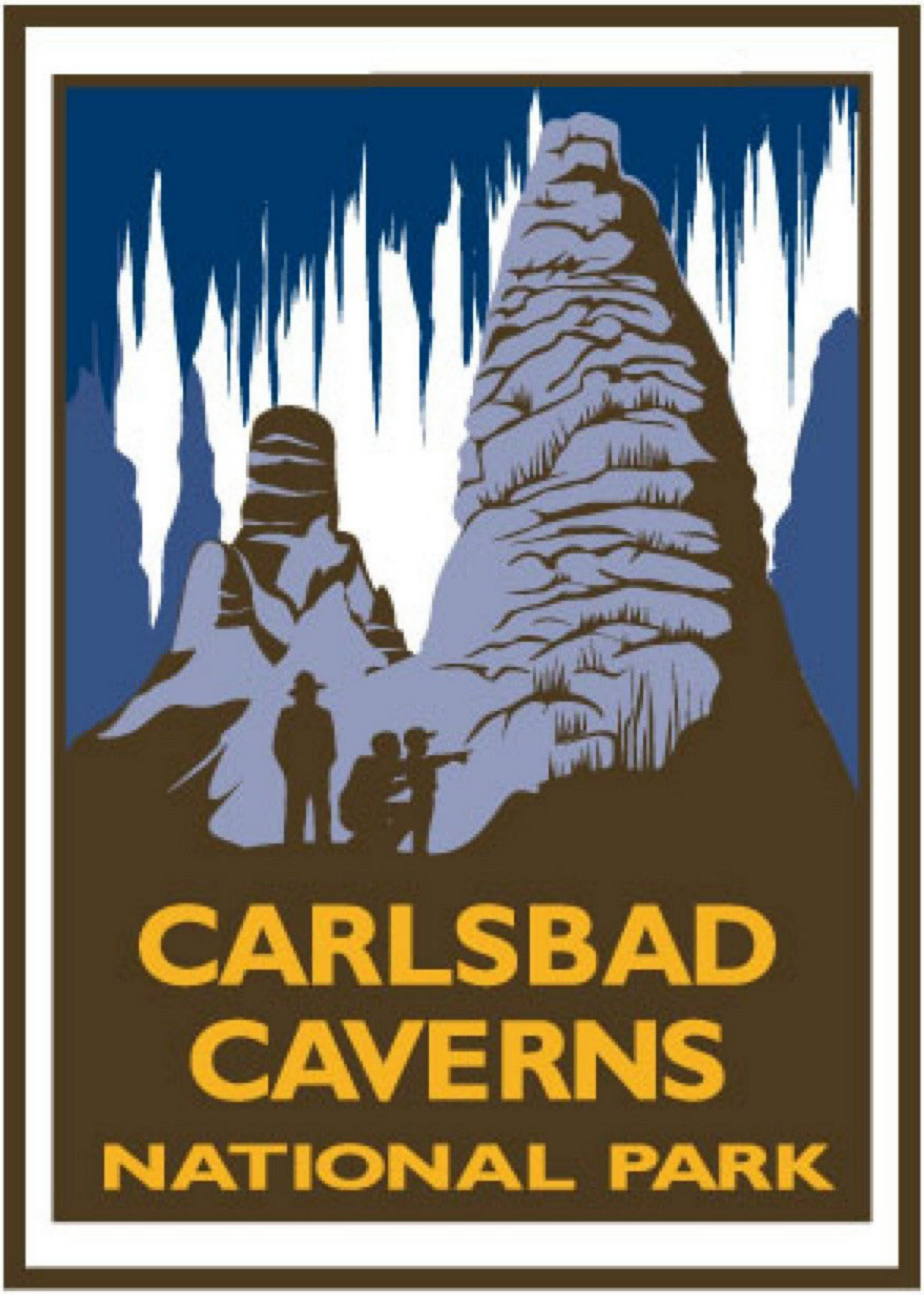
A curriculum and activity guide for Carlsbad Caverns National Park

High School Geology



Carlsbad Caverns National Park

High School Geology Curriculum

The present is the key to the past; unlocking the geologic history of southeastern New Mexico and west Texas

9-12 grades
Lesson #1

Prerequisites: general understanding of weathering and landscape evolution, topographic maps, and map attributes
Estimated time: Labs (50 min/each) or 1 fieldtrip (about 3 hours)
Location: in lab or in field (at the McKittrick Canyon nature loop)

Learner outcomes
The learner will:

- Make field or lab observations of Permian marine fossils.
- Use inquiry and geologic clues to infer paleoenvironment from comparisons with modern analogs.
- Use topographic and geologic maps.
- Learn about the geology of the Delaware Basin and Guadalupe Mountains during the Permian Period.

Vocabulary: Permian Period, geology, geologist, reef, forereef, backreef, lagoon, paleontology, sponge, algae, brachiopods, cephalopods, crinoids, bryozoans, flora, fauna, fossil, fossilization process, deposits, cement, cemented, evaporites, interpretations, iterative process, bathymetric map, bathymetry, aerial photograph, evaporite, landscape, analog, geomorphology, marine environment, paleoenvironment, stratigraphy, geologic formation, geologic cross-section, topographic map, topography, topographic profile, Delaware Basin, Guadalupe Mountains, Carlsbad Caverns National Park, limestone, bluff, corals

Background information
The Delaware Basin and Guadalupe Mountains region of southeastern New Mexico and Western Texas is rich with unique geologic features. Once covered by a sea approximately 250 million years ago during the Permian Period, many of the preserved rocks, fossils, and geologic formations are the best examples of these ancient marine environments in the world.

The Capitan Formation, a resistant limestone bluff that creates the peaks of the Guadalupe Mountains, represents an ancient reef in this sea. Different from modern reefs, which are composed of large branching corals and other flora, the Capitan reef was primarily composed of sponge and algae, containing only a few types of small corals. The Capitan also possessed ample brachiopods, cephalopods, crinoids, and bryozoans. These ancient fauna are preserved in the rocks as fossils resistant to erosion after the fossilization process. Also preserved in the area are the backreef lagoon deposits (the Seven Rivers, Yates, and Tansill Formations), the forereef deposits composed of cemented reef material that slid into the basin, and basin evaporites that were deposited as the sea retreated and evaporated.

Geologists have studied and made interpretations about the area and its ancient deposits since the early 1900s. Further understanding of this ancient landscape, which may be viewed at

Carlsbad Caverns National Park, has been accomplished through comparisons of the preserved Permian deposits and fossils to those found in modern reef systems. The comparison and contrast of fossils and ancient deposits with modern analogs is an iterative process that enables geologists to understand the past history of a region. In this lesson students will infer the Permian paleoenvironment of the region through investigations of geomorphology and faunal observations of ancient and modern marine environments.

Pre-activity thought questions: Do landscapes change through time? What is geology/a geologist? How did the local landscape form? What can fossils tell geologists about a rock?

Materials needed
- Photographs of the Guadalupe Mountains and Delaware Basin (slides #1-7)
- Photographs of modern reefs (slides #35-37)
- Topographic map of Carlsbad Caverns National Park (slide #80)
- Bathymetric image of a carbonate shelf (slide #30)
- Comparative image of Delaware Basin and Bahamas (slide #31)
- Diagram of Delaware Basin (slide #33)
- Science notebooks
- Schematic of the local stratigraphy (slide #19)
- Geologic time chart (slide #8 or 9)
- Guide to Permian marine fossils (slides #104 -109)
- Major Permian marine fossils (either in the rocks on the fieldtrip or invertebrate fossil hand samples for the lab).

Assessment
- Field notes
- Topographic profile

Procedure (if in the field)
The teacher will:

- Show students the satellite image of the Guadalupe Mountains at the entry area of McKittrick Canyon and ask what the mountains might have in common with the photos and bathymetric image of a modern reef (explain satellite images and bathymetric maps if the students haven't seen them before). Give students a chance to respond and think about possible relationships.
- Ask what clues would be necessary to determine a relationship between the two environments (what's missing?). How could the modern geologic configuration be explained?
- Define the term "geology" and explain that geologists put together clues found in the field today to interpret the paleoenvironment of an area.
- Talk about the geologic time chart and explain that life was different in the Permian Period in this region.
- Lead students on the McKittrick Canyon nature trail—have the students look for, describe, and identify several of the fossils using the guide and record their findings in their science notebooks.

- Return to the entry area and discuss findings—show fossil samples.
- Have students brainstorm about the paleoenvironment. Compare Guadalupe Mountains fossils to reconstructed photos and contrast with samples (if possible) of modern reef fauna. Discuss how items became fossils (process of fossilization).
- Define the terms: geologic formation, geologic cross-section, and stratigraphy.
- Look at the stratigraphic diagram and explain where the reef was and which rocks in the Guadalupe Mountains correspond to these sections (The reef of the Capitan formation is the massive limestone bluff; the horizontal layers of the Yates and Tansill behind the bluff are the back reef/lagoon areas; and the sloping layers in front, such as the Lamar Fm. are the forereef deposits, or slump. This was the last unit that was hiked through).
- Back in the lab explain how to construct a topographic profile.
- For homework, have students produce a topographic profile from A to A' on the Carlsbad Caverns National Park map.

