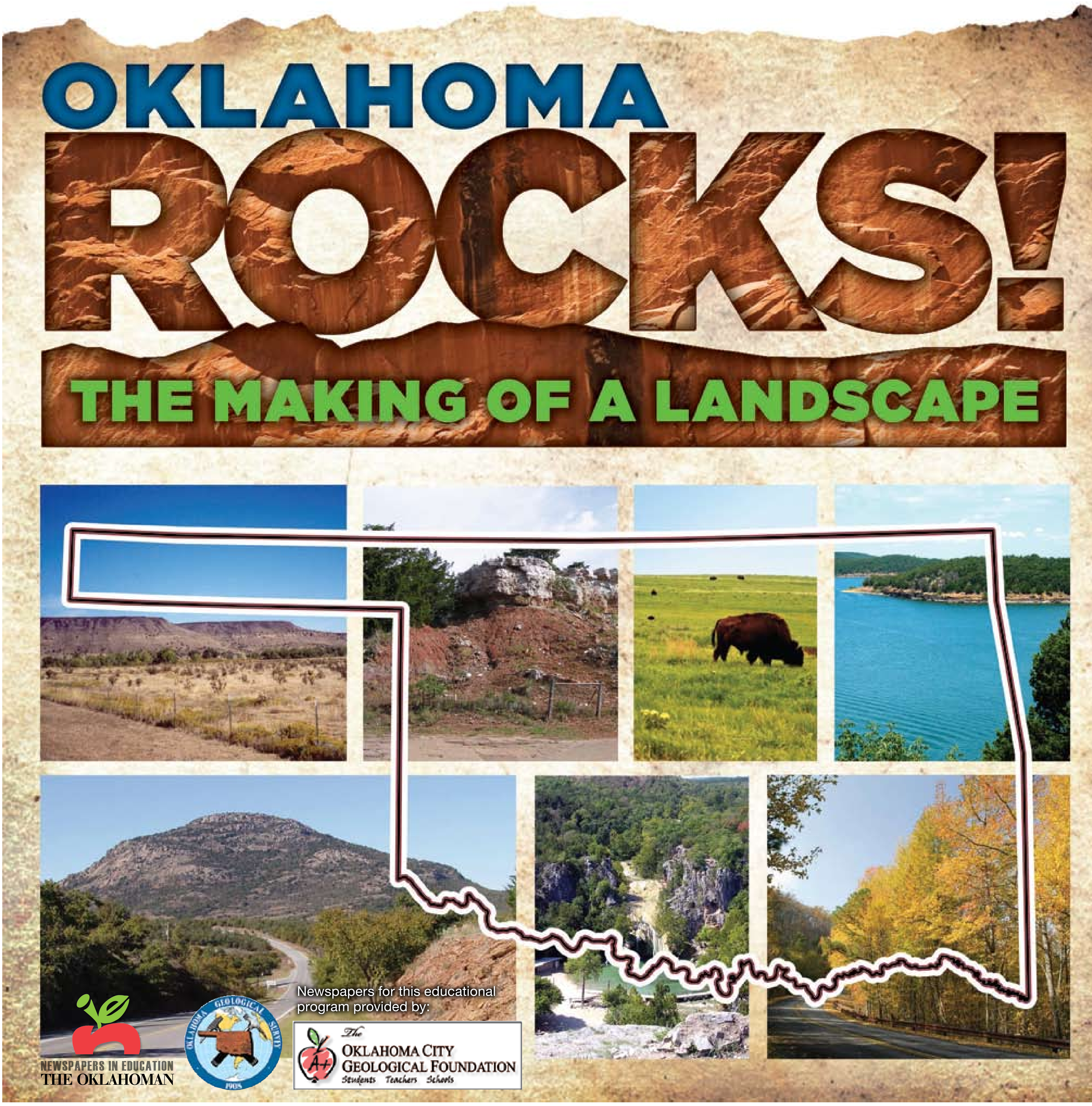



**Resources and general hints:**

For general maps and text about Oklahoma geology, resources, water, and earthquakes go to Educational Publication 9 at http://ogs.ou.edu/level2-earthscied.php.

You can download the entire publication or separate sections by scrolling down on this page. This page also contains other basic maps and an article on the boundaries of Oklahoma, where they are and how and when they were established.

How to read maps—a very useful link to go with this study: http://www.ogs.ou.edu/pubsscanned/EP7.pdf

Geologic maps of Oklahoma: http://ogs.ou.edu/geolmapping.php

OGS offers many non-technical publications for general interest that are free to download from the web http://ogs.ou.edu/pubs.php

Among them are guides to State Parks; information series publications (such as: Gee(whiz)ology; Geology of Arcadia Lake Parks; Is This Dinosaur Dung and other questions answered by the Oklahoma Geological Survey; etc.); Be sure to look for information about your area in the OGS publications in the Guidebooks section: http://ogs.ou.edu/pubsDLGBs.php. While some of the material is older, it still may contain good information and ideas for your area. There is information on State Parks, field trips, general geology, history, resources and sometimes even plants and animals.

For excellent paleographic maps of North America and different points in geologic history, go to: http://www2.nau.edu/rcb7/nam.html . The main website is: http://cpgeosystems.com/index.html

Go to www.travelok.com for information on the Talimena Drive.

Encyclopedia of Oklahoma History and Culture: http://digital.library.okstate.edu/encyclopedia/toc.html

Chronicles of Oklahoma: http://digital.library.okstate.edu/Chronicles/index.html

Oklahoma Atlas Institute: http://www.ok.gov/redirect.php?link_id=560

Oklahoma Historical Society Kids: http://www.okhistory.org/kids/index.html

For Halloween: Abandoned Oklahoma; spooky photos of some of Oklahoma's past: http://www.abandonedok.com/

CONTENTS:




**Credits:**
The content for this program was developed by the Oklahoma Geological Survey. Special acknowledgments go to Dr. G. Randy Keller, OGS director; Connie G. Smith, project coordinator; James H. Anderson, graphics; and OGS geologists: Dr. Neil H. Suneson; Dr. Julie M. Chang; Dr. Thomas M. Stanley; and Dr. Kenneth V. Luza. Special thanks also to the Oklahoma Tourism & Recreation Department for the use of photos from their website http://www.travelok.com/.

The Oklahoma Geological Survey (OGS) provides research and public services related to the state's land, water, mineral and energy resources and to the wise, environmentally sound use of them. The OGS is a state agency affiliated with the University of Oklahoma Mewbourne College of Earth and Energy. The OGS provides resources for teachers and students including publications such as "The Gee(WHIZ)ology of Oklahoma" and other materials for classroom use, plus programs and activities for teachers, available at **www.ogs.ou.edu.**

**Cover photos**
Top row (left to right): Black Mesa in the Oklahoma Panhandle (OGS); red beds of central Oklahoma (OGS); prairie and buffalo in northern Oklahoma (Oklahoma Tourism Department); Tenkiller Lake in eastern Oklahoma (Oklahoma Tourism Department); Bottom row (left to right): Mount Scott in the Wichita Mountains (OGS); Turner Falls near Davis, (Oklahoma Tourism Deptarment); Talimena Drive in southeastern Oklahoma (Oklahoma Tourism Department).

