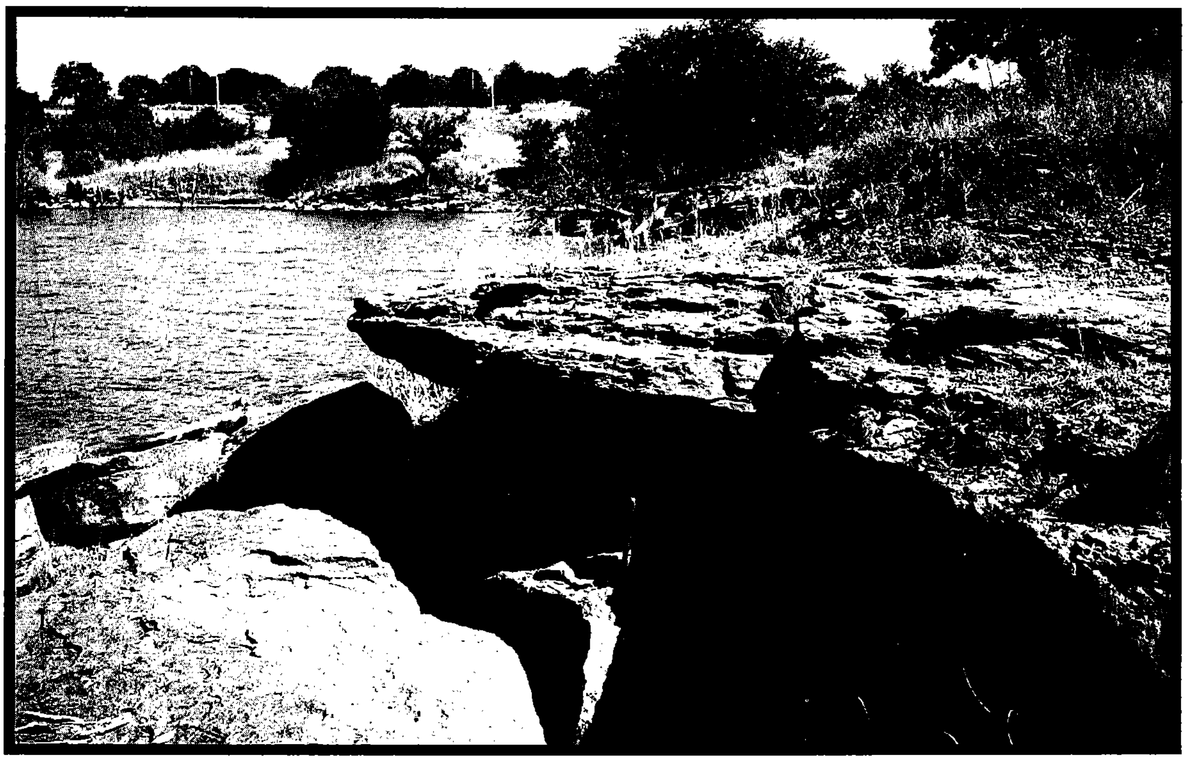
# Geology of Arcadia Lake Parks

## *An Introduction and Field-Trip Guide*

Information Series 7



Modified from *Oklahoma Geology Notes,* v. 60, no. 1, p. 2–17

Oklahoma Geological Survey
Norman, Oklahoma
2000

# on the cover

## Outcrop of Garber Sandstone at Lake Arcadia (near Oklahoma City, Oklahoma)

The cover photograph shows an outcrop of Permian (Leonardian) Garber Sandstone exposed along the north shore of Lake Arcadia near the U.S. Army Corps of Engineers dam. This sandstone is in the lower part of the Garber; new geologic mapping by Hemish and Suneson (1998) shows that the underlying Wellington Formation is exposed at a lower elevation on the downstream side of the dam. The lower part of the Garber consists of sandstone commonly interbedded with shale and siltstone; such finer-grained beds are present at this location, on top of the sandstone (partly grass covered) and in the shadow beneath the overhang.

New geologic studies in the Oklahoma City metropolitan area are being spearheaded by the Oklahoma Geological Survey's (OGS) STATEMAP project. STATEMAP is a cooperative program funded by the OGS and the U.S. Geological Survey under the National Cooperative Geologic Mapping Program. Part of the Oklahoma project is new geologic mapping of urban and rapidly developing areas. The Oklahoma City area has top priority for two reasons: (1) the stratigraphy established by Bingham and Moore (1975) is difficult to recognize in the field, and the map is at too large a scale (1:250,000) to be useful for site-specific studies; and (2) the map published by Wood and Burton (1968) (scale about 1:95,000) was compiled in a reconnaissance manner, not through detailed geologic mapping.

New geologic maps and studies are needed because the Garber Sandstone is one of the area's most important aquifers. Wise land-use policies based on new geologic information will help maintain the Garber as a source of fresh water for future generations. In addition, new studies and maps will provide information about other geologic issues that affect development in the Oklahoma City metropolitan area, such as the extent of expansive clay-rich soils overlying the Hennessey Formation and also the locations of sand and gravel resources.

The City of Edmond's parks at Lake Arcadia are excellent places to examine some of the details of the Garber Sandstone. In addition, the parks have an established naturalist's program, through which visitors can learn about other aspects of the natural history of the area.

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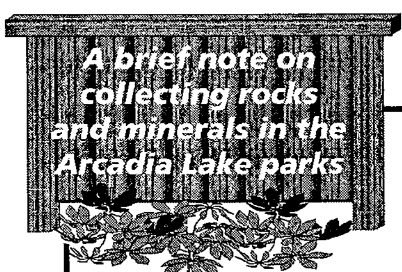
*Neil H. Suneson*




*T*housands of Oklahomans visit the Arcadia Lake parks every year. If each of them took home a small souvenir—such as a wildflower, pine cone, or rock—the natural beauty of the parks would be diminished for future visitors. Please look at, touch, and photograph the geological features described in this guide, but leave them for others to examine. Not only does removing natural objects reduce the value of the parks as places for education and relaxation, but it also is *expressly prohibited* without written permission from the district engineer by U.S. Army Corps of Engineers Title 36, Chapter III, Park 327.14—Rules and Regulations Governing Public Use of Public Property.

# Geology of Arcadia Lake Parks—
# An Introduction and Field-Trip Guide

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## INTRODUCTION TO THE GEOLOGY OF ARCADIA LAKE PARKS

### History of Arcadia Lake Parks

Lake Arcadia is about 3 mi east of U.S. Interstate 35 and 0.5 mi south of historic Route 66 (now State Highway 66; also Second Street in Edmond) on the east side of Edmond in Oklahoma County, Oklahoma (Fig. 1). Oklahoma County is in the Central Redbed Plains geomorphic province, an area of gently rolling hills separated by narrow valleys and broad, flat plains (Johnson and others, 1972). The rocks that make up the province are from the Permian Period of geologic time and are characterized by a brick-red color.

Lake Arcadia was formed by the damming of Deep Fork, a major east-flowing tributary of the North Canadian River that empties into Lake Eufaula just northeast of Henryetta. The U.S. Army Corps of Engineers started building Lake Arcadia dam in October 1980, and it became operational in November 1986. It is 5,250 ft long and rises 102 ft above the stream bed. Lake Arcadia dam was built for multiple reasons, including flood control, water supply, and recreation.

Lake Arcadia itself normally covers about 1,800 acres and holds about 27,520 acre-ft of water. The mean depth of Lake Arcadia is about 15 ft, and the maximum depth is about 56 ft. The area of the drainage basin for the lake is about 105 $mi^2$.

The U.S. Army Corps of Engineers designed and built four recreational facilities on the north and west shores of Lake Arcadia, and the City of Edmond opened these recreational facilities to the public in September 1987. Central State Park, Edmond Park, Spring Creek Park, and Scissortail Campground are known as the Arcadia Lake parks (Fig. 1). (The officially recognized name of the lake is Lake Arcadia, but the name Arcadia Lake commonly is used by the public and in park literature.) Each park has a separate entrance and some unique facilities. For example, Central State Park has a bird-watching blind, Edmond Park has a softball field, and Spring Creek Park has a disc golf course. Together, the Arcadia Lake parks offer visitors a wide range of recreational opportunities in a beautiful setting. More significant from a geological standpoint is what the rock outcrops (exposed rock units) along the lakeshore reveal: evidence of what this part of Oklahoma was like about 260 Ma (million years ago), during the Permian Period.

### General Stratigraphy

One of the goals of many modern geological studies is to determine what an area was like when the sediments that make up the rocks we see on the surface were deposited, or, in the case of petroleum exploration, when rocks in the subsurface were deposited. By carefully studying some of the outcrops in the Arcadia Lake parks and those elsewhere in

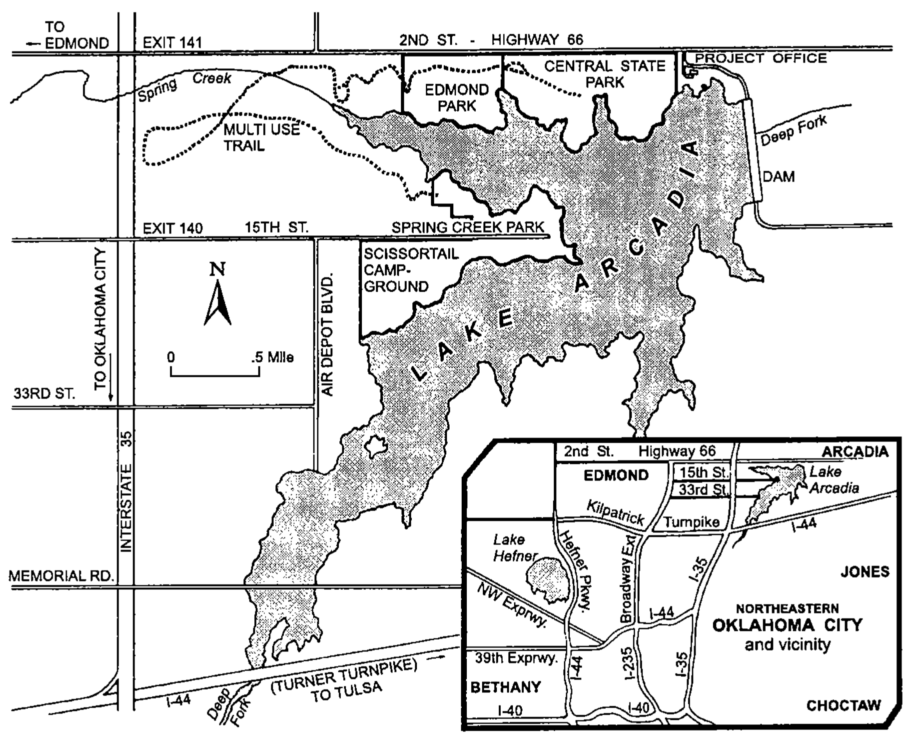


Figure 1. Map of the Lake Arcadia region showing the dam, Central State Park, Edmond Park, Spring Creek Park, and Scissortail Campground. Modified from a map provided by the Edmond Leisure Services Department.

**GENERALIZED STRATIGRAPHY**

| EPOCH/ SERIES | | FORMATION | OUTCROP AREA |
|---|---|---|---|
| LOWER PERMIAN | LEONARDIAN | **Hennessey Formation** | Exposures found in OKC metro area, and areas farther west. Consists mostly of siltstone and shale. |
| | | **Garber Formation** | Consists of sandstone and minor siltstone, shale and conglomerate. ▮ Part of section exposed around lake Arcadia. |
| | | **Wellington Formation** | Exposures common east of Lake Arcadia. Consists of sandstone, siltstone, and shale. |

Figure 2. Generalized stratigraphy (the sequence of rock layers) of Permian bedrock units near Lake Arcadia. Also see Generalized Geologic Time Scale, p. 19.

