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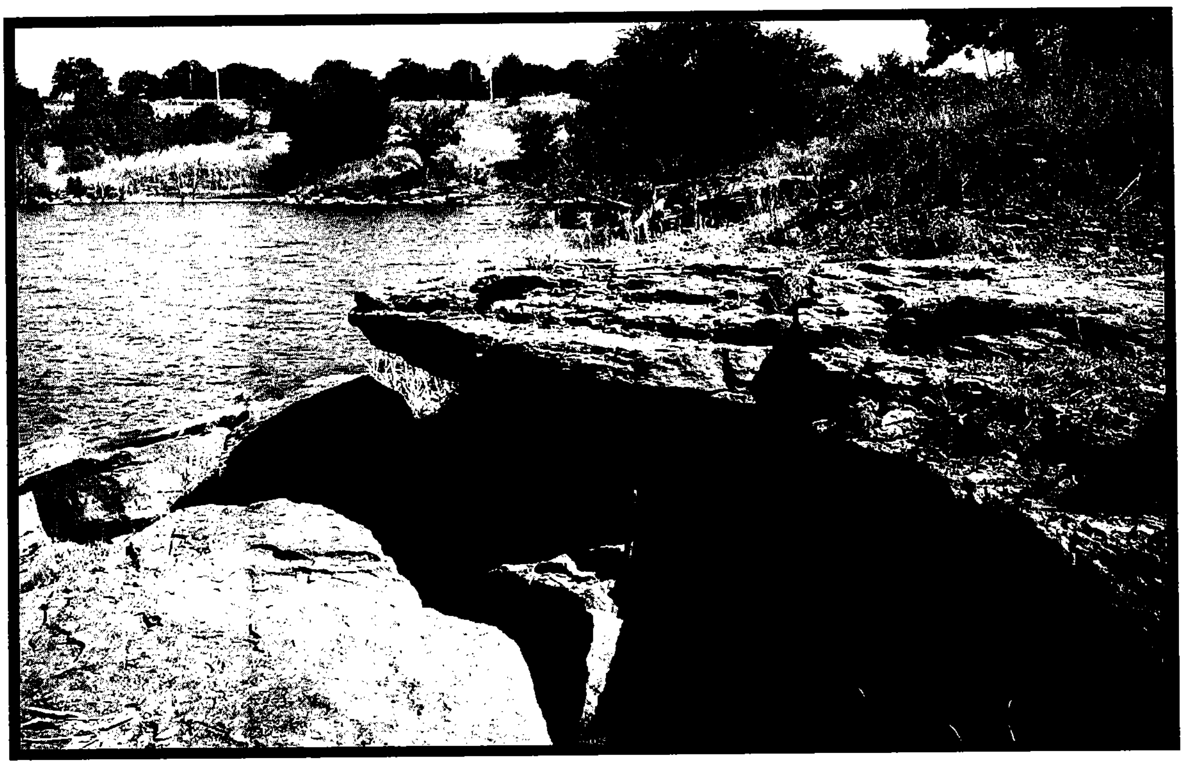

Featuring: ***Geological Guide to Arcadia Lake Parks***

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; (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. The feature article in this issue of the *Notes* (see page 4) is modified from a guidebook and road log being prepared by the same authors as an OGS Information Series publication. It will be available from the OGS and from the Project Office at Lake Arcadia.

References Cited

Bingham, R. H.; and Moore, R. L.,1975, Reconnaissance of the water resources of the Oklahoma City quadrangle, central Oklahoma: Oklahoma Geological Survey Hydrologic Atlas 4, 4 sheets, scale 1:250,000.

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Neil H. Suneson

About the changes to *Oklahoma Geology Notes*

The year of the 60th anniversary of *Oklahoma Geology Notes* seems a fitting time to freshen the design and make some other changes.

Starting with this volume, the *Notes* not only will feature a larger size and a new design, but also will be issued quarterly rather than bimonthly. In addition, Tracy Peeters takes over as the new *Notes* editor (see announcement on page 20).

The *Notes* will continue to be a leading publication in Oklahoma for technical articles and news about Oklahoma geology and the State's fuel and mineral resources.

We also hope to offer more articles that will appeal to a broad readership, such as the feature article in this issue—a guide to the parks surrounding Lake Arcadia in Edmond.

Your suggestions for the content of the *Notes* and your article submissions will continue to be very much appreciated. We also welcome information and news about events that will be of interest to our readers.

Please direct your submissions and ideas to *Oklahoma Geology Notes*, Oklahoma Geological Survey, 100 E. Boyd, Room N-131, Norman, OK 73019; phone (405) 325-3031, fax 405-325-7069.

Thanks for your continued readership. We hope you enjoy the new *Notes!*

—*Christie Cooper*

Oklahoma Geological Survey

CHARLES J. MANKIN
Director

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EDITORIAL MATTER: Short articles on aspects of Oklahoma geology are welcome from contributors; please direct questions or requests for general guidelines to the *NOTES* editor at the address above.

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OKLAHOMA GEOLOGY notes

Vol. 60, No. 1 Spring 2000

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 ~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 Permian and arc 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 ~1,800 acres (top of conservation pool) and holds ~27,520 acre-ft of water. The flood pool is 23.5 ft above the normal pool, covers ~3,820 acres, and contains ~92,000 acre-ft of water. The mean depth of Lake Arcadia at normal pool elevation is ~15 ft, and the maximum depth is ~56 ft. The area of the drainage basin for the lake is ~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. In addition, the rock outcrops along the shore of Lake Arcadia contain evidence of what this part of Oklahoma was like about 260 Ma (million years ago), during the Permian Period of geologic time.

General Stratigraphy

All of the rocks exposed along the shore of Lake Arcadia are in the lower part of the Garber Formation (Fig. 2). In the parks, most of the rocks that make up the Garber Formation are sandstone, but conglomerate, siltstone, and shale also oc-

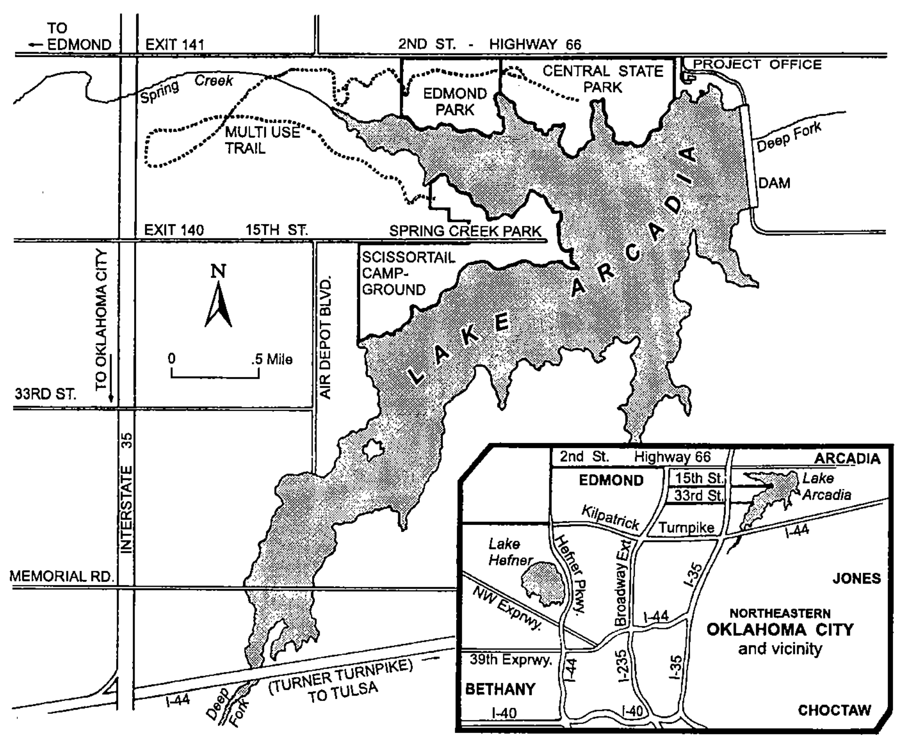


Figure 1. Map of the Lake Arcadia region showing the dam, Central State Park, Edmond Park, Spring Creek Park, and Scissortail Campground. Modified from a map provided by the Edmond Leisure Services Department.

GENERALIZED STRATIGRAPHY

PERIOD/ EPOCH		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 of Permian bedrock units near Lake Arcadia.

cur 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 the Garber's Permian (290–245 Ma) age, 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 of Leonardian (about 270–255 Ma) for the Garber (Fig. 2).

The regional dip of most of the geologic strata in the vicinity of the Arcadia Lake parks is ~50 ft per mile (about 0.5°) to the west (Fig. 3). As a result, the Wellington Formation, which is below the Garber stratigraphically (Fig. 2), is widely exposed east of Lake 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 10). The Hennessey Formation, which overlies the Garber (Fig. 2), is mostly siltstone and shale; it forms the nearly flat countryside west of Edmond.

