, sedimentary – wiggle body like an "S", metamorphic – bend down while pressing their hands together in front of their chest).

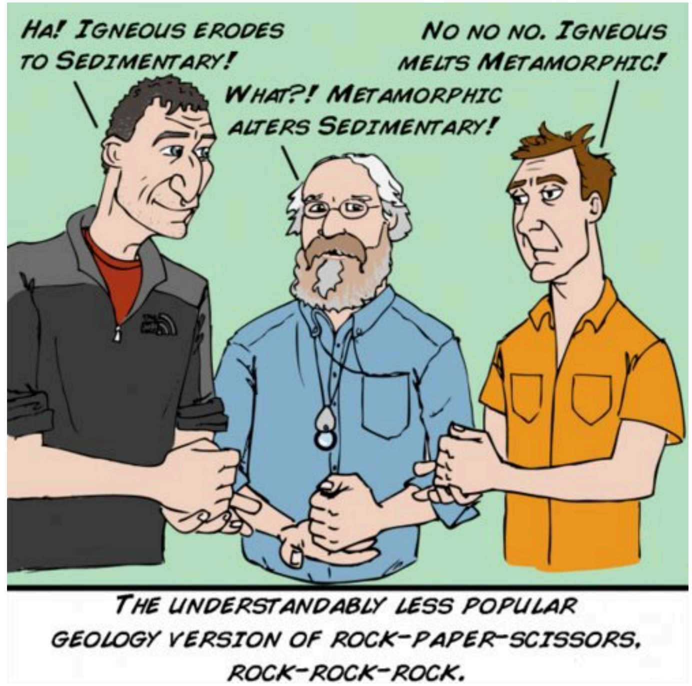


Image: RockRockRock, by Nathan Carroll, cafepress.com

After the poses are decided, break students into two groups. For each round, each group will need to do one of the poses (everyone in the group will need to do the same pose). Each group will have 1 minute to strategize. Once both the groups have their poses ready, the teacher counts down from three (e.g., three, two, one, GO!) and on "GO" the group will need to strike one of the three poses.

Though no rock type beats the others in real life, you can play like this:

- Sedimentary beats igneous
- Igneous beats metamorphic
- Metamorphic beats sedimentary

Play as many times as you like. Best out of five is a good number.

Option 2: Students play a card game in the style of the card game War. Have students cut out the 12 rock cards found at the end of this lesson, shuffle, and divide them equally. Each player flips a card. The winner claims both cards. Play until one person has all the cards or the time is up.

You may also have fun with these two online rock cycle interactive games

https://www.learner.org/series/interactive-rock-cycle/

https://www.learner.org/wp-content/interactive/rockcycle/rockdiagram/

C. Rocks tell stories: Southeast Minnesota's geologic history (15-minute demo or 50-minute activity)

For this section, choose either:

1) A demonstration—where the instructor adds layers to a container while telling about southeast Minnesota's geologic history, or
2) A student activity making sedimentary rocks.

See instructions for the activity here:
https://www.windows2universe.org/teacher_resources/teach_makerock.html.

To make this demonstration Minnesota-specific, use the information that follows. A must-read is the Minnesota Geological Survey's Minnesota at a Glance document called Ancient tropical seas—Paleozoic history of Southeastern Minnesota: https://conservancy.umn.edu/handle/11299/59447.

What sort of rocks do we find in southeast Minnesota? The bedrock is visible along road cuts and bluffs. These are sedimentary rocks.

Review definition of sedimentary rock from introduction. Pass around a sample of sedimentary rock.

Four hundred million years ago, Minnesota was situated near the equator and covered by a shallow ocean—a similar environment to the modern day Caribbean.

The sea was bordered on the northeast side by higher ground. Over the next 200 million years, sediments eroded from high lands to the north and accumulated in more or less flat layers in this sea.

Sand was deposited near the shore, just as it is on beaches on the coasts today. Small grains, such as silt and clay, were washed out further from shore and settled to the ocean bottom as mud. Even further off shore, far away from the sandy beaches, deposits of crushed seashells and marine organisms formed a different kind of mud.

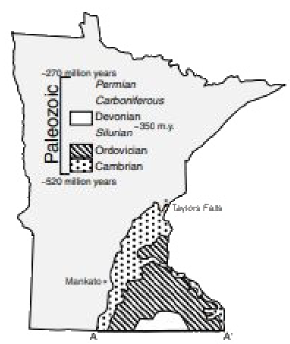


Figure 1. *Distribution of Paleozoic rocks in southeastern Minnesota. Line of cross section A-A' corresponds to Figure 2. Time periods shown in italics are not represented by rocks in Minnesota.*

The position of these sediments from the shoreline shifted in response to frequent changes in sea level. As sea levels fell, sand was carried out further from shore and deposited over mud. As sea levels rose, the mud was deposited above the sand. Over millions of years, these different layers stacked up, hardened, and turned to rock.

Sequence of rocks as the ocean levels rise.	carbonate mudstone sandstone	Sequence of rocks as the ocean levels dropped.	sandstone mudstone carbonate

Sand was turned to sandstone, mud turned to shale, and seashells and mud turned to limestone and dolostone, which we call carbonate rocks. Geologists have assigned names to these individual rock layers.

If doing a demonstration, add layers to the cup. First sand, representing sandstone. These are the coarsest layers and formed when there was shoreline here. Then add fine-grained sand or clay, representing shale. These formed when there was deep water here. Then add chalk, representing limestone and dolostone. These formed when there was deep water here too—and are made of shells and minerals from the water.

Alternate these layers, describing rising and falling sea levels. Create 8-10 layers.

These Paleozoic rock layers are more than 1,500 feet thick in some places, and were deposited over a span of some 200 million years during the three geologic time periods known as the Cambrian, Ordovician, and Devonian (all part of the Paleozoic Era).

Plants and animals from this sea also fell to the ocean floor, and we can find fossils in these layers, too.

The sedimentary rocks in southeast Minnesota are no longer continuous layers like they were when laid down in the ocean. Instead, they have been eroded in places by relatively recent geologic activities, particularly by glaciers and the huge amounts of water that eroded valleys when the glaciers melted. River and stream valleys continue to be carved by water today.

Weathering of rocks is always happening. Sedimentary rocks experience physical weathering (e.g., breaking apart from the expanding and contracting caused by temperature changes) and chemical weathering (dissolving). Yes, southeast Minnesota's sedimentary rock does dissolve! Moreover, this dissolving is what we will learn more about in Lesson two.

D. Fossil boxes (fossil dig simulation and fossil identification) (40-50 minutes)

Gather shoe boxes and sand box sand. Fill the shoe boxes ½ - ¾ with the sand. Cut the fossil cards provided at the end of this lesson and bury paper fossils. Provide student with popsicle sticks, plastic forks…to "dig" the fossils. Students can then match the pictures with the Fossil Identification Chart to identify the Minnesota fossils.

The Fossil ID card sheet is designed for either three or six fossils per student/group. Glue the fossil onto the Fossil Identification Card.

Using the Ordovician Fossils of Minnesota – Identification Chart, students will record the name and type of each fossil they found on the matching card. They will then read the description of that type of fossil and determine the feeding style of each—predator, scavenger or filter feeder.

Other suggestions for this activity:

- Print fossils onto card stock or something more durable so they can be reused. With this option, students will need to draw the fossil onto the fossil ID card, rather than glue.
- Once all the fossils have been discovered and identified students could attach them to a poster of the Geologic Time Scale matching when those animals were alive in Minnesota.

E. Sedimentary rock assessment (20-30 minutes)

Start by using this website to familiarize students with common rocks in Minnesota using a virtual rock collection: https://www.mngs.umn.edu/virt_egg/secondpg.htm

Pass out some sedimentary rocks from southeast Minnesota—either from the learning kit or some that you collect locally. Students will then work with the Southeast Minnesota rock identification worksheet to determine what type of rock they found. This worksheet only steps them through differences in sandstone, limestone, dolostone, or shale. After filling out the worksheet, students will then share with the group where they found their rock, what type of rock they think it is, and the scientific reasoning they used to come to this answer.

