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Guidebook for Geologic Field Trips in North-Central Oklahoma

JOHN D. NAFF

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Charles J. Mankin, *Director*

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GUIDEBOOK FOR GEOLOGIC FIELD TRIPS IN NORTH-CENTRAL OKLAHOMA

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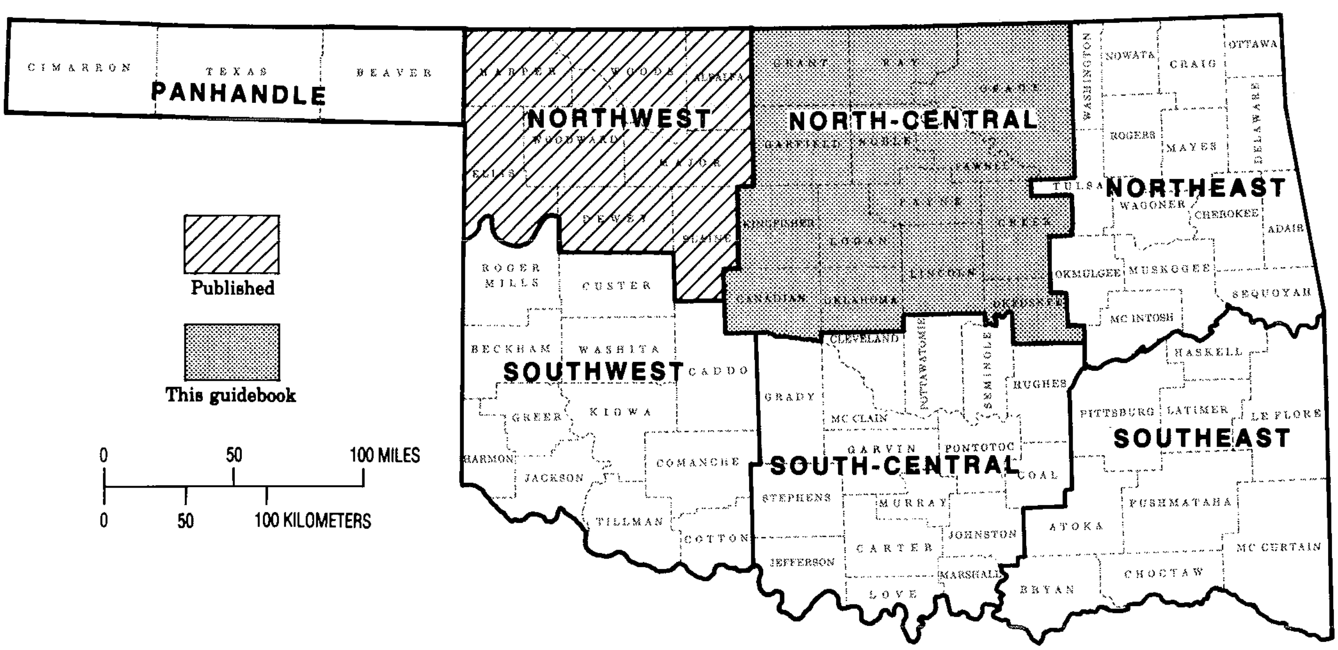
Fossil drawings by Roy D. Davis

Cover Illustration

Vamoosa Sandstone of Late Pennsylvanian age along the Cimarron Turnpike in easternmost Pawnee County, north-central Oklahoma. Crossbedding and channeling are well illustrated here. The base of the Vamoosa is undercut above shale in the underlying Tallant Formation, shown near the bottom of the road cut. Photo by the author.



Index map of Oklahoma showing seven regions for which geologic guidebooks are being prepared

PREFACE

Guidebooks in this series are issued by the Oklahoma Geological Survey in cooperation with the National Science Foundation, the Oklahoma Curriculum Improvement Commission, and the Instructional Division and the Curriculum Section of the Oklahoma State Department of Education. Preparation of material is financed in part by a grant from the National Science Foundation (Grant GW-5726), and publication is supported by funds from Title V, Section 503, of the Elementary and Secondary Education Act of 1965 through The Oklahoma State Department of Education.

Geologic information presented in the series is designed to give teachers sufficient background to direct student field studies, and the guidebook can also be used directly by students and the public in preparing for field trips. The introductory guidebook (Johnson, 1971) contains a nontechnical discussion of the geologic history of Oklahoma along with general information and suggestions on pre-trip planning, the responsibilities of leading a field trip, safety precautions, and recommended student activities in investigating each site. The guidebook for northwest Oklahoma (Johnson, 1972) contains detailed descriptions of the local geology at 26 selected sites, plus information on the regional geology and on viewing oil and gas wells. The present guidebook discusses the regional geology of north-central Oklahoma, as well as details of the local geology at 43 field sites. Each site selected is discussed in relation to the surrounding area, and geological, geographical, and geomorphic factors in its development are examined. Some of the sites are easier to reach, more interesting, and show more geological detail than others, but something can be learned from a study of each.

It is recommended that the earlier publication by Johnson (1971) be examined prior to making a field trip when using this guidebook, and that road maps, the Geologic Map of Oklahoma, and the topographic maps indicated in the text be taken into the field with each group. These maps can be studied at libraries at Oklahoma State University, Stillwater, and Phillips University, Enid, both in the north-central area. Another report of general interest is a series of maps and cross sections on the geology and earth resources of Oklahoma (Johnson and others, 1972), and these data can aid in overall planning of a field trip.

Oklahoma teachers who would like to obtain a free copy of this guidebook should contact the Director of Curriculum, State Department of Education, 2500 North Lincoln Boulevard, Oklahoma City, Oklahoma 73105. Guidebooks are available for purchase from the Oklahoma Geological Survey, The University of Oklahoma, Norman, Oklahoma 73019.

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JOHN D. NAFF[1]

INTRODUCTION TO NORTH-CENTRAL OKLAHOMA

North-Central Oklahoma, as defined in this guidebook, includes Canadian, Creek, Garfield, Grant, Kay, Kingfisher, Lincoln, Logan, Noble, Okfuskee, Oklahoma, Osage, Pawnee, and Payne Counties. In each of these 14 counties, one or several field-trip sites have been selected (fig. 1) to offer interesting and diverse views of geologic processes, rock types, structural and geomorphic developments, and fossil-collecting localities. Sparse to moderate vegetation permits rocks to be well exposed in most of the area, and outcrops are easily accessible at most of the sites described. A fine pattern of major federal and state highways reticulates the area and, coupled with well developed section-line roads, permits easy access to most parts of the region.

The geology is simple yet diverse, and it is interesting to professional geologists as well as to amateurs. Principal mineral resources are petroleum, limestone and dolomite, volcanic ash, brick and foundry clays, and sand and gravel (Johnson, 1969).

Outcrops in the area are sedimentary and include deposits of lithified Pennsylvanian and Permian rocks as well as unconsolidated deposits of Quaternary age (figs. 2 and 3). Rocks have been sculptured into high, nearly level plains, cuestas, hogbacks, buttes, and mesas and have been covered by thick alluvium to form extensive flood plains along many streams. Several cycles of rejuvenation along the major streams have produced upland terraces adjacent to present streams, and some high-level gravels may be remnants of deposits left by Tertiary streams. Identification of rock and mineral materials in some of these upland gravels shows that they came from the Rocky Mountains (Kitts, 1965).

Most of the major streams that drain the area flow from northwest to southeast. The Arkansas River, the largest stream, enters Oklahoma from Kansas and continues to flow southeastward after partially defining western and southern boundaries for Osage County (fig. 2). The Cimarron and North Canadian Rivers flow across north-central Oklahoma, and the Canadian River outlines part of the southern edge of the region. Principal tributaries, Salt Fork, Skeleton Creek, and Deep Fork, reach impressive sizes before joining major streams. The highest point in the north-central region is more than 1,350 feet (near Enid, in Garfield County), and the lowest point is between 600 and 650 feet (where the North Canadian River leaves Okfuskee County in the extreme southeastern part of the area).

General Geology of the Area

All of the lithified rocks that crop out in north-central Oklahoma belong in the Pennsylvanian and Permian Systems (figs. 2 and 3). In about the eastern two-fifths of the area, outcrops are Pennsylvanian in age; in the western three-fifths, outcrops are Permian in age (fig. 2). Most of the major streams and some of the upland areas are covered with unconsolidated sands, gravels, and some volcanic ash of the Cenozoic Era.

During Pennsylvanian and earliest Permian time, a shallow sea covered the region and was the site of a relatively normal succession of beds of marine sedimentary rocks, sandstones, shales, and some limestones. A regional factor that affected sedimentation was the chain of mountains across the southern part of Oklahoma and the Texas Panhandle. These mountains included the Arbuckle Mountains and a buried group of Amarillo Mountains (Naff, 1977), and the area underwent several uplifts during the Pennsylvanian and Permian Periods. Finally, during middle Permian time, an uplift effectively isolated the sea north of the mountains, and the sea disappeared during the Guadalupian Epoch. Meanwhile, desiccating conditions permitted accumulation of several levels of evaporites.

Pennsylvanian Rocks

Early uplifts of the Arbuckle and Criner areas in southern Oklahoma predated the deposition of any rocks that crop out in north-central Oklahoma. Nevertheless, rocks of the Desmoinesian and Missourian Series are normal sequences of shallow-sea, stable-shelf deposition in which normal marine fossils are common and evaporites are not found.

Approximately at the base of the Virgilian Series (Vamoosa Group) the Pennsylvanian rocks become coarser (higher sand-shale ratio) and redder in color (an indication of more oxidation of iron compounds in the rocks during and immediately after deposition). Both coarseness and redder color increase southward toward the Arbuckle Mountains, which apparently underwent their last orogenic up-

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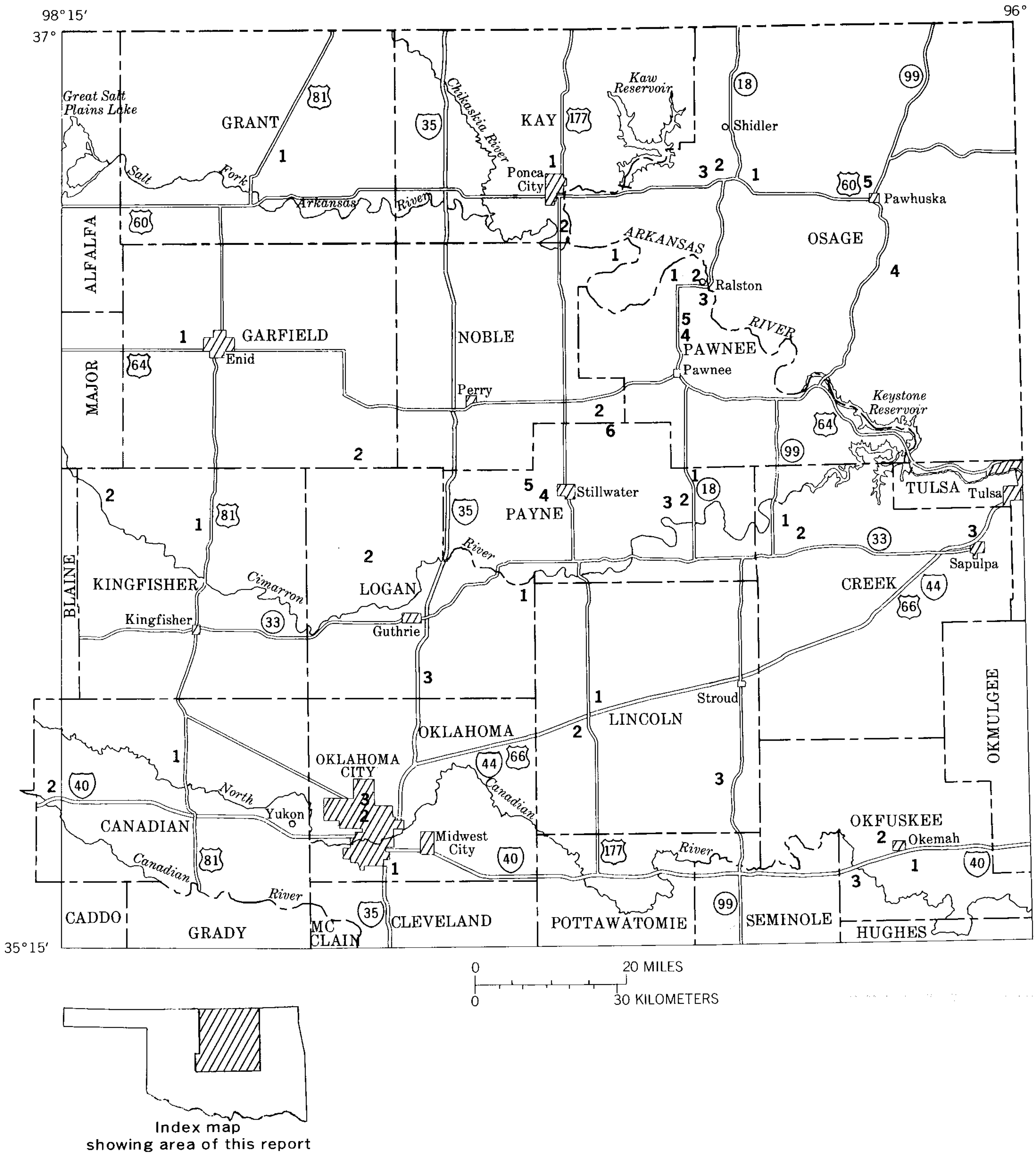


Figure 1. Location of field-trip sites by county and principal highways in north-central Oklahoma.

COUNTY	SITE	DESCRIPTION
Canadian	1	Permian gypsum
	2	Canadian River terraces
Creek	1	Lecompton Limestone outcrop
	2	Old Oilton Oil Field
	3	Sapulpa coal bed
Garfield	1	Gravel pit
	2	Garber Sandstone exposure
Grant	1	Salt Fork of Arkansas River
Kay	1	Limestone cuestas
	2	Herington Limestone outcrop
Kingfisher	1	Gravel plant
	2	Sand dunes
Lincoln	1	High-terrace gravel
	2	Concretions
	3	Sandstone outcrop
Logan	1	Horsethief Canyon
	2	Cimarron River
	3	Red beds
Noble	1	Gravel, fossils, and artifacts
	2	Copper
Okfuskee	1	Volcanic ash
	2	Hogback
	3	Coarse conglomerate
Oklahoma	1	Barite roses
	2	Brick pit
	3	Oklahoma City Oil Field
	4	Sandstone aquifer
Osage	1	Fossils
	2	Burbank Oil Field
	3	Limestone quarry
	4	Fossils
	5	Limestone quarry
Pawnee	1	Limestone quarry
	2	Fusulinids
	3	Admire Sandstone
	4	Fossils
	5	Fossils
Payne	1	Fusulinids
	2	Gano Shale fossils
	3	Loess
	4	Ramsey Oil Field
	5	Fossil plants
	6	Copper mine

lift during late Missourian time (Johnson, 1971). More nearly normal seas covered the region during the middle and late Virgilian, just preceding and during the time of deposition of the Vanoss Group, making possible accumulation of limestones such as the Lecompton, Deer Creek, and Bird Creek formations in the Ada Group, and the Brownville and Grayhorse Limestones of the Vanoss Group.

Permian Rocks

With the exception of the lowermost beds of the Permian System, all of the Permian rocks that crop out in north-central Oklahoma can be classed as red beds and evaporites. During earliest Wolfcampian time, the marine water north of central Payne County was of about normal salinity, and the sea bottom supported a fauna of fusulinids, bryozoans, brachiopods, crinoids, echinoids, pelecypods, and gastropods, while a few sharks and cephalopods swam above or browsed among the plants and creatures on the bottom. Commonly, the water was clear enough and the wave-base shallow enough to permit deposition of relatively mud- and silt-free limestone. Southward from central Payne County, the influence of the Oklahoma Mountains was strongly felt, and enough clastic material was washed into the sea to prevent deposition of much limestone. Evaporites, particularly salt, are exceptionally soluble and, where they are close to the surface, may be dissolved to form sinkholes, caves, and structural irregularities in the rock. Moore and others (1951) report that individual beds of salt in the Wellington Formation attained thicknesses of more than 17 feet at Hutchinson, Lyons, and Kanapolis, Kansas. The lithology of the Wellington in north-central Oklahoma does not suggest that salt beds of these proportions have been dissolved, but upward-migrating brines from salt in the Hennessey Group are responsible for concentrations of selenite crystals at Great Salt Plains, Alfalfa County, in northwest Oklahoma (Johnson, 1972; Naff, 1977).

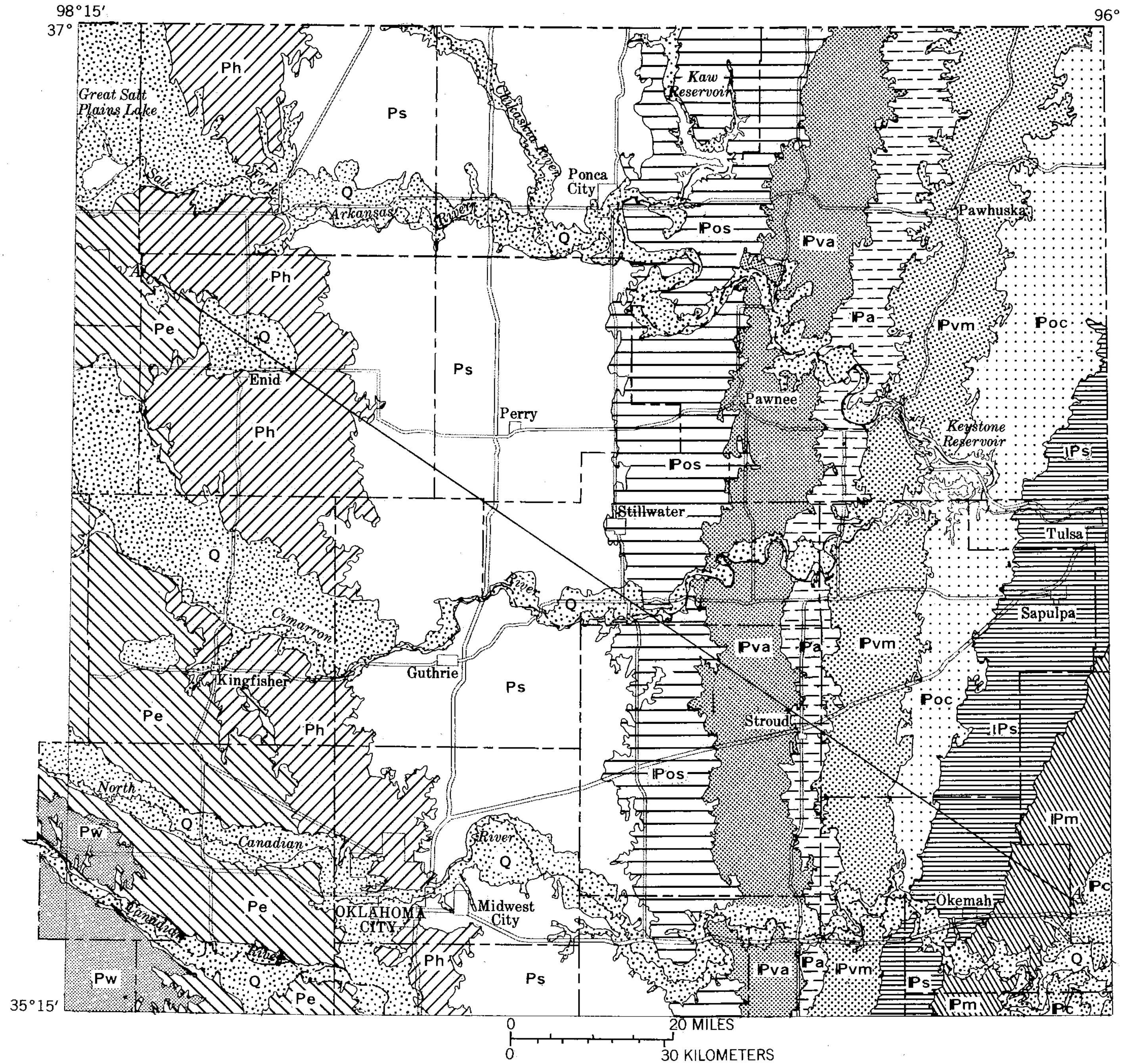
Most of the outcropping Permian evaporites in Oklahoma, however, are west of north-central Oklahoma, where they have been described in publications by Fay and others (1962) and by Johnson (1972).

Quaternary Deposits

Quaternary deposits of north-central Oklahoma consist of Pleistocene (Ice Age) and Holocene (Postglacial) unconsolidated muds, silts, sands, and gravels commonly left by the major streams that flowed eastward across the area (Myers, 1962).

In addition to modern channel and flood-plain deposits, terrace deposits have been left by earlier ancestral streams and now lie scores of feet above the modern streams that have cut down through them. If a stream has undergone several cycles of rejuvenation, its older terrace deposits will be higher and farther away from the present stream. Thus, the higher terraces provide an historical record of streams that date far back into the geological record. Some of the mammoth, mastodon, bison, horse, and other mammal remains found in the high- and medium-level terrace deposits can be dated as Pleistocene. Most shells of Cretaceous age in the region have been transported downstream from Cretaceous outcrops to the west (Johnson, 1972), but some shells probably were barter items used at campsites by early Indians. Appreciable concentrations of worked pieces of chert, flint, or jasper can almost certainly be interpreted as indications of former campsites.

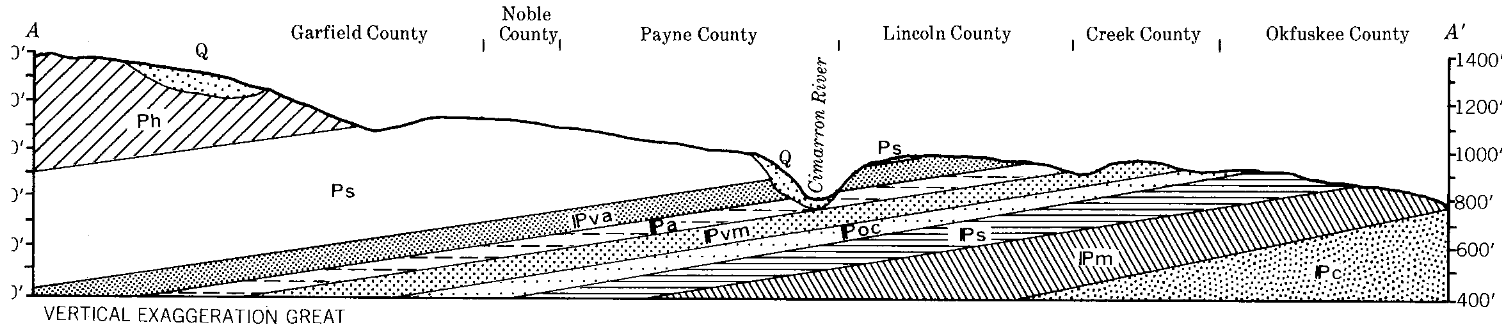
In a few high terraces, concentrations of light-gray to white volcanic ash are found. This ash was probably either blown eastward from volcanic eruptions in Colorado and New Mexico or washed downstream and deposited in flood-plain lakes or marshes. The ash consists mainly of very fine volcanic glass shards that cooled too quickly to permit individual



EXPLANATION

- Q — Quaternary deposits – Includes sand, gravel, and clay along major rivers and high terrace deposits.
- Pw — Whitehorse Group – Red-brown sandstone.
- Pe — El Reno Group – Red-brown shale and sandstone with thin gypsum beds.
- Ph — Hennessey Group – Red-brown shale and sand stone.
- Ps — Sumner Group – Red-brown sandstone and shale.
- IPos — Oscar Group – Red-brown and gray shale and sandstone with thin interbeds of limestone.
- IPva — Vanoss Group – Red-brown and gray shale and sandstone with thin interbeds of limestone.
- IPa — Ada Group – Red-brown sandstone and red-brown to gray shale with thin interbeds of limestone.
- IPvm — Vamoosa Group – Thin to massive layers of sandstone with shale interbeds.
- IPoc — Ochelata Group – Sandstone and shale with interbeds of fossilferous limestone.
- IPs — Skiatook Group – Shale with interbeds of sandstone and fossiliferous limestone.
- IPm — Marmaton Group – Shale with thin beds of sandstone and fossiferous limestone.
- IPc — Cabaniss Group – Thin to massive layers of sandstone with shale interbeds.

Figure 2. Generalized geologic map and cross section of north-central Oklahoma. Map shows areas of outcrop for rock units in report area; cross section shows generalized dip of units.



mineral crystallization and therefore developed a lustrous, glassy texture. This ash is valuable as a principal constituent in scouring powders and in manufacture of some varieties of insulating materials (Burwell and Ham, 1949).

Geomorphology

Curtis and Ham (1972) divided Oklahoma into 22 geomorphic provinces, which they identified by the dominant landforms in each. The north-central region (as delineated in the present guidebook) includes parts of seven of these geomorphic provinces (fig. 4). In each province, topographic forms are influenced by the types of rocks and the characteristics of geologic processes acting on these rocks.

Claremore Cuesta Plains.—Although this province is located almost entirely east of the study area, it does undulate into the easternmost part of Osage County, where deep valleys are cut into resistant Pennsylvanian sandstones and limestones that dip gently westward. Cuestas are not obvious, because of the dense vegetation cover. Streams have developed locally broad flood plains that are deeply alluviated.

Eastern Sandstone Cuesta Plains.—In the northern part of this province, dip of the beds is low and cuestas may more nearly resemble mesas. Thick, resistant sandstone complexes such as those of the Vanoss and Vamoosa Groups dominate the character of the topography in this province. Interbedded shales and a few thin, impure limestones are more easily eroded, resulting in a blocky, steep-walled, hilly forestland characterized by thick, ferruginous, resistant sandstones.

Northern Limestone Cuesta Plains.—This restricted province, coming in like a finger from the Flint Hills of Kansas to the north, is characterized by topography quite different from that of the adjacent provinces. Thin-bedded, moderately thin limestones of Permian age are interbedded with thicker, silty shales. Beds dip gently westward, permitting development of low, east-facing cuestas that are capped in most instances by limestones but occasionally by thin, ferruginous sandstones. The calcareous nature of the rocks of this province fosters luxuriant growth of prairie grasses, with the result that this is some of the finest pastureland in Oklahoma. It is also a picturesque area, partly because unusual cairns of limestone are used as corner markers and fence posts. Many oil fields dot the area, but they are generally well tended; they accent the character of the countryside rather than detracting from its beauty.

