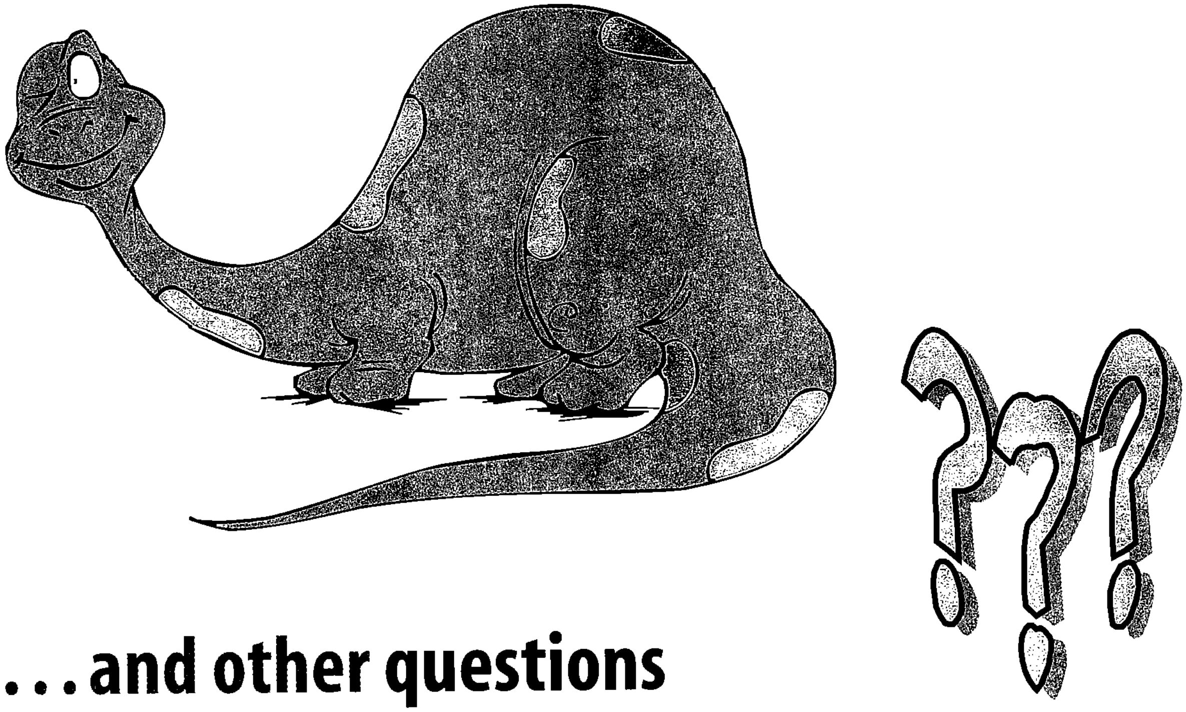
"Is this dinosaur dung?"



...and other questions answered by the Oklahoma Geological Survey

Information Series 8
2000

Oklahoma Geological Survey
Charles J. Mankin, *Director*

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"Is this dinosaur dung?"

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compiled by

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Reference List to Questions

Q. What does the Oklahoma Geological Survey do?

A. The Oklahoma Geological Survey, a research and public-service agency of the State of Oklahoma, was authorized in the State constitution and implemented by action of the first State legislature. The Survey's charter, paraphrased from the language of the enabling legislation, is to investigate the land, water, mineral, and energy resources of our State and to disseminate the results of these investigations to encourage the wise use of our natural resources.

To fulfill its charter responsibilities, the Survey engages in a wide variety of field investigations throughout Oklahoma and performs a broad range of laboratory analysis on materials collected in the conduct of these field studies. Research is undertaken either independently or in concert with other state and federal agencies and encompasses virtually every aspect the State's non-biological natural environment. The results of these studies are made widely available in the form of various publications, including books, maps, and open-file reports.

Charles J. Mankin, *Director*
Oklahoma Geological Survey

Q. Can you survey my land?

A. No, the Oklahoma Geological Survey does not survey land. Commercial survey companies are listed in the yellow pages under "Surveyors—Land."

Introduction

Oklahoma Geological Survey (OGS) geologists and staff members study Oklahoma's geology and natural resources and answer questions from people throughout Oklahoma and the rest of the country. Questions come from individuals ranging from professional geologists with technical problems to school children seeking general information for science projects. Others come from homeowners, teachers, consultants, rock hounds, Scout leaders, university students, petroleum engineers, and government officials.

The range of questions is equally broad. Many deal with aspects of geology unique to Oklahoma, whereas others relate to geology in general. Some questions don't apply to Oklahoma, and some don't even apply to geology!

In 1998, Governor Frank Keating proclaimed the second week in October as Earth Sciences Week in the State of Oklahoma. October 8–14, 2000, marked the third annual celebration. As a contribution to this event, the Oklahoma Geological Survey answers in this publication a few dozen of the most frequently asked questions we receive from the public.

Acknowledgments

The questions and answers in this publication were contributed by many geologists and staff members of the Oklahoma Geological Survey based on years of experience working with the public. I would especially like to thank LeRoy Hemish, Rick Andrews, and Jane Weber for having reviewed all or parts of the manuscript for accuracy. Tracy Peeters, Christie Cooper, Wendell Cochran, and Frances Young contributed many useful ideas, and the publication is significantly better as a result of their efforts. I would also like to thank the individuals who contributed photographs and graphs; they are cited in the figure captions.

General Map Questions

1. What kinds of maps does the OGS sell?

Primarily topographic maps, which show the shape of the Earth's surface (hills, valleys, streams, etc.), and geologic maps, which show geologic formations and rock types.

We sell a wide variety of maps including all the topographic maps of Oklahoma published by the U.S. Geological Survey (USGS). Among them are 7.5′ quadrangles (1 inch = 0.38 mile), 15′ quadrangles (1 inch = 1 mile), 30′ x 60′ sheets (1 inch = 1.6 miles), 1° x 2° sheets (1 inch = 3.9 miles), and a topographic map of the entire State (1 inch = 7.9 miles).

Geologic maps available from the OGS vary widely in scale and coverage, ranging from 7.5′ quadrangles to the "Geologic Map of Oklahoma." Geologic maps of 1° x 2° sheets for the entire State—except the Panhandle—are included in the OGS Hydrologic Atlas series; geologic maps of the Panhandle are available as county maps (1 inch = 2.0 miles) in the USGS Hydrologic Investigations Atlas series. Some geologic maps are sold individually, others only as parts of technical reports.

Many of the geologic maps focus on natural resources, particularly oil and gas, coal, and water.

2. Where is the flattest land in Oklahoma?

Areas of old windblown silt and sand in the Panhandle.

Many places in Oklahoma are remarkably flat, but few cover an extensive area. Floodplains along many of Oklahoma's major rivers are flat, but rarely are more than a mile wide. Some other areas of the State are flat over small areas because the bedrock there is almost horizontal and/or easily eroded.

Perhaps the largest area of flat land in the State is in the Panhandle. An example is the area east and southeast of Guymon. There, the land is flat and featureless, tilting only about 15 feet per mile to the east. The area is flat because (1) the bedrock, the Ogallala Formation (Miocene–Pliocene) (Appendix 6), is nearly horizontal and is covered by a thin veneer of windblown sand and silt but no dunes; and (2) the area is so dry that drainage networks have not developed except near the larger streams. Most of the rain sinks into the soil rather than dissecting the land surface.

3. What topographic map shows my land?

We'll need a legal description of your land—the section, township, and range. Alternatively, give us exact distances and directions from towns or highway intersections (for example, 3.2 miles west and 1.7 miles north of the intersection of Highways 19 and 177, west of Ada.)

Send (or call) the description to our Publication Sales Office (Appendix 1), or ask for a copy of "Oklahoma: Index to Topographic and Other Map Coverage." This free publication, by the U.S. Geological Survey, shows all the quadrangles and townships in the State. Using it you must determine where a particular section lies within a township, and from that you can find the name of the appropriate topographic map.

4. Why aren't hiking trails on the USGS topographic maps?

Many trails are shown. Others are newer than the maps or weren't visible on the aerial photographs used by cartographers to make the maps.

Most USGS topographic maps are made from aerial photographs, and features such as hiking trails that are visible on the photographs typically are shown on the maps. Trails not shown on the maps may have been established after the photographs were made, or were obscured by vegetation. However, some trails that appear on maps no longer exist, or have been overgrown and are barely visible even on the ground. They may have been good trails when the photographs were taken, but are not now.

State and federal agencies in many cases carefully mark trails on their file copies of topographic maps. For example, the Oklahoma Tourism and Recreation Department (Appendix 1) has maps showing trails in many State parks, and the U.S. Forest Service (Appendix 2) has maps showing trails in the Ouachita National Forest. Photocopies of these maps may be available for purchase.

5. What topographic maps cover Wildlife Management areas?

The OGS Publication Sales Office (Appendix 1) has a list of maps covering areas managed by the Oklahoma Department of Wildlife Conservation (Appendix 1). Contact us for information on areas that interest you.

6. Where can I find a fishing map that shows the bottom contours of lakes?

Some of the topographic maps published by the USGS and sold by us show the topography of lake bottoms; others do not. If you have a question about a particular lake, contact the OGS Publication Sales Office (Appendix 1), and we will tell you what maps are available and whether or not bottom contours are shown.

7. Do you have a map showing all the oil and gas wells in Oklahoma?

We have no single map showing all the petroleum wells in the State. However, map GM-28, "Map of Oklahoma Oil and Gas Fields," shows all the oil and gas fields in Oklahoma.

In addition, the OGS can access the Natural Resources Information System (NRIS), a database of all petroleum wells for which a Completion Report (Form 1002A) has been submitted to the Oklahoma Corporation Commission (Appendix 1). Using information from NRIS, maps showing well locations in any given area of the State can be printed at any scale (e.g., Fig. 1). (A fee is charged for this service.) Contact the OGS Computer Facility (Appendix 1) for more information about the NRIS database.

Several commercial firms publish maps of oil and gas wells in Oklahoma: Geo Information Systems, Herndon Map Service, IHS Energy Group, and PennWell Corp. (Appendix 5).

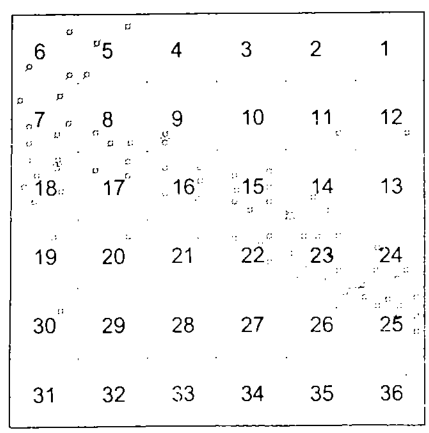

Figure 1 *(questions 7 and 12)*. Map of township T. 15 N., R. 20 W., showing the location of natural-gas wells in the Moorewood NE gas field. Sections are labeled 1 through 36, beginning in the northeast corner of the township. Each section is one square mile. (Map by Jane L. Weber, Oklahoma Geological Survey.)

8. Do you have a map showing Oklahoma's geologic faults?

We have no maps devoted specifically to faults, but the 1954 "Geologic Map of Oklahoma" (scale 1:500,000) shows many of the major faults.

Faults are also shown on larger-scale geologic maps of different parts of the State; these maps are published as parts of map series, bulletins, circulars, and guidebooks, many of which are available from the OGS Publication Sales Office (Appendix 1). Faults are shown on maps published by other geologic and scientific organizations and on maps included in unpublished master's theses and doctoral dissertations.

Some maps show subsurface faults—faults that never reached the surface or are covered by rocks that were deposited after movement on the fault.

9. How can I interpret this topographic map?

You may go to a public library and consult books about hiking, camping, orienteering, and outdoorsmanship. The USGS distributes two useful publications, both free, and the OGS also has one.

A good USGS leaflet is "Topographic Map Symbols": it briefly describes topographic maps and how to read them, and it lists and identifies the symbols that are used on the maps. "Topographic Mapping" is a booklet that describes how topographic maps are made (Fig. 2).

"Topographic Map Reading" by OGS geologist James R. Chaplin is a paper available in OGS Special Publication 96-5. A key feature of this paper is a discussion of all the information in the margins of a standard 7.5′ USGS topographic map—outside the map area (for example: names of adjoining quadrangles). Chaplin also describes the Land Office Grid System (also known as the section-township-range system), which is the basis of legal land descriptions in the State. This system of land subdivision appears on all the USGS 7.5′ topographic maps of Oklahoma (see question 12).

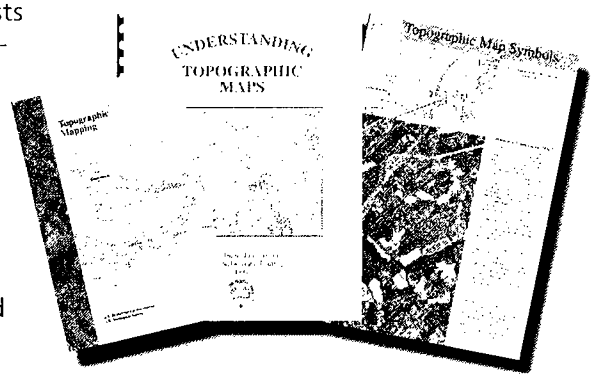

Figure 2 *(question 9)*. Three free or low-cost publications that describe how to interpret topographic maps.

10. I've been wondering about an Oklahoma place name. How do I find where the place is?

Write or call us with the name, and we'll look it up in the USGS Geographic Names Information System.

Many geographic and cultural features such as creeks, mountains, cemeteries, and towns throughout Oklahoma have formal names. In some cases, features in different counties have the same name; for example, there are five streams named Thompson Creek in Oklahoma.

You may call the OGS or consult the USGS website (Appendix 2), where a list of all officially named features is maintained. This website can be used to determine the feature's latitude and longitude, identify what topographic map shows the feature, and display on your computer monitor a map showing the feature.

11. Where is the nearest bench mark?

On a USGS topographic map of your area, look for points marked "B.M."

Several types of location markers are referred to as bench marks. The American Society of Civil Engineers defines a bench mark as "a relatively permanent material object, natural or artificial, bearing a marked point whose elevation above or below an adopted datum is known." On maps, bench marks generally are marked "B.M.," but some maps show permanent bench marks as P.B.M. and temporary bench marks as T.B.M.

12. How do I interpret the different grid systems on this topographic map?

Many topographic maps show three grid systems. Read on.

First: The section-township-range system (also called the Land Office Grid System) is the most common grid system on topographic maps, and also is used for most legal property descriptions of real estate. In Oklahoma, land is divided into squares about six miles on a side; the squares are called townships. (Because of the curvature of the Earth, the squares are not exact.) Except in the Panhandle, the townships lie north or south of an east-west baseline running through Davis, Sulphur, and Duncan about 0.5 mile north of latitude 34°30′N. North of the baseline the townships are labeled T. 1 N. (for the first row), T. 2 N. (the next row north), etc.; south of the baseline are townships T. 1 S., T. 2 S., etc.