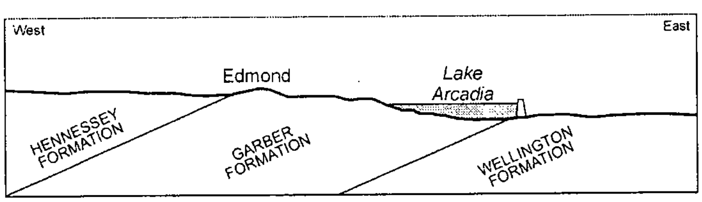


Figure 3. Diagrammatic cross section of Lower Permian strata near Lake Arcadia, where the regional dip is ~50 ft per mile to the west. (For illustration purposes, the dip of the strata is greatly exaggerated in the diagram.)

Aurin and others (1926) divided the Garber in north-central Oklahoma into two members. The lower member—the Lucien Shale—consists mostly of red shale and several red sandstone beds. The upper member—the Hayward Sandstone—consists of red cross-bedded sandstone with minor shale and conglomerate. Patterson (1933), however, showed that there is little evidence to support subdividing the Garber outside north-central Oklahoma.

At Lake Arcadia, most of the Garber Formation consists of moderately friable, poorly cemented, red to reddish brown sandstone. The lack of significant cement makes the Garber an excellent aquifer (discussed on page 10 in "The Garber-Wellington Aquifer" section). The Garber and most of the other red rocks in this part of Oklahoma get their coloring from small amounts of hematite. The hematite occurs as a thin coating on the individual quartz grains that make up the sandstone and forms a weak cement. 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. In some locations, however, the Garber is both red and well cemented.

The sandstones in the Garber also contain a variety of sedimentary structures, such as ripple marks and cross-beds. These features, discussed on pages 7 and 8, 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 more easily eroded and more poorly exposed than the sandstones. 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 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.

Regional Geologic History

Geologists' interpretations of the geologic history of central Oklahoma and the Lake Arcadia area are based on features observed in the rocks exposed at the surface and in subsurface formations that have been drilled in the search for oil and gas. The pre-Permian history (extending back to about 500 Ma) is complex and requires the analysis of thousands of well logs; it is beyond the scope of this brief report. The Early Permian history of Oklahoma can be interpreted from exposures of the Wellington, Garber, and Hennessey Formations in the Oklahoma City area.

During the Early Permian, Oklahoma was at about 15°N. latitude—about the latitude of southern India today. (Oklahoma's present latitude is about 35°N.) 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. The area was sparsely vegetated, and animal life was 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 pebbles 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 diagenetic 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 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 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 Ka [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

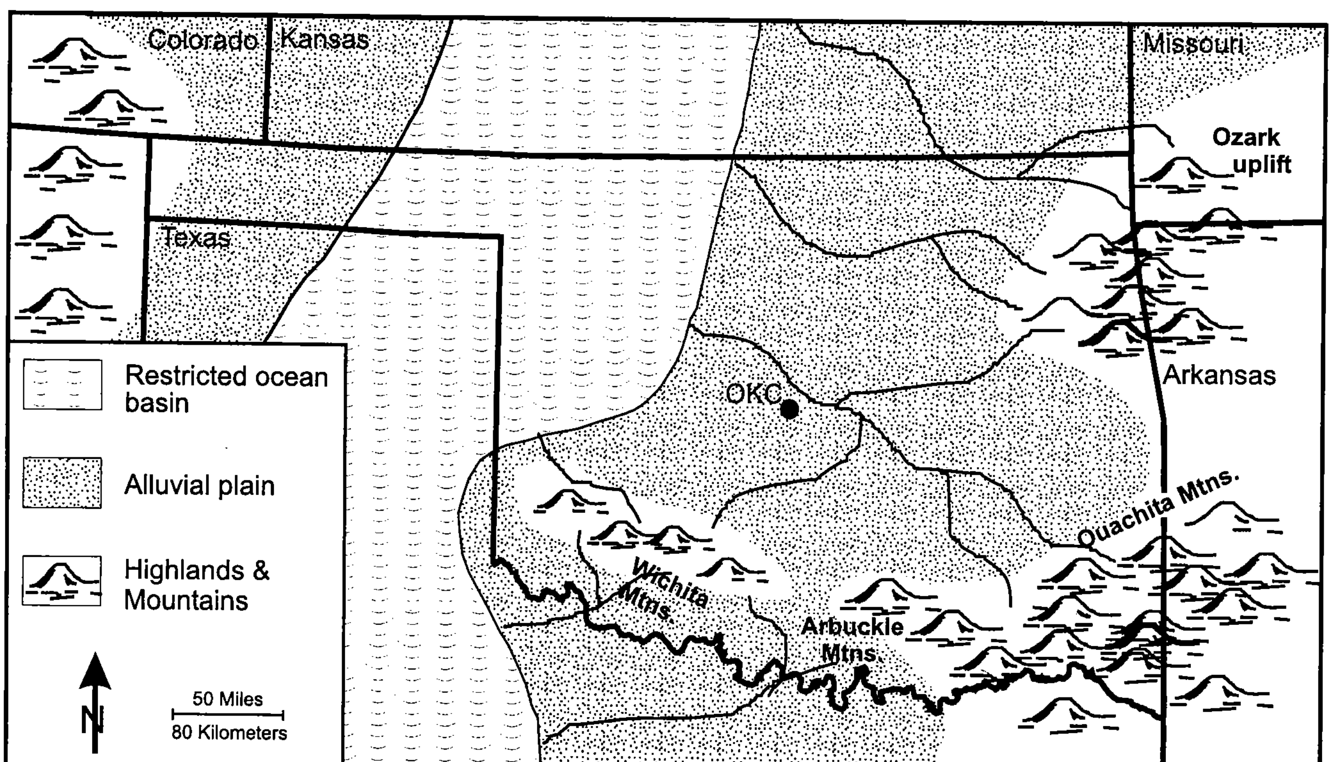


Figure 4. Paleogeographic map of Oklahoma during the Early Permian Period, when Garber Formation sediments were deposited. Most Garber sediments were deposited by rivers that flowed west from highlands in the Ozark uplift, Ouachita Mountains, Arbuckle Mountains, and Wichita Mountains areas. A shallow 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.

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.

During much of the Pleistocene, Oklahoma probably was colder (with an average temperature similar to that of present-day Minnesota's) 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 half of this article (page 11).

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 commonly 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 Oklahma 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 fomed. 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.

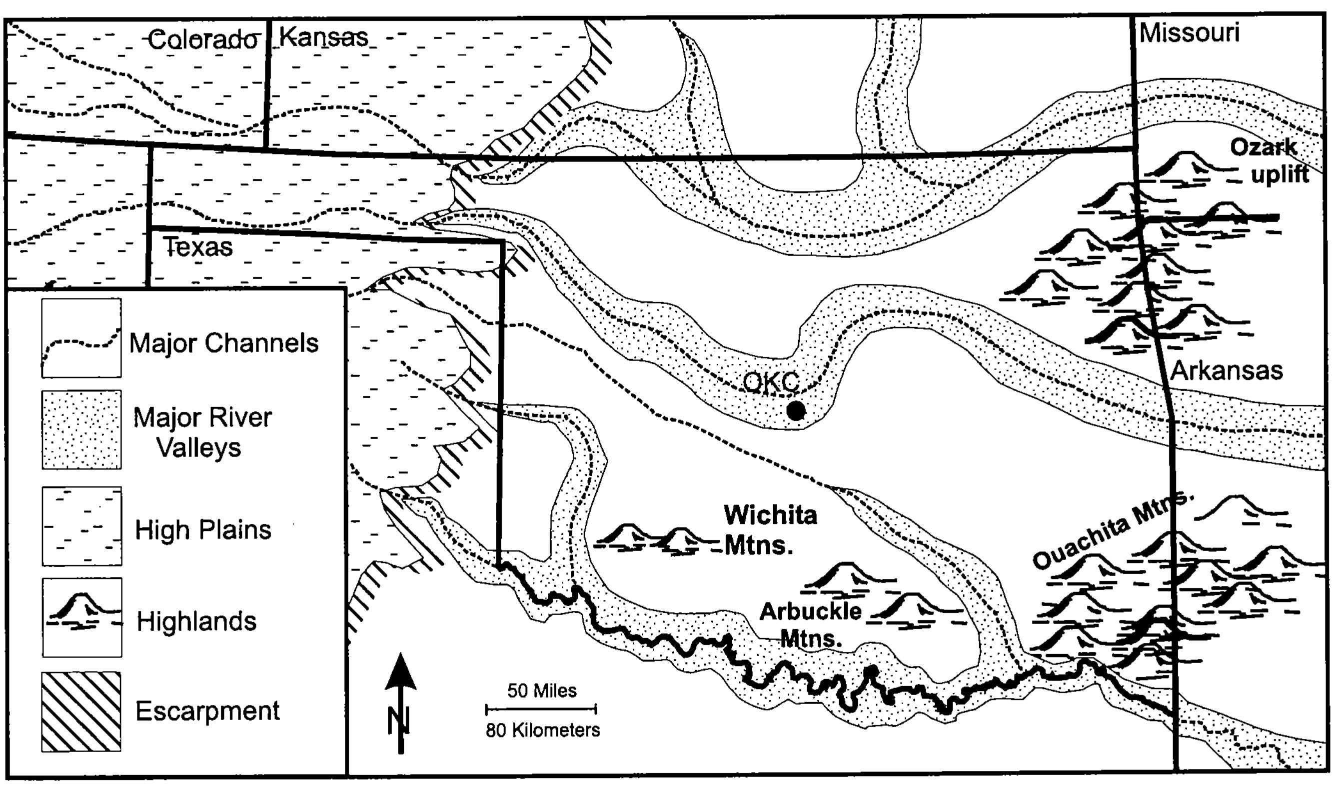


Figure 5. Paleogeographic map of Oklahoma during the Pleistocene epoch, when large rivers fed by meltwater from glaciers in the Rocky Mountains flowed across Oklahoma from west to east.