Oklahoma, geologists can interpret what this area was like about 260 million years ago. Geologists make these interpretations by comparing the rocks and features observed in the rocks with modern sediments and features deposited in known environments.

All of the rocks exposed along the shore of Lake Arcadia are in the lower part of a geologic unit called the Garber Formation (Fig. 2). In the parks, most of the rocks that make up the Garber Formation are sandstone; conglomerate, siltstone, and shale occur in lesser amounts. Aurin and others (1926) first described the Garber Formation in detail and named it for red sandstones that crop out near the town of Garber, Oklahoma. Gould (1905) recognized that the Garber is from the Permian Period (290–245 Ma), although he called it the Enid Formation. Olson's (1967) work on large amphibian and reptile fossils collected just above and below the Garber Formation established a more exact age assignment, placing the Garber in the Leonardian Series of the Permian Period (about 270–255 Ma) (Fig. 2).

The regional dip of most of the geologic strata (rock layers) in the vicinity of the Arcadia Lake parks is about 50 ft per mile (about 0.5°) to the west (Fig. 3). As a result, the Wellington Formation, which is older than the Garber and therefore below it stratigraphically (Fig. 2), is widely exposed east of Lake

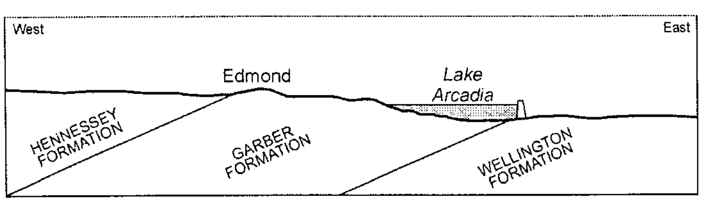



Figure 3. Diagrammatic cross section of Lower Permian strata (rock layers) near Lake Arcadia, where the regional dip (tilt) is about 50 ft per mile to the west. (For illustration purposes, the dip of the strata is greatly exaggerated in the diagram.)

Arcadia. The Wellington is similar in appearance to the Garber but contains less sandstone and more siltstone and shale. The similar appearances of the Garber and Wellington Formations make them difficult to distinguish in many places. Some reports on the ground-water resources of the Oklahoma City area (e.g., Wood and Burton, 1968) combine the two formations into the Garber-Wellington aquifer (discussed on page 9). The Hennessey Formation, which is younger than the Garber and therefore overlies it (Fig. 2), is mostly siltstone and shale; it forms the nearly flat countryside west of Edmond.

At Lake Arcadia, most of the sandstone in the Garber is poorly cemented; it crumbles easily to a fine sand. (A cement is a mineral that binds the individual sand grains together.) Most of the Garber sandstone is cemented only by hematite, which occurs as a thin coating on the individual quartz grains that make up the sandstone. This small amount of hematite gives the Garber sandstone its red color, and also is the coloring agent for most of the other red rocks in Oklahoma. It is possible that the hematite coating of sand grains in the Garber prevented other minerals, such as quartz, calcite, and barite, from filling the spaces between the individual sand grains and forming a stronger cement. The lack of significant cement makes the Garber an excellent aquifer (discussed on page 9 in "The Garber-Wellington Aquifer" section). In some locations, however, the Garber is both red and well cemented.

The sandstones in the Garber also contain a variety of sedimentary structures. These are features formed in sediments that reflect how the sediments were deposited, such as ripple marks and cross-beds, or that were deformed shortly after the sediments were deposited. These structures, discussed on pages 6–8 and in the field-trip guide that begins on page 10, are important clues to the nature of the environments in which the Garber sediments were deposited.

Other rock types in the Garber Formation are shale, siltstone, and conglomerate. The shales and siltstones are similar to sandstones but are finer grained, and are more easily eroded and more poorly exposed. Conglomerate in the Garber commonly is associated with the sandstone beds. Most pebble-size clasts in the conglomerate beds consist of cemented sandstone and siltstone; shale and dolomite clasts are less common. The matrix (finer-grained material surrounding the larger grains or particles) of Garber conglomerates is sandstone. Like the sedimentary structures associated with the sandstone beds, the conglomerates and the fragments that they contain are evidence used to interpret the Garber's depositional environments.

A depositional environment is the geologic setting in which sediments accumulate before they consolidate into a sedimentary rock. (Sandstone, siltstone, shale, and conglomerate all are sedimentary rocks.) One of the characteristics of sedimentary rocks that is related to depositional environment is grain size. In general, the larger the grain size of a sedimentary rock, the more rapidly the current that deposited it was moving. The abundance of sandstone in the Garber is evidence of an active current; the lesser amount of finer-grained sedimentary rocks such as shale (originally mud) is evidence that some of the water that deposited Garber sediment was still or slow-moving. In contrast, the presence of conglomerate beds in the Garber indicates the water was moving very rapidly at times.

## Regional Geologic History

The history of Oklahoma and the Lake Arcadia area before the Permian is complex; it is beyond the scope of this brief guide. The history of Oklahoma in the Early Permian (290–256 Ma) can be interpreted from exposures of the Wellington, Garber, and Hennessey Formations (Fig. 2) in the Oklahoma City area.

Oklahoma's present latitude is about 35°N., but during the Early Permian, Oklahoma was at about 15°N. latitude—about the latitude of southern India today. A shallow sea extended north from western Texas across the western half of the southern midcontinent, including western Oklahoma (Fig. 4). The climate probably was semiarid to subhumid, and like present-day southern India, may have had a monsoonal climate. The area was sparsely vegetated, and animals were uncommon.

Several lines of geologic evidence in the Oklahoma City area and elsewhere in Oklahoma suggest that the Early Permian Garber sandstone was deposited in a very broad river system, or a complex of systems, with a general east-to-west flow. The area was relatively flat and characterized by meandering sand-filled channels separated by muddy flood plains. About 50 mi west of the Oklahoma City area, the Garber rivers emptied into the shallow inland sea (Fig. 4).

Many of the sedimentary structures observed in the Garber Formation along the shores of Lake Arcadia are similar to those observed in modern-day river sediments. Sandstone beds containing trough cross-beds, ripple marks, and rip-up clasts are evidence for deposition in flowing water. Varying current velocities are indicated by sandstone interbedded with siltstone and shale and by planar-bedded sandstone. The presence of mud cracks is evidence that the sediment was periodically exposed to the air and dried.

A harsh, possibly semiarid to subhumid environment can be interpreted from the presence of dolomite pebbles in some of the Garber conglomerate beds. The pebbles probably originally were calcite nodules that formed in soils along the banks of the Garber rivers and streams. Today, calcite nodules can be seen forming in semiarid regions. The scarcity of fossils is further evidence of a harsh environment.

Geologists cannot determine exactly where the Garber sediments came from, but studies throughout Oklahoma suggest an eastern or southern highland source. The present-day Ouachita and Arbuckle Mountains are known to have been high during the Permian, possibly rising as much as 5,000 ft above the surrounding lowlands of central Oklahoma. Therefore, it is likely that the sandstone in the Garber was eroded off Oklahoma's best-known mountain ranges.

From the time the Garber Formation was deposited to the present, the sandstone in it has undergone a variety of chemical and physical changes that are collectively known as *diage-*

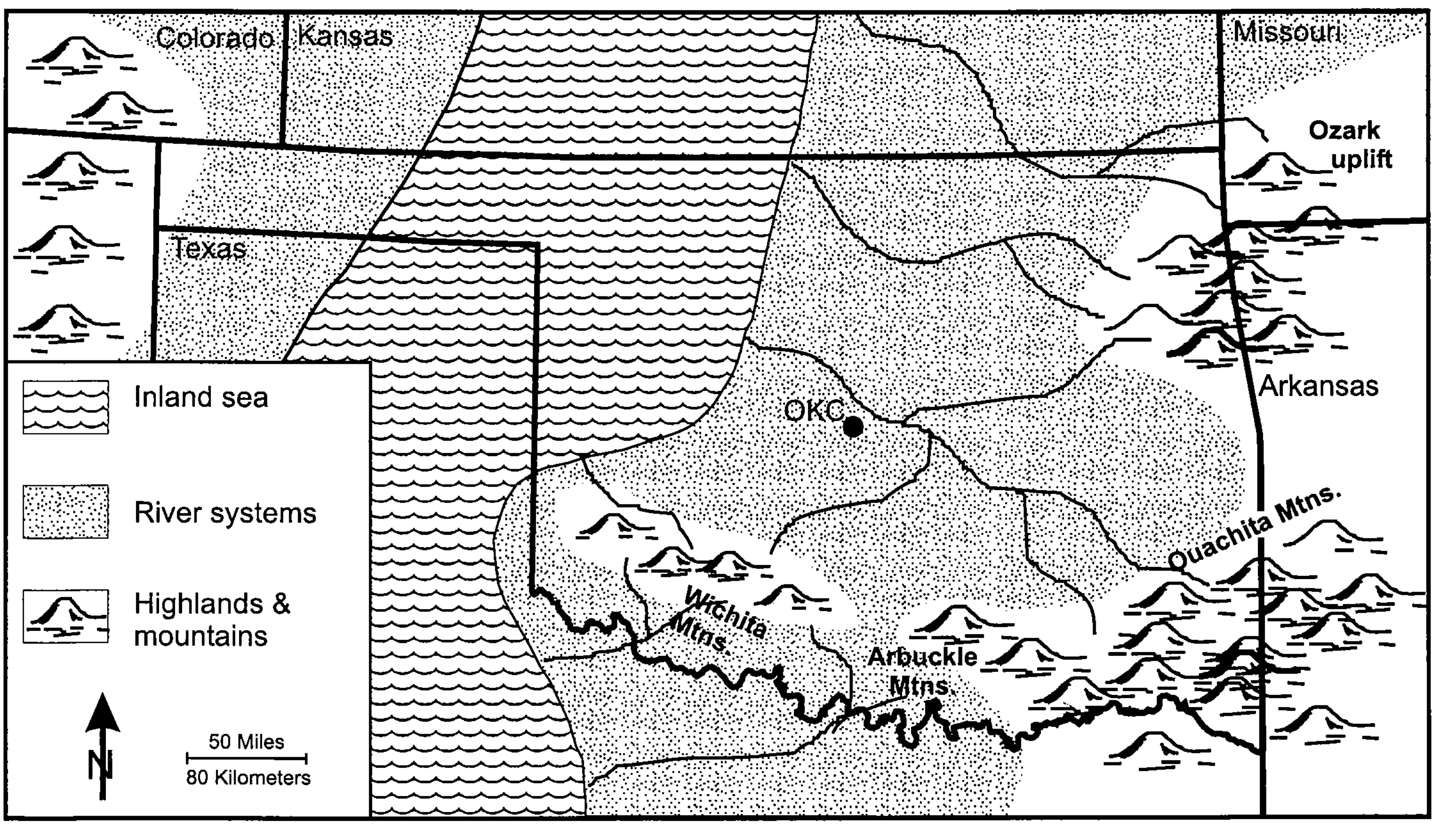



Figure 4. Map of Oklahoma showing its physical geography during the Early Permian Epoch, when Garber Formation sediments were deposited. Most Garber sediments were deposited by rivers that flowed west from highlands in the Ozark uplift, Ouachita Mountains, Arbuckle Mountains, and Wichita Mountains areas. A shallow sea covered northwestern Oklahoma, as well as much of the southern midcontinent; in northwestern Oklahoma, sediments the same age as those of the Garber are mostly marine.