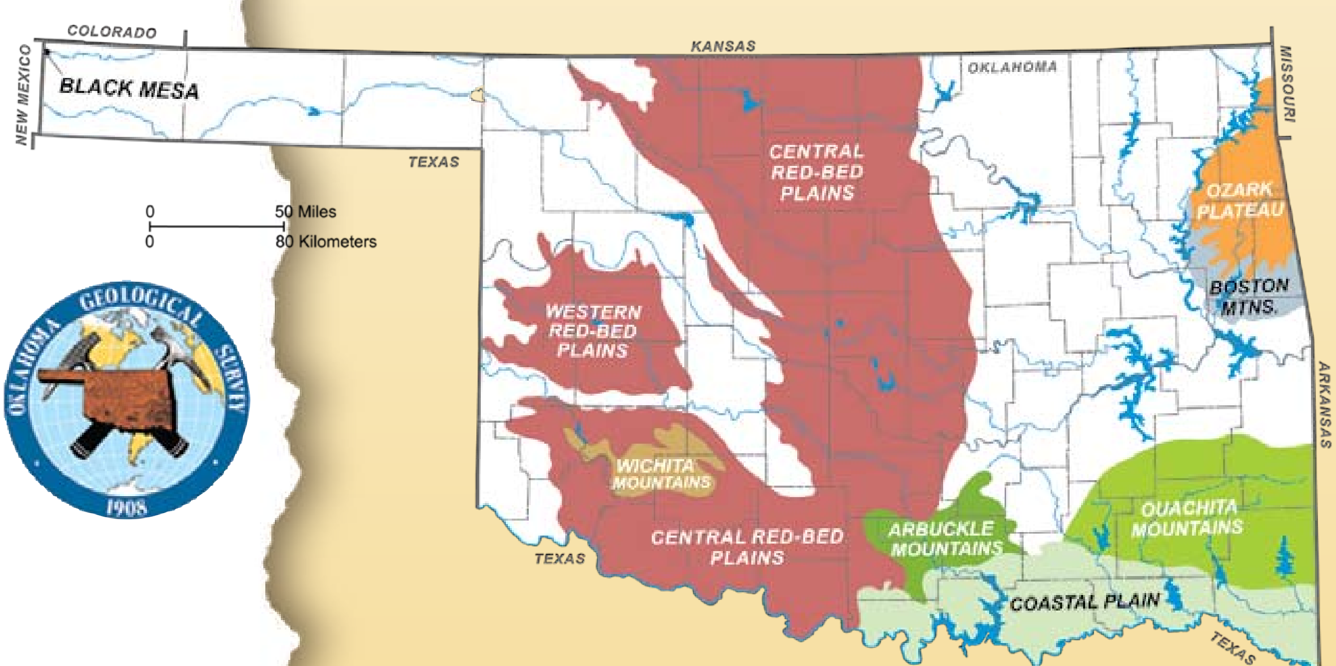

## Oklahoma Geology–more than just OK!

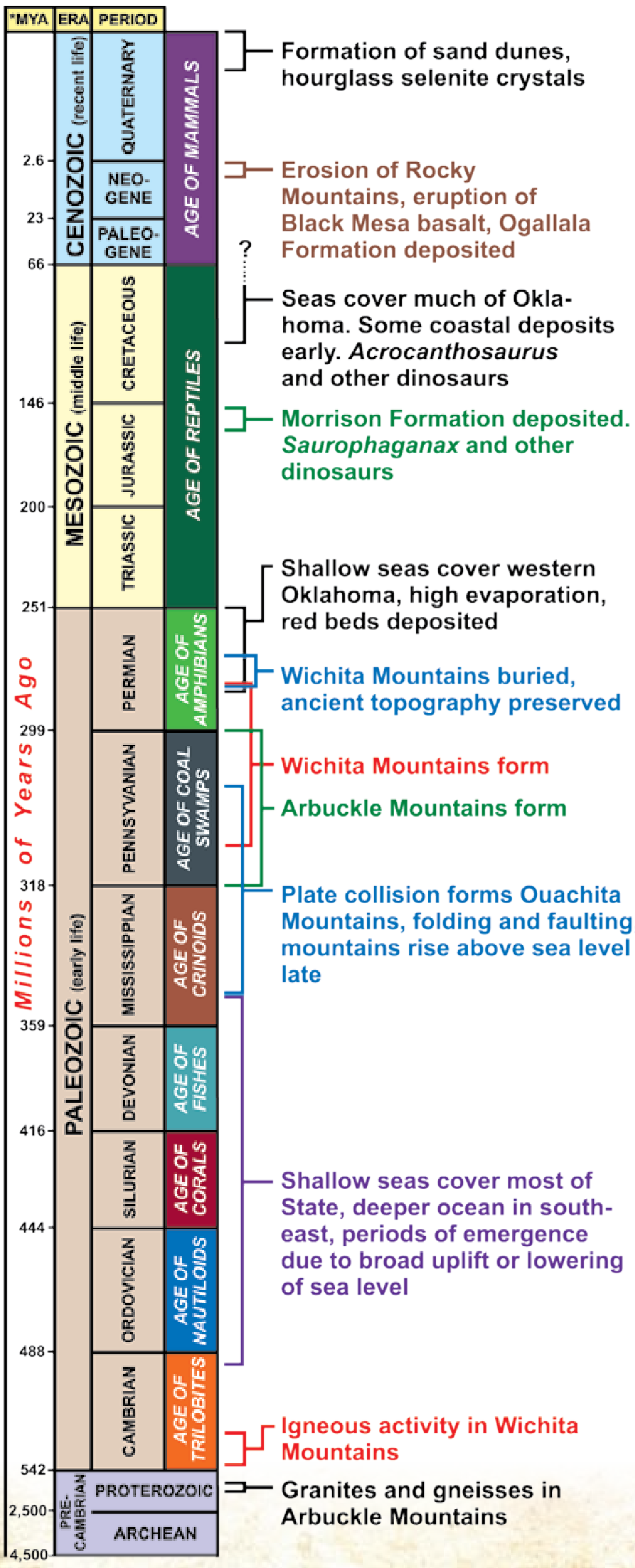
*Throughout its history, going back about 1.6 billion years, Oklahoma has seen more than its share of geological activity. Oklahoma has been covered by warm shallow seas, which receded—only to return. Parts of our state have been the site of mountain ranges in which the rocks have been severely folded and faulted, uplifted, and eroded. For example, the Wichita Mountains provide evidence that volcanoes erupted, leaving behind lava flows that covered the southwestern 25 percent of our state, and in addition, massive amounts of molten rock were intruded into the underlying crust of the earth. Quartz Mountain State Park features hills consisting of these intrusive rocks. The park is at the southern edge of the Anadarko Basin, which is one of the deepest basins on the planet.*

*If one looks northward from the park some 20 miles into this basin, similar rocks to the ones that you are standing on are buried almost 10 miles deep. In fact, the Lone Star well, which for many years held the record for the deepest well ever drilled, penetrated to a depth of more than 31,000 feet and still had a long way to go to reach the bottom of the basin.*

*The rich variety of geologic features that grace our state provides the diverse landscapes and scenery that we see today. Few other states, certainly none our size, can boast of cypress swamps, forest-covered hills and mountains, prairies and sand dunes, and mesas and high plains. Travel Oklahoma and you can see many interesting and world-famous geologic features and the scenery that they have produced.*

*Dr. G. Randy Keller*
*Director, Oklahoma Geological Survey*





*Millions of years ago.

# OVERVIEW

By OGS Geologist Dr. Neil H. Suneson

Oklahoma is a showcase of scenery, from the verdant hills and valleys of the Ouachita Mountains and Ozarks to the crimson plains of central Oklahoma and the chaparral–covered mesas of the northwestern Panhandle. Much of Oklahoma's scenery is due to its varied geology. Did you know that our state's rivers are the products of ancient glaciers that covered the Rocky Mountains tens of thousands of years ago? Did you know that hundreds of 150-million-year-old dinosaur bones have been found in the slopes under those mesas in the Panhandle? And did you know that all of Oklahoma's mountain ranges—the Ouachitas, Arbuckles, and Wichitas—formed at about the same time as the eastern United States' Appalachian Mountains, about 300 million years ago?

How did geologists figure all this out? Does it have anything to do with the Earth's tectonic plates? And what about all those oil and gas wells that we see throughout the state? The answers to some of these questions may surprise you.

Geologists have been studying Oklahoma since before statehood. Many were driven simply by curiosity and the need to know, and others by recognizing that the proper development of the state's resources would require detailed knowledge of the rocks, fossils, and mountain ranges found here. Of prime importance was knowing what Oklahoma looked like in the past. So, geologists spent years and years in the field collecting samples, making maps, and drilling wells.

The oldest exposed rocks in Oklahoma are approximately 1.4 billion years old. Geologists know this because these rocks contain radioactive elements that decay at a known fixed rate into stable elements. Knowing these variables enables geologists to date igneous rocks. In Oklahoma, fossils are even more important for knowing how old the rocks are. Most of the sedimentary rocks in Oklahoma contain fossils. Because many fossils (especially marine) have a worldwide distribution, if they can be dated using nearby igneous rocks in one place, that age can be used elsewhere, including Oklahoma, where igneous rocks are rare. There are other, independent ways to verify these dates, but all of this takes a LOT of study and work.

To complete the picture of what Oklahoma looked like millions and millions of years ago, geologists try to relate the rocks we see to the environments in which the original sediments were deposited. For example, we assume that the features we see in modern river deposits are the same as those preserved in rocks that were deposited in ancient rivers. If we know the ages of the rocks and where and how they were deposited, geologists can construct a "movie" of Oklahoma through the ages. As new information is discovered, the "movie" changes—sometimes a little, sometimes (but rarely) a lot. Today, geologists think they have a pretty good idea of the geological history of Oklahoma.

The geologic time scale on this page will help you make sense of the time frames and geologic age names mentioned in this workbook. The map on page 2 will give you an idea of where the various geologic features can be found in Oklahoma. Refer to these often to put yourself in the correct location and time sequence as you read the sections.

**Find more about Oklahoma's parks at http://www.travelok.com**

## Activities:

1. Create a KWL chart as you go through this workbook about Oklahoma geology. In the left column write down what you know about Oklahoma's rocks, minerals, fossils, and geologic history; in the middle column write down what you would like to know; and in the right column write down what you have learned (do this at the end after you've gone through the workbook).

2. Look at a highway map of Oklahoma. Put a green circle where you live, and then put a red circle around those places in Oklahoma that you've visited with your family or friends. What landforms or other geographic features (for example, hills, rivers, plains, etc.) did you see on your trip and how did they differ from those where you live? Now, think about trips you've taken to neighboring states. Did the scenery change or was it similar to what you saw in Oklahoma?



**Overview:**

Activity 1: Reprint KWL chart from the Energy publication

See EP-9 for additional information and maps on Oklahoma geology: http://ogs.ou.edu/level2-earthscied.php

Activity 2: Request copies of or download Oklahoma highway map: http://www.okladot.state.ok.us/maps/index.htm

Quadrangle maps of Oklahoma: http://ogs.ou.edu/geolmapping.php

**2.** Make a "KWL Chart" about energy. In one column, write what you Know about energy. In the second column, write what you Want to know about energy. At the end of this curriculum, you will fill in the third column with what you have Learned about energy.

| KNOW | WANT TO KNOW | LEARNED |
| --- | --- | --- |
| | | |

By OGS Geologist Dr. Neil H. Suneson

Take a drive through the long, forested ridges and deep, farmed valleys of the Ouachita Mountains of southeastern Oklahoma. Do they remind you of the Appalachian Mountains of the eastern U.S.? They should because there are, in fact, many geological similarities between the two mountain ranges.