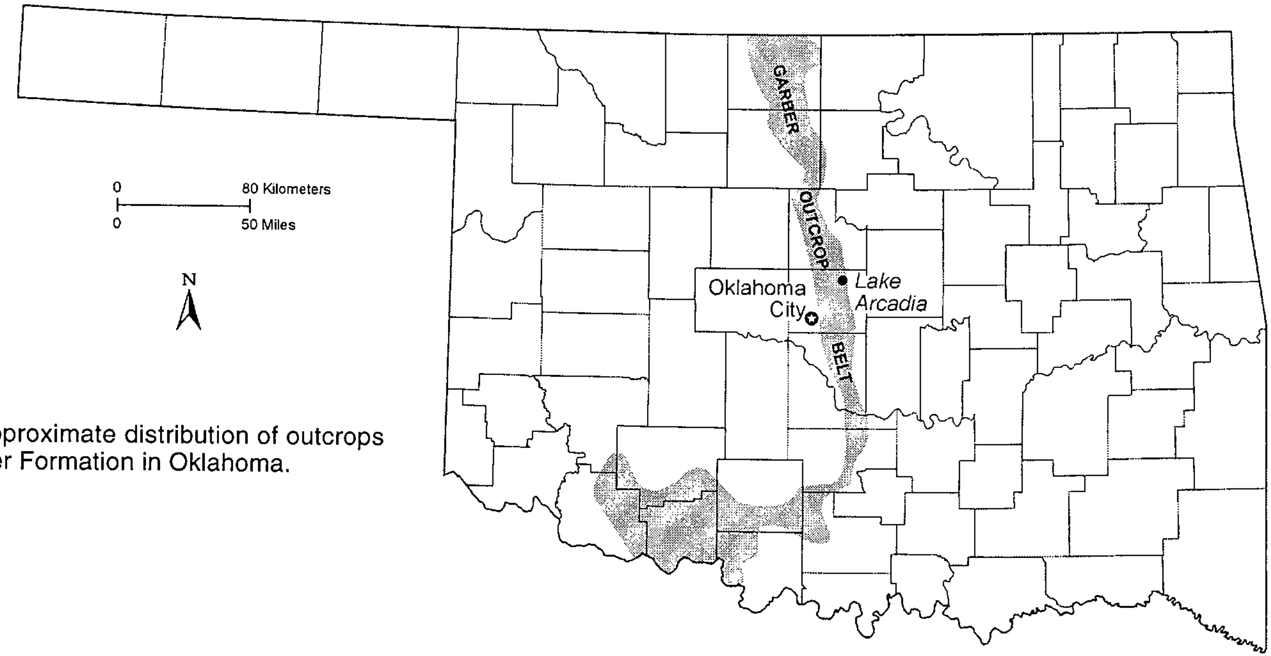
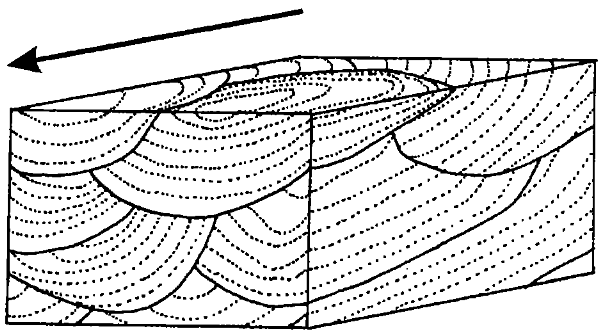
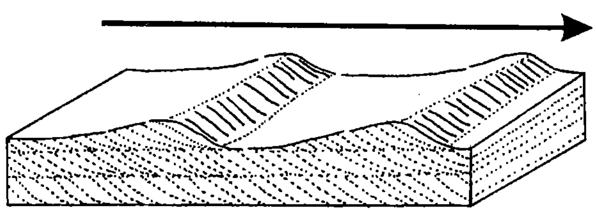


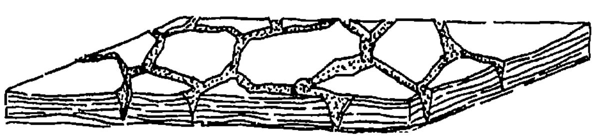
Figure 6. Approximate distribution of outcrops of the Garber Formation in Oklahoma.



(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.

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.

Mud Cracks

Mud cracks (Fig. 7C), a sedimentary feature 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, the conglomerate beds in the Garber Formation contain evidence for the existence of paleosols. Most of the fragments in the conglomerates are sandstone, siltstone, or shale.

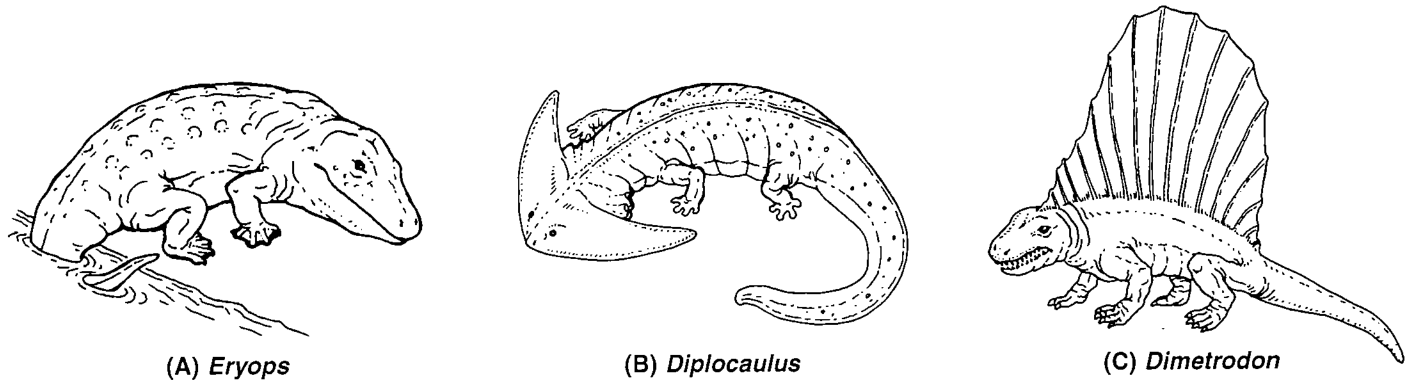


Figure 8. Drawings of the Permian amphibians (A—*Eryops*; B—*Diplocaulus*) and reptile (C—*Dimetrodon*) whose fossils are most commonly found in the Garber Formation in central Oklahoma. Illustrations by Coral McCallister.

A few, however, are dolomite, which probably originally was calcite. The calcite formed as small nodules and tubules in exposed soil under subarid to subhumid conditions. It is likely that the soil was subsequently eroded by a river or stream and that the fragments of calcite were incorporated into the river sediments. Some of the calcium in the calcite was subsequently 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 (leaf and stem impressions and petrified wood) 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. 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 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

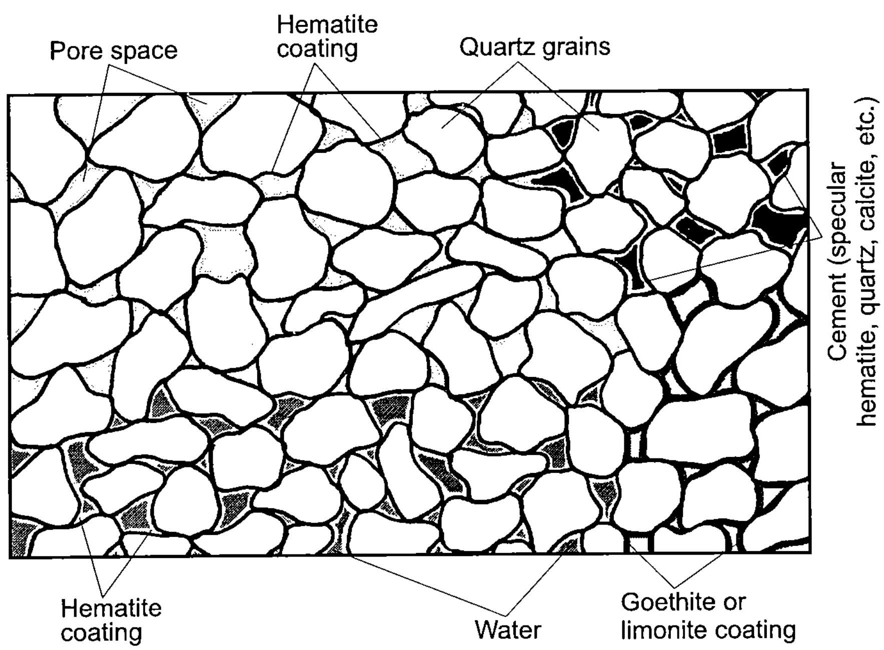


Figure 9. Diagram showing a magnified view of Garber sandstone and some differences in mineral coatings and cement. Pore spaces typically are filled with air near the surface and with water at depth. Abundant, interconnected pore spaces make the Garber an excellent aquifer. Light gray surrounding grains—hematite;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

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 was 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. In addition, the Garber and Wellington Formations are permeable, and they contain a large volume of water that is easy to extract (Wood and Burton, 1968; Christenson, 1998).