*netic changes.* The red color, the color banding, and the different minerals cementing individual quartz grains together all are evidence of the movement through the rocks of water with varying chemistries. In many places, the Garber sandstones are poorly cemented and the pore spaces (open spaces) between the grains contain fresh water. This ground water is used by homeowners and municipalities for many purposes, including drinking.

Little is known about the geologic history of central Oklahoma after the Early Permian until the Pleistocene Epoch because there is no evidence: The rocks are absent. Either they were deposited and later eroded or they were never deposited. Knowledge of the Pleistocene environment of the Lake Arcadia area is based on the remnants of ancient river deposits.

During the Pleistocene—about 1.8 Ma to about 10.5 thousand years ago—large rivers fed mostly by glacial meltwater from the Rocky Mountains flowed from west to east across Oklahoma (Fig. 5). Most of the Pleistocene rivers followed approximately the same courses as Oklahoma's present-day rivers do; in places, however, they flowed down valleys now occupied by small streams. Sand and gravel deposited by the Pleistocene rivers commonly are located at elevations well above present-day stream beds because (1) the Pleistocene rivers were much larger and wider than those of the present and (2) present-day rivers have eroded through and removed most of the Pleistocene deposits. Oklahoma probably also was colder (with an average temperature similar to that of present-day Minnesota) and wetter than now. Forests typical of those in the northern part of the United States today were common in Oklahoma during glacial periods.

## Sedimentary Structures and Depositional Environments of the Garber Formation

Interpretations of the depositional environments of rocks found in Garber outcrops (Fig. 6) or in the subsurface are based on comparisons with present-day sediments that have been deposited in known environments. Sedimentary structures found in Garber Formation outcrops at Lake Arcadia add to evidence found elsewhere that indicates that Garber sediments were deposited in, or near, ancient rivers or streams. A number of these sedimentary structures are included in the field-trip guide that makes up the second part of this publication (page 10).

### *Trough Cross-Bedding*

The sandstone of the Garber Formation along the shores of Lake Arcadia is highly trough cross-bedded (Fig. 7A). Trough cross-bedding is common in river channels and forms when sediment that has been deposited by flowing water is subsequently eroded, or scoured out, by strong currents to form troughs locally. Later, when the water velocity changes, the troughs are filled with other sediment. The process of scour and fill repeats itself, but the overall process is one of deposition. The bedding planes of the sediment that fills the troughs are primary sedimentary structures and com-

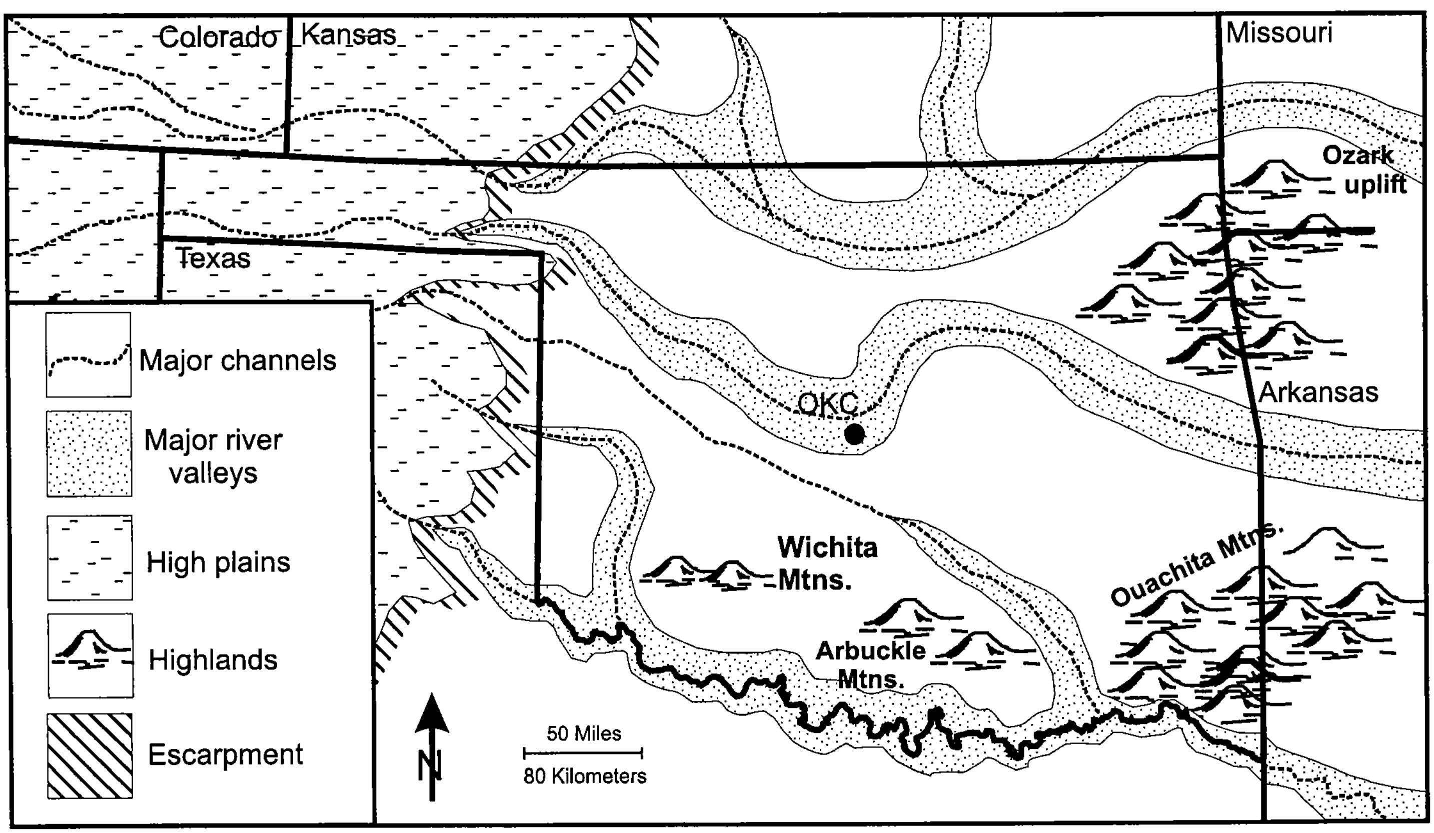



Figure 5. Map of Oklahoma showing its physical geography during the Pleistocene Epoch, when large rivers fed by meltwater from glaciers in the Rocky Mountains flowed across Oklahoma from west to east.

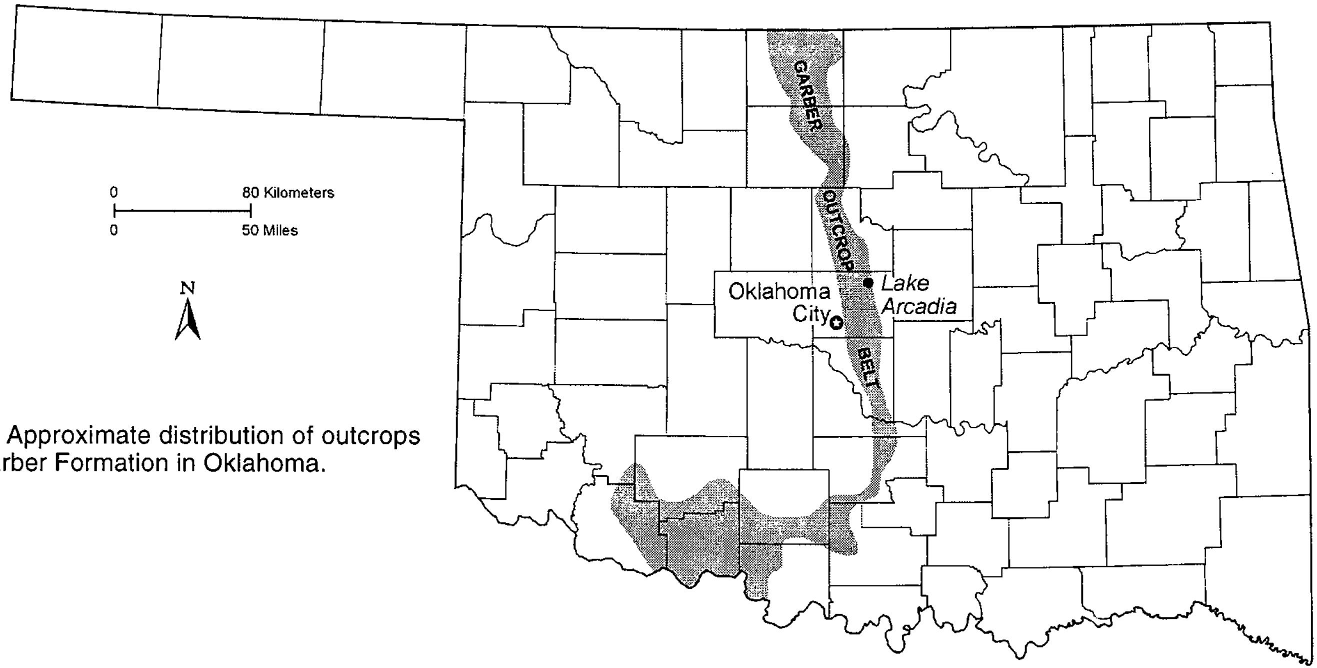
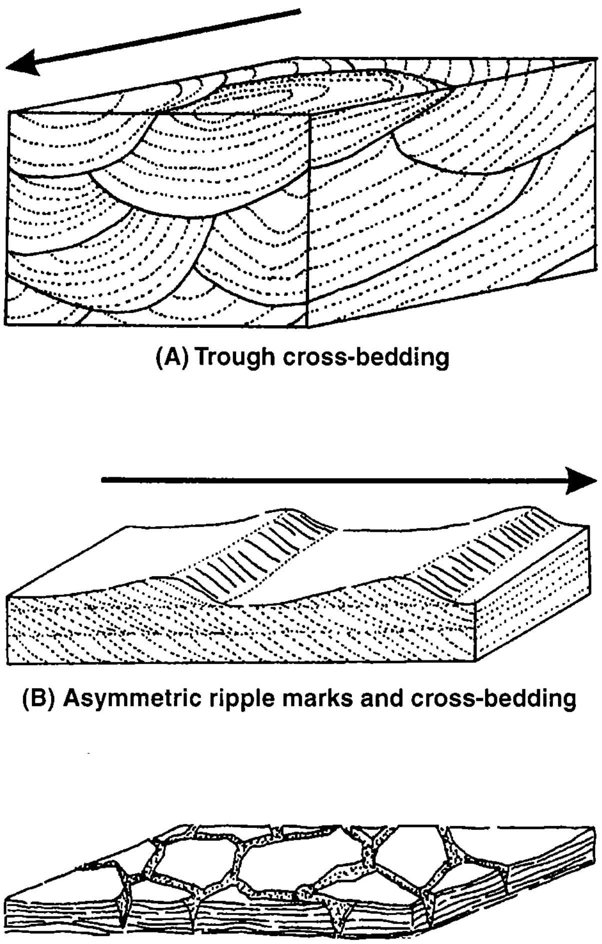



Figure 6. Approximate distribution of outcrops of the Garber Formation in Oklahoma.