Both are what geologists called fold-and-thrust belts–mountain ranges in which the formations are folded into anticlines (up-folds, like an "A") and synclines (down-folds, like the letter "U"). These formations are highly faulted meaning huge blocks of rocks have been shoved (or "thrust") up and over adjacent huge blocks of rocks. This deformation—the folds and thrust faults—results in rocks that typically are tilted, in some cases to near vertical and in some rare cases beyond vertical or, in geological parlance, they are "overturned." This deformation sometimes results in traps for natural gas, which is why natural gas wells are common in the northern part of the Ouachitas.

Both the Ouachitas and Appalachians consist of long parallel ridges and valleys and were formed during the Pennsylvananian Period of the Earth's history. The visible ridges are formed by the upturned edges of rocks that are relatively resistant to erosion. In the Ouachitas, these resistant rocks are typically sandstone. Stop at an outcrop along the Talimena National Scenic Byway (a breathtaking 54-mile route from Talihina, Oklahoma, to Mena, Arkansas), and you can collect a piece of the Jackfork Sandstone, which is commonly found in the area.

Although the rugged topography and more than 2,400 feet elevation of Black Fork Mountain (near Page) suggest otherwise, all the sandstone and shale in the Ouachitas was deposited deep under water. Between about 350 and 307 million years ago, southeast Oklahoma was part of a deep east–west trending ocean basin. Sediments, some of which may have eroded west off of the newly formed Appalachian Mountain range, entered the basin near Little Rock, Arkansas, and spread westward along the sea bottom as fast-moving, bottom-hugging submarine sediment flows. Thousands and thousands of feet of these "turbidites" accumulated in the Ouachitas. As they were buried, the sediments were solidified into rock, and later the rocks were folded, faulted, and uplifted.

The astute visitor to southeast Oklahoma will notice three areas in the Ouachitas with a very different appearance—Black Knob Ridge near Atoka, the Potato Hills west of Talihina, and a large

Right: Folded and faulted rocks along Oklahoma Hwy 82 five miles south of Red Oak. This outcrop of the Atoka Formation is a microcosm of the Ouachita mountain belt where many of the rocks are steeply tilted, folded, and faulted. Deformed rock layers are evidence for ancient mountain building. (OGS photo).

Below: Vertical sandstone and shale west of the Indian Nation Turnpike four miles south of Blanco. The sandstones and shales in the Ouachita Mountains accumulated in a deep basin and were deposited by rapidly moving submarine currents. Originally deposited horizontally; later deformation tilted them to their current vertical position. (OGS photo).

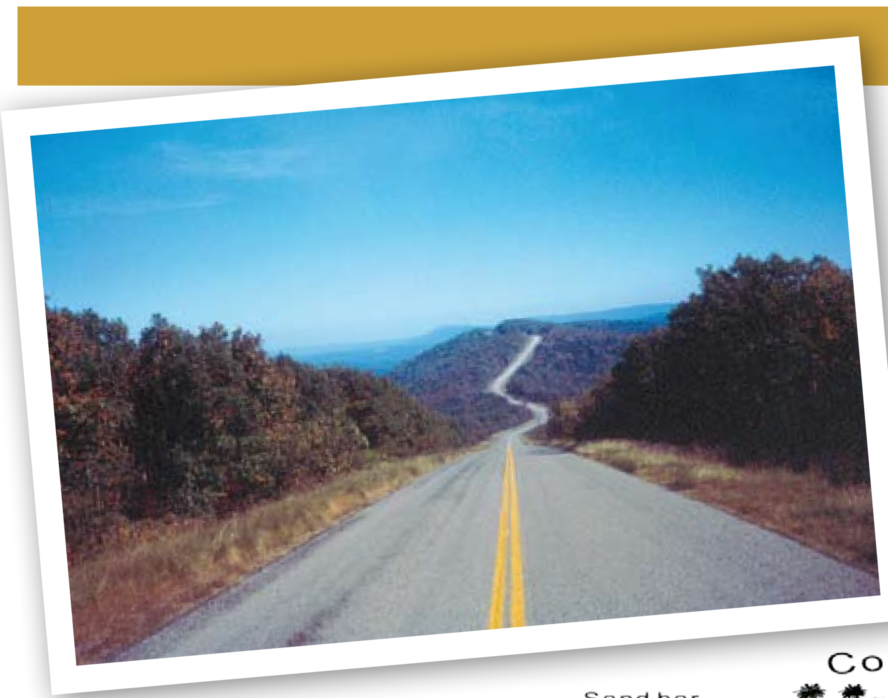


**Southeast Oklahoma and Ouachitas:**

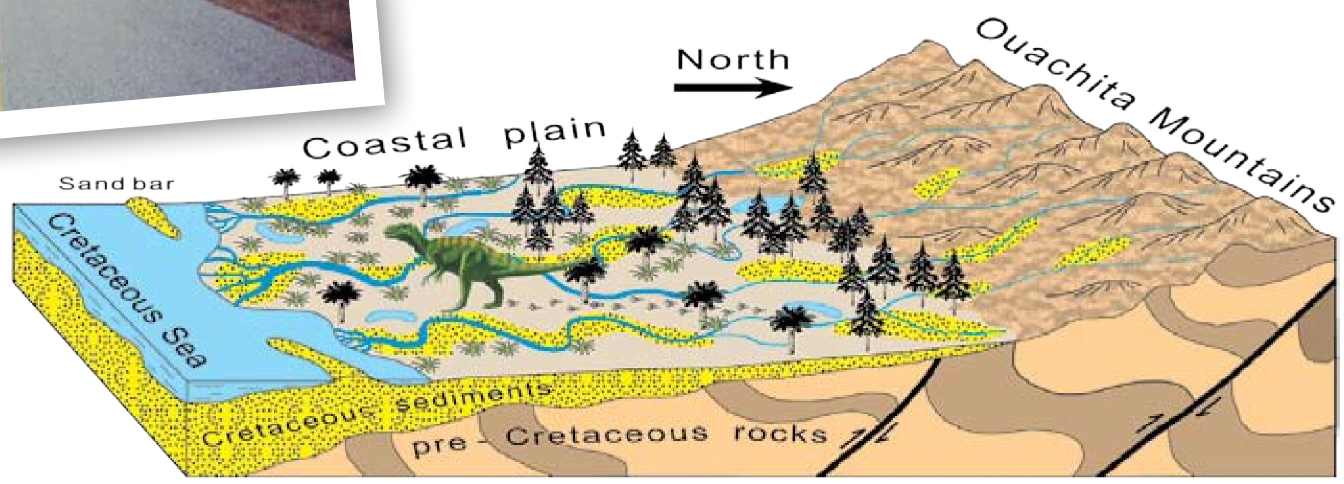
Guidebook to Wister State Park: http://ogs.ou.edu/pubsscanned/guidebooks/GB28wm.pdf

Guidebook to Robber's Cave State Park: http://ogs.ou.edu/pubsscanned/guidebooks/GB22.pdf

Geologic maps of southeast Oklahoma: http://ogs.ou.edu/statemap1_22.php



Left: Talimena Drive (Oklahoma Hwy 1) along the crest of Winding Stair Mountain. One of the truly magnificent drives in the entire state, Talimena Drive has numerous pullouts at scenic overlooks with displays explaining the local history, ecology, and geology. In the fall, the forest is ablaze with color. (OGS photo).




area near Hochatown that geologists call the Broken Bow Uplift. These areas of small but steep hills are underlain by much older rocks—roughly 500 to 350 million years old. The very "bumpy" topography is formed by shale-rich formations (easily eroded, in the valleys) separating formations made of chert (very hard, brittle, tears up hands and boots, forms the ridge tops) and sandstone (also hard). These old rocks are "windows" into an earlier period of Oklahoma's geological history and suggest that this part of the state was under water but not receiving nearly as much sediment as it would later.

To the north of the Ouachitas, the San Bois Mountains record the end of the mountain building. The Ouachita Basin had filled, deformation had largely ceased, and river deltas washed across southeastern Oklahoma as the sea level rose and fell. The area's old coal mines are evidence for periodic, low-lying swamps and marshes at the edge of a coast some 300 million years ago.

The Gulf Coastal Plain to the south is part of Oklahoma's dinosaur country where several specimens of the large T-rex-like carnivore *Acrocanthosaurus atokensis* were found. In this very gently rolling country, broken only by barely perceptible east-west ridges, the rocks are much softer than those in the mountains to the north. The sandstone formations are more "sand" than sand"stone," and they are considerably younger. The oldest formation is "only" about 98 million years old and the youngest about 93 million years. These sediments were deposited during the Cretaceous Period when dinosaurs ruled the Earth and the Gulf of Mexico (GOM) lapped on to the edge of the highly eroded Ouachita Mountains in southeastern Oklahoma. One of the rock types deposited in this early GOM was limestone, and a wide variety of marine fossils can be found in road-cuts and along the shore of Lake Texoma.

## Activities:

1. Visit the Museum of the Red River website. Click on the link that takes you to McCurtain County's dinosaur—*Acrocanthosaurus atokensis*—and read about it http://www.museumoftheredriver.org/. Now go to North Carolina's Museum's website at http://naturalsciences.org/microsites/faqs/acro.html. Read about how old "Acro" is under the "How Old Is It" section, then click on the "Play with a Scale-model Timeline" link. You will find 110 million years near the word "Cretaceous". Scroll down until the word "Cretaceous" is in the middle of your screen and look at the scroll bar on the far right edge. If the age of the Earth is at the bottom of the scroll bar and today is at the top, where does the Cretaceous fit in?