Other sources in addition to the Garber-Wellington aquifer provide municipal, industrial, commercial, and domestic water in the Oklahoma City metropolitan area. As described by the U.S. Geological Survey (USGS), the Central Oklahoma aquifer consists of the Garber-Wellington, as well as geologic formations beneath the Wellington (including the Chase, Admire, and Council Grove Groups) and unconsolidated Quaternary alluvium and terrace deposits (Christenson, 1998). About 95% of the ground water in the Oklahoma City metropolitan area, however, comes from the Garber-Wellington aquifer (John Harrington, director, Water Resources, Association of Central Oklahoma Governments, personal communication, 1999).

Fortunately, the overall quality of water in the aquifer is very good, based on studies by the USGS (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 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.

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 Henessey 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.

A brief note on collecting rocks and minerals in the Arcadia Lake parks

Thousands 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.

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 have many of the features discussed in the preceding introduction to the geology of the area (page 4). 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 ~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 ~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

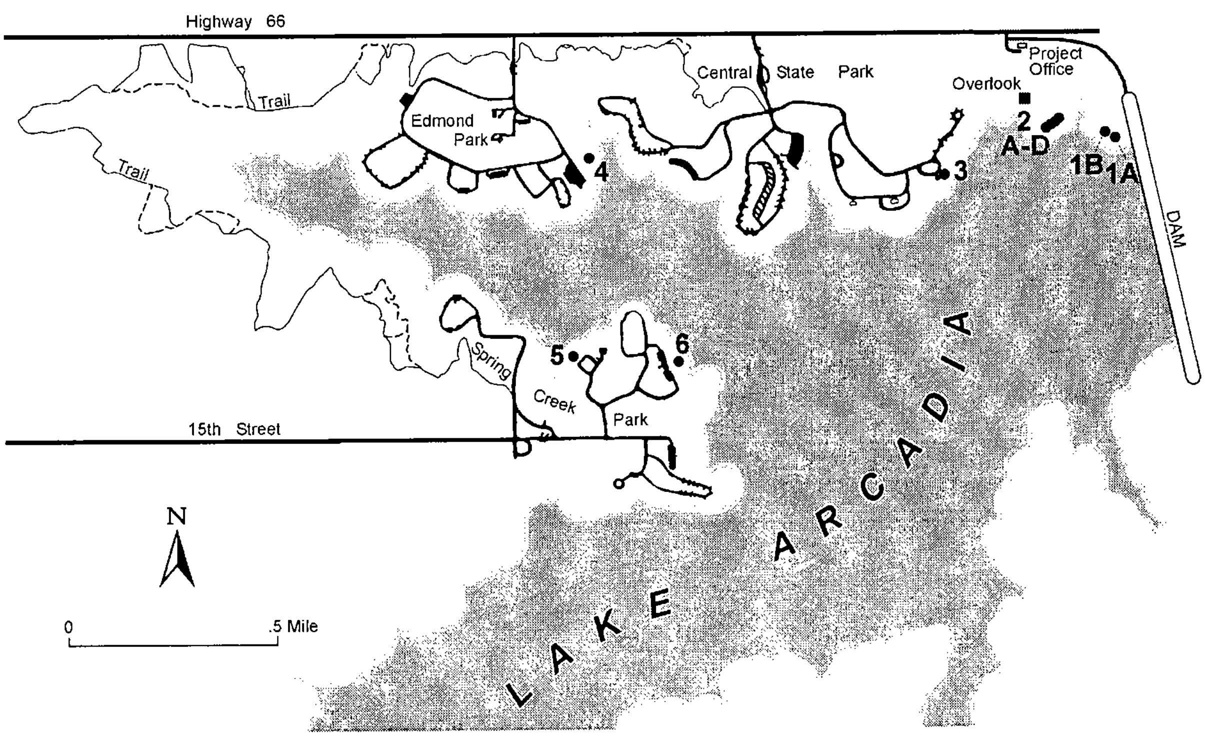


Figure 10. Map of the Arcadia Lake parks showing the locations of the numbered stops described in the guide for a geology field trip.

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 was formed by undercutting. 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, but they have a different origin. Mudballs form when sediment suspended in water comes together to form clot-like masses at the water-sediment interface. If there is a change in the salinity of the water surrounding the subaqueous mudballs, they lose pore water and the centers of the mudballs develop syneresis (shrinkage) cracks. After the mudballs are buried and lithified—forming siltstone—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.

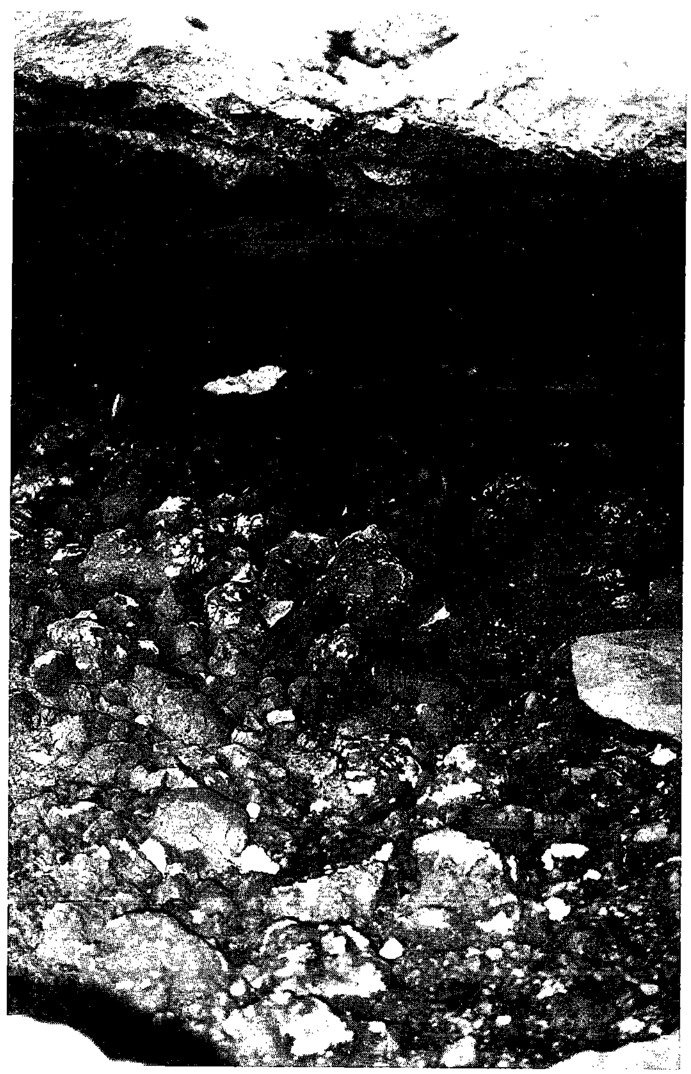


Figure 13. Oklahoma mudballs and other rock fragments on the ground beneath the overhanging ledge shown in Figure 12.

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 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 orthogonal 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 feature 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

Figure 14. Orthogonal 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.