Procedure (if in the lab)
The teacher will:

- Show the satellite image of the Guadalupe Mountains and ask what they might have in common with the photos and bathymetric image of a modern reef (explain satellite images and bathymetric maps if the students haven't seen them before). Give students a chance to respond and think about possible relationships.
- Ask what clues would be necessary to determine a relationship between the two environments (what's missing?). How could the modern geologic configuration be explained?
- Define the term "geology" and explain that geologists put together clues found in the field today to interpret the paleoenvironment of an area.
- Pass out fossil samples and have students describe and identify several of the fossils using the guide and recording their findings in their science notebooks.
- Discuss how items become fossils. Brainstorm about the environment. Compare to diagrams and contrast with samples (if possible) of modern reef fauna.
- Define the terms: geologic formation, geologic cross-section, and stratigraphy.
- Look at the stratigraphic diagram and explain where the reef was and which rocks in the Guadalupe Mountains correspond to these sections (reef is the massive limestone bluff—Capitan formation; horizontal layers of the Yates and Tansill behind the bluff is the back reef/lagoon area; and the sloping layers, such as the Lamar Fm., in the front are the forereef deposits, or slump).
- Back in the lab explain how to construct a topographic profile.
- For homework, have students produce a topographic profile from A to A' on the Carlsbad Caverns National Park map.

Follow-up questions: If the Guadalupe Mountains were a reef 250 million years ago, where did the sea go? What has happened to the landscape between the Permian Period and the present? What other things might geologists need to learn about an area to correctly assess the past environment? What other tools might geologists use to determine geology of this area (other than just fossils—additional research may be done on pisolites, teepee structures, mudcracks)?

Alternative assessments

- Additional research and class presentations on reefs, the Permian period, Carlsbad Caverns National Park and Guadalupe Mountains National Park, disciplines in geology, the geographical region
- Additional exercises with topographic maps

Bibliography

Beaubouef, R.T., Rossen, C. Zelt, F.B, Sullivan, M.D., Mohrig D.C. and D.C. Jeanette. 1999. "Deep-Water Sandstones, Brushy Canyon Formation, West Texas." AAPG Field Guide #40.

Bebout, D.G. and C. Kerans. 1993. *Guide to the Permian Reef Geology Trail, McKittrick Canyon, Guadalupe Mountains National Park, West Texas. Guidebook 26.* Austin, TX: Bureau of Economic Geology.

Hill, C.A. 1996. "Geology of the Delaware Basin Guadalupe, Apache, and Glass Mountains New Mexico and West Texas." Permian Basin Section – SEPM. Pub. No. 96-39.

Marshak, S. 2001. *Earth Portrait of a Planet*. New York: W.W. Norton & Co.

Additional reading and other resources

New Mexico School of Technology virtual fieldtrip of the Guadalupe Mountains: *http://geoinfo.nmt.edu/staff/scholle/guadalupe.html*

USGS web page on fossils: *http://pubs.usgs.gov/gip/fossils/contents.html*

Texas A&M Oceanography class' web resource list: *http://oceanworld.tamu.edu/ocean401/ocng401_hotlinks.html*

Berkeley's Geology homepage (Permian Period): *http://www.ucmp.berkeley.edu/permian/permian.html*

National Oceanic and Atmospheric Association's (NOAA) web page on coral reefs: *http://www.nmfs.noaa.gov/prot_res/PR/coralhome.html*

Putting the puzzle together; internal structure of the Earth and Pangean geography

9-12 grades
Lesson #2
Prerequisites: general knowledge of the geologic time chart
Estimated time: 3 Labs (50 min/each)
Location: in lab

Learner outcomes
The learner will:

- Learn about plate tectonics and the roles of orogenic processes in creating the Guadalupe Mountains region.

Vocabulary: P-waves, S-waves, surface waves, Pangea, plates, glacial striations, plate tectonics, orogeny, paleontology, Alfred Wegner, continental drift, plate boundaries, divergent margin, convergent margin, transverse (strike-slip) margin, crust, mantle, outer core, inner core, surficial landscapes, density, earthquake, seismic waves, lithosphere, asthenosphere, elements, convection, theory, glacier, supercontinent, technology, shadow zone, long axis, Loma Prieta earthquake, scale, model, eruption, schematic diagram, Mesosaurus, Lystrosaurus, Cynognathus, Glossopteris, peer review, hypothesis, scientific community

Background information
Movements within the interior of the Earth affect the Earth's surficial landscapes. The Earth is composed of four basic layers of varying densities and materials, which have been determined by careful examination of earthquake-generated seismic waves through the Earth. Seismic waves are energy waves generated by earthquakes or human generation that travel through the layers of the Earth. There are three types of seismic waves, P-waves, S-waves, and surface waves, each of which travels through materials differently. The P-waves travel through all mediums but move more slowly through liquids, the S-waves do not travel through liquids (they change into other waves), and the surface waves only travel along the surface.

By examining the characteristics of these three seismic waves it was determined that there were four layers of the Earth. These are the inner core, which is solid and composed of heavy metals; the outer core, which consists of liquid, metallic elements; the mantle, the thickest layer with a dense plastic consistency; and finally the thin, brittle and broken crust on which we live. Convective motion in the hot upper mantle moves the pieces of broken crust (called "plates"). This motion causes various interactions between plates that are collectively called "plate tectonics."

The theory of plate tectonics is a relatively recent theory (1970s); however Alfred Wegner suggested "continental drift," a similar process, in the early 1900s. Wegner, a well traveled meteorologist, noticed that there were surprising similarities in fossils, geology, glacial striations on different continents, and several of the continents such as Africa and South America look like they fit well together. Using these various lines of evidence, Wegner proposed that a supercontinent called “Pangea” existed about 200 million years ago from which all the present continents broke away.

Today, we know that Pangea did exist by using many of the same lines of evidence as Wegner in conjunction with more evidence procured with modern technology. Pangea was together during the Permian Period, approximately 250 million years ago, when the sea was present in Delaware Basin.

Pre-activity thought questions: Has the world always appeared as it does now? If not, how has it changed?

Assessments

- Notes in science notebooks
- Scale diagram of the Earth’s interior
- World map with the plate boundaries and labeled plates

Procedure

Activity #1: Earth’s Internal Structure

Materials needed:

- Science notebooks
- Hard-boiled eggs (with shell on)
- Slinkies
- The seismic wave and eruption programs (free download from: *http://www.geol.binghamton.edu/faculty/jones/jones.html*)
- Diagram of the Earth’s interior (slide #10)
- Graph paper

The teacher will:

- Split students into groups and give each group a hard boiled egg with the shell on. Have them crack it lightly and then cut it in half along the long-axis.
- Explain that the layers of the egg are similar to the internal structure of the Earth, where the shell represents the thin, cracked crust, the white of the egg is similar to the mantle, and the yolk represents the inner and outer core.
- Define and diagram the crust, mantle, outer core, and inner core explaining composition and thickness.
- Ask the students to brainstorm on how people might have determined the internal structure of the earth when we have only drilled several km into the crust.
- Define the three types of seismic waves, P-waves (compression waves), S-waves (side-to-side waves), and surface waves (up and down waves).
- Have students demonstrate the different motions of these waves with slinkies and record their observations in their science notebooks.
- Explain that each wave moves differently through different materials (solid and liquids). The P-waves move through both materials and therefore are detected through the inner and outer core, the S-waves don’t move through liquids and therefore the outer core so a “shadow-zone” is seen directly on the other side of the

world from the epicenter of an earthquake, and surface waves only travel along the surface.

- Look at the seismic wave program (Seiswave). Run California's Loma Prieta earthquake and have students look at the seismic waves travel through the Earth. Point out that the S-waves are transformed into different types of waves at the mantle-outer core boundary while the P-waves bend through the liquid outer core and then speed back up through the inner core. (In general, energy waves travel more slowly through liquids than solids. These changes in wave speeds are measured using seismographs, which are located at the top of the screen).
- Have students draw a "scale" model of the Earth's cross-section on graph paper.

Activity #2: Earth's External Disarray
Materials needed:

- Science notebooks
- Foam
- The seismic wave and eruption programs (free download from: *http://www.geol.binghamton.edu/faculty/jones/jones.html*)
- Blank world map (slide #28)
- World map with plates labeled (slides # 29 and 32)

The teacher will:

- Have the students run the "world" demonstration on the seismic eruption program (Seisvole). They should observe the locations where earthquakes and volcanic eruptions occur- do they see a pattern? Pause at the end of the demonstration and have the students draw in the modern plate boundaries on a blank world map.
- Ask students what happens at the plate boundaries to cause earthquakes and volcanoes.
- Using two pieces of foam, have pairs of students work together to model the three different plate margins boundaries (convergent, divergent, and transform). Students should draw schematic diagrams of these boundaries in their science notebooks and list examples of each from the world.

Activity #3: Puzzle of Pangea
Materials needed:

- Photographs of the Guadalupe Mountains and Delaware Basin (slides #1-7)
- Science notebooks
- Pangea puzzle (cut out continents and legend from slide #81)
- Schematic of the local stratigraphy (slide #19)
- Geologic time chart (slide #8 or 9)
- Guide to Permian vertebrate fossils (slides #82)
- Guadalupe Mountains Geologic history video (available from Carlsbad Caverns National Park)

The teacher will:

- Begin by asking students if the crustal plates can move. Has the world always looked the way it does today?
- Have students look at the separated puzzle pieces of Pangea—explain Alfred Wegner's story of continental drift and have the students reconstruct the Permian plate configuration based on fossils and other clues. Students' reconstructed Pangea should be pasted on another piece of paper.
- Once the students have put Pangea back together again, have them compare their answers to the Berkeley University animated site: (*http://www.ucmp.berkeley.edu/geology/tectonics.html*).
- Conclude with a discussion of evidence necessary to solidify the idea of plate tectonics (review last 2 sections) and discuss how these changes have affected the southwestern region.
- Show the silent Guadalupe Mountains Geologic history video (8 minutes).
- With the photographs of the region and the stratigraphic diagram, explain the inland sea in the region during the Permian that produced the Capitan reef and associated geology in relation to the continental configuration.

Follow-up questions: If plate tectonics are still active today, how will the continents be configured in the future? What other clues might be used to determine the previous plate configuration? How is science governed by peer review?