(A) Trough cross-bedding

(B) Asymmetric ripple marks and cross-bedding

(C) Mud cracks

Figure 7. Block diagrams of sedimentary structures in the Garber Formation. A—Trough cross-bedding (arrow shows the direction of the current). B—Asymmetric ripple marks and cross-bedding (arrow shows direction of current). C—Mud cracks.

monly are tilted as much as 30°. This tilt is unrelated to the regional dip (about 0.5°).

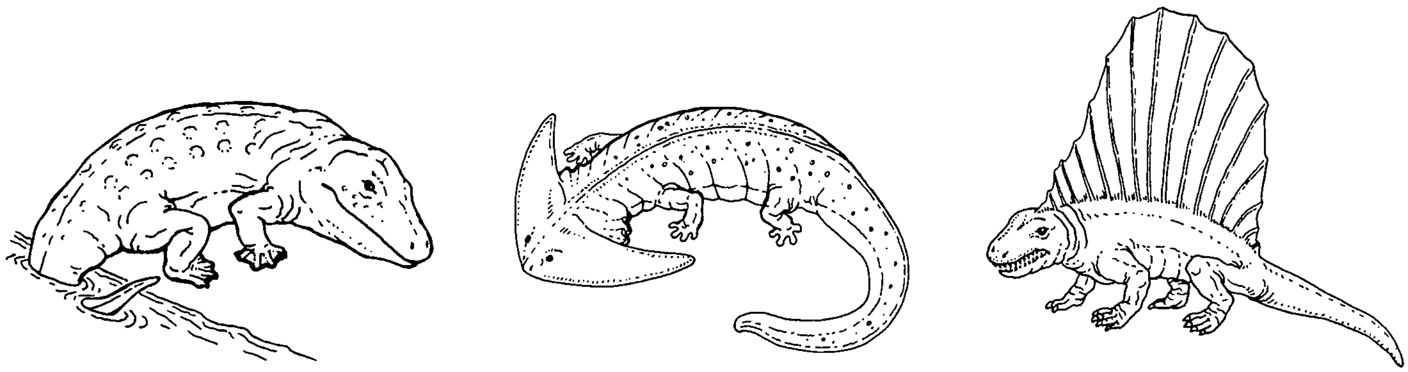
Tilted bedding planes are a common feature throughout the Garber in the Oklahoma City area. The trough cross-bedding and scour-and-fill sedimentary structures occur on all scales in the formation and give it a complex appearance. Viewed from the top, trough cross-beds are crescent-shaped and can be used to determine the direction the current was flowng when they formed. Measurements of paleocurrent directions in the Garber throughout the Oklahoma City area show a general east-to-west flow of the rivers and streams that deposited the Garber sand.

### *Ripple Marks*

Asymmetric ripple marks (Fig. 7B) are common on the tops of Garber sandstone beds in the Oklahoma City area, but do not occur in any of the outcrops in the parks. Like the cross-beds, these ripple marks are evidence that the sand was deposited in flowing water. Asymmetric ripple marks are formed by a current—such as one in a river—moving more or less constantly in one direction. Symmetric ripple marks formed by oscillating water movement, such as that associated with waves, are uncommon in the Garber. They are evidence of local reworking in standing water. Symmetric ripple marks are present locally in sand in the shallow parts of Lake Arcadia, for example, just offshore.

### *Planar Bedding*

Planar-bedded sandstone and siltstone also occur in the Garber and are common at Lake Arcadia. Some of the planar beds probably were deposited in very rapidly moving water, which would deposit sand or even small pebbles. Other planar beds probably were deposited in slowly moving water, which would deposit silt or very fine grained sand. The different types of rocks in the Garber's planar beds are evidence for changing water velocity at different times and in different places.



**(A)** ***Eryops*** **(B)** ***Diplocaulus*** **(C)** ***Dimetrodon***

Figure 8. Drawings of the Permian amphibians (A—*Eryops*; B—*Diplocaulus*) and reptile (C—*Dimetrodon*) whose fossils are most commonly found in the Garber Formation in central Oklahoma. Illustrations by Coral McCallister.

### *Mud Cracks*

Mud cracks (Fig. 7C), a sedimentary structure rarely seen in the Garber Formation, are present in one location along the Lake Arcadia shore. Mud cracks form when silt or mud deposited by a river is exposed to the air and dries. Such a process could occur along the banks or on the flood plain of a river. Mud cracks are preserved when they are quickly buried by sediment from a later flood event, for example.

### *Conglomerate Beds*

The presence of conglomerate beds in the Garber at Lake Arcadia indicates that, at times, the water that deposited the sediments was moving very rapidly. Most of the pebbles in Garber conglomerates are siltstone and shale rip-up clasts that probably were eroded from a nearby source—such as a stream bank or the bottom of a subsidiary channel—and incorporated into the sediment in a main channel.

### *Paleosols*

Some of the Garber sediments, and especially some of those in the underlying Wellington Formation, appear to have been exposed long enough for soil to develop. In the Arcadia Lake Parks, most of the fragments in the conglomerate beds in the Garber Formation are sandstone, siltstone, or shale. A few, however, are dolomite. These dolomite fragments are indirect evidence for the existence of paleosols—ancient soils in the geologic record. The dolomite probably originally was calcite and the calcite likely formed as small nodules and tubules in soil under subarid to subhumid conditions. The soil probably was subsequently eroded by a river or stream and the fragments of calcite were incorporated into the river sediments. Some of the calcium in the calcite was later replaced by magnesium to form dolomite.

### *Fossils*

Fossils are extremely rare in the Garber Formation, and, to date, none have been found at Lake Arcadia. Conditions during the Early Permian may not have been conducive to the preservation of fossils or, alternatively, the climate in central North America may have made the area inhospitable to plants and animals. Nevertheless, some fossil remains of Permian amphibians and reptiles have been found in the Garber elsewhere in the State (Fig. 8), including near Edmond (Olson, 1967). Plant fossils, such as leaf and stem impressions and petrified wood, have been found but are very rare.

## Diagenetic History of the Garber Sandstone

Over time, the Garber sediments were buried by about 2,000–2,500 ft of younger deposits (Breit, 1998) and lithified (changed to rock). During burial, lithification, and later exposure, the rocks were diagenetically altered. Outcrops of the Garber Formation in the Arcadia Lake parks, as well as in other parts of Edmond and Oklahoma City, vary greatly in color and hardness; these differences are evidence of the Garber's complex diagenetic history (Breit, 1998).

One of the most obvious characteristics of the Garber Formation (and of most other Permian formations in Oklahoma) is its red color. The red color is caused by a thin coating of hematite on the quartz grains which make up most of the rock (Fig. 9). Some of the hematite probably formed in soils adjacent to rivers that deposited the Garber sediments. Other hematite, however, probably formed after the sediment was buried and lithified, through the oxidation of iron-bearing minerals in the sandstone. The hematite generally forms a weak cement; rarely, however, the sand grains are cemented by hard, silver-gray specular hematite (Fig. 9).

Variations in the red color of the Garber sandstones are due mostly to differences in the amount of hematite in the rocks (Breit, 1998). In places, Garber sandstones are yellow-brown to brown; these colors are caused by different iron-oxide minerals, such as goethite and limonite (Fig. 9).

Although most of the sandstone in the Garber Formation is weakly cemented by hematite, some is well cemented by calcite, dolomite, barite, or quartz, or by a combination of some or all of these minerals (Breit, 1998) (Fig. 9). These minerals precipitate or crystallize out of ground water that slowly moves through the rocks. At first, they form a thin coating on individual sand grains. With continued precipitation, the mineral coatings on adjacent grains may grow together, possibly filling all the void space. Some of the calcite probably was derived from nodules that formed in the Permian soils in the area; other calcite formed after the Garber Formation was exposed and ground water moved through it. The dolomite and barite precipitated from seawater that probably invaded the Garber sediments after they were deposited. The original source of the quartz cement probably was dissolved silicate minerals, such as feldspar, that originally were in the sediment. To summarize the diagenetic history of Garber cements other than hematite, calcite cements formed both very early (in Permian soils) and very late (after the Garber sandstones were exposed), whereas dolomite, barite, and silica cements formed when the Garber was deeply buried (Breit, 1998).

The Garber Formation also has a number of particularly interesting geologic features due to its complex diagenetic history. Calcite nodules are relatively common in the Garber sandstones. Different nodules, known to rockhounds as Oklahoma mudballs, form in siltstone and shale. They are sparse in the Garber but are widespread in the underlying Wellington Formation. Calcite nodules and Oklahoma mudballs occur in the Arcadia Lake parks. The State Rock of Oklahoma, known as the Barite Rose or Rose Rock, also comes from the Garber Formation, mostly east of Norman, Noble, and Slaughterville. Rose rocks form when barite crystallizes, as divergent groups of tabular crystals, around sand grains coated with red hematite. Rose rocks have not been found at Lake Arcadia.

### The Garber-Wellington Aquifer

Understanding the geology of the Garber Formation is important because the Garber and underlying Wellington Formations supply fresh water to many municipalities in the Oklahoma City area. These two formations are good aquifers because they contain abundant sandstone, and the sandstone commonly is poorly cemented and porous. Rain falling on the surface of the ground either: (1) flows into nearby streams; (2) evaporates; (3) soaks into the ground and is used by plants; or (4) soaks into the ground, accumulates, and becomes what is known as ground water. The ground water is found between the individual grains that make up a sedimentary rock (Fig. 9); in a sandstone such as the Garber, as much as 20% of the rock consists of pore space filled with water. The feature that makes the Garber and Wellington Formations good aquifers is that the pore spaces are connected, making the water easy to extract.

About 95% of the ground water used in the Oklahoma City metropolitan area comes from the Garber-Wellington aquifer (John Harrington, director, Water Resources, Association of Central Oklahoma Governments, personal communication, 1999). Other sources of ground water used to supply municipal, industrial, commercial, and domestic needs in the Oklahoma City metropolitan area are geologic formations beneath the Wellington and unconsolidated Quaternary alluvium and Pleistocene sand and gravel deposits (Christenson, 1998). (Quaternary alluvium is the unconsolidated sediment in the modern river beds and stream beds. Pleistocene sand deposits, discussed in Stop 4 on page 14 of the field guide, consist of similar material, but are much older and are at a higher elevation than the modern deposits.)

Fortunately, the overall quality of water in the aquifer is very good, based on studies by the U.S. Geological Survey (Christenson, 1998). Some naturally occurring trace elements are present in slightly elevated concentrations; they include arsenic, chromium, selenium, and uranium. None of the elements at the concentrations measured, however, are known to pose a health concern. Under some urban areas near Oklahoma City, however, local ground water contains elevated concentrations of herbicides, pesticides, and volatile organic compounds that are known to be used in those urban areas (Christenson, 1998). Most of those areas have been identified and the water is not used.