Alternatively, have students collect a rock from their backyard or street—anywhere in their environment. Refer to *Minnesota Rocks and Minerals: A Field Guide for the Land of 10,000 Lakes* (this book is available in the lesson kit) to identify common rocks in Minnesota.

F. Fossil collecting

When Minnesota was submerged by continental seas millions of years ago, there were marine animals living in the sea whose fossil shells remain in the bedrock of this area.

If you teach near a riverbank or eroded hillside, consider taking students out to explore rocks and fossils. What can be more fun than discovering a fossil from an animal that lived in the sea that once covered Minnesota 400 million years ago?!

III. Extra resources

Minnesota at a Glance: Ancient Tropical Seas – Paleozoic History of Southeastern Minnesota
This is a great overview of the content of this lesson. It is also linked in the text above.
https://conservancy.umn.edu/handle/11299/59447

Minnesota Geology Handbook
A general resource about Minnesota's geologic history
http://files.dnr.state.mn.us/lands_minerals/geologyhandbook.pdf

Minnesota Fossils and Fossiliferous Rocks – Robert E. Sloan
"A quick and easy guide to the collection and identification of the fossils of Minnesota. Close to 3,000 different kinds (species) of fossils have been described from Minnesota rocks so far."
http://www.bluffcountryfossils.net/blog/minnesota-fossils-and-fossiliferous-rocks-robert-e-sloan/

Minnesota at a Glance: Common Minnesota Rocks
Handout from University of Minnesota that gives an overview of the various rocks found in Minnesota, including sandstone, limestone, taconite, and agates.
https://conservancy.umn.edu/handle/11299/59443

Minnesota at a Glance: Fossil Collecting in the Twin Cities Area
A brief overview of fossils in Minnesota.
https://conservancy.umn.edu/handle/11299/59440

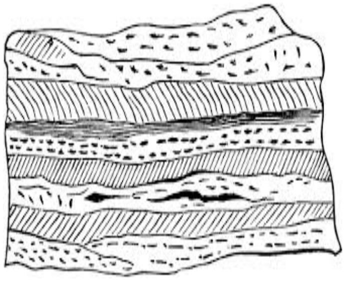
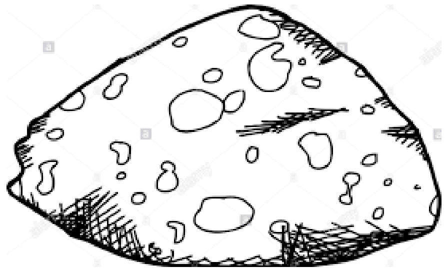
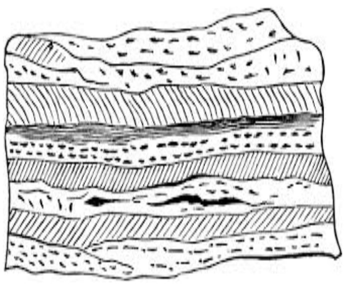
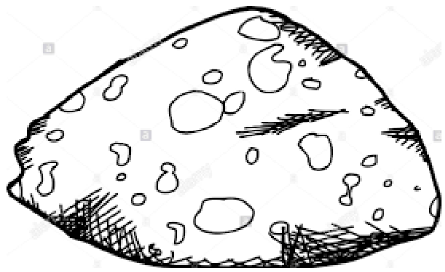
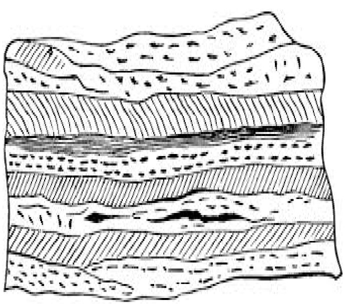
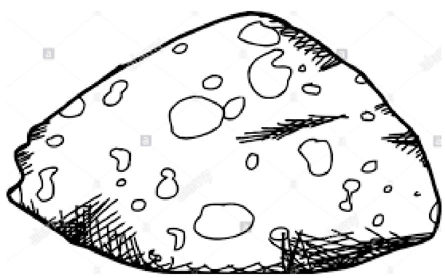
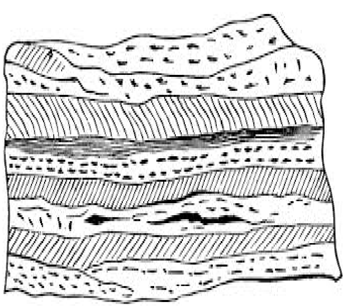
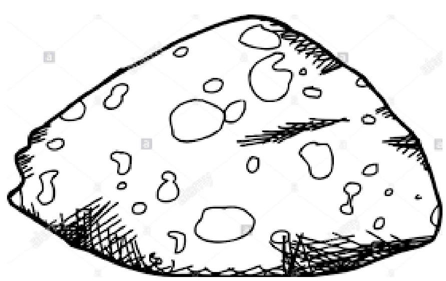
Guide to Fossil Hunting in Minnesota
An electronic copy of a 1965 publication. Page 4 has a nice time and fossil chart.
http://www.bluffcountryfossils.net/blog/wp-content/uploads/2015/08/Guide-to-Fossil-Collecting-in-Minnesota.pdf

IV. Assessment

Create a model to show how sedimentary rock is formed. Include these words: Sea, deposit, deposition, pressure, time, cemented together, formation, fossils, and processes.

Construct a model of the geologic time scale of southeastern Minnesota using your shoe box fossils.

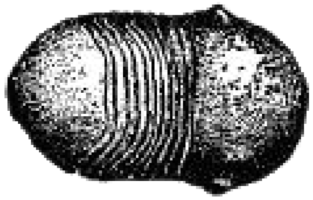
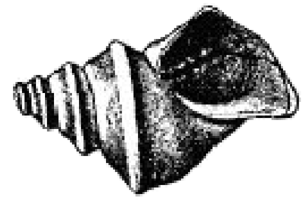
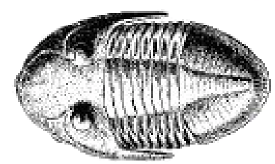
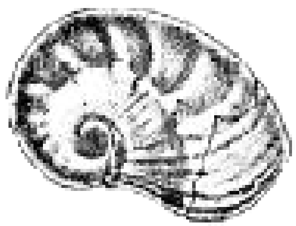
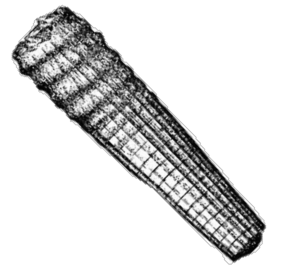
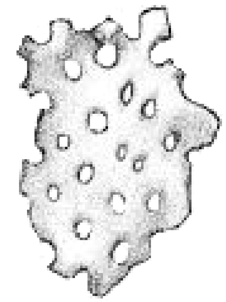
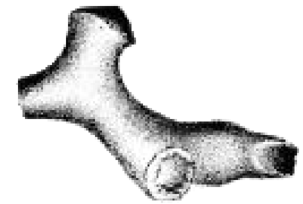
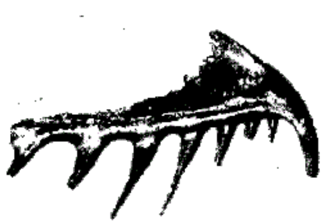
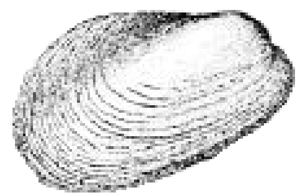
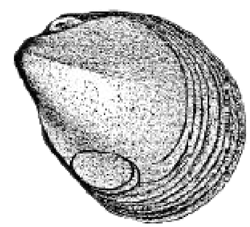
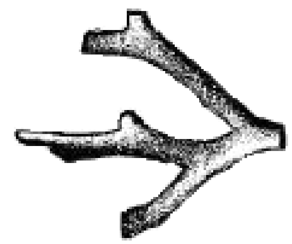
Rock-rock-rock game cards

