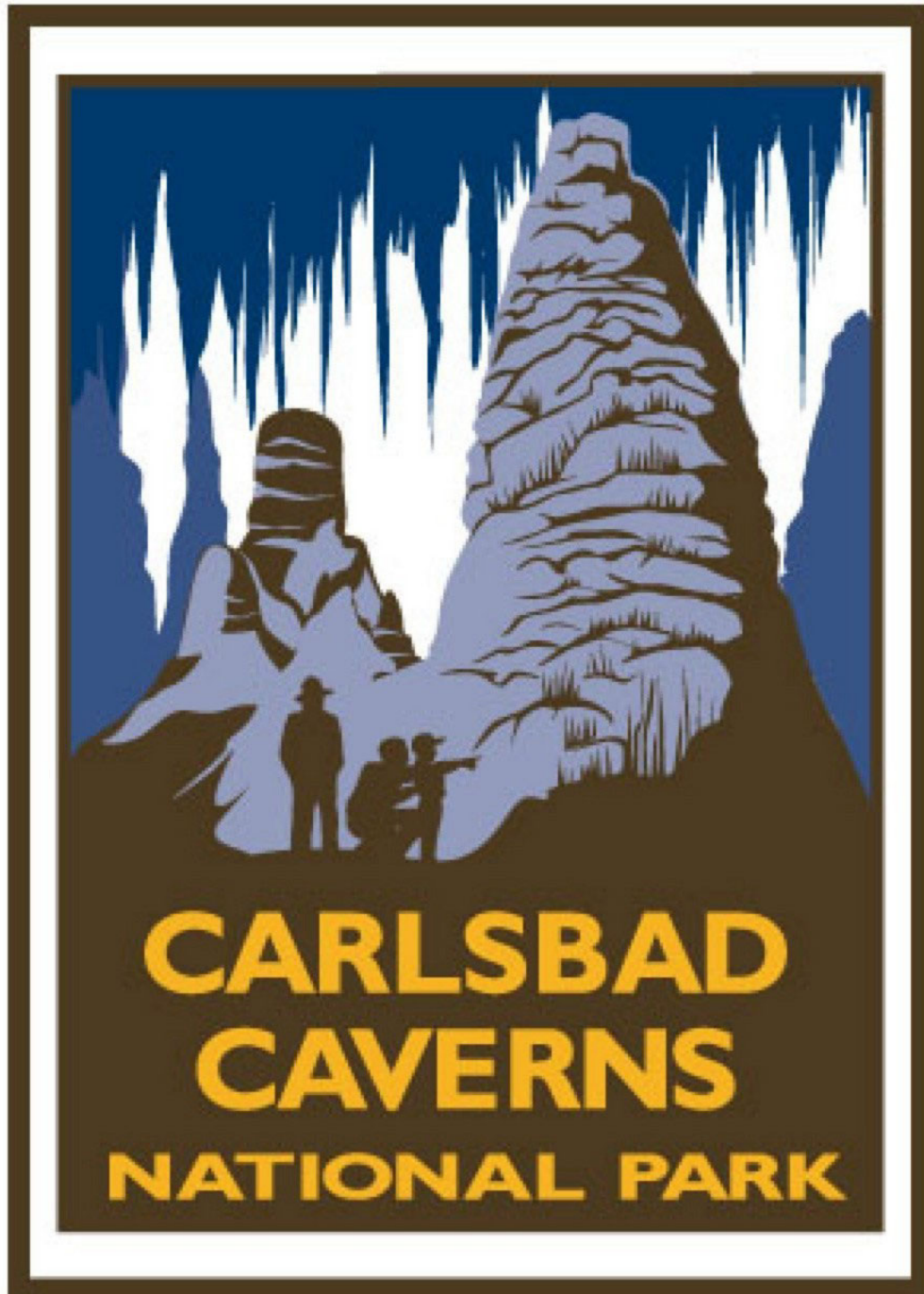




# *High School Geology*



# Carlsbad Caverns National Park

## High School Geology Curriculum

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# Introduction

## **A. Purpose for the curriculum:**

Located in the Guadalupe Mountains on the fringe of the Delaware Basin, a region with unique biologic and geologic features, Carlsbad Caverns National Park has promoted science education through its participation in the National Parks Labs Program with the Chihuahuan Desert Lab (CDL). While the CDL provides projects in biology, botany, hydrology, and GIS technology, both in local high schools and on the internet, none of its projects include geologic investigations. Supported by the National Park Service "Geologist-in-the-Parks" program, a high school level curriculum has been developed emphasizing the regional geology and cavern formation. Built upon the CDL framework, it is our hopes that this curriculum will not only benefit those students in the park's immediate area but also will be available as an online teaching module.

In order to meet this broad student audience, the lessons include field trips to the Permian strata and caverns in conjunction with hands-on, introductory college-style laboratories to provide background geologic concepts. It is through these processes that this curriculum should provide not only an understanding of the regional geology of Carlsbad Caverns National Park, but also a general understanding of geologic history and processes.

## B. Explanation of the curriculum format:

The lessons are organized in a format similar to the CDL to maintain recognition of sections and features. This format is:



Title  
Grades levels appropriate  
Lesson #  
Prerequisites  
Estimated time  
Location

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### Learner outcomes:

The learner will:

- 

### Vocabulary:

### Background information:

### Pre-activity thought questions:

### Materials needed:

- 

### Assessment:

- 

### Procedure:

The teacher will:

- 

### Follow-up questions:

### Alternative assessments:

- 

### Bibliography:

### Additional reading and other resources:

### **C. Fieldtrip information:**

As geology is best understood when seen in person, fieldtrips to Carlsbad Caverns National Park and Guadalupe Mountains National Park are encouraged. Many of the lessons suggest trips and activities that are done in the cave. However, knowing that fieldtrips are expensive and offering this curriculum via the internet, thus reaching people outside of the area, alternatives to most fieldtrips are offered. These alternatives include use of local geology and National Parks, hands-on laboratory activities, and creative cave-making. A great deal of information about the caverns is also available on the internet at: <http://www.carlsbad.caverns.national-park.com/> and <http://www.nps.gov/cave/>.

Should you be in the area of Carlsbad Caverns National Park and would like to gain the full geology experience this curriculum offers, please contact us in advance at:

Education Specialist  
Carlsbad Caverns National Park  
3225 National Park Highway  
Carlsbad, NM 88220  
(505) 785-2232 x432



## 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)

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### 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](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](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

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### 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/lovie/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

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### 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](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

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#### 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.

#### **Bibliography**

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

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](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

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### 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 Niño, 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 Niño, 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<sub>2</sub>S 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?

### **Bibliography**

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.

Caves Reveal Climates Project Proposal: <http://www.ncdc.noaa.gov/ogp/papers/gonzale.html>

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

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

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### 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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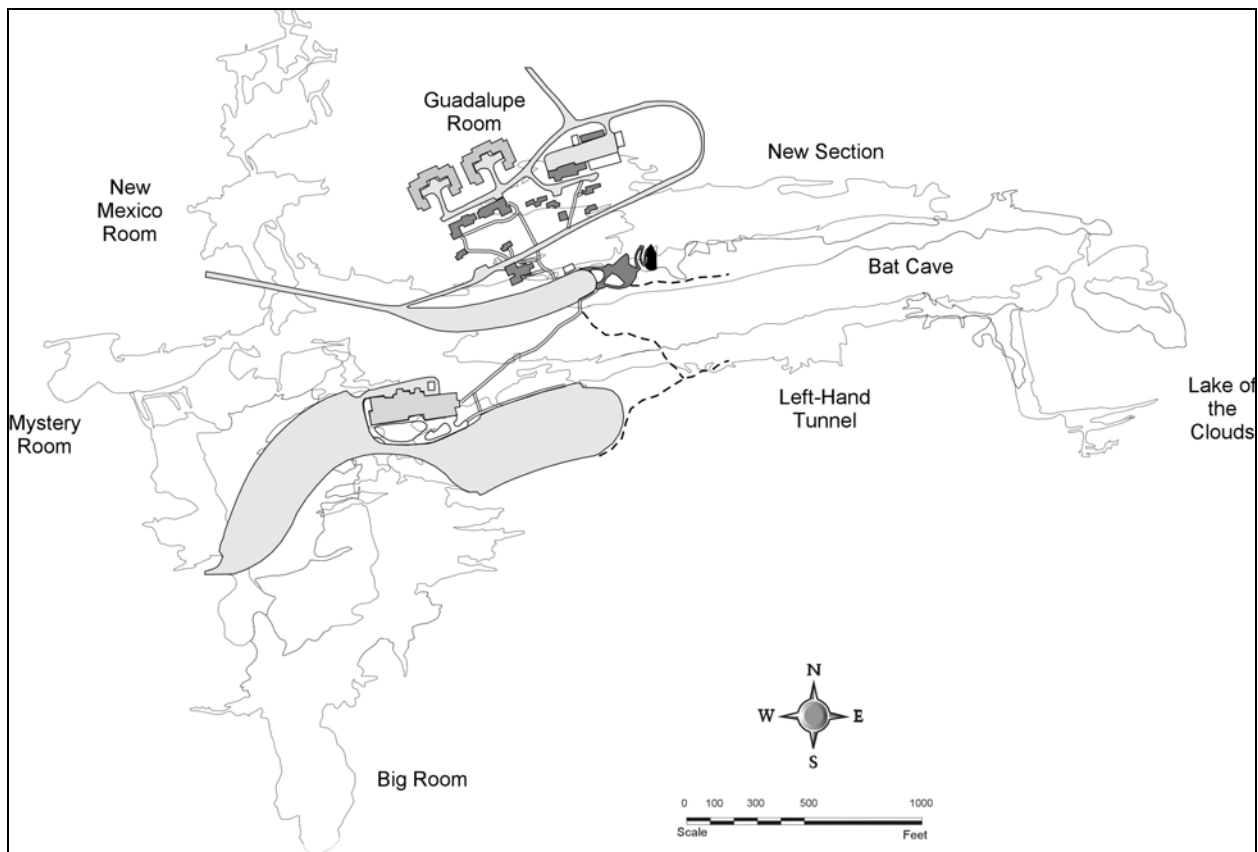
# Hydrology Exercise