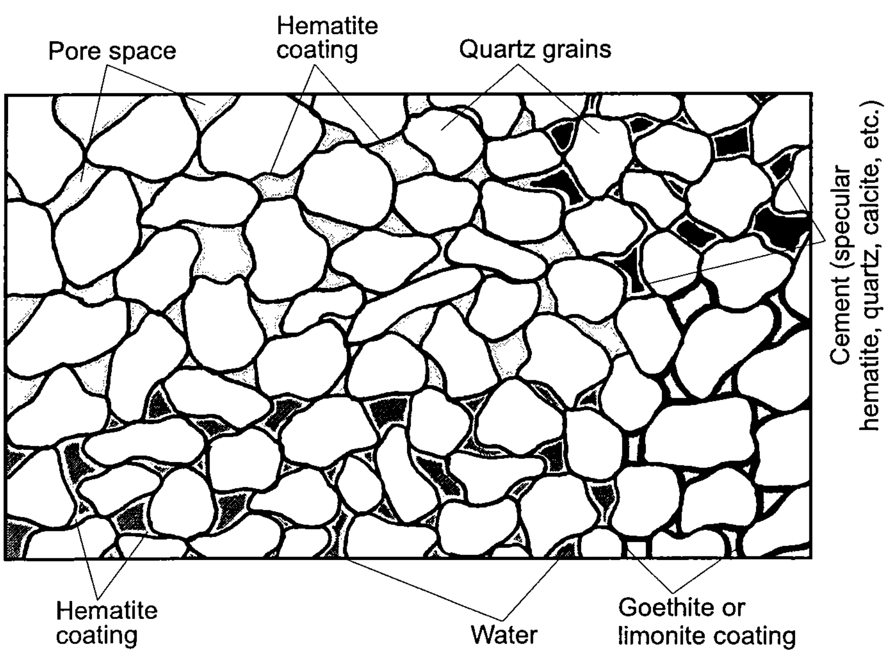



Figure 9. Diagram showing a magnified view of Garber sandstone and some differences in mineral coatings and cement. Pore spaces typically are filled with air near the surface and with water at depth. Abundant, interconnected pore spaces make the Garber an excellent aquifer. Light gray surrounding grains—hematite; dark gray surrounding grains—goethite or limonite; no pattern in pore space—air; dark gray in pore space—water; black in pore space—cement.

### Summary

The rocks exposed in the Arcadia Lake parks are in the Garber Formation. The underlying Wellington Formation is exposed east of Lake Arcadia, and the overlying Hennessey Formation is exposed in, and west of, Edmond.

The sandstone and lesser amounts of conglomerate, siltstone, and shale of the Garber were deposited about 260 Ma in a broad, westerly flowing, Permian river system. Between the different streams that made up the system, sediments were locally exposed long enough for soils to develop. After Garber sediments were buried by younger sediments, the Garber sand underwent a number of diagenetic changes as it lithified to a sandstone. However, most of the pore spaces remained open—a very important non-change, from an economic point of view, because the pore spaces later filled with ground water that now can be retrieved and used.

# GUIDE FOR A GEOLOGY FIELD TRIP IN THE ARCADIA LAKE PARKS

## Introduction

Outcrops of the Garber Formation along the shores of Lake Arcadia in the City of Edmond's parks exhibit many of the features discussed in the preceding introduction to the geology of the area (page 3). Some of the features that can be examined are examples of geological forces acting today; other features formed about 260 Ma (million years ago) during the Permian Period, when the sediments that have become present-day rocks were deposited in an ancient river system. As part of its naturalist's programs in the Arcadia Lake parks, the City of Edmond encourages visitors to follow this guide to Garber outcrops and other geologic features in the parks.

Figure 10 shows the six stops on this geological field trip. Driving or walking directions are given for each stop. Allow three to four hours to visit all the stops and examine the outcrops. Because geological processes—particularly erosion—continue at Lake Arcadia, it may not be possible to see exactly what is shown in every photograph in this guide. However, visitors can use the photographs to help them identify the geological features described at the stops. Please note that there is a per-vehicle fee ($6 Monday–Thursday, $7 Friday–Sunday and holidays) for entering one or all of the three parks in Stops 3–6.

## STOP 1
## Lake Arcadia Dam

*Outcrops below the north end of Lake Arcadia dam*
(Fig. 10, Stops 1A,B)

***Directions:*** From the intersection of State Highway 66 (also called Second Street in Edmond) and Interstate 35, drive east about 3.2 mi. Turn right (south) on the road to the Arcadia Lake Project Office. Park in the parking lot. As you face the office, walk to the right around the building to the service road behind it. Follow the service road toward the dam. Cross the emergency spillway. As the road begins to climb up the north end of the dam, leave the road on the righthand side and follow a faint trail beside the pinkish, stepped concrete at the base of the dam. Stay on the trail as it passes to the left of a group of trees and follow it to the low concrete steps at the lakeshore. Stop 1A is the nearly rectangular slab of sandstone outcrop that juts into the lake about 80 ft from the steps (away from the dam).

### *Stop 1A—Ripple Marks*

There are ripple marks on the surfaces of Garber sandstone slabs at several locations around Lake Arcadia. One of the best places to see them is on the nearly rectangular slab just below the north end of the dam (Fig. 10, Stop 1A). The surface of one of the Garber sandstone beds at this location is covered with U-shaped ripple marks (Fig. 11). Most of the ripples are concave in the down-current direction (right to left in Fig. 11); these are the surface expression of trough

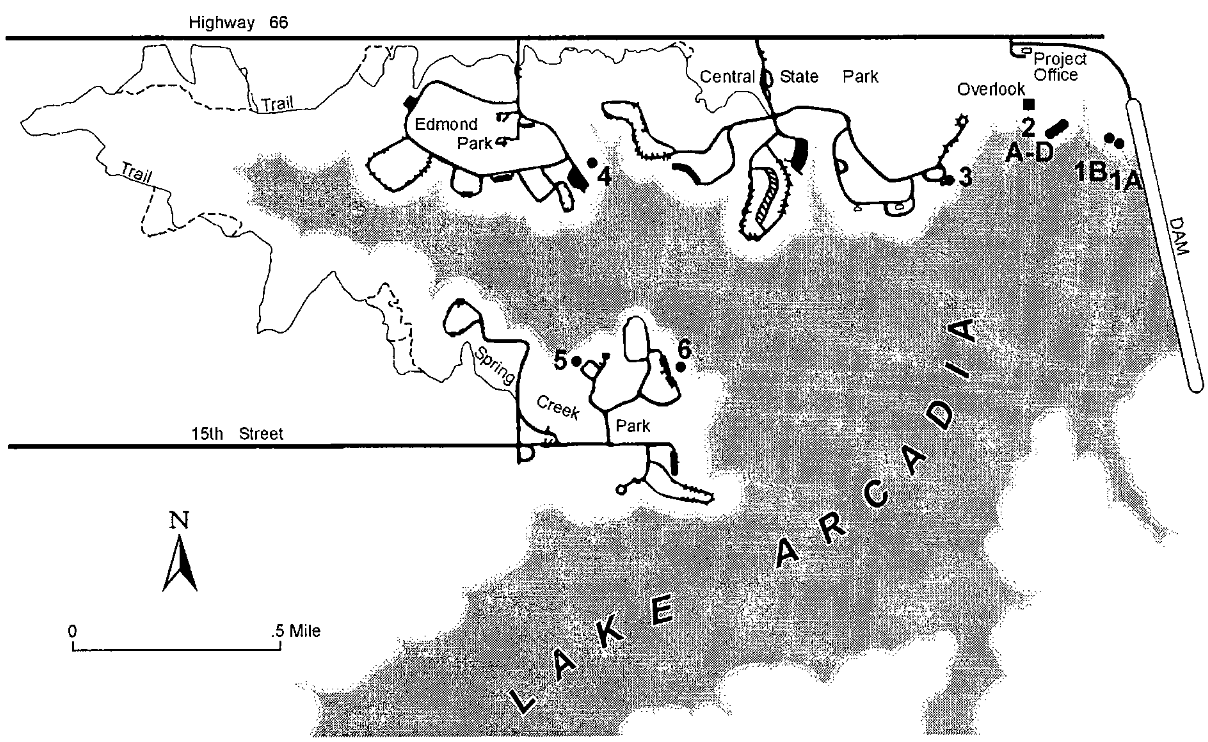



Figure 10. Map of the Arcadia Lake parks showing the locations of the numbered stops described in the guide for a geology field trip.

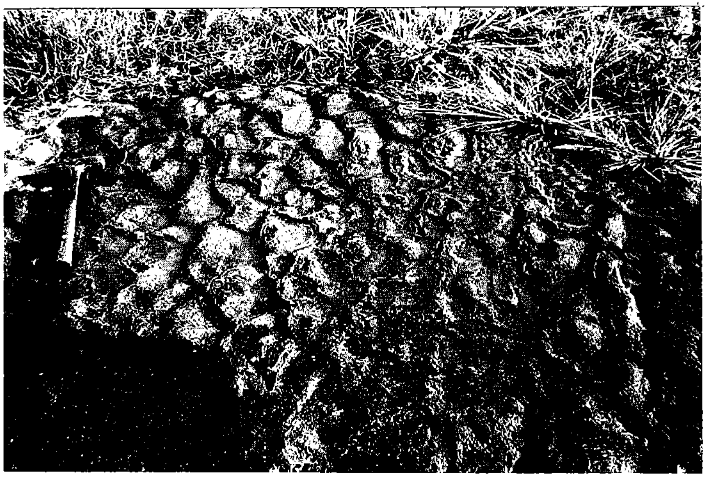


Figure 11. Ripple marks in sandstone of the Garber Formation near the north end of Lake Arcadia dam (Fig. 10, Stop 1A). Two kinds of ripple marks can be seen: lunate (concave in the down-current direction) and linguoid (convex in the down-current direction). These kinds of ripple marks are evidence that the sand was deposited by flowing water. The concave sides of most of the ripple marks face down-current—in this case, from right to left (approximately west). Hammer (13 in. long) for scale. Hammer head points north.

Figure 12. Overhanging ledge of Garber sandstone near the north end of the Lake Arcadia dam (Fig. 10, Stop 1B). The ledge formed because the softer siltstone beneath the sandstone is easily eroded by small waves when the lake level is higher. Hammer (13 in. long) for scale.

cross-beds and are known as lunate ripple marks. Some of the ripple marks are convex in the down-current direction; they are called linguoid ripple marks. Lunate and linguoid ripple marks are formed by water—such as in a river or stream—that moves more or less constantly in a uniform direction.

### *Stop 1B—Sandstone Ledge and Oklahoma Mudballs*

Approximately 125 ft northwest of Stop 1A (away from the dam) is Stop 1B (Fig. 10), a slab of sandstone that has been undercut by the water to form a small overhanging ledge (Fig. 12). The sandstone overlies siltstone, which is softer and more easily eroded than the sandstone. The numerous spherical cobbles on the ground beneath the ledge have eroded out of the siltstone (Fig. 13). Many of these cobbles are "Oklahoma mudballs," the centers of which contain many small cracks and voids that are partially filled with calcite. Oklahoma mudballs resemble geodes (hollow or partly hollow rounded rocks in which the cavity is lined with inward-projecting crystals), but they have a different origin. Mudballs form when sediment suspended in water comes together to form clot-like masses at the top of the sediment. If there is a change in the salinity of the water surrounding the mudballs, water escapes from the pores of the mudballs and the centers develop syneresis (shrinkage) cracks. After the mudballs are buried and lithified, calcite precipitates out of ground water and partially fills the syneresis cracks.

Oklahoma mudballs are common in shale and siltstone layers in the Wellington Formation that underlies the Garber, and the siltstone at this stop is very similar to that in the Wellington. However, the mudball-bearing siltstone at this location is in the Garber. Evidence of this is that a thick Garber sandstone is exposed on the east side of the dam at an elevation below that of this siltstone. Since the siltstone at this stop overlies a Garber sandstone, it is in the Garber also.