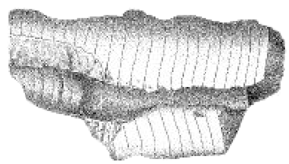
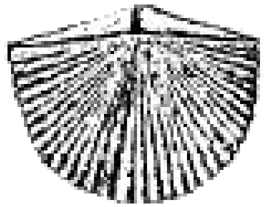
 Sedimentary Rock Beats Igneous	 Igneous Rock Beats Metamorphic	 Metamorphic Rock Beats Sedimentary
 Sedimentary Rock Beats Igneous	 Igneous Rock Beats Metamorphic	 Metamorphic Rock Beats Sedimentary
 Sedimentary Rock Beats Igneous	 Igneous Rock Beats Metamorphic	 Metamorphic Rock Beats Sedimentary
 Sedimentary Rock Beats Igneous	 Igneous Rock Beats Metamorphic	 Metamorphic Rock Beats Sedimentary

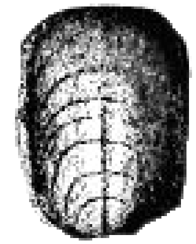
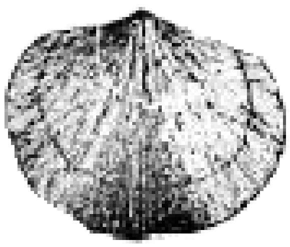
Fossil box identification card

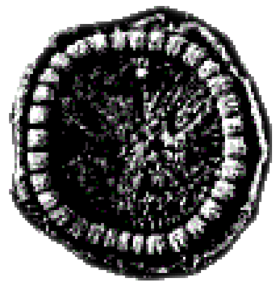
Glue Fossil Here Name of fossil: ____________________________ Type of fossil: _____________________________ How it ate: _______________________________	Glue Fossil Here Name of fossil: ____________________________ Type of fossil: _____________________________ How it ate: _______________________________	Glue Fossil Here Name of fossil: ____________________________ Type of fossil: _____________________________ How it ate: _______________________________
Glue Fossil Here Name of fossil: ____________________________ Type of fossil: _____________________________ How it ate: _______________________________	Glue Fossil Here Name of fossil: ____________________________ Type of fossil: _____________________________ How it ate: _______________________________	Glue Fossil Here Name of fossil: ____________________________ Type of fossil: _____________________________ How it ate: _______________________________

Fossil box: Ordovician fossil images

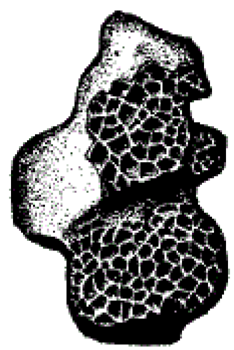
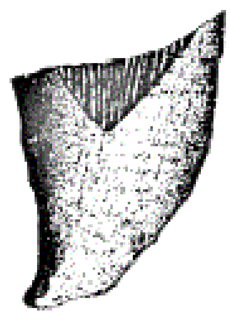
				
				
				

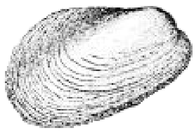
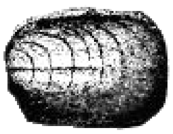
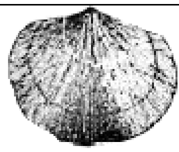
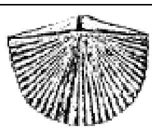
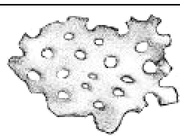
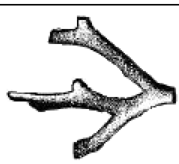
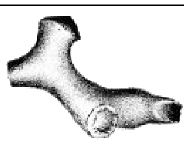
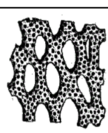




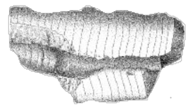
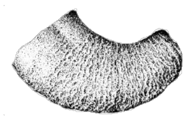
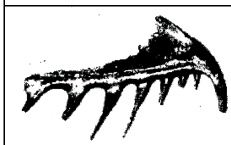
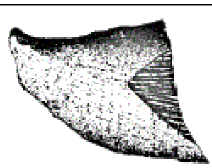
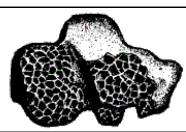


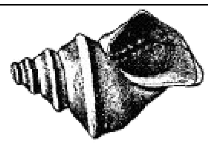
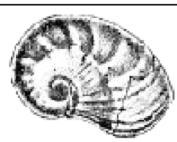
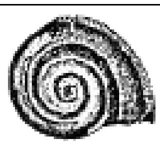
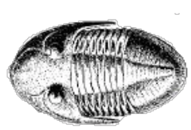
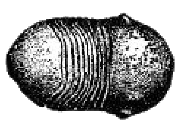


Fossil box: Ordovician fossils of Minnesota – Identification chart

Image	Fossil name	Type	Description of the fossil
	*Modiolopsis plana*	Bivalves (clams)	Bivalves, like brachiopods, are shelled creatures. Generally, their two valves are the same size and are mirror images of each other. Bivalves are filter feeders that can move around by means of a fleshy foot. Commonly, the form of the animal is preserved as a cast of the internal cavity between the two valves. The shells are usually not preserved, and fine growth lines and details are lost.
	*Vanuxemia obstusifrons*		
	*Pseudolingula elderi*	Brachiopods	Brachiopods are shelled organisms. Their shell is composed of two unequal halves called valves. Commonly, thin growth lines and ribs are preserved on the valves. Brachiopods usually attach themselves to the seafloor by a fleshy stalk that extends through one of the valves. They are filter feeders; but their tentacles remain inside their shell. Like bryozoans, they were abundant during the Ordovician Period, but are now rare.
	*Pionoderma subaequta*		
	*Hesperothis tricenara*		
	*Stictoporellina cribrosa*	Bryozoan	These fossils commonly resemble a twig, a ribbon, or a small fan with tiny pores. Others are biscuit or gumdrop shaped or encrust other fossils. Like corals, bryozoans live by filtering food from surrounding water with special tentacles. They are colonial organisms; each pore in the skeleton is home to one tiny animal. They were abundant during the Ordovician Period, but they are scarce in modern seas.
	*Stictopora mutabilis*		
	*Nematopora*		
	*Batostoma minnesotense*		
	*Constellaria*		

	*Cameroceras*	Cephalopods	Cephalopods of today include the octopus, squid, and the only living representatives with an outer shell – the pearly nautilus. The bodies of Ordovician cephalopods were like those of modern squid or octopuses, but the ancient cephalopods had an external shell that grew as a series of chambers. The animal occupied only the last, largest chamber. Ancient cephalopods were able to jet themselves rapidly through the water like the modern octopus and squid, and like them, captured their prey with their tentacles.
	*Metaspyroceras bilineatum*		
	*Zitteloceras clarkeanum*		
	*Chirognathus*	Conodonts	Conodonts are an extinct group of marine animals identified by their microscopic mineralized skeletal element. Their rapidly changing shape makes them good geologic time tools. Conodonts are believed to be jawless eel-like creatures. Scientists now agree that they were most likely predators and not filter feeders. They grew no larger than a few centimeters. Very few fossils of the soft body parts have been discovered.
	*Cordylodus*		
	Fisherites	Corals	Corals commonly found in the Decorah Shale are valley horn corals because their skeleton, which is preserved, looks like a tiny horn. Corals are simple animals that filter feed by capturing small floating sea life with their tentacles. Most modern corals are colonial, which means that many animals live together in one skeleton. Ordovician horn corals were solitary (having only one animal per coral skeleton). Many types of corals are abundant in today's oceans, but horn corals are extinct.
	*Lambeophyllum profundum*		
	*Lichenaria*		
	*Ectenocrinus*	Crinoids	Crinoids, relatives of sea stars and sea urchins, are spiny-skinned animals with five-fold body symmetry. The animal has a small, cup-shaped body made of calcified plates. Five arms, each with many branchlets, extend from this cup. The crinoid attaches itself to the sea floor by a stem and feeds itself by filtering food from the surrounding water with its branchlets. The columnals, which made up the stem, are common fossils. The body plates are less common, but also may be found.
	*Quintuplexacrinus*		