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

<u>Multiply</u>	<u>by</u>	<u>to get</u>
Cubic feet	7.48	gallons
Liters	0.264	gallons
Milligrams	$2.2 \times 10^{-6}$	pounds



## Part I: Water flow from the parking lots

### Paved Area

Bat Cave Draw Parking Lot: 100,290ft<sup>2</sup>

Visitor Center East: 188,280 ft<sup>2</sup>

Visitor Center West: 169,200 ft<sup>2</sup>

### 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

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### Learner outcomes

The learner will:

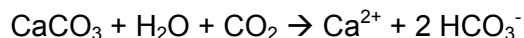
- Learn about karst and some karst features.

**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<sub>2</sub>), water (H<sub>2</sub>O), carbonic acid (HCO<sub>3</sub><sup>-</sup>), calcite (Ca<sup>2+</sup>), solution, permeate, evaporate, speleothem, sulfuric acid (H<sub>2</sub>SO<sub>4</sub>), 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<sub>2</sub>) from the atmosphere or from soil organics is incorporated with water (H<sub>2</sub>O) creating a mild carbonic acid (HCO<sub>3</sub><sup>-</sup>). As this acid flows through carbonate rocks, the rocks are dissolved and the calcite (Ca<sup>2+</sup>) is taken up into solution.



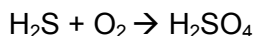
When this solution permeates into a pre-dissolved cave, the drops come down from the roof or along the walls of the cave, the water evaporates, and limestone cave decorations are produced.



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<sub>2</sub>SO<sub>4</sub>) was formed when hydrogen sulfide gas (H<sub>2</sub>S) from the hydrocarbons in the basin migrated upwards into the Capitan Formation. In the Permian Reef deposits, the

H<sub>2</sub>S mixed with dissolved oxygen (O<sub>2</sub>) in the groundwater (H<sub>2</sub>O) and formed a strong sulfuric acid.



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<sub>4</sub>·2(H<sub>2</sub>O), 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<sub>4</sub>·2(H<sub>2</sub>O), 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.).

#### **Bibliography**

Veni, G., DuChene, H., Crawford, N.C., Groves, C.G., Huppert, G.N., Kastning, E.H., Olson, R., and B.J. Wheeler. 2001. *Living with Karst - A Fragile Foundation*. American Geological Institute.

Jagnow, D.H. and H.R. DuChene. 1986. *NSS Geology Field Trip Guidebook*.

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.



## 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

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### 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 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](http://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

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#### Learner outcomes

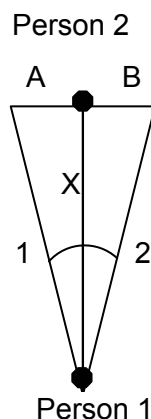
The learner will:

- 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

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#### 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 use 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](http://www.nabgg.org)*

# New Mexico Content Standards and Benchmarks

## Science

Content Standards	Benchmarks
1. Students will understand science concepts of order and organization.	b
2. Students will use evidence, models, and explanations to explore the physical world.	b
3. Students will use form and function to organize and understand the physical world.	none
4. Students will understand the physical world through the concepts of change, equilibrium, and measurement.	a, b, c, e, f
5. Students will acquire the ability to do scientific inquiry.	a, b,
6. Students will understand the process of scientific inquiry.	a, c, d, g, h
7. Students will know and understand the properties of matter.	a, b, c
8. Students will know and understand the properties of fields, forces, and motion.	none
9. Students will know and understand the concepts of energy and the transformation of energy.	a, b
10. Students will know and understand the characteristics that are the basis for classifying organisms.	a
11. Students will know and understand the synergy among organisms and the environments of organisms.	b, c, e, f,
12. Students will know and understand properties of Earth Science.	a, b, c, d, e, f, g, h
13. Students will know and understand basic concepts of cosmology.	none
14. Students will know and understand the differences between science and technology.	d
15. Students will know and understand the impact between science and technology in society.	e, g
16. The students will know and understand the relationship between natural hazards and environmental risks for organisms.	c

# Texas Essential Knowledge and Skills for Science

## *112.42 Integrated Physics and Chemistry*

<b>Scientific Processes and Concepts</b>	<b>Student Expectations</b>
1. The student, for at least 40% of instructional time, conducts field and laboratory investigations using safe, environmentally appropriate, and ethical practices.	
2. The student uses scientific methods during field and laboratory investigations.	
3. The student uses critical thinking and scientific problem solving to make informed decisions.	
4. The student knows concepts of force and motion evident in everyday life.	
5. The student knows the effects of waves on everyday life.	
6. The student knows the impact of energy transformations in everyday life.	
7. The student knows relationships exist between properties of matter and its components.	
8. The student knows that changes in matter affect everyday life.	
9. The student knows how solution chemistry is a part of everyday life.	

# Texas Essential Knowledge and Skills for Science

## 112.43 Biology

Scientific Processes and Concepts	Student Expectations
1. Scientific processes. The student, for at least 40% of instructional time, conducts field and laboratory investigations using safe, environmentally appropriate, and ethical practices.	
2. Scientific processes. The student uses scientific methods during field and laboratory investigations.	
3. Scientific processes. The student uses critical thinking and scientific problem solving to make informed decisions.	
4. Science concepts. The student knows that cells are basic structures of all living things and have specialized parts that perform specific functions, and that viruses are different from cells and have different properties and functions.	
5. Science concepts. The student knows how an organism grows and how specialized cells, tissues, and organs develop.	
6. Science concepts. The student knows the structures and functions of nucleic acids in the mechanisms of genetics.	
7. Science concepts. The student knows the theory of biological evolution.	
8. Science concepts. The student knows applications of taxonomy and can identify its limitations.	
9. Science concepts. The student knows metabolic processes and energy transfers that occur in living organisms.	
10. Science concepts. The student knows that, at all levels of nature, living systems are found within other living systems, each with its own boundary and limits.	
11. Science concepts. The student knows that organisms maintain homeostasis.	
12. Science concepts. The student knows that interdependence and interactions occur within an ecosystem.	
13. Science concepts. The student knows the significance of plants in the environment.	

# Texas Essential Knowledge and Skills for Science

## 112.44 Environmental Systems

Scientific Processes and Concepts	Student Expectations
1. Scientific processes. The student, for at least 40% of instructional time, conducts field and laboratory investigations using safe, environmentally appropriate, and ethical practices.	
2. Scientific processes. The student uses scientific methods during field and laboratory investigations.	
3. Scientific processes. The student uses critical thinking and scientific problem solving to make informed decisions.	
4. Science concepts. The student knows the relationships of biotic and abiotic factors within habitats, ecosystems, and biomes.	
5. Science concepts. The student knows the interrelationships among the resources within the local environmental system.	
6. Science concepts. The student knows the sources and flow of energy through an environmental system.	
7. Science concepts. The student knows the relationship between carrying capacity and changes in populations and ecosystems.	
8. Science concepts. The student knows that environments change.	



# Texas Essential Knowledge and Skills for Science

## 112.45 Chemistry

Scientific Processes and Concepts	Student Expectations
1. The student, for at least 40% of instructional time, conducts field and laboratory investigations using safe, environmentally appropriate, and ethical practices.	
2. The student uses scientific methods during field and laboratory investigations.	
3. Scientific processes. The student uses critical thinking and scientific problem solving to make informed decisions.	
4. The student knows the characteristics of matter.	
5. The student knows that energy transformations occur during physical or chemical changes in matter.	
6. The student knows that atomic structure is determined by nuclear composition, allowable electron cloud, and subatomic particles.	
7. The student knows the variables that influence the behavior of gases.	
8. The student knows how atoms form bonds to acquire a stable arrangement of electrons.	
9. The student knows the processes, effects, and significance of nuclear fission and nuclear fusion.	
10. The student knows common oxidation-reduction reactions.	
11. The student knows that balanced chemical equations are used to interpret and describe the interactions of matter.	
12. The student knows the factors that influence the solubility of solutes in a solvent.	
13. The student knows the relationships among the concentration, electrical conductivity, and colligative properties of a solution.	
14. The student knows the properties and behavior of acids and bases.	
15. The student knows factors involved in chemical reactions.	