Alternative assessments

- Student presentations on other possible hypotheses for similarities in fossil records, geology, etc. and supporting evidence to emphasize the use of peer review and alternative hypotheses in science. Discuss why more evidence was necessary before the scientific community would accept Wegner's ideas.
- Have each student plot ten recent earthquakes on a world map and discuss modern movement along the plate boundaries, which should be outlined.

Bibliography

Hill, C.A. 1996. "Geology of the Delaware Basin Guadalupe, Apache, and Glass Mountains New Mexico and West Texas." Permian Basin Section – SEPM. Pub. No. 96-39.

Jones, A. State University of New York at Binghamton Geology Department.

Marshak, S. 2001. *Earth Portrait of a Planet*. New York: W.W. Norton & Co.

Seismic/Eruption and Seismic Waves computer simulations: *http://www.geol.binghamton.edu/faculty/jones/jones.html*

University of Berkeley's Plate Tectonics simulations: *http://www.ucmp.berkeley.edu/geology/tectonics.html*

Additional reading and other resources

University of Nevada- Reno Plate tectonics web page: *http://www.seismo.unr.edu/ftp/pub/louie/class/100/plate-tectonics.html*

USGS web page on plate tectonics: *http://geology.er.usgs.gov/eastern/tectonic.html*

American Geological Institute's Earth Science Educational Resources page: *http://www.agiweb.org/education/resources.html*

Global building blocks; rocks and mineral identification

9-12
Lesson #3
Prerequisites: knowledge of elements
Estimated time: 2 labs (50 min/each)
Location: in lab

Learner outcomes
The learner will:

- Learn about mineral composition and identification.
- Understand the rock cycle and identify some common rocks in each group.
- Apply this knowledge to geology in the Guadalupe Mountains region.

Vocabulary: mineral, rock, crystal structure, chemical composition, hardness, luster, cleavage, carbonates, rock cycle, igneous rock, metamorphic rock, sediment, clast, chemical sedimentary rock, biochemical sedimentary rock, siliciclastic sedimentary rock, sedimentary rock, parent rock, metamorphism, magma, crystallization, cementation, evaporite, metallic, nonmetallic, striations, rhombus, transparent, translucent, physical weathering, chemical weathering, erosion, rock cycle, basalt, granite, trona, limestone, conglomerate, sandstone, shale, coquina, coal, gneiss, schist, marble, slate, mafic, felsic, foliated, crystalline, texture, vesicular, ooids, pebbles, sand, gravel, grain size, clay, organic material, ultraviolet light, hydrochloric acid, effervescence, streak, calcite, dolomite, gypsum, halite, sulfur, pyrite, muscovite mica, orthoclase feldspar, quartz

Background information
The Earth's building blocks are rocks and minerals. Minerals, of which rocks are composed, are defined by standard criteria: 1) specific chemical composition, 2) inorganic, 3) regular crystalline structure, and 4) naturally occurring. While it is tempting to use color to determine the type of mineral, many of the same minerals come in a variety of colors so other characteristics must be used. Diagnostic tests for identifying minerals are: hardness (on a scale from one being the softest mineral, talc, to ten, a diamond, the hardest mineral found), streak (on a porcelain plate), cleavage (the ways a mineral naturally breaks), effervescence (reaction of mineral to weak HCl, hydrochloric acid), magnetism (attracted to magnets or not), taste (however some minerals are toxic, so you don't want to lick them all) and fluorescence (fluorescence when exposed to an ultraviolet light or not). While there are many different minerals found throughout the world, some minerals specific to the Guadalupe Mountains, Delaware Basin, and Carlsbad Caverns are calcite, dolomite, gypsum, halite, sulfur, and pyrite. The majority of the Earth's surface is composed of quartz and feldspar, two other minerals that are not as common in this area of carbonates.

Rocks, in turn, are composed of minerals. There are three types of rocks: 1) igneous rocks where the interlocking minerals crystallize out of molten material, 2) sedimentary rocks composed of cemented physically-weathered sediments derived from other rocks or chemically precipitated from saturated solutions, and finally 3) metamorphic rocks, which are pressure and temperature “cooked” versions of any of these three types of rock. The most common rock in the area is limestone, which is composed of the mineral calcite.

Identification of rocks and minerals allows geologists to produce geologic maps. This knowledge can aid in the understanding of the paleoenvironment and time period in which the rocks and minerals formed. This activity will introduce common rocks and minerals found in the Carlsbad Cavern region as well as others that are common elsewhere. Identification of samples will also enhance students’ observational and classification skills. Once the students have identified the rocks and minerals, they will be able to understand a geologic map.

Pre-activity thought questions: What is the Earth made of? What is the difference between a rock and a mineral? What types of rocks and minerals are found in your region?

Assessments

- List of identified minerals
- Venn Diagram of several local minerals
- List of identified rocks

Procedure

Activity #1: Minerals

Materials needed:

- Mineral kit including: quartz, calcite, muscovite mica, gypsum, dolomite, sulfur, halite, pyrite, orthoclase feldspar
- Mineral identification kit including: penny, glass plate, porcelain tile, weak HCl acid (10%), hand lens
- Mineral identification flow-chart (Slide #23)
- Venn Diagram (Slide #24)

The teacher will:

- Explain that the Earth is composed of rocks, which are composed of minerals. Define each.
- Define the properties of minerals and explain that these characteristics may be examined and tested on hand samples.
- Pass out the mineral samples to identify with the testing kits and the flow chart. Explain that these are just a few of the minerals that are represented in the Guadalupe Mountains—emphasize that there are many more in the area and the world!
- Let the students work together to identify the different minerals using the standard tests and have them record the names and some characteristics in their notebooks.
- After checking students’ answers, have students complete a Venn diagram for common minerals in the region (i.e. calcite, dolomite, and gypsum).

Activity #2: Rocks and rock cycle

Materials needed:

- Rock cycle chart (Slide #25)
- Rock identification flow charts (Slide #26)

- Rock kit including: limestone (coquina and crystalline limestone), trona, conglomerate, sandstone, shale, coal, granite, basalt, gneiss, schist, and marble
- Carlsbad Caverns National Park geologic map (Slide #110)
- Carlsbad Caverns National Park geologic formation descriptions (Slide #111)

The teacher will:

- Explain the rock cycle and that rocks are composed of different minerals. While there are three different types of rocks, for the Guadalupe Mountains and Carlsbad Cavern story, we are mainly interested in sedimentary rocks so these will be the majority of the rocks the students will identify.
- Once the rock samples are passed out and the students are divided into groups, help the class separate the different rock types.
- Pass out the three different rock flow charts and have students use the charts to identify the different rock samples. They should write descriptions and identifications in their science notebooks. The students may also look for their minerals in the rocks, but keep the samples separate to avoid confusion.
- Using the Carlsbad Caverns National Park geology map and formation descriptions, have students link the geologic formations with their rock and mineral characterizations. Students should record these descriptions of each unit in their science notebooks.

Follow-up questions: What are some diagnostic properties of each mineral? Is color a reliable characteristic to use when trying to identify minerals? How can the different rock types be deciphered? What does the type of rock say about the environment in which it formed?

Alternative assessments

- Have students draw a schematic diagram of the backreef, reef, and forereef area. Label the different units and minerals found in each environment (similar to the schematic cross-section used in Lesson 1).
- Students should list different environments where each type of sedimentary rock is found (i.e. sandstone may be formed in rivers, beaches, mountains, deltas, etc.) to show the complexity of paleoenvironmental reconstructions using only rock types.
- Have students identify minerals used in everyday products (i.e. drywall, toothpaste, lipstick, milkshakes, vitamins, etc.).

Bibliography

Beaubouef, R.T., Rossen, C, Zelt, F.B, Sullivan, M.D., Mohrig D.C. and D.C. Jeanette. 1999. “Deep-Water Sandstones, Brushy Canyon Formation, West Texas.” AAPG Field Guide #40.

Marshak, S. 2001. *Earth Portrait of a Planet.* New York: W.W. Norton & Co.

USGS Learning Web, Rocks and minerals web page: *http://interactive2.usgs.gov/learningweb/explorer/topic_rocks.htm*

Additional reading and other resources:

Amethyst Galleries Inc. Mineral Gallery web page: *http://mineral.galleries.com/*

USGS Rocks and Minerals web page: *http://geology.er.usgs.gov/eastern/rocks.html*

It's not your average Friday night; relative and absolute dating of geologic materials

9-12
Lesson #4
Prerequisites: some knowledge of elements
Estimated time: 2 Labs (50 min/ each)
Location: in lab

Learner outcomes
The learner will:

- Understand the difference between relative dating and absolute dating techniques used to determine the age of geologic deposits.
- Recognize some of the ways each dating technique may be used in the Carlsbad Caverns National Park area or local National Park.

Vocabulary: radiometric dating, half-life, geologic laws, cross-cutting relationships, billions of years, Uranium/Thorium dating, Potassium/ Argon dating, luminescence dating, electron-spin resonance dating, absolute dating, cultural materials, Law of Horizontality, Law of Superposition, Law of Uniformitarianism, crosscutting relationships, biomarkers, volcanic ash, parent material, daughter product, elements, radioactive decay, half-life, radiocarbon, biomarkers, ash, timeline, schematic diagram, cross-section, exponential decay, x-y graph, results, constant decay curve, average, unconformity

Background information
Geologists determine the age of rocks through two different methods: relative dating and absolute dating. Relative dates of rocks are determined using standard geologic laws (Law of Horizontality, Law of Superposition, and Law of Uniformitarianism), crosscutting relationships, fossils, and cultural materials to tell "relative ages" from one geologic unit relative to another. The Law of Horizontality suggests that layers of rock are deposited horizontally and those that are not horizontal have been subjected to later movement. The Law of Superposition states that the lower layers of rock are older than those deposited above them. And the Law of Uniformitarianism suggests that Earth processes that occur today occurred in the past and produced similar geologic features. Crosscutting relationships look at how rocks and sediments are deposited in relation to each other (if a river erodes a previous river deposit and then the new river deposits sediment, the younger deposit versus older layer may be deciphered. As organisms and humans have evolved through time, fossils and archaeological sites may also give a relative age to the rock in which they are found. Any of these relative dating techniques or a combination of several of them enable geologists to determine that "rock layer X is older than the layer below it, rock layer Y," but they do not allow geologists to attach an age number to the rocks.