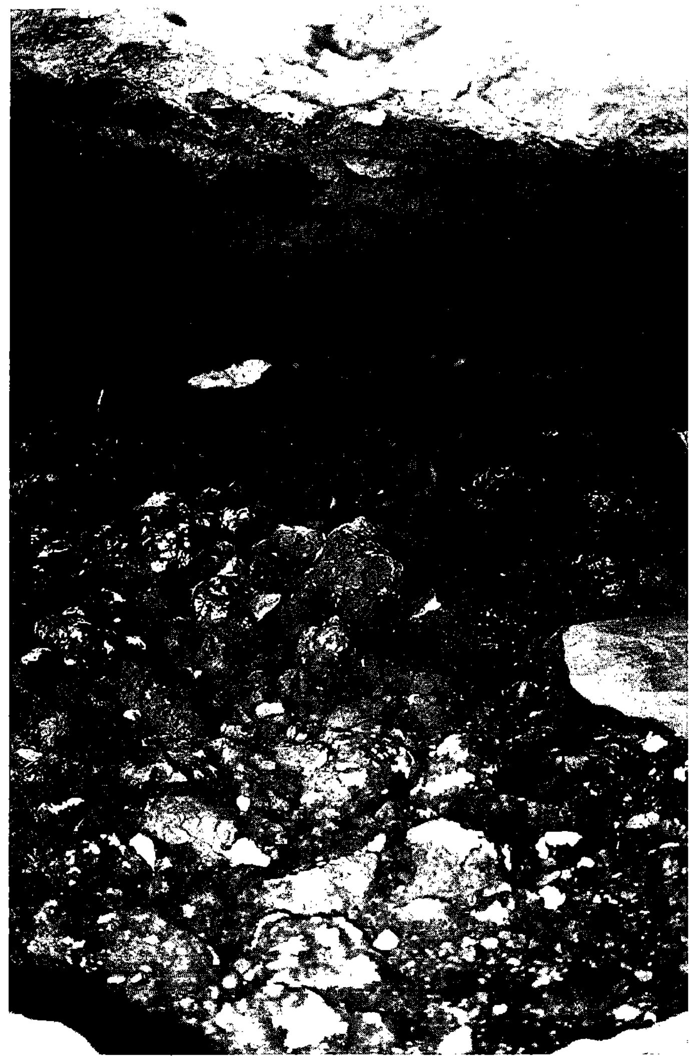


Figure 13. Oklahoma mudballs and other rock fragments on the ground beneath the overhanging ledge shown in Figure 12.

The sandstone that forms the "ceiling" of the overhang is light blue-gray in color, rather than the brick red that is typical of Garber sandstone. Throughout the Garber Formation, sandstone immediately overlying a finer grained rock, such as siltstone or shale, commonly is this color. There are two possible explanations for the discoloration: (1) The very base of the sandstone may have had a higher content of organic material than did most of the sandstone. Decay of the organic material produced a very localized geochemical environment (reducing environment) at the base of the sandstone. In such an environment, iron-bearing minerals would not be oxidized, and the red color would not form. (2) It is also possible that ground water percolated down through the sandstone and "pooled" at the base of the sandstone (immediately above the less permeable siltstone). Thus, the lower part of the sandstone would be saturated more frequently and for longer periods than the upper part. Ground water with a slightly reducing geochemistry would therefore affect the base of the sandstone more than the rest of it, resulting in a red (oxidized) sandstone bed with a discolored or light blue-gray (reduced) base.

## STOP 2
## Overlook Point

*Outcrops on and near peninsula below overlook pavilion*
(Fig. 10, Stops 2A–D)

***Directions:*** Follow the directions given for Stop 1 to the parking lot in front of the Arcadia Lake Project Office; or, from Stop 1, return to the Project Office. Follow the paved walk that goes to the overlook. About 75 ft before you reach the overlook pavilion, take the dirt trail on the left that goes to the lakeshore. At the fork in the trail, stay to the right and walk to the flat outcrop that forms a small point jutting into lake. This is Stop 2A.

### *Stop 2A—Jointing*

A nearly perpendicular set of joints (fractures) gives the sandstone in this outcrop a blocky appearance (Fig. 14). In general, deformation of the Earth's crust produces joints. However, in this part of Oklahoma, the rocks are almost undeformed, and the origin of these particular joints is unclear. They may be associated with past movement of the Nemaha uplift, a buried tectonic feature that trends north–south beneath the Oklahoma City metropolitan area (Luza, 1995).

### *Stop 2B—Mud Cracks*

About 60 ft northeast along the shoreline (back in the direction of Stop 1) (Fig. 10, Stop 2B) is a structure that provides additional clues about the environment in which Garber sediments were deposited. Mud cracks are rarely preserved in the Garber, but appear on the surface of a siltstone bed at this location (Fig. 15). In order for mud cracks to form, sediments must be exposed to the atmosphere long enough to dry before they are buried by younger sediments. Such exposure could occur anywhere in a river system that is periodically flooded by high water.

### *Stop 2C—Calcite Nodules*

About 30 ft northeast of the mud cracks (Fig. 10, Stop 2C) is a red Garber sandstone with small spheroidal bumps on its surface (Fig. 16). The spheroidal bumps are calcite nodules. Calcite nodules form when solids in the sandstone react with water supplied largely by rain. As rainwater moves down through pores (open spaces) in sandstone, it dissolves some of the calcium in the rock. When the water table rises, the ground water closest to the surface begins to evaporate and becomes saturated with calcium. The calcium combines with carbon dioxide (from the atmosphere) to form calcite, which is deposited in the pores of the sandstone. The calcite typically crystallizes around individual points and, thus, forms small spheres in the rock. The calcite nodules stand in relief (Fig. 16) because the calcite-cemented sandstone is more resistant to erosion than the rest of the rock.

A low embankment (about 6 ft high) of soft, easily eroded siltstone, predominately red with a thin blue-gray band, is present in the opposite direction from the lake. The siltstone is similar to that in the Wellington Formation, but here it clearly overlies the Garber sandstone that contains calcite nodules. As has been pointed out, the contact between the Garber and

Figure 14. Perpendicular joints in an outcrop of Garber sandstone on the shore of Lake Arcadia near the north end of the dam (Fig. 10, Stop 2A). The arrow points S. 75° W.

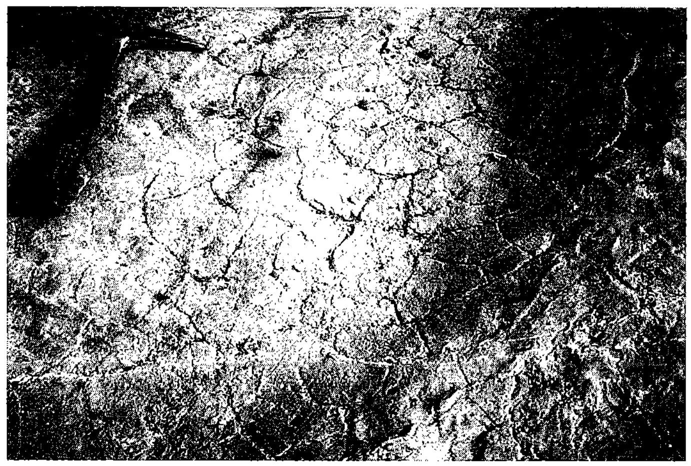


Figure 15. Mud cracks appear as faint lines on the surface of a Garber siltstone bed on the shore of Lake Arcadia near the north end of the dam (Fig. 10, Stop 2B). Mud cracks indicate that an area was exposed to the atmosphere, allowing wet sediments to dry shortly after deposition. Hammer (13 in. long) for scale.

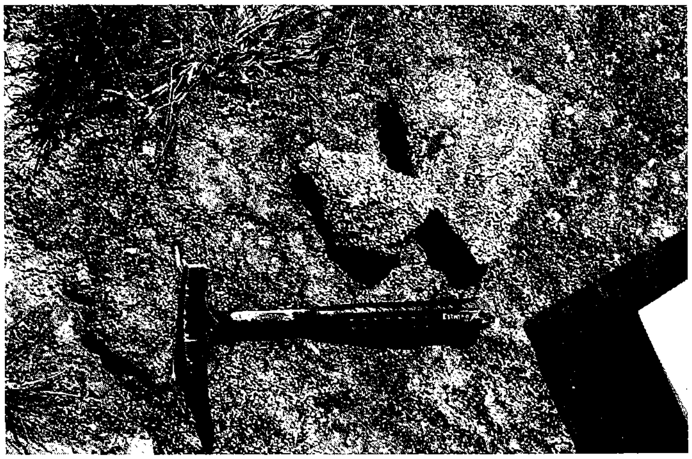


Fig. 16. Small calcite nodules (small spheroidal bumps) on a surface of Garber sandstone on the shore of Lake Arcadia near the north end of the dam (Fig. 10, Stop 2C). Hammer (13 in. long) for scale.

Figure 17. Cross section of trough-cross-bedded sandstone in a Garber Formation outcrop on the shore of Lake Arcadia near the north end of the dam (Fig. 10, Stop 2D). Trough cross-bedding is evidence for erosion and deposition of sand by flowing water; it is common in river-channel depositional environments. Hammer (13 in. long) for scale.

Wellington Formations is not clear-cut, and siltstone and shale similar to those in the Wellington occur in the lower part of the Garber. The blue-gray coloration of the siltstone and shale here is parallel to the bedding planes, as it is in the sandstone at Stop 1B. Different iron-bearing minerals in the beds probably cause the different colors (red or blue-gray). The different minerals, in turn, probably are due to slightly different chemistries in the original beds. The amount of organic material in the sediments, in particular, would influence the chemistry of the beds.

### *Stop 2D—Trough Cross-Bedding*

The 8-ft-high outcrop about 150 ft farther along the shoreline (Fig. 10, Stop 2D) shows large-scale trough cross-bedding (Fig. 17). Bedding is the manner in which the different layers of sediment or sedimentary rock are deposited. Most sediments are deposited uniformly, one on top of the other, and the bedding planes are horizontal and parallel to each other. Trough cross-bedding, however, results from sporadically deposited sediments and tilted, non-parallel bedding planes. Trough cross-bedding forms when sediments that have been deposited by flowing water are subsequently eroded, or scoured out, by strong currents to form troughs locally. Later, when the water velocity changes or the position of the channel shifts, the troughs are filled with other sediments. Trough cross-bedding is common in a river-channel environment. The process commonly produces tilted bedding planes, which are found throughout the Garber in this area.

## STOP 3
## Central State Park Cherokee Pavilion

*Outcrops along the north shore of Lake Arcadia, below Central State Park's Cherokee Pavilion in Picnic Area B*
(Fig. 10, Stop 3)

***Directions:*** From the parking lot at the Arcadia Lake Project Office, return to State Highway 66. Turn left (west) on Hwy. 66 and drive 0.6 mi to the entrance to Central State Park on the left (south). Turn left into the park. Drive south past the entrance station about 0.1 mi and turn left (east); follow the signs to Picnic Area B. Drive about 0.5 mi and turn right to Picnic Area B and the Cherokee Pavilion. Park at the pavilion (immediately on the right) and walk down to the large outcrops along the lake.

### *Conglomerate*

Most of the large rock slabs on the point below the pavilion are conglomerate (Fig. 18). The conglomerate at this location is trough cross-bedded, like the sandstone at Stop 2D, but on a much smaller scale.

Figure 18. Conglomerate in the Garber Formation on the shore of Lake Arcadia just below the Cherokee Pavilion, Picnic Area B, Central State Park (Fig. 10, Stop 3). Most of the pebble-size clasts in the conglomerate are fragments of sandstone and siltstone, or are shale rip-up clasts. Some of the fragments are dolomite that probably formed when magnesium replaced calcium in calcite nodules. It is likely that the calcite had formed in Permian soils. Hammer (13 in. long) for scale.