# Texas Essential Knowledge and Skills for Science

## 112.46 Aquatic Science

Scientific Processes and Concepts	Student Expectations
1. Scientific processes. The student, for at least 40% of instructional time, conducts field and laboratory investigations using safe, environmentally appropriate, and ethical practices.	
2. Scientific processes. The student uses scientific methods during field and laboratory investigations.	
3. Scientific processes. The student uses critical thinking and scientific problem solving to make informed decisions.	
4. Science concepts. The student knows the components of aquatic ecosystems.	
5. Science concepts. The student knows the relationships within and among the aquatic habitats and ecosystems in an aquatic environment.	
6. Science concepts. The student knows the roles of cycles in an aquatic environment.	
7. Science concepts. The student knows environmental adaptations of aquatic organisms.	
8. Science concepts. The student knows that aquatic environments change.	
9. Science concepts. The student knows that geological phenomena and fluid dynamics affect aquatic systems.	
10. Science concepts. The student knows the origin and use of water in a watershed.	

# Texas Essential Knowledge and Skills for Science

## *112.49 Geology, Meteorology, and Oceanography*

Scientific Processes and Concepts	Student Expectations
1. Scientific processes. The student, for at least 40% of instructional time, conducts field and laboratory investigations using safe, environmentally appropriate, and ethical practices.	
2. Scientific processes. The student uses scientific methods during field and laboratory investigations.	
3. Scientific processes. The student uses critical thinking and scientific problem solving to make informed decisions.	
4. Science concepts. The student knows the Earth's unique characteristics and conditions.	
5. Science concepts. The student knows about the formation and history of the Earth.	
6. Science concepts. The student knows the processes of plate tectonics.	
7. Science concepts. The student knows the origin and composition of minerals and rocks and the significance of the rock cycle.	
8. Science concepts. The student knows the processes and end products of weathering.	
9. Science concepts. The student knows the role of natural energy resources.	
10. Science concepts. The student knows the interactions that occur in a watershed.	
11. Science concepts. The student knows characteristics of oceans.	
12. Science concepts. The student knows characteristics of the atmosphere.	
13. Science concepts. The student knows the role of energy in governing weather and climate.	

# Texas Essential Knowledge and Skills for Science

## 112.47 Physics

Scientific Processes and Concepts	Student Expectations
1. Scientific processes. The student, for at least 40% of instructional time, conducts field and laboratory investigations using safe, environmentally appropriate, and ethical practices.	
2. Scientific processes. The student uses scientific methods during field and laboratory investigations.	
3. Scientific processes. The student uses critical thinking and scientific problem solving to make informed decisions.	
4. Science concepts. The student knows the laws governing motion.	
5. Science concepts. The student knows that changes occur within a physical system and recognizes that energy and momentum are conserved.	
6. Science concepts. The student knows forces in nature.	
7. Science concepts. The student knows the laws of thermodynamics.	
8. Science concepts. The student knows the characteristics and behavior of waves.	
9. Science concepts. The student knows simple examples of quantum physics.	

# Glossary of Terms

## A

**Absolute dating:** dating techniques performed to produce a numerical age in years.

**Aerial photograph:** photograph of the Earth from the air, either by plane or space shuttle.

**Alfred Wegner:** the German meteorologist who used: 1) the fit of the continents, 2) locations of past glaciations, 3) distribution of equatorial regions, 4) distribution of fossils, and 5) matching geologic units to suggest the previous existence of Pangea and the Theory of Continental drift in the 1930s.

**Algae:** a collection of plant species that thrive in wet conditions; many are unicellular organisms (common types found in the Capitan Formation during the Permian were: *Tubiphytes* and *Archaeolithoporella*).

**Algal mat:** a layered communal growth of algae observed in fossils and in present day tidal zones associated with carbonate sediments.

**Alluvium:** unconsolidated terrestrial sediment composed of sorted or unsorted sand, gravel, and clay that had been deposited by water.

**Ammonite:** an extinct marine Cephalopod mollusk that had an elaborately coiled and chambered shell which display intricately shaped septa and sutures.

**Analog:** a modern environmental setting and associated geological processes that are analogous or similar to a paleoenvironment and the processes that formed it.

**Anticline:** a fold with an arch-like shape (convex-up).

**Aquifer:** sediment or rocks, such as cavernous limestone or unconsolidated

sand, which stores, conducts, and transmits large quantities of water easily.

**Aquitard (confining layer):** sediment or rock that does not transmit water easily and thus hinders the flow of the water.

**Aquiclude:** sediment or rock that transmits no water.

**Archaeological artifact:** something created by humans usually for decorative or practical purposes; physical evidence of human presence.

**Artesian wells:** see *Spring*.

**Asthenosphere:** the layer of the Earth that lies beneath the lithosphere; it is believed to have a plastic consistency.

**Average:** the mean of a set of numbers.

**Azimuth scale:** a circular scale that goes clockwise from 0 at the north point through 360 degrees.

## B

**Backreef:** the region of shallow water shoreward of the reef; often a lagoon.

**Balloon:** small, gas-filled pouch usually composed of the mineral hydromagnesite that is thought to form when pressurized mineral-saturated water seeps through cracks and upon meeting moonmilk on its way out, it expands like a rubber balloon.

**Basalt:** a fine-grained, dark, mafic igneous rock composed largely of plagioclase feldspar and pyroxene minerals.

**Basin:** in tectonics, a circular, syncline-like depression of rocks. In sedimentology, the site of accumulation of a large thickness of sediments.

**Bathymetric map:** a map representing a body of water's bathymetry.

**Bathymetry:** the measurement of water depth or the mapping of sea-floor topography in a body of water, such as the ocean or a lake.

**Bell Canyon Formation:** Permian marine formation of sandstone, siltstone, and some limestone; it extends from the reef margin into the basin.**Billion:** a term representing numbers that are  $10^9$ , or 1,000,000,000. The Earth is approximately 4.6 billion years old.

**Biochemical sedimentary rock:** a sedimentary rock, such as limestone, formed from elements extracted from sea water by living organisms or sedimentary rocks derived primarily of pieces of organisms (i.e. shells or plant fragments).

**Bivalves:** an animal (as a clam) with a 2-valved shell.**Bluff:** a high steep bank; a cliff.

**Brachiopods:** an invertebrate animal with a pair of protective shells, a stalk anchoring it to the floor, and tiny tentacles to catch food. They came in all shapes and sizes before they all nearly became extinct at the end of the Permian Period.

**Brine:** a strong saline solution.

**Bryozoans:** a phylum of animals, often called "moss animals," that had a fan-like or boxwork-like frame built from colonies of individual organisms.

## C

**Calcite:** a rhombohedral, carbonate mineral with the chemical composition of  $\text{CaCO}_3$  (calcium carbonate).

**Capitan Aquifer:** karst aquifer in the Capitan Formation.

**Capitan Limestone:** Permian marine limestone formation composed of reef deposits and abundant marine fossils (reef).**Carbonate:** a group of minerals with the base chemical composition of  $\text{CaCO}_3$  (calcium carbonate).

**Carbonic acid:** a mild, naturally occurring acid, formed when water combines with atmospheric and/or soil  $\text{CO}_2$ , which is very common in groundwater and readily dissolves carbonates and sulfates to form karst landscapes.

**Carbon cycle:** the cycle of carbon through the earth's atmosphere as  $\text{CO}_2$ , geosphere (in carbonate rocks and reefs), and ecosystems in which carbon dioxide is used by photosynthetic organisms and then ultimately restored to the atmosphere by respiration.

**Carbon dioxide ( $\text{CO}_2$ ):** a colorless greenhouse gas that plays an integral role in the geological cycle; creates carbonic acid ( $\text{H}_2\text{CO}_3$ ) when dissolved in water (as is found in carbonated sodas).

**Carlsbad Caverns National Park:** located in south eastern New Mexico in the Guadalupe Mountains, the park was designated a National Park in 1930; it includes 46,766 acres and more than 86 other smaller caves.

**Castile Formation:** Permian evaporite formation in the Delaware Basin of layered gypsum, anhydrite, and halite.**Cave:** a natural open space underground, generally with a connection to the surface and large enough for a person to enter.

**Cement:** mineral material that precipitates from water and fills the voids between grains, holding the grains together.

**Cementation:** the phase of lithification where cement fills the voids between grains attaching them to each other.

**Cephalopods:** an organized group of mollusks in the Class Cephalopoda that are free-swimming aggressive carnivores with tentacles to capture prey and a siphon to move using jet-propulsion. This Class includes Nautiloids and Ammonites.

**Chemical composition:** the specific chemical (elemental) make-up of rocks and minerals.

**Chemical sedimentary rock:** a sedimentary rock that is formed at or near its place of deposition by chemical precipitation, usually from sea water or other saline waters.

**Chemical weathering:** the process in which chemical reactions alter or destroy minerals when rock is in contact with air or water solutions.

**Clastic sedimentary rock:** a sedimentary rock formed from clasts that were mechanically transported.

**Clasts:** mineral particles or sediments.

**Clay:** a) one of a number of hydrous aluminosilicate minerals formed by weathering and hydration of other silicates; b) any mineral fragment smaller than 1/255 mm.