2. Cavanal Mountain has been called the world's "highest hill". Research Cavanal Mountain. Do you think it is a hill or mountain? Why? For more info, read page 8 in OGS Guidebook 34 at http://www.ogs.ou.edu/pubsscanned/guidebooks/GB34mm.pdf

 By OGS Geologist Dr. Julie M. Chang

Above: View of Turner Falls from the overlook. The tan colored material in the creek bed is tufa. (Oklahoma Tourism Department photo).

Spectacular examples of folded, faulted, and steeply dipping rocks occur along I-35 in the Arbuckle Mountains of southern Oklahoma. In order to understand how these Paleozoic sedimentary rocks came to be, you have to start from the beginning.

The oldest rocks exposed in the Arbuckle Mountains are some of the oldest in the state and, in fact, some of the oldest in the world. These rocks are approximately 1.4 billion years old and were formed during Precambrian time. In the Arbuckle Mountains, these rocks are called the Tishomingo Granite, Troy Granite, and Blue River Gneiss. Granite is an igneous rock formed by the slow cooling of magma, and gneiss is a banded metamorphic rock formed when granite is exposed to high pressures and temperatures. The Precambrian granite and gneiss are called "basement" rocks, as they form the base on which younger rocks are deposited.

These "younger" rocks are those observed along I-35, although in geologic time, they are not young at all. The oldest of these rocks is the Colbert Rhyolite, which formed approximately 525 million years ago during the Cambrian Period. The rhyolite is an igneous rock that formed when the crust was rifted, or pulled apart, and formed at the same time as the igneous rocks of the Wichita Mountains.

After this rifting event, a sea covered southern Oklahoma, which resulted in the deposition of primarily marine sedimentary rocks including sandstone, limestone, and shale. Deposition of these rocks throughout the Paleozoic (490–290 million years ago) Era resulted in 11,000 feet of rocks. The Cambrian and Ordovician age Fort Sill Limestone and Arbuckle Group are thought to be one of the thickest and best exposed limestone sequences in the world. Marine invertebrate fossils such as crinoids, brachiopods, bryozoans, and trilobites are abundant in the limestones. Along I-35, the Arbuckle Group weathers into unique features called "tombstone topography," so called because alternating limestone and shale give the appearance of rows of tombstones.

During Pennsylvanian time (318–299 million years ago), collision of two continental landmasses caused uplift and deformation of the formerly flat-



**South Central Oklahoma and the Arbuckles:**

Activity 1: What are minerals used for? From the Utah Geological Survey http://geology.utah.gov/surveynotes/gladasked/gladminused.htm

Geologic map and cross sections of the Arbuckles: http://ogs.ou.edu/geolmapping/Arbuckle_Map.pdf lying rocks, resulting in the folding and faulting of the rocks that we see in the Arbuckle Mountains today. Pebbles and cobbles eroded from the mountains were cemented together to form rocks called conglomerates that were deposited on top of the folded marine rocks.

Turner Falls State Park is located within the Arbuckle Mountains and contains 77-foot-high Turner Falls, the tallest waterfall in Oklahoma. Rocks here are Ordovician-aged Arbuckle Group limestones. Stromatolites can be seen in some of the limestones. Stromatolites are hummocky-looking features that form when small microorganisms called cyanobacteria trap and cement sediments. Stromatolites were more abundant during the Precambrian than they are today and are important geologically because they represent some of the oldest forms of life on earth.

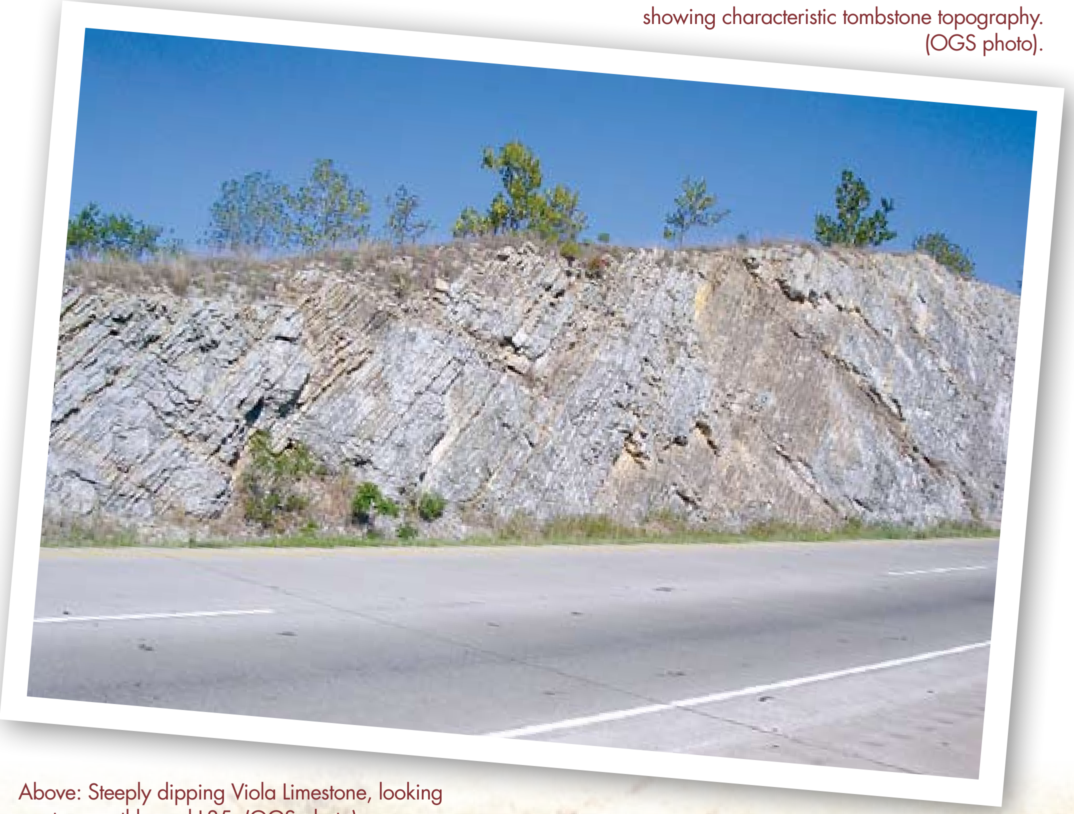
Turner Falls itself is unusual in that it is actively depositing tufa, a type of carbonate. The tufa is the yellowish-tan material exposed in the stream bed. The amount of carbonate being deposited is equal to, or slightly exceeds, the amount of material being eroded during times of flooding. This results in the waterfall building up rather than eroding down as is usual for most waterfalls.

Above: Limestones in the Arbuckle Mountains showing characteristic tombstone topography. (OGS photo).

## Activities:

1. The Arbuckle Mountains contain a number of geological resources important to the state, such as limestone. Large limestone quarries are easily visible on the north side of the mountains just west of I-35. Limestone is an important component of cement and is used for a variety of construction purposes. Crushed limestone is known as "aggregate." See http://www.mii.org/commonminerals.html to learn more about how limestone is used. Make a list of the materials used in and around your house that probably contain limestone. Visit http://ogs.ou.edu/pubsscanned/EP9p10_11minoilgas.pdf. Where else in Oklahoma is limestone found? What counties have limestone quarries? Compare your list based on the map above with a more recent list compiled by the Oklahoma Department of Mines in 2010 at http://www.ok.gov/mines/documents/ODMAnnualReport0809October2010.pdf. Using the 2009 production figures, make a chart showing the amount of limestone produced in different counties. Make a pie chart showing, for example, the top six counties plus all the rest, or a bar graph showing all the counties.

2. The average person in the U.S. uses about 90 gallons of water per day. Using the link below, calculate how much water your city or town uses per day. The largest spring discharging from the Hunton Anticline is Byrds Mill Spring. Is it large enough to supply water to your town? How many towns this size could it supply? See http://waterdata.usgs.gov/ok/nwis/uv?07334200.

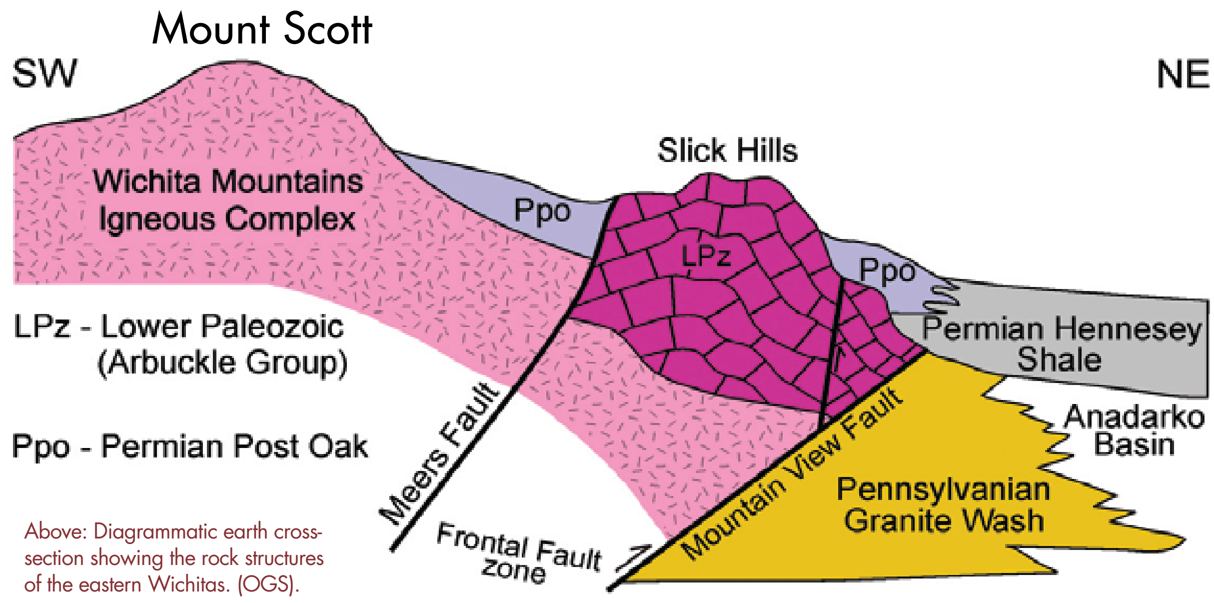


Above: Steeply dipping Viola Limestone, looking west on northbound I-35. (OGS photo).