### Sandstone, Siltstone, and Shale Clasts

Most of the pebble-size clasts in the conglomerate consist of sandstone, siltstone, and shale that is similar to the same kinds of rocks elsewhere in the Garber. The pebbles probably consist of moderately consolidated Garber sediment that was eroded (in a process similar to that which formed the trough cross-bedding at Stop 2D) and redeposited, partly as pebbles. Clasts that have this kind of origin are called "rip-up" clasts. The shale rip-up clasts may be the upturned edges of mud cracks (similar to those at Stop 2B) that broke off and were incorporated in the conglomerate.

Many of the pebbles and cobbles on the ground at this stop appear to be mudballs (discussed at Stop 1B). However, unlike mudballs, they are unusually heavy for their sizes. The sandstone pebbles and cobbles are cemented by barite, which has a high specific gravity (the ratio between the weight of a substance and the weight of an equal volume of water) of 4.5. Unlike the barite in Oklahoma rose rocks (discussed on page 9), the barite here did not form tabular crystals.

### Dolomite Clasts

White or cream-colored dolomite clasts also occur in this conglomerate. Originally, the clasts that now are dolomite probably were calcite that had formed as small nodules and tubules in Permian soils in this part of Oklahoma. Along the banks of rivers, the soil—and the calcite nodules in the soil—were eroded by the river and became part of the river's sediment. Later, some of the calcium in the calcite was replaced by magnesium, forming the dolomite.

### Clast Size and Degree of Roundness

The size of the clasts and their degree of roundness also provide clues to how the conglomerate was formed. The relatively large size (pebble size) of the sandstone, siltstone, shale, and dolomite clasts indicates that they were deposited by a strong current, such as might occur during a flood. One explanation for the mixture of rounded and angular clasts in the conglomerate is that their source area consisted of both moderately and well consolidated sediments. Moderately consolidated clasts would be rounded more quickly by moving water than would well-consolidated clasts. An alternative explanation is that most of the clasts were equally consolidated, but the more rounded clasts came from farther away and were subjected to erosion by moving water for longer periods than were the angular clasts.

## STOP 4
## Edmond Park Boat Dock

***Sand deposits from the Pleistocene Epoch on the shore of Lake Arcadia, near the boat dock*** (Fig. 10, Stop 4)

***Directions:*** From Stop 3, return to State Highway 66. Turn left (west) and drive 0.6 mi to the entrance to Edmond Park, on left (south). Turn left (south) into Edmond Park. Pass the entrance station and continue straight. Follow the main road (past the roads to the police department and lake patrol, softball field, and beach, picnic areas, and playground). Continue straight ahead to the parking lot. Park at the end close to the lake, near the boat dock. Walk toward the boat dock; turn left (north) at the shore and walk about 200 ft to the covered housing for the lake patrol boat (just on the other side of the dock).

### *Pleistocene Sand Deposits*

Unlike the rocky shoreline around much of Lake Arcadia, this area is sandy. Relatively thin deposits of Pleistocene river sands occur in many of the major stream valleys in the Oklahoma City area, including that of Deep Fork. These deposits were formed when large rivers carrying glacial meltwater flowed east from the Rocky Mountains across Oklahoma (Fig. 5). In places, these rivers followed the courses now marked by the major rivers of Oklahoma—the Cimarron, the North Canadian, the Canadian, and the Red. Elsewhere, the Pleistocene rivers followed the courses of smaller rivers. The valleys of Spring Creek and Deep Fork (both now partly occupied by Lake Arcadia) are unusually wide for the size of the small streams that now run through them. This is evidence that the streams were once much larger (Fig. 19).

The sand near here also contains a wide variety of rounded pebbles that are very different from those in the conglomerate near Cherokee Pavilion in Central State Park (Stop 3). Most of the pebbles here consist of quartz and quartzite that probably came from the Rocky Mountains—further evidence that large streams and rivers of glacial meltwater once flowed east across central Oklahoma carrying debris eroded by glaciers to the west.

There are also several outcrops of red Garber sandstone along the shore. The Pleistocene sand irregularly overlies the Garber and, in some places, the Garber occurs higher up the hill (away from the lake) (Fig. 19) than the sand. This is evidence that the sand is only locally preserved on the sides of an old valley formerly occupied by the much larger streams and rivers associated with melting of the glaciers.

### *Present-Day Sedimentary Structures*

Present-day sedimentary structures occur in the sand here, both above and below the water. For example, in places, ripple marks have formed on the surface of the sand beneath the water (Fig. 20). These ripple marks are long and linear; they probably are symmetrical in cross-section. These kinds of ripples form from wave action, in contrast to the lunate and linguoid ripple marks at Stop 1A, which formed from a current flowing in one direction.

Very commonly, many different types of organisms live in, or move over, the sand. They may leave evidence behind—tracks on the sand or burrows in it, for example. A track, trail, burrow, tube, boring, or tunnel made by an ancient animal and preserved in rock is called a trace fossil. Trace fossils are useful to geologists because they show that animals were

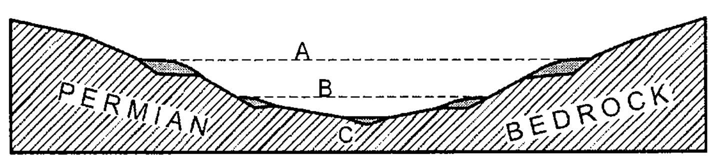



Figure 19. Sketch cross section across hypothetical Pleistocene river channel. Gray areas are sand and gravel deposits preserved on the sides of modern valleys. "A" represents the size (width) of the river channel and the original level of river sediment. "B" represents a lower level of sediment deposited by a smaller and younger Pleistocene river. "C" is a modern-day stream channel. In this sketch, the present level of Lake Arcadia would be just below "A."

Figure 20. Present-day symmetrical ripple marks on the sand in shallow water near the covered boat housing in Edmond Park (Fig. 10, Stop 4). Symmetrical ripple marks are formed by an oscillating current, such as that produced by waves.

present even without the evidence of body fossils. In some cases, certain kinds of trace fossils occur only in certain environments; for example, amphibian footprints occur in continental deposits, but not in marine sediments. It is not unusual to find fresh animal trails across the soft sand at this stop.

## STOP 5

### Spring Creek Park Comanche Pavilion

*Banded sandstone outcrop on the shore of Lake Arcadia near Spring Creek Park's Comanche Pavilion (in Picnic Area B)*
(Fig. 10, Stop 5)

*Directions:* From Stop 4, return to State Highway 66 and turn left (west). Drive about 1.8 mi to the frontage road just east of Interstate 35. Turn left (south) and drive 1 mi south. Turn left (east) on 15th Street. (Or, use Interstate 35 instead of the frontage road and drive 1 mi south to exit 140 [15th Street]. Turn left [east] on 15th Street.) On 15th Street, drive 2 mi east to the entrance station to Spring Creek Park. About 0.1 mi past the entrance station, turn left (north). When the road forks after about 0.1 mi, take the left fork to Picnic Area B and Comanche Pavilion. Drive 0.1 mi, then turn left into the picnic area (just before rest rooms). Park in the first two-car angled parking area on the right and walk down to the lakeshore, to the large, 9-ft-high outcrop.

#### *Liesegang Bands*

Many sandstone outcrops along the shore of Lake Arcadia (and in the Edmond and Oklahoma City areas) are colored a variety of reds, yellows, and browns. In places, the colors form distinct bands at an oblique angle to the bedding planes in the sandstone (Fig. 21). Such colored bands are called Liesegang bands—named for R. E. Liesegang, the chemist who first studied them in 1896.

The origin of Liesegang bands is related to the chemistry of the water filling the pore spaces in sandstone. "Oxidizing" water (water with the ability to precipitate oxide and hydroxide minerals) may move through a rock, displacing "reducing" water (water in which non-oxide minerals such as sulfides, and organic matter, are stable). The boundary between the two waters with different chemistries is a "diffusion" front. The change in water chemistry causes the oxidizing water to become supersaturated in iron, and a variety of iron-oxide minerals typically precipitates just behind the front. As the iron-oxide minerals form, iron in solution is drawn toward the minerals, leaving behind iron-deficient zones. As the diffusion front moves through the rock, the process repeats itself, producing bands of iron-oxide minerals separated by bands with little iron. The different colors are caused by different iron-oxide minerals.

Liesegang bands can also form near the surface of the earth when a rock dries. In this case, the diffusion front separates sandstone saturated with oxidizing water from sandstone in which the pore spaces are filled with air. Water just behind the front becomes supersaturated in iron, iron-oxide minerals precipitate, leaving behind iron-deficient water. Bands are formed as the "drying" front moves through the rock.

Liesegang bands commonly follow joints in the rock. Colored bands similar to Liesegang bands, but parallel to the bedding planes in a rock, typically form because the sedimentary layers have different original chemistries (e.g., they contain more or less organic material). Because of different water chemistries, different iron-oxide minerals precipitate. In places, the different kinds of banding form complex and beautiful patterns. Some craft and souvenir stores sell sandstone coasters with Liesengang bands that resemble scenery. Unfortunately, the Garber sandstone cannot be fashioned into coasters because it is too poorly cemented.

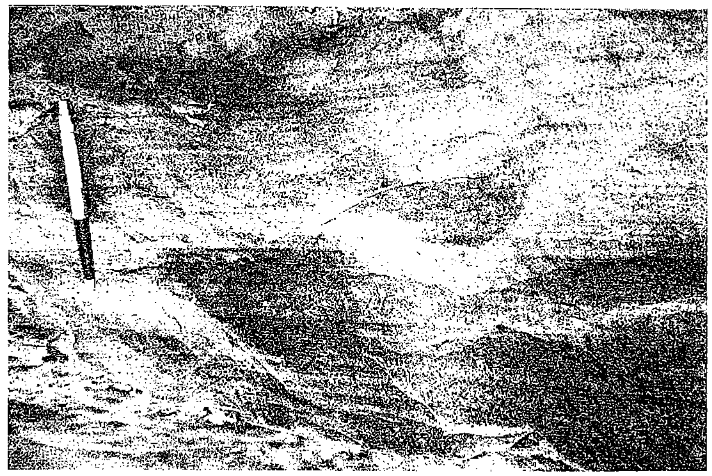


Figure 21. Liesegang bands in an outcrop of Garber sandstone on the shore of Lake Arcadia near the Comanche Pavilion, Picnic Area B, Spring Creek Park (Fig. 10, Stop 5). Liesegang bands, which typically are oblique to the bedding planes in a sedimentary rock, are formed by chemical diffusion in fluid-saturated rock. Pen (about 5.5 in. long) for scale.

## STOP 6

### Spring Creek Park Boat Ramp Parking Area

*Limestone riprap for erosion control along shore of Lake Arcadia near Spring Creek Park's boat ramp*
(Fig. 10, Stop 6)

*Directions:* From Stop 5, continue about 0.1 mi to the fork in the road. Turn left at the fork to the boat ramp. Drive 0.1 mi; turn right. Drive another 0.1 mi to the parking area for the boat ramp. Park and walk to the gray limestone boulders along the lakeshore.

### *Limestone riprap*

Gray limestone boulders similar to those at this stop are piled up in several locations around the lake in the Arcadia Lake parks. These piles of boulders are known as riprap; they are used to help prevent erosion of the lakeshore next to roads and boat ramps. The limestone boulders used for riprap around Lake Arcadia were quarried in south-central Oklahoma in the Arbuckle Mountains region and probably date from the Ordovician Period (510–439 Ma).