Townships are also designated east and west of a north-south line called the principal meridian. In Oklahoma, this line is called the Indian Meridian. It is about 0.2 mile east of longitude 97°15′W and passes just west of Pauls Valley. Townships east of the meridian are labeled R. 1 E. (the first column), R. 2 E. (the second), etc., and to the west they are R. 1 W., R. 2 W., etc.

Thus, all the townships in most of Oklahoma can be located north or south and east or west of the intersection of the point where the baseline intersects the Indian Meridian. Example: T. 16 N., R. 21 E. (The Panhandle counties have a different baseline and principal meridian; thus, the townships are designated differently than the rest of Oklahoma.)

Each township is divided into 36 square miles called sections. (Again, the squares are inexact.) The sections are numbered beginning with Section 1 in the northeast corner of the township; Section 2 is immediately to the west. The numbering "snakes" through the township, with Section 6 in the northwest corner, 7 south of 6, etc. (Fig. 1).

Sections make up the most obvious grid system on the USGS topographic maps; other systems are less apparent.

Second: All topographic maps show latitude and longitude in degrees, minutes, and seconds; most USGS maps are bounded by degrees and minutes, and may be identified that way. For example, the 1:24,000-scale maps also are called "seven-and-a-half-minute maps" because they are 7.5 minutes on a side. The 1:100,000-scale maps also are called "one-degree maps" (even though they are 1° east-west by 30′ north-south).

Latitude and longitude are given at map corners; intermediate divisions are marked along the sides by small tick marks and inside the mapped area by small crosses.

Third: Another grid system is Universal Transverse Mercator, or UTM; it is becoming increasingly popular because hand-held Global Positioning System (or GPS) receivers are widely used, and most models display readings directly as UTM numbers. On some maps, the UTM system can be identified by numbers and grid ticks along the sides of the map; the ticks identify points that are 1 kilometer apart on the ground. On other maps, the UTM grid lines extend across the map.

The UTM system is based on distance in meters north (or south) of the equator and east of arbitrary lines of longitude at 6° intervals. Oklahoma lies in three UTM zones: zone 13 (which includes the western part of the Panhandle) is bounded on the west by longitude 108°W; zone 14 (most of Oklahoma) is bounded on the west by longitude 102°W; zone 15 (eastern Oklahoma) is bounded on the west by longitude 96°W.

As an example of locating a point using the UTM grid system, consider the tower on the State Fairgrounds in Oklahoma City: it lies between the 3926000 and 3927000 east-west grid lines (labeled on the left and right sides of the Oklahoma City 7.5′ quadrangle map) and 629000 and 630000 north-south grid lines (unlabeled along the top and bottom of the map). These numbers mean that the tower is between 3,926,000 and 3,927,000 meters north of the equator and between 629,000 and 630,000 meters east of the 102°W longitude line. Careful measurement between the UTM grid lines on the map could locate the tower more precisely.

13. What is magnetic declination?

From any point on the Earth's surface, it's the angle between a line pointing to the geographic North Pole and another line pointing to the magnetic pole.

The geographic North and South poles mark the Earth's axis of rotation and do not coincide with the magnetic north and south poles. At the present time, magnetic north is located at about 71° N latitude, 96° W longitude, just southeast of Prince of Wales Island, Nunavut, Canada. This is about 1,300 miles from geographic north.

A compass needle in the Northern Hemisphere points to magnetic north, whereas most maps are oriented with geographic north at the top. The angle between magnetic north and geographic north is the magnetic declination; the angle (in degrees) is shown by two diverging arrows near the bottom of a topographic map.

In northern Maine, magnetic north is about 23° west of geographic north; in Washington State, magnetic north is about 23° east of geographic north. A line of zero declination extends through eastern Georgia, eastern Tennessee, Kentucky, eastern Indiana, and Lake Michigan. Along this line, geographic north and magnetic north lie in the same direction.

Magnetic north is east of geographic north everywhere in Oklahoma. In the western Panhandle the declination is about 12° east, and in most of eastern Oklahoma it is about 8° east. However, the Earth's magnetic field is neither uniform nor constant; as a result, the magnetic declination in some parts of eastern Oklahoma is as little as 6.5° east.

General Questions

14. What do you have about water?

The OGS publishes many maps and technical reports concerning the quality, quantity, and location of ground water, and we stock other publications by the USGS.

Our most popular publications about water are sets of maps in the OGS Hydrologic Atlas series. Each set covers about one-ninth of the State at a scale of 1:250,000 (except the Panhandle, described below). A set consists of four maps showing (1) the geology, (2) the principal aquifers and water-well information, (3) the chemical quality of ground water, and (4) surface-water information.

Each hydrologic atlas of the counties in the Panhandle, published by the USGS and available from OGS Publication Sales (Appendix 1), consists of three maps each at a scale of 1:125,000. They show the geology, depth to ground water, chemical quality of the water, areas favorable for irrigation, thickness of unconsolidated deposits, and thickness of saturated zones.

We also have a set of two maps showing Oklahoma's ground-water resources, published in cooperation with the Oklahoma Department of Health. One map shows unconsolidated alluvium and terrace deposits; the other shows bedrock aquifers and recharge areas. Several technical reports by the OGS focus on the geohydrology of specific aquifers, quality of water in abandoned mines, and ground-water resources of specific counties.

Other important sources of information on water in Oklahoma are the Water Resources Division of the USGS (Appendix 2), the Oklahoma Water Resources Board (Appendix 1), and the Oklahoma Department of Environmental Quality (Appendix 1).

15. Do you have any publications for my child?

We have many publications for the public, including older children, but none specifically for children of elementary-school age. Most of these are nontechnical Guidebooks, Educational Publications, Geocalendars, and Information Series booklets (see back cover).

Full-color educational posters that appeal to children include OGS Educational Publication 6 ("Oklahoma Generalized Geologic Time Scale") and OGS Geocalendars. Our Information Series includes "Gee*(whiz)*ology of Oklahoma," "Mountains, Streams, and Lakes of Oklahoma," "Geology and Mineral Resources of Oklahoma," and "Oklahoma and the Petroleum Industry." We also have handouts on fossil collecting, earthquakes, and rose rocks.

The OGS maintains a teaching collection of rocks, minerals, and fossils of Oklahoma. Teachers, home-school parents, Scout leaders, and others are encouraged to visit our collection and take specimens that will help them teach children about geology and the earth sciences. For more information about the collection, contact the OGS Core and Sample Library (Appendix 1).

16. Do you have any field-trip guidebooks for the area near where I live?

Guidebooks are available for interesting areas such as State parks and Oklahoma's mountain areas. See our free catalog, "List of Available Publications," for areas near you.

Descriptions of geologic field trips (Fig. 3) are available in our Guidebook series, as well as in Special Publications, Open-File Reports, etc. Several guidebooks describe trips in the Ozark, Ouachita, Arbuckle, and Wichita Mountains; most of these are technical. Guidebooks also are available for State parks, including Roman Nose, Beavers Bend, Alabaster Cavern, Robbers Cave, Wister, Red Rock Canyon, Lake Murray, and Black Mesa. Our Educational Publication series includes guides to northwestern and north-central Oklahoma. Other areas, such as the Gypsum Hills near Woodward and the Tallgrass Prairie Preserve near Pawhuska, also are covered by guidebooks. Our free "List of Available Publications" lists all the guidebooks that are currently available.

Other organizations have published geologic guides to different parts of Oklahoma. The most complete list of field-trip guides is the "Union List of Geologic Field Trip Guidebooks of North America," compiled by the Geoscience Information Society (GIS) (Appendix 3) and published by the American Geological Institute. The "Union List" is available at most college and university libraries and at the GIS website. Most of the guidebooks can be found at the Laurence S. Youngblood Energy Library, University of Oklahoma (Appendix 5); they may be borrowed through interlibrary loan.

Additional sources of information about geologic field trips are local geologists, earth-science teachers, and rock and mineral clubs (Appendix 4). Some active rock quarries allow visitors, particularly school groups. (See OGS Educational Publication 5 for a slightly dated list of quarries.)

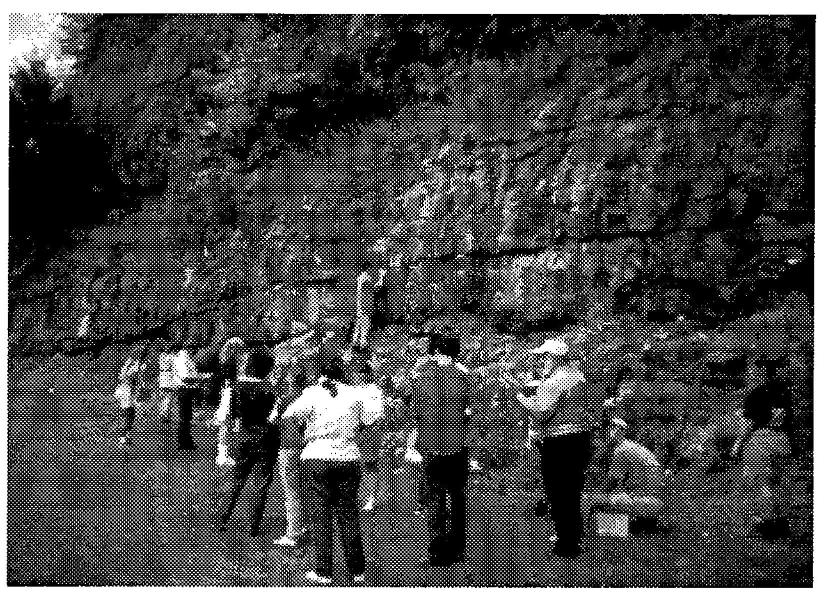

Figure 3 *(question 16)*. Members of the Oklahoma Academy of Science examining outcrop of Mississippian Pitkin Formation overlain by Pennsylvanian Sausbee Formation on the west side of Fort Gibson Dam.

Fossils

17. Do you have any literature on fossils, dinosaurs, and collecting sites in Oklahoma?

A handout, "Information Regarding Mineral/Rock/Fossil Collecting in Oklahoma," by OGS geologist James R. Chaplin, lists publications (technical and nontechnical) on Oklahoma fossils and describes some places where fossils can be found. Several recent field-trip guidebooks, suitable for nongeologists, contain brief summaries of some Oklahoma fossils.

Most of the literature on Oklahoma fossils and dinosaurs available from the OGS is technical. Different aspects of Oklahoma paleontology are being studied by geologists at the University of Oklahoma, Oklahoma State University, the University of Tulsa, and the Sam Noble Oklahoma Museum of Natural History (Appendix 5). This work is published by the OGS and in professional journals. The Museum has several vertebrate paleontologists who can answer many questions about Oklahoma dinosaurs.

Fossils (e.g., Fig. 4) may be collected at many places in Oklahoma in addition to those listed by Chaplin. Many road cuts in far southeastern Oklahoma expose fossiliferous Cretaceous limestone (Appendix 6). Plant fossils, including leaf and stem impressions, are common in Pennsylvanian rocks of eastern Oklahoma (except in the Ouachita Mountains). Marine invertebrate fossils occur in some of the limestone formations in the Ozarks and in Pennsylvanian formations in north-central Oklahoma. In the Arbuckle Mountains, many outcrops and road cuts contain fossils ranging in age from Ordovician to Pennsylvanian. A popular locality for collecting a wide variety of well-preserved fossils is White Mound, near Dougherty (Appendix 5); a fee is charged for collecting there.

Dinosaur bones have been found in southeastern Oklahoma and the Panhandle; however, collecting vertebrate (which include dinosaur) fossils is prohibited on public land (see question 19).

Rock, mineral, and fossil clubs (Appendix 4) are excellent sources of information about collecting sites in Oklahoma. They often go on collecting trips and welcome new members and visitors.

Fossil collecting is a popular pastime for many Oklahomans. *Keep in mind:* (1) don't trespass on private land, (2) use common sense and obey traffic regulations if stopping at a road cut, and (3) collecting vertebrate fossils on public land is illegal.

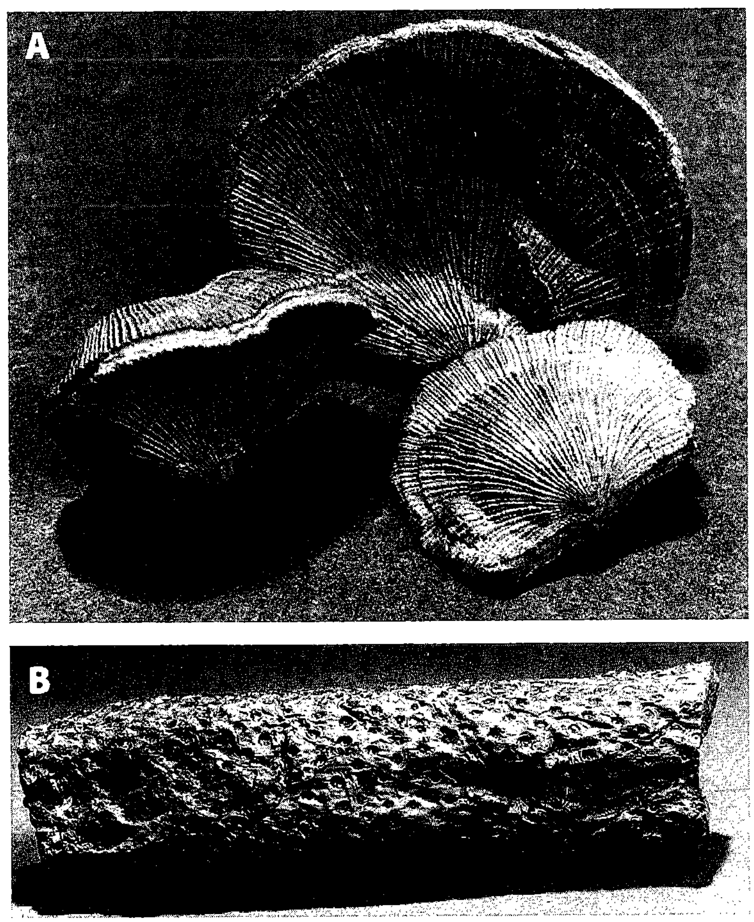

Figure 4 *(question 17)*. Photographs of common Oklahoma animal (A) and plant (B) fossils. (A) Brachiopod *Derbyia crassa*. Brachiopods are a bivalve (two shells) in which each shell is symmetrical. *D. crassa* is found in some Pennsylvanian-aged limestones and shales in Oklahoma. Scale: large brachiopod in rear is 2 inches across. (B) Cast of *Stigmaria*, the underground or rootlike part of lycopods. Lycopods comprise about 20% of the fossil plants found in Pennsylvanian-aged sedimentary rocks. Most were large trees with narrow grass-like leaves. They were among the largest plants in the Pennsylvanian swamps, some being over 100 feet tall with trunks 3 to 4 feet in diameter. (Photographs by Robert Taylor, OU Electronic Media and Photographic Services.)