For determining the age of a rock in more specific numbers, geologists need to absolutely date the rocks. While there are different methods of absolute dating techniques that cover different time spans (it is hard to determine the age of rocks that are billions of years old!), the most common way of determining absolute ages is with radiometric dating. Radiometric dating can be performed on minerals within the rocks because certain elements within the minerals decay through time at a known rate. Radiocarbon dating, a form of radiometric dating that is performed on carbon materials, may date carbon material grown the last 40,000 years. Radiocarbon dating is useful in determining the age of archaeological material as well as other carbon and carbon dioxide, such as that found in carbonates and groundwater. Most cave decorations or speleothems are dated with Uranium series (U-Th dating) techniques, another radiometric dating technique however. In this lesson, students will learn the difference between relative and absolute dating techniques through hand-on activities.

Pre-activity thought questions: How can you tell the age of objects? Rocks? Landscapes?

Assessments

- Relative age timeline for schematic cross section
- Relative age timeline for the Delaware Basin and Carlsbad Caverns National Park region
- Graph of exponential decay

Procedure

Activity #1: Relative dating

Materials needed:

- “Geologic” layers of cake
- Containers of frosting
- Candy “fossils” (M&Ms, sprinkles, etc.)
- Schematic cross-sections (slide #19)
- Relative dating sheets and overheads (slides #87-103)

The teacher will:

- Define relative dating, Law of Horizontality, Law of Superposition, crosscutting relationships, and Law of Uniformitarianism.
- Demonstrate the law of horizontality, superposition, crosscutting relationships, and Uniformitarianism with a geologic cake of your area or the Guadalupe Mountains, the Delaware Basin, and Carlsbad Cavern.
- Students should be given the schematic geologic cross-section to determine the relative ages of the rock units. Timelines for the successive geologic layers should be written in their science notebooks.
- After they have tried to sort out the relative ages of the layers and written out their timeline, they should be given the matching set of the key handouts to crosscheck their work (students should cut off the lower, black part of the key handouts; this may also be demonstrated with the associated overhead transparencies).
- Students should create a relative timeline for the Guadalupe Mountains using the cross-section for homework.

Activity #2: Absolute dating

Materials needed:

- M&Ms or pennies (100 each group)
- Plastic containers with lids
- Graph paper

The teacher will:

- Define absolute dating and discuss several types.
- Give students, separated in groups, a plastic container filled with 100 pennies or M&Ms.
- Have them turn the pennies or M&Ms face up (either heads up or with the Ms showing, respectively). X-Y graphs should be discussed because this experiment should be plotted on the graph paper with number of shakes on the x-axis and the number of heads/Ms remaining face-up on the y-axis.
- The students should shake the plastic container (with the lid on) just once and remove the pennies or Ms facing downward and count the number of remaining heads or Ms face up. Again, students should plot results after each shake.
- Continue the process until all the pennies or M&Ms have faced down and have been removed from the container. Students should produce exponential decay curves representing the exponential decay of elements, which is measured in the laboratory to produce a "constant decay rate" that is used in absolute dating.

Follow-up questions: In what instances would you use relative dating? Where would you use absolute dating? How do you think the ages of the Delaware Basin and Carlsbad Cavern were determined?

Alternative assessments

- Have students research specific radiometric dating techniques (i.e. radiocarbon, electron spin resonance, luminescence dating, Uranium-Thorium dating, Potassium-argon dating, etc.)—be sure they include the type of material that is dated, the half-life of the element, and the time span applicable.
- Research the specific dating controls used in the Delaware Basin and Carlsbad Caverns National Park or your local National Park.

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USGS geologic time web page: *http://pubs.usgs.gov/gip/geotime/*

Additional reading and other resources

Minnesota State University Archaeology Department web page:
http://emuseum.mnsu.edu/archaeology/dating/index.shtml

Montana State University Dating Vocabulary:
http://btc.montana.edu/nten/trc/lesson5/vocab5_text.shtml

Suggestions for constructing a geologic cake

1) Be sure to have ample cake mix (different types of cake mixes help to visualize different formations), frosting, and pans (cookie sheets work well if filled).
2) Construct the cake with student participation in class while explaining the geology through time.
3) Guadalupe Mountains offers a nice way to demonstrate the accumulation of sediment through time and the cake may be modeled after the cross section (slide #19). It may be done just with the backreef Seven Rivers, Yates, and Tansill Formations, the reef Capitan Formation, and the forereef and basinward Bell Canyon Formation. Be sure to add fossils in the reefs!

4) Other good props for geologic cakes in other areas are: whipped cream, pudding, and use of knives for erosion.
5) If possible, cut the cake and show the students the inner cross section of the “geologic layers.”
6) Be creative, have fun, and *bon appetite*!

Ocean-front property in New Mexico? Where did the oceans go?

9-12
Lesson #5
Prerequisites: understanding of Permian geography in the southwest
Estimated time: 2 Labs (50 min/ each)
Location: in lab

Learner outcomes
The learner will:

- Understand the external forces that aid landscape evolution.
- Apply this understanding to the Carlsbad Caverns National Park, the Delaware basin area, or your local geography.

Vocabulary: internal mechanisms, external mechanisms, external forces, lithology, feedbacks, landscape evolution, mineralogy, lithology, fractures, feedbacks, climate change, tectonics, carbon dioxide, water vapor, methane, eccentricity, sea level, glacier, convection, ecology, hydrologic cycle, oceanic cycle, gas cycle, tilt, precession, obliquity, climate, evaporation/condensation rates, ocean bottom water, ocean surface water, precipitation, climate change, Milankovitch cycles, conveyor belt, greenhouse gas, solar energy, El Niňo, uplift, orogeny, structure, fold, fault, compressional stress, extensional stress, syncline, anticline, hanging wall, foot wall, normal fault, reverse fault, evaporite, extinction, extinct, ice cores, ocean cores, tree rings, pollen records, paleontological records, speleothems, archaeological records, glacier, speleothems, Pleistocene Epoch, groundwater, sulfuric acid, volcanics, uplift, Cretaceous Period, physiographic provinces

Background information
While landscape evolution is dependent upon internal mechanisms to control the ways in which it changes (mineralogy, lithology, fractures, etc.), external driving mechanisms are responsible for causing landscape changes. While there are many geologic responses to external forces and feedbacks associated with each, the primary external mechanisms for landscape change are climate change and tectonics.

Climate change is driven by changes in incoming solar energy, which affects the global hydrologic, oceanic and gas cycles. Levels of solar energy fluctuate regularly over various time spans. The most recognizable fluctuations in solar energy, or solar cycles, are the Milankovitch cycles that occur approximately every 21,000 years, 41,000 years, and 100,000 years due to alterations in the Earth's precession (the wobbly path traced out by Earth's spinning axis which varies), tilt, and eccentricity around the sun, respectively. These cycles alter the Earth's climate by increasing or reducing the energy that drives global cycles such as some atmospheric cycles (by increasing or decreasing greenhouse gases such as carbon dioxide, water vapor, methane, etc.), the hydrologic cycle (through increasing temperature and changing evaporation/ condensation rates which in turn change the global cloud and ice coverage and thus lead to a rise or fall in sea level), and the ocean cycle, or ocean conveyor belt (a global circulation of the oceans that mixes the warm water with the cold water). An example of a climate change due to a change in the oceanic cycle is El Niňo, which occurs every 3 to 7 years due to shifting of the warm surface water in the Pacific Ocean.

Each of these cycles affects the global climate and in turn alters regional ecology and geology. Thus, geological and ecological records are excellent measures of past climate changes. Records that are reliable measures of past climate changes are rock records (geology), ice cores, ocean cores, tree rings, pollen records, paleontological records, speleothems, and archaeological records.

Tectonics also plays a major role in shaping the global landscape. While plate tectonics is a major force in forming and shaping the global landmasses, small scale structural changes in regional geology also play a large role in the evolution of landscapes. Plate tectonics affects landscapes through either compressional or extensional stresses. These stresses create folds, bends, or wrinkles in rock layers, and/or faults, fractures in rocks where one body of rock slides past another, in the rocks they are acting upon. Folds may be simply divided into two major types: those where rocks are buckled up into a hump, called anticlines, and those where layers of rock are folded into a U-shape, called synclines. There are also several different types of faults, however all faults are described by the relative motion of the upper side of the break, called the headwall or hanging wall, in respect to the lower side or the footwall. A normal fault is a fault in which the hanging-wall block moves down the fault slope in relation to the footwall whereas a reverse, or thrust fault, is a steeply dipping fault on which the hanging wall slides up relative to the footwall.

Both climate change and tectonics have affected the geology and ecology of the Guadalupe Mountains and Carlsbad Caverns National Park area since the Permian Period. At the end of the Permian Period, the sea level in the area dropped leaving behind thick evaporite deposits. At this time, a massive global extinction also occurred and nearly 90% of all life on the Earth, such as most of those fossils seen at Carlsbad Caverns National Park, became extinct. Millions of years later, in the Cretaceous, a shallow sea returned to North America leaving marine deposits in mid-continent America once again. During the last million years, in the Pleistocene Period, North America has been subjected to glacial advances—the most recent of which occurred a mere 18,000 years ago. While the glaciers did not advance as far south as New Mexico and Texas, the climate in the region is believed to have been considerably cooler and wetter. It was at this time that many of the cave decorations, or speleothems at Carlsbad Caverns National Park were probably formed.