Central Redbed Plains.—This province, which contains a large part of the area covered in this guidebook, consists of gently rolling hills cut into outcrops of Permian red shales, siltstones, and sandstones. Most of the rock units are members of the Wellington and Garber formations (Sumner Group), or the Hennessey Group, or the Cedar Hills Sandstone, which belongs to the El Reno Group. The surface slope of the area is generally eastward with a high, broad divide near Enid. Covering much of the surface is loose, gravelly soil developed from weathered Quaternary alluvium.

Cimarron Gypsum Hills.—A narrow band of this province extends into Kingfisher and Canadian Counties from the northwest. Only a small amount of gypsum crops out in north-central Oklahoma in contrast to the large extended escarpments described by Johnson (1972) in northwest Oklahoma. Small amounts of gypsum have been quarried locally and are discussed briefly under the section on Canadian County.

Western Sandstone Hills.—In this province, thick, soft, red sandstones of the Rush Springs and Marlow formations are nearly horizontal and form a gently rolling, even-topped plain into which deep, steep-walled canyons have been cut. The extreme southwestern corner of Canadian County falls within this province.

Western Sand Dune Belts.—These elongate belts of hummocky topography lie in comparatively narrow strips paralleling the north and east sides of major streams. Most of the dunes have been stabilized by vegetation, but some areas still show active, shifting sand dunes. The source of the sand is from the braided stream channels themselves or from reworked Quaternary material left behind as the streams moved gradually to the southwest. Prevailing winds are from the southwest and carry most of the sand to the northeastern banks of the streams. The porous nature of the dune material, and the moderately low rainfall, permit few streams to cross

SYSTEM	SERIES		GROUP	FORMATION
QUATER-NARY	Holocene and Pleistocene			High, isolated gravel deposits, several levels of stream terraces, some volcanic-ash deposits, and Holocene flood-plain and channel deposits. Sand-dune areas are generally northeast of major streams.
PERMIAN	Custerian	Guadalupian*	Whitehorse	Rush Springs Sandstone Marlow Formation
PERMIAN	Cimarronian	Guadalupian*	El Reno	Dog Creek Shale Blaine Formation Flowerpot Shale Cedar Hills Sandstone
PERMIAN	Cimarronian	Leonardian*	Hennessey	Bison Formation Salt Plains Formation Kingman Siltstone Fairmont Shale
PERMIAN	Cimarronian	Leonardian*	Sumner	Garber Sandstone Wellington Formation (contains Fallis Sandstone member)
PENNSYLVANIAN	Gearyan	Wolfcampian*	Oscar	Herington Limestone Winfield Limestone Fort Riley Limestone Wreford Limestone Funston Limestone Crouse Limestone Cottonwood Limestone Eskridge Shale Neva Limestone
PENNSYLVANIAN	Gearyan	Wolfcampian* / Cisco*	Vanoss	Sallyards Limestone Roca Shale Red Eagle Limestone Johnson Shale Foraker Limestone (=Long Creek Limestone at top) Hughes Creek Shale Five Point Limestone Admire Sandstone Brownville Limestone Grayhorse Limestone Reading Limestone
PENNSYLVANIAN	Virgilian	Cisco*	Ada	Auburn Shale Bird Creek Limestone Turkey Run Limestone Little Hominy Limestone Deer Creek Limestone Lecompton Limestone
PENNSYLVANIAN	Virgilian	Cisco*	Vamoosa	Elgin Sandstone Oread Limestone Boley Conglomerate
PENNSYLVANIAN	Missourian	Canyon*	Ochelata	Tallant Formation Barnsdall Formation (containing Wildhorse Dolomite) Wann Formation Iola Formation (=Avant Limestone) Chanute Formation Dewey Formation
PENNSYLVANIAN	Missourian	Canyon*	Skiatook	Nellie Bly Formation Hogshooter Limestone Coffeyville Formation (=Seminole Formation) Checkerboard Limestone
PENNSYLVANIAN	Desmoinesian	Strawn*	Marmaton	Holdenville Formation Oologah Formation Labette Shale Fort Scott Limestone
PENNSYLVANIAN	Desmoinesian	Strawn*	Cabaniss	Wetumka Shale Calvin Sandstone Senora Sandstone

Figure 3. Generalized stratigraphic section showing identifiable rock units that crop out in north-central Oklahoma. Usage of formation names may not be consistent throughout area; names used here are believed to be of greatest value and most widespread in recognition. Asterisks (*) indicate nomenclature used in west Texas and Texas Panhandle. Pennsylvanian–Permian boundary in Texas is placed at Cisco–Wolfcampian contact.

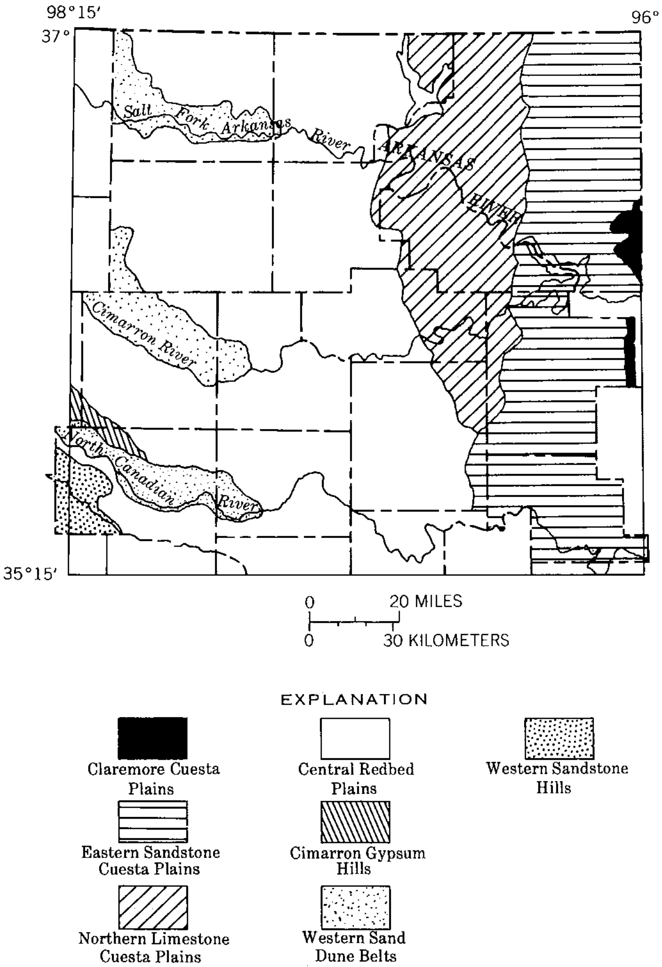


Figure 4. Geomorphic provinces of north-central Oklahoma (after Curtis and Ham, 1972).

the dune belt, although a noteworthy exception is Turkey Creek where it joins the Cimarron River west of Dover in Kingfisher County.

Subsurface Rocks

Rocks of all of the Paleozoic systems are beneath the surface of north-central Oklahoma. At a depth of more than a mile, the oldest of these sedimentary rocks overlie Precambrian granite. Most of the older subsurface rocks are marine limestones, shales, and sandstones that maintain reasonably constant thicknesses throughout the area covered in this report. West and south of this area, the subsurface rocks thicken dramatically as the surface of the Precambrian basement rocks dips into the Anadarko Basin (Johnson, 1972).

Oil and gas have been recovered from many producing zones in subsurface rocks in north-central Oklahoma. Some of the more important production zones are: Cambro-Ordovician, Arbuckle Limestone or Arbuckle Group; Ordovician, members of the Simpson Group (sometimes called "Wilcox" sand); Silurian-Devonian, Hunton Group; Mississippian, Misener sand, Mississippi lime, and Mississippi "Chat"; Pennsylvanian, Dutcher, Gilcrease, Booch, Bartlesville, Red Fork, Skinner, Prue, Oswego, Big Lime, Cleveland, Layton, Tonkawa, and Hoover. This list is by no means exhaustive, but it provides a framework of well-known and generally highly productive petroleum zones.

In general, the subsurface rocks dip from 10 to about 100 feet per mile westward off the Ozark Uplift. The gentle structure of this homocline is interrupted locally in many places by local anticlines and monoclines that show closures of up to a few tens of feet. Important unconformities are present above the Hunton rocks and above the Mississippi lime. It was during the erosion and development of the latter of these unconformities that the karst surface on the Mississippi lime produced the Mississippi "Chat" from which much oil and gas has been recovered since the early 1950's.

A buried granite ridge called the Nemaha Ridge extends southward through Kay, Noble, Logan, and Oklahoma Counties, ending at about the locality of the West Edmond Oil Field. This ridge is essentially an elongate horst that continued its structural development until Early Pennsylvanian time. As a result of this structure, all of the older formations are faulted on the flanks of the ridge, are thin over the top of it, or dip rather sharply away from it. Many oil fields are located on top of or on the flanks of the Nemaha Ridge.

FIELD-TRIP SITES

Canadian County

The outcropping rocks of Canadian County are all Permian or Quaternary. Most of the upland surface is sculptured by streams that have eroded canyons, wide and flat uplands, and other essentially early-mature features where Permian red beds of differential hardness crop out. Dip of the Permian beds is less than 1° westward to southwestward and is imperceptible to the eye. The oldest rocks are in the Hennessey Group, which crops out east of Piedmont, and the youngest Permian beds are in the Rush Springs Sandstone (Whitehorse Group) in the southwestern corner of the county (fig. 3).

Quaternary terrace materials lie above the flood plains of the Canadian and North Canadian Rivers, both of which drain the county, flowing eastward. These terraces are well developed along the Canadian River in the western part of the county, at some places maintaining their identity as much as 90 to 100 feet above the present flood plain. Occasionally, specimens of Pleistocene mammoth or mastodon teeth and tusks are dug out of sand or gravel pits in older terraces.

One of the most interesting geomorphic developments in Canadian County is the large number of deep, steep-walled canyons cut into hard sandstones of the uplands. These canyons are smaller replicas of Red Rock Canyon, which has been cut into Rush Springs Sandstone south of Hinton in Caddo County (a few miles west of Canadian County). In places where the Permian sandstones are thick and relatively well cemented, the floors of the canyons are commonly more than 70 feet below the wind-scoured upland. Deciduous and coniferous trees, protected from the wind and having more than normal moisture in the canyon bottoms, flourish considerably west of their normal indigenous areas. It is not uncommon to find stands of chestnut oak, spanish oak, white oak, elm, cottonwood, locust, and more than an occasional maple on the floors of these canyons.

Canadian County Site 1: Permian gypsum

Access: Leave U.S. Highway 270 at Calumet and drive straight north, crossing the tracks of the Chicago, Rock Island & Pacific Railroad and the North Canadian River. Continue north to 1 mile south of the Kingfisher County line. Turn west, and continue about a quarter of a mile to the gypsum quarry on the right. Owner of the quarry, Mr. Ray Schweitzer, Rt. 2, Okarche, would like to be notified in advance.

Site location: SE¼ sec. 2, T. 14 N., R. 9 W.

Topographic map: Fort Reno (15′).

References: Mogg, Schoff, and Reed (1960).

The material being quarried at this site (fig. 5) is essentially the same as that exposed northwest of here, at Roman Nose State Park in Blaine County (Fay, 1959). Gypsum, a common mineral in Permian rocks of Oklahoma, is hydrous calcium sulfate ($CaSO_4 \cdot 2H_2O$), a soft, white mineral that can be scratched with the fingernail. Three varieties of the mineral can be found at this site: (1) selenite, a highly translucent to transparent, flaky form that resembles white mica except for its lack of elasticity; (2) satin spar, a fibrous form consisting of minute columnar fibers of selenite usually developed at right angles to the bedding or vein direction of the mineral; and (3) massive gypsum, a finely crystalline form resembling a soft rock with no consistent direction of grain orientation. Massive gypsum in red beds is commonly colored red by hematite. The mineral was deposited in the evaporating Permian sea mentioned earlier in the section on general geology. Some of it may have been deposited on the surface of the floor of the shallow sea, but probably it was deposited immediately underneath the surface of highly saline mud and ooze on the sea bottom.

Gypsum quarried at this site is used for soil conditioning and other agricultural purposes. Thicker, more widespread gypsum accumulations provide the basic material used in the manufacture of wallboard, plaster of paris, and medicinal gypsum.

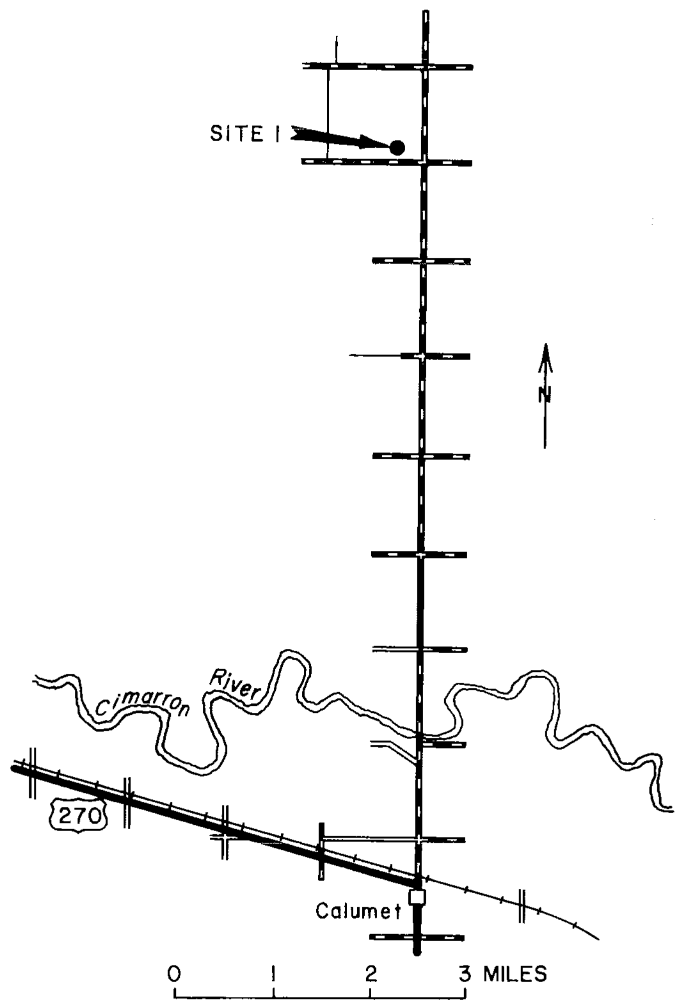


Figure 5. Location map for Canadian County site 1.

Canadian County Site 2: Canadian River terraces

Access: From Interstate Highway 40, turn north onto U.S. Highway 281. Follow 281 westward to the intersection with Oklahoma Highway 8. Turn left and cross to the south side of the Canadian River via an old bridge.

Site location: This is not a pinpoint site but rather is a short trip along the upper valley walls and alluvial materials of the Canadian River in secs. 4, 5, 6, 7, and 8, T. 12 N., R. 10 W.

Topographic map: Geary (15′).

References: Mogg and others (1960), Miser (1954).

Red beds of Permian age crop out on the walls of the wide valley of the Canadian River in this area (fig. 6). Close examination of the sand and silt grains of these beds will show that most of the color is on the outside of the grains and is hematite, red oxide of iron (Fe_2O_3). Colors of most of the flood-plain and terrace materials of the streams are normally much less red, because they are derived largely from these same sands and silts after the surface coating of hematite has been weathered or abraded. At places where outcrops of Permian rocks are seen, light-gray, greenish-gray, or white beds may be seen (for instance, north of the flood plain in the NE¼ sec. 5, T. 12 N., R. 10 W.). These light-colored beds usually have been produced by reduction of the iron oxide to a duller color. Some of the light beds are slightly gypsiferous.

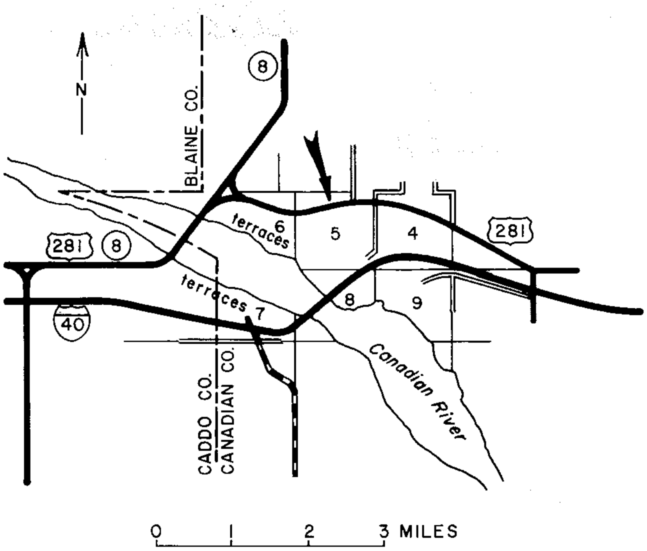


Figure 6. Location map for Canadian County site 2, Canadian River terraces.

By looking upstream (westward) from a high vantage point on either side of the valley, one can see remnants of former flood plains now exposed as upland terraces. These features indicate rejuvenation of the Canadian River, permitting it to cut into and remove portions of its former flood plains, leaving behind the parts which now form the terraces. Careful observation will show fragments of several terrace levels here. As rejuvenation stages permit the river to cut continually deeper, the older terraces stand above younger ones (fig. 7).

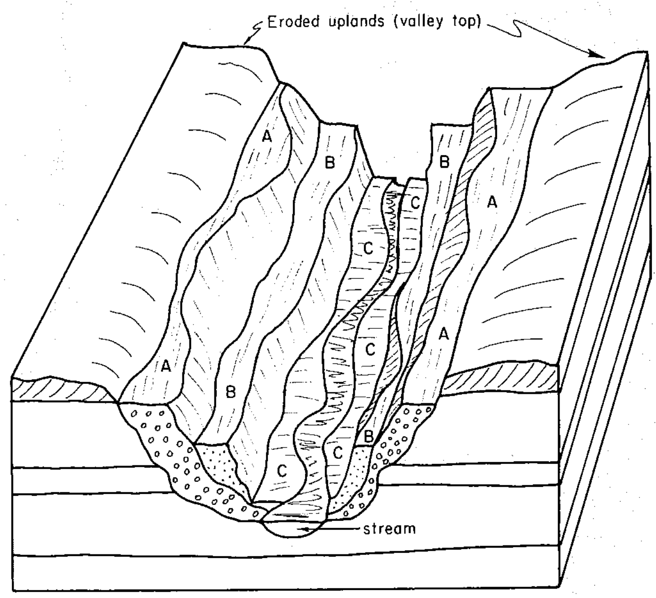


Figure 7. Diagram of stream-terrace development with rejuvenation. Oldest terrace, *A*, is highest. First rejuvenation permitted stream to cut into *A* and develop new flood plain at *B*, where second terrace is shown. A second rejuvenation allowed stream to produce present flood plain, *C*, which will cut into remnants of *A* and *B* as future erosion occurs.

Creek County

Creek County is an area of nearly 1,000 square miles, consisting of a dissected, relatively flat upland sloping about 250 feet eastward. The total relief is also about 250 feet, with some slopes and stream gradients locally steep.

Principal streams in the county are the Cimarron River in the northwest and Deep Fork Creek in the south. Salt Creek and Little Deep Fork Creek, tributaries of Deep Fork, have developed flood plains covered by considerable amounts of Quaternary alluvium.

All of the surface exposures in Creek County are Pennsylvanian or Quaternary in age. There is no lithified Quaternary material in the county. The oldest Pennsylvanian rocks are the Holdenville Shale of the Desmoinesian Series, and the youngest are in the Vanoss Group of the Gearyan Series. Beds show a regional dip of less than 1° westward and except in rare instances appear horizontal to the eye.

The sandstones are colored tan to brown by limonite, the hydrous oxide of iron. Many sandstones show a speckled appearance on a freshly broken face, indicating that limonite is not uniformly disseminated throughout the rock.

Creek County Site 1: Lecompton Limestone outcrop

Access: From intersection of Oklahoma Highways 51 and 99, north of Oilton, drive south 1.5 miles (2.4 km) on Oklahoma Highway 99 and stop at good outcrop on north slope of Cimarron River valley.

Site location: NE¼ sec. 28, T. 19 N., R. 7 E.
Topographic map: Yale, 1929 (15′).
References: Oakes (1959).

Approaching this site from either direction (fig. 8), one cannot fail to be impressed by the striking outcrop that has been produced by the road cut. The Lecompton Limestone, basal member of the Virgilian Ada Group, has thinned considerably and is quite a bit siltier than at the Sedan Limestone Quarry where the formation is discussed in the section on Osage County: however, its conformable relationship with the underlying Vamoosa Group is quite readily discernible here, and changes in lithology can be observed (fig. 3).

During the Late Pennsylvanian, the elongate chain of the Oklahoma Mountains, including the Arbuckle Mountains located a hundred miles south of this site, underwent the last real orogenic uplift of their history. This uplift steepened gradients of streams flowing out of the mountains and made more clastic materials available for the sea to the north. The increase of silt and sand, accompanied by a decrease in number and thicknesses of limestone beds is a reflection of this uplift to the south. Pure limestone was deposited where small amounts of clastic materials were available. This condition can be met where borderland masses are far enough away or of insufficient relief to provide much clastic material or where the source rocks are entirely limestones (which may, by their very nature, provide additional calcareous materials permitting deposition of clastic limestone).

The Lecompton Limestone at this site is a typically silty to sandy limestone, blue gray on the fresh surface, which weathers buff to orange by oxidation of the limonite content. Bedding is thin, wavy, and uneven, with thin shale or siltstone partings. The formation is about 9½ feet thick, standing out starkly from the grayish-buff to red shales and siltstones above and below. Although many fossil fragments can be seen on a fresh break, few fossils can be collected, because they and the enclosing rock are of equal resistance. Along the top of the upper ledge, however, and in some of the shale breaks between the beds, crinoid-stem fragments, brachiopods, and gastropods can be found.

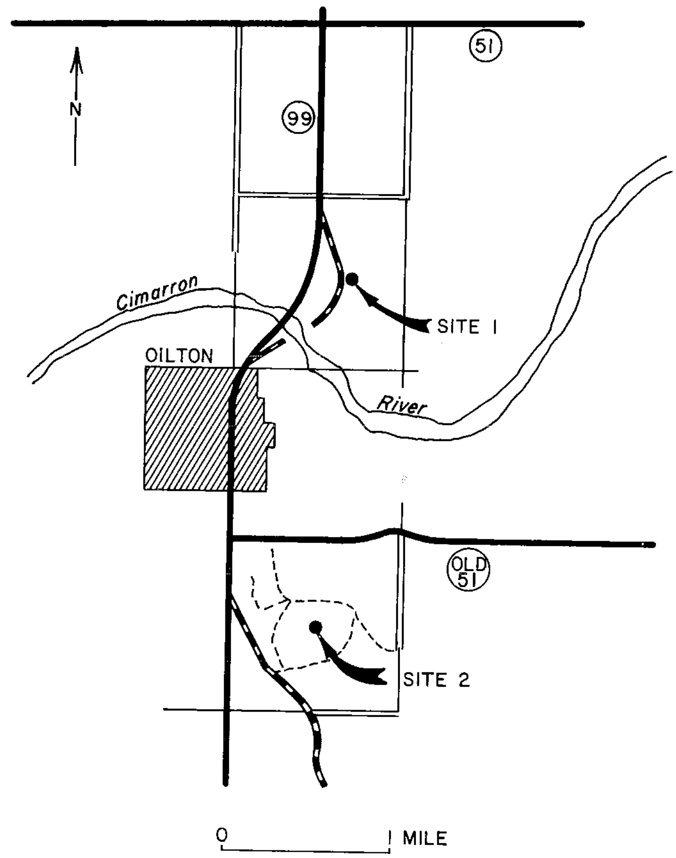


Figure 8. Location map for Creek County site 1, Lecompton Limestone outcrop, and Creek County site 2, old Oilton Oil Field.

Creek County Site 2: Old Oilton Oil Field

Access: On old Oklahoma Highway 51, go about .25 mile (.4 km) east of the intersection with Oklahoma Highway 99 (on the south edge of Oilton). Turn right (south), cross cattle guard, and follow road to crest of hill. Stop near one of the old concrete foundations; get out and look around.
Site location: Near C sec. 4, T. 18 N., R. 7 E.
Topographic map: Yale, 1929 (15′).
References: Oakes (1959), Bullard (1928).

This site (fig. 8) is of cultural and historical interest rather than being limited strictly to geology. Lensing, crossbedded sandstones, shales, and siltstones of the Vamoosa Group are exposed from the bottom to the top of the hill at this site. These clastic rocks range from almost white to a dark chestnut brown depending on the amount of weathered iron oxide (limonite) they contain. The sandstones are poorly cemented, quickly weathering and wasting to rounded edges as weather and vehicular traffic attack exposures. Except where crossbedding has developed, the beds appear mostly to be flat lying.

Oilton is a relatively old oil field, dating back to 1914. After the discovery of Cushing and Drumright in 1912, 2 years elapsed before the Oilton discovery well was drilled by McMan Oil Company in sec. 32, T. 19 N., R. 7 E. This well, which produced from the Bartlesville sand, was drilled to 2,599 feet about a mile northwest of the hill on which you are now standing. Development of the field moved up the flanks of a dome and centered on the hill. Production has been from 8 Pennsylvanian zones and from at least 3 Ordovician sands. Both stratigraphic and structural traps have produced oil and some gas. Some of the production has been from shallow wells. A 25-foot-thick Missourian sand called the Musselman produced oil and gas from a depth of only 700 feet.

During peak operation of the Oilton Field, a pumping-processing plant was constructed on the hilltop. Concrete foundations and abutments from the buildings are still numerous in the vicinity and make an interesting historical site to investigate. Foundations of a variety of oil-field items from individual derricks to large pumping stations can be seen with interconnecting walkways of concrete and pebbles to facilitate exploration. Lilacs and other ornamental shrubs were left behind in mute evidence that this place was cared for and that it was intended for long-term use. Quite a few of the wells are still pumping and cared for, but it is doubtful that any of them produce the hundreds of barrels per day boasted by their predecessors.