**Cleavage:** the tendency of a mineral to break along preferred planes. The majority of minerals break along 1, 2, or 3 cleavage planes.

**Climate:** the average weather conditions, along with the range of conditions, of a region over a year.

**Climate change:** a change in the average weather conditions, along with the range of conditions, of a region.

**Clinometer:** an instrument that is used to measure angles of elevation or inclination.

**Coal:** a sedimentary rock which is a product of stratified plant remains; contains more than 50 percent carbon compounds and burns readily.

**Columns:** speleothems formed by: 1) the unions of stalagmites and stalactites, 2) the union of a stalactite with the floor, 3) the growth of a stalagmite to the ceiling.

**Compass:** a device for determining directions by means of a magnetic needle or group of needles that turns freely on a pivot and points to the magnetic north.

**Compass directions:** the four cardinal directions are north, south, east, and west.

**Compressional stress:** a force that compresses or squeezes a body or rock layers together.

**Condensation:** the conversion of a substance (such as water) from the vapor state to a denser liquid or solid state usually initiated by a reduction in temperature of the vapor.

**Confined aquifer:** an aquifer that is separated from the Earth's surface by an overlying aquitard.

**Confining unit:** see *Aquitard*.

**Conglomerate:** a sedimentary rock composed of rounded, coarse-grained sediment (such as pebbles or gravel) cemented together.

**Connectivity:** the amount of connected spaces in rock or sediment through which air or water can flow.

**Contaminant:** unwholesome or undesirable elements whose introduction into a system contaminate or make the elements of the system unfit for use.

**Contamination:** the process of being contaminated.

**Continental crust:** the crust of which the continents are composed; composed of relatively light felsic rocks such as quartz and feldspar. Continental crust is less dense than oceanic crust and therefore will be the buoyant crust at convergent plate margins.

**Continental-drift hypothesis:** Alfred Wegner's hypothesis that continents have moved and are still moving across Earth's surface.

**Continental rift:** the formation of a divergent plate margin along a belt where the continent stretches and spreads apart.

**Convection:** a heat transfer that occurs when warmer, less dense material rises while cooler, denser material sinks; the

main mechanism believed to drive plate tectonics.

**Convergent margin (convergent plate boundary):** a boundary at which two plates move towards each other so that one plate sinks (subducts) below the other; only oceanic lithospheric crust is dense enough to subduct.

**Conveyor belt:** see *thermohaline circulation*.

**Coquina:** a bioclastic sedimentary rock primarily composed of cemented shell pieces.

**Coral:** the calcareous or horny skeletal deposit produced by marine invertebrates. **Cracks:** breaks in rock.

**Cretaceous Period:** the geologic time period spanning 66 and 144 million years ago; the height of the dinosaur age and the introduction of flowering plants.

**Crinoids:** part of the Class Crinoidea in the phylum Echinodermata, these are sea-lily animals with segmented stalks to root them to the ground and a flower-like head with tentacles to catch prey. The stalks are most commonly found fossilized whole with the segments still together or with the segments separated as little disks.

**Cross-cutting relationships:** how rocks and sediments are deposited relative to previous deposits.

**Cross section:** a diagram depicting the geometry of geologic materials as an imaginary vertical slice.

**Crust:** the rock that makes up the thin, outermost layer of the Earth (oceanic crust is about 7-10km thick and continental is 30-40km thick).

**Crystal:** a single, continuous piece of a mineral bounded by flat surfaces that formed naturally as the mineral grew.

**Crystalline:** a texture describing a rock that is massive (without internal structure) and sparkling.

**Crystallization:** the act of forming crystals.

**Crystal form:** the geometric shape of a crystal, defined by the arrangement of the crystal faces.

**Crystal habit:** the general shape of a crystal or cluster of crystals that grew unimpeded.

**Cultural materials:** see *archaeological artifact*.

**Cynognathus:** a carnivorous, wolf-sized, mammal-like reptile (not a dinosaur) that lived on open plains in Africa and South America roughly 230-245 million years ago.

## D

**Daughter isotope:** the decay product of radioactive decay of a parent isotope.

**Decay curve:** a curve on an X-Y graph indicating exponential decay.

**Deflected stalactites:** unusual stalactites that are curved due to either: 1) strong cave air flow, 2) disruption of the water flow down the outside of the stalactite by crusts or popcorn formed on the outside, or 3) corrosional wind eroding on one side of the speleothem.

**Delaware Basin:** the paleo-oceanic and sedimentary basin in southeastern New Mexico and West Texas; formed in the Permian and current hydrocarbon producer.

**Density:** a measurement of a substance based on its mass versus its volume (Density = Mass/Volume).

**Deposition:** the process by which sediment settles out of a transporting medium.

**Deposits:** the sediments/rocks/minerals that are left behind after transportation ceases.



**Disappearing stream:** a stream that intersects a crack or sinkhole leading to an underground cavity, so that the water disappears below the surface and becomes an underground stream.

**Discharge:** A volumetric measurement of flowing water.

**Dissolution:** the process of dissolving rocks and minerals with liquid (usually slightly acidic water).

**Divergent margin (Divergent plate boundary):** a boundary at which two lithosphere plates move away from each other; they are marked by mid-ocean ridges and rift valleys.

**Dolines:** see *Sinkholes*

**Dolomite:** a carbonate mineral with the chemical composition  $\text{CaMg}(\text{CO}_3)_2$ ; it possesses cleavage in three directions and effervesces when powdered.

**Draperies:** speleothems resembling curtains that are deposited when calcite-rich solutions flow along an overhung surface where surface tension allows these solutions to cling to the ceiling and deposit calcite in thin trails.

## E

**Earthquake:** a vibration caused by the sudden breaking or frictional sliding of rock in the Earth.

**Eccentricity:** the shape of the Earth's orbit around the sun (low eccentricity = more circular and high eccentricity = more elliptical) which varies on a 100,000yr cycle affecting global climate.

**Ecology:** the study of the life cycles, populations, and interactions of various biological species as controlled by their physical environment (living and nonliving components), including also the effect of life forms upon the environment.

**Ecosystem:** a community of organisms and the environment in which they live including

the non-living factors that exist and affect the community.

**Effervesce:** to bubble, hiss, and foam as gas escapes (like a carbonate when treated with hydrochloric acid).

**El Capitan:** the prominent dolomite bluff composed of the Capitan Formation in Guadalupe Mountains National Park.

**Electron-spin resonance dating (ESR):** a dating technique, extending up to about 1 million years, that measures the number of electrons stored in the crystal lattice of minerals; it may be used to determine the ages of carbonates, speleothems, and corals.

**Element:** any one of more than 100 fundamental substances that consists of atoms of only one kind and that singly or in combination constitute all matter.

**El Nino:** the westerly flow of warm water east from the eastern Pacific Ocean, reversing the upwelling of cold water along the west coast of North and South America and causing significant global changes in weather patterns (occurring on a 3-7 year time scale).

**English system:** the foot-pound-second system of units.

**Environmental geologist:** a geologist that studies the interaction between the geosphere, hydrosphere, atmosphere, biosphere, and human activities.

**Environmental geology:** the study of the interactions between the environment and geologic materials and the contamination of geologic materials.

**Environmental Protection Agency (EPA):** a United States governmental agency with the mission to protect human health and to safeguard the natural environment, air, water, and land, upon which life depends.

**Ephemeral stream:** a stream whose bed lies above the water table, so that the stream only flows when precipitation rates

exceed rates of that the water infiltrates the ground.

**Erosion:** the break up and removal of the Earth surface by moving water, wind, or ice.

**Eruption:** to force out or release suddenly and often violently something (as lava or steam) that is pent up.

**Evaporation:** to convert from liquid into vapor.

**Evapotranspiration:** the sum of evaporation from bodies of water and the ground surface and transpiration from plants and animals.

**Evaporite:** a chemical sedimentary rock or a mineral precipitated through the evaporation of a chemically saturated solution.

**Evolution:** process of changing through time.

**Exponential decay:** the decline of a population (isotopes, critters, etc.) at an exponential rate as expressed in the equation:  $\ln(N/N_0) = k * t$  (where  $N_0$  is the initial population,  $N$  is the final population,  $k$  is the decay constant, and  $t$  is the time passed).

**Extensional stress:** a force that extends or pulls a body or rock layers apart.

**External mechanism:** a force upon geologic processes outside of the geologic medium itself (i.e. climate, tectonics, humans).

**Extinct:** no longer existing (i.e. an extinct animal).

**Extinction:** the act of making extinct; extinction events caused by different reasons have occurred periodically throughout geologic history.

## F

**Fault:** a fracture in rocks where one rock body slides past another.

**Fauna:** animal life.

**Feedbacks:** complex interactions between different systems, which then interfere with each other.

**Feldspar:** a silicate mineral with varying chemical compositions depending on the type of feldspar ( $AlSiO_2$ ); it possesses 2-directional cleavage and potassium feldspar is often pink or flesh colored while sodium or calcium-rich feldspar have linear striations (they appear as thin lines on the crystal face).

**Felsic:** an adjective used to describe a light-colored igneous rock poor in iron and magnesium content, abundant in the minerals feldspars and quartz.