	*Cyclocystoides*	Echinoidea	Echinoidea belong the class of animals that include the starfish and crinoids. They have five-fold body symmetry. Echinoidea are globular to flattened skeletons composed of plates made of calcium with internal columns. Some may have had external spines. The mouth is typically located centrally on the underside and were first thought to be gill slits. Echinoidea would have eaten by gathering and filtering food using flexible tube feet that would filter sand and move food to the mouth.
	*Edrioasteroidea*		
	*Lophospira*	Gastropods	Gastropods most commonly possess one tightly coiled shell. Some shells are coiled in a plane (like a garden hose), and some are coiled in a spiral (like a cone). Snails without shells are called slugs. Although some modern snails have lungs and live on land, many others live under water. They are scavengers, finding food along the seafloor.
	*Crytolites retrotsus*		
	*Ophiletina angularis*		
	*Isotelus maximus*	Trilobites	Trilobites are long-extinct relatives of modern arthropods such as crabs and lobsters. Like these modern relatives, they shed or molted their hard external skeletons as they grew. Many of the fragments of trilobites found in rocks may be molted segments. Most commonly, the fossilized fragments are from the head or tail of the animal. Trilobites fed by scavenging along the sea bottom or by burrowed for food. Trilobite fossils are typically the most sought-after fossils, and the most difficult to find intact.
	*Bumastoides milleri*		

Sources:

Mossler, J.; Benson, S.; Runkel, A.C. (1995). Minnesota at a Glance Fossil Collecting in the Twin Cities Area. Minnesota Geological Survey. Retrieved from the University of Minnesota Digital Conservancy, http://hdl.handle.net/11299/59440

Minnesota Fossils and Fossiliferous Rocks, by Robert E. Sloan (2005). Privately printed (Winona, MN).

Southeast Minnesota sedimentary rock identification worksheet

This is what my rock looks like: (Draw a picture of the rock or describe using adjectives.)

Its chemical and physical properties include…

Hardness =

- ✓ Can the rock be scratched by a fingernail (hardness of 1-2.5)?
- ✓ Can the rock be scratched by a penny (hardness of 3-4)?
- ✓ Can the rock be scratched by a metal nail (hardness of 5-6)?

Grain size

- ✓ Are the grains visible without using a microscope (you might have to get close to the rock to see)?

Appearance

- ✓ What color is the rock—tan, gray, olive, slate, yellow, or red?

- ✓ Does the rock contain any fossils?

Now, identify your rock: These are rocks that are common in southeast Minnesota. Could it be….

- Sandstone: True to its name, sandstone consists of sand grains that have been cemented together as a result of time and pressure. Individual grains will be hard to identify with the eye, but the rock will have a rough and granular texture. Sometimes grains can be rubbed off, as they are not completely cemented together.
- Dolostone: This rock contains a large concentration of the mineral dolomite. The crystals can be transparent, gray, white, or pink. The rocks will be gray, tan, or white. It has a medium hardness of about 3-4.
- Limestone: Closely related to dolostone, limestone may contain shells and skeletal fossils of underwater creatures that once roamed the ocean when Minnesota was underwater. The rock appears tan to gray and does not break easily.
- Shale: Formed from muddy sediments deposits from ancient coastlines, shale appears greenish gray. The rock is soft and may chip into rough pieces that can be easily converted back into mud if soaked in water.

Your answer, and why:

Lesson two: What is karst?

I. Overview

This lesson explores the chemistry behind karst geology and the dissolving power of water—the reaction between limestone and naturally occurring acidic water. Students will then identify and map their community's karst features or water features and conduct oral history projects about water in their community.

MN State Science Standards

6E 3.1.1.2

Learning targets

1. Students will observe and compare the dissolution of materials in classroom experiments with the slow dissolution of karst bedrock, which causes gaps and openings in the rock.
2. Students will describe their own southeast Minnesota community, including karst features and human connection to that place.

Vocabulary

Familiarize yourself with the following terms: Dissolution, fracture, solvent, acid, base, watershed, and karst.

Materials

*An asterisk means the item is available in the lesson kit, see the "about" section for information.

For dissolving rocks demonstration

Teaspoon of salt
½ cup of water
Spoon
Tablespoon of baking soda
Vinegar
Dilute hydrochloric acid (Check with Chemistry staff at your district's high school)
Pipette (eyedropper)
Beaker (any clear jar or bottle)
*Carbonate rock

For exploring karst features

*Karst Plexiglas 3D model
*groundwater beads demonstration
*Decoding the Driftless documentary film (2018)
Map of karst regions (print or project on screen)
https://files.dnr.state.mn.us/waters/groundwater_section/mapping/gw/gw01_report.pdf

For community mapping and oral histories

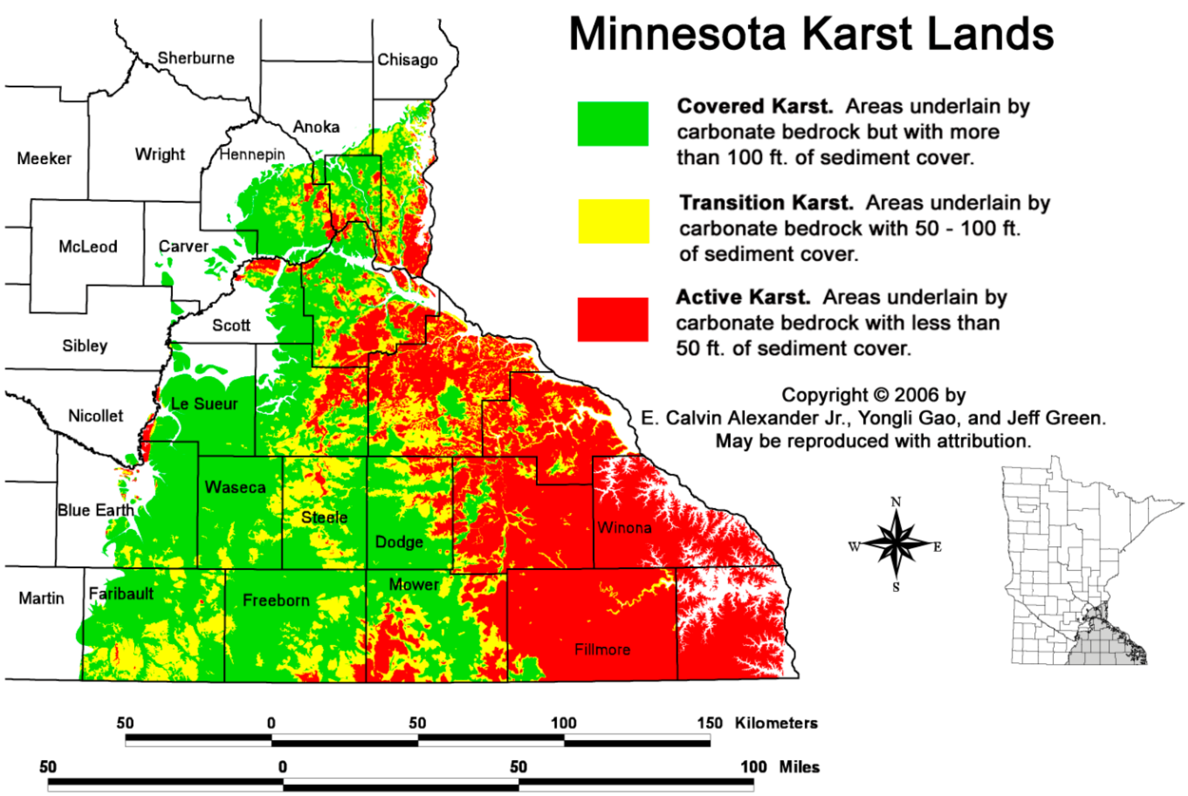
Small paper (like post-its), markers, large paper

II. Activities

A. Review of lesson one (5 minutes)

Southeast Minnesota has sedimentary bedrock—these are layers of sandstone, shale, limestone, and dolostone. Limestone and dolostone are carbonate rocks. Carbonate rocks are dissolvable by water. Cracks and openings have formed over thousands of years, and this is what we call karst geology. Today we will explore how dissolving rocks is possible.