Creek County Site 3: Sapulpa coal bed

Access: On the Turner Turnpike in northern Sapulpa, stop underneath the overpass that provides a crossing for Oklahoma Highway 97.
Site location: SE¼NW¼ sec. 26, T. 18 N., R. 11 E.
Topographic map: Sapulpa North, 1956 (7½′).
References: Oakes (1959).

No commercial coal is mined in Creek County, according to Oakes (1959), but this easily accessible outcrop (fig. 9) of a thin, poor-grade coal will give students and other interested persons an opportunity to see a miniature environmental situation, which, if amplified, could have produced commercial coal. The coal bed, less than six inches thick, crops out about 18 inches below the Hogshooter Limestone (Missourian Series, fig. 3), recognizable near the top of the road cut. Some limited digging, or rather scraping, may be required to expose the coal from beneath the weathered, silty shale. The coal commonly is brown from limonite stain, but in a fresh break it is quite black, showing conchoidal fracture and a glossy luster. In the silty shales above and below the coal, careful searching and a bit of luck might yield a few specimens of *Pecopteris* and highly-crushed, small pieces of *Calamites* (fig. 10). *Pecopteris* is usually found adhering to or impressed upon a bedding plane, whereas *Calamites* commonly weathers free and is found as a siltstone cast or replacement. Both are shown natural size in the figure, but *Calamites* grew to many times this size at maximum growth. Both of these plants were plentiful in coal-forming environments in Oklahoma, and both have left a trail of descendants recognizable today as ferns and rushes.

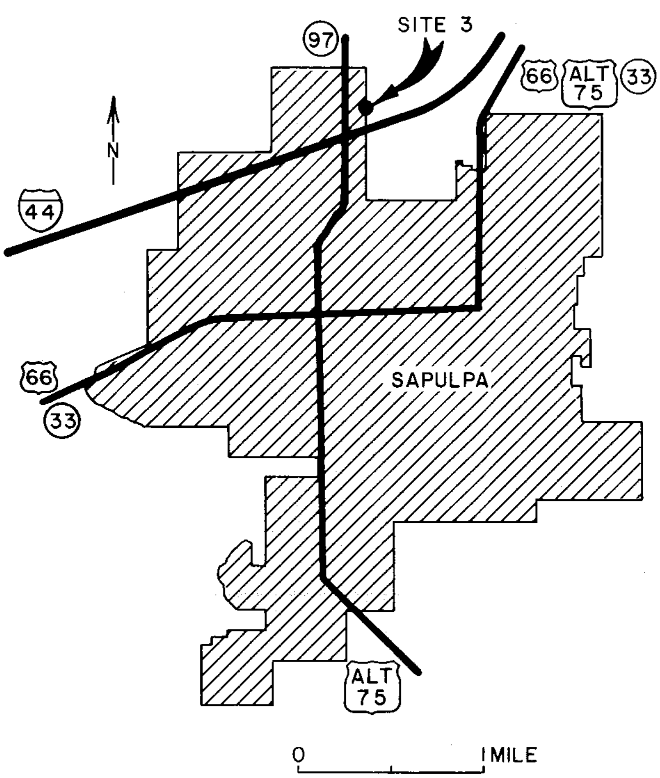


Figure 9. Location map for Creek County site 3, Sapulpa coal bed.

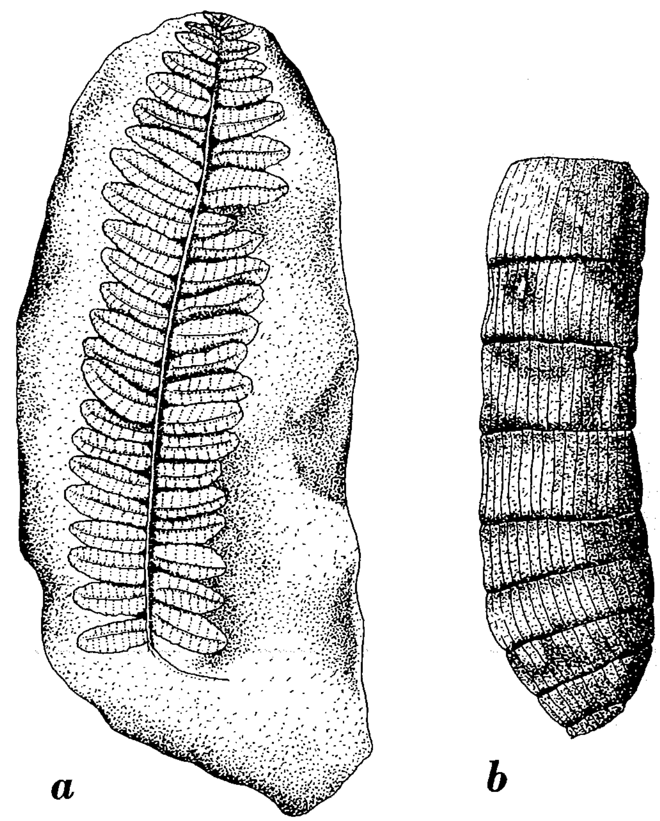


Figure 10. Drawing of *Pecopteris* sp., *a*, a fern, and *Calamites* sp., *b*, a rush, often found in silty shale underlying coal beds. Actual size.

Garfield County

Garfield County occupies a geographic position on a major divide. No major stream flows through the county. The Salt Fork of the Arkansas River flows through Grant County to the north; the Cimarron River flows through Kingfisher and Logan Counties to the south, and tributaries to these streams have their headwaters near Enid in Garfield County. A drive through the countryside around Enid, or more appropriately, a flight in a small plane over this high, flat county will reveal that the gradients of most of the streams are low, permitting meandering courses to develop, and that slightly entrenched meanders, low terraces, and well-developed slip-off slopes are obvious along most of the streams. These features show up particularly well late in the afternoon when the low angle of the sun casts long shadows which seem to etch the topography into bold relief.

All of the exposed bedrock in Garfield County is Permian with broad exposures of the Wellington Formation, Garber Sandstone, and formations of the Hennessey Group striking west of north across terrane (fig. 3). The type locality of the Garber Sandstone is in the county, and it and the Cedar Hills Sandstone are the most resistant rocks in the county and form the principal topographic features.

Garfield County Site 1: Gravel pit

Access: From the intersection of Owen K. Garriott and Van Buren Boulevards in Enid, go west on Garriott (U.S. Highway 60) 7 miles (11.2 km) and turn north (right) on Oklahoma Highway 132. Go north 1 mile (1.6 km) and turn east on section-line road. You will see large excavated gravel pits on the left (north) side of road. Turn into quarrying operation and check with Dee Browner, superintendent, for permission to collect.
Site location: SW¼ sec. 1, T. 22 N., R. 8 W.
Topographic map: Ringwood, 1956 (15′).
References: Miser (1954).

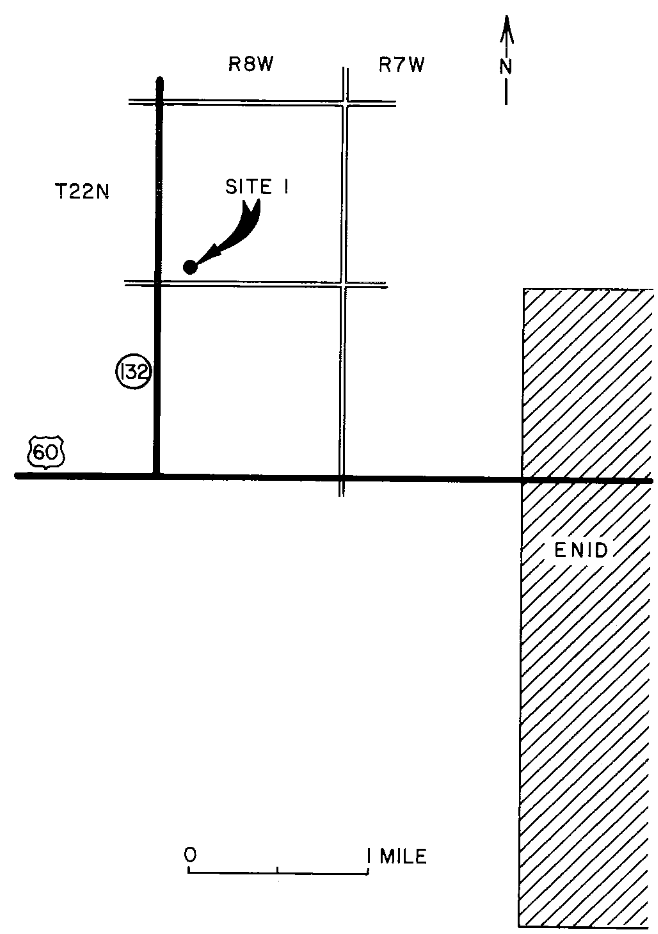


Figure 11. Location map for Garfield County site 1.

Covering more than a township north and west of Enid is an upland area surfaced mostly with high terrace deposits of Quaternary age. These deposits range from clay to gravel in size and were apparently left as alluvial deposits of a forerunner of the present Cimarron River.

Gravel extraction, washing, and sorting are in progress at this pit (fig. 11), but collecting activity is permitted as long as you do not get in the way of workers or truckers. Cobble-size fragments are commonplace, and a variety of rock, mineral, and fossil materials can be found. In only a few minutes it is easy to find several varieties of quartz and its derivatives. Clear quartz, smoky quartz, rose quartz, and citrine (yellow quartz) are among the more common pebbles found. Also common are chert, flint, chalcedony, jasper, orthoclase, plagioclase, hematite, limonite nodules, and small fragments of ferromagnesian minerals. Numerous pieces of silicified (agatized) wood are in the gravels, as well as pebbles and cobbles of basalt, granite, gneiss, and somewhat uncommon fragments of schist and phyllite. The original source of most of these specimens, almost certainly, was the Rocky Mountains.

More interesting to some collectors than the rock specimens will be the relatively large number of bone and tooth fragments in these gravels. Well-preserved teeth of mammoths, mastodons, and other smaller mammals such as bison, deer, and elk have been found here. Perhaps the most interesting of these are the mammoth and mastodon teeth (fig. 12). Large conical projections on mastodon teeth gave them the name "breast tooth." Several of these grew in each upper and lower jaw, resulting in a long jawline. In *Mammut*, forerunner of true elephants, short-rooted teeth grew one at a time in each jaw, resulting in a short, high head. Teeth were replaced as many as six times as they wore down from grinding grass containing abrasive sand and silt. Both of these proboscids (trunked animals) were in North America when man arrived some 10,000 to 20,000 years ago, and both have been found along stream courses and were hunted by man. Mammoth stock evolved elsewhere into modern elephants, and mastodon lineage apparently reached a dead end shortly after the end of the Pleistocene Epoch. Horses were also upon the North American Continent during Tertiary and early Quaternary time but had disappeared before man came to this part of the world. Small horse fossils are not uncommon in some of the early and middle Tertiary deposits of Oklahoma and other plains states.

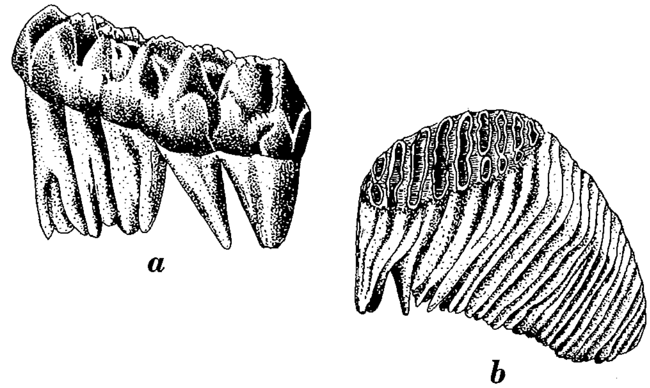


Figure 12. Drawing showing differences in enamel patterns and root structures of teeth of *a*, *Mastodon*, and *b*, *Mammut* (Mammoth).

Garfield County Site 2: Garber Sandstone exposure

Access: Drive south of Covington on Oklahoma Highway 74. Stop at Garber Sandstone outcrop in Otter Creek drainage.
Site location: SE¼NE¼ sec. 35, T. 20 N., R. 4 W.
Topographic map: Marshall East, 1974 (7½′).
References: Miser (1954).

This site (fig. 13) offers an outcrop of Garber Sandstone near the type locality and quite a few miles north of outcrops of the same formation in Oklahoma and Logan Counties. At this site the sand is somewhat finer than it is farther south, and there is more silt and clay in the beds. Color variations are more pronounced here than in the exposures father south, because the shales on a fresh surface show greater concentrations of hematite-coated grains. The color of these hematitic shales is rich enough that they were used as paint pigment by Indians living in this area.

These rocks appear to be flat lying here, although regional dip is in the order of ½° westward. Locally, as seen at this site, crossbedding can be seen to cause confusion in interpreting regional dip.

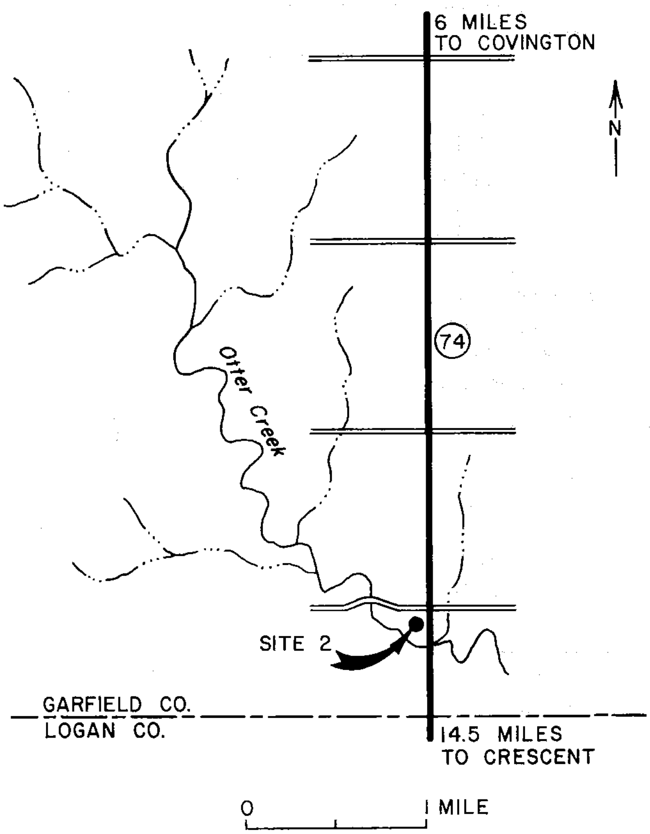


Figure 13. Location map for Garfield County site 2.

Grant County

Grant County, the northwesternmost of the counties covered in this report, contains Permian red beds, Pleistocene and Holocene stream alluvium, and limited areas of windblown sand dunes. The only major stream is the Salt Fork of the Arkansas River, and the entire surface of the county (with the exception of a few square miles north of Renfrow) is in its watershed. Outcrops include the Garber Sandstone and rocks of the Hennessey Group, and the Cedar Hills Sandstone of the El Reno Group crops out in the southwesternmost square mile of the county.

Grant County Site 1: Salt Fork of Arkansas River

Access: Drive north 1.5 miles (2.4 km) from center of Pond Creek on U.S. Highway 81; park at end of bridge over Salt Fork of the Arkansas River.
Site location: NW¼ sec. 36, T. 26 N., R. 6 W., NE¼ sec. 35, T. 26 N., R. 6 W.
Topographic map: Pond Creek, 1968 (7½′).
References: Johnson and others (1972), Naff (1977).

A fine opportunity to study river development is afforded at this area along the Salt Fork of the Arkansas River (fig. 14). Easy accessibility, sparse vegetation, meandering pattern, and development of terraces offer a fine field laboratory. In addition, the river carries more than 2,000 tons of salt daily from Great Salt Plains in Alfalfa County, to the west, and this mineral (NaCl) commonly coats and encrusts flood plains and desiccation ponds, giving one a chance to see microscopic salt crystals during dry weather.

Just downstream from the bridge in sec. 36, T. 26 N., R. 6 W., the stream makes a northward meander that has migrated toward the north or left bank throughout Holocene geologic time. As the stream has moved northward and continued to cut downward slightly, it has produced across most of section 36 a feature called a "slip-off-slope" on which it has deposited sand, silt, and mud in its channel. Drying of these deposited materials has allowed prevailing winds from the southwest and south to pick up some of the sediment and carry it across the river, where it has been deposited as low sand dunes. These dunes also extend northwest of the U.S. Highway 81 bridge, where they have been stabilized by vegetation. Examination of the dune sand shows it to be mostly quite fine grained. The winds are normally not strong enough to move medium and coarse sand in quantities sufficient to make dunes, and the silt and clay particles are mostly blown away by the process of deflation, leaving the fine sand in the dune ridges. This fine sand is what is called "blow sand" in the construction trade, and it is widely used as concrete mix and as fill material. Close examination of this sand will show that during its development as river alluvium and then its short journey as windblown sand, it has lost a great deal of the hematite coating that it had as a part of the Permian red beds and that it is now considerably lighter in color than it was in its bedrock state.

During most of the time, the channel can contain most of the flow of the Salt Fork. During floods, however, the stream leaves its banks and expands onto the flood plain. Both sides of the river, upstream and downstream from the bridge, contain areas of flood plain.

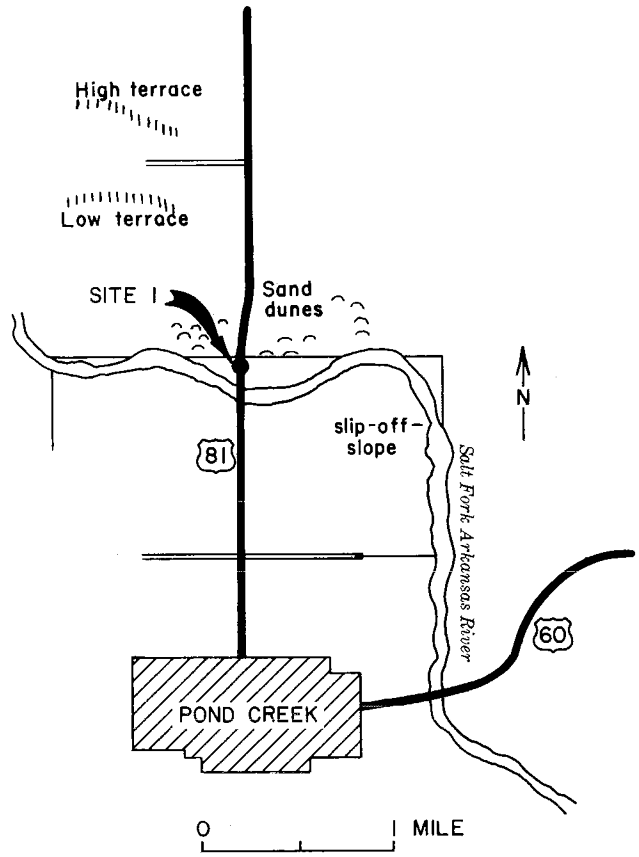


Figure 14. Location map for Grant County site 1, Salt Fork of Arkansas River.

About 1 ¼ miles (2 km) north of the bridge, the section-line road to the west offers a view of 2 terraces. The higher terrace (flat area on the right) is an older terrace developed as a flood plain when the stream was at a higher level. On the left, and closer to the stream, is a flat remnant of a younger terrace developed between the present flood plain and the older terrace. Examination of the sediment in these terraces will reveal mostly sand, with some fine gravel, some silt and clay, all showing a paler, pinker red than the red beds from which they were derived.

Kay County

Kay County offers an ideal place to study the differences between two geomorphic provinces of Oklahoma, the Northern Limestone Cuesta Plains and the Central Redbed Plains. The boundary line between these two provinces bisects Kay County, and the differences in geomorphology are apparent. It is true that the same boundary line bisects Payne County, farther south, but in that county the limestones have largely lost their identity and do not contrast as strongly with the red beds in the west as they do in Kay County.

The Arkansas River, the largest stream in Oklahoma, flows through northern Kay County and defines a portion of its boundary with Osage County. The Salt Fork of the Arkansas River flows across the southern part of Kay County before its confluence with the Arkansas River.

Kay County Site 1: Limestone cuestas

Access: From the intersection of Oklahoma Highways 18 and 119 in Shidler, Osage County, drive 6 miles (8.2 km) west on Oklahoma Highway 119 or start at Kaw City on the Kaw reservoir, cross the causeway on 119, and drive 3.5 miles (5.6 km) east.
Site location: General area, secs. 27, 28, 29, 30, 31, 32, 33, T. 27 N., R. 5 E.
Topographic map: Kaw City, 1964 (7½′).
References: Miser (1954).

A drive through eastern Kay and western Osage Counties reveals some of the most nearly classic cuesta topography seen anywhere. From this site (fig. 15), a view westward will show the road going through a limestone cuesta in a man-made cut. If you stop in this cut and climb to the top, you will be standing on the Cottonwood Limestone of the Oscar Group, considered by the Oklahoma Geological Survey at the top of the Pennsylvanian System (fig. 3). If you look north or south, you will see a view similar to the one shown in figure 16. Alternating limestones and shales that dip gently westward produce east-facing cuestas when eroded. Consequent streams flow down gentle dip slopes and steeper face slopes. Subsequent streams erode soft shales in valleys between cuestas. Almost as far as one can see, this succession of cuestas facing east will be repeated. The rocks of this area dip westward at somewhat less than one degree.

In the area from Shidler west to Kaw City, the cuestas are capped with the following limestones in ascending order: Neva Limestone, Cottonwood Limestone, Crouse Limestone, Funston Limestone, Wreford Limestone, and Fort Riley Limestone (fig. 3). Rocks that underlie the escarpment face and the low land between cuestas are easily eroded shales interbedded with the resistant limestones (fig. 16). In no one cross section are all of these limestones found, but locally—if only for a short distance and insignificant height—each can be observed to hold up a small cuesta. Most of these limestones are fossiliferous, and it would be worthwhile to search for fossils if outcrops are not too difficult to reach.

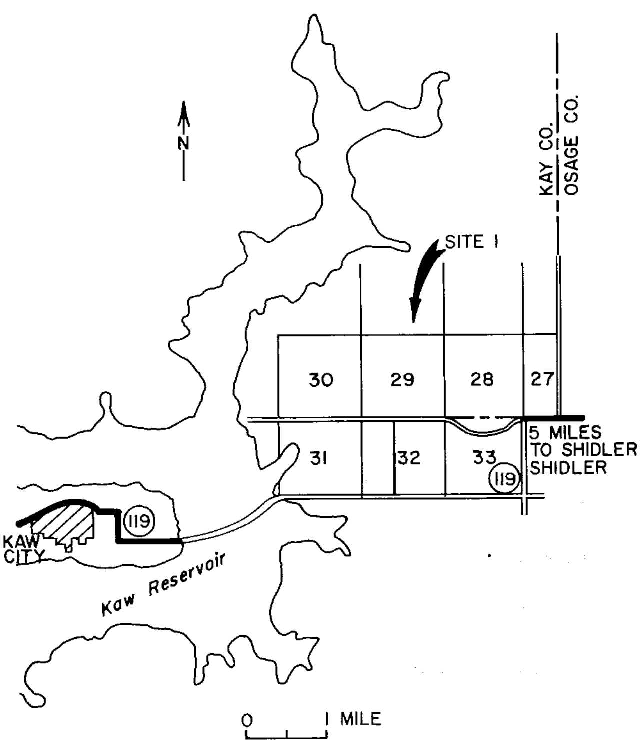


Figure 15. Location map for Kay County site 1.

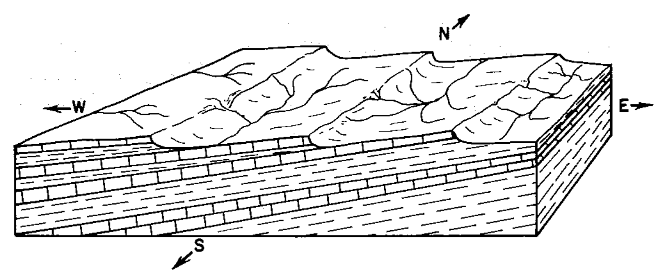


Figure 16. Diagrammatic view of cuesta topography of western Osage and eastern Kay Counties. (Dip exaggerated.)

Kay County Site 2: Herington Limestone outcrop

Access: From intersection of U.S. Highways 177 and 60 on south edge of Ponca City, turn east on 60 and drive .4 mile (.65 km). Stop at road cut on either side of road. Also drive into highway maintenance area just south of road to look for fossils.
Site location: NE¼ sec. 3, T. 25 N., R. 2 E.
Topographic map: Ponca City, 1968 (7½′).

Examination of the rocks (fig. 17) at this area will reveal what was happening to the environment during the Late Pennsylvanian Period. The gray, calcareous, silty shale exposed here is the Herington Limestone (Oscar Group) almost as far south as it can be recognized. Check with the field-trip sites described in Pawnee and Payne Counties to see that the older Neva and Red Eagle Limestones (fig. 3) can be traced and identified, and fossils can be collected from them, well down into Payne County. By the time of Herington deposition, however, the mountain barrier in southern Oklahoma must have been more effective as a source of fine-grained sediment, because the Herington can be traced scarcely south of the Noble County line before it becomes silty and shaly and loses its limestone lithology. The climate also was becoming dry, and soon afterward, in the Wellington Formation, which is just above the Herington, individual salt beds as much as 17 feet thick began to accumulate in a shallow sea a short distance farther west.

At this site, however, the Herington still contains a few marine fossils, and a careful search will provide the collector with a few crushed specimens of *Composita*, *Aviculopecten*, an occasional *Pseudorthoceras*, and scattered crinoid columnals.