By OGS Geologist Dr. Julie M. Chang

Northeast of Lawton, high mountains and hills rise up from the surrounding red bed plains. These are the Wichita Mountains. If you drive through them and think to yourself, "These rocks look different from any that I've seen before in Oklahoma," you would be right! The Wichita Mountains are composed of igneous rocks, which are a rarity in Oklahoma because they are exposed at the surface in few other localities in the state, including the Arbuckle Mountains, the Ozark Mountains, and Black Mesa.

The igneous rocks of the Wichita Mountains formed 540–525 million years ago in the Cambrian Period. During this time, a continental rift developed in southern Oklahoma, pulling the Earth's crust apart. The pulling apart of the crust caused molten magma to flow from deep within the Earth to the surface as rhyolite and basalt




Above: Diagrammatic earth cross-section showing the rock structures of the eastern Wichitas. (OGS).

Below: View of Baldy Point, Quartz Mountain State Park, showing Cambrian basement rocks overlain by Permian strata. (OGS photo).



**Southwest Oklahoma and the Wichitas:**

Wichita Mountains Wildlife Preserve: http://www.fws.gov/southwest/refuges/oklahoma/wichitamountains/

Information about culture, history and geology: http://digital.library.okstate.edu/encyclopedia/entries/W/WI002.html

Meers store: http://www.meersstore.com/

lava. Underground, the magma crystallized as granite and gabbro. Similar geologic environments today include the Rio Grande Rift of Texas and New Mexico and the East African Rift.

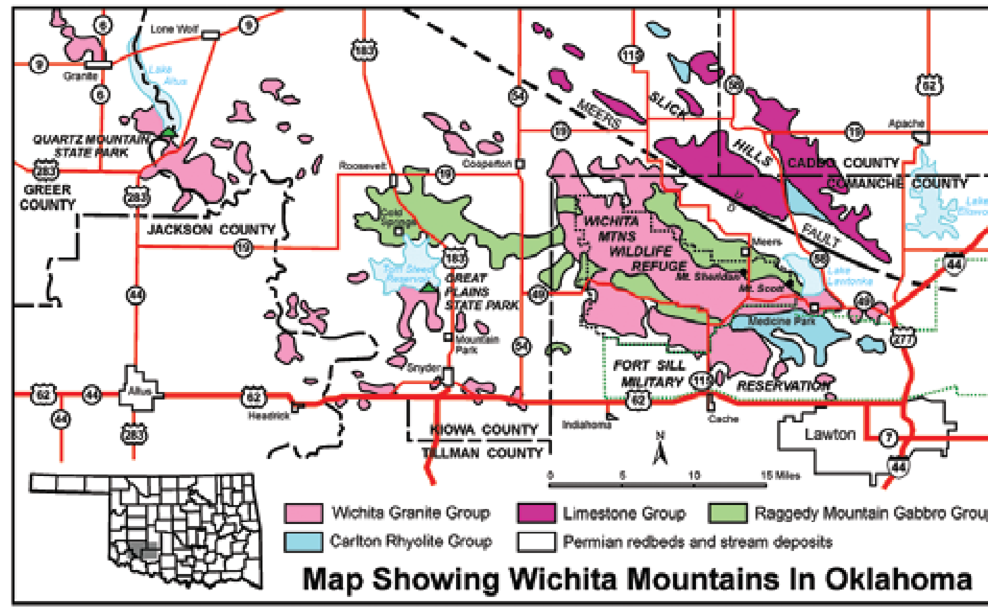
In Cambrian and Ordovician time (495–472 million years ago), a sea covered southern Oklahoma. During this time, sedimentary rocks like sandstone and limestone formed in layers on top of the igneous rocks. These sedimentary rocks can be seen in the Slick Hills, which are located in the northeastern part of the Wichita Mountains. Wind farms in the Slick Hills can be seen for miles around. The Slick Hills are separated from the igneous rocks of the Wichita Mountains by a large fault named the Meers Fault.

Between Early Pennsylvanian and Early Permian time, a collision between what is now South America and North America resulted in folding, faulting, and uplift of the Wichita Mountains. During and shortly after uplift, erosion of the overlying sedimentary rocks exposed the older igneous rocks of the mountains. These rocks were not eroded from the Slick Hills, however, where Cambrian and Ordovician sedimentary rocks still overlie older igneous rocks. The rocks that were eroded can be found in the foothills of the mountains, where they form conglomerates composed of eroded pebbles, cobbles and boulders. Because the mountains are above sea level, erosion is still continuing today.

The Wichita Mountains provide plentiful resources for the people of Oklahoma. Granite, limestone, and gravel are all quarried in the Wichita Mountains. In the early 1900s, the Wichita Mountains experienced a gold rush, with 20,000 people flocking to the area. Although little gold had been found, the gold rush was spurred on by fraudulent claims of high gold assays and claims of profitable gold extraction methods. In the end, only small amounts of metals (gold, silver, lead, copper, tin, molybdenum, iron, and zinc) were found.

Today, the Wichita Mountains are home to the Wichita Wildlife Refuge and two state parks, Great Plains State Park and Quartz Mountain Nature Park. Coarse-grained Reformatory Granite and fine-grained Lugert Granite can be seen at Quartz Mountain Nature Park. The Wichita Wildlife Refuge contains some of the last untilled native prairies in the U.S., which support animals such as bison, elk, white-tailed deer, and Texas longhorn cattle. Here, good examples of the igneous rocks peculiar to the Wichita Mountains can also be seen. Coarse-grained Quanah Granite can be seen at Quanah Parker Lake dam. Take a drive up Mount Scott, one of the tallest peaks at 2,464 feet, and get a glimpse of the Mount Scott granite. At the top is a great view of the surrounding plains and the Slick Hills to the north!

Right: Aerial photograph showing the trace of the Meers Fault. The photograph is looking north, and the fault is oriented northwest. (OGS photo).




Above: Map showing the Wichita Mountains in Oklahoma. (OGS).

## Activities:

1. As you drive through the Wichita Mountains, you will note that the most common rock is granite. It is also one of the many resources in the area. How is granite formed geologically? What occurred in the area to have formed granite? What are some uses of granite? Check around your community and your home and see if granite is being used. Explain what you have found. See http://www.ogs.ou.edu/pdf/WichitasBrochure2011.pdf.

2. Willis Granite Company in the town of Granite is one of Oklahoma's most well-known producers of dimension stone. Go to the Willis photo gallery at http://willisgranite.com/drupal/?q=image and look at some of the markers and memorials that are made of granite. Have you seen any of these or other granite markers in your travels around Oklahoma? Are there any monuments or markers in your town that have used granite?

By OGS Geologist Dr. Thomas M. Stanley

When you first drive west into the panhandle of Oklahoma, you will notice it looks nothing like the rest of the state. Gone are the red, rolling hills and steep, white bluffs of the western Permian interior, and instead, the landscape is sculpted as flat as a kitchen table. You have entered the geomorphic realm of the High Plains, a flat, featureless plain that is a result of the arid climate and prevailing southerly winds typical of this part of Oklahoma.

Everything isn't flat and featureless, however. If you were to drive north or south off the main highway, you would encounter a very important, light-colored rock formation—the Ogallala Formation—that crops out in many of the shallow draws and coulees.

The Ogallala extends north from the Texas Panhandle to western Nebraska and into eastern Colorado. It is composed of coarse sand-sized grains of quartz and pebbles of rock fragments, forming what geologists call sandstone and conglomerate. It was deposited some 10 million years ago by braided streams and rivers that carried eroded material eastward from the newly uplifted Rocky Mountains. As you continue to drive west, you should notice numerous center-pivot irrigation systems that highlight the true importance of the Ogallala Formation—water! The Ogallala has many open spaces, called pores, between sand grains and rock fragments that hold ground water. It supplies most of the water for irrigation to many farms of the western Great Plains.

In the far northwest corner of the Panhandle we come across another unique area—Black Mesa State Park. Standing at 4,973 feet, Black Mesa represents the highest point in the state and is one of Oklahoma's most impressive sights. The reason for Black Mesa's height is that it is capped by a volcanic basalt flow, called the Raton Basalt, which is resistant to weathering and erosion. The basalt is a hard, fine-grained, volcanic rock that is pockmarked with numerous small holes called vesicles. The vesicles formed when gas was trapped in the cooling lava as it flowed from fissures and volcanoes that

Above: Rocks exposed in the foreground are from the Triassic period, called the Dockum Group. In the immediate background is the Exeter Sandstone. Note that you can see the Exeter way off in the distance at the bottom of that far-off butte. Due to its resistance to weathering, and to its easily recognizable color, the Exeter Sandstone is very useful for mapping the geology of the Black Mesa area. (OGS photo).