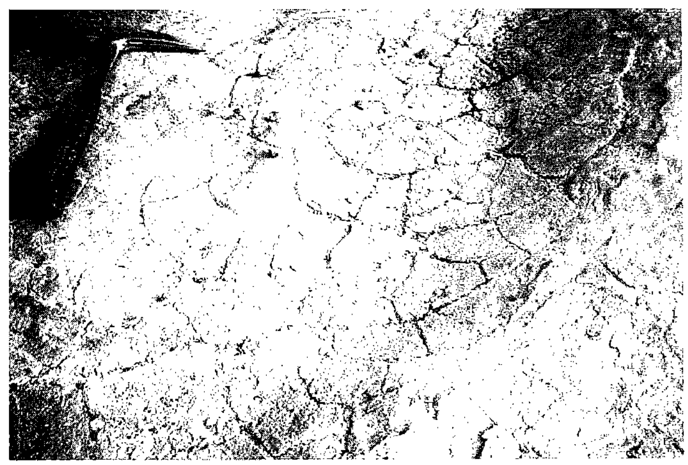


Figure 15. Mud cracks appear as faint lines on the surface of a Garber siltstone bed on the shore of Lake Arcadia near the north end of the dam (Fig. 10, Stop 2B). Mud cracks indicate that an area was exposed to the atmosphere, allowing wet sediments to dry shortly after deposition. Hammer (13 in. long)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

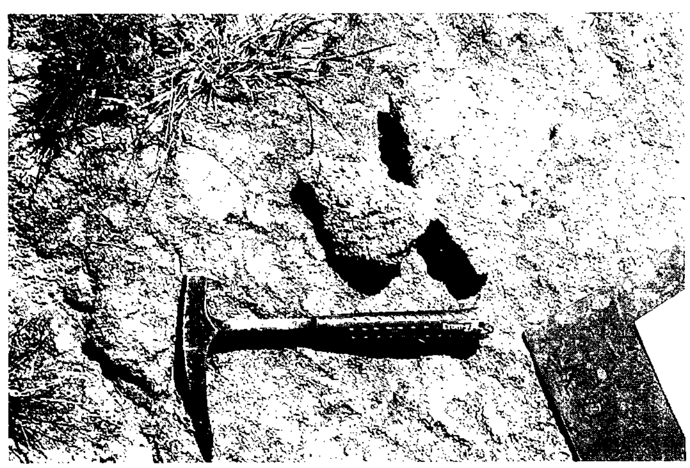


Fig. 16. Small calcite nodules (small spheroidal bumps) on a surface of Garber sandstone on the shore of Lake Arcadia near the north end of the dam (Fig. 10, Stop 2C). Hammer (13 in. long) for scale.

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.

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 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 centers of nucleation 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 (~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 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 ~150 ft farther along the shoreline (Fig. 10, Stop 2D) shows large-scale trough cross-bedding (Fig. 17). 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, a feature 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 ~0.1 mi and turn left (east); follow the signs to Picnic Area B. Drive ~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.

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 redepos-

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.

ited, 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 (4.5) specific gravity. Unlike the barite in Oklahoma rose rocks (discussed on page 10), 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 than were the angular clasts.

STOP 4
Edmond Park Boat Dock

Pleistocene sand deposits 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 ~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

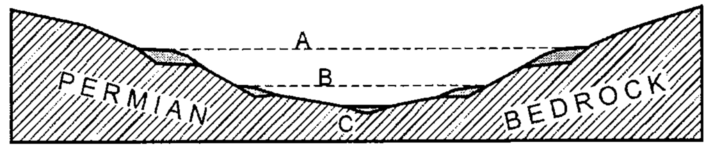


Figure 19. Sketch cross section across hypothetical Pleistocene river channel. Gray areas are sand and gravel deposits preserved on the sides of modern valleys. "A" represents the size (width) of the river channel and the original level of river sediment. "B" represents a lower level of sediment deposited 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."

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 (now partly occupied by Lake Arcadia) are wide in contrast to the small sizes of their present-day streams, indicating that the streams once were 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 old valley sides formerly occupied by the much larger streams and rivers associated with melting of the glaciers.

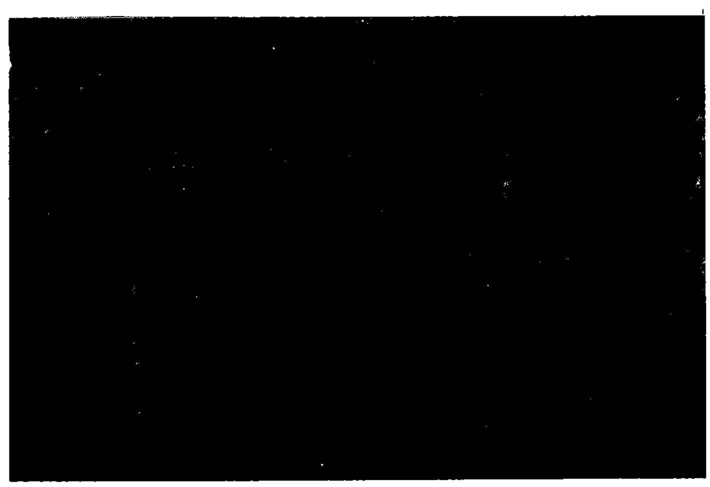


Figure 20. Present-day symmetrical ripple marks on the sand in shallow water near the covered boat housing in Edmond Park (Fig. 10, Stop 4). Symmetrical ripple marks are formed by an oscillating current, such as that produced by waves.

Present-Day Sedimentary Features

Present-day sedimentary features 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–linguoid ripple marks at Stop 1A, which formed from a unidirectional current.

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 preserved in rock is called a trace fossil—a trace left behind by an ancient animal. Trace fossils are useful to geologists because they show that animals were 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 very likely that animals have left 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 ~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 ~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.

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 (~5.5 in. long) for scale.

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.

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 ~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 are Ordovician (510–439 Ma) in age.

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

The Oklahoma Geological Survey's (OGS) work around Lake Arcadia is part of a larger program of new geological mapping of the Oklahoma City metropolitan area (Hemish and Suneson, 1998; Suneson and Hemish, 1998; Stanley and Suneson, 1999). This program, called STATEMAP, is funded by the OGS and the U.S. Geological Survey, under the National Cooperative Geologic Mapping Program.

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Guidelines Help Users Find Field-Trip Guidebooks

Field-trip guidebooks are a significant contribution to geoscience literature. They are often the most current or only synopsis of an area's geology, and as such, are essential to researchers and students. But often they can be difficult for searchers to find. A potential user may have an idea of the area that a guidebook covers and know the organization that published it, but still not have enough information to find it. Part of the problem is that guidebooks often are published more informally than other types of publications—for a one-time field trip, for example—and libraries may not even be aware that the publication exists.

The Geoscience Information Society (GIS) encourages guidebook editors and compilers to include specific information on the cover and preliminary pages of every guidebook, so that this important literature can be identified, acquired, and used by the geoscience community. Claren M. Kidd, head librarian for the Youngblood Energy Library at the University of Oklahoma and chair of the GIS Guidebook Standards Committee, says that following these guidelines will help users locate a particular guidebook by ensuring that a guidebook contains the essential components to become an identifiable and permanent part of the geoscience literature.

TITLE PAGE

The field-trip guidebook title page (Fig. 1) should include:

- **Title**—A clearly indicated title identical to that on the cover. The title should be consistent wherever it is used throughout the publication. If a subtitle is used, it should follow the same rules.
- **Geographic area**—The geographic area, including state or province covered by the field trip, should be included as a part of the title or subtitle.
- **Dates**—Day(s), month, and year of the field trip, preferably should be on the title page.
- **Meeting name**—Name and place of the meeting should be included when the field trip is held in conjunction with a meeting. If it is a regular, numbered meeting, specify the number of the meeting.
- **Field-trip number**—If several field trips take place at a meeting, specify the number of each field trip.
- **Series title and number**—If issued as a number within a series, the series title should remain the same from year to year. That title should be the same on the title page, cover, and wherever else it appears. Be sure to include the number of the series.
- **Volumes within a set**—If issued as volumes of a set, each volume should be identified with the same overall title. This exact title should be repeated on the title page and cover of each individual guidebook. Also include on each individual volume the name of the meeting for which the guidebooks were prepared, and the volume number of each volume indicated near the overall title. For example, all 15 guidebooks from the 1979 International Congress of Carboniferous Stratigraphy and Geology should have this exact name repeated on the title page and cover of each individual guidebook.
- **Field-trip leaders and guidebook editors**—Name the first several field-trip leader(s) and/or editor(s) and indicate the responsibility of each person.
- **Reprint**—If this guidebook is a reprint, indicate the title and the year of publication of the original. If it is part of a reprint series, include that series title and series number.
- **Publisher name and address**—Name and full address of the publisher may appear here or on the back of the title page.
- **Date of publication.**

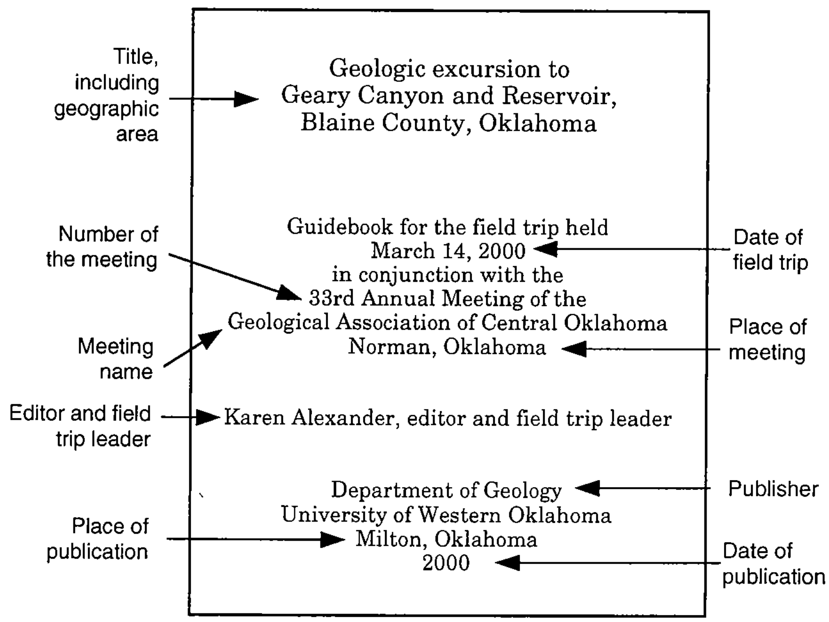


Figure 1. Sample title page (fictitious) for a field-trip guidebook.