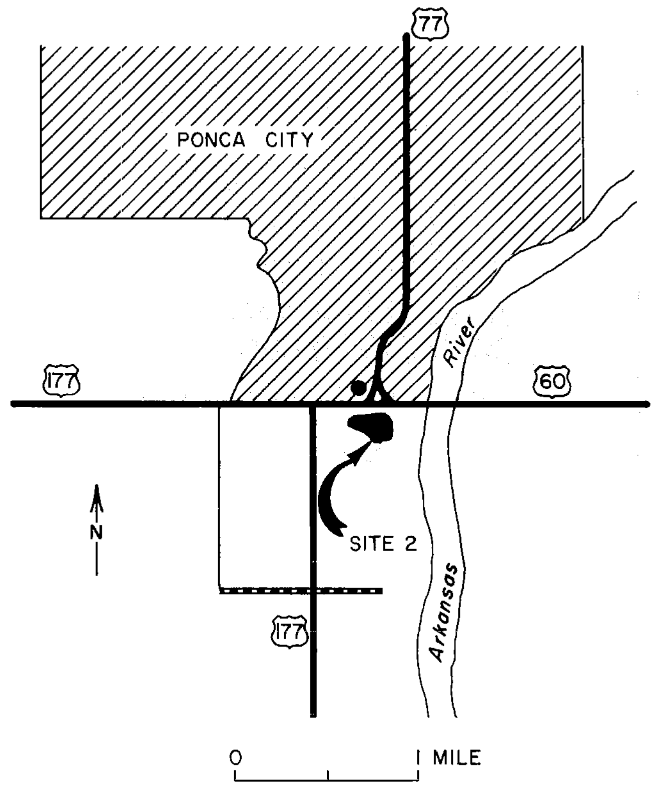


Figure 17. Location map for Kay County site 2.

Kingfisher County

Kingfisher County, one of the most western counties of this report, is essentially bisected by the Cimarron River, which enters at the northwest corner of the rectangular county and leaves near the southwestern corner. Skeleton Creek, one of the Cimarron's major tributaries, cuts across the northeastern section of the county, and Turkey Creek, which flows almost straight south, joins the Cimarron just upstream from Dover.

All lithified rocks in Kingfisher County are Permian, belonging to the Hennessey and El Reno Groups (fig. 3). The Cedar Hills Sandstone, at the base of the El Reno Group, is resistant enough to form topographic highs across the central part of the county. A very broad belt of mostly stabilized sand dunes is almost continuous across the county along the north and east banks of the Cimarron River.

Kingfisher County Site 1: Gravel plant

Access: Eight-tenths of a mile (1.3 km) south of Dover on U.S. Highway 81, turn west (right) into Dolese gravel extraction and sorting plant. Drive past pond and on behind headquarters trailer to dune area near washing flume. Stop at headquarters trailer, if occupied, and ask permission to visit.
Site location: Sec. 11, T. 17 N., R. 7 W.
Topographic map: Dover (7½′).
References: Johnson and others (1972).

This site is just north of the Cimarron River and is on the south edge of the broad dune area north of the river (fig. 18). From where you park your car, it will be necessary to walk across dunes to the area where gravel is being washed. Under the end of the washing flume and in the runout gully below lies a heterogeneous assortment of gravel that will offer many hours of happy hunting for collectors. Some of the pebbles and cobbles are several inches long, and many kinds of rocks are represented. Pieces of petrified wood are common, all silicified, and they represent several kinds of wood. Quartz, chalcedony, jasper, and chert are common in many sizes and shapes; most are subangular. Very good specimens of orthoclase feldspar (potassium aluminum silicate) are plentiful, all showing good cleavage planes and the beautiful greasy luster for which this pinkish feldspar is famous. Pieces of feldspar the size of tennis balls document the power of this stream's erosion during the waning phases of the Pleistocene Epoch, for they have come from the Rocky Mountains, more than 500 miles to the west. To move rocks of this size down the present Cimarron River is almost unthinkable, but since the Cimarron has flowed under torrential flood conditions many times in the past million years or so, it is simple to imagine that it transported relatively large rocks along its channel, and the rocks were preserved in terraces as the stream cut through its old deposits. It is also easy to imagine animals drowning in such a stream, being covered up on the flood plain, and their bones later washing out to be incorporated with the gravels. Many, many bones are found at this site. Most of them, however, appear to be modern horse or cow bones. At other sites, bones of mammoths and mastodons are relatively common.

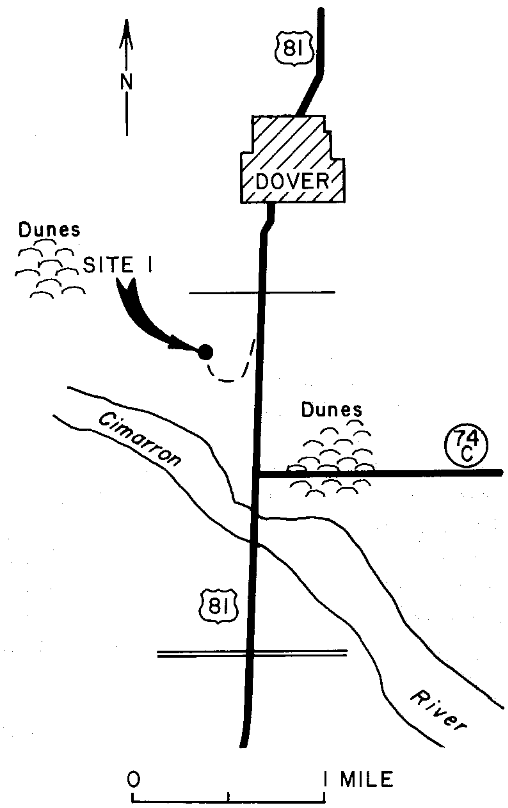


Figure 18. Location map for Kingfisher County site 1, Dolese gravel plant.

Kingfisher County Site 2: Sand dunes

Access: Drive 4.4 miles (7 km) west of Lacey on Oklahoma Highway 51 and stop at the pull-out east of the bridge that crosses the Cimarron River.
Site location: C sec. 16, T. 19 N., R. 9 W.
Topographic map: Ames, 1956 (15′).
References: Miser (1954).

This site (fig. 19) provides a good view of and easy access to the broad band of sand dunes that parallels the left bank of the Cimarron River for many miles, including the entire width of Kingfisher County. One of the factors necessary for development of extensive sand dunes is a nearby source of sand. Major streams such as the Cimarron River cross the plains and become good sources of such supplies of sand. The streams commonly have uneven or perhaps intermittent flow, permitting their broad channel floors to dry out. At most places along the stream courses, sediment is deep in the channel, and the prevailing winds from the southwest and the south pick up the dry sediment and transport it to the area north and east of the stream. Wind has a pronounced sorting effect upon the sediment, carrying the clay and silt particles far away by a process called deflation and permitting the sand to lag behind and be heaped up into dunes. Coarser sand is left behind, as it is too large for the wind to remove from the stream bed. By this process of selection and winnowing out, the sand dunes are composed of well-sorted sand. Examination of the sand in the stream here shows it to have some red iron oxide (hematite) on its grains, but even in the

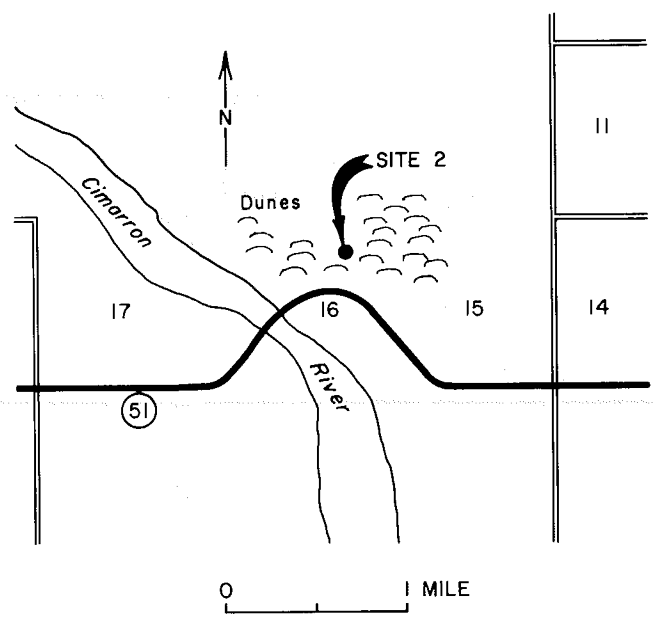


Figure 19. Location map for Kingfisher County site 2.

stream it has already lost much of the deep- to bright-red color that it had when it was part of the Permian bedrock. Further loss of iron oxide coating occurs when the wind carries the sand into the dunes, and scraping of the grains against each other produces a frosted appearance that can be seen on some grains with a hand lens.

The band of dunes on the leeward (north) side of the river seldom becomes very wide, because dune growth is slow, and vegetation grows on the dunes and stabilizes their migration downwind.

When dunes develop where the wind is from a generally prevailing direction, their slopes are asymmetrical, showing the lee slope to be somewhat steeper than that of the windward side. Figure 20 diagrams how dunes are shaped and how growth and migration occur. Slopes of windward sides are determined by size and sphericity of grains. Lee slopes are determined by angle of repose of dry sand. If supply is interrupted, or if moisture increases, vegetation will stabilize dune growth and movement. In dry, windy climatic cycles, dunes will grow and will migrate downwind.

If you visit this site at the right time, you will see that the Cimarron River shows a braided stream flow similar to that discussed in the section on Canadian County. Here the stream floor is easily accessible, and you can walk right out onto it to study the sand. If the wind is brisk, you can see that even with water in the stream's braided pattern the islands between are losing sand as their tops dry off, and some of this sand is carried by the wind into the dunes on the bank of the channel. It is by such minuscule amounts as you can observe that the vast dune areas have been built and maintained over the centuries of recent geologic time.

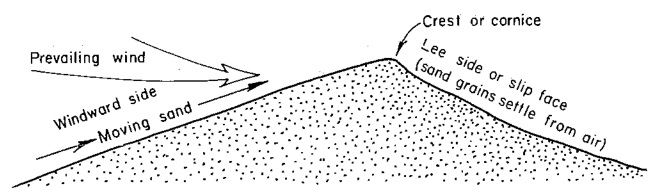


Figure 20. Diagram indicating mechanics of sand-dune growth and migration.

Lincoln County

Surface exposures in Lincoln County are sedimentary rocks of Late Pennsylvanian and Early Permian age. Relief is locally high near major creeks, because most of the rocks are relatively massive sandstone units. Oldest rocks in the county belong to the Vamoosa Group of Virgilian (Pennsylvanian) age, exposed in a small area along the eastern border of the county; the youngest Paleozoic rocks are in the part of the Wellington Formation that is above the Fallis Sandstone Member (fig. 3). Deep Fork Creek crosses essentially the central part of the county, from west to east, and it has left patches of high terraces in the uplands as it has cut down to its present level. Fine exposures are numerous along stream banks and in road cuts where the thick sandstones crop out.

Dip of the rocks is less than 1° westward, and the rocks strike almost due north-south.

Lincoln County Site 1: High-terrace gravel

Access: From the intersection with U.S. Highway 66 in Warwick, drive 3 miles (4.8 km) north on U.S. Highway 177, passing over Deep Fork and beneath Turner Turnpike on the way. Turn onto gravel road leading east, and stop on left (north) side after about 80 feet.
Site location: SW¼SW¼ sec. 32, T. 15 N., R. 2 E.
Topographic map: Wellston, 1966 (7½′).
References: Miser (1954).

Exposed at this stop is a small area of upland terrace gravel left by an early stage of Deep Fork or one of its ancestral streams (fig. 21). Such high exposures of terrace remnants are not uncommon in Oklahoma and adjacent states, and where a number of them can be found, they are useful in calculating former stream courses. Many such gravels can be found on hilltops across counties in north-central

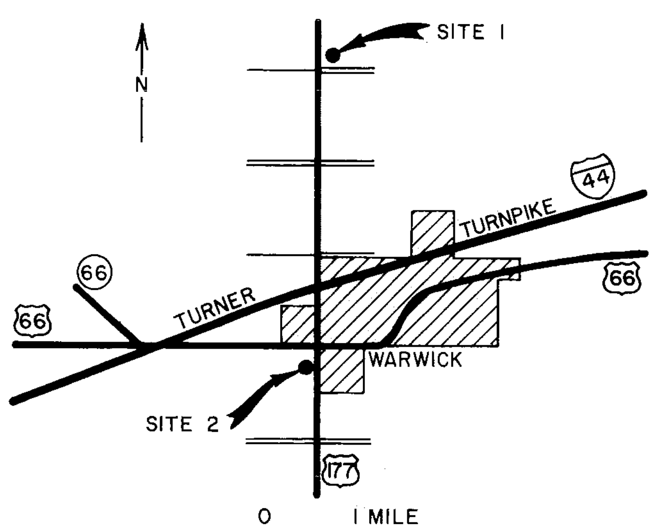


Figure 21. Location map for Lincoln County sites 1 and 2.

Oklahoma, this one duplicating others with the exception of its being easily accessible to the road.

The gravel deposit is unconsolidated; rock fragments range in size up to small cobbles and are a diverse assortment of material. The writer has found pieces of fresh orthoclase feldspar as large as 1.2 inch in length, basalt pebbles, golf-ball-size granite pebbles, weathered and poorly preserved pieces of schist and phyllite, jasper fragments, quartz pebbles, and many pieces of silicified wood. The wood fragments are easily identified as such by their rather angular, blocky shape and the ridged striations of their flat sides.

Some of the fragments could not have come from anywhere within the current watershed of Deep Fork, and the fact that they are in these gravels suggests that they may have been derived by erosion of Tertiary deposits of the High Plains that once extended farther east than their present limits, or that the terrace materials may have been left by the North Canadian or the Cimarron River. If this latter assumption is true, one of these rivers has migrated laterally a number of miles to reach its present course. Such a wide migration of a major stream is not uncommon in geomorphic development.

Lincoln County Site 2: Concretions

Access: From the intersection of U.S. Highways 66 and 177, go .25 mile (.4 km) south on 177 and stop at long outcrop of nodular red beds on right side of highway.
Site location: E. line NE¼ sec. 19, T. 14 N., R. 3 E.
Topographic map: Wellston, 1966 (7½′).
References: Miser (1954), Johnson (1972), Ham and Merritt (1944).

Concretions are rounded, nodular, dog-bone-shaped or irregular masses formed when ground water concentrates material (usually calcite) by precipitating it from solution. They are common in certain parts of Oklahoma and are widespread in their geographical distribution. At this site (fig. 21), the concretions are quite rough and irregular. Inside, however, the concretions are filled with calcite crystals that developed in a central cavity that was opened when shrinkage of the calcareous clay caused the rounded masses to crack. In some of the concretions, the cracks have formed a star-shaped pattern that is a beautiful collector's specimen. The outsides and the unfilled interiors of these concretions are red, ranging from orange-red to purplish-maroon, contrasting sharply with the translucent blue-gray of the calcite fillings. I have found a number of these geode-like concretions in which the filling material is barite. The mineral ($BaSO_4$) superficially resembles calcite ($CaCO_3$) but is quite a bit heavier, having a specific gravity of 4.5 compared with calcite at 2.72. This means that barite is 4½ times as heavy as an equal volume of water, a specific gravity that you can not fail to notice when you pick up a specimen.

Lincoln County Site 3: Sandstone outcrop

Access: From intersection of U.S. Highway 62 and Oklahoma Highway 99 in center of Prague, go north 4.5 miles (7.2 km) on Oklahoma Highway 99 to where the road jogs slightly northeastward. Turn west at this jog and go 0.9 mile (1.45 km) to sandstone outcrop just west of section-line road.
Site location: SE¼ sec. 31, T. 13 N., R. 6 E.
Topographic map: Arlington, 1974 (7½′).
References: Johnson (1972), Miser (1954), Ford (1978).

Good exposures of sandstone from the Vanoss Group are relatively numerous in this section (fig. 22). The rocks are principally red to orange-red, medium-grained sandstone, poorly cemented and with moderate crossbedding. Channeling and ripple marks are seen on some exposures, which indicates that the water was not very deep when this sediment was deposited, and that the depositional site was probably not very far offshore. Crossbedding is difficult to see on this particular outcrop because of advanced weathering, but on fresher exposures nearby it shows up well. Dip of the rocks at this site is almost indiscernible to the unaided eye but is about a quar-

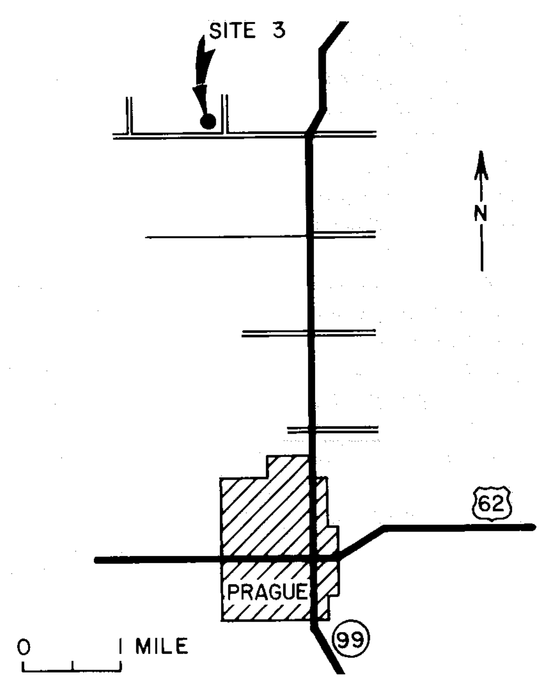


Figure 22. Location map for Lincoln County site 3.

ter of a degree to the west. In beds showing crossbedding, channeling, and interdigitation, such as these, low angles of dip are hard to determine. From this locality, the Vanoss Group changes character northward and southward. To the south, toward the clastic source, the grain size becomes coarser, and chert pebbles more than 0.5 inch long can be found in Vanoss sandstones east of Shawnee. On Turner Turnpike west of Stroud, a 1-foot bed of impure, silty limestone at the top of the stratigraphic section is identified as Brownville Limestone. Poorly preserved specimens of a fossil clam (*Myalina*) can be found in the Brownville outcrops. Also in these northern exposures, molds of a fossil productid brachiopod (*Linoproductus*) are relatively common in some yellowish-brown, fine-grained sandstone beds.

Logan County

Logan County is a small county, not quite 21 square townships in area, whose entire surface (with the exception of Quaternary alluvial deposits) is composed of Permian rocks of the Sumner and Hennessey Groups (fig. 3). Strike of the rocks is nearly due north-south, and dip is less than 1° west.

The topography of Logan County is mostly low, rolling hills developed to early maturity by a number of reasonably large streams. The Cimarron River is the principal stream, and its main tributaries are Skeleton Creek and Beaver Creek, along both of which are terraces that show evidence of 2 or 3 cycles of rejuvenation.

Logan County Site 1: Horsethief Canyon

Access: From stop sign in the center of Perkins, Payne County, go south on U.S. Highway 177, 1.3 miles (2.09 km) across Cimarron River. Turn west; drive through small community of Vinco and follow road until it trends straight west. Turn left (south) at a small, abandoned school 6.4 miles (10.3 km) from point you left U.S. Highway 177. Go .5 mile (.8 km) farther and turn west on relatively poor road. Seven-tenths of a mile (1.1 km) along the road, you will pass through a gate (be sure to close this gate) and will take the left fork of the pasture road. Stop car .5 mile (.8 km) past the gate, at the south end of Horsethief Canyon.

Site location: C S. Line, sec. 14, T. 17 N., R. 1 E.

Topographic map: Perkins, 1907 (15′).

References: Miser (1954).

This site (fig. 23) is one of diverse interest; geomorphic development of stratigraphic units has provided an unusual site for human use. Vinco rests on a terrace on the south bank of the Cimarron River. In the roadside ditches near it, contacts between the Permian bedrock and overlying terrace materials can be seen in several places. Along the north side of the road, past the school, are limited outcrops of loess, a windblown deposit discussed in further detail under Payne County sites.

The Cimarron River has cut about 80 feet into the old, reasonably flat upland surface along these reaches in Logan County. The map shows that this location is on the outside of a meander in the river and that here the flood plain is entirely on the north of the stream. Topography rises abruptly on the right bank (south side), and several small tributary streams or gullies enter the Cimarron along short, steep gradients. Horsethief Canyon is the most strikingly developed of these tributaries. As in the case of longer canyons discussed earlier in the section on Canadian County, Horsethief Canyon has provided considerable protection for deciduous trees, some of which appear to be hundreds of years old. Large elms, hackberries, chestnut oaks, and a few hickories grow in a thick forest along the bottom and up the sides of the canyon.

No permanent stream occupies the bottom of the canyon, but perhaps during the last of the Pleistocene Epoch the water table was high enough to provide perennial flow. Most of the present enlargement of the canyon head is excavated by basal sapping and mass wasting of alternating sandstones and soft shales. You will have parked your car on the Fallis Sandstone Member of the Wellington Formation, the basal unit of the Sumner Group of the Permian Sys-

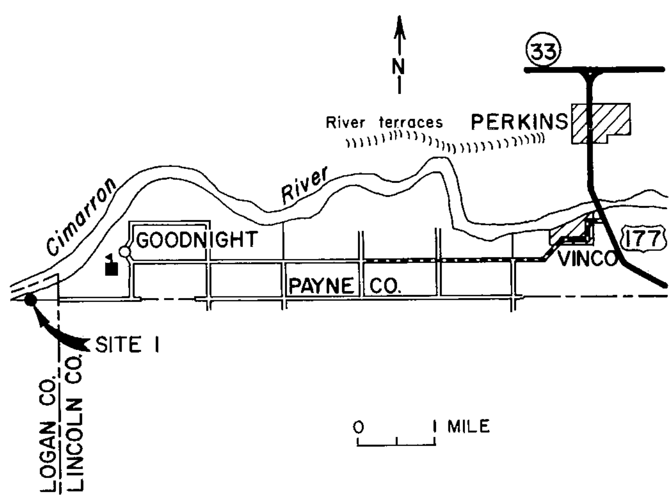


Figure 23. Location map for Logan County site 1, Horsethief Canyon.

tem (fig. 3). Here the Fallis is quite thick, consisting of alternating thick sandstones and thinner beds of more easily weathered shales and siltstones. All of the rocks are stained with red iron oxide (hematite), and a few samples of very dark maroon ironstone can be picked up here and there. On well-exposed faces, crossbedding can be found on most of the thick sandstone beds, indicating deposition in shallow water. No marine fossils have been found at this site. A section of the exposed upper portion of the Fallis Member at Horsethief Canyon is shown in figure 24.

Local history relates tales of many badmen and would-be badmen using this canyon as a haven of shelter and safety when trying to elude pursuers during the early history of our State. Names carved into the soft sandstone or scraped into the soot of the protected walls are said formerly to have included members of the Doolins, the Dalton gang, and other outlaws known to have worked this area. One can hear accounts that even the notorious Jesse James hid out here on more than one occasion. It is true that many inscriptions deface the rocks, but any signatures of notorious bandits or other outlaws have been collected by chipping away, or have failed to endure the ravages of weathering and basal sapping that have gone on since they were chipped into the rocks. Needless to say, however, these tales are the source of the name Horsethief Canyon.

From a high bluff on the eastern side of the canyon, a magnificent view of a considerable length of the Cimarron River can be seen. Old railroad spikes can be collected at the base of the bluff from an abandoned trace of A. T. & S. F. railroad, which ran along the south side of the Cimarron River.

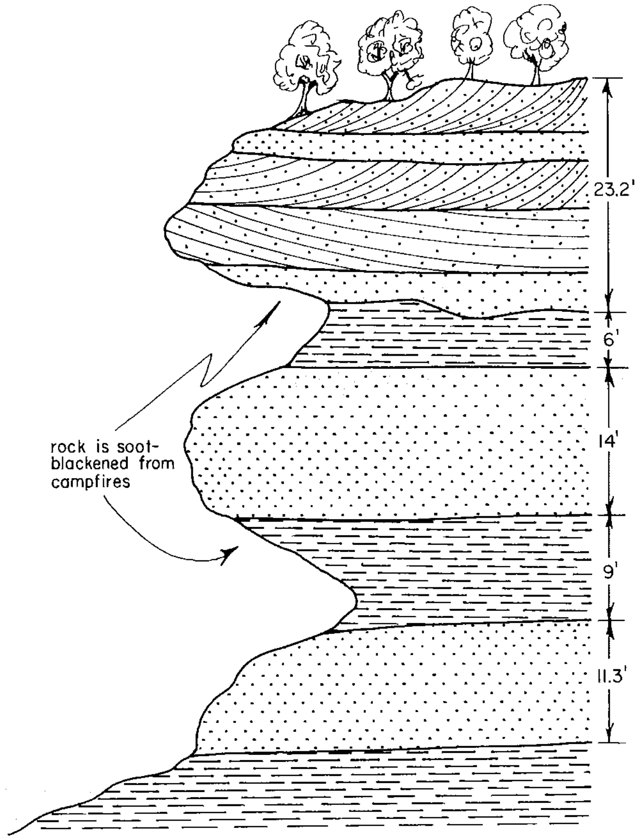


Figure 24. Exposed section of upper part of Fallis Sandstone Member of the Wellington Formation (Permian) in Horsethief Canyon. Thickness of massive sandstone units makes possible the development of steep-walled canyons such as Horsethief Canyon, and undercutting of these sandstones provides relatively well-protected shelters.

Logan County Site 2: Cimarron River

Access: Drive 4.75 miles (7.7 km) south from center of Crescent and park near bridge that crosses Cimarron River.
Site location: SE¼ sec. 2, T. 16 N., R. 4 W.
Topographic map: Crescent, 1970 (7½′).
References: Gilluly and others (1950).

Where Oklahoma Highway 74 crosses the Cimarron River, south of Crescent, several geomorphic identities can be seen (fig. 25). One of the most obvious features is an accumulation of sand dunes north of the river in the S½ sec. 2, T. 16 N., R. 4 W. These dunes are the result of prevailing southwesterly winds that derive sand from the river and pile it up along the flood plain and on terraces on the left bank of the river. Although most of the dunes are stabilized by growth of grass and small shrubs and trees, their fundamental asymmetrical shapes are apparent; the north or northeast slopes show steeper sides than the southern slopes. These dunes are identical in materials, relationship to the river, and relative degree of stabilization to those discussed in greater detail in the section on Kingfisher County.