This map shows Minnesota karst lands. The green areas have thick sediment cover left by glaciers, called glacial till. The red areas were not covered by the most recent glaciers. They have thin sediment cover. The bedrock is very near the surface.



An electronic version of this map, to print or show map on screen, can be found here: https://stormwater.pca.state.mn.us/images/f/fb/Minnesota_karst_lands.png

B. Dissolving rocks! A demonstration (15 minutes)

In chemistry, solvents are substances that dissolve other substances. Water is sometimes called the "universal solvent" as it dissolves many different substances.

You have seen water dissolve things many times. If you have ever put sugar in a drink, you were dissolving it. We are going dissolve salt (a mineral) in water to experiment with water's dissolving power.

- Place a couple scoops of salt in a beaker and make sure all students can see it. Then fill the beaker with water.

The salt appears to be gone, but it did not disappear. In fact, the salt is still in the beaker. We cannot see the salt because it has dissolved.

But rocks, even carbonate rocks, are not dissolved by plain water. The water must become acidic first.

Acids form when compounds dissolve in water and make hydrogen ions (H^+). The H^+ ions are corrosive, or highly reactive. They can destroy solid materials by a chemical reaction.

Vinegar is a weak acid. Hydrochloric acid, which they put in many cleaners, is a strong acid. Baking soda, the opposite of an acid, is known as a base. As a base, the baking soda reacts with the acidic vinegar and is dissolved.

- Place 1 tablespoon of baking soda in the beaker. Add 1-teaspoon vinegar (the acid) to the beaker using the pipette. Watch the reaction.

In southeast Minnesota, a similar reaction occurs between carbonate rocks and water in the soil.

Rain passes through Earth's atmosphere picking up carbon dioxide (CO_2), which dissolves in the water. Once the rain reaches the ground, it may pass through the soil where it gets more CO_2 from the air in the soil.

H_2O	+	CO_2	→	H_2CO_3
Water		Carbon dioxide		Carbonic acid

H_2CO_3 is a weak acid. The weak acid reacts with limestone or dolomite (carbonate rocks) causing them to slowly dissolve much in the same way the vinegar reacted with the baking soda.

$CaCO_3$	+ H_2CO_3	→ Ca^{2+}	+ 2 HCO_3
Calcium carbonate	Carbonic acid	Calcium ions	bicarbonate

- Place a carbonate rock on the table (limestone works best). Add 2-3 drops of diluted hydrochloric acid* (explain this acid does not occur in nature but will show more quickly how the process works) on the rock. Watch the reaction. What did students observe?
  *You should wear safety goggles and be sure to not get the acid on our skin, wash immediately to avoid irritation.

Compared to other rocks, carbonate rocks dissolve relatively fast by water. Carbonate rocks dissolve at a rate of about a half inch every 1,000 years— a rate similar to those evident on marble gravestones, where inscriptions from the late 1800s are becoming unreadable.

In geologic time, this rate is quite fast. Since the last glaciation, 10,000 years ago, this would equate to about five inches of weathering on a rock face, or close to a foot of weathering on opposing walls of a bedrock passage.

Over time, the carbonate bedrock develops a variety of gaps and spaces that water can enter into and move through at different speeds.

Places on earth with this type of bedrock are called karst regions or karst landscapes. Karst is a *terrain with distinctive landforms and the hydrology created from the dissolution of soluble rocks.*

Karst regions have both surface features that can be seen and underground features. On the surface, we see springs, sinkholes, and disappearing streams. Underground there are fractures, conduits, rapid groundwater flow, and caves. In karst landscapes, groundwater may emerge as a spring and flow a short distance above ground only to vanish in a disappearing stream—then possibly re-emerge farther downstream again as surface water.

If you have the lesson kit, let students play with the groundwater beads that flow through cracks and gaps in the rock, and set up the karst 3D Plexiglas model.

Unlike in other areas, rainwater does not collect in surface water like streams or lakes (which results in less mosquitoes, a plus in Minnesota!). Instead, water moves into these conduits, fractures, and pore spaces nearly everywhere across the watershed.

If there is contamination in the water, it can travel rapidly through the bedrock to drinking water wells and springs, which means our water is more easily polluted. More on that in Lesson three.

C. Decoding the Driftless – documentary film (90 min)

This feature length film, available in the lesson kit, is a film of science exploration and adventure. The filmmakers explore and decipher ancient clues of archaeology, paleontology, geology, and biology of the Driftless Region, with its captivating scenic beauty.

Learn more about this film at www.sustainabledriftless.org

D. Exploring karst features – online story map exploration (20-30 minutes)

Using computers or tablets, let students explore 14 karst features around southeastern Minnesota. You will visit springs, sinkholes, and caves. The student worksheet provided at the end of this lesson can guide students through the content.

The story map can be found at this link:

- https://mpca.maps.arcgis.com/apps/MapTour/index.html?appid=cb108141401d4e2bbb5b8b1356673ad5#

E. Mapping your community (20-30 minutes)

Having learned a little more about karst in southeast Minnesota, it is time to focus on our local community.

Pass out materials (post-its, markers, paper) and have the group construct a map of their community as they know it. Specifically, note places or karst features or where water flows/is used. Include community landmarks such as the school, post office, or sledding hill.

Here are a few examples of areas that could be included:

- Waterways: streams, rivers, lakes, ponds
- Water towers
- Water treatment facilities

- Parks, pools, and sport fields
- Environmental organizations, clubs, businesses, and schools
- Recycling or waste management areas
- Hiking and bike trails
- Farm fields

Ask participants to take turns naming places and drawing them in their location. Encourage participants to think about how places have connections to water. The more places that are mapped, the more you will be able to infer about how the group understands their community.

If desired, allow individuals to write short descriptions or memories of a time they interacted with water on notecards or sticky notes and locate them on the map. Point out the things they mapped that are karst features. Keep this map to refer back to during the oral history project (below) and the Living on Karst student research project (lesson #4).

F. Collecting stories from community members (oral histories)

An oral history is a history “based on storytelling and listening” (Kathy Walbert, Duke University and the Southern Oral History Program, www.sohp.org). Individuals can produce simple oral histories of their community’s water story by interviewing others about past and present water use. Group members can interview family members, neighbors, or friends. Alternatively, a teacher or group leader can invite older community members into the classroom to speak to the group and answer questions. A partnership with a local senior center might be a good source of stories.

Conducting interviews teaches useful skills for carrying out conversations and attentive listening. Go over a simple interview process and safety precautions with participants before they conduct their interviews.

- Make plans: coordinate times and locations with the interviewee, prepare questions.
- Be safe. Tell someone where you are going and when you plan to be back.
- Take careful notes—even if using a recording device. Note *where* certain stories took place and ask permission to take a picture of the interviewee.
- Be curious and respectful. Ask follow-up questions to show that you are listening and that the interviewee’s stories are important to you. Follow the interviewee’s lead on the level of formality and listen to their cues.

Have students practice interviewing each other before interviewing community members.

Gathering stories

1. Use the Interviewing Community Members Guide to conduct interviews.
2. Remember to bring along a notebook and writing utensils, a list of questions, and perhaps a camera or audio recorder.

Sharing our stories

When the interviews are complete, have the group discuss their findings, first in small groups and then as a whole. Ask participants in their small groups to select a few key points or quotes from their interviews to share with the whole.

a. What was the experience of interviewing like? What were the challenges/successes?
b. What did you learn from your interviewee?