18. Where can I get permission to collect fossils on public land?

In Oklahoma, public land includes city, county, State, and federal property. You must first determine what agency manages the land that interests you. A city or county clerk usually knows who owns what land in their area of jurisdiction.

No current laws govern fossil collecting on city or county land, including road cuts. However, common sense dictates obeying traffic laws, parking as far off the road as possible, and avoiding stopping along interstate highways (where only emergency parking is allowed). Collecting on most State land (such as State parks and wildlife conservation areas) is prohibited, although some agencies will issue special permits. (In Oklahoma, the Tourism and Recreation Department and the Department of Wildlife Conservation [Appendix 1] have significant land-management responsibilities.)

Most collecting (excluding that on private land and along road cuts) is done on federally managed land, where specific regulations apply. Collecting vertebrate fossils such as dinosaur bones is prohibited. You may collect petrified wood only if it is for personal use—you must not sell it—and you are limited to 25 pounds plus one piece per day with a yearly maximum of 250 pounds. Collecting fossils of plants and invertebrate animals for noncommercial use is permitted but generally requires written permission, which can take a long time to secure.

School groups, Scout groups, and rock and mineral clubs often collect fossils on public land without formal permission. Most public-land managers recognize this as a valid educational or recreational activity and allow it. However, collecting fossils on public land is a privilege and not a right. Abuse of that privilege (such as driving off the road, leaving gates open, surface disruption such as digging, and collecting vertebrate fossils) will often cause land managers to enforce the regulations.

19. Where can I find fossilized dinosaur bones in Oklahoma?

Dinosaur bones have been found in southeastern Oklahoma and in Cimarron County in the Panhandle. Outcrop areas of the Antlers Formation (Cretaceous) and Morrison Formation (Jurassic) have proven productive in the past and can be located using geologic maps.

Dinosaurs probably once roamed throughout the area we now call Oklahoma, but most of the evidence for this has been removed through erosion. Rocks deposited during Mesozoic time (the "Age of Dinosaurs") are exposed in southeastern Oklahoma and in northwestern Cimarron County, and dinosaur bones have been found in both areas. From 1935 to 1942, J. Willis Stovall, professor of geology at the University of Oklahoma and director of the University Museum (later the Stovall Museum of Science and History, now the Sam Noble Oklahoma Museum of Natural History), excavated 17 sites in Cimarron County and recovered about 6,000 bones. Recent studies of his collection by paleontologists at the Museum have resulted in the discovery of new species of dinosaurs, including *Saurophaganax maximus*, the State Fossil (see question 21). All the bones collected by Stovall were from the Morrison Formation (Jurassic in age), which is perhaps the most well-known dinosaur-bone-bearing formation in the western U.S.

Dinosaur bones also have been found in the Antlers Formation (Cretaceous) in southeastern Oklahoma. The most complete skeleton of *Acrocanthosaurus atokensis* (named after Atoka County) was found near Eagletown and later sold to the North Carolina State Museum of Natural Sciences for about $3 million. Bones of the raptor dinosaur *Deinonychus* were recently discovered in Atoka County with bones of its presumed prey, the ornithopod dinosaur *Tenontosaurus*.

Collecting vertebrate fossils is prohibited on public land. You may collect vertebrates on private land with permission of the landowner. The best places to look for dinosaur bones are in areas where the Morrison and Antlers Formations crop out. Geologic maps available from the OGS (Appendix 1) show where these formations occur at the surface.

20. Is this dinosaur dung?

Possibly, but coprolites (the geological term for fossilized excrement of vertebrates, including dinosaur dung) are extremely rare. Most likely it's a concretion.

The "Glossary of Geology" (Jackson, 1997) defines coprolite as "the fossilized excrement of vertebrates such as fishes, reptiles, and mammals, . . . measuring up to 20 cm in length, characterized by an ovoid to elongate form, a surface marked by annular convolutions, and a brown or black color; commonly composed largely of calcium phosphate; petrified excrement." (Fig. 5.)

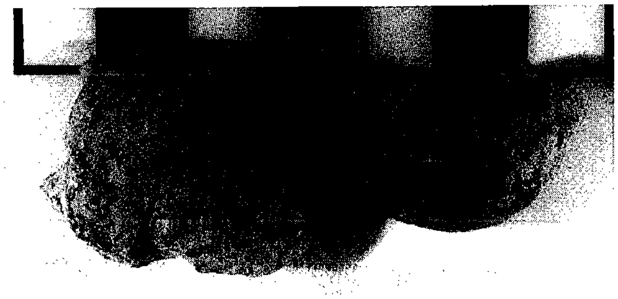

Figure 5 *(question 20).* Photograph of probable reptile coprolites from the Morrison Formation (Jurassic), Cimarron County, Oklahoma. Scale bar = 1 centimeter. Specimen no. OMNH01032, Sam Noble Oklahoma Museum of Natural History. (Photograph by T. Wayne Furr, Oklahoma Geological Survey.)

In many cases, natural concretions resemble coprolites. Concretions are unusually well-cemented masses of rock that may be spherical or disk-shaped or extremely irregular. Some can be as large as nine feet in diameter. They commonly form in sedimentary rock shortly after the sediment is deposited or as the sediment is lithified. Concretions have been mistakenly identified as coprolites and as fossils or meteorites.

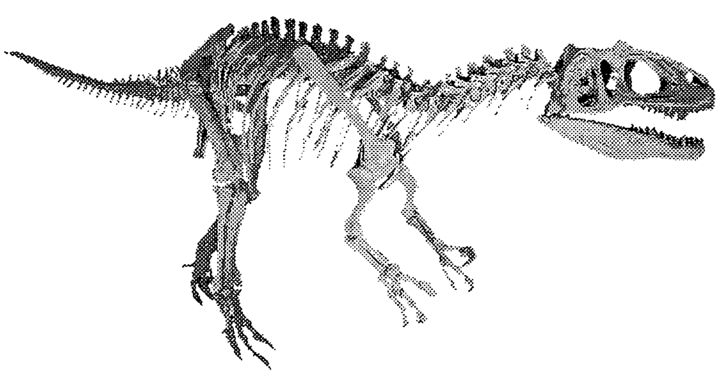

Figure 6 *(question 21).* Reconstructed skeleton of *Saurophaganax maximus*, the State Fossil of Oklahoma. The skull is 48 inches long. *Saurophaganax* is on display at the Sam Noble Oklahoma Museum of Natural History. (Image by Patrick Fisher, Sam Noble Oklahoma Museum of Natural History.)

21. What is the State Fossil of Oklahoma?

Saurophaganax maximus, a Jurassic-aged carnivorous dinosaur.

The State Fossil of Oklahoma is *Saurophaganax maximus* (Fig. 6). The only known skeletal remains of this carnivorous dinosaur were found about 70 years ago in the Morrison Formation (Jurassic) in Cimarron County. The living animal was about 40 feet long, weighed about two tons, and likely was as ferocious as *Tyrannosaurous rex*. The Sam Noble Oklahoma Museum of Natural History's website (Appendix 5) has a more complete description of the dinosaur.

Cub Scouts of Den 3, Pack 349, Edmond, are credited with suggesting that the State Legislature designate a State Fossil. Governor Frank Keating signed the enabling legislation on April 17, 2000.

22. Where can I buy fossils?

The Internet and rock-hound publications carry advertisements for fossil dealers; rock and mineral clubs may know about local shows and swap meets.

Largely because of the movie "Jurassic Park," dinosaur bones—and fossils, in general—have become extremely popular to collect, study, and own. Thousands of businesses sell fossils; they range from small rock shops to large companies that supply schools and museums across the country. The Internet is the best place to see the range of fossils available for sale; search under "fossils" or "fossils for sale."

Many popular rock-hound publications carry advertisements by fossil dealers, and they list shows and meetings where dealers exhibit and sell fossils. Two such publications are "Rock and Gem" and "Rocks and Minerals" (Appendix 5); they are available at many public libraries and bookstores.

Additional sources of information about fossil dealers are local rock and mineral clubs (Appendix 4). Many club members sell and trade fossils from their homes and at shows and at swap meets. The clubs also know about local shows where individuals can buy specimens. The OGS also lists nearby shows and swap meets on its website (Appendix 1).

Rocks and Minerals

23. What kind of rock or mineral is this?

Most libraries have books that can help you identify rocks and minerals. Professional geologists and experienced amateurs such as rock hounds may also be able to help you.

There are thousands of different rocks and minerals and probably several hundred common ones. Most public libraries have books on rocks and minerals. The first step in identifying a specimen is to closely examine it (including under a magnifying glass) and compare it to the descriptions and pictures in a book. You may need to look at a fresh surface—one not changed by weathering—which may require breaking the specimen.

A second alternative for identifying a rock or mineral is to have a trained nonprofessional (e.g., a rock hound) or professional geologist examine the specimen. Many of these individuals have seen a wide variety of rocks and minerals and might be able to identify it. They also may have knowledge of special tests that can be done on the specimen and/or have special testing equipment. Where the specimen was found may be helpful in identifying it. OGS geologists are willing to examine, and can usually identify, hand samples of specimens brought or mailed to them.

A third method, generally somewhat costly, is to cut one or more thin sections (30-micron-thick transparent slices of the specimen) and examine them under a petrographic microscope. Rocks and minerals also can be identified using a variety of techniques such as wet-chemical analyses, X-ray diffractometry, and scanning electron microscopy.

Precious metals may be detected by assaying the sample, but Oklahoma has no assay labs. To locate out-of-state assayers, use the Internet yellow pages. Most large western cities (e.g., Denver, Tucson, Salt Lake City) list several companies under the business category "assayers." Assay methods generally are definitive but require extensive sample preparation, sophisticated equipment, and trained personnel.

24. Why are there so many red rocks in Oklahoma?

Many rocks contain iron oxide minerals—"rust"—because ancient climates favored their formation.

Most of the red rocks in Oklahoma are Permian in age (290 to 245 million years ago). Permian rocks cover most of the western part of the State, except for the Wichita Mountains and western Panhandle. Most of the red color is caused by the mineral hematite (Fe_2O_3), an iron oxide. The hematite occurs as a thin coating on the individual mineral grains that make up the rocks, and in some cases it also forms a weak cement binding individual grains together. Only 2–3% of the rock is iron oxide, but that is enough to stain it red. Much of the hematite probably was deposited as part of the sediment that makes up the rock, but some may have formed after sediment deposition as an alteration product of other iron minerals.

During Permian time in Oklahoma, the climate was monsoonal; the alternating periods of wet and dry promoted the oxidation of iron in soil and sediments. In addition, most of the red Permian sediments were deposited in rivers, streams, floodplains, and nearshore marine environments, all of which would have been subjected to periodic drying resulting in the formation of hematite.

25. Where can I find barite roses, the State Rock of Oklahoma?

Most occur between Guthrie and Pauls Valley. Noble calls itself the Rose Rock capitol of the world.

On April 8, 1968, the barite rose (also known as rose rock) became the official State Rock of Oklahoma. It is probably more common in Oklahoma than anywhere else in the world. The rock's petal-shaped clusters are caused by the intergrowth of divergent blades of barite (barium sulfate—$BaSO_4$) crystals.

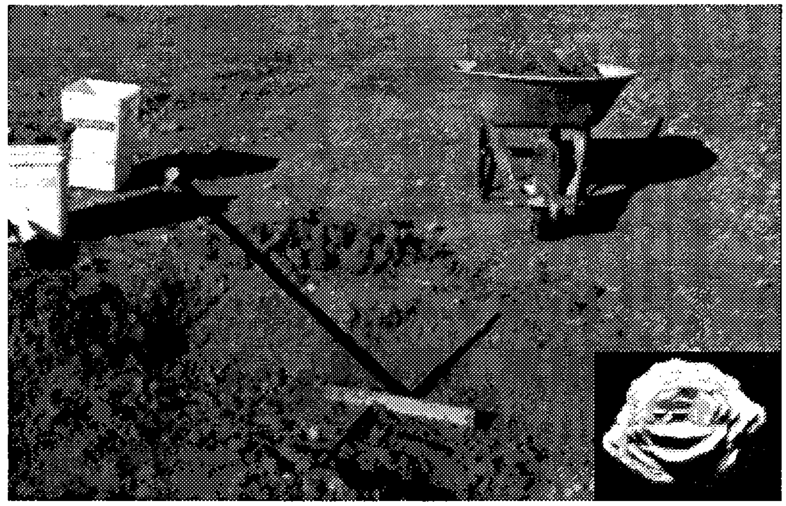

Figure 7 *(question 25)*. Barite roses—the State Rock—at a collection site near Noble, in Cleveland County. Most barite roses occur near the surface and collecting them typically involves a geologic hammer, pick, shovel, rake, and wheelbarrow. Large and especially fine specimens require removal with a pry bar. Inset photograph of an individual barite rose. (Outcrop photograph by Dave London, School of Geology and Geophysics, University of Oklahoma; inset photograph by Kenneth S. Johnson, Oklahoma Geological Survey.)

Barite roses are present in the Permian-age (Appendix 6) Garber Formation in a narrow belt that extends 80 miles approximately north-south through central Oklahoma. The most abundant and well-formed specimens (Fig. 7) are found just east of Norman and Noble. You can find small barite roses weathering out of the red sandy soil that forms on the Garber Formation along many county roads. Some landowners allow collecting on their land for a small fee; check with the Chamber of Commerce or the Timberlake Rose Rock Gallery and Museum in Noble (Appendix 5) for information about possible collecting sites. Local rock and mineral clubs (Appendix 4) also know where you can collect barite roses.

26. Is this a meteorite?

Possibly, especially if it's magnetic, looks metallic on a fresh surface, and has a crust that looks as though it melted.

Meteorites are broadly classified into three groups—stony, stony-iron, and iron. About 80% of meteorite finds are stony and about 20% are stony-iron and iron. There are several properties of meteorites that, when used in combination, enable geologists to distinguish them from terrestrial rocks and minerals:

(Information from the Institute of Meteoritics, Dept. of Earth and Planetary Sciences, University of New Mexico; see Appendix 5.)

1. Iron metal (actually an iron-nickel alloy) is visible on a broken surface. Irons are all metal; stony-irons are about half metal; and stonies contain only small flecks of metal.

2. Many meteorites, particularly the irons, are much denser (heavier) than most terrestrial rocks.

3. Most meteorites are magnetic. The stonies are less so than the stony-irons; and the stony-irons less so than the irons.