The Cimarron River south of Crescent, except in

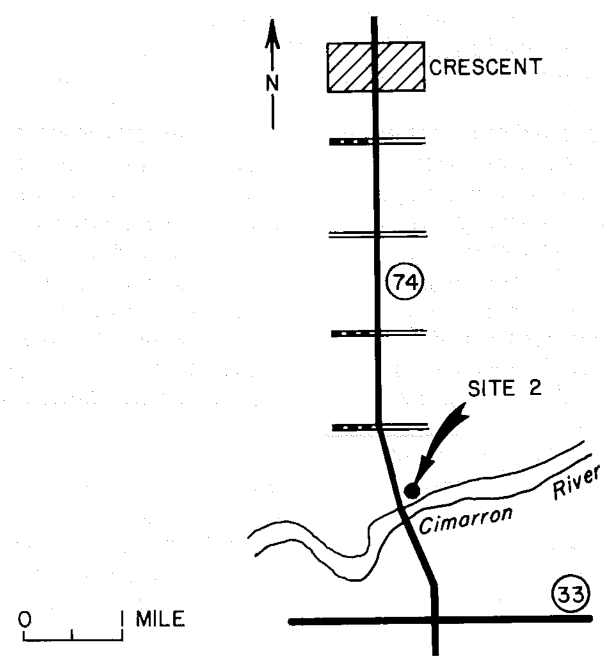


Figure 25. Location map for Logan County site 2, Cimarron River south of Crescent.

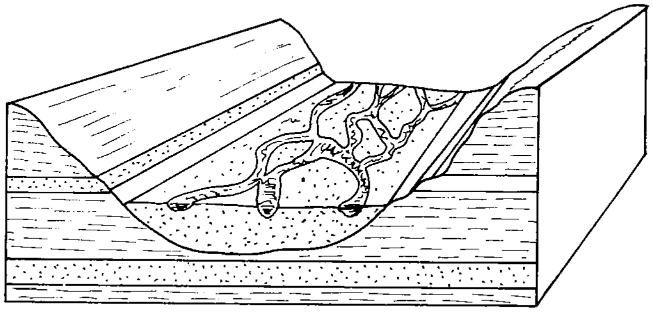


Figure 26. Diagrammatic sketch of a stream that has broken into many channels.

times of unusually full flow, shows a braided pattern. Figure 26 is a diagram of this flow pattern. Braided streams develop when a stream that usually handles a limited amount of water is furnished with more material than the moderate water flow can handle. This sediment, usually sand, causes damming and diversion of the stream in the bottom of a low-gradient channel, permitting the water to split and rejoin. It resembles the loosened braids of a rope, as shown in figure 26, and the process is sometimes called anastomosing. The abundant sands in streams flowing across the plains areas are principally from two sources: (1) channel and flood-plain sand left over from streams of much greater flow during late Pleistocene and immediately post-Pleistocene time; and (2) disintegrating outcrops of Paleozoic or Mesozoic sandstones in or near the streams. Sands from both sources are available for the Cimarron and other rivers crossing Oklahoma. Through long transport by streams or short transport by winds, much, if not all, of the superficial red iron oxide (hematite) coating is lost, and these sand grains are much less red than those of the original Permian bedrock.

Logan County Site 3: Red beds

Access: Visit any of the road cuts along Interstate Highway 35—from Cimarron River, 7 miles (11.3 km) north of Guthrie to south line of Logan County, 10.5 miles (16.9 km) south of Guthrie.
Site location: No exact or restricted spot for study of Permian red beds along highway.
Topographic maps: Guthrie North, 1970 (7½′), Guthrie South, 1970 (7½′), Edmond, 1966 (7½′).
References: Shelton (1973).

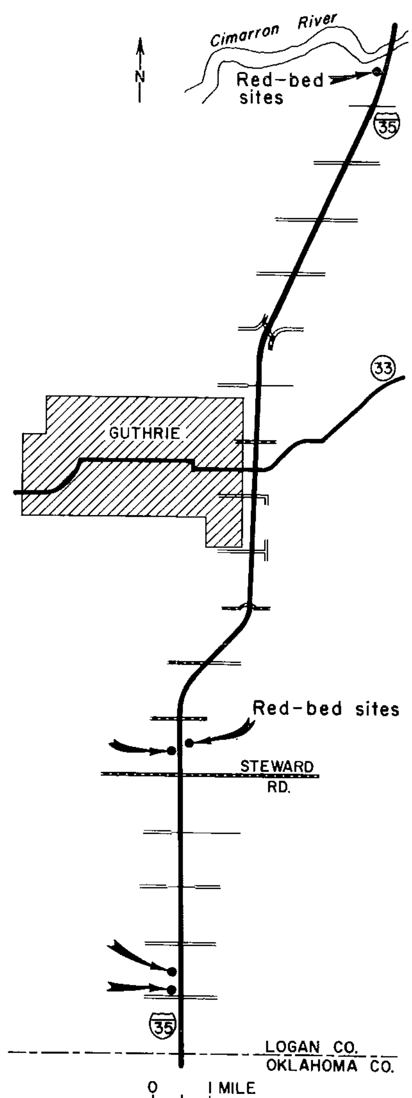


Figure 27. Location map for Logan County site 3, red beds.

During early-middle Permian time, north-central Oklahoma was bordered on the south by the Arbuckle and Wichita Mountains, on the southeast by the Ouachita highland, and on the east by the Ozark highlands. These relatively high areas provided sources for large amounts of clastic sediment that washed north and west into the broad sea covering northern Oklahoma, Kansas, and Nebraska. In the shallow southern and eastern regions of this sea, and extending beyond the actual shoreline as alluvial plains, great compound deltas were built from this sediment. Alternate wetting and drying provided oxidizing conditions in which iron oxides coated many of the clastic fragments and colored them bright red. Exposures of the Garber Sandstone along Interstate Highway 35 in the Guthrie area (fig. 27) show these beds to be a part of that delta and alluvial-plain system. Figure 28 shows a diagrammatic cross section of the types of beds found in a delta. In mobile basins, such as geosynclines and continental shelves, subsidence permits accumulation of thousands of feet of delta beds, but in stable, intracratonic areas such as Oklahoma and Kansas, delta thicknesses are generally limited to a few tens of feet.

Along Interstate Highway 35 and in exposures on adjacent country roads, features such as crossbedding, ripple marks, and interrelationships between various bedding types are easily observed. Variations in shades or degrees of iron oxide coloration are due to climatic conditions during and immediately after deposition, differences in amount of available iron oxide, and a variety of post-depositional weathering relationships.

Other geomorphic features seen along this stretch of highway are slump scars and small amounts of float and rock-fall. Immediately south of the Cimarron River bridge, on both sides of the road, the cut was made in soft shale with a high clay content. Although the slope of the cut appears to be quite low, overwetting from hard rains or snow-melt has allowed development of several slump areas that can be identified by their crescent-shaped upper scarps, giving way downslope to tongue-shaped displacements of shale and soil.

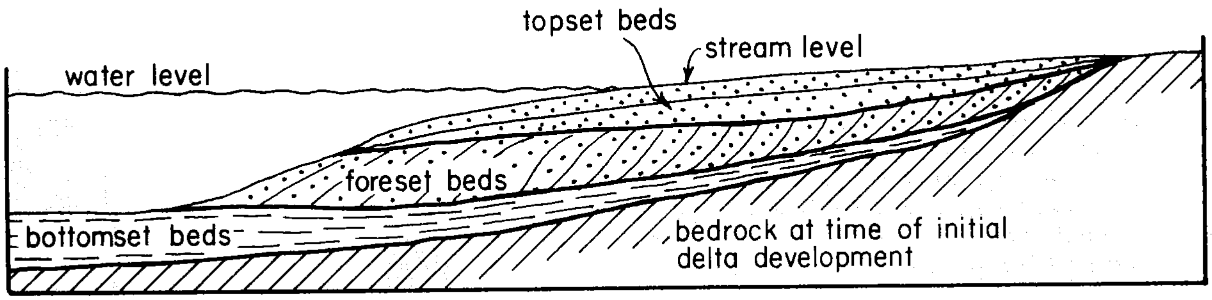


Figure 28. Diagrammatic cross section along delta showing different types of stratified rock layers. Bottomset beds are finest grained material, whereas foreset beds are coarsest and commonly are conspicuously crossbedded. Deposition of material in basin allows extension of topset beds in stream channels and along flood plains, causing inner portion of delta to pass into alluvial plain.

Noble County

Noble County outcrops consist of Permian red beds and Quaternary alluvium containing a wide variety of materials. The rocks dip very gently to the west, appearing to be horizontal in a limited view. The major stream in the area is the Arkansas River, which defines a part of the northwest boundary. A couple of meander loops of the Salt Fork of the Arkansas River enter the northernmost part of the county. Two relatively large tributaries to the Arkansas River, Red Rock Creek and Black Bear Creek, drain most of the county eastward, and in the southernmost part, headwaters of Beaver Creek, Stillwater Creek, and North Stillwater Creek drain into Cimarron River.

Noble County Site 1: Gravel, fossils, and artifacts

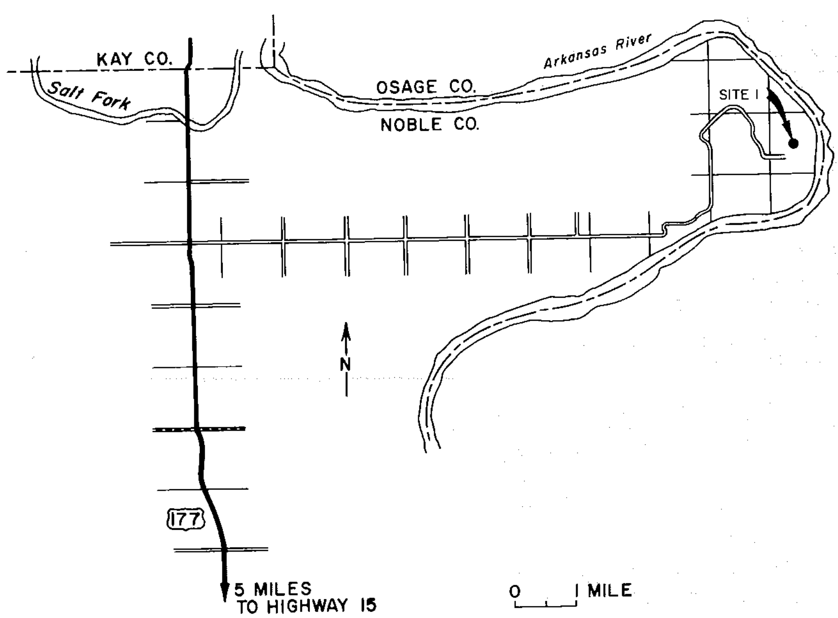


Figure 29. Location map for Noble County site 1, gravel, fossils, and artifacts along Arkansas River.

Access: Take section-line road that goes east from U.S. Highway 177, 2 miles (3.2 km) south of bridge over Salt Fork River. Proceed east on this road until it stops (11.8 miles or 18.8 km). You will be in a large meander loop of the Arkansas River. This site is not easily accessible if the roads are wet.
Site location: Near Ç sec. 8, T. 24 N., R. 4 E.
Topographic map: Belford, 1930 (15′).
References: Miser (1954).

When you stop your automobile, you will notice that you are on a rather narrow slip-off slope on the inside of a meander loop of the Arkansas River (fig. 29). The area is just downstream from the new Kaw Dam and may not be subject to flooding as frequently as it was prior to the construction of the dam. Find a site where coarse gravels are exposed and look in the gravel for chert and flint pebbles, quartz cobbles, and pieces of agatized wood. This site was used as a camp area by Indians in time past, as shards of obviously hand-worked chert are numerous in certain locations. Also, occasional abraded specimens of a Cretaceous fossil oyster (*Gryphaea*) can be found here (fig. 30). Although these items may be a part of the river gravel transported naturally from farther upstream, it is probable that these shells were trade items and had some monetary or ceremonial significance. Limited outcrops of Cretaceous marine beds containing *Gryphaea* shells crop out in Oklahoma and Kansas west of this site (Johnson and others, 1972).

Although this site produces interesting fossils and artifacts when one can find them, the uncertainty of being able to find exposed gravel on repeated trips and the poor condition of the road make it a site of questionable value, particularly for large student groups.

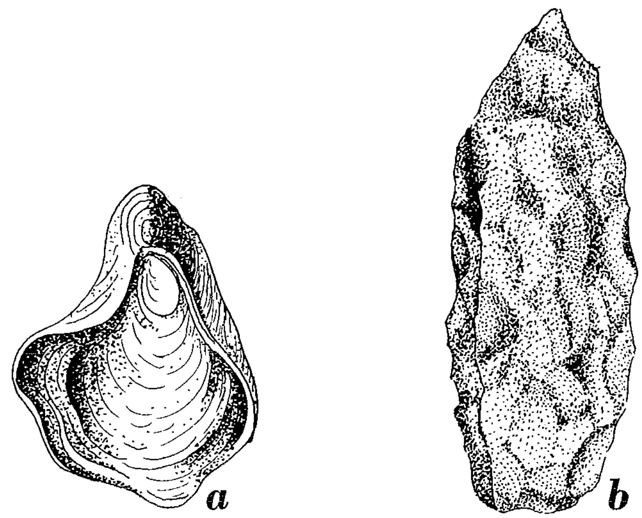


Figure 30. Drawing of *Gryphaea*, *a*, a genus of oyster of Cretaceous age, and pieces of obviously shaped and worked chert, *b*, found in gravels at Noble County site 1. Actual size.

Noble County Site 2: Copper

Access: From Morrison on U.S. Highway 64, drive east 2.5 miles (4 km) and turn right (south) on section-line road. Drive south 3.1 miles (4.8 km), turn right and go .2 of a mile (.32 km) and stop at bridge. Outcrops of red sandstone north of bridge, along Oak Creek, are the rocks for observation.
Site location: SE¼ sec. 27, T. 21 N., R. 3 E.
Topographic map: Lela, 1978 (7½′).
References: Heine (1975), Al-Shaieb and Heine (1976).

Copper deposits of generally low value are found in several counties of north-central Oklahoma. Some have been mined—with only moderate success—but some exploratory activity continues in search of economic deposits. At this site (fig. 31), the copper occurs principally as chalcocite (Cu_2S) replacement of fossil-wood fragments in red, crossbedded siltstone and sandstone of a deltaic facies. Nothing of commercial value has been found at this site, but pretty, collectable specimens of chalcocite, the surfaces of which have been oxidized to green-to-turquoise-colored malachite or azurite, are interesting to find. Other specimens in which ground water has caused copper to replace nodules of pyrite or marcasite are occasionally found at these sandstone localities.

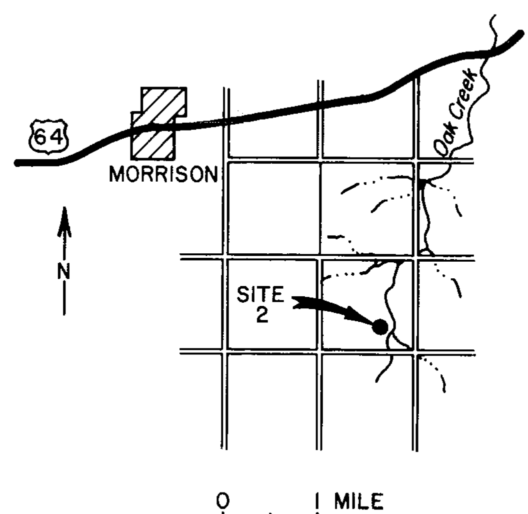


Figure 31. Location map for Noble County site 2.

Okfuskee County

Okfuskee County is the southeasternmost of the counties covered in this report. All of the exposures are Pennsylvanian (Paleozoic) or Cenozoic in age. The Pennsylvanian rocks range from shales and sandstones of the Senora Formation through reddish-brown sandstones and shales of the Vanoss Group.

Principal drainage is provided by the North Canadian River in the south and Deep Fork of the Canadian River in the north. Okemah, the county seat and principal town, rests on a divide between these two drainage areas.

Few cuestas are visible in Okfuskee County; however, the rocks dip gently to the west, and some cuestas have formed through erosion along en-echelon faults trending in belts parallel to the strike of the bedrock.

Okfuskee County Site 1: Volcanic ash

Access: From the intersection with Oklahoma Highway 56 (east of Okemah), drive east 1 mile (1.6 km) on old U.S. Highway 62. Turn south (right) on section-line road and follow it for 3 miles (4.8 km); turn east and go 1 mile (1.6 km), then turn south and stop after .5 mile (.8 km). You are now on a high Quaternary terrace left by the North Canadian River.

Site location: secs. 34 and 35, T. 11 N., R. 10 E.

Topographic map: Clearview, 1967 (7½′).

References: Ries (1954), Burwell and Ham (1949).

This site is one of several sites along the high terraces of the Canadian River system where fairly extensive deposits of volcanic ash can be found (fig. 32). The dust-sized ash was blown from volcanoes in Colorado and New Mexico and settled in this area during Pleistocene time. The ash was then eroded from surrounding uplands and accumulated in areas which at that time were depressions. The ash here is present over about 100 acres and reaches a maximum thickness of 5.5 feet. It is white, unconsolidated, and can easily be dug with a geology pick or with the

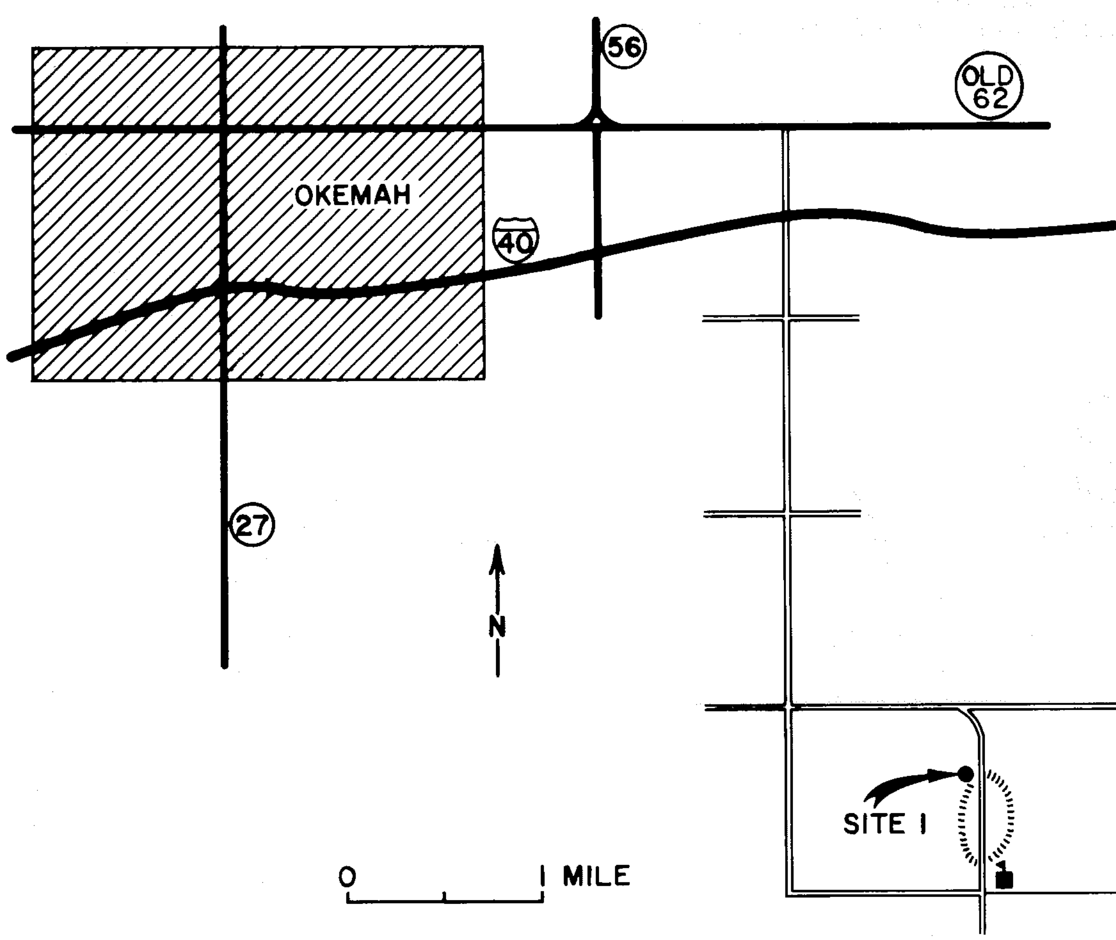


Figure 32. Location map for Okfuskee County site 1.

hands. Examination with a lens shows the ash to be composed principally of angular, glassy shards with some subrounded quartz grains. Materials enclosing the volcanic-ash deposits are reddish-brown, silty deposits not unlike loess in habit. These deposits have stained the surface of the ash, which, on a freshly exposed face, is white. This ash is of a purity that makes it suitable for abrasive use, and similar deposits have been mined nearby at Dustin, in Hughes County, to the south.

Okfuskee County Site 2: Hogback

Access: Drive north 6.1 miles (9.8 km) on Oklahoma Highway 48 from its intersection with U.S. Highway 62 on the southwest edge of Castle. Turn west on road and drive .8 mile (1.3 km) until road goes through a low road cut.
Site location: C W½ sec. 31, T. 13 N., R. 9 E.
Topographic map: Welty, 1973 (7½′).
References: Ries (1954).

This site (fig. 33) affords a fine opportunity to see the relationship between geologic structure and erosion of strata. Dip of the rocks in Okfuskee County is low, between ½° and 1° westward. Most of the geomorphic features, therefore, are insignificant. There are, however, several sets of en-echelon faults that strike in a general northwest-southeast direction, about 40° to 45° from the strike of the rocks. Vertical displacement across the faults ranges from about 10 to 150 feet (Ries, 1954).

The hogback that crosses the road at this site is obvious, with a dip of about 8°–10° westward. It is the

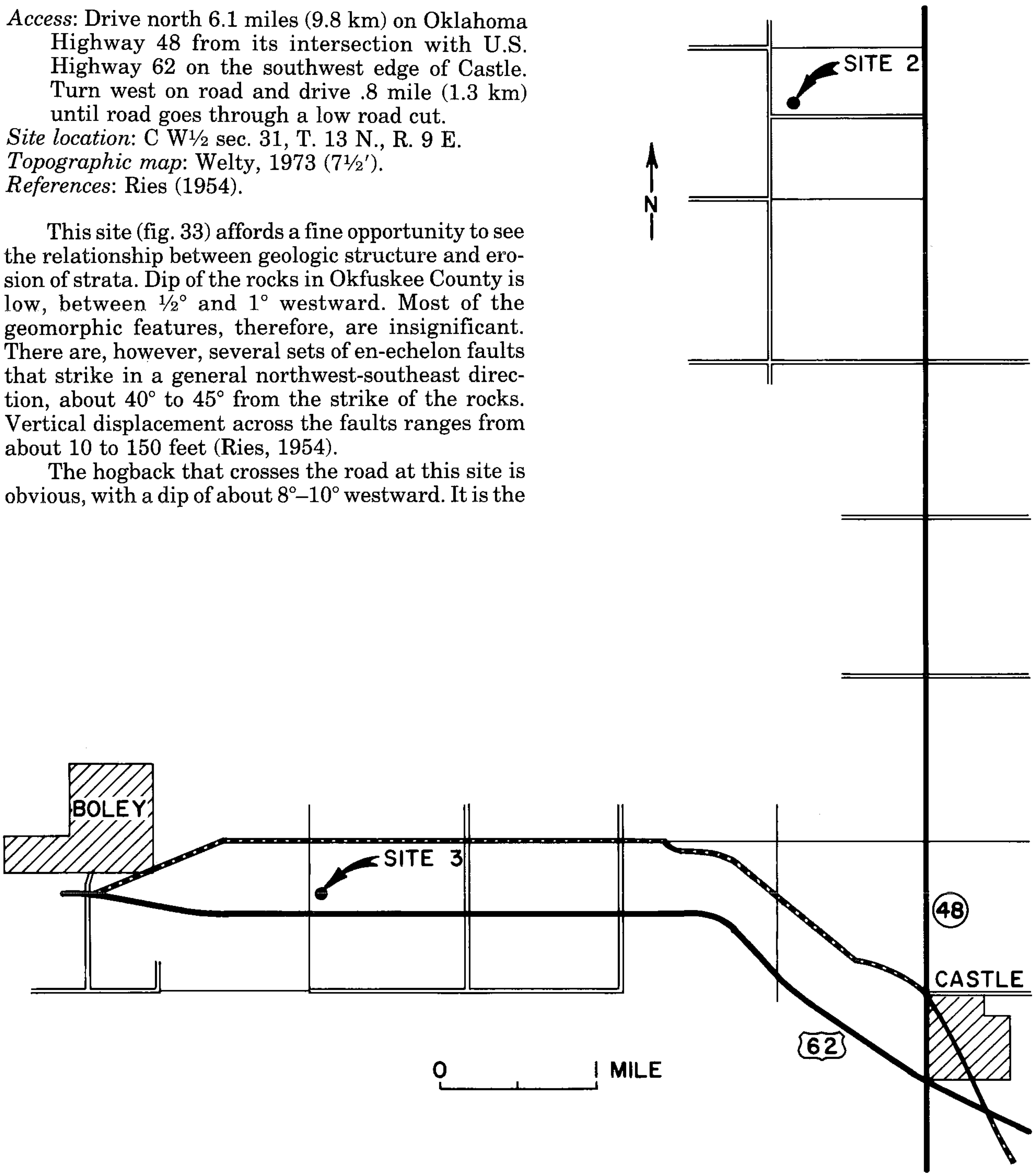


Figure 33. Location map for Okfuskee County site 2, hogback, and site 3, coarse conglomerate.

result of erosion of a fault, downthrown on the east side, that has brought into contact the friable, brown siltstones of the Barnsdall Formation (Ochelata Group of Missourian age) on the east with grayish-brown, more resistant sandstone of the lower Chanute Formation (also Ochelata Group) on the west (fig. 34). Several of these small hogbacks and cuestas can be found in Okfuskee County, but this one in sec. 31 is the most prominent.

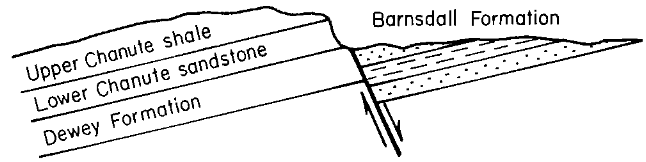


Figure 34. Diagrammatic sketch showing how differential erosion has produced hogback in sec. 31, T. 13 N., R. 9 E., Okfuskee County site 2.