Tectonics also played a large role in the formation of the Guadalupe Mountains and Carlsbad Cavern. After the Capitan Reef was formed in the Permian Period, the basin filled with evaporites and other sediments. However, during the Tertiary Period, regional uplift began to raise the sturdy Permian deposits and the overlying material was eroded off. This increasing uplift allowed the groundwater, rich in sulfuric acid from the mixing of H_2S gas with the oxygen in the water to lower in level and carve out the lower caves. Therefore, caves deepest in the mountains are those most recently formed. These caves are later believed to have been decorated during the more moist Pleistocene Epoch when the abundant water flowed through the rocks, dissolved some of the limestone, and redeposited the calcite as cave decorations or speleothems.

In this lesson, students will examine two common external factors that control geologic landscapes: climate and tectonics. When complete, students should understand the role of each in the geology of the Guadalupe Mountains and in modern geologic events.

Pre-activity thought questions: Do landscapes change through time? What are possible causes for changes in landscapes? How have changing climates and tectonics affected

Carlsbad Cavern and Guadalupe Mountains? Have changing climates and tectonics affected our area?

Assessments

- Presentations
- Structure diagrams

Procedure

Activity #1: Climate change; its causes and effects:

Materials needed:

- Global Geography slides (slides #11-18)

The teacher will:

- Define climate change.
- Discuss different mechanisms for climate change (solar flux and Milankovitch cycles, ocean conveyor belt, greenhouse gases, etc.) and show the paleogeography changes through time.
- Divide class into four groups with the following headings and have each person in the group research a topic under the heading (these topics may be modified depending on the size of the class and the resources available):
    - Causes for past climate changes
        - Solar fluctuations
        - Ocean fluctuations
        - Tectonics (mountain building and volcanics)
        - Greenhouse gases
    - Records of climate change
        - Ice cores
        - Marine cores
        - Tree-rings
        - Speleothems
    - Environments in the Guadalupe Mountains and Carlsbad Caverns National Park through time
        - Permian Period
        - Cretaceous Period
        - Pleistocene Epoch
    - Future Climate Change
        - Potential causes
        - Possible effects
        - Potential cures
- Have each group present research and then individual students should write a summary/thought paper on what past climate change may tell us about the future climate.

Activity #2: Tectonics and resulting geologic structures
Materials needed:

- Clay (3 sticks for each pair of students)
- Structure slides (slides #112 – 115)
- Science notebooks

The teacher will:

- Review plate tectonics. Discuss how this might have affected the southwest and Carlsbad Caverns National Park.
- Talk about converging physiographic provinces.
- Discuss the smaller scale effects this has on a local region (define types of folds and faults—these may be demonstrated in front of the class with the foam used in lesson #2).
- Split students up into pairs and have them model each of the folds and faults in three layers of rock made out of clay. Have them draw the cross-sections of these features in their science notebooks.
- Look at the present configuration of the Guadalupe Mountains and Carlsbad Cavern—discuss the role of tectonics in the formation of these features.

Follow-up questions: What might the landscape of southeastern New Mexico and west Texas look like had there not been the uplift and erosion since the Permian? Which climate record do you think is the most reliable? What might be other climate records? What do you believe the climate will be like in the future? How do you think humans might prepare for future climate and tectonic changes?

Alternative assessments

- Have students construct paper fault models from the USGS (*http://wrgis.wr.usgs.gov/docs/parks/deform/7modelsa.html*)
- Have students research some of the famous faults and folds (San Andreas Fault in California, the Black Hills dome, etc.).
- Research the tectonic activity in your area—are there faults? Are there folds?

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NOAA's "Paleo-perspective" webpage: *http://www.ngdc.noaa.gov/paleo/globalwarming/home.html*

Additional reading and other resources
Climate Internet links: *http://www.istl.org/01-fall/internet.html*

Bridge over troubled waters: What is an aquifer and how can we protect our groundwater?

9-12
Lesson #6
Prerequisites: knowledge of sedimentary layers
Estimated time: 2 Labs (50 min/ each)
Location: in lab

Learner outcomes
The learner will:

- learn about the water cycle, siliciclastic and karst aquifers, groundwater movement, and groundwater contamination through the use of models.
- learn that both surface and groundwater follow laws of gravity.
- learn that contaminants in the groundwater and surface water may affect the aquifer used for drinking water.

Vocabulary: hydrologic cycle, impermeable, permeability, porosity, aquifer, aquitard, aquiclude, groundwater, confining layer, confined aquifer, permeable, impermeable, unconfined aquifer, contamination, wells, recharge, emergence, siliciclastic, karst, potentiometric, alluvial, evaporite, models, surface water, fresh water, saline water, brine, confining layer, springs, pore spaces, cracks, fissures, connectivity, interlocking crystals, sediments, caverns, water table, precipitation, artesian wells, wells, Ogallala Aquifer, Capitan Aquifer, Great Plains, Environmental Protection Agency (EPA), volume, discharge, injection well, infiltration, runoff, ecology

Background information
Water, an integral component to life on Earth, is found in many forms all of which participate in the hydrological cycle. About 80% of the Earth is covered with water, however only 3% of this abundant supply is freshwater, 2% of which is locked up in glaciers, making only 1% of the global water available for human consumption. This freshwater is divided into surface water, water found on the surface of the Earth (rivers, lakes, springs, etc.), and groundwater, water that is found below the surface of the Earth.

Groundwater, unlike a river or other surface waters, does not move quickly. Instead, groundwater moves through the pore spaces between sediment grains (sand, gravel, silt) or in cracks and fissures of impermeable rocks (granite, limestone, basalt, evaporites, etc.). The sediment or rock that easily stores, conducts, and transmits large flows of groundwater is called an aquifer. The rate of groundwater movement is dependent on the sediment or rock porosity, the amount of empty space between the sediment or in the rocks, and permeability, the connectivity of these empty spaces allowing water to flow through. Some rocks have a higher permeability and porosity making them good aquifers (i.e. sandstone or gravel), whereas others contain interlocking crystals (igneous rocks) or are so compact (metamorphic rocks and mudstones) that water is unable to pass through them at all. These rocks that act as barriers to groundwater flow are called aquicludes or aquitards. The larger the porosity and permeability, the more water the aquifer can hold and the faster it is able to travel through. Variations in permeability and porosity may also be found between aquifers in siliciclastic sediments such as sand or gravel and karst aquifers. In general, the large fissures and caverns found in karst landscapes are excellent aquifers when below the water table.

Aquitards often separate different aquifers making some confined (those below the aquiclude and not in contact with water from precipitation on the surface) or unconfined (those above any aquiclude and in direct communication with the surface waters). Both types of aquifers need to have some input of water however to maintain water levels if being pumped by humans. These areas are called recharge areas where water is able to enter the aquifer. Water in aquifers moves very slowly. Some water in aquifers may be thousands of years old!

Wells for cities and housing are placed into aquifers and contamination, either from wells or from surface water connected to groundwater, will affect all those wells in the area. Clean up of such contamination is a very difficult and slow process since the water is below the surface.

In Carlsbad Caverns National Park, water comes from the local Capitan Aquifer in the Capitan Formation and seeps off of it at the natural artesian wells at Rattlesnake Springs. Much of New Mexico and Texas use water from the large Ogallala Aquifer, which is in the Ogallala Formation's sands and gravels that extend along the Great Plains from Texas to north of Nebraska.

Pre-activity thought questions: How much fresh water is there in the world? Where does the water we drink come from? Can human activities affect our drinking water?

Assessments

- Groundwater models
- Definitions in science notebooks

Procedure

Activity #1: Groundwater models and water table gradient

Materials needed:

- 64 oz. Glad container (or any other larger sized clear container)
- coarse sand or fine gravel
- clay-based modeling clay
- straws
- coffee filters
- water
- food coloring
- Groundwater slides (slides #40-48)
- Science notebooks
- Potentiometric map (slide #83)

The teacher will:

- Discuss the water cycle and where local drinking water comes from.
- Define the terms permeability and porosity.

- Demonstrate permeability and porosity with fine sand, gravel, and simulated karst (Styrofoam with holes carved out) in two beakers filled with water (see supplement #).
- Define the terms aquifer, groundwater, confining layer, permeable layer, confined aquifer, unconfined aquifer, and well.
- Have groups of three or four students build the two groundwater models.
- Once the models are constructed, the students should sketch them in their notebooks labeling each layer correctly. Students should also compare and contrast the confined and unconfined aquifers, the siliciclastic and the karst models, recharge and emergence areas, etc.
- Have students look at the “Potentiometric Map of the alluvial-evaporite aquifer.
- On graph paper, students should map the groundwater gradient from A to A' along the Black River on the map and compare to surface topography (how are the surface topography and groundwater table levels related?).