**Fissures:** see *Cracks*.

**Flora:** plant or bacterial life.

**Flowstone:** common carbonate speleothem that forms in thin layers, initially taking the shape of the underlying floor or wall bedrock beneath, but then becomes rounded as it gets thicker.

**Fold:** a planar set of rocks that has been strongly warped and crinkled, presumably by ductile deformation.

**Foliation:** alignment of minerals or compositional banding of mineral concentrations including cleavage, found in a metamorphic rock.

**Footwall:** the rock or sediment below an inclined fault.

**Foreereef:** the steep slope basinward of the reef composed of cemented reef talus that broke off and slid downslope creating the steeply-dipping foreereef beds.

**Formation:** the basic unit for the naming of rocks in stratigraphy; a set of rocks that are or once were horizontally continuous, that share some distinct features of lithology, and are large enough to be mappable.

**Fossil:** the remnant, or trace, of an ancient living organism that is preserved in a rock or

sediment after the original organic material is transformed or removed.

**Fossilization process:** the process of creating a fossil through a variety of methods: 1) freezing or drying (i.e. the Siberian woolly mammoth or Egyptian mummies), 2) encapsulation in amber or tar (i.e. insects in amber or the La Brea Tar Pits in Los Angeles), 3) preserved or mineralogically replaced bones, teeth, or shells, 4) permineralization (the act of replacing plant material with minerals to produce a rock; i.e. petrified wood), 5) molds or casts of bones, shells, or plants, 6) carbonized impressions (where soft or semisoft organisms leave dark-colored, carbonized impressions when buried in sediment), 7) trace fossils (impressions of organism activity but not the organism itself, such as footprints, burrows, etc.).

**Fractures:** a break or crack in rocks along which fluids, such as groundwater, may flow.

## G

**Guadalupe Mountains:** mountains in southeastern New Mexico and west Texas composed of an uplifted and exposed Permian reef and the associated basin.

**Guadalupe Mountains National Park:** located in west Texas in the southeastern edge of the Guadalupe Mountains, the park was designated a National Park in 1972; it includes 86,415 acres and boasts the highest peak in Texas, Guadalupe Peak.

**Guadalupe Peak:** located in Guadalupe Mountains National Park this peak, standing at 8,749 feet, is the highest point in Texas. It is composed of the Capitan Formation with apparent reef and forereef deposits.

**Gastropods:** any of a large class (Gastropoda) of mollusks (as snails and slugs) usually with a soft unsegmented body enclosed in a calcareous shell.

**Geochemistry:** the study of the chemical composition and chemical reactions within Earth materials.

**Geochronologist:** a geologist that uses 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.

**Geochronology:** the science of absolute and relative dating of geologic events and materials.

**Geology:** the study of the Earth, including its composition, processes, and history.

**Geologic cross-section:** a slice cut through the Earth or an Earth structure revealing the internal composition.

**Geologic formation:** see *Formation*.

**Geologic history:** the sequence of geologic events that has occurred in a region.

**Geologic map:** a map showing the distribution of rock units and structures across a region.

**Geologic principle:** an explanation of a set of related geologic observations or events based upon proven hypotheses and verified multiple times by detached groups of researchers.

**Geologic time scale:** the division of geologic history into eras, periods, and epochs accomplished through stratigraphy and paleontology.

**Geomorphologist:** a geologist who studies 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.

**Geomorphology:** the study of the Earth surface landforms and the processes and causal mechanisms (such as climate and geology) by which they are shaped.

**Glacial deposits:** sediment deposited in glacial environments (may range from clay-size to large boulders).

**Glacial striations:** abrasion marks on a rock left by a glacier containing sediment at its base.

**Glaciation:** a period of time during which glaciers grew and covered substantial areas of the continents; the most recent Pleistocene glaciation (the Ice Age) reached its peak approximately 18,000 years ago and ended about 10,000 years ago.

**Glacier:** A river or sheet of ice that slowly flows down mountains or across the land surface, respectively, and lasts year round.

**Glossopteris:** an extinct group of seed plants that arose during the early Permian Period and became a dominant part of the southern flora of Pangea until they dwindled to extinction by the end of the Triassic Period.

**Gneiss:** a banded or foliated metamorphic rock derived from metamorphosed granite or schist.

**Goat Seep Formation:** Permian-age, dolomitized limestone composed of abundant fossils; beginning of reef building in the Delaware Basin (forereef). **Gorge:** a canyon carved by running water.

**Grain size:** the size of a fragment of a mineral crystal or rock; the sediment classifications range from: < 1/256mm (clay), 1/256mm – 1/16mm (silt), 1/16mm – 2mm (sand), 2mm - 64mm (pebbles), 64mm – 256mm (cobbles), and > 256mm (boulders).

**Granite:** a felsic, igneous rock with large, intergrown mineral crystals; primarily contains quartz and feldspar minerals.

**Gravel:** another term for pebbles (see grain size).

**Grayburg Formation:** Permian marine dolomite and sandstone layers composed of fossils (beginning of reef in the Delaware

Basin). **Great Plains:** a geographic region of broad, gently-sloping land in the central United States constructed from eroded materials off of the Rocky Mountains.

**Greenhouse gases:** atmospheric gases, such as carbon dioxide, water, and methane that regulate the Earth's atmospheric temperature by absorbing infrared radiation.

**Groundwater:** water that resides under the surface of the Earth, mostly in pores or cracks of grains; it is expressed as surface water in most lakes and rivers.

**Groundwater recharge:** the process of adding water to an aquifer through either surface water infiltration at specific spots (sinkholes or rivers) or through wide areas (bedrock or porous sediment).

**Groundwater discharge:** the process of removing groundwater from an aquifer through either specific spots (springs or wells) or over larger areas (springs, seeps, or rivers).

**Guano:** accumulations of dung in caves, usually from bats.

**Gypsum:** a sulfate mineral with the chemical composition of  $\text{CaSO}_4 \cdot 2(\text{H}_2\text{O})$ . There are three polymorphs- selenite, satin spar, and alabaster.

## H

**Half-life:** the time it takes for one-half of a homogeneous group of a radioactive element's parent isotopes to decay.

**Halite:** an evaporite mineral with the chemical formula of NaCl. Commonly known as "table salt" it possesses 3-directional cleavage and is usually transparent or translucent.

**Hanging wall:** the rock or sediment above an inclined fault.

**Hardness:** a mineral property used to identify the mineral; the 1-10 Mohs hardness scale ranges from talc at 1 to diamond as 10.

**Helictites:** contorted speleothems that are formed when calcite-laden waters under hydrostatic pressure seep through tiny pores in the rock and are deposited in any direction.

**Hot spot:** a fixed location at the top of the mantle where exceptional temperatures cause melting of the overlying lithosphere and plate (i.e. Hawaiian Islands and the Yellowstone Hot Spot).

**Hydrocarbons:** a chain-like or ring-like molecule made of hydrogen and carbon atoms; petroleum and natural gas are hydrocarbons.

**Hydrochloric acid (HCl):** an acid that causes effervescence when put in contact with a carbonate rock or mineral.

**Hydrogen sulfide (H<sub>2</sub>S):** a gas produced by hydrocarbons in contact with sulfur-bearing minerals and rocks.

**Hydrogeology:** the study of groundwater, its movement, and its reaction with rock and soil.

**Hydrologic cycle:** the continual passage of water from reservoir (such as surface water, groundwater, and atmospheric liquid water) to reservoir in the Earth system.

**Hydrologist:** a professional that studies groundwater and surface water.

**Hydromagnesite:** a carbonate mineral with the chemical formula of  $Mg_5(CO_3)_4(OH)_2 \cdot 4H_2O$ , Hydrated Magnesium Carbonate Hydroxide, often found in caves.

**Hypothesis:** an educated guess that includes a prediction about what will happen, a possible explanation for why it will happen, and a test through experimentation and observation.

## I

**Ice cores:** columns of ice that are obtained by drilling vertically through a glacier and collected in order to study the ice layers.

**Igneous rock:** rock that forms when hot molten rock (lava above ground or magma beneath the Earth's surface) cools quickly or slowly.

**Index fossil:** a fossil usually with a narrow time range and wide spatial distribution that is used in the identification of related geologic formations.

**Infiltration:** the passage of water into or through sediment or rock by filtering or permeating.

**Injection well:** a well through which dye or contamination can be introduced to an aquifer.

**Inner core:** the inner section of the Earth's core consisting of solid iron alloy; 5,155km from the Earth's surface to the Earth's center at 6,371km.

**Inorganic:** not composed of living carbon molecules.

**Interlocking crystals:** mineral crystals that have grown together as an igneous rock cooled from lava or magma.

**Interpret:** to explain or tell the meaning of; to present technical information in understandable terms.

**Internal mechanisms:** forces upon geologic processes inside the geologic medium itself (i.e. rock type, topography, etc.).

**Island Arc:** a chain or arc of islands formed by volcanoes along a convergent plate boundary between two oceanic plates (i.e. Aleutian Islands or Japan).

**Isotope:** one of several forms of an element, all having the same number of protons in the nucleus, but different numbers of neutrons and therefore different atomic weights.

**Iterative process:** a process where studies and observations are repeated, each time a variable may be tweaked to approach better understanding.