Okfuskee County Site 3: Coarse conglomerate

Access: Drive 1 mile (1.6 km) east of Boley on U.S. Highway 62, turn north on poor road and drive north .5 mile (.8 km). Climb low promontory north of stop.
Site location: SW¼NW¼ sec. 27, T. 12 N., R. 8 E.
Topographic map: Boley, 1967 (7½′).
References: Ries (1954), Ford (1978).

Across Okfuskee County and into adjoining counties, the bottom 50 to 60 feet of the Vamoosa Group is represented by a persistent, coarse conglomerate with its type locality at Boley in sec. 20, T. 12 N., R. 8 E., Okfuskee County. This conglomerate is well exposed in road cuts, gullies, and on hillsides in and around Boley, and it caps the small promontory at this site. It is also exposed in sec. 34, T. 13 N., R. 8 E., but this locality is not easily accessible because of poor roads.

The conglomerate contains large numbers of cobble-sized fragments up to 6 inches in diameter—chalcedony, chert, silicified fossiliferous limestone, and oolite. Some of the limestone fragments contain crinoid fragments, fenestrate bryozoans, and gastropod shells. Ford (1978) indicated that a depositional site of a gently westward-sloping alluvial plain is suggested and that the source seems to have been highlands to the southeast in the area of the Ouachita Mountains. Interesting collections of these cobbles can be made from a number of localities from the base of the Boley Conglomerate where it unconformably overlies the Barnsdall and Tallant Formations.

Oklahoma County

Much of the surface of Oklahoma County is highly developed for industrial or domestic purposes, and in these areas outcrops may be hard to find. There are, however, many sites from which rock or mineral specimens may be collected, and the rich, fascinating history of the development of petroleum in the county is a fine subject for study. Other than Quaternary terrace and flood-plain materials, the rocks are all of the Permian System, ranging in age from the Fallis Sandstone member of the Wellington Formation in the eastern portion through the lower part of the Flowerpot Shale in the southwestern corner, at Wheatland. Throughout the central part of the county, the Garber Sandstone commonly is responsible for relatively prominent topographic features, and the shaly Hennessey Group forms the surface of gently rolling pasturelands.

Massive, channeled sandstones that were deposited during building of the immense Permian delta that covered the entire county crop out in prominent crossbedded exposures. Prominent crossbedding indicates foreset beds locally, and colorful encrustation of sand grains with hematite shows that paleochemical environmental balance was toward an oxidation condition.

Oklahoma County Site 1: Barite roses

Access: Go south on Oklahoma City's Eastern Avenue, .5 mile (.8 km) from its intersection with Southeast 29th Street. Turn left (east) on blacktop road into Trosper Park and continue east .2 mile (.32 km) before turning left (north) into parking lot for archery range. Park and walk past restroom building, 50 yards due north, to flight 2 on archery range. Walk west 65 yards to number 2 target, turn north and walk 50 yards to a series of small gullies in Garber Sandstone (in headwaters of Crooked Oak Creek) and along course of flight 3. Although the archery range is usually deserted, use extreme care in this area, and make your presence known to any shooters.
Site location: NW¼ sec. 13, T. 11 N., R. 3 W.
Topographic map: Midwest City (7½′).
References: Ham and Merritt (1944), Wood and Burton (1968).

This easily accessible area (fig. 35) offers some of the most exquisitely formed and easily collectable barite roses in the world. The barite rose was de-

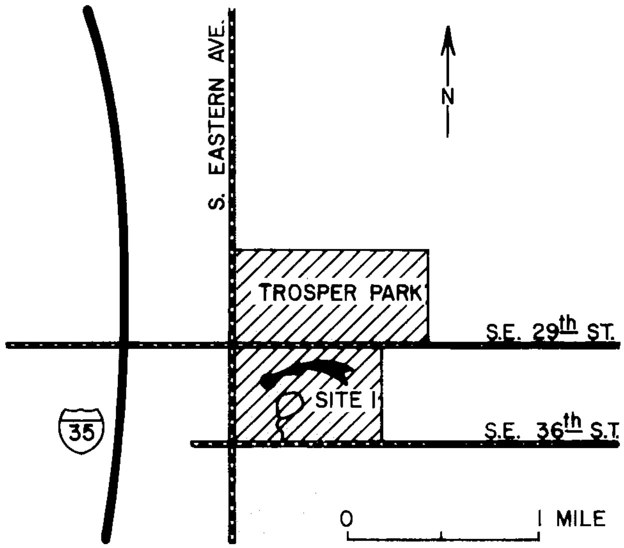


Figure 35. Location map for Oklahoma County site 1, barite roses.

clared the official State Rock of Oklahoma in 1968. These colorful, picturesque specimens are formed from concretionary twinned masses of the mineral barite ($BaSO_4$). The crystal clusters grow in a shape that resembles rosebuds just prior to their opening. The central Oklahoma rosettes are distinctive because they grew within an ancient red sandstone, incorporating quartz sand grains and acquiring the red color of the host rock. These concretions consist of sand and barite in nearly equal proportions and thus are best known to geologists as sand-barite rosettes, but they also are called rose rocks, barite roses, or petrified roses. Well-formed specimens are highly prized by collectors.

The illusion that these rocks are roses is heightened by their development in rock-forming minerals and is even further strengthened by the red color of the Permian sandstones in which they form. Oklahoma is one of the very few places in the world where barite roses are found, and even here they occur in a relatively narrow band along the strike of Garber Sandstone outcrops from a short distance north of the Stillwater latitude to somewhat southeast of Norman.

Oklahoma County Site 2: Brick pit

Access: This site, the Acme Brick Pit, is on the south side of Northwest 10th Street in Oklahoma City, between Pennsylvania and May Avenues, just a few blocks east of the Oklahoma State Fairgrounds.
Site location: Near C N. line, sec. 31, T. 12 N., R. 3 W.
Topographic map: Oklahoma City, 1956 (7½′).
References: Wood and Burton (1968).

This shale pit (fig. 36) has been in intermittent use for more than 40 years but is now idle except for use as a landfill for various sorts of nongarbage materials. If it is not reopened for brick clay, it will serve as a landfill area and may later be used for new construction. In this way it will have provided multiple use of the land for mineral resources, waste disposal, and construction.

The pit is about 60 feet deep, in shale of the Hennessey Group of Permian age. At this site, the shale shows several shades of red (hematite) color and ranges from quite good clay to medium silt too coarse for brick manufacture. Subspherical spots of greenish-gray shale probably result from inclusion of pieces of organic matter or slightly radioactive material in the host shale. Walls of the pit are well exposed along the north and south faces, and they permit good views of the thin-bedded shale and siltstone that were deposited in a relatively quiet, offshore bottom of the Permian sea. During Permian time this area was quiet enough to prevent wave energy from winnowing out finer clay materials, permitting them to settle to the bottom in considerable thicknesses. Salt content of the water may have been slightly higher than normal marine salinity, and this could be the reason why fossils are quite scarce in these clays. There have been, however, no molds or casts of salt crystals reported, so the waters were probably not excessively hypersaline. During mining of the shale, a large specimen (5 feet across) of the Permian reptile *Cotylorhynchus* was uncovered, suggesting that the area was perhaps occasionally a delta or nearshore environment or that the remains of the reptile were washed out into the shallow sea and then buried.

A similar brick pit in shale of the Hennessey Group can be seen just southwest of Edmond and east of where North 122d Street jogs south at the railroad tracks. At that locality, however, the clay in the shale is much thinner than at this site.

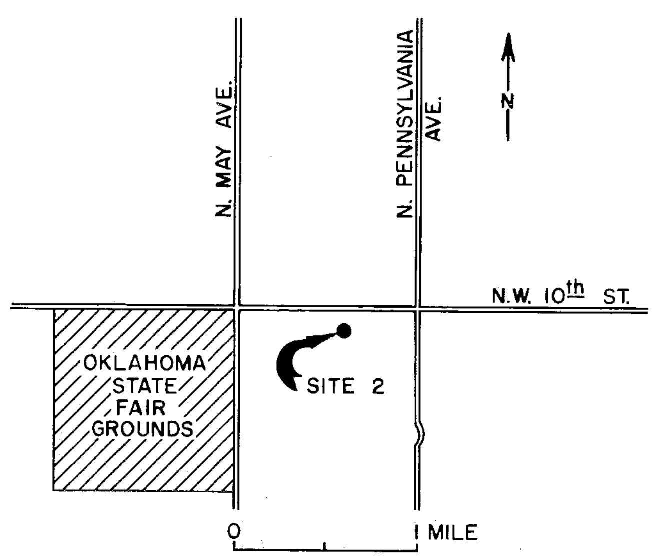


Figure 36. Location map for Oklahoma County site 2, brick pit.

Oklahoma County Site 3: Oklahoma City Oil Field

Access: Drive to the Oklahoma State Capitol Building, south of Northwest 23d Street, and park in the lot south of the main building. Walk to the geological sign, just south of the capitol entrance.
Site location: sec. 27, T. 12 N., R. 3 W.
Topographic map: Oklahoma City, 1956 (7½′).
References: Powers (1928), Travis (1930).

Although attempts at drilling successful oil wells had been made in the Oklahoma City area since 1917, the discovery well for the Oklahoma City Oil Field was not drilled until the Indian Territory Illuminating Oil Co. (I.T.I.O.), later Cities Service, began the Foster Petroleum Corp. 1 Oklahoma City well in June 1928. In December of that year the well was completed in rocks of the Arbuckle Group at 6,402 feet. Initial measure was 6,565 barrels of 39°-gravity oil per day. This well was drilled in the SE¼SE¼ sec. 24, T. 11 N., R. 3 W., several miles south of the present Capitol. Since the drilling of this initial well, the Oklahoma City Field has produced nearly 750 million barrels of oil and more than 2 trillion cubic feet of natural gas from more than 26 productive zones.

Truly one of the world's great oil fields, the Oklahoma City Field shows production from both structural and stratigraphic traps. Sedimentation began about 500 million years ago in Late Cambrian time with a thick sequence of Arbuckle Group limestones and dolomites of Cambrian and Ordovician ages. Somewhat different conditions prevailed during Middle Ordovician time when more highly clastic (fragmented) beds of the Simpson Group were deposited. These beds include the famous "Wilcox" sands, which commonly produce from anticlines or domes. The coarsely crystalline Viola Limestone overlies the Simpson and is overlain by more than 100 feet of the relatively impervious Sylvan Shale of Late Ordovician age. After deposition of the Sylvan, rocks of the Hunton Group of Silurian and Devonian ages were laid down. These consist of more than 300 feet of buff, marly limestones that are hard to differentiate into specific formations. Above the Hunton are deposited, in order, the Woodford Formation and the "Mississippi lime," containing, at the top, a weathered, cherty zone identified as the Mississippi "Chat." Sometime after deposition of the Mississippian formations, the area was uplifted and a dome was produced. The dome was faulted, down on the right or east side and up in the center and west. This uplift and faulting permitted differential thicknesses of overlying Pennsylvanian rocks to accumulate and to develop stratigraphic as well as structural traps.

Current production from this magnificent oil field has lessened somewhat, and ultimate production has been projected to more than 770 million barrels.

This site (fig. 37) is a very good one for school groups, inasmuch as it is easily accessible and offers insight not only into geology but into the history and development of the oil industry in our State.

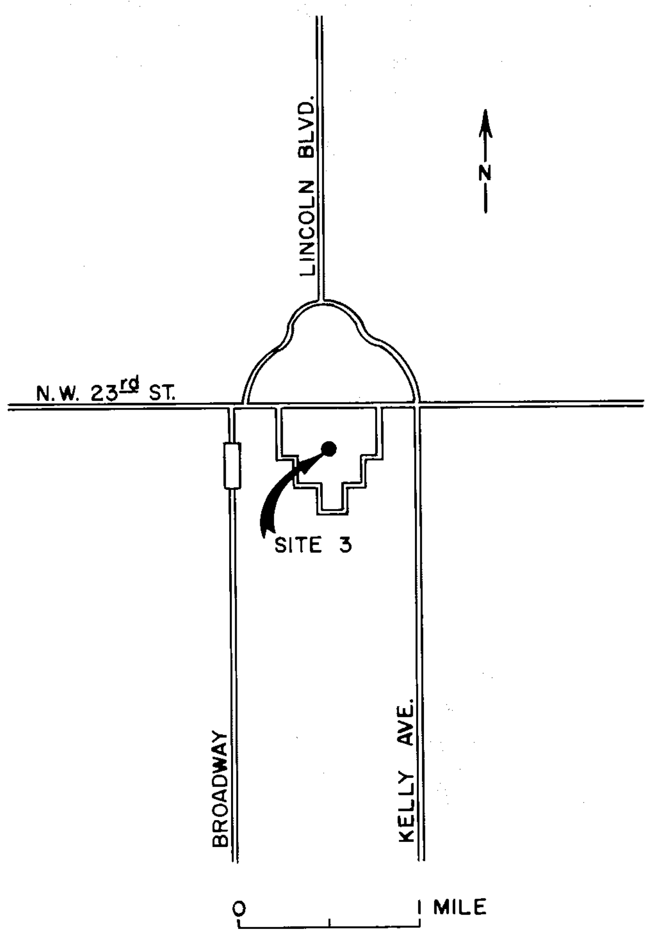


Figure 37. Location map for Oklahoma County site 3, Oklahoma City Oil Field.

Oklahoma County Site 4: Sandstone aquifer

Access: Drive to Lincoln Park and park in available space close to creek west of Interstate Highway 35.

Site location: sec. 13, T. 12 N., R. 3 W.

Topographic map: Spencer, 1975 (7½′).

References: Johnson and others (1972).

The creek running northward through Lincoln Park fills Northeast Lake and is tributary to Deep Fork, draining the Oklahoma City area north and east (fig. 38). Along the creek in Lincoln Park, many fine outcrops of Garber Sandstone of Permian age are seen. The hematite-stained sandstone is bright red on some of the fresher exposures, making it possible to determine with a hand lens that most of this iron stain is on the surface of the quartz sand grains. If one were to soak this sandstone in a weak solution of oxalic acid, most of the superficial iron stain would be removed, and relatively clear quartz would be seen.

Garber Sandstone exposures are especially important as gathering-ground or intake area for ground water that enters into this sandstone, which dips gently westward beneath most of Oklahoma County and parts of Logan, Lincoln, Pottawatomie, and Cleveland Counties, where it functions as an aquifer providing ground water of only moderate mineralization. The sandstone is quite porous and at most sites is coarse enough to provide adequate permeability to serve as a fine aquifer (fig. 39). The actual percentage of space that can be occupied by fluid is the porosity of a rock, whereas the ease with which fluid can flow through or out of the rock is related to the permeability. As the Garber dips further beneath the surface to the west, mineralization becomes too high for the water to be usable for agricultural, industrial, or domestic purposes.

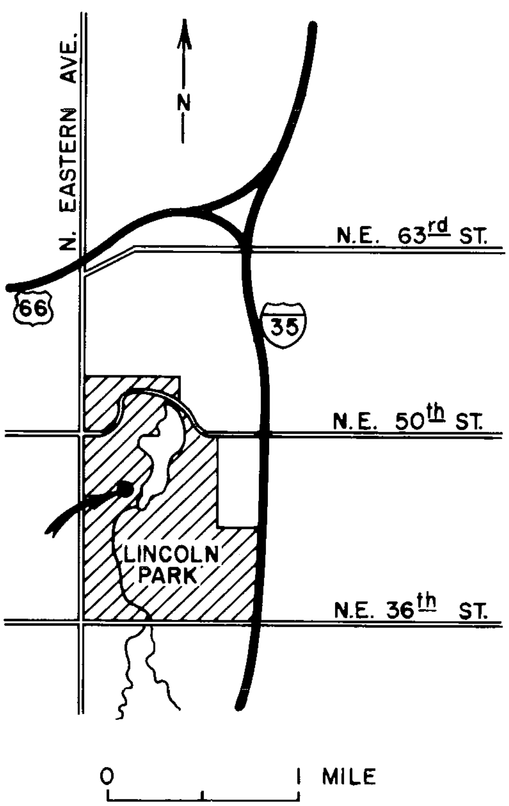


Figure 38. Location map for Oklahoma County site 4.

The sequence of beds including the Garber Sandstone is part of a great compound delta that spread northwestward into the shallow Permian sea from the Arbuckle and Ouachita Mountains to the south and the Ozark highlands to the east. Various delta features are shown in these beds, the Garber beds showing fine crossbedding in foreset beds and channel deposits. In Lincoln Park, and all along Interstate Highway 35 from Guthrie southward through Norman, this unusual form of stratification is well shown. Crossbedding sequences are deposited as in figure 40, with a slight concavity upward.

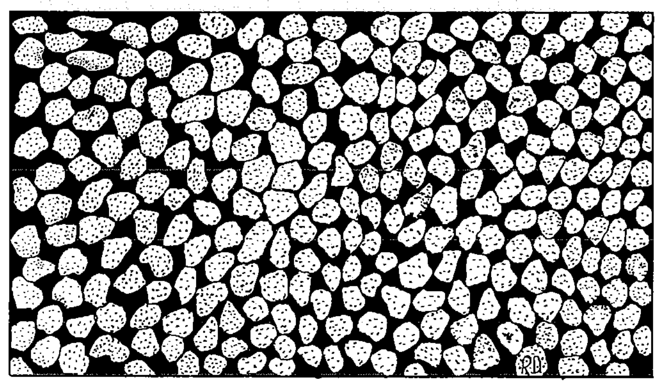


Figure 39. Sketch showing how water (or oil) surrounds the grains of a sandstone and occupies the spaces between them. Stippled areas are subrounded to angular sand grains, and dark areas are fluids.

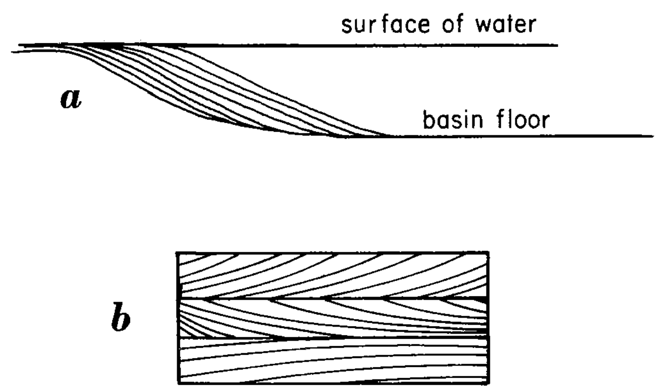


Figure 40. Diagram indicating crossbedding in *a*, foreset beds of delta on shallow basin floor close to source stream, and *b*, sequence of crossbedded strata indicating currents from different directions but still in attitude of deposition.

Osage County

Osage County, the largest county in the State, is the northeasternmost county covered in this report. Rocks in the area range in age from the Coffeyville Formation of early Missourian (Pennsylvanian) age, in the easternmost part, to the Wellington Formation of early Leonardian (Permian) age in the western part near Ponca City. Many of the rocks have a high carbonate content and promote growth of prairie grass and other pastureland vegetation. Rocks strike a few degrees east of due north, and the low dip (about

.5° W) has caused development of a succession of east-facing cuestas that are much more apparent in the western part of the county than in the eastern part.

The Arkansas River defines most of the southwestern and western boundaries of the county and is the major stream. Other streams of considerable size are Bird Creek, Hominy Creek, Hickory Creek, and Caney River, all of which have developed flood plains of considerable width and are in maturity in the eastern part of the county.

Relief is sharp, and upper reaches of stream courses are steep in the eastern part of Osage County. Dense vegetation, mostly post oak in the uplands, has forced ranchers near Pawhuska, Avant, Skiatook, and Nelagoney to employ the use of herbicides to produce extensive areas of upland pasture.

Osage County Site 1: Fossils

Access: Stop at the intersection of U.S. Highway 60 and Oklahoma Highway 18, 2 miles (3.2 km) east of Burbank.

Site location: 400 feet N. of C E. line, sec. 31, T. 26 N., R. 6 E.

Topographic map: Fairfax, 1929 (15′).

References: Bellis and Rowland (1976), Vosburg (1954).

On all four corners of this intersection (fig. 41), the Sallyards Limestone of Late Pennsylvanian age (fig. 3) caps low hills on man-made road cuts. A rich fauna can be collected here from the weathered Sallyards Limestone and the underlying Roca Shale (fig. 42).

The Sallyards fauna is what is usually found in Late Pennsylvanian and Early Permian limestones of Oklahoma and Kansas, being made up principally of brachiopods (Spiriferids, Productids, and Rhynchonellids). One does not have to look long to find *Neospirifer, Composita, Cryrithyris, Juresania, Marginifera, Dictyoclostus,* and *Linoproductus*. Good luck or a longer search commonly produces a few specimens of *Rhipidomella, Wellerella, Hustedia, Derbyia,* and an occasional crinoid dorsal cup.

The underlying Roca Shale has a less commonly found fauna, which suggests shallower water, perhaps closer to shore than the environment indicated in the Sallyards. The Roca consists mostly of variegated gray and reddish shales with very thin silty beds of limestone. These limestone beds are exceptionally fossiliferous, commonly consisting of a fossil coquina of tiny, high-spired gastropods (*Stegocoelia*) that seem to form entire bedding-plane surfaces. In addition, numerous specimens of *Pharkidonotus* and *Cymatospira* are obtainable, as well as *Myalina, Pseudorthoceras, Aviculopecten,* and uncommon ostracodes. All in all, this is a very worthwhile fossil-collecting stop offering diverse marine environments and a very prolific, easily collected fauna.

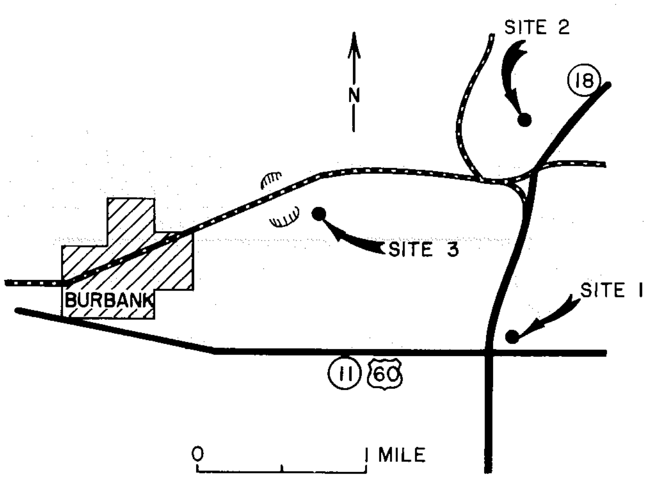


Figure 41. Location map for Osage County sites 1, 2, and 3.

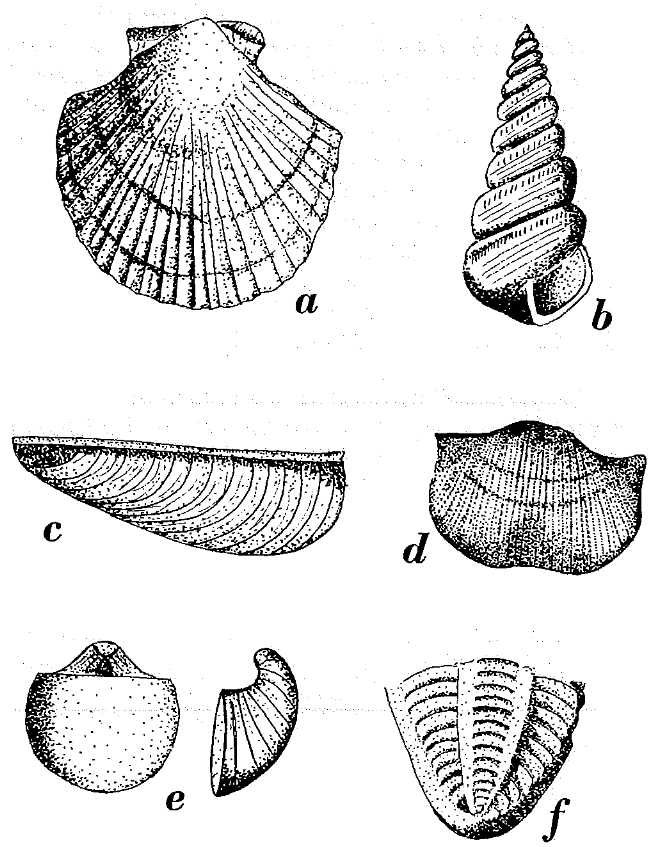


Figure 42. Drawings of characteristic fossils found at Osage County site 1: *a*, a pelecypod, *Aviculopecten*, ×1; *b*, a gastropod, *Stegocoelia*, ×5; *c*, a pelecypod, *Aviculopinna*, ×½; *d*, a brachiopod, *Marginifera*, ×1; *e*, a brachiopod, *Crurithyris*, ×2; and *f*, a trilobite pygidium, *Ameura*, ×2.

Osage County Site 2: Burbank Oil Field

Access: From intersection of U.S. Highway 60 and Oklahoma Highway 18, drive north on Oklahoma Highway 18 for 4.3 miles (6.9 km) and turn left (west) on gravel road. Continue northwestward for .9 mile (1.4 km) until road is paved. Drive north for .2 mile (.32 km), and you will be at about the center of the west flank of the Burbank Oil Field.
Site location: Ts. 26 and 27 N., Rs. 5 and 6 E.
Topographic maps: Fairfax, 1929 (15′), Kaw City, 1964 (7½′), Shidler, 1964 (7½′), Burbank, 1978 (7½′).
References: Beckwith (1927), Vosburg (1954).

The Burbank is one of the oldest large oil fields in Oklahoma, and one of the most productive. The discovery well was drilled by Marland Oil Company in May 1920, in the SE¼ sec. 36, T. 27 N., R. 5 E., just a few hundred feet from where you are standing (fig. 41). Since that time, several hundred million barrels of oil have been recovered.

The principal structure is a northwest-trending monocline with small domes superimposed on it. The principal producing formation has been the Burbank sand, which is 50 to 80 feet thick and is encountered from 2,800 to 3,200 feet beneath the surface. After the discovery, Carter Oil Company was instrumental in development of the field, which produces from several Pennsylvanian zones. Total thickness of the Pennsylvanian section at Burbank is about 2,800 feet, and the dip is about ⅓° northwestward. Oil accumulation probably occurred as a result of decreased porosity and permeability eastward. In the thirties and forties, deeper wells found production from Mississippian limes and the Misener sand near the base of the Chattanooga Shale. Added emphasis during the fifties and later produced quite a bit of oil from the weathered zone called the Mississippi "Chat" at the top of the Mississippi lime.