Right: Close-up of gravel and coarse sand-sized material from the Ogallala Formation. (OGS photo).



**Northwest Oklahoma and Black Mesa:**

Topographic map showing Black Mesa (hint: go to the far northwest corner of the map):
http://ogs.ou.edu/StatemapOGQ/OGQ-43_Boise_City_100K.pdf

Open-file information about Black Mesa area: http://ogs.ou.edu/pubsscanned/openfile/OF4_99.pdf

Dinosaur tracks: http://www.travelok.com/listings/view.profile/id.2245

Dinosaur tracks in southwest Arkansas: http://www.4029tv.com/r/29393569/detail.html

http://www.news9.com/story/15628400/new-dinosaur-tracks-found-in-southwestern-arkansas

http://newsok.com/discover-oklahoma-museums-uncover-dinosaurs-tracks/article/1860664 erupted about 5 million years ago in southeastern Colorado.

Below the Raton Basalt are Triassic- and Jurassic-age formations that are found nowhere else in Oklahoma. Of these units, the Morrison Formation (Jurassic) is the most interesting because it hosts some of the finest examples of Late Jurassic dinosaurs ever collected. During the 1930s and 1940s, over 6,000 bones belonging to various species of dinosaur were excavated from 17 sites. Some of the more common species include *Apatosaurus, Stegosaurus, Camptosaurus, Allosaurus*, and *Diplodocus*. Besides dinosaur bones, the Morrison Formation contains well-preserved dinosaur trackways that can be viewed near the main road into the park. The Morrison Formation contains sandstones and shales deposited within broad river plains and freshwater lakes, similar to what we see today within the Mississippi and Missouri River valleys and their tributaries

Cropping out between the Morrison Formation below and the Raton Basalt above are Cretaceous-age rocks, belonging mostly to the Dakota and Colorado Groups, that tell a story of progressive marine incursion into this part of Oklahoma and all the way into central Colorado. Evidence for this sea can be found in some outcrops of the Colorado Group that contain large marine clams called *Inocermus* and straight and coiled ammonites.

Above: A look at Black Mesa from the east. You can see the Raton Basalt as a resistant ledge of outcrop at the very top of the mesa. The white band near the bottom is the Exeter Sandstone, the lowest formation of Jurassic age in the area. The Morrison Formation is just above the Exeter. (OGS photo).

Above: Close-up of a dinosaur footprint as seen in the Morrison Formation. Note the 'three toed' structure of the print, which is typical of dinosaurs. The rock hammer to the left of the print is 16 inches long. (OGS photo).

Left: Small, hand specimens of the Raton Basalt. Note their dark color and the numerous holes, called vesicles, scattered throughout. (OGS photo).

## Activities:

1. Ranching and farming are major industries in Oklahoma's Panhandle; both require water. The Ogallala (High Plains) aquifer is the country's largest fresh water aquifer and is found under much of the nation's richest and most productive farmland. What states does the Ogallala aquifer underlie? http://co.water.usgs.gov/nawqa/hpgw/images/figure1.jpg and http://www.kerrcenter.com/publications/ogallala_aquifer.pdf

2. Review the fact sheet that the U.S. Geological Survey (USGS) published (http://pubs.usgs.gov/fs/FS-081-00/pdf/fs-081-00.pdf) and answer the following: a) For what use is most of the water pumped from the aquifer? b) Which county in the Panhandle uses the most water? c) Has the water level in the aquifer gone up in more places than it's gone down, or the reverse? d) When did most of the large-capacity center-pivot irrigation wells start being used in the Panhandle? e) Does the USGS think the water level in the Ogallala aquifer in Oklahoma will go up, stay the same, or go down by 2020?

3. The NW corner of Cimarron County once was a hotbed of paleontological activity. Between 1935 and 1942, Dr. J.W. Stovall from the University of Oklahoma excavated 17 dinosaur-bone quarries in the area.

Many of the bones are now part of the research collection at the Sam Noble Oklahoma Museum of Natural History. The giant carnivore *Saurophaganax maximus* on display at the museum is Oklahoma's state fossil.

All of Stovall's bone finds came from the Jurassic age Morrison Formation, which contains dinosaur bones in many locations throughout the western U.S. Based on what you know about *Acrocanthosaurus* (Ouachita section), which carnivore is older? Why have Oklahoma's dinosaur discoveries occurred in the southeast and northwest parts of the state and not in other parts of Oklahoma?

The Oklahoma red beds cover the whole, western half of Oklahoma. Topographically, the area is characterized by broad, flat plains interspersed with areas of gently rolling, grass-covered hills. The reason for this is the underlying geology, where the rolling hills are held up by resistant sandstone formations, while softer weathering shales underlie the plains. These sandstone and shale-dominated formations where formed during the Permian Period, about 299–251 million years ago.

By the beginning of the Permian in Oklahoma, the Arbuckle and Wichita Mountains were worn down through weathering and erosion into foothills that barely jutted above the broad coastal plains. Sand and clay were transported from these highlands and deposited as deltas by rivers that emptied into a shallow inland sea that covered most of western Oklahoma. The same situation occurs today, as the Mississippi delta builds outward into the Gulf of Mexico with sediment supplied from upland areas by the Mississippi River.

The distinctive trait of all our Permian units is their deep red color, giving this part of Oklahoma its most recognizable property—red earth. The red color is due to the oxidation of iron within the rocks. The same process occurs when metal rusts from exposure to water and air. It is thought by most geologists that the pervasive red color indicates that the Permian rocks were formed under very hot, oxidizing climatic conditions. You can see good examples of Permian red beds at Red Rock Canyon State Park near Hinton, as well as along most county roads west of Oklahoma City.

The reason geologists believe the climate during the Permian Period was hot is due to the presence of abundant gypsum within the red beds. Gypsum is a mineral that only forms when seawater evaporates. The Permian inland sea that covered much of western Oklahoma was very restricted and had minimal circulation. As a result, seawater in the basin evaporated causing dissolved salts to concentrate in the water column to the point where gypsum, and even halite (rock salt), precipitated onto the shallow sea floor.

Almost all our Permian units contain some gypsum; but two, the Blaine and Cloud Chief Formations, have thick beds of precipitated gypsum. The Blaine gypsums form a characteristic ledge, called the 'Blaine Escarpment', above the softer Permian shales. The escarpment can be seen best at the Glass (or "Gloss") Mountains and around Roman Nose State Park. Where gypsum beds are exceptionally thick, ground water activity flowing through the rocks dissolves the gypsum, forming extensive caves such as Alabaster Caverns and the gypsum Corn Caves around Crowder Lake.

Due to gypsum's easy solubility in water, ground water in aquifers below the Blaine Escarpment tends to be high in concentrations of calcium sulfate. In some areas, such as around the Great Salt Plains Lake, gypsum crystallizes out of solution a few feet below the ground at the top of the ground water table. Here, sulfate-rich ground water begins to evaporate. As the gypsum crystallizes it incorporates some of the loose soil in its crystal structure, forming hourglass selenite crystals. In the late spring and summer months, the selenite crystals are easily collected using a shovel and bucket.

Not all fun and interesting features of the red bed country are products of the Permian Period. Some, like the annual formation of selenite, are geologically recent events. Another such recent event is the formation of vast sand dune fields that developed on the north side of major rivers, like

Above: View of Great Salt Plains Lake Wildlife Refuge and Park from the west. It doesn't look like much, but dig down a foot of two on the other side of the fence and you can collect nice selenite crystals. (OGS photo).

Above: Hourglass selenite crystals collected at Great Salt Plains State Park. (OGS photo).



**Central, Western Oklahoma and the Red Beds:**

Oklahoma Geological Survey, Red Beds Brochure: http://ogs.ou.edu/pdf/roserockbroch.pdf

Geology of Red Rock Canyon: http://www.ogs.ou.edu/pubsscanned/InfSeries/IS5.pdf

Geology of Arcadia Lake Park: http://www.ogs.ou.edu/pubsscanned/InfSeries/IS7.pdf those of Little Sahara State Park. These dune fields developed because of the extreme dryness found in this part of Oklahoma, coupled with the ever pervasive, strong, southerly wind. The lack of rainfall inhibits plant growth. Therefore, there are few to no binding roots that can stabilize the loose soil, silt and sand. All of this loose material is then blown up and over the north banks of these major rivers by winds, forming extensive areas of dunes and sheet sand deposits.

Above: The thick, white bed at the top of the outcrop is a single, ten foot thick bed of gypsum from the Blaine Formation. This Blaine Formation exposure is typical of the ones that can be seen around Roman Nose State Park. (OGS photo).

Right: Red bed shales (bottom of hill) and red bed sandstones (top of hill) exposed along State Highway 281 between Geary and Watonga. Note the thin, light colored beds within the red shale. These are thin beds of gypsum, which are commonly found in many of the Permian-age formations. (OGS photo).

Above: Part of the Blaine Escarpment seen in the Glass (or "Gloss") Mountains along State Highway 412, west of Fairview. The white bed that caps the escarpment is the basal gypsum bed of the Blaine Formation. The Flowerpot Formation is the softer weathering, red shale below the gypsum. (OGS photo).

Above: Typical sandstone of the Rush Springs Formation, exposed in Red Rock Canyon State Park. Note the thin ridges that slope to the left at the top of the sandstone. These are cross-beds, and they indicate the water current at the time the sandstone was deposited was moving from right to left. (OGS photo).