## J

**Joints:** naturally formed cracks in rocks.

## K

**Karst landscape:** landforms produced primarily through the dissolving of rock, such as limestone, dolomite, marble, gypsum, and halite; features include sinkholes, caves, large springs, dry valleys, and sinking streams.

**Karst aquifer:** an aquifer where the water resides and flows through fractures or other openings that have been created through natural dissolution processes.

## L

**Lagoon:** a body of shallow seawater separated from the open ocean by a barrier island.

**Landscape:** the natural features of a land surface of a region in the aggregate.

**Legend:** a map key or guide to symbols representing information on a map.

**Limestone:** a sedimentary rock primarily consisting of calcium carbonate,  $\text{CaCO}_3$ , primarily in the form of the mineral calcite.

**Lithology:** the study/type of rocks. From the Greek “lithos” meaning rock.

**Lithosphere:** the relatively rigid, nonflowing, outer 100–150 km thick layer of the Earth; comprised of the crust and the upper part of the mantle.

**Loma Prieta earthquake:** a 7.1 (Richter scale) earthquake that occurred along the San Andreas Fault in California on October 17, 1989.

**Long-axis:** the longest of imaginary line axes through an object (the “length” direction rather than the “width”).

**Luminescence dating:** a dating technique, extending up to about 800,000 years, that measures the number of electrons stored in the crystal lattice of minerals when the sample is exposed to light; it is primarily used to determine the ages of quartz and feldspar.

**Luster:** the way a mineral scatters light. Lusters may be: metallic, nonmetallic, waxy, transparent, translucent, shiny, etc.

**Lystrosaurus:** a 3-foot-long, plant-eating, mammal-like reptile (not a dinosaur) with tusks that lived during the Permian and Triassic periods on Pangea.

## M

**Mafic:** an adjective used to describe a dark-colored igneous rock rich in iron and magnesium content.

**Magma:** molten rock below the Earth’s surface.

**Magnetic:** an object having the property of attracting iron and producing a magnetic field external to itself.

**Mantle:** the thick layer of rock below the Earth’s crust and above the core (from about 10km at the base of the oceanic crust and 40km at the base of the continental crust to the depth of 2,900km).

**Map scale:** a scale to determine distance on the map relative to real distance on the Earth.

**Map symbols:** a set of symbols used on maps to represent real objects or features on the Earth’s surface.

**Marble:** a metamorphic rock consisting primarily of recrystallized limestone or the minerals calcite or dolomite; it often contains marine fossils and is used as decorative stone.

**Marine environment:** the ocean environment- may be shallow or deep marine.

**Melting:** transformation of a solid into a liquid; occurs when chemical bonds holding mineral atoms or ions to the crystal lattice are broken by excessive thermal vibrations.

**Mesosaurus:** a crocodile-like, fresh-water dwelling reptile (not a dinosaur) that lived from the late Carboniferous period to the early Permian Period in South America and Africa; it was one of the first aquatic reptiles.

**Metallic luster:** a mineral appearance similar to metal (shiny, opaque, pliable).

**Methane:** a gas with the chemical formula of CH<sub>4</sub>.

**Metamorphic rock:** a rock that forms when metamorphism changes a preexisting rock into a new rock.

**Metamorphism:** the process by which elevated temperatures, pressures, or shearing under elevated temperatures alter one of the three types of rock into a metamorphic rock without melting it.

**Metric system:** a decimal system of weights and measures based on the meter and on the kilogram.

**Milankovitch cycles:** variations in the Earth's movement around the sun on time scales of roughly 100,000 years, 41,000 years, and 22,000 years which affect global climate cycles.

**Milutin Milankovitch:** a Serbian astronomer and geophysicist who determined that changes in the Earth's orbit occurred cyclically and were responsible for some of the global climate changes.

**Mineral:** a homogeneous, naturally occurring, solid, inorganic substance with a definable chemical composition and an internal structure characterized by an orderly arrangement of atoms, ions, or molecules in a lattice.

**Mineralogy:** the study of the chemistry and physical properties of minerals.

**Model:** a scale replica or schematic diagram (two-dimensional or three-dimensional) of a physical feature or process.

**Mollusks:** any of a large phylum (Mollusca) of invertebrate animals (as snails, clams, or squids) with a soft unsegmented body usually enclosed in a calcareous shell.

**Molten:** melted rock.

**Moonmilk:** a carbonaceous liquid (when wet) or a white deposit formed of aggregates of very fine carbonaceous crystals (when dry).

**Muscovite mica:** a silicate mineral with the chemical formula of  $KAl_2(AlSi_3O_{10})(F, OH)_2$ ; it possesses a sheet-like 1-directional cleavage, it is transparent to translucent, and the sheets are semi-flexible.

## N

**National Park Service:** a national agency established in 1916 conserve natural resources and historical sites in the United States and provide for their enjoyment; under the US Department of the Interior.

**Natural gas:** gaseous hydrocarbons that are formed from decayed organisms and are trapped in rocks. Primarily composed of methane.

**Nautilus:** a Cephalopod mollusk with a spirally coiled shell composed of a series of chambers that grow with age. The animal has a siphuncle that moves liquid from chambers and replaces it with gas giving the animal buoyancy. Today, the sole surviving genus is found in the deep ocean of the South Pacific and the Indian Ocean.

**Nonmagnetic:** is not magnetic (see *Magnetic*).

**Nonmetallic luster:** the mineral appearance does not resemble metal (see *Metallic luster*).

**Normal fault:** a fault in which the hanging-wall block moves down the fault slope in relation to the footwall.

## O

**Obliquity:** the angle between the planes of the Earth's equator and orbit (plane of the ecliptic) varies between 22.5° and 24.5° with a frequency of about 41,000 years causing global climate changes (currently the tilt is 23°27').

**Ocean bottom water:** the cold, dense ocean water flowing at the sea floor.

**Ocean cores:** long sections of oceanic sediments and rocks vertically extracted from the ocean floor by drilling; used to examine a continuous record of marine geology, flora, and fauna.

**Ocean surface water:** the warm, lighter ocean water flowing on the surface of the sea.

**Oceanic cycle:** see *Thermohaline circulation*.

**Oceanic crust:** the crust beneath the oceans; composed of dense gabbro and basalt. Oceanic crust is denser than Continental crust and therefore will subduct below continental crust at convergent plate margins.

**Oceanic spreading ridge:** the formation of a divergent plate margin along a belt where the oceanic plate stretches and spreads apart.

**Ogallala Aquifer:** a large aquifer in sand and gravel extending from Texas to South Dakota in the plains area.

**Oil:** a hydrocarbon byproduct of decayed organisms that broke down anaerobically and were preserved in rock layers.

**Ooids:** round, sand-sized carbonate sediment formed in marine settings by accumulation of carbonate mud around a nucleus rotated by wave agitation.

**Organic material:** material composed of carbon from an organism.

**Orthoclase:** a mineral with the chemical composition  $KAlSi_3O_8$ ; otherwise known as potassium feldspar, displays a 2-directional cleavage, and may have a pinkish or flesh color.

**Orogeny:** a mountain-building event.

**Outer core:** the section of the core, between 2,900 and 5,150 km deep, that consists of liquid iron alloy.

## P

**Paleontological records:** records of ancient life through fossils.

**Paleontology:** the study of fossils, ancient flora and fauna, and their evolution as preserved in the rock record.

**Paleoenvironment:** an Earth environment at a given time in the past.

**Paleoclimate:** the climate of a given period of time and place in the geologic past.

**Paleokarst:** ancient karst features that have subsequently been buried by other sediments.

**Paleozoic Era:** a geological division of time that spanned from 545–245 million years ago.

**Pangea:** a supercontinent that assembled at the end of the Paleozoic Era.

**Parent isotope:** a radioactive isotope that undergoes decay and produces daughter isotopes.

**Parent rock:** the original rock, or protolith, from which a metamorphic rock forms.

**Pavement:** an armored surface of sediment (often gravel) resistant to erosion; generally created when the surrounding material (usually finer-grained sediment) is eroded away leaving the larger sediments.

**Pearls:** a concentric spherical, cylindrical, elliptical, and even cubical concretion found



in shallow cave pools ranging from sand grain-size to golf ball-sized. Cave pearls form when water dripping into the pool loses carbon dioxide and precipitates calcite around a nucleus of sand, bones, or fragments of soda straws or rafts. The typical roundness is controversial and believed to be due to either the uniform growth of the pearl or due to rotation of the pearl when dripping water agitates the pool.

**Pebbles:** sediment within the 2mm - 64mm grain size range.

**Peer review:** the standard practice of evaluating the intellectual merit and the broader impacts of scientific research by other scientists within the community.

**Permeability:** the degree to which a rock or sediment allows fluids to pass through it via interconnected networks of pores and cracks.

**Permeable layer:** a rock or sediment layer through which water can pass.

**Permian extinction:** the largest extinction known in geologic history, serving as the boundary between the Permian Period and the Tertiary Period, 245 million years ago, killed up to 90% of all species living on Earth. It was believed to have been caused by extreme volcanic activity that released gases into the atmosphere and changed the Earth climate.

**Permian Period:** a geologic period between approximately 285 million years and 245 million years ago in the Paleozoic Era.