4. About 90% of the stony meteorites are called chondrites. (The others are achondrites.) They contain chondrules, small balls of stony material about 1 mm in diameter.

5. Many meteorites have a thin fusion crust, which forms as the meteorite's surface melts during its fall to Earth. If fresh, this crust resembles a black eggshell; terrestrial weathering turns the crust brown.

6. Some meteorites develop thumbprint-like depressions, called regmaglypts, as they fall through the Earth's atmosphere.

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Meteorites commonly are confused with natural and man-made objects such as iron grinding balls, slag from smelters, iron fragments, the minerals magnetite and hematite, and volcanic rocks such as basalt. Most meteorites in Oklahoma have been found in the open prairies and grasslands of the western part of the State, commonly during plowing or harvesting. Meteorites probably are equally common in eastern Oklahoma, but there they are more likely to be hidden by thick vegetation.

Oklahoma's largest known meteorite is the Lake Murray meteorite (Fig. 8), which was found in 1931 near the lake in Carter County. When it was discovered, it was embedded in sandstone of the Antlers Formation; therefore, geologists believe it fell to Earth in Cretaceous time (Appendix 6). It is about 23 inches long and 16 inches in diameter; its original weight is estimated at 3,040 pounds. Half the core of the meteorite is on display at the Tucker Tower Museum in Lake Murray State Park.

On November 25, 1943, a fireball (a bright or brilliant meteor) broke up over Butler in Custer County and separated into multiple fireballs. The next day, residents near Leedey collected 24 meteorites weighing a total of 114 pounds from a strewn field 11 miles long and 2 miles wide.

On January 3, 1970, a meteorite fell near Lost City in Osage County, and four pieces were recovered weighing a total of about 37 pounds. The impact site is the first to have been located by the use of automatic camera stations that photographed and tracked the meteorite's path and impact site. (Information from Kenneth S. Johnson, 2000, written communication.)

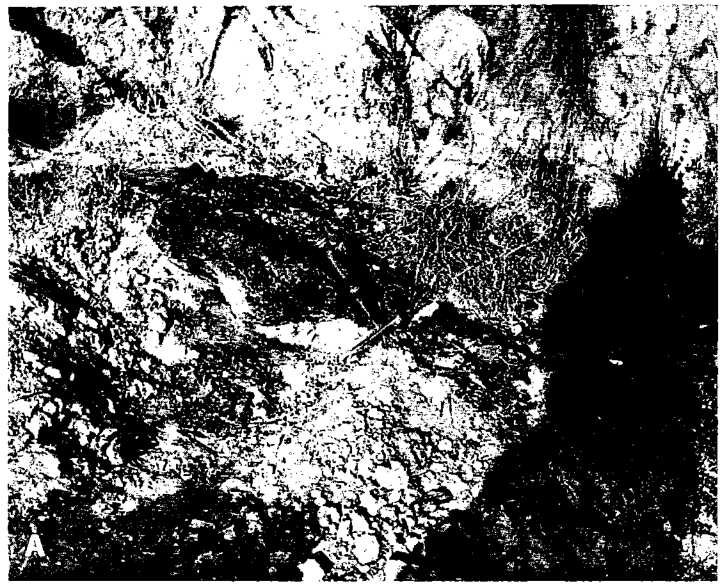
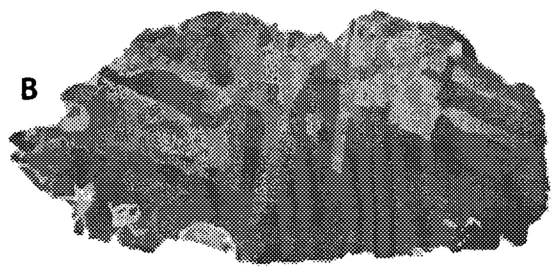


Figure 8 *(question 26)*. (A) The Lake Murray meteorite embedded in the Cretaceous Antlers Sandstone. (B) Photograph of slabbed Lake Murray meteorite. The polished interior of the Lake Murray meteorite shows a Widmanstätten pattern, which consists of an octahedral crystal arrangement of kamacite and taenite, two iron-nickel alloy minerals. The unusual crystal structure is the result of very slow crystallization under conditions of zero gravity. (Photograph A from Graffham, 1964, p. 215; photograph B by O. Richard Norton, Science Graphics, Bend, Oregon.)

B



Resources: Oil and Gas, Coal

27. Do I have oil or gas on my property?

You probably do have oil or gas beneath your property, but most likely not enough to justify the cost of drilling and completing a well.

In Oklahoma, there is a good chance that your property is underlain by oil and/or gas, because only a few counties have no known hydrocarbon resources. The real question is, "Can my oil and gas be produced economically?" Another question is whether you really own the mineral rights to your land; this is best answered by an attorney.

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Because most of Oklahoma is well explored, the first step in determining whether petroleum is present *in paying amounts* is to find out whether nearby wells, if any, are productive. Active wells can generally be identified by pumpjacks (oil wells) and "Christmas trees" (gas). Published maps such as OGS map GM-28, "Map of Oklahoma Oil and Gas Fields with Field Supplements," shows the location of hydrocarbon-producing areas (see question 7).

Another source of information is the Natural Resources Information System (NRIS), a database that contains information from all well-completion reports (Form 1002A) that have been filed with the Oklahoma Corporation Commission. For a small charge you may access the NRIS database at the OGS Computer Facility (Appendix 1).

Some commercial firms have maps showing the locations of oil and gas wells in Oklahoma. Geo Information Systems, Herndon Map Service, IHS Energy Group, and PennWell Corp. (Appendix 5) are among the more widely known.

Another way to learn about producing oil and gas wells in Oklahoma is to examine scout tickets; these are 4- x 6-inch index cards containing much of the same information as in the NRIS database. Scout tickets for all of Oklahoma may be examined at the Laurence S. Youngblood Energy Library (Appendix 5) on the University of Oklahoma campus (there is no fee). They may also be examined at the Oklahoma City Geological Society Library in Oklahoma City and at the Oklahoma Well Log Library in Tulsa (Appendix 3).

Even if producing wells are, or once were, nearby, the only way to determine whether oil or gas is present on your property is to drill. And before a company will commit to drilling a well, many exploration, land, geological, and engineering issues must be addressed.

Of course, it is always possible that oil or gas will be found where none was previously known. But these kinds of discoveries are made only after extensive and expensive exploration (see question 35).

28. I think I may have some valuable minerals/oil/gas on my land. How can I evaluate the mineral potential of my land?

Mineral evaluation requires an expert—most likely, a geologist. Ultimately, however, a well or core hole must be drilled.

Evaluating the mineral or petroleum potential of a property must be done by a trained geologist. Even then, the evaluation is an interpretation based on *available* data. Ultimately, the mineral potential of a property must be tested with a well or, in the case of minerals or coal, with one or more core holes.

Mineral evaluations can be done by an independent consulting geologist. Names of consulting geologists are listed in the yellow pages of the telephone directory under "Geologists." The Ardmore, Oklahoma City, and Tulsa Geological Societies (Appendix 3) are professional organizations that have the resumes, special qualifications, and areas of geographic expertise of consulting geologists.

29. A company wants to lease the mineral rights to my land. How much should I lease it for?

Lease rates are based on several factors, including past production, current activity, and trade secrets.

The value of mineral rights for petroleum is related to nearby drilling and/or production, or the exploration potential of an area. For example, if there are no

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productive wells near your land or no wells are currently being drilled, your mineral rights may not be worth much, perhaps a few dollars per acre. However, if the company you're dealing with has been exploring in the area and believes petroleum is present, it may be worth much more. Of course, the oil company will attempt to keep their ideas secret and lease as much land for as low a price as possible. In areas close to active drilling or significant production, the value of a lease may be worth $200–$400 per acre or more.

Getting a fair price for a lease may involve talking with neighbors—how much are they asking or getting? If much land is involved, development drilling is active, or the exploration potential is high, you may want to hire a petroleum landman. A list of them is in the yellow pages of the telephone directory under "Oil Land Leases." Information about individual petroleum landmen may be obtained from the Oklahoma City or Tulsa Association of Petroleum Landmen (Appendix 3).

30. Who owns the mineral rights to my property?

Records of surface and mineral ownership rights are maintained at county courthouses and are open to the public. You can examine these records by contacting the county clerk. Complex mineral rights should be determined by a petroleum landman.

Professional petroleum landmen are experienced in determining mineral and surface rights. If your property is large or has a complex history of ownerships, there may be a long and complicated "paper trail" associated with the land. In this case, you may want to hire a petroleum landman (see question 29).

31. What are the names of the formations that produce oil/gas near where I live?

Many geological formations in Oklahoma produce oil and gas. Most have names; in some cases, several. Stratigraphic charts and completion reports show productive formations.

There are hundreds, if not thousands, of formations in Oklahoma that produce oil and/or gas. In some parts of Oklahoma, only one formation is productive; in other parts, many formations produce oil or gas. Stratigraphic nomenclature in Oklahoma is complicated for several reasons. (1) In some cases, several names have been used for the same formation; in other cases, the same name has been applied to different formations. (2) Some companies apply their own terminology to the formations they encounter in their wells, ignoring generally accepted names. (3) A formation exposed on the surface may have a name that is entirely different from the name for the same formation in the subsurface. (4) A formation name once in general use may become obsolete and be abandoned. (5) Geologists may disagree about how to define a formation and what to call it.

The best initial reference for determining the name of a producing formation is a stratigraphic chart showing the subsurface formation names for different parts of Oklahoma. You can obtain these from the OGS (Appendix 1) or from the Ardmore, Oklahoma City, or Tulsa Geological Societies (Appendix 3). The Natural Resources Information System (NRIS) database and scout tickets (see question 27) also list productive formations, but the formation names listed are those reported by the oil companies, which may be inaccurate, misleading, or obsolete.

32. I've seen some drilling rigs operating near my land. What company is doing the drilling and why?

Industry newsletters report current drilling activity in Oklahoma.

Active drilling is reported in industry newsletters such as PI/Dwights Plus Drilling Wire, which is published daily, weekly, and monthly by IHS Energy Group (Appendix 5). Drilling Wire lists all petroleum wells that have been formally located (i.e., proposed), are currently drilling, or are awaiting completion. The drilling reports locate wells by county and by the section, township, and range system. The reports typically include company, well name, exact location, spud date, expected productive zone and depth, planned depth of well, and kind of well (exploration, development, water injection, etc.). After the well has been drilled, logged, and completed, the report may include information such as total depth, log tops, and initial production.

PI/Dwights Plus Drilling Wire may be found at some public and university libraries. The Oklahoma Marginal Wells Commission (Appendix 1) has current and back issues available for examination at its office.

33. Can you tell me the production potential of a particular zone in this well log?

Possibly. Well-log interpretation is a highly specialized field and typically requires experience in the geographic area of the well.

Well-log interpretation, also known as formation evaluation, is extremely important in the petroleum industry. Poor interpretations can result in the abandonment of potentially successful wells or the expensive completion of a well with little potential for commercial production.

Good well-log interpretation requires extensive training and years of experience, but in many cases the techniques or "tricks" used to evaluate wells in one area or of one formation cannot be used in another area or with a different formation. One technique used by formation-evaluation specialists is to compare the logs of a new well with those of nearby wells that have known production histories. Resistivity and porosity logs are essential for proper interpretation, and many other special logs are helpful (Fig. 9). Computers with highly sophisticated software are increasingly being used.

All major petroleum companies have formation-evaluation specialists on their staffs. Smaller companies and individuals may hire consulting geologists (see question 28) as needed. In some cases, petroleum geologists at the OGS will interpret well logs and estimate the qualitative production potential of a particular zone in a well.

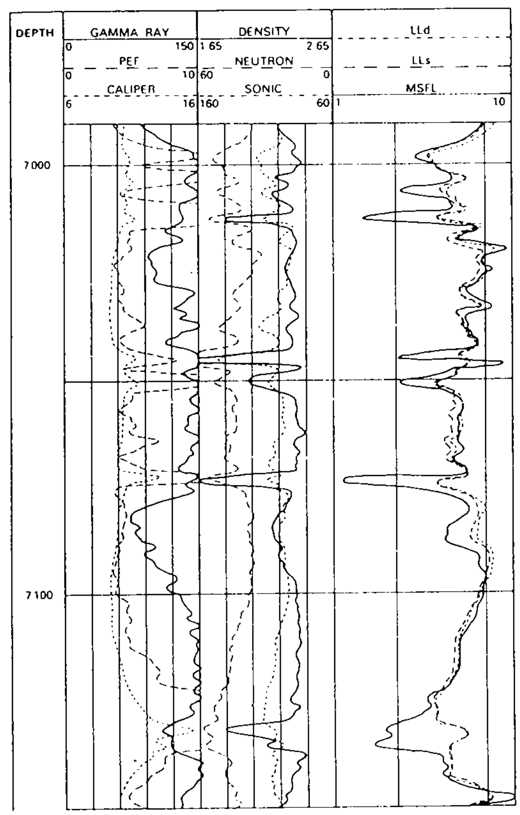

Figure 9 *(question 33)*. Example of a modern petroleum well log. (Modified from Serra, 1985.)

34. How much oil or gas has this particular well produced?

In Oklahoma, production is reported by lease, and a single lease may have many wells. Therefore, figures for an individual well may not be available, but they can be estimated.

Oil and gas producers report petroleum production to the Oklahoma Tax Commission (Appendix 1) by lease, and a lease may have one well or many. Production on single-well

(continued on next page)

leases is straightforward. For multiple-well leases, a formation-evaluation specialist may be able to estimate production from individual wells, but most likely that assignment is just an educated estimate.

Oil and gas production figures may be obtained from the Oklahoma Tax Commission (Appendix 1), Geo Information Systems (Appendix 5), IHS Energy Group (Appendix 5), and some consulting geologists (see question 28). Another source is the Natural Resources Information System (NRIS) database, which can be accessed at the OGS Computer Facility (Appendix 1). The NRIS database includes monthly lease and field production from 1979 to the present, using figures reported to the Oklahoma Tax Commission.

35. Has anyone ever explored for oil and gas in my area? What is the possibility of future production here?

Drilled wells and seismic lines are evidence for exploration. The potential for future production is dependent on technical evaluation and the price of petroleum.

The best way to determine whether there has been any exploration in your area is to determine whether any wells have been drilled. A number of organizations have maps showing the locations of all the oil and gas wells in Oklahoma; they are described in question 27. In some cases, seismic exploration may have been done in an area but was not followed up with a well. Numerous private brokers of seismic data have maps showing where seismic lines have been run. (The seismic data are extremely expensive, but maps of the lines are not.) However, no broker knows the locations of all the seismic lines, and those run for major oil and gas companies are proprietary and neither the data nor the locations of the lines are available.