Have each participant write down key quotes or stories they learned from their interview twice each on notecards or sticky notes.

a. Post the first set of quotes around the map with string or drawn lines pointing to the location of the story. Include the pictures if possible.
b. Identify common themes/celebrations/concerns about water in your community from the selected quotes/stories. List these commonalities as headings on a large piece of paper or whiteboard and post the second set of quotes under the best fitting heading. Discuss any patterns you notice.

Post the map. Consider posting it in a public place such as a library or community center and providing materials so others can add their own stories and memories.

Optional extension: Create an ArcGIS story map. https://storymaps.arcgis.com/en/

Optional extension: Have participants write an essay about their community's water story incorporating quotes from interviewees. What makes your community's stories unique?

G. Visit a real cave!

If you live near Mystery Cave State Park or Niagara Cave, consider visiting! These caves are safe and legal to visit. Other caves may be on private property or dangerous. Only visit safe, legal caves.

III. Extra resources

Minnesota Pollution Control Agency Legislative Fact Sheet, Karst Workgroup recommendations. This provides background into management strategies and background into the potential issues with karst geology: https://www.pca.state.mn.us/sites/default/files/karst01.pdf

Karst Topography—Teacher's Guide and Paper Model from USGS
Report provides background into karst and offers more insights into caves which could provide the basis for a field trip: https://geomaps.wr.usgs.gov/parks/cave/karst.html

National Parks Cave and Karst Interactive Tour
http://pbs.panda-prod.cdn.s3.amazonaws.com/media/assets/wgbh/ess05/ess05_int_caveintro/index.htm

PBS Learning Community: Cave formation – Kane Cave
https://tpt.pbslearningmedia.org/resource/ess05.sci.ess.earthsys.kanecave/cave-formation-kane-cave/

Minnesota Spring Index – Interactive map of springs throughout the state. This interactive map allows people to see where springs are located in the state and find out some basic information about the spring. https://www.dnr.state.mn.us/waters/groundwater_section/springs/msi.html

The **Minnesota Groundwater Tracing Database** (MGTD) contains information from nearly 400 groundwater traces in Minnesota.
https://www.dnr.state.mn.us/waters/programs/gw_section/springs/dtr-list.html

IV. Assessment

Pick a karst feature and create a model by drawing a picture of it. Include what can be seen on the surface as well as what the underlying layers look like. Describe how the feature is formed using vocabulary like dissolving, carbonate rock, chemical reaction, acid, bedrock, or aquifer.

Karst in Minnesota story map tour

Story map can be found at:
https://mpca.maps.arcgis.com/apps/MapTour/index.html?appid=cb108141401d4e2bbb5b8b1356673ad5#

1. Limestone cutaway: What clues of karst can we find in roadside cutaways?

2. Fountain's Big Spring: How do you think the presence of a spring impacts its surrounding area?

3. Muddy springs: When a spring is muddy, where is that excess sediment coming from? Where have you seen erosion in your community or where do you think the landscape would be vulnerable to erosion?

4. Trout streams: What could some ecological, social, and economic impacts be of losing brook trout in southeastern Minnesota?

5. Sinkholes: Look at the image of this sinkhole and at the satellite map imagery. What potential pollutants could enter our groundwater here?

6. Fountain Sinkhole: People did remediation work on this sinkhole and instilled a drain to prevent the sinkhole from getting any bigger. Look at the map and notice all the dots of trees in the middle of farm fields. These are all sinkholes. What might the presence of so many sinkholes in farm fields mean for the water quality in Fountain, Minnesota?

7. Sinkhole dumps: Historically dumping waste in sinkholes was very common. This still occurs today in some places, and many sinkholes are still filled with trash. What are the consequences of dumping garbage in a sinkhole? What can we do to stop this from happening? List some ideas.

8. Dye tracing: Why is it hard to understand where water comes from and goes to in karst country?

9. Moth Spring: Look at the map. Where does the water from Moth Spring flow to?

10. York dye tracing: Describe a disappearing stream.

11. Holy Grail Cave: What can happen in karst landscapes when vast amounts of water flood the system?

12. Odessa Spring: Zoom out on the map until you can see the place markers labeled 10, 11, and 12. What is the relationship between these sites on the map?

13. Devil’s Den Spring: Have you ever visited a spring or a cave? Tell about it.

14. Goliath’s Entrance: What impact might the restoration of native prairie have on the water quality around the Cherry Grove Blind Valley SNA?

Interviewing community members guide

We can learn about the history of our watershed by interviewing community members. At your interview site, introduce yourself and explain the purpose of the project. Be prepared to share about yourself during the conversation.

Ask some of the following questions and the ones you have brainstormed, listen carefully, write down major points, and ask follow-up questions.

- How long have you lived in this area?
- What childhood memories do you have relating to the water in our area?
- Have any of your jobs ever depended on local waters?
- Can you tell any stories of using local water for pleasure or recreation?
- Do you know of any old customs or traditions that involved the water?
- Can you tell any stories of memorable characters in our community relating to the water?
- What changes have you seen in the area relating to the water or the area surrounding the water?
- Do you know of any pollution affecting the water in our area, either now or in the past?
- What changes would you like to see in the future that relate to our water?

In your notes, write down at least two interesting quotes from the interview, which illustrate the history of the area and activities relating to the water.

Be sure to thank your interviewee for their time and stories!

Lesson three: How does groundwater move in karst landscapes?

I. Overview

In this lesson, students use a phenomenon statement to facilitate inquiry about karst and groundwater. They will learn about aquifers, how water moves in southeast Minnesota, and why southeast Minnesota aquifers are vulnerable to contamination.

MN State Science Standards
6E 3.2.1.2

Learning target(s)

1. Students will describe the hydrologic, or water, cycle, especially the groundwater recharge process.
2. Students will examine how pollutants can threaten groundwater health and make management difficult.
3. Students will discover where their water comes from in their city and home.

Vocabulary
Familiarize yourself with the following terms:
Groundwater recharge, glacial till, nitrate

Materials
*An asterisk means the item is available in the lesson kit, see the "about" section for information

Kitchen tap water contaminant phenomenon statement

Poster paper (3-5/class)
Small paper (like post-its)

Aquifer demonstration

Sand, water, clear container, soap pump

How groundwater moves in SE Minnesota
Link to videos and posters
Copies of worksheet

Geologic problem solving
Online access to the Fillmore County Geologic Atlas (link below)
Copies of the problem solving scenarios

II. Activities

A. Kitchen tap water contaminant phenomenon statement (40-50 minutes)

One spring day, a woman was drawing some water from her kitchen tap, and she noticed grains of wheat in the water.

Read the phenomenon statement to the class.

1. Divide your class into groups and give them a copy of the statement.

2. Instruct them to come up with questions/ideas/observations from the story.
    a. Place ONE question/idea/observation on each post-it.
    b. Come up as many different things as possible. Examples: Why wheat? Could other solids come through? What would allow that to happen? Where did the wheat come from? Could it happen at my house?

3. Groups will read out one of their post-its to the class, any groups with a similar question will take their post-it and attach them together like a chain on the board.

4. Repeat Step 3 until no new chains can be built. (Groups may have post-its left.)

5. Decide on a category for each of the post-its now chained together. Label as many posters as needed for the categories. Place each chain on one of the posters with the category now labeled on it.

6. Continue the process with your students to create 3-5 labeled posters and have the groups sort and place all their remaining post-its on the matching poster. (Examples: Why did it happen? Could it happen at my house? How can it be fixed? One could even be labeled miscellaneous.)

Your class has created a list of questions that should inspire, intrigue, and hook them into learning more about the karst topography and the importance of protecting its watershed and ground water.

Once you have completed the activity, you can choose to read the Wheat in Water story, provided at the end of this lesson, to your students or have them read it in their groups. What other discussion does the full story elicit?

B. Aquifer in a cup (20 min)

In most of Minnesota, groundwater is the water we drink and the water that grows our food. A few communities use surface water streams for water supply. Groundwater is found underground in the cracks and spaces between sand and soil and in bedrock formations. These saturated underground formations where water can be extracted are called aquifers. We are going to build an aquifer in a cup to simulate the groundwater recharge process.