**Perennial stream:** a river that flows throughout the year.

**Petroleum geologist:** a geologist involved in exploration for and production of oil and natural gas resources.

**Petrology:** the study of rocks and their formation.

**Physical weathering:** the process in which intact rocks break into smaller pieces or grains (becoming loose sediment).

**Physiographic provinces:** geographic landmasses that are classified by physiological Characteristics (i.e. the Basin and Range, the Rocky Mountains, the Colorado Plateau, etc.).

**Phreatic zone:** the zone below the water table where all of the pore spaces are saturated or filled with water.

**Plane of the ecliptic:** the plane as defined by a planets orbit around the sun.

**Planview map:** a map of a feature from above.

**Plate:** one of about 20 distinct pieces of the relatively rigid Lithosphere; on these ride the dense oceanic crust and the less dense continental crust.

**Plateau:** a land area having a relatively level surface raised sharply above adjacent land on at least one side.

**Plate boundaries:** the border between two adjacent Lithospheric plates.

**Pollen:** spores of a plant.

**Pollen records:** accumulations of pollen preserved in geologic deposits through time; often used to evaluate changes in vegetation through time.

**Popcorn:** a knob-shaped speleothem composed of concentric layering of micro-crystalline calcite and formed either in air (subaerially) from thin, evenly distributed solution films evaporating, or within still cave pools (subaqueously).

**Pore space:** the space between sediment that would allow the passage of air or water.

**Porosity:** the percentage of the bulk volume of a rock or sediment that is occupied by pore space.

**Potassium/ Argon dating (K-Ar):** a dating technique used on igneous rocks that measures the ratio of decayed potassium ( $K^{40}$ ) to its daughter product, Argon ( $Ar^{40}$ ). While the resolution is nearly a million years, it may be used to determine the age

of rocks from 4.3 billion years to 100,000 years old.

**Precession:** The gradual conical path traced out by Earth's spinning axis; simply put, it is the "wobble" of the Earth's axis which varies approximately every 22,000 years causing global climate changes.

**Precipitation:** (1) the process by which atoms dissolved in a solution come together and form a solid; (2) rainfall or snow.

**Principle of cross-cutting relationships:** The principle that if one geologic feature cuts across another, the feature cut is the older of the two.

**Principle of original continuity:** The principle that sediments usually are deposited in continuous sheets.

**Principle of original horizontality:** the principle that sediments are usually deposited in a horizontal fashion.

**Principle of superposition:** the principle that sediments which accumulate through time are successively younger towards the top of the sequence (the oldest is on the bottom and the youngest on the top).

**Principle of Uniformitarianism:** the principle which states that the present is the key to the past (that processes occurring today in the world similarly occurred at similar rates in the past).

**P- Waves:** compressional seismic waves that move through the body of the Earth.

**Pyrite:** a gold, metallic mineral with the chemical composition of  $\text{FeS}_2$ .

## Q

**Quartz:** a silicate mineral with the chemical composition of  $\text{SiO}_2$ ; it has a hardness of 7, possesses no cleavage, is generally transparent to translucent, and may be found in a variety of colors (smoky, pink, colorless, purple).

**Quaternary Period:** the geologic time period extending from approximately 2

million years ago to about 10,000 years ago; it is commonly noted for its extensive glaciations.

**Queen Formation:** Permian-age, marine dolomite and sandstone layers composed of fossils in the Delaware Basin; it also contains ripple marks and channels suggesting shallow water levels (backreef).R

**Radioactive decay:** the process by which a radioactive atom undergoes fission or releases particles.

**Radioactive isotope:** an unstable isotope of a given element.

**Carbon 14 (Radiocarbon):** a heavy radioactive isotope of carbon of mass number 14 used especially in dating archaeological and geological materials.

**Radiometric dating:** the science of dating geologic events in years by measuring the ratio of parent atoms to daughter atoms in a rock's radioactive elements.

**Recharge area:** a region of porous and permeable rock or sediment where meteoric water replenishes the aquifer.

**Reef:** a porous, often delicate mass of calcium carbonate and some silicon composed of skeletons of marine corals and sponges.

**Results:** the outcomes of a scientific experiment.

**Resurgence area:** area where water emerges or discharges from the aquifer and becomes surficial water.

**Resurgent stream:** the reemergent disappearing stream to the surface.

**Reverse (thrust) fault:** a steeply dipping fault on which the hanging wall slides up relative to the footwall.

**Rhombohedron:** a 3-dimensional cube composed of four parallelograms with four equal sides and sometimes one with no right angles.

**Richter scale:** an open-ended logarithmic scale for expressing the magnitude of a seismic disturbance (as an earthquake) in terms of the energy dissipated in it with 1.5 indicating the smallest earthquake that can be felt, 4.5 an earthquake causing slight damage, and 8.5 a very devastating earthquake.

**Right triangle:** a triangle having a right angle.

**Rift zone:** an area where a fault trough is formed in a divergence zone or other area of tension.

**Riparian zone:** area along the bank of a natural watercourse (such as a river) or sometimes of a lake or a tidewater.

**Rock:** a coherent, naturally occurring solid, consisting of an aggregate of minerals or a mass of glass.

**Rock cycle:** the succession of events that results in the transformation of Earth materials from one rock type to another, then another, and so on.

**Runoff:** water that is unable to permeate sediment or rock because of saturation.

**Rustler Formation:** Late Permian-age, marine formation of dolomite, siltstone, anhydrite, and halite; deposited as sea level lowered in the Delaware Basin. **S**

**San Andres Formation:** Early Permian-age marine formation of dolomite and chert deposited as sea level began to rise (beginning of Permian reef formation in the Delaware Basin). **Sand:** sediment that is within the grain size range of 1/16mm–2mm.

**Sandstone:** a sedimentary rock composed of sediment grains within the size range of 1/16mm–2mm.

**Satellite image:** images of Earth features created from data collected by orbiting satellites; these data are composed of signals within the electro-magnetic

spectrum such as the visible, infrared, and thermal ranges.

**Saturation:** filled completely with something that permeates or pervades such as water, air, or chemical compounds.

**Scale:** a proportion between two sets of dimensions (as between those of a drawing or a model and its original).

**Schematic diagram:** an approximate drawing for demonstration purposes rather than an actual representation of an objects.

**Schist:** a metamorphic rock with foliation and often recrystallization of minerals such as garnet; its protolith is slate.

**Scientific community:** the group of scientists who research and apply scientific topics as a whole.

**Scientific law:** a statement of fact generally accepted to be true and universal meant to explain, in concise terms, an action or set of actions; sometimes it may be expressed in terms of a single mathematical equation (such as the law of gravity and the law of thermodynamics).

**Scientific Theory:** an explanation of a set of related observations or events based upon proven hypotheses and verified multiple times by detached groups of researchers.

**Sea Level:** the ocean surface level at its mean position midway between mean high and low water which is used as a global datum, representing zero elevation, to determine the relative elevation of the land surface.

**Sediment:** pieces of rock or minerals that are not cemented together.

**Sedimentary rock:** a rock that forms either by the cementing together of fragments of preexisting rocks or by the precipitation of mineral crystals out of water solutions at or near the Earth's surface.

**Sedimentology:** the study of sediments and their deposition.

**Seismic-reflection profile:** a cross-sectional view of the crust made by measuring the reflection of artificial seismic waves off boundaries between different layers of rock in the crust.

**Seismic waves:** waves of energy emitted at the focus of an earthquake or a man-made source of energy.

**Seismology:** the study of earthquakes and the Earth's interior as revealed by earthquake and synthesized waves.

**Seven Rivers Formation:** Permian-age, shallow marine formation of sandstone and Mudstone in the Delaware Basin (backreef).

**Shadow zone:** a region on the opposite side of the globe that does not receive S-waves from an earthquake because they do not travel through the liquid outer core.

**Shale:** a sedimentary rock composed of cemented fine-grained clay sediments.

**Shelf:** a flat edge of a continent covered by an ocean.

**Shield volcano:** a volcano with broad, gently sloping sides, formed by either from low viscosity basaltic lava or large sheets of deposited ash.

**Siliciclastic sedimentary rock:** a sedimentary rock composed of cemented sediments or clasts.

**Silt:** sediment within the 1/256mm–1/16mm grain size.

**Sinkhole:** a funnel-shaped depression in a karst area, commonly with a circular or bowl-shaped pattern. Sinkhole drainage is subterranean and sinkhole size is usually measured in meters or tens of meters. Common sinkhole types include those formed by dissolution, where the land is dissolved downward into the funnel shape and by collapse where the land falls into an underlying cave.

**Sinking stream:** a surface stream that loses water to the underground in a karst region (also called a *disappearing stream* or an *underground stream*).

**Slate:** a metamorphic rock formed by metamorphosis of shale; previously used as chalk boards.

**Soda straw:** a hollow, elongate, and generally translucent tube of calcite equal in diameter to the water drops conducted along their length; a speleothem representing the earliest growth of stalactites.

**Solar flux:** changes in the intensity of solar radiation to the Earth due to sunspots, solar flares, or changes in the Earth's orbital pattern.

**Solution:** a) an act or the process by which a solid, liquid, or gaseous substance is homogeneously mixed with a liquid or sometimes a gas or solid; b) a homogeneous mixture formed by this process; c) the condition of being dissolved.