The potential for future production can be determined only by trained geologists and geophysicists. After examining enormous amounts of data, they may recommend drilling a well to test the area. Whether the well can produce oil or gas in economic amounts depends on a number of factors, not the least of which is the market price of the oil or gas. More land in Oklahoma becomes prospective if the price of oil and gas is high rather than low.

36. How much oil and gas is left in Oklahoma?

The State has about 599 million barrels of proved crude oil reserves, 59 million barrels of indicated additional crude oil reserves, 13,645 billion cubic feet of proved dry natural gas reserves, and 698 million barrels of proved natural gas liquids reserves. (A barrel is 42 U.S. gallons.) (Figures from "U.S. Crude Oil, Natural Gas, and Natural Gas Liquids Reserves, 1998 Annual Report," by the U.S. Department of Energy.)

Proved reserves of crude oil are the "estimated quantities . . . of crude oil which geological and engineering data demonstrate with reasonable certainty to be recoverable in future years from known reservoirs under existing economic and operating conditions." Proved reserves of natural gas are the "estimated quantities which analysis of geological and engineering data demonstrate with reasonable certainty to be recoverable in future years from known reservoirs under existing economic and operating conditions." Proved reserves of natural gas liquids are "those volumes of natural gas liquids (including condensate) demonstrated with reasonable certainty to be separable in the future from proved natural gas reserves, under existing economic and operating conditions." Indicated additional reserves of crude oil are "quantities of crude oil (other than proved reserves) which may become economically recoverable from existing productive reservoirs through the application of improved recovery techniques using current technology." (Definitions from U.S. Department of Energy report cited above.)

As the definitions suggest, the amount of crude oil and natural gas reserves in Oklahoma depends on economic conditions, specifically, the price of oil and gas. There are far more oil reserves in Oklahoma if the price is $50 per barrel than if it's $20 per barrel.

37. How much oil and gas have been produced in Oklahoma?

Since 1891, Oklahoma has produced about 14 billion barrels of oil and 83 trillion cubic feet of natural gas (Fig. 10).

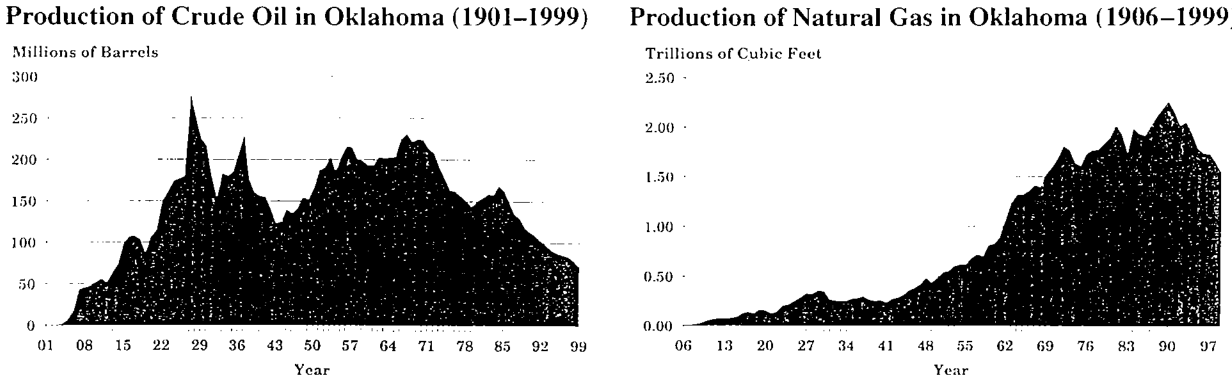

Figure 10 *(question 37)*. Graphs showing production of oil and gas in Oklahoma throughout the 1900s. (Graphs by Charles J. Mankin, Oklahoma Geological Survey.)

38. If oil companies spent more on exploration, couldn't Oklahoma supply all the oil needed in the U.S.?

No. U.S. demand far exceeds Oklahoma's supply.

This year, U.S. demand for petroleum is about 20 million barrels per day. Oklahoma's reserves (see question 36) total about 1,356 million barrels. Thus, if we could magically produce all our petroleum reserves today, we could supply the U.S. for about two months.

Most of the petroleum, particularly crude oil, in Oklahoma that can be easily produced has been produced. Most of the remaining undiscovered reservoirs will be relatively small and their development unprofitable for large multinational companies that have high overhead exploration and production costs. Small companies that have expertise and experience in local petroleum geology, however, may be able to successfully develop some of Oklahoma's undiscovered or partly drained oil fields, even without large exploration budgets.

Most future increases in Oklahoma's petroleum reserves will not come from the discovery of new fields; rather, increased production will result from applying new methods for recovering oil (and gas, to a lesser extent) that has been "left behind" in known reservoirs.

39. Why is seismic exploration rare in northeastern Oklahoma?

Seismic exploration is expensive; and the reservoirs in northeastern Oklahoma are shallow and production potential small.

No petroleum is being produced in Cherokee, Delaware, and Adair Counties, and very little in Craig, Mayes, and Ottawa Counties (from Oklahoma Corporation Commission report titled "1999 Report on Oil and Natural Gas Activity within the State of Oklahoma," by Larry Claxton). The primary reason for this is that any potential petroleum reservoirs in northeastern Oklahoma are near the surface and any oil or gas that once may have been present probably has leaked out. Therefore, the likelihood of discovering any oil or gas in this part of the State is very low.

Numerous small oil and gas fields are present west and southwest of these counties; most of the reservoirs in these fields are shallow and have been producing for many years. New wells typically are drilled near existing wells and are designed to more efficiently produce from an already partly drained reservoir. The best northeastern Oklahoma wells typically begin producing at a few tens of barrels per day and quickly decline to one to five barrels per day. Such low volumes do not justify expensive seismic exploration.

40. What causes tools, pump rods, etc. to stick in my well, and often in two or three nearby wells at about the same time?

Slow movement along undetected faults can damage a wellbore.

Oilfield equipment can fail for a number of reasons. In some cases, rods in several close wells can fortuitously stick at the same time for different (or the same) reasons. However, there may be a geological explanation—"slow earthquakes." These are movements along faults that are too slow to produce seismic waves. Neither the faults nor motion can be detected by seismographs, hence, faults are unknown until they damage tools or well casing.

41. What kind of coal, and how much, does Oklahoma have?

About 8.1 billion short tons (1 short ton equals 2,000 pounds) of bituminous coal resources remain in about 8,000 square miles in 20 counties in eastern Oklahoma. About 1.6 billion short tons of bituminous coal reserves (the economically recoverable part of coal resources) remain in Oklahoma.

Bituminous coal is intermediate in rank between subbituminous coal and anthracite (Fig. 11). During "coalification," peat (unconsolidated plant remains) changes into lignite. As compaction and loss of water continues, lignite changes progressively into subbituminous coal, then bituminous coal, and finally anthracite. The most abundant rank of coal is bituminous.

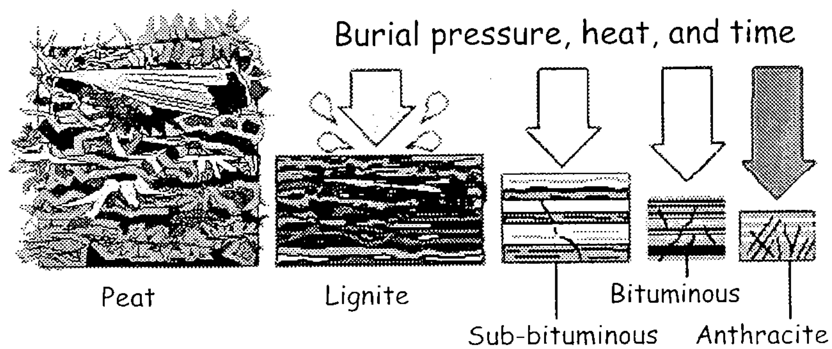

Figure 11 *(question 41)*. Diagram showing the transformation of peat into the different kinds of coal. As pressure and heat (typically due to increasing depth of burial) and time increase, water is expelled causing peat to change into lignite, then subbituminous, then bituminous coal. With continued increasing pressure, heat, and time, volatile matter (e.g., methane) is expelled and bituminous coal changes into anthracite. (Figure from Kentucky Geological Survey, accessed 2000.)

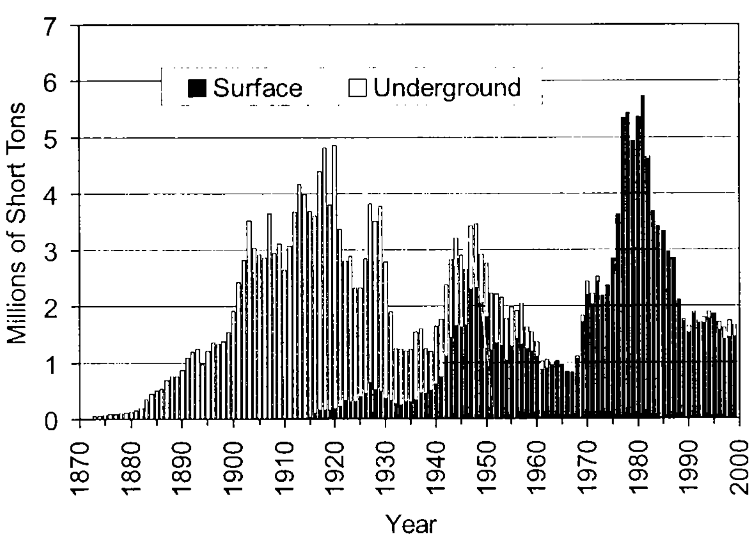

Figure 12 *(question 42)*. Graph showing coal production in Oklahoma from 1873 to 1999. (Graph by Brian J. Cardott, Oklahoma Geological Survey.)

42. How much coal has been produced in Oklahoma?

Since 1873, about 278 million short tons of bituminous coal. Annual coal production peaked in 1981 at about 5.7 million short tons (Fig. 12).

Resources: Water

43. Is there ground water under my property?

Ground water exists almost everywhere, but the water table may be deep, the water may be salty, and the aquifer may have a low yield.

The occurrence of ground water depends on the local geology: the type of rock or soil, their porosity and permeability, and whether that rock or soil contains good-quality ground water. About half of Oklahoma is underlain by major ground-water aquifers, such as the Ogallala, Garber–Wellington, and Alluvium (Fig. 13), in which a well should yield at least 25 gallons per minute of good water. In the rest of the State, where the rock or soil is slightly or moderately weathered, fractured, or porous, the potential yield is 2–10 gallons per minute of acceptable water.

Because ground water conditions vary so much from site to site, you should ask your neighbors about their experience concerning ground-water depth, quality, and yield. Other sources of information are geologists, hydrologists, and water-well drillers with experience in your area.

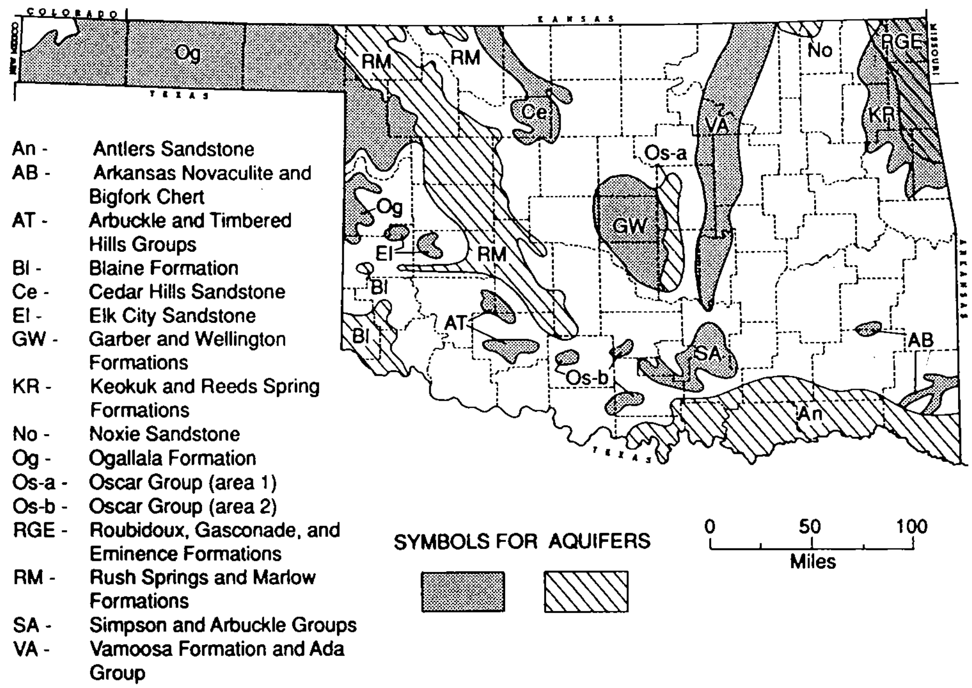

Figure 13 *(question 43)*. Map showing the principal bedrock aquifers in Oklahoma. Aquifers in recent sand and gravel deposits (alluvium) are not shown on this map; these aquifers follow the courses of the major rivers in Oklahoma. (Modified from Johnson, 1983.)

44. How deep will I have to drill to find water on my property?

It depends on the local geology and hydrology, but nearby water wells may be a guide.

The depth to ground water is based on local geology (see question 43) and the amount of precipitation in an area. Rainwater (and snowmelt) will penetrate the pores and fractures in the local bedrock and accumulate at a certain level (or depth); that level is known as the ground-water table. If a well is drilled below the water table and if there is sufficient water and permeability to allow water to flow through the pores and fractures to the wellbore, water can be pumped to the surface. Neighbors and experienced specialists (such as a geologist, hydrologist, or well-driller) may be helpful for predicting how deep the ground-water table on your property is.

Earthquakes

Cherokee Advocate.

PUBLISHED EVERY FRIDAY BY THE

CHEROKEE NATION.

Official Journal of the Nation.

FRIDAY. OCTOBER 27. 1882.

SHAKE.

Sunday afternoon last, about four o'clock, three distinct shakes of the earth were felt at Ft. Gibson, this, and other places in our Nation. A rumbling noise, which was distinctly heard by many, accompanied the shaking. At Ft. Gibson, the trembling and vibrating were so severe as to cause door and window shutters to open and shut, hogs in pens to fall and squeal, poultry to run and hide, the tops of weeds to dip, cattle to lowe, &c., &c. Immediately preceding and after the shake there was not a particle of movement, visible, in the atmosphere. Our exchanges speak of the earthquake as having been felt over a large area in the south and west. Eight or ten years ago a shock was felt in many places in this country, but it was a "wee bit" of a thing compared with that of Sunday last.

Figure 14 *(question 45)*. Short article from the October 27, 1882 *Cherokee Advocate* describing the October 22 earthquake. The location of the epicenter of this earthquake, which was felt in Kansas, Missouri, Arkansas, Texas, and the Indian Territory, is unknown. Based on historical records of damage, it appears to have been centered near Ft. Gibson. (Copy of article courtesy of the Oklahoma Historical Society, Oklahoma City.)