Directions for constructing and experimenting with the siliciclastic ground water model:

1. On one end of the Glad container, pile up some sand (this will be your confined aquifer).
2. On the end of the tub with the sand, insert 2 straws covered with pieces of coffee filter on the bottom end (so as not to suck up sand)—make sure the straws are visible along the back so the level of the water table is determinable (it may be attached with clear plastic tape to ensure no movement) and that they don’t touch the bottom so water can be inserted or withdrawn.
3. Over this sand, place a clay layer (this is the aquitard or impermeable layer). Be sure not to poke any holes in the clay and plaster it tightly up against the straw and the walls of the container—not high up the sides though as the object of this model is to look at the sides of the model as well
4. One of the straws in this layer should be designated the injection well—in this straw, inject enough water with green food coloring to saturate the sand. If this water is seen outside of the clay layer, you have sprung a leak—repair before continuing.
5. On top of the clay, pour more sand at an angle to about 2/3 of the way up the sides. In this sand layer, place another two straws with coffee filters in the ends along the side (be sure not to poke through the lower clay layer).
6. Over this layer of sand, place a strip of coffee filter over the upper end (the recharge area) and after making a depression at the lower end (a lake) cover it with coffee filter paper as well.
7. Hold the coffee filters in place with colored clay along the sides (white for the recharge area and blue near the lake) and then cover the rest of the exposed sand with the heavy fabric (stuck to the sides with clay again) to demonstrate infiltration. This is the ground surface and the fabric weight may be changed to demonstrate changes in runoff.
8. To demonstrate the experiment, slowly begin adding blue water in the higher end. Watch as the water moves with gravity to the lower end in the lake. Discuss the movement of groundwater with gravity and the interactions between groundwater and surface water.

9. Discuss the groundwater table and observe the level in the wells—discuss the differences between confined and unconfined aquifers (this can be seen by "pumping" water out of the wells in each with a syringe or by sucking—if the sand has been cleaned). Which color water comes from which layer? Is there mixing?
10. Introduce a "contamination spill" into the recharge area differently colored dyed water). Which aquifer is affected? Which house would still have clean water? Would the ecology of the lake be affected?

Directions for constructing and experimenting with the karst ground water model:

1. Find a chunk of Styrofoam that fits snugly within the glad containers.
2. Construct a 3" tall and sloping to about ½ the length of the container cave out of Styrofoam by carving out holes and connecting passages in the Styrofoam to simulate caverns (be sure that the cave will remain snug in the container once carved and also have caverns on the side so the water flow may be viewed from the side.
3. On the end of the tub with the cave, insert two straws, covered with pieces of coffee filter on the bottom end, along the side (so as to not suck up sand)—make sure the straws are visible along the back so the level of the water table is determinable (they may be attached with clear plastic tape to ensure no movement) and that they don't touch the bottom so water can be inserted or withdrawn.
4. Over the cave place and attach a layer of pre-moistened coffee filters.
5. On top of the filters, pour in some sand to the other end, still maintaining the slope.
6. In the sand, place two straws along the end opposite the caves so they are visible along the end of the container.
7. Over this layer of sand, place a narrow strip of coffee filter over the upper end and hold in place with tape or clay (the recharge area over the cave).
8. Over this sand, place a clay layer (this is the impermeable surface layer). Be sure to only poke one hole in the clay at the lower end of the model to represent a seep. Also plaster the clay tightly up against the straws and the walls of the container—but not too high up the sides as the object of this model is to look at the sides of the model as well.
9. One of the straws in the cave should be designated the injection well—in this straw, inject enough water with green food coloring to saturate the sand. If this water is seen outside of the clay layer, you have sprung a leak—repair before continuing.
10. To demonstrate the experiment, slowly begin adding blue water in the higher end. Watch as the water moves with gravity to the seep in the lower end. Discuss the movement of groundwater with gravity and the interactions between groundwater and surface water.
11. Discuss the groundwater table and observe the level in the wells—discuss the differences between siliciclastic and karst aquifers. Which holds a greater volume of water? Which has a higher porosity? Permeability?
12. Introduce a "contamination spill" into the recharge area differently colored dyed water). Is the cave contaminated? Does the contamination spread to the seep (surface water)?

Activity #2: Cave Contamination

Materials needed:

- Hydrology exercise
- Science notebooks
- Calculators

The teacher will:

- Discuss ground water contamination problems and potential effects upon the cave.
- Have students brainstorm about potential contamination from surface water to ground water and water within Carlsbad Cavern.
- After explanation of the Hydrology exercise, assign the exercise to the students.
- Discuss the results of the exercise and lead an in-class discussion on the "Things to Consider" section.

Follow-up questions: In which aquifer would contamination be the least of a threat? How is it possible to clean a contaminated aquifer? Which aquifer could support the most people without being affected?

Alternative assessments

- Have students research actual groundwater contamination cases and analyze the results and the effects upon people (one well known case is depicted in the movie "Erin Brockovich").
- Research your local aquifer and the chemicals detected within the water
- Research contamination cases found in other caves and discuss potential management policies to reduce the problems

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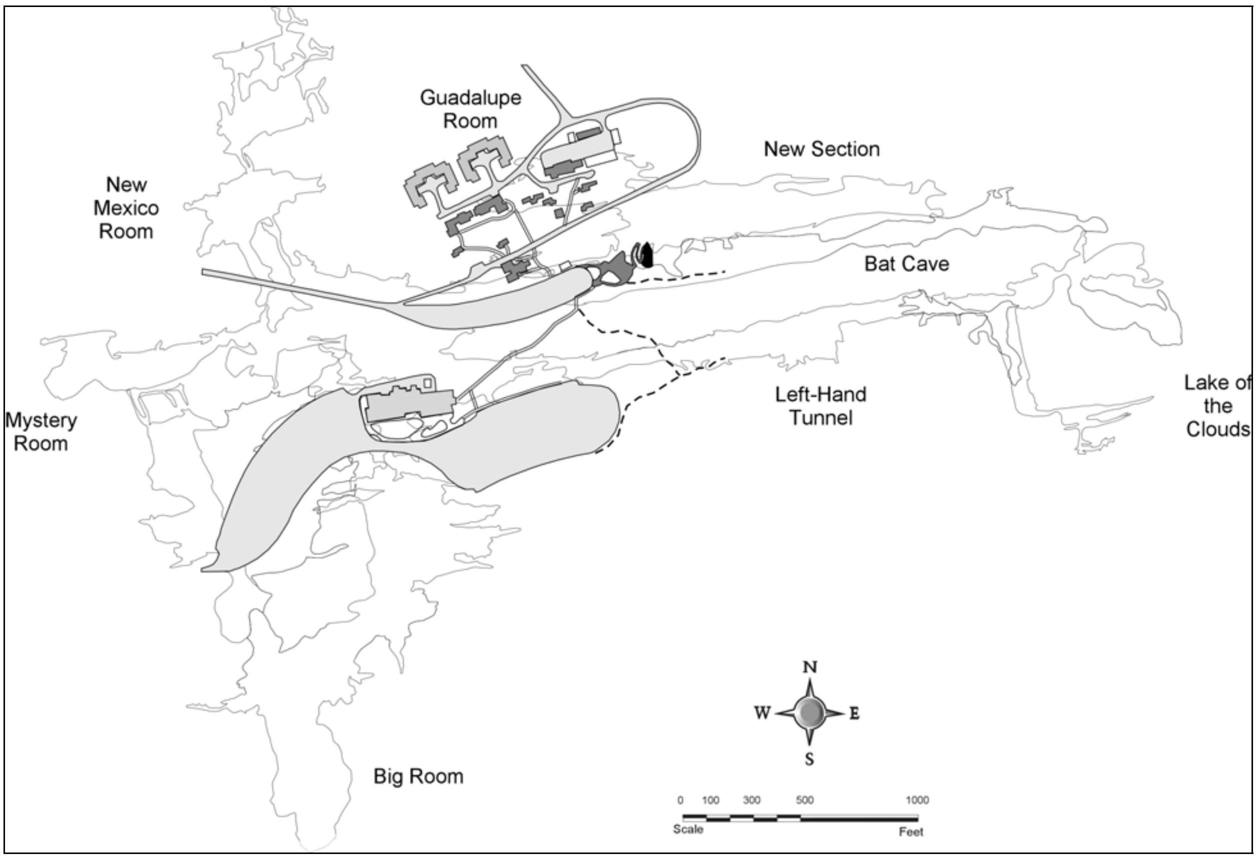
Hydrology Exercise

By Paul Burger, Carlsbad Caverns National Park Hydrologist

Objectives: To calculate how much contaminated water runs off the parking lots at Carlsbad Caverns National Park. To determine the mass of some contaminants being carried into the cave on a yearly basis.

Important Conversion Factors

Multiply	by	to get
Cubic feet	7.48	gallons
Liters	0.264	gallons
Milligrams	2.2×10^{-6}	pounds



Part I: Water flow from the parking lots

Paved Area

Bat Cave Draw Parking Lot: 100,290ft^2
Visitor Center East: 188,280 ft^2
Visitor Center West: 169,200 ft^2

Rainfall

0.5 inches of rain carry most of the contaminants
10 storms of 0.5 inches of rain/year

What is the total flow off of each parking lot per 0.5-inch storm, in gallons? What is the total flow per year?

Part II: Amount of contamination entering the cave

Chemistry of Runoff

Aluminum 4.3 ppm (mg/l)
Zinc 0.391 ppm (mg/l)
Total Dissolved Solids 215 ppm (mg/l)

How much aluminum is washed into the cave from the parking lots each year, in pounds? Zinc? Total solids? How much for each of these in ten years?

Part III: Things to Consider

What non-geologic controls are there on infiltration?

Why would the chemistry of the pools be different than the chemistry of the parking lot runoff?

What would be some ways to stop this contamination?

This is worse than Swiss cheese! What is karst why is it important?

9-12

Lesson #7

Prerequisites: knowledge of carbonate minerals and groundwater

Estimated time: 1 Lab (50 min)

Location: in lab

Learner outcomes

The learner will:

- Learn about karst and some karst features.