## Activities:

1. Take a photo tour of western Oklahoma with your class. Using the TravelOK website (http://www.travelok.com/listings/sid.1/tag.State_Parks), visit all the region's state parks. Notice that in all of the parks, there are cliffs of red rocks. Do you think the red color is just a surface coating on the rocks or does it go all the way thought the rocks? Remembering what you have learned, how do the rocks get their distinct red color?

2. Roman Nose and Gloss Mountain State Parks feature another rock that is commonly associated with Oklahoma's red beds – gypsum. As one of the leading producers of gypsum in the country, it is a valuable mineral for our state.

Make a pie chart showing the different counties and how much gypsum they produced using the 2009 production figures found on page 25 of the Oklahoma Department of Mines website (http://www.ok.gov/mines/Minerals_Program/Mineral_Information_by_Type/Gypsum/index.html)

Then, make a graph showing the total U.S. gypsum production from 2005 – 2009 using information found on the USGS website (http://minerals.usgs.gov/minerals/pubs/commodity/gypsum/mcs-2010-gypsu.pdf).
Analyze the data and hypothesize why the production of gypsum has changed over the past few years.

# NORTHEAST OKLAHOMA AND THE OZARKS

By OGS Geologist Dr. Kenneth V. Luza

Northeast Oklahoma is bordered on the north by the state of Kansas and on the east by the states of Arkansas and Missouri. The region consists of all the land drained by the Arkansas River and its tributaries from below Keystone Dam to a point where the Arkansas River leaves the state. The major streams are the Illinois, Verdigris, Caney and Grand Rivers. The oldest rock in the region is the Spavinaw Granite that is 1.24 billion years old and is exposed in small areas in Mayes County. A majority of the rocks that crop out in this region belong to the Mississippian and Pennsylvanian Periods.

Part of northeast Oklahoma is on the southwest flank of the Ozark Plateau. The Ozark Plateau is a broad asymmetrical dome that occupies an area of approximately 40,000 square miles in Missouri, Arkansas, and Oklahoma. The dome was produced by a series of minor uplifts during the early and middle Pennsylvanian Period. These formations strike in an arcuate pattern and dip away from the axis of the uplift. The general regional dip of 25 to 50 feet per mile is interrupted by a series of northeast-trending folds and faults whose alignment roughly parallels the axis of the Ozark uplift. The streams and rivers created sharp relief locally by cutting down into resistant limestones and sandstones.

This region underwent successive submergences and emergences from seas during the Paleozoic Era. The plateau is underlain mostly by cherty limestone beds of the Mississippian Boone Formation. Marine fossils, such as brachiopods, bryozoans, crinoids, corals and an occasional shark's tooth, are found in the limestone beds. Karst features, such as sinkholes and caves, are common.

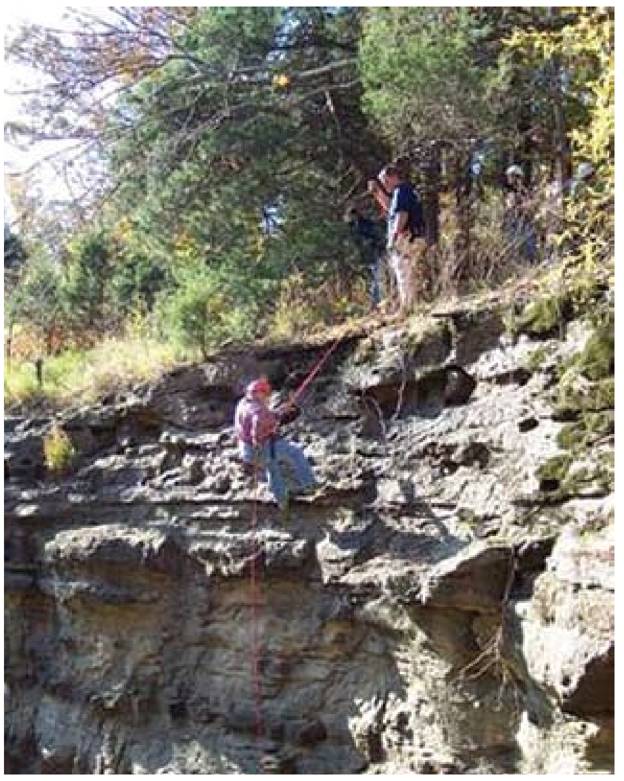
Cool, perennial, spring-fed streams such as five of Oklahoma's scenic rivers (parts of the Illinois River, and Flint, Barren (Baron) Fork, Little Lee and Lee Creeks) occur in this region. A sixth scenic river, Upper Mountain Fork, occurs in McCurtain County in southeast Oklahoma. This area contains dense growths of oak, hickory, and other hardwoods, with a scattering of pine and cedar.

South of the Ozark Plateau are the Boston Mountains. They occur mostly in northern Sequoyah and southwest Cherokee Counties and extend east into Arkansas. The area is deeply dissected and composed of Pennsylvanian sandstone and shale. A mosaic of oak-hickory forest and woodlands grows in this area; the flatter areas are used as pastures or for hay.

East of the Spring and Grand Rivers is the Central Irregular Plains. They consist of irregular to undulating plains that are underlain by interbedded westward-dipping sandstone, shale and limestone. East-facing cuestas and low hills are capped by resistant limestone and sandstone beds with intervening valleys excavated in shale beds. Natural vegetation is mostly tall grass prairie, but a mix of tall grass prairie and oak-hickory forest is native to eastern areas.

U.S. Highway 66 (Route 66) closely parallels I-44 in northeast Oklahoma. West of Quapaw, light-colored, man-made hills rise 150–200 feet above the prairie north of Route 66. These hills and/or chat piles were created during the milling of lead-zinc ores in 1915–1970. Today, the material in these chat piles, mostly chert fragments, is used to make various asphalt mixes for roads in Kansas and Oklahoma. Other mineral resources in this region include oil and gas, coal, limestone to make cement and concrete aggregate, tripoli (weathered chert) used in buffing compounds, sand and gravel, clay and shale used in making cement and brick, and sandstone for dimension stone.

There are 16 state parks in northeast Oklahoma. Western Hills Guest Ranch and Sequoyah State Park has a lodge and is located on Fort Gibson Lake. State Parks with cabins include Greenleaf, Sequoyah Bay, and Tenkiller. Recreational activities include golf, hiking, biking, horseback riding, fishing, bird watching, and water skiing.



Above: These women are using rocks at Tenkiller State Park to learn rappelling skills during an annual Women in the Outdoors event. (Oklahoma Department of Tourism photo).

Above: The road into Okmulgee State Park runs alongside an outcrop of a sandstone in the Wewoka Formation that is typical of the area. Nearby is Dripping Springs Park, which makes it convenient for visitors to enjoy both sites in one trip. (Oklahoma Department of Tourism photo).



**Northeast Oklahoma and the Ozarks:**

Mountains, Streams, and Lakes of Oklahoma: http://www.ogs.ou.edu/pubsscanned/InfSeries/infseries1.pdf

Geology of Tallgrass Prairie Preserve is an unpublished, open-file report that contains lots of illustrations of fossils, some good basic geology, and some more technical sections: http://www.ogs.ou.edu/pubsscanned/openfile/OF1_2000.pdf

Priority Academic Student Skills (PASS) standards addressed (grades 7-12)

**GRADES 7-10**
**TECHNOLOGY EDUCATION**

Standard 5: The student will recognize the effects of technology on the environment.

1. Describe technologies used to repair damage in the environment.

2. Examine ways to reduce resource use through technology.

3. Identify practices available for monitoring the environment to provide feedback for decisions.

Standard 6: The student will determine the connection between technological demands, values and interests of society and the impact of these on the environment.

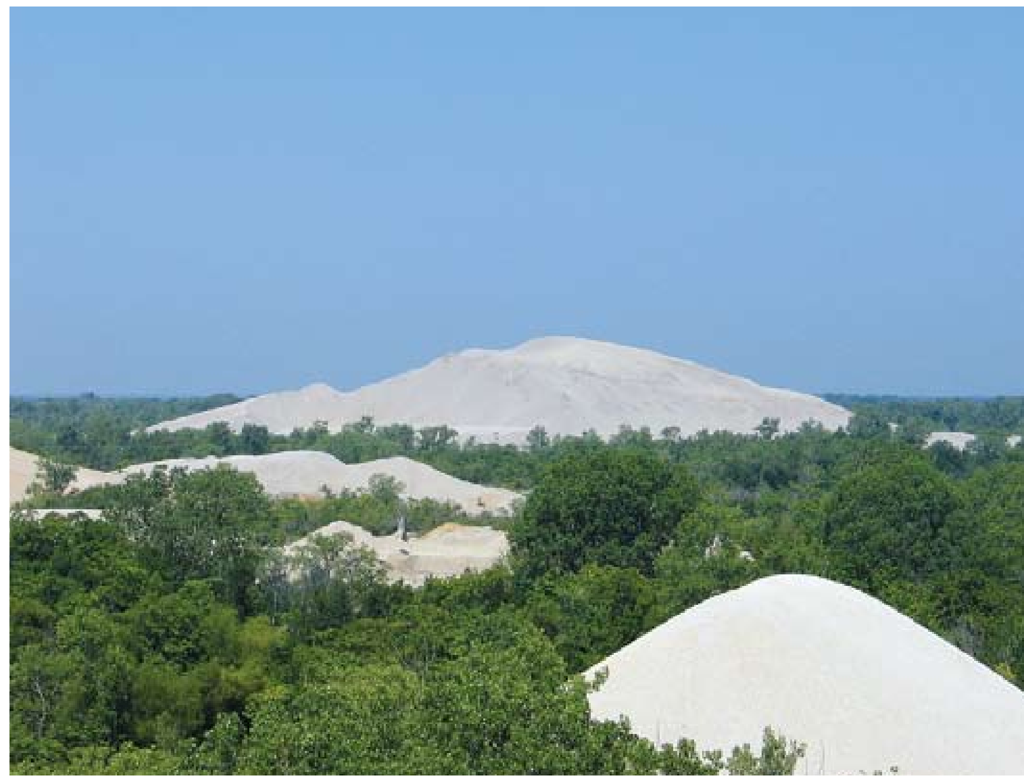
Above: Chat piles from over the town of Picher in far Northeast Oklahoma. The area was part of the Tar Creek Superfuel site and was also devastated by a tornado in 2008.