45. What was Oklahoma's largest earthquake?

The largest known earthquake centered in Oklahoma occurred near El Reno on April 9, 1952; its magnitude was 5.5.

The 1952 El Reno earthquake was felt as far away as Austin, Texas, and Des Moines, Iowa, and was felt over an area of about 140,000 square miles. However, damage from the earthquake was not severe. The shock caused cracks in several buildings, including the State Capitol Office Building and an office building in Tulsa. A chimney in El Reno fell through a roof. Mostly, windows and dishes rattled and wall hangings were knocked askew.

The earliest historical earthquakes reported in present-day Oklahoma (then Arkansas Territory) are the New Madrid earthquakes of December 1811 through February 1812; the epicenters were near the boot heel of Missouri. An earthquake in October 1822 may have been centered in Oklahoma (Fig. 14). The earliest recorded earthquake with a positively identified epicenter in Oklahoma occurred on December 2, 1897, near Jefferson in Grant County.

46. How many earthquakes occur in Oklahoma each year?

During the 22 years from 1978 through 1999, 1,449 earthquakes were recorded in Oklahoma. This averages to about 66 per year.

Beginning in 1978, the Oklahoma Geological Survey has recorded every Oklahoma earthquake of magnitude 1.6 or greater (Fig. 15). The most active year, 1995, had 167 earthquakes. The least active year was 1978 when 35 earthquakes were recorded. Two to four earthquakes are felt by Oklahomans each year. Graphs and tables of annual earthquake occurrences may be found at the Oklahoma Geophysical Observatory's website (Appendix 1).

47. When was the last earthquake in Oklahoma?

Since this answer was printed.

The last earthquake in Oklahoma (and several others before it) occurred after this report was written. The Oklahoma Geophysical Observatory's website (Appendix 1) has a catalog of all recent Oklahoma earthquakes. (The latest earthquake is at the bottom of the list. Click the underlined link for seismograms [Fig. 16] or other information.)

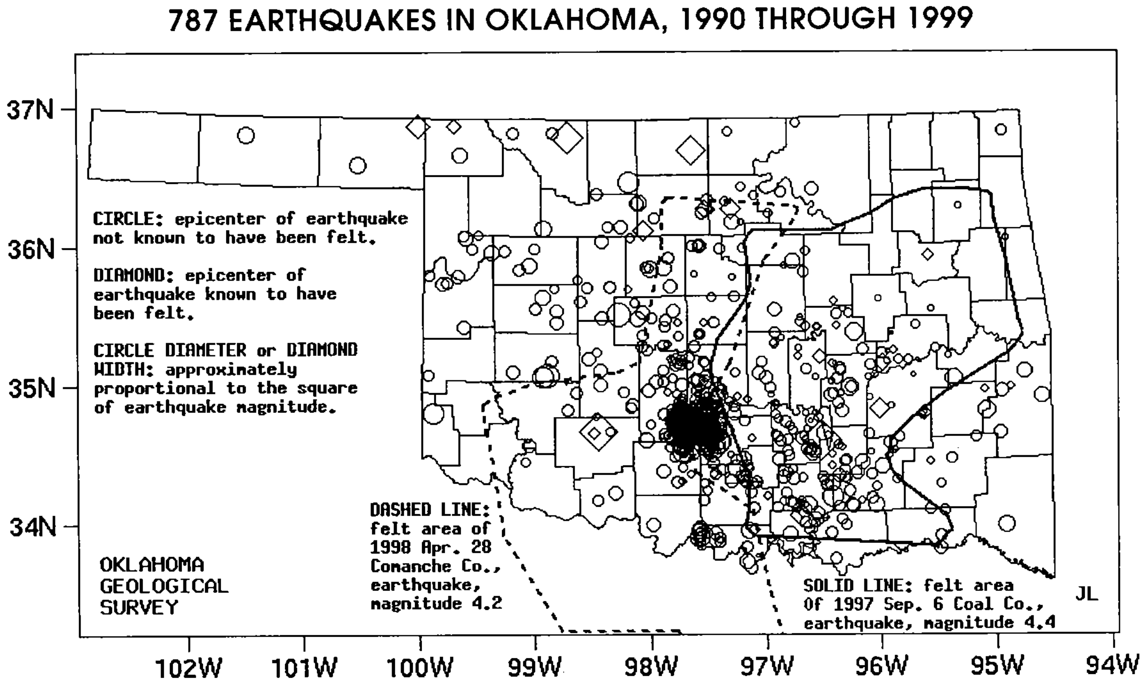

Figure 15 *(question 46)*. Map showing 1990–1999 Oklahoma earthquake epicenters. Note the very large concentration of earthquakes near Pauls Valley. (Map by Jim Lawson, Oklahoma Geophysical Observatory.)

48. What causes Oklahoma's earthquakes?

Stress that gradually builds up within the North American plate.

Most earthquakes occur along the margins of the tectonic plates that make up the Earth's lithosphere (crust plus upper mantle). Oklahoma lies in the interior of the North American plate, which includes all of Canada and most of the U.S. and Mexico. The eastern edge of the North American plate is the mid-Atlantic ridge; the western edge is, in part, the San Andreas fault in California.

The North American plate is moving west-northwest about 1 to 2 inches per year. As it moves, stress builds up within the plate. This stress is relieved by small adjustments along pre-existing faults, most of which are very old. Because most of these faults are very deep and relative movement along them is small, most Oklahoma earthquakes are not felt by humans.

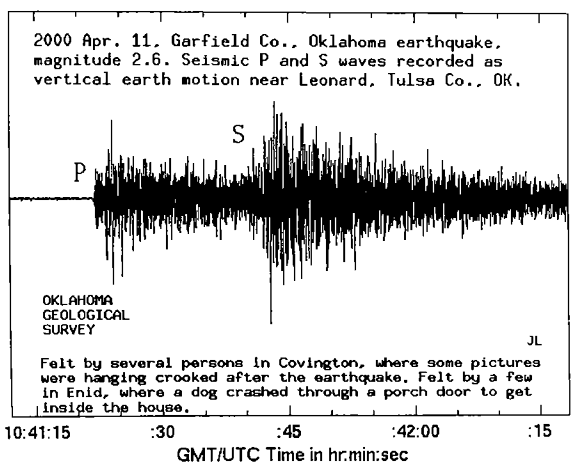

Figure 16 *(question 47)*. Seismogram of April 11, 2000, earthquake centered in Garfield County, Oklahoma. GMT/UTC refers to Greenwich Mean Time/Coordinated Universal Time. GMT/UTC is six hours ahead of Central Standard Time (five hours ahead of Central Daylight Time). (Seismogram from Jim Lawson, Oklahoma Geophysical Observatory.)

49. Is the occurrence of earthquakes influenced by the season? Time of day? Sunspots? Alignment of the planets? Earth tides?

No. These phenomena seem to have no effect on the stresses that build up over time in the Earth's crust and upper mantle.

General Geology

50. What geologic formation is under my property?

Geologic maps show the different formations in the State. Knowing the legal description of your property should enable you to locate it on a geologic map.

The OGS has an extensive collection of geologic maps of the State at many different scales. These maps show the distribution of geologic formations and most show the section-township-range grid system. Perhaps the most popular and frequently used geologic maps are in the OGS Hydrologic Atlas series at a scale of 1:250,000 (see question 14). Although they are somewhat generalized, they include an index map showing the detailed maps used in their compilation. Many of the geologic maps published by the OGS are for sale (Appendix 1). Other maps, including those in unpublished theses or ones that are out of print, may be consulted in college or university libraries.

If you know the legal description of your property, OGS geologists can determine what maps or reports show the geology of your area or what formation underlies your property.

51. What kind of soil is on my property?

The best source of information on Oklahoma soils are the U.S. Department of Agriculture county soil surveys.

There are many different kinds of soil throughout the State. The best source of information on these is a series of county soil surveys; these books are available for all of Oklahoma's 77 counties and can be found in many public and university libraries. Many of the books also are in-print and can be purchased from the U.S. Natural Resources Conservation Service (formerly the Soil Conservation Service) of the U.S. Department of Agriculture (Appendix 2). Other sources of information on soils are the National Soil Survey Center (Appendix 2) and the Oklahoma Conservation Commission (Appendix 1).

The OGS has no soil scientists on its staff, nor any research programs concerning Oklahoma soils.

52. Where are the oldest rocks in Oklahoma located? How old are they?

The oldest rocks in Oklahoma are in the eastern Arbuckle Mountains, mostly in northern Johnston County. They are about 1.4 billion years old.

The oldest rocks exposed at the surface in Oklahoma are in the eastern Arbuckle Mountains. All are plutonic (molten magma that slowly cooled and crystallized while deeply buried) and granitic in composition. Four different formations have been described: (1) an unnamed granodiorite (more than 1.399 billion years old), (2) the Troy Granite (about 1.399 billion), (3) the Blue River Gneiss (about 1.396 billion), and (4) the Tishomingo Granite (about 1.374 billion) (Fig. 17).

A geologic map showing the distribution of these rocks is available from the OGS: Map GM-31, "Geologic Map and Sections of the Arbuckle Mountains, Oklahoma." These rocks can be seen along Highway 1 north of Ravia, Highway 99 north of Tishomingo, and Highway 7 near Reagan and west of Wapanucka.

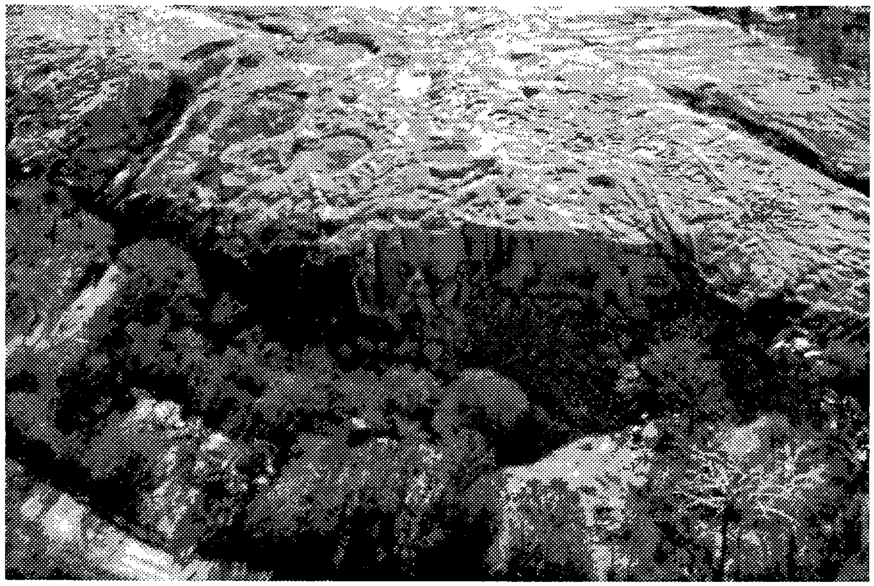

Figure 17 *(question 52)*. Aerial photograph of the Capitol Quarry and Ten Acre Rock, located about 1 mile east of Troy, Oklahoma. Ten Mile Rock was a prominent landmark when this part of Oklahoma was first settled. The approximately 1.4-billion-year-old Tishomingo granite was quarried about 1916 for use in the ground floors of the State Capitol Office Building in Oklahoma City. (Photograph by M. Charles Gilbert, School of Geology and Geophysics, University of Oklahoma.)

53. How did the Ice Ages affect Oklahoma?

The continental glaciers came no closer to Oklahoma than northeastern Kansas, but the climate during the Pleistocene was cooler and wetter than it is now. Animal and plant life reflected these conditions.

Although the continental glaciers that covered much of North America during the Pleistocene epoch never extended as far south as present-day Oklahoma, the climate then was much different than it is today. Based on studies of plant fossils, geologists know that the average summer temperatures during the four glacial periods probably were 5° to 10°F cooler than now, but winters were slightly warmer. Cooler summers meant that precipitation did not evaporate as quickly as now; as a result, the climate was more humid and forests grew farther west than they do today. The dominant trees were spruce, fir, pine, and northern hardwoods. Oklahoma's western prairies did not exist. However, during the Pleistocene interglacial periods, the climate probably was similar to what it is today in northeastern Oklahoma, and grasslands and forests of oak-hickory and pine were common.

A wide variety of fish, amphibians, reptiles, birds, and mammals lived in Oklahoma during the Pleistocene. Most notable among these were musk-ox, saber-toothed cats, giant beavers, Columbian mammoths, camels, ground sloths, bison, tapirs, short-faced bears (Fig. 18), and precursors of modern horses.

During the interglaciel periods, when the alpine glaciers in what is now Colorado and New Mexico were melting, the major east-flowing rivers of Oklahoma were much larger than they are today. Wind eroded fine sediment from the mud-, sand-, and gravel-choked rivers and floodplains and deposited it across much of the Panhandle. Elsewhere, extensive sand-dune fields formed, especially near the rivers.

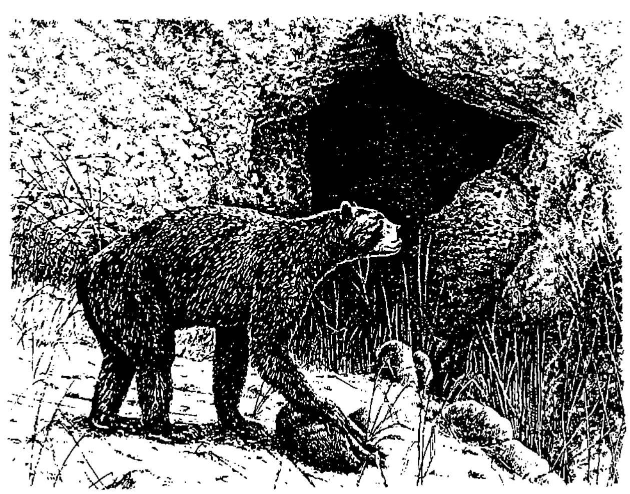

Figure 18 *(question 53)*. Reconstruction of *Arctodus simus* (Cope), short-faced bear. The right lower molar of a probable *A. simus* was discovered in Gittin' Down Mountain Cave, Adair County, in 1975 and is the only known occurrence of the short-faced bear in Oklahoma (Smith and Cifelli, 2000, p. 17). (From Feldmann, 1996, p. 369. Reconstruction by James L. Glover, Ohio Department of Natural Resources, Division of Parks and Recreation.)

54. Were there ever volcanoes in Oklahoma?

Yes, though millions of years ago. And some volcanic formations in Oklahoma were erupted from outside the State.