BACK OF THE TITLE PAGE

The back of the title page (Fig. 2) should include:

- **Publisher name and address**—Name and full address of the publisher may appear here if it is not on the title page, and the distributor, if different from the publisher. Include an e-mail or web address, as appropriate.
- **Internet availability**—Provide the URL if the guidebook is available online.
- **Price of the publication.**

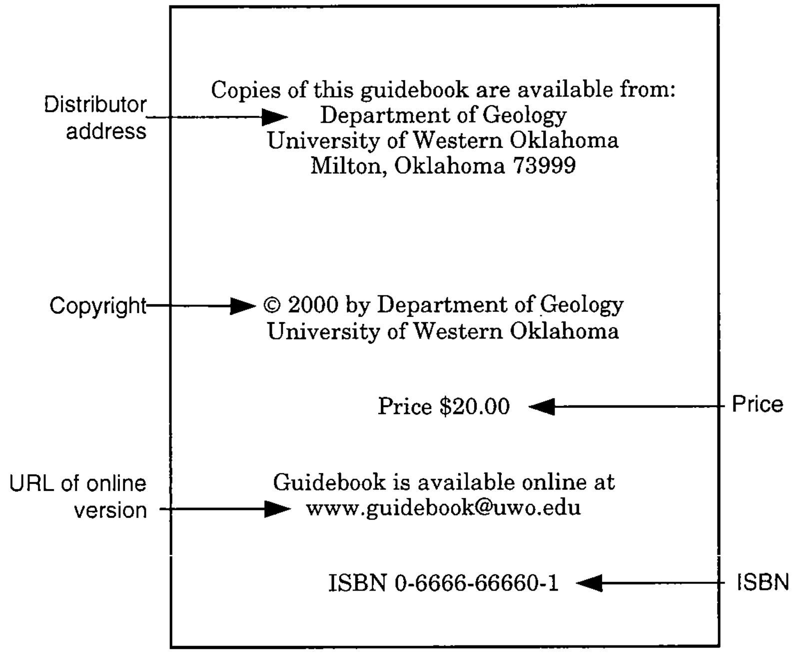


Figure 2. Sample back for title page (fictitious) for a field-trip guidebook.

GENERAL RECOMMENDATIONS

Publication content and format

- **Road log**—A road log creates a more site specific guide. Its presence is required for inclusion in the *Union List of Geologic Field Trip Guidebooks of North America.*
- **Paper, printing, and binding**—Use good quality paper, printing, and binding (preferably not spiral binding, because this type of binding disintegrates under library use). If spiral binding is unavoidable, provide a "gutter margin" of at least 1 inch between the spiral and the text, to enable libraries to bind the volume.
- **Page numbering**—Number the pages consecutively.
- **Table of contents**—Include a table of contents page if the guidebook contains more than one paper, and/or illustrations that can be listed, and/or unbound materials found in the pocket.
- **Illustrations**—Identify all illustrations with a text caption.
- **Title**—Identify the guidebook on the first page of each article. This ensures that reprints of single articles can be properly referenced.

Distribution

- **Print count**—Print more copies of the guidebook than are needed for field-trip participants. Remember, this is a contribution to the literature of geology. Your potential market may be numerous libraries holding geological collections.
- **Advertising/publicity**—Send publication announcements containing all pertinent information that appears on the title page and its reverse to *Geotimes* (c/o American Geological Institute, 4220 King St., Alexandria, VA 22302; fax 703-379-7563; www.geotimes.org) and similar geological news publications.

  Also send publication announcements to potentially interested libraries. Specifically, send announcements to libraries in the region where the field trip was held; those listed in the *Union List of Geologic Field Trip Guidebooks of North America*; and to members of the Geoscience Information Society. GIS membership mailing labels can be purchased by contacting the GIS Secretary at: Geoscience Information Society, c/o American Geological Institute, 4220 King St., Alexandria, VA 22302; www.geoinfo.org.

  Announce the publication of your guidebook on GEONET-L, a distribution list of geoscience librarians maintained by GIS.
- **Depository copy**—Deposit a copy of the guidebook in your nation's largest geological library. In the United States send a copy to U.S. Geological Survey Library in Reston, Virginia, and to one or more regional USGS Libraries. Also deposit a copy in the nearest library or libraries listed in the *Union List of Geologic Field Trip Guidebooks of North America.*

How to find existing guidebooks

The sixth edition of *Union List of Geologic Field Trip Guidebooks of North America,* compiled by members of the Geoscience Information Society, can be an invaluable aid for locating guidebooks and is available for purchase from the American Geological Institute. The *Union List* enumerates most of the geological field-trip guidebooks found in libraries across North America. Updates to the sixth edition now appear as a Web version at http://www.agiweb.org/pubs/unionlist.

Tracy Peeters

Tracy Peeters Named New *Notes* Editor

Beginning with this issue, Tracy Peeters assumes the position of editor for *Oklahoma Geology Notes.* She has served as associate editor of the Oklahoma Geological Survey since 1997, and will retain that title.

As editor of the *Notes,* Tracy gathers the variety of geologic papers, abstracts, news items, and photographs that appear in each issue. She also is responsible for design and layout and overseeing the printing process.

Tracy also works closely with OGS managing editor Christie Cooper to produce OGS bulletins, circulars, guidebooks, educational publications, and other products—acting as a liaison between technical editors and authors, designing and producing page layout for publications, and working with printers and other personnel involved in the production process.

Tracy has been with the OGS since 1995, when she began working as an editorial assistant while pursuing a master's degree in journalism at the University of Oklahoma.

An honor student at the University of Texas at Austin, Tracy graduated with degrees in magazine journalism and liberal arts. She says she also was interested in earth science, fulfilling her science requirements, as well as some electives, with geology courses.

Tracy brought to the OGS several years of experience in writing and editing for travel magazines in Texas, including *Texas Highways,* the magazine of the Texas Department of Transportation.

Tracy currently is continuing her education with courses in management information systems (MIS) at OU's College of Business Administration. Tracy also volunteers several hours a week for the WildCare Foundation, a nonprofit organization based in Noble, Oklahoma, that rehabilitates injured and orphaned wild animals. Besides attending sick and injured wildlife, Tracy produces WildCare's quarterly newsletter.

Upcoming meetings

OGS to Hold Coalbed Methane Workshop in Tulsa

The Oklahoma Geological Survey (OGS) and Tulsa Geological Society (TGS) will cosponsor a half-day workshop on coalbed methane in Tulsa on May 24, 2000. The workshop is a supplement to the one-day coalbed methane workshop that was held in Norman on Dec. 1, 1999.

Papers to be presented at the workshop include:

- Introduction to coal as gas source rock and reservoir, by Brian J. Cardott (OGS)
- Overview of Oklahoma coalfield with emphasis on the coal stratigraphy of the northeast Oklahoma shelf area, by LeRoy A. Hemish (OGS, retired)
- Coalbed methane activity in Oklahoma, by Brian J. Cardott (OGS)
- Coalbed methane completion practices on the Cherokee Platform, by William T. Stoeckinger (consulting geologist)
- Hartshorne CBM play in Oklahoma: selected production and economic viability, by Matthew A. Biddick (Fractal Oil Company, Norman)

The registration fee for the workshop is $30 for TGS members and Society of Petroleum Engineers members, $35 for all others. The cost includes a copy of the workshop publications, OGS Open-File Reports 6-99 and 2-2000.

For more details about the workshop, or for registration forms, contact Michelle Summers, Oklahoma Geological Survey, 100 E. Boyd, Room N-131, Norman, OK 73019; (405) 325-3031 or (800) 330-3996; fax 405-325-7069.

JUNE 2000

Geological Society of America Penrose Conference: Great Cascadia Earthquake Tricentennial, June 4–8, 2000, Seaside, Oregon. Information: Lois J. Elms, 926 Hover Ridge Circle, Longmont, CO 80501; (302) 485-0083, fax 303-485-5291; e-mail: LJElms@aol.com.