Vocabulary: karst, dolines, soluble, sinkholes, sinking stream, resurgence, recharge, dissolution, disappearing streams, ephemeral stream, perennial stream, limestone, dolomite, marble, gypsum, halite, caves, chemical reactions, acid, carbonate, carbon dioxide (CO_2), water (H_2O), carbonic acid (HCO_3^-), calcite (Ca^{2+}), solution, permeate, evaporate, speleothem, sulfuric acid (H_2SO_4), Parks Ranch, Black River, Bureau of Land Management, National Park Service, National Speleological Society

Background information

Carlsbad Caverns National Park, Guadalupe Mountains, and Delaware Basin are noted for their exquisite karst landforms. A karst landscape is one that is produced primarily through the dissolving of soluble rocks, such as limestone, dolomite, marble, gypsum, and halite. The dissolution of rock to create features such as caves, sinkholes, and disappearing rivers is accomplished through several different chemical reactions which involve the incorporation of other chemicals into groundwater or surface water that then create acids capable of dissolving rocks.

Karst is primarily formed in limestone or other carbonate rocks. This is most commonly done when carbon dioxide (CO_2) from the atmosphere or from soil organics is incorporated with water (H_2O) creating a mild carbonic acid (HCO_3^-). As this acid flows through carbonate rocks, the rocks are dissolved and the calcite (Ca^{2+}) is taken up into solution.

$$CaCO_3 + H_2O + CO_2 \rightarrow Ca^{2+} + 2\ HCO_3^-$$

When this solution permeates into a pre-dissolved cave, the drops come down from the roof or along the walls of the cave, the water evaporates, and limestone cave decorations are produced.

$$Ca^{2+} + 2\ HCO_3^- \rightarrow CaCO_3 + H_2O + CO_2$$

This is typically how limestone caves are formed and how Carlsbad Cavern was decorated. The initial dissolution of the limestone in the caves of Carlsbad Caverns National Park was uniquely due to sulfuric acid instead.

The sulfuric acid (H_2SO_4) was formed when hydrogen sulfide gas (H_2S) from the hydrocarbons in the basin migrated upwards into the Capitan Formation. In the Permian Reef deposits, the

H_2S mixed with dissolved oxygen (O_2) in the groundwater (H_2O) and formed a strong sulfuric acid.

$$H_2S + O_2 \rightarrow H_2SO_4$$

Sulfuric acid is much stronger than the carbonic acid that forms most caves thus the dissolution resulted in larger caverns than most carbonic acid caves. With such great amounts of sulfur in the water and dissolved limestone, deposition of gypsum, $CaSO_4$-2(H_2O), occurred in the cave and may be seen as massive blocks within Carlsbad Cavern's Big Room. Native Sulfur may also be found at some locations within the cave. As the Guadalupe Mountains were uplifted, the groundwater level dropped creating a series of downward-stepping large rooms, believed to have formed at water table level, connected by steep, smaller passages.

In the basin, karst formations are found in gypsum, $CaSO_4$-2(H_2O), and halite, NaCl, layers rather than the limestone in the uplands. In the Delaware Basin, karst features such as sinkholes, caves such as Parks Ranch, and sinking rivers such as the Black River may be seen. In this lesson, students will learn about karst and understand that Carlsbad Cavern and other caves are just one karst feature.

Pre-activity thought questions: Are all aquifers the same? How do caves form? If caves can form in limestone and other carbonates, what other features might also be found in those rocks due to erosion/deposition by water?

Materials needed

- AGI "Living with Karst" booklet (available from the AGI publication office: *http://www.agiweb.org/pubs/pubdetail.html?item=630601*)
- USGS Karst paper model (*http://wrgis.wr.usgs.gov/docs/parks/cave/karstmodel.html*)
- Glue
- Scissors
- Science notebooks
- Delaware Basin hydrology maps (slide #83 and 84)

Assessments

- Definitions in science notebooks
- Karst model
- Labeled maps

Procedure

The teacher will:

- Assign chapters 1-4 from the AGI "Living with Karst" booklet and have students define the bold terms in their science notebooks.
- Discuss these terms and the AGI material with the class.
- Discuss the chemical reactions that occur to cause dissolution of karst and formation of cave decorations, or speleothems.
- Have individual or pairs of students construct a karst paper model from the USGS Report.
- Students should compare features in this model and terms they learned from the AGI paper to maps of the region.

- Have the students locate and label karst features on the maps (i.e. sinking rivers, dolines, etc.).

Follow-up questions: What are potential problems with such a large karst area? What potential effects might use of this region have on groundwater supplies? How should this area be managed?

Alternative assessments

- Have students research karst remediation practices.
- Have students research local land use practices of the area (contact the Bureau of Land Management).
- Contrast this region and the karst caves formed in the gypsum to Carlsbad Cavern and other karst areas around the country (Florida, Mammoth Cave, etc.).

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Caves… a journey to the center of the Earth

9-12

Lesson #8

Prerequisites: knowledge of carbonate minerals and groundwater

Estimated time: 1 Lab (50 min)

Location: in lab

Learner outcomes

The learner will:

- Understand that there are different types of caves which are formed differently.
- Learn about the unique caves at Carlsbad Caverns National Park.
- Learn and recognize various cave decorations, or speleothems.
- Learn how to read a plan view cave map.

Vocabulary: cave, speleothem, dissolution, plan view map, map symbols, legend, ammonite, balloon, brachiopods, carbonic acid, cementation, columns, deflected stalactites, dolomite, draperies, flowstone, geochronology, gypsum, guano, helictites, hydromagnesite, limestone, moonmilk, National Park Service, paleokarst, pearls, popcorn, soda straw, stalactite, stalagmite, speleogenesis

Background information

There are many different caves found throughout the world. Common types of caves are: lava tube caves, glacier caves, sea caves, and solution caves. Lava tube caves are formed when the outer layer of a lava flow cools and solidifies forming a lava tube, a conduit for lava flow below the surface. Glaciers form glacier caves when meltwater flows under glaciers and erodes passages in the ice. And sea caves are created along coastlines when waves crash into the shore and erode the coastal material. Dissolution caves, which form when acidic waters flow into soluble rocks (limestone, gypsum, etc.), are of primary interest to this lesson however.

Two types of dissolution caves are found in karst environments. Dissolution caves similar to Mammoth Cave and many others in the southeastern United States are formed by acidic running water through a karst landscape which eventually creates flow patterns below the surface of the ground. Other dissolution caves, such as Carlsbad Cavern and other caves in the Guadalupe Mountains, were formed by acidic groundwater in carbonate rocks rather than flowing water. This dissolution of the ancient reef occurred when the groundwater, laden with sulfuric acid formed from the mixture of hydrogen sulfide and dissolved oxygen in the water, preferentially flowed along joints and fractures dissolving out cave passages.

In the first type of dissolution caves, as the acidic water (usually carbonic acid) flows through the carbonate rocks it carries the dissolved calcite. This saturated solution deposits the calcite in the form of cave decorations, or speleothems, once it hits the air and the water evaporates. In the second dissolution cave, the speleothems are a formed during a second time of deposition rather than simultaneous with the sulfuric acid dissolution. In Carlsbad Cavern, after the initial sulfuric acid dissolution of the large caverns, a second period of decoration occurred as carbonic acid, flowing through the rocks during a wet period, became saturated with calcite and deposited speleothems.

Common speleothems seen in Carlsbad Cavern and other dissolution caves are: stalactites, stalagmites, soda straws, columns, draperies, popcorn, flowstone, and pearls.

Speleothems, each type forming differently, create the decorations seen in many of the show-caves that may be visited today. Stalactites and stalagmites, two common speleothems, are often confused. Stalactites are conical speleothems that begin as a plugged soda straw on the ceiling and grow with precipitation from carbonate-rich water flowing down with gravity (stalactites hang "tite" to the ceiling) whereas stalagmites are speleothems composed of massive calcite mounds deposited from dripping water that grow upwards (stalagmites "mite" reach the ceiling). Soda straws and columns represent the birth and maturity of stalactites and stalagmites. Soda straws are hollow, elongate, and generally translucent tubes representing the earliest growth of stalactites, while columns are joined stalagmites and stalactites or the union of a stalactite or a stalagmite with the floor or the ceiling, respectively. Draperies are speleothems that resemble curtains along an overhung surface and pearls are concentric spherical, cylindrical, elliptical, and even cubical concretions found in shallow cave pools. Cave popcorn is a knob-shaped speleothem in contrast to the smooth flowstone, which forms in thin layers, taking the shape of the underlying floor.

These speleothems are used as landmarks when people create maps of caves. In this lesson, students will learn about common types of speleothems and be able to recognize them.

Pre-activity thought questions: How do caves form? Are all caves formed in the same way? What processes form the delicate cave structures? How do people explore and map caves? How are cave resources protected?

Assessments

- Science notebook notes
- Speleothem quiz

Materials needed

- March 1991 issue of National Geographic magazine featuring Lechuguilla Cave
- "Caves & Caverns" video (available through Carlsbad Caverns National Park)
- "Spirit of Exploration" video (available through Carlsbad Caverns National Park)
- National Geographic Society "Mysteries Underground" video (available through National Geographic Society or *www.amazon.com*)
- Photographs of Lechuguilla Cave at Carlsbad Caverns National Park (slides #53-78)

Procedure

Cavern formation and speleogenesis

The teacher will:

- Assign the National Geographic article to students to read at home; be sure to have students note the different types of speleothems mentioned in the article.
- Show the "Caves & Caverns" video (12minutes), the beginning of the "Spirit of Exploration" video, and National Geographic's "Mysteries Underground" in class and have students take notes on the cavern formation process.
- Lead an in-class discussion comparing and contrasting the Guadalupe Mountains caverns and other caves.
- Discuss speleogenesis and speleothems.

- Show slides of Lechuguilla Cave to point out various types of speleothems; students should take notes on speleothem names and formation.
- Administer a quiz on speleothem identification using several of the Lechuguilla slides.

Follow-up questions: How would map-making be different outside of a cave? Does biology play a role in the formation of speleothems?