Osage County Site 3: Limestone quarry

Access: From the intersection of U.S. Highway 60 and Oklahoma Highway 18, east of Burbank, drive north on 18 for 1 mile (1.6 km) and bear left from Oklahoma Highway 18 on blacktop road. Take next left after about 200 yards of blacktop road and drive west 1.2 miles (1.9 km) to quarry. Park in convenient place. This quarry is being worked on an irregular basis, so be sure to check with the superintendent or foreman. Operation of the quarry at the present time is by Standard Industries, Inc., of Tulsa.
Site location: SE¼ sec. 25, T. 26 N., R. 5 E.
Topographic map: Fairfax, 1929 (15′).
References: Bellis and Rowland (1976).

The principal interest at this stop is the contrast between a reasonably thick limestone formation viewed in naturally occurring outcrops along pasturelands and woods as compared to exposure in man-made quarry faces. In the Burbank Limestone Quarry (fig. 41), the upper surface of the limestone is covered with Roca Shale that is more than 5 feet thick. Below this shale, a 27-foot-thick vertical section of Red Eagle Limestone is being quarried. The limestone is of a quality suitable for road-base and roofing gravel but contains too much shale to serve well as concrete aggregate or other purposes. At the quarry, the limestone section contains some beds of crystalline limestone, a few algal zones, and some coarse, silty beds. It is buff to bluish gray on the freshly broken surface, weathering buff to medium brown in a relatively short time.

Fossils are scarce at the Burbank Quarry, and unless one can find some on top, weathered from the Roca Shale, it is not suitable as a fossil-collecting stop.

Osage County Site 4: Fossils

Access: From intersection of Oklahoma Highways 99 and 20 in Hominy, drive east on Oklahoma Highway 20 for 8.9 miles (14.3 km). Cross Wildhorse Creek and proceed eastward for .7 mile (1.1 km), where a private road intersects Highway 20. This place will be easily recognizable by the large float blocks (Wildhorse Dolomite) on the slopes.
Site location: SW¼NW¼ sec. 21, T. 22 N., R. 10 E.
Topographic map: Avant SW, New Prue (7½′).
References: Bellis and Rowland (1976).

At this site (fig. 43) on both sides of Oklahoma Highway 20, you can collect many fossils—but you may have to pick up scores before you can find a fine specimen. In the gray shale just beneath the ledges of the Wildhorse Dolomite Member of the Barnsdall Formation (fig. 3), large numbers of individual fossils have weathered out in a relatively poorly preserved condition. Most of the specimens appear to have been broken or are replaced with ocherous limonite and have suffered much more from weathering than those at localities where they have been replaced with calcite.

There are, however, some rather large, unusual fossils here—which make the stop worthwhile for collectors (fig. 44). Among the more interesting ones are specimens of an unusual pelecypod, *Conocar-*

dium, two gastropods, *Trepospira* and *Worthenia*, a brachiopod, *Nudirostra*, and a cephalopod, *Pseudorthoceras*.

Not much is known about the environmental associations of *Nudirostra*, but all of the others are believed to have been tolerant of relatively shallow water with more than a normal amount of clay and silt in suspension. The silty shale in which this fauna is found is evidence that this was the case on the Pennsylvanian sea bottom on which the animals lived. It is by piecing together such meager bits of evidence that geologists reconstruct a picture of the past.

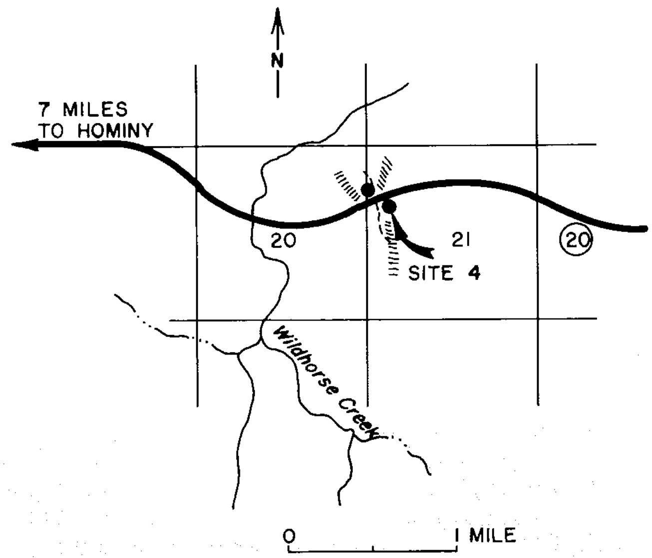


Figure 43. Location map for Osage County site 4, fossils at Wildhorse Creek.

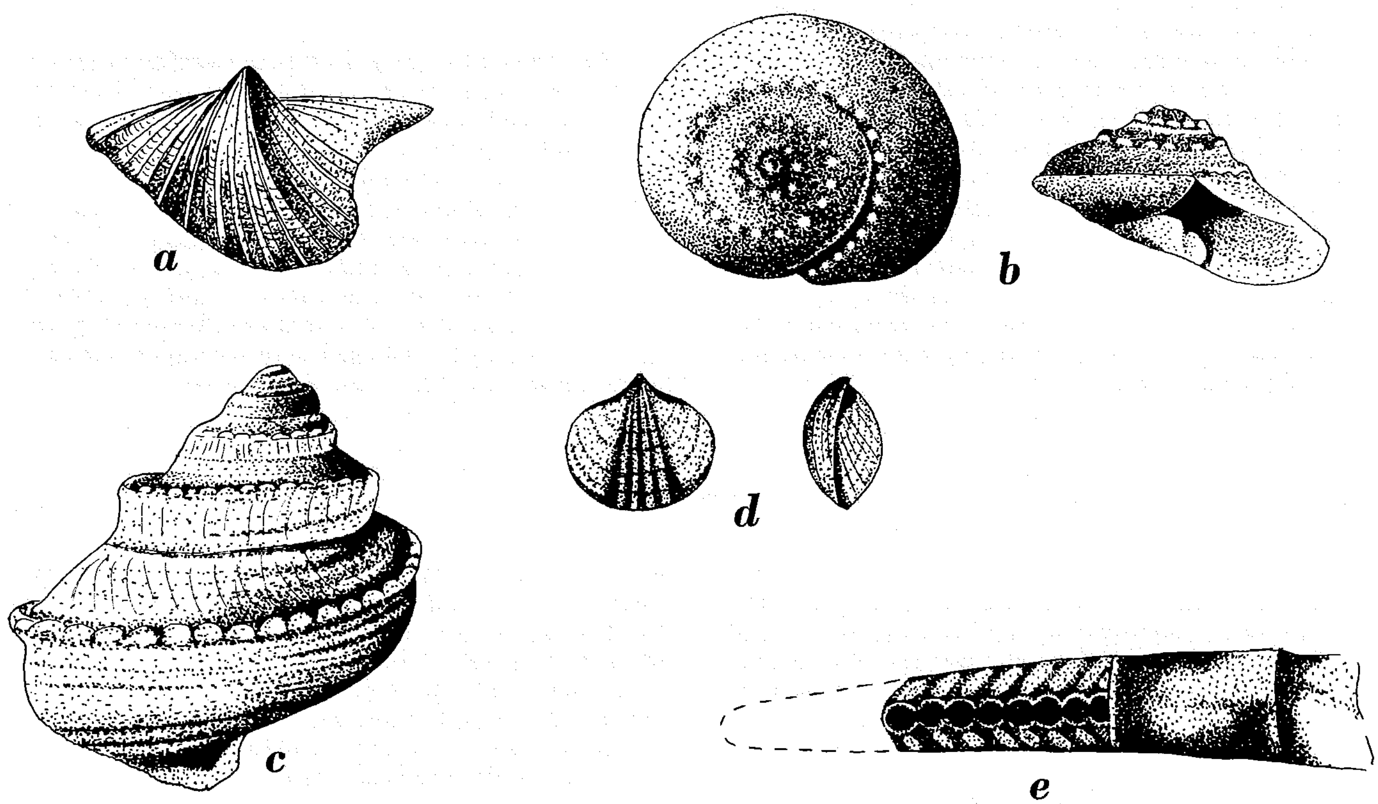


Figure 44. Sketches of five common fossils found at Osage County site 4: *a*, a pelecypod, *Conocardium*; *b*, a large gastropod, *Trepospira*; *c*, a large gastropod, *Worthenia*; *d*, a brachiopod, *Nudirostra*; and *e*, a cephalopod, *Pseudorthoceras*. Actual size.

Osage County Site 5: Limestone quarry

Access: Drive 4.3 miles (6.9 km) west on U.S. Highway 60 from its junction with Oklahoma Highway 99 in Pawhuska. This will bring you to the Pawhuska Airport, on the north side of the road. The quarry where the Deer Creek-Lecompton Limestone is being worked is on the south side of the road, across from the airport. It operates regularly but not on a continuous basis under supervision of Sedan Limestone Company of Kansas. If the quarry is operating when you visit, be sure to get permission from the foreman. If you are at the quarry at the right time, you may be able to see the steps in crushing, sorting, conveying, and loading the limestone after it is quarried. Check with someone in authority before approaching machinery and vehicles used in processing operations.

Site location: About 100 feet S. of C N. line, NE¼ sec. 11, T. 25 N., R. 8 E.

Topographic map: Bluestem Lake, 1960 (7½′).

References: Bellis and Rowland (1976), Tanner (1956).

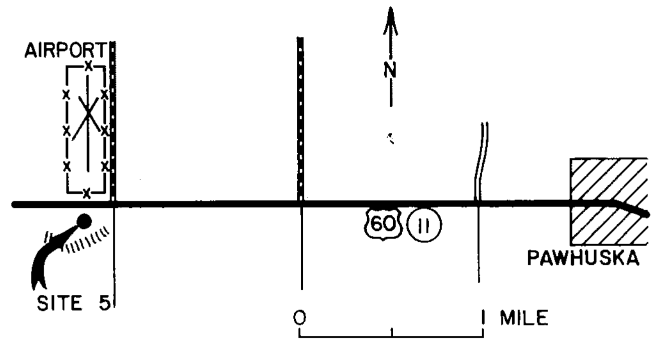


Figure 45. Location map for Osage County site 5, limestone quarry.

This rather large quarry (fig. 45) is one of the few really productive quarries in Osage County using Deer Creek–Lecompton Limestone (Ada Group, fig. 3) for commercial purposes. About 27 feet of limestone is exposed in the quarry face. The bottom 4 feet of the Lecompton is dolomitic on most of the exposures, containing as much as 35 percent dolomite, $CaMg(CO_3)_2$, making it unsuitable for portland cement or chemical-grade stone. The middle and upper parts of the Deer Creek–Lecompton contain more than 95 percent calcite ($CaCO_3$) here and at other sites in the county and can be used for portland cement as well as for less critical purposes.

This is a large quarry, showing a rather neat operation that has quarried limestone down to the top of the underlying, shaly Elgin Sandstone (Vamoosa Group). Overburden—overlying rock that must be stripped away to quarry the good limestone—consists of shale and fragments of impure Little Hominy Limestone (Ada Group). In the quarry the limestone occurs as thin- to medium-bedded, gray to blue-gray rock. The beds range from about an inch to somewhat over a foot in thickness, demonstrating wavy bedding planes separated by thin, calcareous, gray-shale partings.

Fossils are plentiful in the Deer Creek–Lecompton Limestone, but this is not a good site for fossil collecting, because the fossils and the matrix rock are of equal hardness; resistance to weathering makes it difficult or impossible to separate fossils from the rock. On a freshly broken surface, one can see cross sections of shells, but they are difficult to identify.

The fresh blue-gray limestone weathers quickly to buff or orange brown owing to iron oxide content. In the red beds discussed earlier, in counties to the south and west, the iron oxide is hematite (Fe_2O_3). These red beds were oxidized under much dryer conditions. The yellowish-brown oxide that colors the rocks in eastern Osage County is limonite ($Fe_2O_3 \cdot H_2O$), a hydrous iron oxide resembling rust. As the water content of limonite varies, slightly different varieties of the mineral are produced. Where they are abundant enough to be used as iron ores, hematite is much more valuable as an iron source.

Pawnee County

Central Pawnee County is a fine area for collecting fossils of Early Permian age. Near Pawnee, the county seat, outcrops of marine limestones and shales are well exposed, providing opportunities for selecting fossils of several different phyla and of many genera and species. There is a general similarity of forms in Late Pennsylvanian and Early Permian faunules, making it easy for novice collectors to recognize fossils from rocks of these ages. Animals, however, have always preferred certain more or less restricted environmental and ecological situations. In Pawnee County, nearly all of the fossils will be from marine beds, but within the broad marine environment a collector can relate fossils to nearshore, far-offshore, mud-bottom, sandy-bottom, clear-water or turbid-water environments. Near-perfect preservation of fossils is common at many Pawnee County sites.

Pawnee County Site 1: Limestone quarry

Access: On Oklahoma Highway 18, drive 11.7 miles (18.8 km) north of Pawnee Courthouse to place where highway makes a 90° swing to east. Continue straight north on gravel road and follow gravel road as it swings westward into quarry about 1.8 miles (2.8 km) from where you left highway. Drive as far north as you can in quarry.

Site location: SW¼ sec. 30, T. 24 N., R. 5 E.

Topographic map: Belford (15′).

References: Greig (1959).

Limestone quarried at this site (fig. 46) is in the Neva Limestone of the Oscar Group (fig. 3). Rock is being used mostly as aggregate and as ballast; the chert content is too high to provide limestone for cement making.

In the north part of the quarry there are areas where the limestone has been removed from above a dark-gray, calcareous shale in the base of the Neva. It is where this shale has been scraped up and mounded into ridges that the best fossils can be collected. The fauna is principally brachiopods, but occasional gastropods, bryozoans, and cephalopods are found. Exquisitely preserved specimens of *Neospirifer*, *Composita*, *Juresania*, *Dictyoclostus*, *Meekella*, *Rhipidomella*, *Derbyia*, and *Marginifera* can be picked up within a few minutes collecting from this quarry floor (fig. 47). Numerous fusulinids of the genus *Triticites* are in the cherty limestone but do not weather out well enough to be satisfactorily collected. There is, however, the opportunity to collect fine chert specimens showing various sections of these fusulinids. The chert can be cut and polished to make impressive book ends and paperweights.

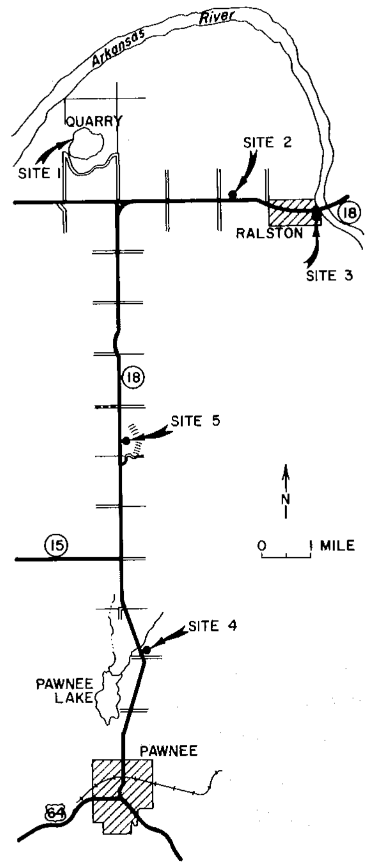


Figure 46. Location map for Pawnee County sites 1, 2, 3, 4, and 5, north of Pawnee.

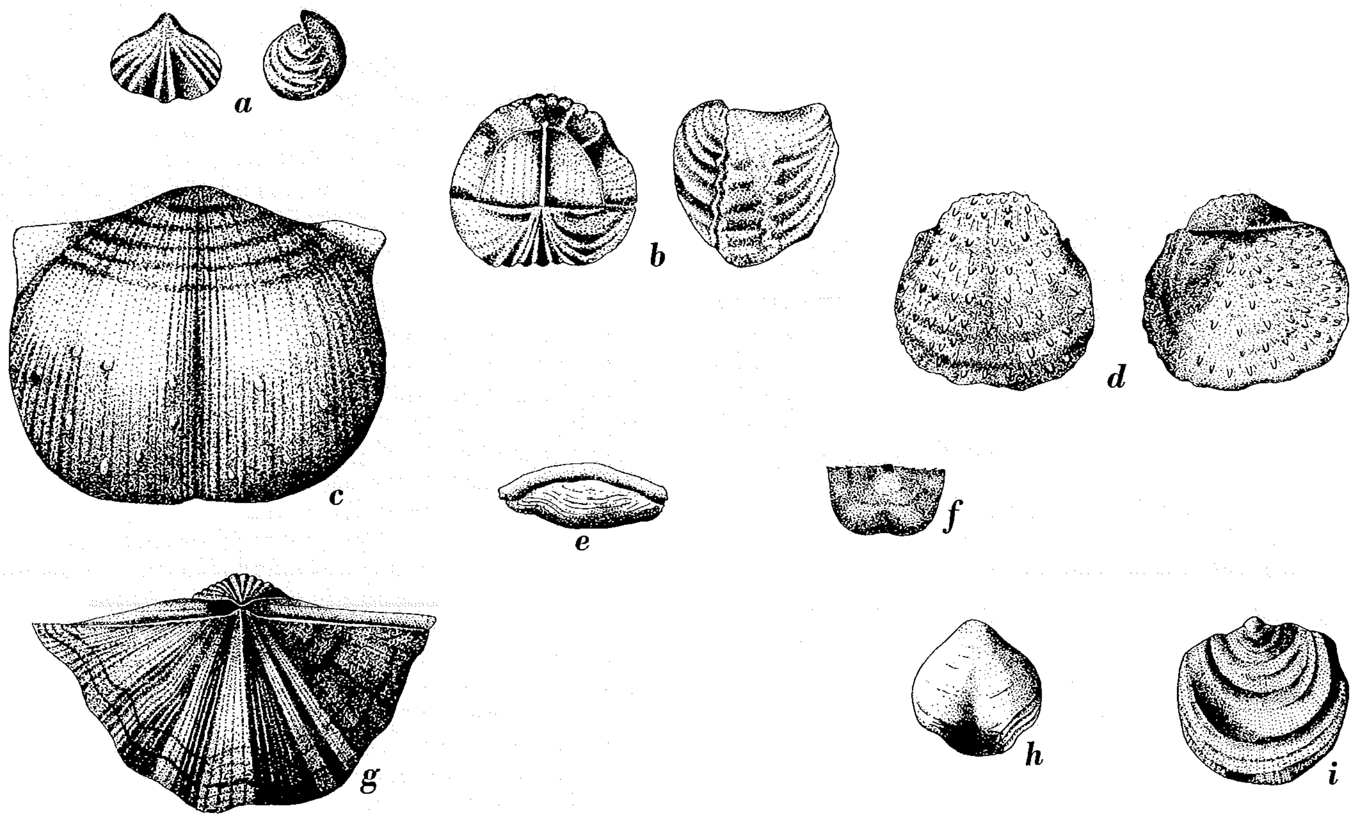


Figure 47. Drawings of fossils, mostly brachiopods, commonly found in Neva, Red Eagle, and Foraker Limestones and representative of these formations: *a*, *Wellerella* × 1½; *b*, *Meekella*, × ¾; *c*, *Antiquatonia ("Dictyoclostus")*, × ¾; *d*, *Juresania*, × ¾; *e*, a fusulinid, *Triticites*, × 1½; *f*, *Chonetes*, × ¾; *g*, *Neospirifer*, × ¾; *h*, *Composita*, × ¾; *i*, *Derbyia*, × ¾.

Pawnee County Site 2: Fusulinids

Access: From where Oklahoma Highway 18 turns east (11.7 miles or 18.8 km north of Pawnee Courthouse), continue east for 2.4 miles (3.8 km), at which point a shallow road cut exposes Long Creek Limestone on both sides of the road.
Site location: SE¼SW¼ sec. 34, T. 24 N., R. 5 E.
Topographic map: Fairfax (15′).
References: Greig (1959), Ham (1949).

Large slump blocks of limestone on the north side of the road (fig. 46) contain numerous weathered-out specimens of the fusulinid genus *Triticites*, which can be collected easily. An occasional horn coral of the genus *Lophophyllidium* is found at this site, and numerous bryozoans (*Fistulipora* and *Rhombopora*) are collected from beneath the blocks of limestone. The author found his best trilobite ever (*Ditomopyge*) from the Hughes Creek Shale, which forms the slope beneath the Long Creek Limestone (fig. 3). That specimen was enrolled, but uncommonly found specimens of pygidiums occur in the Hughes Creek Shale and overlying Long Creek Limestone of the Vanoss Group.

Pawnee County Site 3: Admire Sandstone

Access: On the eastern edge of Ralston, just west of bridge across Arkansas River, turn south on dirt road leading down to river. Park as close to river as you care to drive; then walk out to sandstone ledges forming the river bank.

Site location: NE¼ sec. 2, T. 23 N., R. 5 E.

Topographic map: Fairfax (15′).

References: Greig (1959), Moore and others (1951).

This sandstone correlates with the Indian Cave Sandstone of Kansas, which reaches a thickness of 250 feet in Pottawatomie County. The basal sandstone unit on which you stand (fig. 46) is approximately 13 to 15 feet thick and was considered for years to be the base of the Permian System in northern Oklahoma. Outcrops are uncommon in the Admire, and the historical significance of this unit makes it worthy of a brief examination.

Pawnee County Site 4: Fossils

Access: Drive north from Pawnee on Oklahoma Highway 18 and begin mileage at railroad tracks on north edge of town. At .1 mile you cross Black Bear Creek, a rather large tributary to Arkansas River. Black Bear is a rejuvenated, mature stream that floods frequently. Evidence of this flooding is often seen along the course and in the bottomlands near Pawnee. At 1.6 miles (2.6 km) you will pass Pawnee Lake on the left (west). The Red Eagle Limestone (fig. 3) crops out around the north end of the lake, but exposures are poor and better fossils can be collected elsewhere; 2.7 miles north of the railroad tracks, pull off on the road shoulder next to a small, unimpressive outcrop of Roca Shale.
Site location: SW¼ sec. 17, T. 22 N., R. 5 E.
Topographic map: Pawnee (15′).
References: Greig (1959).

All along Oklahoma Highway 18 north of Pawnee, excellent Roca Shale (Vanoss Group) exposures crop out. Some are quite fossiliferous, and I have selected a few sites at which different fossils and somewhat diverse ecological situations can be observed. At this Roca Shale site (fig. 46) you can see red shale, gray shale, and limestone. The thin gray to buff limestone in the ditch right next to the road is within the Roca, whereas the more prominent limestone on top of the ridge 100 yards to the east is the Neva (Oscar Group). A rather good outcrop of crystalline limestone at the top of the creek channel to the north is the Red Eagle Limestone, which crops out across the road also. A very good and quite prolific fauna can be collected from the gray Roca shales and limestones. *Chonetes* and *Chonetinella* are prominent, as are *Composita*, *Linoproductus*, and *Marginifera*. On the flat spots in the bottom of the ditch, tiny but rather obscure fossils are collected. Two prominent bryozoans are *Rhombopora*, a minuscule branching type, and *Meekopora*, a ribbon or encrusting form with raised rims around its pores. Also, small brachiopods of the genera *Rhipidomella* and *Crurithyris* should be found. In the limestone on the east part of the upper ditch, numerous complete dorsal cups of a crinoid, *Delocrinus*, have been collected. Spines, disarticulated plates, and columnal segments of crinoids are numerous in the floor of the ditch. You will notice that where the shale is red rather than gray, few or no fossils will be found. The red color is due to oxidation conditions during deposition of the sediments. Few animals prefer waters of these chemical trends; therefore, red shales are commonly devoid of fossils unless their red color has been introduced as a post-depositional alteration. In the nearby outcrops of Red Eagle Limestone, good brachiopods of the genera *Wellerella*, *Hustedia*, and an occasional *Punctospirifer* can be collected.

Pawnee County Site 5: Fossils

Access: Start mileage at railroad tracks on Oklahoma Highway 18 at north edge of Pawnee. Drive 6.7 miles (10.7 km) north to exposure of Roca Shale (Permian) on right. Pull onto shoulder of road and cross small drainage ditch to gray portion of outcrop.
Site location: C W. line, SW¼ sec. 29, T. 23 N., R. 5 E.
Topographic map: Pawnee (15′).
References: Greig (1959).

As in the previous site description, the Roca Shale here grades laterally from gray to red, and the red portions do not provide sufficient collecting to be worthwhile. The gray portions, however, yield numerous specimens; most are fragmented or crushed, but the intact pieces are exquisitely preserved. The fossils at this site are so numerous that were it not for the silt and clay content of the rock, their remains would form a fossil coquina. The fractured state of the fossils suggests that the water was shallow and that the wave-base was deep enough to provide considerable energy on the bottom.

Fossils at this site (fig. 46) include some of the same brachiopods described from earlier sites, but most are too broken or crushed to be worth saving. A new selection of genera, however, is worth collecting and can be cleaned up nicely for display. Fenestrate bryozoans are represented by several genera, prominent among which are *Fenestrellina* and *Penireteopora* (fig. 48). Many pelecypods are found here; some of the more numerous are *Astartella*, *Aviculopina*, *Myalina*, and *Wilkingia*. The pseudoplanospiral gastropod *Amphiscapha* is abundant, and less easily found is the planospiral gastropod *Pharkidonotus*, a beautiful shell with rows of nodes along its outer margin. Rather common specimens of a straight cephalopod, *Pseudorthoceras*, are picked up along the south end of the outcrop, and seldom does a group collect from here that a large shark tooth from *Petalodus destructor* is not found.