1. Start by filling a clear cup with sand/gravel.
2. Add water, filling the cup until half of the sand/gravel is saturated. Where did the water go?
3. The water filled in the spaces between the particles of sand/gravel. This represents groundwater. It is stored in formations called aquifers.
4. Look closely at the line created by the water. This line is called the water table. The area below the water table is called the saturated zone. The unsaturated zone is above the water table.
5. Add more water; pretend the water is rain from a storm cloud. Watch the water table. The groundwater supply has been recharged. This is what happens when it rains or snows and water infiltrates (sinks) into the ground.
6. Continue to fill the cup with water until the water covers the gravel/sand. This water is called surface water. It includes rivers, lakes, and oceans.
7. Use a clean soap or lotion pump to simulate a well. Wells bring groundwater up to our houses and towns. Pump groundwater out of the model aquifer.

See “Aquifer in cup” for the origin of this activity:
https://www.groundwater.org/kids/popularactivities.html

C. Video: How water moves in southeast Minnesota (25 minutes)

How groundwater moves in southeast Minnesota was produced in 2020 and is available online. Part one describes the hydrogeology of the Root River watershed in southeast Minnesota. It steps through the differences between glacial till, karst, and bluffland karst landscapes. Drone footage and computer images show how water moves into, through, and out of karst bedrock. Part two describes the possible movement of contaminants in these landscapes and points out vulnerabilities.

- Visit https://www.mda.state.mn.us/segwresources

Students can follow along and answer questions on the worksheet found at the end of this lesson. Printable posters of the three landscapes are also available on the website.

D. Geologic problem solving using a geologic atlas (30 minutes)

Karst aquifers’ vulnerability to pollution makes living in these areas unique, especially for governments, businesses, and homeowners who must think about their impact on the land before acting. This activity presents a series of environmental policy scenarios for students to work through, testing their problem solving skills using maps.

Introduce students to the Fillmore County Geologic Atlas.

The worksheet provided at the end of this lesson presents two scenarios for student to problem solve. Students should have access to the “Fillmore County Geological Atlas” plates to decide which factors they will use to give a solution, found here:

https://www.dnr.state.mn.us/waters/groundwater_section/mapping/county-geo-atlas.html

This is a challenging exercise, so consider doing the first one together, and then having students work on the second one in pairs or groups or as homework.

III. Extra resources

Minnesota Groundwater Provinces Map

This map provides context for the groundwater in Minnesota and describes the characteristics of the provinces. https://www.dnr.state.mn.us/waters/groundwater_section/mapping/provinces.html

Groundwater atlas of the U.S.

This website gives a detailed, high-level background about the aquifer that Minnesota shares with Iowa, Michigan, and Wisconsin. https://pubs.usgs.gov/ha/ha730/ch_j/

DNR guest lecture

The Minnesota Department of Natural Resources employs many hydrogeologists, many of whom are willing to share about their work with students! The DNR also owns a groundwater model that can show how water moves. Reach out to your local DNR office to inquire about a visit from a professional: www.dnr.state.mn.us

IV. Assessment

Online groundwater vocabulary test

This website provides a fun fill-in-the-blank game about groundwater vocabulary http://pbslm-contrib.s3.amazonaws.com/NET_NEB/WaterTermGame/index.html#&panel1-1

Wheat in the water

This is a memory told by Dr. James VanAlstine Sr., Professor of Geology, University of Minnesota-Morris. His story was retold by email on February 29, 2020, for this project.

“Here is the story as best I can remember it. Hope this helps”.

“Over 30 years ago, I was working on groundwater issues with local units of government, and part of the process was to hold meetings to discuss issues at the county level with local regulators. Groundwater pollution was always the main topic. At one meeting in southeast Minnesota, I was told about a farm family living in rural Fillmore County in the heart of the Minnesota karst region that had the following experience. I did not talk to them personally, but have no reason to doubt this narrative.

The family’s drinking water supply was from a shallow well in the surficial aquifer. The well was less than 30 feet deep, old, poorly screened, and obviously in poor shape. The aquifer was in the decomposed limestone karst bedrock that underlies much of southeast Minnesota. The karst formation is the same unit that contains the southeast Minnesota cave and cavern systems. Groundwater in that system flowed like streams through cracks and crevasses in the rock, instead of soaking through pores in sand or gravel. The karst bedrock topography is recognized on the ground surface by prominent sinkholes, depressions resulting from the surface soil falling or washing down into the underlying caves. This material ends up in underground streams in the caverns, where it flows unfiltered by soil or gravel until it comes out as a spring on the surface at some other place.

The family had used this well for years. One spring day, the husband was getting rid of some old waste grain from one of their storage bins, and threw it into a nearby sinkhole. It was a convenient hole in the ground that needed to be filled in [according to his thinking]. Things thrown into the sinkhole often disappeared after heavy rains, which he considered a bonus. Out of sight out of mind.

He didn’t know that the sink hole led directly to the source of their drinking water. A day or so later, the wife was drawing some water from the kitchen tap, and she noticed grains of wheat in the water. They called the county officials who investigated the sink hole that still contained some of the grain her husband had thrown in, a couple of old cars, and a dead cow and two pigs, all mostly decomposed. All of that, as well as anything else that had been washed or thrown into the sinkhole was part of their drinking water.

Needless to say, they quit using the surficial karst system aquifer, and started looking for a deeper aquifer, from a rock unit that provided filtration as the water moved through it.

Don’t know what ever happened to the family.”

How groundwater moves in southeast Minnesota – video worksheet

Video can be found at: www.mda.state.mn.us/segwresources

1. Groundwater can move down due to _________________________, sideways due to different rock properties, and upwards due to _________________________.
2. Glacial till is material laid down over bedrock by ___________________________.
3. Limestone dissolves relatively fast because of ___________________ water in rain and soils.
4. ____________________is characterized by springs, sinkholes, disappearing streams, enlarged bedrock fractures, rapid groundwater flow, and caves.
5. Most rain and snowmelt becomes groundwater NOT by flowing into ______________________ but through infiltration into the ground and rock throughout the entire land surface.
6. The _____________________ of the space dictates how fast water moves through karst bedrock.
7. Conduits large enough to walk through are called _______________.
8. Groundwater found below shale layers may be _______________________ old.
9. The bluffland karst area has groundwater pushing upwards and supplies the cold water for ______________ streams.
10. Most contaminants in the ground water are a result of human activity on _____________________.
11. The most common water contaminant is ________________________ from human waste, animal manure, and fertilizer.
12. Downward movement of nitrate through soil is known as ______________________________.
13. Shallow wells typically have a __higher or lower_____ concentration of nitrates and deep well (Choose one) typically have a ____higher or lower_______ concentration of nitrates. (Choose one)
14. Nitrate concentration is increasing at a rate of __________% per year.
15. Rural homeowners are doing many things to protect groundwater. Name any two ways they are doing this. ________________________________ & ______________________________

Answer key

1. Gravity, pressure
2. Glaciers or glacial ice
3. Acidic
4. Karst
5. Sinkholes
6. Size
7. Caves
8. Centuries
9. Trout
10. Land surface
11. Nitrate
12. Leaching
13. High, low
14. 2
15. (Any 2) Sealing abandoned wells, fixing leaky septic systems, keeping sinkholes free of trash, using household hazardous waste collection programs

Geologic problem solving

Our community needs to make some decisions. You will use underground maps, called geologic atlases, to recommend what to do.

To answer these questions, you will need access to the Fillmore County Geologic Atlas plates, found here: https://www.dnr.state.mn.us/waters/groundwater_section/mapping/county-geo-atlas.html

Scenario One:

The county needs a new landfill. The new site will need to have geology that can deal with the impacts of contaminants and pollution leakage. Desirable site characteristics include:

- Bedrock deeper than 50 feet
- Sensitivity of the aquifer to pollution
- Low water table (deep under high elevations and shallow under lowlands)
- Non-geological factors: access to roads, short distance for the garbage to be hauled, etc.
- Land factors: proximity to homes or farms, proximity to karst features

What type of information will you need to come up with a solution?