The limestone boulders contain many geological features that do not occur in the natural outcrops of the Garber Formation around Lake Arcadia. The most abundant features are algal mats, which appear as thin, wavy light and dark gray layers that are oriented nearly parallel to one another. Other layering consists of alternating light brown and gray rock; the light brown rock is sandstone (probably limey) and the gray rock is pure limestone. Some of the limestone consists of limestone fragments. Like the conglomerate at Stop 3, these limestone conglomerates also formed in moving water. Pyrite occurs as small gold- and red-colored crystals on the boulders. The red color is caused by the oxidation of the pyrite. Fossils are rare in the riprap boulders; however, some gastropod (snail) fossils are present.

## CONCLUSION

The geology of the Arcadia Lake parks is an important aspect of the natural history of the area. Recognizing and understanding some of the features seen in the rocks provides a window to the past. The evidence contained in the Garber Formation around the shores of Lake Arcadia (and elsewhere in central Oklahoma) provides clues to what this part of the world was like about 260 Ma during the Early Permian. Geology is also a window to the future. We must learn as much as we can about how water moves in the Garber sandstone and what happens to it over time, in order to provide future generations with a clean and reliable source of fresh water.

## ACKNOWLEDGMENTS

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## GLOSSARY OF TERMS

(mostly from Jackson, 1997)

**algal mat**—A layer of blue-green algae and fungi growing over the surface of sediment.

**aquifer**—A body of rock permeable enough to yield significant quantities of ground water to wells and springs.

**asymmetric ripple marks**—See *ripple marks.*

**barite**—An unusually dense mineral, barium sulfate, $BaSO_4$.

**bed**—A layer of sediment or sedimentary rock bounded by bedding planes.

**bedding plane**—A planar surface that separates successive layers of stratified rock; a plane of deposition.

**calcite**—A mineral, calcium carbonate, $CaCO_3$; the principal component of limestone and a common cement of sandstones.

**cement**—Mineral material, usually chemically precipitated, that occurs in the pore spaces of a sedimentary rock thereby binding the individual grains together.

**clast**—An individual grain or fragment of a sediment or rock.

**conglomerate**—A rock composed of rounded fragments larger than 2 mm in diameter embedded in a finer-grained matrix.

**cross-beds (cross-bedding, cross-bedded)**—The internal arrangement of the layers in a sedimentary rock, usually sandstone, in which minor beds are more or less regularly inclined at various angles (typically 10°–40°) to the principal layers in the rock; produced when sediments are deposited by moving air or water. Compare *planar beds.*

**cross section**—A diagram or drawing that shows features cut by a vertical plane.

**crystallize (crystallization)**—The process by which material becomes crystalline, i.e., acquires an orderly arrangement of atoms or molecules.

**deformation**—A general term for the process of folding, faulting, shearing, compressing, or extending rocks as a result of various Earth forces.

**depositional environment**—The geologic setting in which sediments accumulate, e.g., river, shoreline, lake, shallow marine, etc.

**diagenesis (diagenetic, diagenetically)**—All the chemical, physical, and biologic changes undergone by a sediment after its initial deposition, and during and after its lithification, exclusive of weathering and metamorphism.

**dolomite**—A mineral, calcium-magnesium carbonate, $CaMg(CaCO_3)_2$.

**erosion (eroded)**—The general process or processes whereby the materials of the Earth's crust are loosened, dissolved, or worn away, and moved from one place to another, by natural agencies.

**feldspar**—A group of alumino-silicate minerals with the general composition $M[Al(Al,Si)_3O_8]$, where M usually is K, Na, or Ca; the most abundant (60%) mineral in the Earth's crust.

**flood plain**—The relatively smooth land adjacent to a river channel constructed by the river and covered with water during floods.

**formation**—A body of rock that can be recognized at different locations because of the rock types it contains and its position relative to underlying and overlying formations; it is the fundamental mappable geologic unit. A rock unit usually is given a formation name if all the rocks in that unit are similar, contain similar fossils, or show the same repetitions of different kinds of rocks.

**geomorphic**—Pertaining to the general configuration of the Earth's surface or its surface features.

**goethite**—A mineral, hydrated ferric oxide, $HFeO_2$.

**ground water**—That part of subsurface water that is in the zone of saturation, in which all the spaces between rocks and the particles that make up the rocks are filled with water.

**group**—Two or more contiguous formations with significant and diagnostic features in common; a unit next in rank above formation.

**hematite**—A common iron oxide mineral, $Fe_2O_3$; commonly a deep-red or red-brown.

**interbedded**—Said of beds lying between or alternating with others of different character.

**joint**—A planar fracture or crack in a rock along which no movement has occurred.

**limestone**—A common sedimentary rock composed mostly of calcite and formed by either organic or inorganic processes; many contain fossils.

**limonite**—A general field term for a group of brown, amorphous, hydrous ferric oxides with variable chemical and physical properties.

**linguoid ripple mark**—See *ripple mark.*

**lithify (lithification)**—To consolidate from a loose sediment to a solid rock.

**lunate ripple mark**—See *ripple mark.*

**Ma**—Million years old.

**meandering**—Said of a stream that has regular freely developing sinuous curves, bends, loops, turns, or windings.

**member**—A geologic unit next in rank below a formation, comprising some specially developed part of a formation.

**mud crack**—A crudely polygonal fracture formed by the shrinkage of clay, silt, or mud as a result of drying under atmospheric conditions.

**nodule**—A small, irregularly rounded mass of a mineral or mineral aggregate, usually with a different composition from the enclosing sediment or rock matrix.

**outcrop**—That part of a geologic formation that appears at the Earth's surface.

**oxidizing environment (oxidizing water, oxidized, oxidation)**—A natural environment in which the minerals formed typically are oxides.

**paleosol**—A soil that formed on a landscape in the past and has been preserved in the geologic record.

**permeable**—Said of a porous rock that easily transmits a fluid, such as water or oil. A rock can be porous but not permeable if the pore spaces between the grains are not connected.

**Permian**—In geologic time, about 290 to 245 million years ago. Most of the rock outcrops in central and western Oklahoma, especially those that are red, are Permian.

**planar beds (planar bedding)**—The internal arrangement of the layers of a sedimentary rock in which minor beds are parallel to the principal layers in the rock; typically produced when sediments are deposited by still or slowly moving water, rarely by very rapidly moving water. Compare *cross-beds.*

**Pleistocene Epoch**—In geologic time, about 1.6 million years ago to 10,000 years ago.

**pore space**—The open spaces in a rock or sediment.

**porous**—Having numerous pore spaces, whether connected or isolated. In a sandstone, the spaces occur between the individual sand grains.

**precipitate (precipitation)**—The process by which a substance is deposited in solid form from a solution in which it is present.

**primary sedimentary structure**—See *sedimentary structure.*

**pyrite**—A mineral, iron sulfide, $FeS_2$.

**quartz**—A common rock-forming mineral, crystalline silica, $SiO_2$.

**quartzite**—Either a metamorphosed sandstone or a very hard but unmetamorphosed sandstone consisting of quartz grains thoroughly cemented together by secondary silica.

**Quaternary Period**—The current period of geologic time; it began 1.6 million years ago and consists of two epochs: Pleistocene and Holocene (Recent).

**reducing environment (reducing geochemistry, reduced, reducing water)**—A natural environment in which the sediments that accumulate typically are rich in organic carbon and iron sulfide.

**ripple mark**—An undulatory surface on a sediment or sedimentary rock produced on land by wind and subaqueously by currents or wave action. Ripple marks can be symmetric (crest of ripple mostly straight, sides of ripple similarly shaped), asymmetric (crest of ripple straight or curved, down-current side of ripple short and steep, up-current side of ripple long and gentle), linguoid (crests highly irregular with a tongue-shaped outline open in the up-current direction), and lunate (crests highly irregular with a tongue-shaped outline open in the down-current direction).

**riprap**—A layer of large, durable fragments of broken rock, specially selected and graded, thrown together irregularly or fitted together, designed to prevent erosion by waves or currents.

**rip-up clast**—A clast that has been "ripped up" by currents from a semiconsolidated sediment (usually mud) and transported to a new depositional site.

**sandstone**—A rock composed dominantly of sand grains that are cemented together.

**scour-and-fill**—A sedimentary structure consisting of a small erosional channel, generally ellipsoidal, that is subsequently filled.

**sedimentary rock**—A rock resulting from the consolidation of loose sediment that accumulated in layers; the loose sediment may consist of clasts, chemical precipitates, or organic material.

**sedimentary structure**—Features formed in sediments that reflect how they were deposited (primary) or deformed shortly after they were deposited (secondary).

**shale**—A rock composed mostly of clay-sized minerals formed by the consolidation of clay or mud.

**silica**—Silicon dioxide ($SiO_2$). It occurs naturally in many forms, including the mineral quartz and in less pure forms such as sand.

**silicate (minerals)**—A compound whose crystal structure contains $SiO_4$ tetrahedra.

**siltstone**—A rock composed mostly of silt-sized clasts; more coarse-grained than shale but finer-grained than sandstone.

**specular hematite**—A black or gray variety of hematite with a glossy metallic luster.

**strata**—Plural of stratum. Sheetlike layers of sedimentary rock, visually separable from other layers above and below; each typically greater than 1 cm thick and constituting part of a bed.

**stratigraphy**—The science of rock strata; concerned with the original succession, age relations, form, distribution, rock types, fossils, etc.—indeed, with all the characteristics and attributes of rocks as strata, and their interpretation in terms of environment or mode of origin, and geologic history.

**supersaturated**—Said of a solution that contains more of a dissolved substance than is normally present in a saturated solution.

**symmetric ripple mark**—See *ripple mark.*

**syneresis**—The separation of a liquid from or by a gel during aging, resulting in shrinkage and the formation of cracks.

**tabular crystals**—Crystals that have two dimensions that are much larger or longer than the third.

**tectonic**—Pertaining to the forces involved in the broad architecture of the outer part of the Earth. Tectonics is a branch of geology dealing with the regional assembling of large features on the Earth, including their mutual relations, origin, and historical evolution.

**trace element**—An element that is a very minor component of a mineral or rock.

**tributary**—A stream feeding, joining, or flowing into a larger stream.

**trough cross-bedding (trough cross-bedded)**—Cross-bedding in which the lower bounding surfaces are curved surfaces of erosion, resulting from local scour-and-fill.

**tubule**—A twiglike or branchlike concretion, typically cemented by calcite.

**water table**—The upper surface of a body of ground water.

# 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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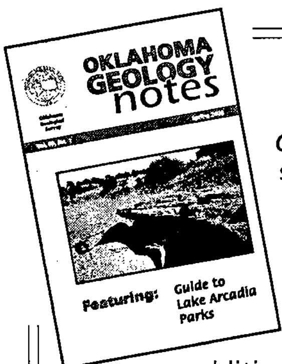


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- OF4-99. A field trip guide to the geology of the Black Mesa State Park area, Cimarron County, Oklahoma, by Neil H. Suneson and Kenneth V. Luza. Prepared for the fall meeting of the Oklahoma Academy of Science, September 17–19, 1999, Black Mesa State Park, Kenton, Oklahoma. 52 pages. 1999. $5.50.

## Overview of Oklahoma geological history:

- Educational Publication 6. Oklahoma generalized geologic time scale—the story told by rocks, by James R. Chaplin. Full-color, 22- x 34-inch poster. 1999. $3.00, folded; $4.00, laminated and rolled in tube.

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