**Speleogenesis:** the creation and formation of speleothems.

**Speleothem:** a formation that grows in a limestone cave by the accumulation of travertine precipitated from water solutions dripping, flowing down the walls, or flowing on the floor in the cave.

**Sponge:** the common name for an animal in the Phylum Porifera that primarily resides in shallow, temperate marine waters in colonies. Permian sponges, such as *Girvanella*, *Mizza*, and *Solenopora*, are the most abundant organisms visible in the rocks; over 4,500 species are known today.

**Spring:** a natural artesian well where groundwater flows to the surface.

**Stalactite:** a conical speleothem that begins as a plugged soda straw on the ceiling and grows with precipitation from carbonate-rich water flowing down with gravity (stalactites hang "tite" to the ceiling).

**Stalagmite:** speleothems that are upward-growing, massive calcite mounds deposited from dripping water (stalagmites “mite” reach the ceiling).

**Strata:** layers of rocks (usually sedimentary rock).

**Stratigraphic column:** a cross-section diagram of a sequence of strata summarizing information about the rock sequence.

**Stratigrapher:** a geologist that investigates the time and space relationships of rocks, on a local, regional, and global scale throughout geologic time.

**Stratigraphy:** the science of the description, correlation, and classification of strata in sedimentary rocks, including the interpretation of the depositional environment of those strata.

**Stratovolcano:** a large cone-shaped volcano with steep slopes consisting of alternating layers of lava and ash.

**Striations:** linear scratches in the rock or mineral.

**Stromatolite:** a laminated sedimentary fossil formed from layers of colonies of blue-green algae. **Structural geology:** the study of rock deformation in response to the application of a force.

**Subduction:** the process of an oceanic plate dipping under another plate at a convergent plate boundary.

**Sulfur:** a sulfate mineral whose chemical composition is S.

**Sulfuric Acid (H<sub>2</sub>SO<sub>4</sub>):** a strong acid believed to have been the primary agent of dissolution at Carlsbad Cavern, other caves at Carlsbad Caverns National Park, and several other caves around the world.

**Supercontinent:** a continent larger than those found today.

**Surface water:** water flowing on the surface of the Earth (includes oceans, rivers, lakes, etc.).

**Surface waves:** seismic waves that travel along the Earth’s surface.

**Surficial:** relating to the surface of the Earth.

**Surveying:** applied mathematics that determines: 1) the area of any portion of the Earth’s surface, 2) the lengths and directions of boundary lines of this portion, 3) the contour of the surface, and 4) accurately delineates all of these measurements on paper.

**Swallow Hole:** see *Sinkhole*.

**S-Waves:** seismic shear waves that pass through the body of the Earth.

**Syncline:** a trough-shaped fold that is concave-up.

## T

**Talus:** a deposit of large angular fragments of physically weathered bedrock, usually at the base of a cliff or steep slope.

**Tansill Formation:** Permian-age, shallow marine formation of dolomite, gypsum, red clay, and silt in the Delaware Basin (reef - backreef).

**Technology:** the practical application of knowledge especially in a particular area (i.e. scientific technology).

**Tectonics:** the science of regional geologic features (such as mountain belts), plate movements, and their consequences.

**Terra Rossa:** soils or ancient soils developed on limestone in warm climate regions.

**Texture:** rock characteristics of grain or crystal size, size variability, rounding or angularity, and preferred orientation.

**Theory of Plate Tectonics:** the theory that the outer layer of the Earth (the lithosphere)

consists of separate plates that move with respect to one another.

**Thermohaline Circulation:** the upwelling and downwelling of less dense warm and denser cold ocean water, respectively, drive this global oceanic circulation.

**Tilt:** see *Obliquity*.

**Timeline:** a linear representation of events in chronological order through time.

**Topographic map:** a 2-dimensional map representing the 3-dimensional shape of the Earth's surface, above and below sea level, using contour lines and hachures to represent elevations.

**Topographic profile:** a 2-dimensional slice through a topographic map representing surface elevation changes.

**Topography:** the configuration of the Earth's surface including its relief and the position of its natural and man-made features.

**Transform plate boundary:** a boundary at which the lithospheric plates slip laterally past each other.

**Translucent:** able to transmit light through but diffusing it so that objects beyond cannot be seen clearly.

**Transparent:** able to transmit light without diffusion so that objects lying beyond are seen clearly.

**Travertine:** a secondary deposit of carbonate minerals formed in caves and around hot springs where cooling, carbonate-saturated groundwater is exposed to the air.

**Tree rings:** the rings seen in tree trunks when they are cut perpendicular to their growth; each ring represents a year of growth and may be used to determine the age of the tree.

**Trench:** a deep elongate trough defining a convergent plate boundary.

**Trilobites:** any of numerous extinct Paleozoic marine arthropods (group Trilobita) having the segments of the body divided by furrows on the dorsal surface into three lobes.

**Trona:** a gray-white or yellowish white mineral composed of sodium carbonate,  $\text{Na}_3(\text{HCO}_3)(\text{CO}_3) \cdot 2\text{H}_2\text{O}$ .

## U

**Ultraviolet light:** light situated beyond the visible spectrum at its violet with wavelengths shorter than visible light.

**Unconfined aquifer:** an aquifer that intersects the surface of the Earth.

**Underground stream:** a stream that flows in cavities below the surface of the Earth.

**United States Geological Survey (USGS):** an agency within the Department of the Interior to collect, monitor, analyze, and provide scientific understanding about natural resource conditions, issues, and problems.

**Uplift:** a broad and gentle epeirogenic increase in the elevation of a region without a eustatic change of sea level.

**Uranium/Thorium dating:** dating technique that uses the decay of  $\text{U}^{238}$  to  $\text{Th}^{230}$  to determine the age of geologic materials.

## V

**Vadose zone:** the subsurface area between the surface of the land and the water table that contains air within the pore spaces or fractures (the unsaturated zone).

**Vesicular:** a texture in igneous rocks containing small cavities formed by trapped air bubbles in cooling lava.

**Viscosity:** the property of resistance to flow in a fluid or semifluid (maple syrup in winter has a high viscosity, whereas hot honey has a low viscosity).

**Volcanic ash:** tiny glass shards formed when a fine spray of volcanic lava freezes

instantly when it comes in contact with Earth's atmosphere.

**Volume:** a unit measuring how much "space" something occupies.

## W

**Water cycle:** see *hydrologic cycle*

**Water table:** the boundary, approximately parallel with Earth's surface, that separates substrate in which groundwater fills the pores (the phreatic zone) from substrate in which air fills the pores (the vadose zone).

**Water vapor:** the gaseous form of water, H<sub>2</sub>O.

**Weathering:** the set of all processes that decay and break up bedrock, by a combination of physically fracturing (physical weathering) or chemical decomposition (chemical weathering).

**Well:** a deep vertical hole in the ground dug or drilled in order to draw out water or hydrocarbons.

## X

**X-Y graph:** a point graph with two axes, a horizontal X-axis and a vertical Y-axis.

## Y

**Yates Formation:** Permian-age, shallow marine formation of sandstone, siltstone, dolomite, gypsum, and red clay in the Delaware Basin (backreef). **Yeso**

**Formation:** Early Permian-age, shallow marine formation of shale, sandstone, and Limestone in the Delaware Basin (shelf).

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Biological Dictionary: <http://biotech.icmb.utexas.edu/search/dict-search.html>

Marine Biology Encyclopedia: <http://www.bartleby.com/65/ma/marinebi.html>

Merriam Webster Dictionary on-line: <http://www.m-w.com/home.htm>

Virtual Cave: <http://www.goodearthgraphics.com/virtcave.html>

Geological Terms: <http://www.usgs.gov>



# Purchasing Supplies List

Ward's Geology Catalog (1-800-962-2660, [www.wardsci.com](http://www.wardsci.com))

## Minerals (pick your own collection, pkg. of 10):

- Calcite
- Dolomite (coarse or with cleavage)
- Gypsum (selenite or massive)
- Halite
- Muscovite Mica
- Pyrite
- Quartz (milky)
- Orthoclase Feldspar (pink)

## Rocks (pick your own collection, pkg. of 10):

- Limestone (gray and Coquina)
- Sandstone (siliceous or red)
- Shale (carbonaceous)
- Conglomerate
- Coal (bituminous)
- Granite (porphyritic)
- Basalt (massive or vesicular)
- Gneiss (gray banded)
- Schist (mica or garnet)
- Travertine (Trona)
- Marble (coarse white)

## Other hand samples:

- Stalactite
- Bryozoan (*Tabulipora Urei*) – Permian
- Brachiopods (Composite Sp.) – Pennsylvanian/Permian
- Cephalopods
- Trilobites – Devonian?
- Crinoid stems – Pennsylvanian

## Mineral Testing Kits

- Pre-Made kits (minus acid)
- or
- Make your own
  - Streak plates (pkg. 10)
  - Glass plates (pkg. 10)
  - Grain size charts (pkg. 5)
  - Acid bottles (pkg. 12)
  - Magnifying glasses (individual)

## Miscellaneous

- Geologic time chart
- Earth history chart
- Map of the lithospheric plates
- Dictionary of Geological Terms
- Roadside Geology of NM and TX books
- Blacklight