Alternative assessments

- Have each student research the formation of a specific speleothem. They should present their research in a paper or a presentation to the class.
- Research the role of biology in speleothem formation.
- Examine other caves and compare and contrast their speleothems with Carlsbad Cavern.

Bibliography

Gillieson, D. 1996. *Caves: Processes, Development, Management.* MA: Blackwell Publishers.

Cahill, T. 1991. “Charting the Splendors of Lechuguilla Cave.” National Geographic Society Magazine, vol. 179, no. 3.

Hill, C.A. 1996. “Geology of the Delaware Basin Guadalupe, Apache, and Glass Mountains New Mexico and West Texas.” Permian Basin Section – SEPM. Pub. No. 96-39.

Marshak, S. 2001. *Earth Portrait of a Planet*. NY: W.W. Norton & Co.

“Caves & Caverns” video

“Spirit of Exploration” video

“Mysteries Underground” video, National Geographic Society

Additional reading and other resources

NSS News, October 1988, Special Issue: The exploration of Lechuguilla Cave Part I.

NSS News November 1988, Special Issue: The exploration of Lechuguilla Cave Part II.

Perpetually in the dark: Mapping caves

9-12

Lesson #9

Prerequisites: knowledge of carbonate minerals and groundwater, knowledge of basic geometry and trigonometry

Estimated time: 2 Labs (50 min/ each)

Location: in lab or in a cave

Learner outcomes

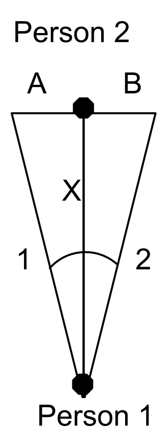
The learner will:

- Understand the purpose of mapping caves.
- Learn how caves are mapped.
- Be able to read existing cave maps.
- Learn how to map a cave with a compass, clinometer, and a measuring tape.

Vocabulary: Cave, surveying, compass, clinometer, compass directions, azimuth scale, metric units, map scale, right triangle

Background information

Mapping caves is tricky business since modern technology such as Global Positioning Systems (GPS) that use satellites to determine location may not be used underground. Commonly cave mapping is done with survey teams of at least three people using instruments such as a compass, a clinometer, and a measuring tape. With these instruments, surveyors determine the length, width, height, and slope of one section of cave passage at a time. The length is measured with a measuring tape between two people, as is the width when possible. If the cave is too wide or the entire width is impassable then a triangulation is performed using right triangles between two people. This triangulation is determined by locating the length with the measuring tape between person 1 and person 2, X, and angles 1 and 2 with a compass. Lengths A and B can then be determined by taking the tangent of the angle: tan 1= A/X and tan 2= B/X. Then the width is equal to A + B. A similar triangulation is used to determine the height of tall passages.



Once collected, the individual map sections are compiled to create a plan view map, a map from above with landmarks drawn in, and a profile map, a map slice through the cave to show elevation changes. This map must be accurate because future visitors will use it to navigate the cave. In addition, sketch artists usually draw cross-sections of the cave passage at the measurement points and sketch other possible side passages off the mapped path. In this lesson, students will learn how to read existing plan view and profile maps. Students will also map their own cave passage to compile a plan view and profile map.

Pre-activity thought questions: How are geological features mapped today? How could caves be mapped if they are below ground? How could you measure the height of a cave if it is too high to reach?

Materials needed

- Maps of Carlsbad Cavern (slides 85 and 86)
- Jim Nieland's "Cave Surveying" paper (supplement #1)
- compass
- measuring tape
- clinometer (pre-made one or a protractor, straw, string, tape, and a weight)
- science notebooks
- if mapping a pseudo-cave in hall, need objects to represent stalactites, stalagmites, columns, and other speleothems.

Assessments

- Speleothem notes in science notebooks
- Annotated Carlsbad Cavern map
- Survey notes in science notebooks
- Final plan view and profile maps

Procedure

Activity #1: Mapping caves and recognizing speleothems

The teacher will:

- Discuss map making in caves and explain the planview Carlsbad Caverns map and the map symbols.
- Lead students on fieldtrip to Carlsbad Caverns National Park.
- In teams of two, have the students use the Carlsbad Caverns map to examine and describe speleothems in their notebooks and look for other formations not depicted on the map. All findings and descriptions should be marked as stations on the map and well described in their notes.

Activity #2: Making your own cave map

The teacher will:

- Assign Jim Nieland's "Cave Surveying" paper.
- Discuss the ways caves are mapped and the purpose of mapping caves.
- Arrange students in groups of 3-4 for "surveying teams."
- If in Carlsbad Caverns National Park or another cave, orient the students with a ranger and begin mapping the section assigned by the ranger.

- If at the school, once a makeshift cavern has been established with “speleothems” in a hallway or several rooms, have surveying teams of 3-4 students map the “cave” as they would a real cave passage. Symbols as those in Nieland’s paper should be used on each map.
- The teams of students should produce a plan-view and a cross-sectional map of their cave.

Follow-up questions: How easy is it to map a cave? In what ways might your map be inaccurate? What might happen if a real cave is inaccurately mapped?

Alternative assessments

- Compare other cave maps to Carlsbad Cavern maps.
- Visit other caverns in your area and attempt to map them as well.

Bibliography:

Nieland, J. *Cave Surveying*. SCS 7801 (available from Carlsbad Caverns National Park).

Gillieson, D. 1996. *Caves: Processes, Development, Management.* MA: Blackwell Publishers.

Geology is gneiss, but isn't it outdated? Why understanding geology is important today.

9-12

Lesson #10

Prerequisites: knowledge of basic geology concepts

Estimated time: 1 Lab (50 min)

Location: in lab

Learner outcomes

The learner will:

- Understand the importance of geology today.
- Learn about some of the geological fields that people are working in today.

Vocabulary: hydrocarbon, oil, natural gas, seismic profile, National Park Service, United States Geological Survey

Background information

While geology is the study of the Earth and Earth processes over the last 4.6 billion years, geological research is being conducted today. As seen in this curriculum, there are many aspects of the Earth that still need to be investigated and there are internal divisions within the field of geology that focus specifically on the topics discussed here in much greater detail.

Examples of careers in geology are: petroleum geologists, geochronologists, geomorphologists, stratigraphers, and environmental geologists. Petroleum geologists are involved in exploration for and production of oil and natural gas resources. As most of own motor vehicles for transportation and many of us use natural gas to heat our homes, a petroleum geologist is imperative to find and maximize retrieval of hydrocarbons. Geochronologists use the rates of radioactive decay of certain elements in rocks to determine their age and the time sequence of events in the history of the Earth. Absolute ages of geologic deposits are necessary to help geomorphologists, those geologists who study how the Earth's landscapes responds to specific geologic events such as climate changes, tectonic events, or human activity in hopes of predicting landscape changes in the future. Stratigraphers also use geochronology to investigate the time and space relationships of rocks, on a local, regional, and global scale throughout geologic time. And environmental geologists study the interaction between the geosphere, hydrosphere, atmosphere, biosphere, and human activities. These environmental studies may be used to solve problems associated with pollution, waste management, urbanization, and natural hazards, such as flooding and erosion.

These geologists may work in the lab or in the field and are employed in governmental agencies, industry, private companies, and universities. Common workplaces in the government for geologists are: 1) the United States Geological Survey, 2) the US Forest Service, 3) the Bureau of Land Management, and 4) in many of the state Geological Surveys. In these positions, geologists are often conducting research and helping to determine resource management practices and policies. The oil industry is a major employer of geologists as well as petroleum geologists searching for hydrocarbons and environmental geologists ensuring that minimal environmental damage is incurred when drilling for hydrocarbons. In private companies, geologists are often on contracted, short-term projects for other companies or the government. These positions may require the geologist to take samples in the field, work in the lab, and write technical reports summarizing the results. Universities also employ geologists as educators and to conduct fieldwork and lab work on large research projects.

Geologists at Carlsbad Caverns National Park are in hydrology and interpretation. The role of the hydrologist in the park is varied—on a given day, the park hydrologist may be collecting water samples from the Carlsbad Cavern, mapping passages in new caves or making more accurate measurements on existing maps, determining the best way to manage and protect the cave resources, talking with visitors to the cave about the geology of the area, or teaching a class on caving. As an interpretive ranger, a geologist's primary responsibility is to teach the visitors to the cave about the geological resources within the park. This may be accomplished through tours, presentations at the park and in the community, and developing written literature to hand out to visitors.

This lesson should be used to summarize the geologic concepts discussed throughout the curriculum and give students an idea about the everyday applications of and employment opportunities within geology.

Pre-activity thought questions: Why is geology important? How many geological things do we use each day? What are they?

Assessments
- Science notebooks
- Student presentations

Materials needed
- Science notebooks
- AGI's web page brochure on geological careers: *http://www.earthscienceworld.org/careers/brochure.html*

Procedure

How does geology affect our lives?

The teacher will:

- Lead a summary discussion on the lessons within this curriculum.
- Brainstorm with students about the different ways in which we uses geology everyday:
  - Oil
  - Gas
  - Metal
  - Plasterboard (sheetrock is made out of gypsum)
  - Salt
  - Water
- Have students research different occupations within geology on the American Geological Institute's web page and present their findings.
- Invite a geologist into the classroom to discuss their career choices and responsibilities.

Follow-up questions: Could we live without geology? Can anyone be a geologist?

Bibliography

Marshak, S. 2001. *Earth Portrait of a Planet*. NY: W.W. Norton & Co.

AGI's "Careers in the Geosciences" brochure:
http://www.earthscienceworld.org/careers/brochure.html

USGS webpage: *http://geology.usgs.gov/index.shtml*

Association for Women Geoscientists: *http://www.awg.org/*

The National Association for Black Geologists and Geophysicists (NABGG): *www.nabgg.org*