Grand Canyon/Colorado River Geology Symposium, June 7–9, 2000, Grand Canyon National Park, Arizona. Information: R. A. Young, Geological Sciences, SUNY, Geneseo, NY 14454; (716) 245-5296, fax 716-245-5288; e-mail: young@geneseo.edu.

Interstate Oil and Gas Compact Commission Midyear Meeting, June 11–13, 2000, Lexington, Kentucky. Information: IOGCC, P.O. Box 53127, Oklahoma City, OK 73152; (405) 525-3556, fax 405-525-3592; e-mail: iogcc@iogcc.state.ok.us.

Clay Minerals Society 37th Annual Meeting, June 24–29, 2000, Chicago, Illinois. Information: Alanah Fitch, Loyola University of Chicago, 6525 N. Sheridan Road, Chicago, IL 60626; (773) 508-3119, fax 773-508-3086; e-mail: afitch@luc.edu.

AUGUST 2000

Conference on the History of Geologic Pioneers, August 3–5, 2000, Troy, New York. Information: Gerald M. Friedman, fax 518-273-3249; e-mail: gmfriedman@juno.com.

GeoDenver 2000, conference by the Geo-Institute of the American Society of Civil Engineers, August 5–8, 2000, Denver, Colorado. Information: http://www.acse.org/conferences/geo2000.

Society of Exploration Geophysicists International Exposition and 70th Annual Meeting, Calgary, Canada, August 6–11, 2000. Information: SEG Business Office, (918) 497-5500, fax 918-497-5557; http://seg.org.

31st International Geological Congress, August 6–17, 2000, Rio de Janeiro, Brazil. Information: 31st International Geological Congress, Casa Brazil 2000, Av. Pasteur, 404, Urca, Rio de Janeiro, RJ, Brazil; phone 55-21-295-5847, fax 55-21-295-8094; http://www.31igc.org.

SEPTEMBER 2000

GIS Oil and Gas Conference, September 18–21, 2000, Houston, Texas. Information: (303) 337-0513; e-mail: erberts@gita.org.

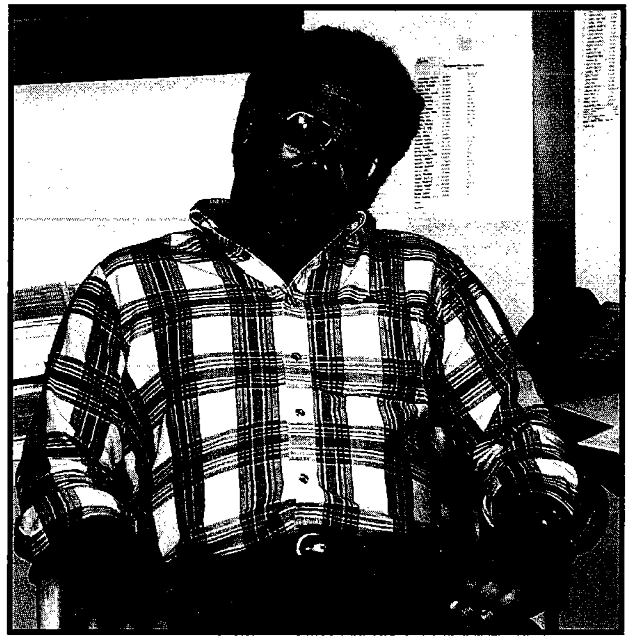
Hartshorne Play Workshop *(repeat of 1998 OGS workshop),* September 20, 2000, Oklahoma City, Oklahoma. Information: Carol Jones, Oklahoma City Geological Society, (405) 236-8086, ext. 11.

Oil Information Library Plans Fall Symposium

The Oil Information Library of Fort Worth will host the Barnett Shale Symposium in fall 2000. The Oil Information Library, a nonprofit organization, was established in 1985 to serve the needs of the petroleum professional.

Technological advancements in drilling and completion practices have made the Barnett Shale an increasingly attractive target in the Fort Worth Basin in the last 10 years. Information from more than 400 Barnett wells has provided insight into the complex nature of this gas-rich reservoir. The symposium is designed to help answer questions of reservoir extents and limits, drainage area, completion/frac practices, reserves, trends, and profitability.

Contact Mike McKee, (817) 335-1179, e-mail mmcKee@jettapc.com, if interested in attending or presenting a paper at this symposium.



Tom Bingham
1951–1999

Tom L. Bingham

OGS petroleum geologist Tom Lee Bingham passed away on December 13, 1999, after battling a debilitating illness. He was 48.

Tom was a petroleum geologist for the Survey. He handled countless requests for information and technical assistance on petroleum matters from oil and gas operators, consultants, and the general public. He dealt with all questions, both complex and simple, in a professional and courteous manner.

Tom came to the OGS in 1987 with extensive experience in petroleum exploration and prospect evaluation after working as an independent consultant for several years. As a consulting geologist, he prepared lease evaluations and prospect packages for a number of clients. He also served as the senior consulting geologist on retainer to a consulting firm in Oklahoma City. He worked mainly in eastern and northeastern Oklahoma.

Before working independently, Tom had been an exploration geologist with Palace Exploration Company in Oklahoma City until the company ceased operations in 1982. He also worked for Information Systems Programs at the University of Oklahoma. Among a wide-ranging set of duties there, he managed mineral and geothermal data bases and was a member of a team that evaluated and analyzed production and reserve data on fields around the country.

Tom's career didn't begin in petroleum geology, although it certainly became his specialty. After earning a B.S. in geology at Oklahoma State University in 1975, and then a secondary science teaching certificate there in 1977, he took a job working as a coal geologist with Lone Star Steel Company. He stayed there for just a matter of months before accepting a petroleum geologist position with the Oklahoma Corporation Commission, where he remained until 1980.

While working for the OGS, Tom found time to contribute to other professional activities in the Survey. He was an active member of the Midcontinent Oil and Gas Association's Nomenclature Committee, which names and draws boundaries for new oil and gas fields in Oklahoma and redefines boundaries for existing fields when updating is necessary. Tom belonged to the committee from 1987 until his death, and served several terms each as its chair and vice-chair. In 1993 the Association presented him with a Distinguished Service award.

At the time of his death, Tom was working on an update of OGS Geologic Map 28, *Map of Oil and Gas Fields of Oklahoma.* His experience and leadership of the Nomenclature Committee for the Midcontinent Oil and Gas Association was instrumental in these efforts.

Tom is survived by his wife, Shelagh, and son, Adam, a student at the University of Rochester.

Tom was a valued member of the Survey and a good friend. In spite of his long battle with a very serious illness, he maintained a positive outlook and never complained about his situation. Instead, he focused his energy on his professional activities and took deserved pride in his accomplishments. His passing has left a void in the Survey that will not be easy to fill.

—*Charles J. Mankin*

Oklahoma abstracts

The Oklahoma Geological Survey thanks the Geological Society of America for permission to reprint the following abstracts of interest to Oklahoma geologists.

Luminescence Dating of Canadian River Sediments at the Norman Landfill Toxics Site, Cleveland County, Okla.

SHANNON A. MAHAN and *JOHN WHITNEY,* U.S. Geological Survey, P.O. Box 25046, MS 974, Denver, CO 80225

Thermoluminescence (TL) and infrared stimulated luminescence (IRSL) dating techniques were used for geochronological reconstruction of the Quaternary fluvial environments of the Canadian River system in the vicinity of Norman, Okla. Luminescence dating was used to obtain burial ages on silt-sized quartz and feldspar. Fluvial sediments were cored near the Norman landfill and the Canadian River. The cores were extracted by either rotosonic coring or shallow push coring. Silt samples for luminescence were collected from eight cores that contained at least several layers of silty mud between massive sand deposits. Twenty-four ages were determined for twenty-six samples that were collected from April 1996 to October 1997.

TL results indicate a variety of problems with this method of age determination at this site, mostly due to incomplete resetting of sample grains in sunlight prior to deposition, a common occurrence in fluvial environments. However, IRSL ages also showed incomplete setting, a surprising result, since IRSL resets in two to three minutes of exposure to sunlight. In three shallow cores of less than one meter, expected residual levels were not found. These very young or modern deposits, as verified by radiocarbon, showed 20 to 80 percent more IRSL than a modern fluvial sample collected in the present day Canadian River sediment. IRSL ages were consistent with stratigraphy, but varied in their agreement with radiocarbon ages obtained for material from the same core interval. This incomplete resetting may be due to catastrophic dumping of sediment into the Canadian River system. There is evidence of several floods penetrating up to five meters of the fluvial deposits. A juxtaposition of ages observed in some cores might reflect such events as thunderstorms and local flooding that cause cloudy, turbid water to mix and remix sediments.

Reprinted as published in the Geological Society of America *1999 Abstracts with Programs,* v. 31, no. 7, p. A-55.