The oldest volcanic formations in Oklahoma are the Colbert Rhyolite in the Arbuckle Mountains and the Carlton Rhyolite in the Wichita Mountains. Both are Cambrian in age (about 525 million years old). The rhyolite volcanoes are associated with a large rift zone that formed when southern Oklahoma tried to pull south away from the rest of Oklahoma. Fortunately, it failed.

The next oldest volcanic rocks in the State are several tuffs in the lower part of the Stanley Formation (Mississippian, probably about 360 million years old). The best-studied of these are named the Hatton, Beavers Bend, and Mud Creek tuffs. All are exposed in the Ouachita Mountains in southeastern Oklahoma; the best-known exposure is the Beavers Bend tuff on Rattlesnake Bluff, east of the Mountain Fork River in Beavers Bend State Park. The source of the tuffs was a volcanic vent located to the south, perhaps in Texas, and now buried by younger rocks.

Figure 19 *(question 54)*. Black Mesa, Cimarron County, Oklahoma. Black Mesa is capped by a basalt lava flow that originated from vents about 40 miles to the west-northwest in Las Animas County, Colorado.

Oklahoma's youngest volcanic formation is the basalt lava flow that caps Black Mesa in extreme northwestern Cimarron County (Fig. 19). The flow, less than 5 million years old, was erupted from still-recognizable vents in southeastern Colorado. The basalt on Black Mesa is part of a large volcanic field that includes Capulin volcano in northeastern New Mexico, a popular tourist attraction and national monument.

Thin layers of volcanic ash are present in some river and lake deposits in Oklahoma. These ashes were erupted from Quaternary volcanoes throughout the western U.S., including the Jemez caldera in New Mexico, Long Valley caldera in California, and Yellowstone caldera in Wyoming.

55. Is there gold in Oklahoma?

Very little. Trace amounts of gold have been reported in the Wichita, Arbuckle, and Ouachita Mountains.

Oklahoma has no commercial gold deposits. Although trace amounts of gold have been reported in the Wichita, Arbuckle, and Ouachita Mountains, Fay (1976) concluded that the only authentic report of gold in Oklahoma was in a 1904 report by Edwin DeBarr. DeBarr assayed a number of samples from the Wichita Mountains and found one that contained gold. "No. 136 was obtained from washing placer material south of Brushy and Bald Mountains and Gold Hill, in the creeks and in Deep Red in which material there is a very small quantity of exceedingly fine gold in a limited area. The lack of water and the black iron in which it is found, together with the limited amount of gold therein, renders it unprofitable for working." Fay (1976) concluded that the sample was collected southeast of Snyder, in Kiowa County.

Perhaps the best description of "gold fever" in Oklahoma was written a century ago by Charles N. Gould, then director of the Oklahoma Geological Survey:

(continued on next page)

"At the time of the opening of the Kiowa and Comanche country to settlement in 1901, there was much activity in the Wichita Mountains. It has been estimated that at one time there were more than 2,000 miners at work in the region. The mountains were once bristling with claim notices, and honeycombed with mining shafts. Scores of camps were scattered throughout the mountains. According to various estimates all the way from half a million to a million and a quarter dollars have been spent in sinking shafts in the Wichita Mountains [Fig. 20]. Some of the shafts reached a depth of 200 to 250 feet, although most of them were less than 25 feet deep. Several small smelters were erected, and a number of car loads of ore was shipped to large smelters at Pueblo and Denver. Hundreds of assays have been published, many of them claiming values running sometimes as high as several hundreds, or even thousands, of dollars per ton. Several reports have been published by government and other officials on the occurrence of gold and silver in the Wichita Mountains."

Figure 20 *(question 55)*. Headframe of gold mine in Wichita Mountains. Thousands of prospectors explored the Wichita Mountains for gold between 1901 and 1907, and more than 2,500 prospect shafts and adits were dug. Assays as high as $3,000 per ton were reported, but in fact, little if any gold was ever discovered in the Wichitas. (Photograph courtesy Western History Collections, University of Oklahoma Libraries.)

Gold is exceedingly rare in Oklahoma because the geologic environment in which gold typically forms never occurred in the State. Most gold deposits in the U.S. fall into three broad categories: (1) those associated with Precambrian greenstones, such as that at the Homestake Mine, Black Hills, South Dakota; (2) those that formed at shallow (0.5 to 3 miles) depths and relatively low temperatures (350°–500°F) and associated with Cenozoic magmatism, such as at Carlin, Nevada; and (3) those associated with quartz veins in metamorphic rocks in a convergent plate-tectonic setting, such as the Mother Lode in California.

56. Have diamonds ever been found in Oklahoma?

No, despite a public diamond-collecting area nearby in Arkansas.

Diamonds have never been found in Oklahoma. "Kimberlite pipes" are the most important source for diamonds, and no such pipes have been identified in the State. Kimberlite is an igneous rock that contains minerals derived from deep in the Earth's crust or upper mantle. A pipe is the vertical conduit below a volcano; it's roughly cylindrical and penetrates the crust. Kimberlite pipes typically contain highly fragmented igneous rocks, and some contain minerals, such as diamonds, that formed at high temperatures and pressures. A secondary source of diamonds is the material eroded from kimberlite pipes and transported elsewhere by moving water; these kinds of diamonds are called "alluvial diamonds."

In contrast to Oklahoma, diamond-bearing pipes do occur in neighboring Arkansas. Crater of Diamonds State Park near Murfreesboro is located on a lamproite (related to kimberlite) pipe, and the public is allowed to collect diamonds there. Some geologists estimate that the diamonds at Crater of Diamonds formed at 3100°F and 60 miles deep. The Arkansas Geological Commission (Appendix 1) has much information on the geology of the park and the origin of the diamonds found there.

57. Are there caves in Oklahoma? Where?

Yes. Limestone caves are present in the Ozarks and Arbuckles; gypsum caves occur in western Oklahoma.

Caves occur in some of the limestone formations of the Ozark Plateau, in northeastern Oklahoma, and in the Arbuckle Mountains in the south-central part of the State. Western Oklahoma is unusual in having caves in gypsum formations, including Alabaster Caverns State Park near Freedom (the largest commercial gypsum cave in North America) and Jester Cave in Greer County (the longest gypsum cave in the world outside of Russia).

"Pseudo-caves"—some little more than deep overhangs of rock—occur throughout the State. One is Robbers Cave State Park, near Wilburton.

Locations of most cave entrances are not publicized because vandals and thoughtless visitors deface caverns and disturb the animal communities (typically bats) that live in caves. Also, most cave entrances in Oklahoma are on private land, where permission is required for access.

Local organizations associated with the National Speleological Society are the Central Oklahoma Grotto and the Tulsa Regional Oklahoma Grotto (Appendix 5). Their members, being concerned with the geological and ecological value of caves, engage in cave mapping and conservation work, and explore caves only where damage can be kept to a minimum. The Central Oklahoma Grotto publishes an annual journal, "Oklahoma Underground."

Geography

58. Can I name a creek or hill on my land?

Yes, but certain procedures must be followed.

The U.S. Board on Geographic Names has established "principles, policies, and procedures" that you must follow before a name can be approved for use in federal publications and on maps. In general, the Oklahoma Board of Geographic Names follows the same guidelines, but also makes decisions based on State needs. For more information, contact the Oklahoma Board at the OGS (Appendix 1).

59. Why do place names change?

Despite official recognition, names change with common usage.

Every case is different; call the Oklahoma Board of Geographic Names at the OGS for a particular name change. An interesting example is the name change from "Grand Lake" to "Lake of the Cherokees." This is one of the most misunderstood geographic names in Oklahoma. The feature has been called Grand Lake, Grand Lake O' The Cherokees, Lake of the Cherokees, Lake O' the Cherokees, and several additional variants.

In 1941, the State Legislature adopted House Bills No. 431 and No. 459, naming the body of water impounded by the Pensacola Dam "Lake O' The Cherokees." However, the lake included a stretch of the Neosho River, locally known as "Grand River," and the reservoir quickly became known as "Grand Lake." Over the next three decades the confusion of names grew, finally

(continued on next page)

attracting official attention. In 1981, the House Bill No. 1053 added "Grand" to the name, making it "Grand Lake O' The Cherokees." But neither the Oklahoma Board nor the U.S. Board on Geographic Names was notified of the change, so the lake had an official State name and a different official federal name. But local people continued calling it by a third name, "Grand Lake."

In 1995, the Oklahoma Board recommended "Grand Lake O' The Cherokees" as the official name for both State and federal use, with "Grand Lake" to be the official short form for use on maps and in other publications. However, the Oklahoma and federal boards were not the only boards to have to rule on the case. The waters of the reservoir back up into the State of Missouri, therefore, the Missouri Board was also asked for a ruling. Eventually, all agreed on the official name, "Grand Lake O' The Cherokees" (Fig. 21).

Figure 21 *(question 59)*. Photograph of Grand Lake O' The Cherokees, Delaware County, Oklahoma. (Photograph courtesy Fred W. Marvel, Oklahoma Tourism and Recreation Department.)

60. Where did this place name come from?

George Shirk's *Oklahoma Place Names* (1974) describes the origins of many town and city names.

This question translates to, "How did any given name come into common use in Oklahoma or anywhere in the world?" There are many books on place names that you can refer to. For most of the towns, cities, and major features in Oklahoma, refer to George Shirk's *Oklahoma Place Names* (1974); however, more in-depth research generally uncovers additional answers.

Consider the Cimarron River. In American Spanish, *cimarrón* means "wild, unmanageable," a good meaning for a word whose origins have been conspicuously intractable. In New Mexico, the place name *Cimarron* was applied first either to the Cimarron Mountains in northeastern New Mexico or to the river originating in them; in either case, the name was used later for other features. The Cimarron River itself heads at the junction of the Dry Cimarron River and Carrizozo Creek in Cimarron County, flows from Oklahoma into Kansas and back into Oklahoma, eventually joining the Arkansas River near Tulsa.

The most widely accepted explanation attributes the name to a sheep that was once abundant in northeastern New Mexico and there called *canero cimarrón*, meaning "wild sheep." Over time, wild horses and cattle began to be called *cimarrónes.* Another plausible explanation is that the name comes from the wild red plum that grew profusely along the river and was called *ciruela cimarróna* by local people. Similarly, the wild rose is called *rosa cimarróna*. Also, in New Mexico, *cimarrón* was used to refer to fugitive Indians. Finally, there is the story of a cowboy cook who, when checking his cooking pot and finding the beans still hard, exclaimed, "Simmer on!" (Julyan, 1996).

61. I'm testing a new Global Positioning System receiver and need to know my exact latitude and longitude. Where am I?

The latitude and longitude of any location can be interpolated from the USGS 1:24,000-scale topographic maps. Note that your GPS unit may use UTM coordinates, which also can be read off topographic maps (see questions 9 and 12).

Hazards

62. Can my house ever be flooded?

FEMA's flood insurance rate maps show areas that may be flooded periodically. The Oklahoma Water Resources Board also has information about flooding, and you can consult your local floodplain administrator.

Many of Oklahoma's streams and rivers are subject to flooding, and, as development continues, the pressure to build in areas of potential danger will increase. The OGS has the series "Flood Insurance Rate Maps" by the Federal Emergency Management Agency for the entire State. (FEMA's Map Service Center [Appendix 2] also sells the maps at a nominal cost.) These maps show areas of "100-year" and "500-year" flooding, and areas of minimal flooding. However, a special note at the bottom of the maps states that they are "for flood insurance purposes only" and do "not necessarily show all areas subject to flooding."

An excellent source of information on flooding is the Oklahoma Water Resources Board (Appendix 1). You may call them or access their website. Also, most parts of the State have floodplain administrators who have detailed knowledge of local areas. The floodplain administrator may be a city planner, a water or sewer supervisor, or other city official.

63. Will my house's foundation ever crack?

Foundation cracking depends on many factors, including soil composition, drainage, and construction methods used. Clays that have a high shrink-swell potential are common in some geologic formations in Oklahoma, and maps and reports that document this are available.

The primary cause of foundation cracking is seasonal shrinking of soils that are rich in certain clay minerals. These soils, which commonly develop on shale, typically expand when wet and shrink as they dry. During periods of severe drought, the soil may shrink to such an extent that it "pulls away" from your house's foundation, leaving it unsupported and subject to cracking.

Several nongeological factors also can contribute to foundation cracking over time, including poor site drainage, improperly compacted fill, plumbing leaks, poor construction, and the wrong kinds of plants next to the house.

The kind and amount of clay in a soil is important for determining whether the soil near your house is likely to shrink and swell. A clay mineral that is especially susceptible to shrinking and swelling is montmorillonite; clays that are less so are illite, kaolinite, and chlorite. Some clays are "mixed-layer clays" and consist of two or more different clay minerals. In southeastern Oklahoma, the Eagle Ford and Bokchito Formations (both Cretaceous) contain shale layers rich in montmorillonite. Elsewhere in the State other formations contain shale with minor montmorillonite, generally as mixed-layer clays.

Detailed, large-scale geologic maps typically show the distribution of shale-rich formations, and some reports describe the clay mineralogy of those formations. For example, the Fairmont Shale (a part of the Permian-aged Hennessey Formation), which is widely exposed near Oklahoma City, has "a low to medium shrink-swell potential" (Johnson and others, 1980, p. 18).

Geologically, it is safer to build a home on soils derived from sandstone or limestone than shale. Most Oklahoma shales contain little montmorillonite, but in times of severe drought, even a small amount of montmorillonite can cause foundation problems.