Which map "plate(s)" did you consult to solve this?

What is your proposed solution? What actors (governments, businesses, citizens, etc.) will be affected?

Scenario Two:

A gasoline truck heading toward a gas station in Preston via US-52 turns over just north of Fountain, Minnesota, causing its contents to leak onto the ground. The contaminants need to be stopped before they damage the groundwater in the area.

What plate(s) should you consult?

What aquifers would be at risk?

Once in an aquifer, where would the gasoline go?

How could this problem be avoided in the future? What actors would need to be involved?

Lesson four: Living on karst

I. Overview

Students will research types of groundwater pollution, where the contaminants come from, and what communities are doing to protect the health of people and wildlife in the karst region of Minnesota.

MN State Science Standard(S)

6E 2.1.1.3

6E 3.2.1.3

Learning targets

1. Students will recognize the challenges of living in karst regions.
2. Students will describe technological advancements and solutions to common karst features.
3. Students will identify human influences on karst features.

Materials

This lesson does not require any extra materials.

II. Activities

A. Issue investigation (40-50 minutes)

From what we learned in lesson three, we know that groundwater in karst is sensitive to pollution. Let's explore types of pollution, where they come from, and what communities are doing to protect the health of people and wildlife.

Choose one or more of these investigation activities for your students:

- Students choose a groundwater contaminant to learn about and make a poster. Some good choices to guide them toward or assign would be nitrate-nitrogen, phosphorus, and bacteria. Posters could include information on sources, why it is a problem, and solutions for reducing this contaminant and/or protecting people and wildlife. Present posters to each other.
- Have students research a problem from a karst region such as Altura's sewage lagoon, the Petersen fish hatchery, or Fountain's storm water and how the community solved the problem and what measures they are taking to prevent further problems.
- Give students a description of a real Legacy Amendment grant from Fillmore County for a water conservation project. Ask them to talk through the problem that the area was facing and the proposed solution. Fillmore County Legacy Amendment Projects found here: https://www.legacy.mn.gov/projects?search_api_fulltext=fillmore+county+&f%5B0%5D=project_facet_source%3A10

III. Extra resources

Nitrate in drinking water

Information from the Department of Health.
https://www.health.state.mn.us/communities/environment/water/contaminants/nitrate.html

How is the water?

An overview of Minnesota's common pollutants and where they come from.
https://www.pca.state.mn.us/hows-the-water

IV. Assessment

Personal action plan

Have each student develop and write a personal action plan for preventing groundwater contamination. This is a personal action plan, so they are developing a way to modify their behavior (and their family's behavior) to limit the amount of groundwater contamination caused by them.

Appendix: Karst lessons science standard alignment

This chart shows the Minnesota K-12 Academic Standards in Science with which each lesson aligns.

Grade 6
Earth's Systems and Processes

Strand	Standard	Code	Benchmark	Lesson and Activity
1. Exploring phenomena or engineering problems	Students will be able to ask questions about aspects of the phenomena they observe, the conclusions they draw from their models or scientific investigations, each other's ideas, and the information they read.	6E.1.1.1.1	Ask questions to examine an interpretation about the relative ages of different rock layers within a sequence of several rock layers. (P: 1, CC: 1, CI: ESS1) *Emphasis is on the interpretation of rock layers using geologic principles like superposition and cross-cutting relationships*.	1
2. Looking at data and empirical evidence to understand phenomena or solve problems	2.1.1 Students will be able to represent observations and data in order to recognize patterns in the data, the meaning of those patterns, and possible relationships between variables.	6E 2.1.1.2	Develop a model, based on observational evidence, to describe the cycling and movement of Earth's rock material and the energy that drives these processes. (P: 2, CC: 5, CI: ESS2) *Emphasis of the practice is on using observations of processes like weathering and erosion of soil and rock, deposition of sediment, and crystallization of lava to inform model development. Emphasis of the core idea is on how these processes operate over geologic time to form rocks and minerals through the cycling of Earth's materials. Examples of models may be conceptual or physical.*	1 & 2
3. Developing possible explanations of phenomena or designing	3.1.1 Students will be able to develop, revise, and use models to represent the students'	6E 3.1.1.3	Develop a model, based on observational and experimental evidence, to describe the cycling of water through Earth's systems driven by energy from the sun	4

Strand	Standard	Code	Benchmark	Lesson and Activity
solutions to engineer problems	understanding of phenomena or systems as they develop questions, predictions and/or explanations, and communicate ideas to others.		and the force of gravity. (P: 2, CC: 5, CI: ESS2) *Emphasis of the practice is on developing a way to represent the mechanisms of water changing state, the global movements of water and energy, and on how the observational and experimental evidence supports the model. Examples of models may be conceptual or physical.*	
3. Developing possible explanations of phenomena or designing solutions to engineer problems	3.2.1 Students will be able to apply scientific principles and empirical evidence (primary or secondary) to explain the causes of phenomena or identify weaknesses in explanations developed by the students or others.	6E 3.2.1.1	Construct a scientific explanation based on evidence from rock strata for how the geologic time scale is used to organize Earth's 4.6-billion-year-old history. (P: 6, CC: 3, CI: ESS1) *Emphasis is on how analyses of rock formations and the fossils they contain are used to establish relative ages of major events in Earth's history. Examples of major events may include the evolution or extinction of particular organisms, the formation of mountain chains and the formation of ocean basins. Not included is using radioactive decay to age date rocks.*	1
3. Developing possible explanations of phenomena or designing solutions to engineer problems	3.2.1 Students will be able to apply scientific principles and empirical evidence (primary or secondary) to explain the causes of phenomena or identify weaknesses in explanations developed by the students or others.	6E 3.2.1.2	Construct a scientific explanation based on evidence for how the uneven distribution of Earth's mineral, energy, or groundwater resources is the result of past geological processes. (P: 6, CC: 2, CI: ESS3) *Emphasis is on how these resources are limited and typically non-renewable on a human timeframe. Examples of uneven distribution of resources may include petroleum (like in the North Dakota Bakken Shale),*	3

Strand	Standard	Code	Benchmark	Lesson and Activity
			metal ores (like iron in the rocks of Minnesota's Iron Range), or groundwater in the different regions of Minnesota.	
3. Developing possible explanations of phenomena or designing solutions to engineer problems	3.2.1 Students will be able to apply scientific principles and empirical evidence (primary or secondary) to explain the causes of phenomena or identify weaknesses in explanations developed by the students or others.	6E 3.2.1.3	Apply scientific principles to design a method for monitoring and minimizing a human impact on the environment.* (P: 6, CC: 2, CI: ESS3, ETS1) *Emphasis of the practice is on applying scientific principles about Earth's natural processes (like how water moves through the ground and air) to designing solutions to problems caused by human activity. Emphasis of the core idea is on how human activity impacts Earth's environments. Examples of parts of the design process may include assessing the kinds of solutions that are feasible, and designing and evaluating solutions that may reduce those impacts. Examples of human activities that impact the environment may include withdrawing too much water from aquifers, altering stream flow by building dams or levees, increasing runoff caused by impermeable surfaces like parking lots, or adding undesirable materials to the air, water or land.*	4
4. Communicating reasons, arguments and ideas to others	4.1.1 Students will be able to engage in argument from evidence for the explanations the students construct, defend and revise their interpretations when presented with	6E 4.1.1.1	Construct an argument, supported by evidence, for how geoscience processes have changed Earth's surface at varying time and spatial scales. (P: 7, CC: 3, CI: ESS2) *Emphasis is on how processes like erosion, deposition, mountain building, and volcanism affect the surface of Earth. Some processes, like*	2

Strand	Standard	Code	Benchmark	Lesson and Activity
	new evidence, critically evaluate the scientific arguments of others, and present counter arguments.		*mountain building take a long time. Other processes, like landslides, happen quickly. Examples may include how weathering, erosion and glacial activity have shaped the surface of Minnesota.*	