Stream Erosion at a Toxic Landfill, Canadian River Floodplain, Norman, OK

J. A. CURTIS, Dept. of Geology, Humboldt State University, Arcata, CA 95521

The unlined Norman landfill, located on the floodplain of the Canadian River in central Oklahoma, was closed and capped in 1985. Subsequently, the landfill was identified as a source of leachate composed of organic and inorganic toxic compounds dissolved in groundwater. The Canadian River, a sandbed river with a characteristic wide floodplain and erodible channel boundaries, meanders within the confines of an entrenched bedrock valley. Analysis of historic channel changes along a 14 km reach adjacent to the landfill, using a series of airphotos spanning 1937 to 1997, indicates that the channel has undergone episodic floodplain destruction through channel widening and subsequent construction by lateral and vertical accretion. Although as much as 2.5 m of scour and fill can occur during large discharge events, there has been no net change in mean channel bed elevation. In October 1986 a long duration, 15-year flood event, with a peak discharge of 2,200 cms and associated peak stream power of 100 W/m^2, induced cutbank erosion within the study reach and eroded a portion of the landfill. In May 1987 a higher magnitude, shorter duration, 30-year event occurred, with a peak discharge of 2,900 cms and associated peak stream power of 116 W/m^2. These two events combined initiated an avulsion of the thalweg away from the base of the landfill and as much as 300 m of floodplain erosion. The 1986 event occurred over a 6-day period with a total energy expenditure of $9{,}400 \times 10^3$ (joules). In comparison, the 1987 event occurred over a 3-day period with a total energy expenditure of only $6{,}400 \times 10^3$ (joules). Documented erosion induced by the 1986 event indicates that flood events with lower instantaneous peak discharge values and associated stream power can have an equal or greater geomorphic impact than floods with larger peak discharge values (i.e., 1987); therefore knowledge of the duration as well as the magnitude of flood events is integral to predicting resultant erosion.

Reprinted as published in the Geological Society of America *1999 Abstracts with Programs,* v. 31, no. 7, p. A-254.

Simulation of Ground-Water Flow in the High Plains Aquifer of Oklahoma and Adjacent Areas

RICHARD R. LUCKEY, U.S. Geological Survey, P.O. Box 25046, MS 406, Denver, CO 80225; and *MARK F. BECKER,* U.S. Geological Survey, Water Resources Division, 202 N.W. 66th St., Oklahoma City, OK 73116

The U.S. Geological Survey, in cooperation with the Oklahoma Water Resources Board, began a modeling study of the High Plains aquifer in 1996. This aquifer underlies 7,100 square miles of northwestern Oklahoma. Water use exceeds recharge and water levels have declined over large areas of the Panhandle. However in some areas water levels have risen because of enhanced recharge due to dryland cultivation. The model was calibrated using observed water levels, water-level changes, and stream flows. The model extends from the Canadian River to the Arkansas River to provide appropriate hydrologic boundaries. The model has 21,073 active cells, a fixed grid of 6,000 feet, and one layer. Predevelopment model calibration substantially reduced estimates for hydraulic conductivity in areas where strata were disrupted by salt dissolution in underlying rocks. Recharge was estimated as 4.0% of precipitation in zones of sand dunes and very sandy soils and 0.37% in the rest of the area. At 86 observation wells, 76% of simulated and observed predevelopment water levels agreed within 50 feet. Simulated discharge to the Beaver River was much greater than the discharge indicated by streamflow records; simulated discharge to other streams generally matched observed discharge.

Calibration for 1946–98 conditions reduced estimated specific yield by 15% in Oklahoma east of the Cimarron–Texas county line. Simulated recharge due to irrigation ranged from 24% of pumpage when flood irrigation resulted in low irrigation efficiencies to 2% when precision applications resulted in high irrigation efficiencies. Estimated recharge due to dryland cultivation was about 0.75 inch per year over the area in dryland cultivation. At 162 observation wells, 57% of simulated and observed changes agreed within 10 feet.

Reprinted as published in the Geological Society of America *1999 Abstracts with Programs*, v. 31, no. 7, p. A-492.

Water Quality of the Ogallala Formation of the High Plains Aquifer System in the Central High Plains

MARK F. BECKER, U.S. Geological Survey, Water Resources Division, 202 N.W. 66th St., Oklahoma City, OK 73116

As part of the U.S. Geological Survey High Plains National Water Quality Assessment (NAWQA) program, ground-water samples were obtained from the Ogallala Formation of the High Plains aquifer at 75 sites over an area of 38,000 square miles in parts of Kansas, Colorado, Oklahoma, Texas, and New Mexico. Analyses include major ions, trace elements, nutrients, volatile organic compounds, pesticides, radon, and dissolved organic carbon. These analyses were used to assess the general water quality in the Ogallala Formation, to describe the quality of the water used for domestic supply, and to establish baseline water-quality conditions.

The region is heavily irrigated in places, sparsely populated, and dependent upon agriculture. Over 90 percent of the water is used for irrigation. Domestic supply and stock use comprise a minor amount of the remaining water used. Principal crops are wheat, corn, and sorghum. Animal feeding operations are common, primarily cattle, but swine operations are expanding.

All wells sampled were used for domestic supply. Most of the wells sampled were in a rural, agricultural setting with depths to water ranging from less than 50 to over 400 feet. Results of this water-quality assessment indicate that agricultural practices have affected water quality of the High Plains aquifer in the central High Plains.

Reprinted as published in the Geological Society of America *1999 Abstracts with Programs*, v. 31, no. 7, p. A-493.

Aeolian/Fluvial Interactions in Landscape Formation, Major County, Oklahoma

GREGORY F. SCOTT, USDA-NRCS, 4900 Oklahoma, Ste. 300, Woodward, OK 73801

Western Oklahoma, on the boundary between humid and arid climates, is subject to fluctuating aeolian and fluvial processes in response to climatic shifts. These processes are reflected in the integration of the landforms throughout the region. Pleistocene terraces on the north side of the Cimarron River in Major County are fluvial landforms, but obvious aeolian forms are present on them. A combination of soil-stratigraphic, photointerpretative, and radiometric dating studies were undertaken to assess the chronology of the landscape development and the timing of the geomorphic processes. Detailed studies were made at two sites where the T2 terrace has been engulfed by dunes and sand sheets.

Geomorphic mapping shows that the surfaces of the terrace system have been extensively modified by aeolian processes. Each of the seven fluvial terrace levels has a belt of sandhills associated with it, which masks the terrace escarpments. Scattered sand sheets are also present on these terrace surfaces. Evidence shows that the initial deposition ot the aeolian sand occurred along the river banks during arid periods. As the river lowered the valley, the floodplains become terraces with associated sand hills.

Sand dunes and sand sheets on the terraces record the dramatic changes in the climate and resulting geomorphic processes. Most of the soil profiles on dunes record at least two periods of aeolian deposition. Below the aeolian sediments, buried truncated soil profiles give evidence of erosion at the start of arid episodes. But if the rate of sand supply exceeded the rate of fluvial erosion, the channels of streams on the backswamp of the terraces were buried by sand.

Radiocarbon dating of soil humates and thermoluminescence dating of aeolian sands establishes the dates that delimit when each process was dominant. These dates correspond with similar events reported for other locations in the Great Plains.

Reprinted as published in the Geological Society of America *1999 Abstracts with Programs*, v. 31, no. 7, p. A-50.

Radiometric Ages of Ancient Hydrothermal Flow and Hydrocarbon Transport in the Midwest

RAYMOND M. COVENEY, JR., Dept. of Geosciences, University of Missouri, Kansas City, MO 64110; *VIRGINIA M. RAGAN*, Maple Woods Community College, Kansas City, MO 64156; and *JOYCE C. BRANNON*, Washington University, St. Louis, MO 63130

Th–Pb and U–Pb dates for calcite crystals from ores and trace occurrences of Mississippi Valley-type (MVT) mineralization in Carboniferous beds in and near the Tri-State Zn–Pb district of Missouri, Kansas, and Oklahoma indicate that hydrothermal fluids were present periodically between ~251 and 66 Ma and possibly as recently as 39 Ma before present. All five dates exceed the ages of the MVT host rocks by about 50–200 million years. Fluid inclusions record successively lower homogenization temperatures ranging from 122 degrees Celsius at 251 Ma to 62 degrees in the 39 Ma crystals. Salinities decline from a high of 23% equivalent NaCl in the oldest calcite crystals to near zero. Petroleum inclusions are common in early calcite, but rare in younger crystals. The results demonstrate flushing of hydrothermal brines and mobile hydrocarbons through remarkably persistent permeable zones in Paleozoic strata of the Midwest for up to 200 million years following the Pennsylvanian–Permian Ouachita orogeny—a likely impetus for regional hydrothermal flow and hydrocarbon transport. These data provide key benchmarks to guide modeling of the fracture-controlled flow that led to the world-class Tri-State district Zn–Pb ores and the hydrocarbon fields of the U.S. Midcontinent.

Reprinted as published in the Geological Society of America *1999 Abstracts with Programs*, v. 31, no. 7, p. A-31.