Appendixes

Appendix 1
STATE AGENCIES

Arkansas Geological Commission
3815 W. Roosevelt Rd.
Little Rock, AR 72204
(501) 296-1877
http://www.state.ar.us/agc/agc.htm

Oklahoma Conservation Commission
2800 N. Lincoln Blvd., Suite 160
Oklahoma City, OK 73105
(405) 521-2384
http://www.okcc.okstate.ok.us/
For County Information:
Click: Directory >> Districts [searchable by county name]

Oklahoma Corporation Commission
P.O. Box 52000-2000
Oklahoma City, OK 73152-2000
(405) 521-2211
www.occ.state.ok.us/

Oklahoma Department of Environmental Quality
P.O. Box 1677
Oklahoma City, OK 73101-1677
(405) 702-1000
www.deq.state.ok.us/
For Water Quality Information:
http://www.deq.state.ok.us/Water1/home.index.html

Oklahoma Department of Wildlife Conservation
1801 N. Lincoln
Oklahoma City, OK 73105
(405) 521-3851
http://www.wildlifedepartment.com/

Oklahoma Geological Survey
Main Office
100 E. Boyd St., Room N-131
Norman, OK 73019-0628
(405) 325-3031
http://www.ou.edu/special/ogs-pttc/
For Rock Hound Club Shows and Swaps:
Click: Rock Club Events

Oklahoma Geological Survey
Publication Sales Office and Computer Facility
1218-B W. Rock Creek Rd.
Norman, OK 73069-8590
(405) 360-2886

Oklahoma Geological Survey
Core and Sample Library
2725 S. Jenkins
Norman, OK 73019
(405) 325-4386

Oklahoma Geophysical Observatory
P.O. Box 8
Leonard, OK 74043
(918) 366-4152
http://www.okgeosurvey1.gov/
For Annual Earthquake Occurrences:
Click: Oklahoma earthquake catalog >> 1977–1998
For Recent Earthquakes:
Click: Oklahoma earthquake catalog >> 2000

Oklahoma Marginal Wells Commission
1218-B W. Rock Creek Rd.
Norman, OK 73069
(405) 366-8688
http://www.state.ok.us/~marginal/

Oklahoma Tax Commission
Main Office
2501 N. Lincoln Blvd.
Oklahoma City, OK 73194
(405) 521-4321
http://www.oktax.state.ok.us/

Oklahoma Tourism and Recreation Department
Director of Administrative Services
15 N. Robinson, Suite 300
Oklahoma City, OK 73102
http://www.otrd.state.ok.us/

Oklahoma Water Resources Board
3800 N. Classen
Oklahoma City, OK 73118
(405) 530-8800
http://www.state.ok.us/~owrb/
For Information on Floodplains:
Click: Planning and Management >> Floodplain Management
For List of Floodplain Administrators:
Click: Floodplain management (above) >> List of Floodplain Administrators

Appendix 2
FEDERAL AGENCIES

Federal Emergency Management Agency
Region VI
(940) 898-5399
http://www.fema.gov/reg-vi/

Also:
FEMA Map Service Center
P.O. Box 1038
Jessup, MD 20794-1038
(800) 358-9616
http://www.fema.gov/maps/
Click: Flood Hazard Mapping

U.S. Army Corps of Engineers
Tulsa District
1645 S. 101st East Ave.
Tulsa, OK 74128-4609
(918) 669-7366
http://www.swt.usace.army.mil/

U.S. Bureau of Reclamation
Great Plains Regional Office
P.O. Box 36900
Billings, MT 59107-6900
(406) 247-7614
http://www.gp.usbr.gov/ok/okrec1.htm

U.S. Fish and Wildlife Service
Southwest Region
P.O. Box 1306
Albuquerque, NM 87103-1308
(505) 248-6911
http://southwest.fws.gov/statelink/oklahomalinks.htm

U.S. Forest Service
Ouachita National Forest
P.O. Box 1270
Hot Springs, AR 71902
(501) 321-5202
http://www.fs.fed.us/oonf/ouachita.htm

U.S. Geological Survey
National Center
12201 Sunrise Valley Drive
Reston, VA 20192
(703) 648-4000
http://www.usgs.gov/
For Geographic Names:
http://mapping.usgs.gov/www/gnis/gnisform.html

U.S. Geological Survey
Water Resources Division
202 N.W. 66th St., Bldg. 7
Oklahoma City, OK 73116
(405) 843-7570
http://ok.water.usgs.gov/

U.S. Natural Resources Conservation Service
State Conservationist
100 USDA, Suite 203
Stillwater, OK 74074-2655
(405) 742-1248
http://www.nrcs.usda.gov/

Also:
National Soil Survey Center
http://www.statlab.iastate.edu/soils/nssc/

Appendix 3
PROFESSIONAL ORGANIZATIONS

Ardmore Geological Society
Box 1552
Ardmore, OK 73402

Geoscience Information Society
Attn: Secretary
c/o American Geological Institute
4200 King St.
Alexandria, VA 22302
http://www.geoinfo.org/
For Union List of Geological Guidebooks:
http://www.geoinfo.org/pubs/unionlist/
Click: View Database >> Geography >> United States >> Oklahoma

Oklahoma City Association of Petrolem Landmen
3035 N.W. 63rd St., Suite 209
Oklahoma City, OK 73116
(405) 840-4111
E-mail: ocapl@flash.net

Oklahoma City Geological Society
227 W. Park Ave.
Oklahoma City, OK 73102
(405) 236-8086
http://www.ocgs.org

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Oklahoma City Geological Society Library
227 W. Park Ave.
Oklahoma City, OK 73102
(405) 235-3648, ext. 11
http://www.ocgs.org/library.asp

Oklahoma Well Log Library
427 S. Boston Ave., Suite 1100
Tulsa, OK 74103-4116
(918) 582-6188

Tulsa Association of Petroleum Landmen
P.O. Box 1342
Tulsa, OK 74101

Tulsa Geological Society
P.O. Box 4508
Tulsa, OK 74159-0508
(918) 582-4762
http://tulsageology.org/

Appendix 4

ROCK AND MINERAL CLUBS OF OKLAHOMA

Ada Gem, Mineral, and Fossil Club
P.O. Box 117
Clarita, OK 74535
Contact: Bill Lyon, (580) 332-8666,
jblyon@chickasaw.com

Enid Gem and Mineral Society
2614 West Oklahoma
Enid, OK 73703-5121
Contact: Frances Johnson, (580) 233-1852

McCurtain County Gem and Mineral Club
Route 4, Box 60
Broken Bow, OK 74728
Contact: Cephis Hall, (580) 494-6612

Oklahoma Mineral and Gem Society
P.O. Box 25632
Oklahoma City, OK 73125
Contact: Max or Arlene Burkhalter,
(405) 732-0808, maburk1@msn.com

Osage Hills Gem and Mineral Society
P.O. Box 612
Bartlesville, OK 74005
Contact: Mel Albright, (918) 336-8036,
mela@galstar.com

Rough and Tumbled Rock and Gem Club
129 Viola Ave.
Ponca City, OK 74601
Contact: Don Hopkins, (580) 762-5287,
donalma@poncacity.net

Shawnee Gem and Mineral Club
111 W. Hickory
Shawnee, OK 74804
Contact: Tom Morris, (405) 386-2314,
dethwrdn@flash.net

Stillwater Mineral and Gem Society
1116 S. Gray St.
Stillwater, OK 74074-5446
Contact: Dan and Ruby Lingelbach,
(405) 372-8635

Tahlequah Rock and Mineral Society
P.O. Box 932
Tahlequah, OK 74465
Contact: Maxene Woods, (918) 456-8198

Tulsa Rock and Mineral Society
P.O. Box 2292
Tulsa, OK 74101
Contact: Bob Shaha, (918) 342-5661

Appendix 5

OTHER ORGANIZATIONS

Central Oklahoma Grotto
c/o John and Sue Bozeman
2624 Chaucer Drive
Oklahoma City, OK 73120-3407

Geo Information Systems
1818 W. Lindsey St., Suite A105
Norman, OK 73069-4160
(405) 325-3131
http://www.geo.ou.edu

Herndon Map Service
3816 N. Maney St.
Oklahoma City, OK 73112-2929
(405) 946-5858

(continued on next page)

IHS Energy Group
Petroleum Information/Dwights Plus Drilling Wire
15 Inverness Way East
Englewood, CO 80112-5776
http://www.ihsenergy.com/
For Information on Drilling Wire:
Click: Products and Services >> Publications, Submit

Institute of Meteoritics
Dept. of Earth and Planetary Sciences
University of New Mexico
Northrop Hall
200 Yale Blvd., N.E.
Albuquerque, NM 87131
(505) 277-4204
http://epswww.unm.edu/iom/home.htm

Laurence S. Youngblood Energy Library
Sarkeys Energy Center
University of Oklahoma
100 E. Boyd St., Room R-220
Norman, OK 73019
(405) 325-6451
http://libraries.ou.edu/depts/geol/index.html
Click: OU libraries >> Online catalog >> Public catalog

Noble Chamber of Commerce
118 S. Main St.
Noble, OK 73068
(405) 872-5535

Oklahoma State University
School of Geology
105 Noble Research Center
Stillwater,OK 74078-3031
(405) 744-6358
http://www.okstate.edu/geology/

PennWell Corp.
1421 S. Sheridan Rd.
Tulsa, OK 74112
(918) 835-3161
http://www.pennwell.com

Rock and Gem Magazine
Miller Magazines, Inc.
4880 Market St.
Ventura, CA 93003-7783
(805) 644-3824
http://www.rockngem.com

Rocks and Minerals Magazine
Heldref Publications
1319 Eightennth St., N.W.
Washington, D.C. 20036-1802
(202) 296-6267
http://www.rocksandminerals.org

Sam Noble Oklahoma Museum of Natural History
2401 Chautauqua Ave.
Norman, OK 73072
(405) 325-4712
http://www.snomnh.ou.edu/
For Information on Saurophaganax maximus*:*
http://www.snomnh.ou.edu/mediarelations/saurophaganx

Timberlake Rose Rock Gallery and Museum
419 South U.S. Highway 77
Noble, OK 73068
(405) 872-9838

Tulsa Regional Oklahoma Grotto
P.O. Box 1305
Broken Arrow, OK 74013-1305

University of Oklahoma
School of Geology and Geophysics
Sarkeys Energy Center
100 E. Boyd St., Room 810
Norman, OK 73019
(405) 325-3253
http://geology.ou.edu/n/home.html

University of Tulsa
Dept. of Geosciences
600 S. College Ave.
Tulsa, OK 74104-3189
(918) 631-3018
http://www.geo.utulsa.edu/

White Mound
Pat and Merylyn Howe
Rt. 1, Box 323
Sulphur, OK 73086
(580) 622-5366

Appendix 6

GENERALIZED GEOLOGIC TIME SCALE

DIVISIONS OF GEOLOGIC TIME					Age (approx.) in millions of years
Eon	Era	Period		Epoch	
Phanerozoic	Cenozoic	Quaternary		Holocene	0.010
				Pleistocene	1.6
		Tertiary		Pliocene	5
				Miocene	23
				Oligocene	35
				Eocene	57
				Paleocene	65
	Mesozoic	Cretaceous		Late	97
				Early	146
		Jurassic		Late	157
				Middle	178
				Early	208
		Triassic		Late	235
				Middle	241
				Early	245
	Paleozoic	Permian		Late	256
				Early	290
		Carboniferous	Pennsylvanian	Late	303
				Middle	311
				Early	323
			Mississippian	Late	345
				Early	363
		Devonian		Late	377
				Middle	386
				Early	409
		Silurian		Late	424
				Early	439
		Ordovician		Late	464
				Middle	476
				Early	510
		Cambrian		Late	517
				Middle	536
				Early	570

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Selected Oklahoma Geological Survey Publications

Booklets & Pamphlets

(Except where noted, there is no charge for a single copy; two or more copies cost 25¢ each plus postage.)

A few geo-facts about Oklahoma: collected for Earth Sciences Week in Oklahoma, 1998 (29-page booklet).

Geology of Oklahoma (postcard). No charge for single postcard; price for additional postcards is 15¢ each, or two for 25¢.

Geology of Oklahoma—a summary.

Index to topographic maps of Oklahoma, by the U.S. Geological Survey.

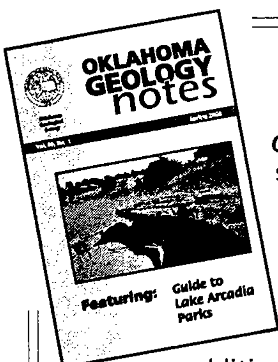
Oklahoma earthquakes.

The petroleum industry in Oklahoma (pamphlet), by the Oklahoma Mid-Continent Oil and Gas Association.

Rose rocks in Oklahoma (pamphlet).

Information Series:

- IS-1. Mountains, streams, and lakes of Oklahoma.
- IS-2. Geology and mineral resources of Oklahoma.
- IS-3. An enduring partnership—Oklahoma and the petroleum industry (21-page booklet). $1.00.
- IS-4. Industrial-mineral resources of Oklahoma.
- IS-5. Geology of Red Rock Canyon State Park (20-page booklet) (previously Open-File Report 6-96). $1.00.
- IS-6. Gee*(whiz!)*ology of Oklahoma (20-page booklet). $1.00.
- IS-7. Geology of Arcadia Lake Parks (20-page booklet). $1.00.
- IS-8. "Is this dinosaur dung?"... and other questions answered by the Oklahoma Geological Survey (35-page booklet). $1.00.



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- Guidebook 9. Guide to Roman Nose State Park, Blaine County, Oklahoma. 31 pages. 1959; 4th printing, 1998. $2.00.
- Guidebook 11. Guide to Beavers Bend State Park. 46 pages. 1963; 2nd printing, 1982. $2.00.
- Guidebook 15. Guide to Alabaster Cavern and Woodward County, Oklahoma [revised edition]. 38 pages. 1969; 7th printing, 1994. $1.00.
- Guidebook 22. Guide to Robbers Cave State Park. 48 pages. 1986. $5.00.
- Guidebook 28. Geology of the Wister State Park area, Le Flore County, Oklahoma. 28 pages. 1993. $5.00.
- Open-File Report 2-96. Geology of the Ardmore basin in the Lake Murray State Park area, Oklahoma: an introduction and field-trip guide. 32 pages. 1996. $1.80.
- Open-File Report 4-99. A field-trip guide to the geology of the Black Mesa State Park area, Cimarron County, Oklahoma. 52 pages. 1999. $5.50.
- Open-File Report 1-2000. Geology of Tallgrass Prairie Preserve, Osage County, Oklahoma: an introduction and field-trip guide. 36 pages. 2000. $4.00.

Educational Publications:

- EP-1. Geology and earth resources of Oklahoma—an atlas of maps and cross sections. 8 pages. Introductory text; 7 pages of maps and cross sections of Oklahoma at a scale of 1:2,000,000 (1 in. = 32 mi) showing topography, geomorphic provinces, geology, and mineral and water resources. 1972; 2nd printing, 1979. $2.00.
- EP-2. Introduction, guidelines, and geologic history of Oklahoma. *Book I of* Guidebook for geologic field trips in Oklahoma. 15 pages. 1971; 3rd printing, 1987. $2.00.
- EP-3. Northwest Oklahoma. *Book II of* Guidebook for geologic field trips in Oklahoma. 42 pages, 26 field-trip sites. 1972; 5th printing, 1999. $2.00.
- EP-4. Guidebook for geologic field trips in north-central Oklahoma. 42 pages, 43 field-trip sites. 1981. $3.00.
- EP-5. Guide to resources for earth science information in Oklahoma. 76 pages. 1996. $4.00.
- EP-6. Oklahoma generalized geologic time scale—the story told by rocks. Full-color, 22- × 34-inch poster. 1999. $3.00, folded; $4.00, laminated and rolled in tube.

Geocalendars:

- Geocalendar 1996. Oklahoma dinosaur days—*Acrocanthosaurus atokensis*. Full-color educational poster and 4-page booklet, rolled in tube. 1995. $2.00; booklet alone, $1.00.
- Geocalendar 1997. Oklahoma's Ice Age. Full-color educational poster and 8-page booklet, rolled in tube. 1996. $2.00; booklet alone, $1.00.

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