Standard 14: The student will identify and describe advances and innovation in the energy-power, biotechnology, communications, transportation, manufacturing, construction, and agriculture techniques used to improve each field.

Standard 15: The student will identify and describe energy-power, biotechnology, communications, transportation, manufacturing, construction, and agriculture technology principles necessary to create products and processes.

Above: Ice on the trees and "the island" at Lake Tenkiller remind us that Oklahoma's State Parks are beautiful in all seasons. (Oklahoma Department of Tourism photo).

Above: Beautiful Lake Tenkiller is a favorite recreation spot in northeast Oklahoma. (Oklahoma Department of Tourism photo).



Above: Chat piles near Quapaw in northeast Oklahoma are left from lead and zinc mining in the area from 1915–1970. Parts of this area were included in the Tar Creek Superfund site after contaminated water and soil were identified. (OGS photo).

## Activities:

1. How many scenic rivers are located in northeast Oklahoma? (Hint: see pages 12–14 at http://www.ogs.ou.edu/pubsscanned/EP9p12_14water.pdf). How many of Oklahoma's major lakes are located in this part of the state? Why do you think northeast Oklahoma has so many more lakes than other parts of the state?

2. Historically, extreme northeast Oklahoma is the site of a great deal of lead and zinc mining. Oklahoma led the nation in zinc production almost every year from 1918–1945, and in 1926 Ottawa County led the world in lead and zinc production. Some people maintain that area mines helped the U.S. and Allies win World War I. To learn more, research Oklahoma's Miami-Picher mining district.

3. Using the internet, learn what you can about the Tar Creek Superfund site. Problems with the collapse of abandoned mines, water pollution, and lead in the environment put this area first on the list when the Superfund was created. Towns in the area were bought out and residents and schools were moved. Write an essay on what happened in Pitcher.



**GRADES 7-12**
**INFORMATION LITERACY**

Standard 1: The student who is information literate accesses information efficiently and effectively.

4. The student will demonstrate he/she knows how to access information from a variety of sources – print, nonprint and electronic.

**GRADE 7**
**WORLD GEOGRAPHY**

Standard 1. The student will use maps and other geographic representations, tools, and technologies to analyze relationships between people, places, and environments of world regions from a spatial perspective.

2. Apply the concepts of scale, distance, direction, relative location, latitude and longitude.

3. Construct and use maps, globes, graphs, charts, models, and databases to analyze spatial distributions and patterns.

4. Recognize the characteristics, functions and applications of maps, globes, aerial and other photographs, satellite images, and models.

Standard 2: The student will examine the major cultural and physical regions of the world to interpret the earth's complexity.

4. Define, recognize, and locate on appropriate maps and globes basic landforms and bodies of water, and major cities, rivers, mountain ranges, regions, biomes, and countries of the world.

Standard 3: The student will examine the interactions of physical systems that shape the patterns of the earth's 66 67 resources.

1. Identify forces beneath and above the earth's crust, explaining the processes and agents that influence the distribution of resources.

Standard 4. The student will evaluate the human systems of the world.

2. Explain patterns and processes of global economic interdependence (e.g., developed and developing countries, economic activities, and world trade).

Standard 5. The student will examine the interactions of humans and their environment.

2. Evaluate the effects of human modification of and adaptation to the natural environment (e.g., use of the steel plow, crop rotation, types of housing, flood prevention, discovery of valuable mineral deposits, the greenhouse effect, desertification, clear-cutting forests, air and water pollution, urban sprawl, and use of pesticides and herbicides in agriculture).

Standard 6: The student will analyze problems and issues from a geographic perspective using the skills and tools of geography.

1. Evaluate and draw conclusions from different kinds of maps, graphs, charts, diagrams, and other sources and representations (e.g., aerial and shuttle photographs, satellite-produced images, the

geographic information system (GIS), atlases, almanacs, and computer-based technologies).

2. Explain the influence of geographic features on the development of historic events and movements.

## MATHEMATICS PROCESS STANDARDS

Process Standard 4: Connections

1. Apply mathematical strategies to solve problems that arise from other disciplines and the real world.

2. Connect one area or idea of mathematics to another (e.g., relate equivalent number representations to each other, relate experiences with geometric shapes to understanding ratio and proportion).

## MATHEMATICS CONTENT STANDARDS

Standard 2: Number Sense and Operation – The student will use numbers and number relationships to solve a variety of problems.

1. Number Sense

c. Demonstrate the concept of ratio and proportion with models (e.g., similar geometric shapes, scale models).

## GRADE 8
## EARTH/SPACE SCIENCE

Standard 5: Earth's History - The Earth's history involves periodic changes in the structures of the earth over time. The student will engage in investigations that integrate the process standards and lead to the discovery of the following objectives:

1. Earth's history has been punctuated by occasional catastrophic events, such as the impact of asteroids or comets, enormous volcanic eruptions, periods of continental glaciation, and the rise and fall of sea level.

2. Fossils provide important evidence of how life and environmental conditions have changed.

## MATHEMATICS PROCESS STANDARDS

Process Standard 4: Connections 68 69

1. Apply mathematical strategies to solve problems that arise from other disciplines and the real world.

2. Connect one area or idea of mathematics to another (e.g., relate equivalent number representations to each other, relate experiences with geometric shapes to understanding ratio and proportion).

## HIGH SCHOOL
## PHYSICAL SCIENCE

Standard 3: Interactions of Energy and Matter - Energy, such as potential, kinetic, and field, interacts with matter and is transferred during these interactions. The student will engage in investigations that integrate the process standards and lead to the discovery of the following objectives:

2. Waves, including sounds and seismic waves, waves on water, and light waves, have energy and can transfer energy when they interact with matter (such as used in telescopes, solar power, and telecommunication technology).

Standard 4: The Earth System - A system that has changed over time, which includes dynamic changes in the earth's crust, is the Earth system. The student will engage in investigations that integrate the process standards and lead to the discovery of the following objectives:

1. Geologic time can be estimated by observing rock sequences and using fossils to correlate the sequences at various locations.

2. The solid crust of the earth consists of separate plates that move very slowly pressing against one another in some places and pulling apart in other places (i.e., volcanoes, earthquakes and mountain building).

## OKLAHOMA HISTORY

Standard 1. The student will demonstrate process skills in social studies.

1. Identify, analyze, and interpret primary and secondary sources (e.g., artifacts, diaries, letters, art, music, literature, photographs, documents, newspapers, and contemporary media).

2. Identify, evaluate, and explain the relationships between the geography of Oklahoma and its historical development by using different kinds of maps, graphs, charts, diagrams, and other representations such as photographs, satellite-produced images, and computer-based technologies.

Standard 6. The student will investigate the geography and economic assets of Oklahoma and trace their effects on the history of the state.

1. Locate the significant physical and human features of the state on a map (e.g., major waterways, cities, natural resources, military installations, major highways, and major landform regions).

## WORLD GEOGRAPHY

Standard 2: The student will use the concepts of places and regions as the basic units of geographic inquiry.

1. Identify the human and physical characteristics of particular places and regions.

2. Conduct regional analysis of geographic issues and questions.
Standard 3: The student will examine earth's physical processes (e.g., climate and landforms) and organize them into ecosystems.

4. Analyze patterns of natural phenomena such as earthquakes, volcanic eruptions, tornadoes, and hurricanes.

Standard 4: The student will examine human cultures, populations and activities such as settlement, migration, commerce, conflict, and cooperation.

2. Interpret the patterns and networks of economic interdependence on earth's surface. 68 69

Standard 5: The student will evaluate the interactions between humans and their environment.

1. Explain how human actions modify the physical environment.

3. Explain the changes that occur in the meaning, use, distribution, and importance of resources.

4. Observe and predict the possible economic effects and environmental changes resulting from natural phenomena (e.g., tornadoes, hurricanes, droughts, insect infestations, earthquakes, El Nino, and volcanoes).

## ECONOMICS

Standard 2: The student will explain how prices are set in a market economy by using supply and demand graphs, and determine how prices provide incentives to buyers and sellers.

1. Determine how price and nonprice factors affect the demand and supply of goods and services available in the marketplace.

2. Explain what causes shortages and surpluses, including government imposed price floors and price ceilings; and determine the impact they have on prices and people's decisions to buy or sell.

## MATHEMATICS

Process Standard 4: Connections

1. Link mathematical ideas to the real world (e.g., statistics helps qualify the confidence we can have when drawing conclusions based on a sample). 2. Apply mathematical problem-solving skills to other disciplines.