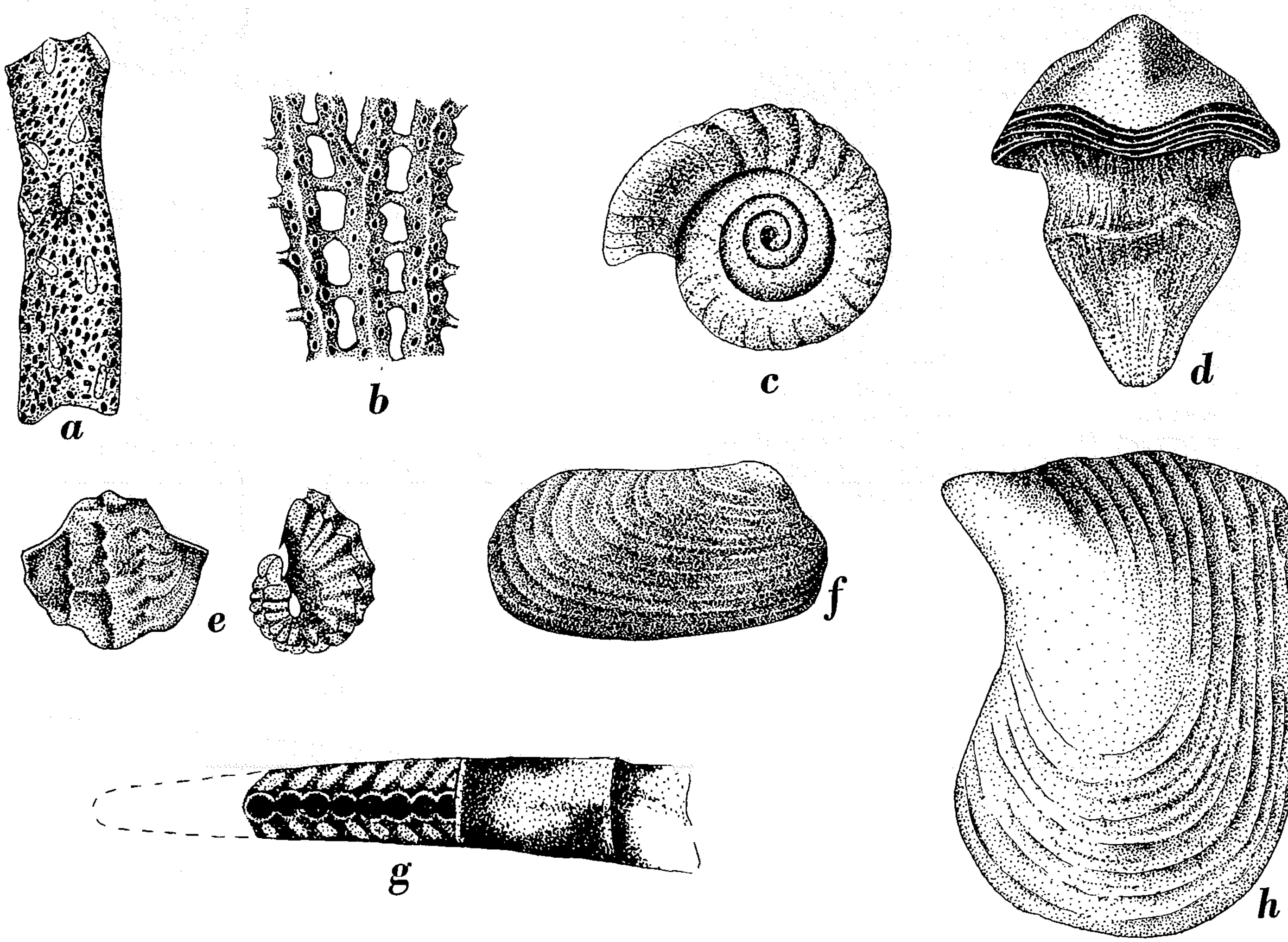


Figure 48. Drawings of fossils commonly found in Roca Shale at Pawnee County site 5: *a*, a bryozoan, *Meekopora*, ×2; *b*, a bryozoan, *Fenestrellina*, ×2; *c*, a gastropod, *Amphiscapha*, ×1; *d*, a shark tooth, *Petalodus destructor*, ×1, *e*, a gastropod, *Pharkidonotus*, ×1; *f*, a pelecypod, *Wilkingia*, ×⅓; *g*, a nautiloid cephalopod, *Pseudorthoceras*, ×1; and *h*, a pelecypod, *Orthomyalina*, ×½.

Payne County

This county, just south of Pawnee County, has far less good marine rock from which to collect. During the Pennsylvanian Period, the mountains of southern Oklahoma, including the Arbuckles directly to the south, were uplifted, and large amounts of gravel, sand, and clay washed into the shallow seas to their north. Payne County was enough closer to these mountains than Pawnee County that the coarse clastic materials inhibited deposition of marine limestones and calcareous shales during most of Late Pennsylvanian and Permian time. One of the most obvious changes in the rocks of Payne County (compared with those of Pawnee County) is the increase in number and thickness of red sandstones and a lessening of marine limestones and gray, fossiliferous shales. These trends are directly related to the presence of the Arbuckles and other mountains to the south. The course of the Cimarron River along the southern part of Payne County provides numerous features of geologic interest, some of which will be discussed.

Payne County Site 1: Fusulinids

Access: On Oklahoma Highway 18, drive north 1.5 miles (2.41 km) from intersection with Oklahoma Highway 51 west of Yale. Turn east on Old Highway 51, and drive .2 mile (.32 km). Turn south (right) into obscure road that leads sharply back to the southwest. Forty yards down this road, drive onto an outcrop of the Grayhorse Limestone of Pennsylvanian age, exposed in the bed of a small, intermittent stream.
Site location: NW¼ sec. 15, T. 19 N., R. 5 E.
Topographic map: Ripley (15′).
References: Ross (1972).

The outcrop under study (fig. 49) is a light-gray, algal limestone with a high argillaceous content. The bedding planes are lumpy and wavy, owing to algal masses within that limestone. Many thousands of large fusulinids of the genus *Triticites* can be collected here, and occasionally a few horn corals (*Lophophyllidium*) can be collected. Brachiopods and lacy (fenestrate) bryozoans are rare at this site. A few feet downstream, a low waterfall about 7 feet high has developed. The Grayhorse forms the brink rock, and a well-developed plunge pool has undercut the limestone into the soft shale beneath.

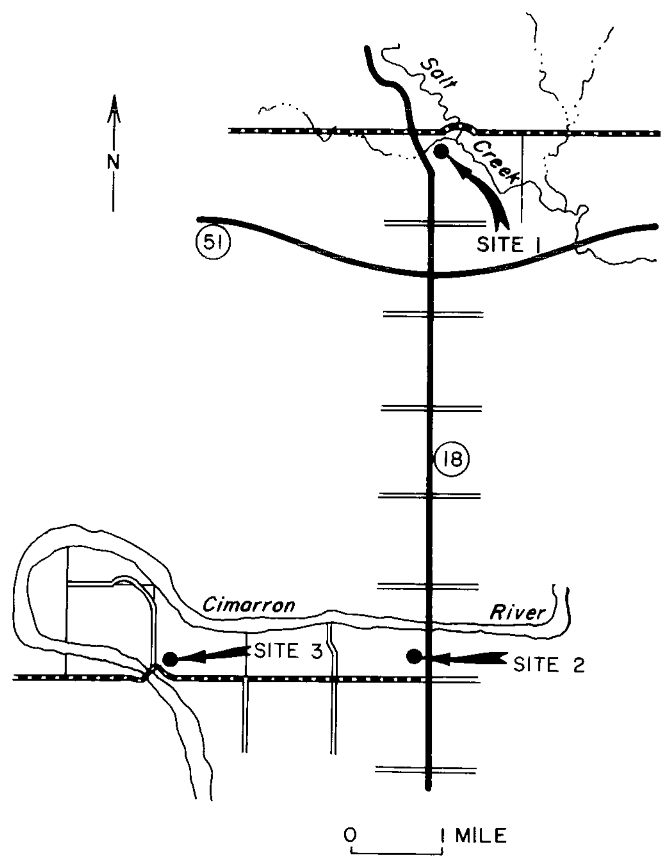


Figure 49. Location map for Payne County site 1, fusulinids in Grayhorse Limestone, site 2, Gano Shale fossils, and site 3, loess.

Payne County Site 2: Gano Shale fossils

Access: On Oklahoma Highway 18, go south .5 mile (.8 km) from Cimarron River and stop next to flat, exposed area on right of road. This area is just north of the place where the road cuts through a low hill.

Site location: C of E. line, SE¼ sec. 9, T. 18 N., R. 5 E.
Topographic map: Ripley (15′).
References: Ross (1972).

The Gano Shale is silty, calcareous, and somewhat micaceous, containing a rich diverse fauna of nearshore marine animals. On the flat area (fig. 49), one can find good specimens of bryozoans (*Fistulipora*, *Rhombopora*, and *Lioclema*), brachiopods (*Rhipidomella*, *Derbyia*, *Composita*, *Wellerella*, *Hustedia*, and *Punctospirifer*), gastropods (*Amphiscapha* and *Phymatopleura*), and cephalopods (*Pseudorthoceras*) (fig. 50). In the old road bed that leads south from the flat area, numerous good specimens of inarticulate brachiopods (*Orbiculoidea* and *Trigonoglossa*) can be found.

Rock lithology and composition of the fauna suggest that this was a shallow-water, marine area close to shore and that moderately large amounts of silt reached the bottom, on which wave energy was enough to break some of the shells prior to incorporation into the sediment. The crushed state of nearly all spiriferids and productids suggests rather rapid burial of the calcareous muds prior to lithification.

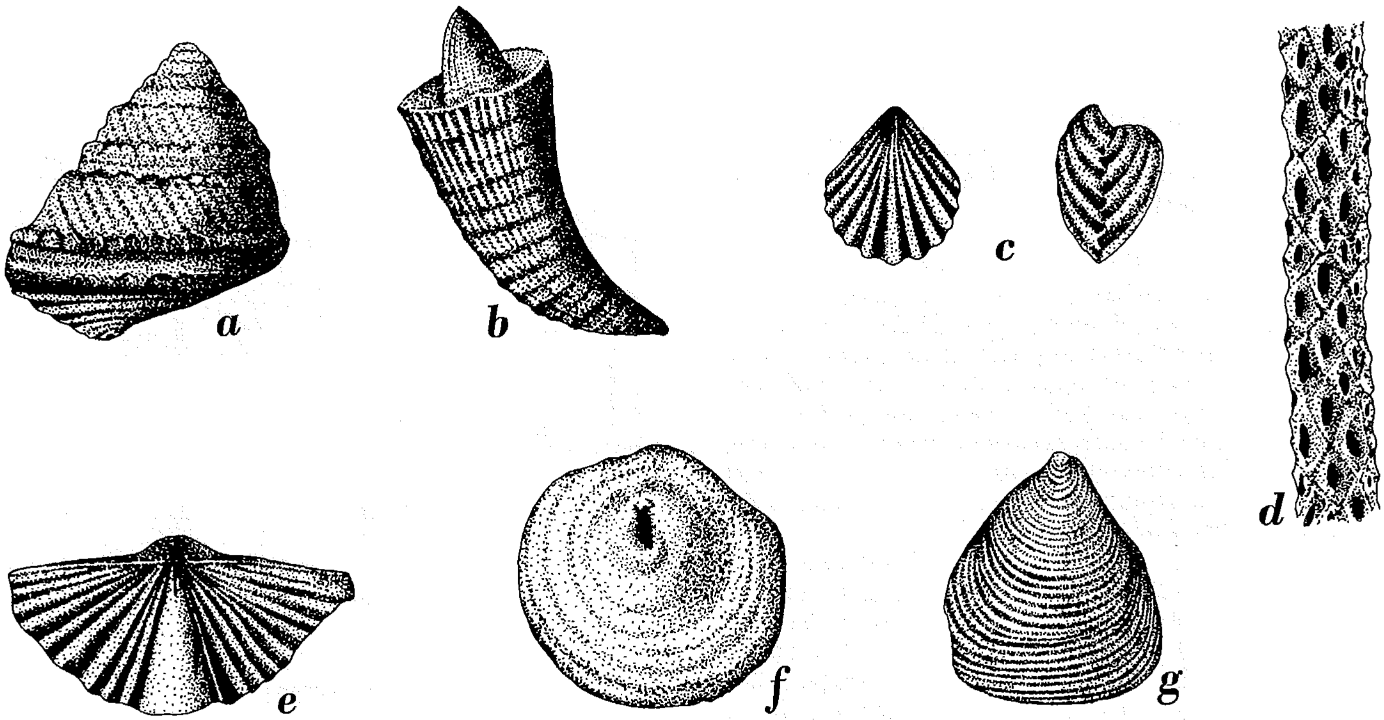


Figure 50. Drawings of fossils characteristic of Gano Shale at Payne County site 2, south of Cimarron River: *a*, a gastropod, *Phymatopleura*, × 5; *b*, a horn coral, *Lophophyllidium*, × 2; *c*, a brachiopod, *Hustedia*, × 2½; *d*, a bryozoan, *Rhombopora*, × 10; *e*, a brachiopod, *Punctospirifer*, × 3; *f*, a brachiopod, *Orbiculoidea*, × 2; and *g*, a brachiopod, *Trigonoglossa*, × 2.

Payne County Site 3: Loess

Access: Drive .5 mile (.8 km) from south end of Oklahoma Highway 18 bridge across Cimarron River. (You can reach the same point by driving north for 2.6 miles (4.1 km) from railroad crossing at north edge of Cushing.) Turn west on blacktop road and go 3 miles to east end of bridge across Cimarron River.
Site location: SW cor. sec. 7, T. 18 N., R. 5 E.
Topographic map: Ripley (15′).
References: Ross (1972).

Across the road from the northeast end of the bridge at this site (fig. 49), a large cliff of loess is exposed. This material is unusual because of its ability to support itself in vertical cliffs despite the fact that it is unconsolidated. It is composed of coarse silt-size angular fragments that have accumulated by eolian (wind) action from river flood plains or from periglacial areas. The angularity of the fragments and the presence of rapidly growing grass permit the material to maintain a vertical face, and shrinkage after deposition causes a vertical joint pattern resembling columnar jointing in igneous rocks. The best examples of true loess in North America are along the Mississippi River Valley, but these beds along western rivers are noteworthy for their bright colors and their jointed appearance.

The Cimarron River at this locality makes a big S-shaped meander loop (see location map, figure 49) and has developed a flood plain several miles wide. On low terraces adjacent to the flood plain, numerous oil wells, some of which are still in operation, provide testimony of frenetic activity in the North Cushing Oil Field in the 1920's and 1930's.

One mile south of the southwest end of the bridge across the Cimarron River, the road passes through an area of stabilized dunes occupying about 6 square miles. Most of the dunes are covered with deciduous trees or native grass, and stabilization is sufficient to prevent migration or even severe blowouts. If, however, you can find an exposure of the sand, you can (by scraping the surface) identify the relatively steep crossbedding of the unconsolidated material. Dunes of this nature are common along the northeast sides or within meander patterns of many streams in the plains states.

Payne County Site 4: Ramsey Oil Field

Access: From the traffic light at the intersection of Oklahoma Highway 51 and Western Road, on the west edge of Stillwater, drive west 2 miles (3.2 km) and turn south on gravel road. Continue south on this road for 5 miles (8 km) and turn west on gravel road. Go west for 1 mile (1.6 km) and turn south into the central part of the Ramsey Oil Field.

Site location: Most of secs. 16, 17, 18, and 19, T. 18 N., R. 2 E., and secs. 13, 24, and 25, T. 18 N., R. 1 E.

Topographic map: Stillwater SW, 1967 (7½′).

References: Garden (1973).

Ramsey Oil Field has been a large, successful Payne County producer for many years (fig. 51). Its discovery well was drilled in the 1930's, and production is from anticlinal traps in Simpson rocks of Ordovician age. Until the early 1960's, many steel derricks stood above the wells, making the field a noteworthy landmark easily seen from many miles away. Removal of the derricks is nearly complete now, but reading the location markers on the wells makes for an interesting few hours.

Nice views of Stillwater, the Oklahoma State University campus, and the general countryside are seen from the hill on which the oil field is located. Relatively high relief of about 120 feet provides a good opportunity to study a fine mature stage of fluvial cycle in alternating siltstones and relatively massive, channeled red sandstones.

On the western edge of the Ramsey Field is the old Paradise Cemetery, kept in fairly good state by local residents. One mile west and .25 mile north of the cemetery, a gravel road crosses headwaters of Wildhorse Creek on a thick ledge of red sandstone. The deep red color of this sandstone is caused by an iron oxide, hematite (Fe_2O_3), which can be found in dark-red, nodular or platy masses called "ironstone" by many natives of this area. Hematite is the chief ore from which commercial iron is produced, but it is not sufficiently concentrated in Permian red beds of Oklahoma to be mined. Downstream, about 100 yards from where the creek crosses the road, a ledge of sandstone has produced the rimrock of a waterfall about 8 feet high. During rainy seasons the plunge pool at the base of this fall is rather large and is 6 to 8 feet deep. Undercutting is developed beneath the overhang, making this a fine spot at which to take pictures or, if time permits, to have a picnic lunch. On the south bank of the creek, downstream from the fall, a fine stand of the horsetail rush *Equisetum* provides insight into how this area must have looked

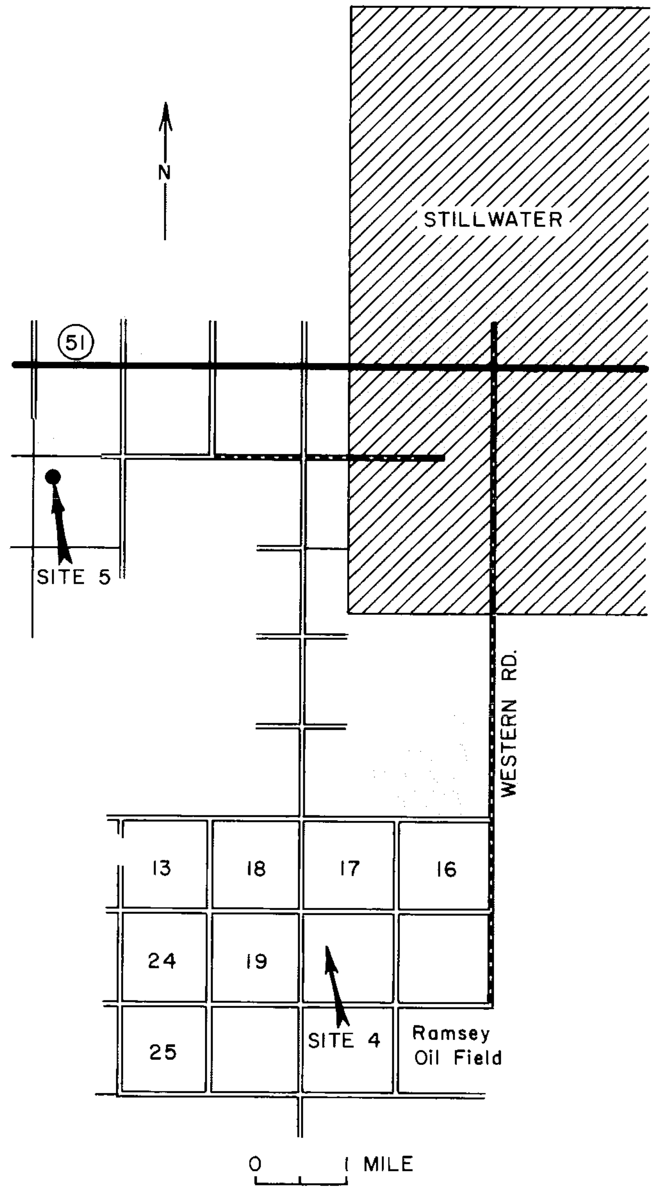


Figure 51. Location map for Payne County site 4, Ramsey Oil Field, and site 5, fossil plants.

during Permian time when the sandstones and siltstones were being deposited. Along many bedding planes in these Permian sandstones and siltstones, fossilized fragments of *Calamites*, a late Paleozoic rush, ancestral to the small *Equisetum* growing at the fall, can be found.

Payne County Site 5: Fossil plants

Access: Drive west on Highway 51—4 miles (6.4 km) from traffic light at Western Road, west edge of Stillwater. Turn south on dirt road (note: may be slippery after rain). After 1 mile (1.6 km), turn west onto poor field road and ascend slight grade for .12 mile before turning left into OSU Land Utilization and Research area. Close the gate after you pass through. Continue west .5 mile,

along fence, until you come out into clear, pasture-type fields.
Site location: Entire NW¼ sec. 26, T. 19 N., R. 1 E.
Topographic map: Stillwater SW, 1967 (7½′).
References: Garden (1973).

The fields in this area (fig. 51) are gullied with shallow erosion ditches that have numerous fragments of fossil wood embedded in the side walls. Most of the fragments are too small to be specifically identified, but a number of larger pieces can be identified as *Lepidodendron*, *Sigillaria*, or *Calamites*. It was reported to the writer that a party working in the fields in the 1930's discovered an entire tree, complete with branches, more than 90 feet long. After extensive searching of the area, however, I have been unable to find anything approaching these dimensions.

The wood fragments are preserved as limonite, a hydrous oxide of iron ($Fe_2O_3 \cdot H_2O$). This oxide is brown or ochre colored, rather than red, and can result from hydration of hematite. Some flakes and small pebbles of "ironstone" are found in these fields, but none that I have found are identifiable as fossil wood.

At the time the trees and rushes were growing here (Permian time), the area was probably a swamp on the lowland of the immense compound delta that spread northward into the epicontinental sea that lay over most of northern Oklahoma, Kansas, southern Nebraska, and eastern Colorado. The newly formed mountain regions to the south and low uplands in the Ozark region to the east were source areas for the clastic materials of this delta. Coarse-grained channel sandstones finger out northward from the source areas, but between the sandstones, flood-plain, levee, and paludal (swamp) deposits are finer. At this location, the deposits are fine siltstones and flaky, friable shales. The prominence of wood specimens suggests that this was a Permian swamp area with a moderately profuse growth of scale trees, ferns, and rushes.

Payne County Site 6: Copper mine

Access: From the north edge of Glencoe, drive 2 miles (3.2 km) south on Oklahoma Highway 108. Turn right (west) on second section-line road south of Glencoe and go 2 miles (3.2 km) farther. Turn south and drive .75 mile (1.2 km). Stop at house and ask permission to visit old copper mine. You can drive right up to the mine. (Please close all gates.) Trees of considerable size now grow on the edges of the mine opening, and the tunnel is mostly filled with water. The mine should not be entered because of the potential for collapse.
Site location: SE¼ sec. 22, T. 20 N., R. 3 E.
Topographic map: Ripley, 1929 (15′).
References: Ross (1972), Heine (1975).

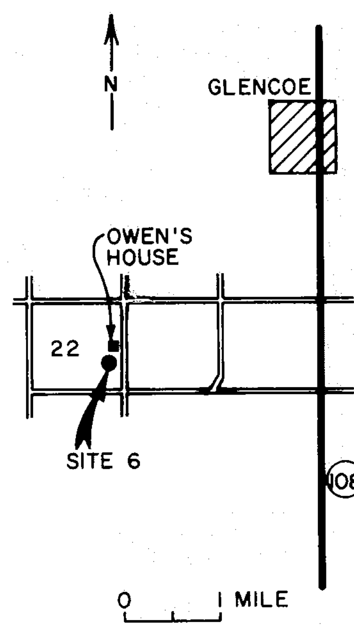


Figure 52. Location map for Payne County site 6, copper mine.

Copper minerals were discovered in this area (fig. 52) in 1901 and have since been mined with limited success, although interest has increased lately (stimulated by rising copper prices). A tunnel more than 60 feet long was cut into the Permian red beds, and a modicum of copper was mined during World War I. Principal copper mineral is chalcocite (Cu_2S), which has replaced wood fragments and pyrite (FeS_2) nodules. Also found in smaller amounts are malachite ($Cu_2CO_3(OH)_2$) and azurite ($Cu_3(CO_3)_2\,(OH)_2$), which stain the sandstones and shales green and blue, respectively, and provide colorful samples for collection. Small amounts of gold and silver are found in samples from this mine, but amounts have never been considered adequate for production. Identifiable samples can be found on the old dump material in front of the mine.

REFERENCES CITED

Al-Shaieb, Zuhair, and **Heine, R. R.,** 1976 [1977], Geochemical exploration for red-bed copper deposits in north-central Oklahoma, *in* Johnson, K. S., and Croy, R. L. (editors), Stratiform copper deposits of the Midcontinent region, a symposium: Oklahoma Geological Survey Circular 77, p. 69–75.

Beckwith, H. T., 1927, Geology of Osage County, *chapter 1 of* Oil and gas in Oklahoma: Oklahoma Geological Survey Bulletin 40-T, 63 p.

Bellis, W. H., and **Rowland, T. L.,** 1976, Shale and carbonate-rock resources of Osage County, Oklahoma: Oklahoma Geological Survey Circular 76, 50 p.

Bingham, R. H., and **Bergman, D. L.,** 1980, Reconnaissance of the water resources of the Enid Quadrangle, north-central Oklahoma: Oklahoma Geological Survey Hydrologic Atlas 7, 4 sheets, scale 1:250,000.

Bullard, F. M., 1928, Digest of Oklahoma oil and gas fields, *in* Oil and gas in Oklahoma: Oklahoma Geological Survey Bulletin 40, v. 1, p. 101–276.

Burwell, A. L., and **Ham, W. E.,** 1949, Cellular products from Oklahoma volcanic ash: Oklahoma Geological Survey Circular 27, 89 p.

Curtis, N. M., Jr., and **Ham, W. E.,** 1972, Geomorphic Provinces of Oklahoma *in* Johnson, K. S., Branson, C. C., Curtis, N. M., Jr., Ham, W. E., Marcher, M. V., and Roberts, J. F., Geology and earth resources of Oklahoma—an atlas of maps and cross sections: Oklahoma Geological Survey Educational Publication 1, p. 3.

Fay, R. O., 1959, Guide to Roman Nose State Park, Blaine County, Oklahoma: Oklahoma Geological Survey Guidebook 9, 31 p.

Fay, R. O., Ham, W. E., Bado, J. T., and **Jordan, Louise,** 1962, Geology and mineral resources of Blaine County, Oklahoma: Oklahoma Geological Survey Bulletin 89, 252 p.

Ford, G. W., 1978, Genesis and trend of the lowermost unit of the Vamoosa Formation (Gypsy Sandstone) in parts of northeastern and central Oklahoma: Oklahoma State University unpublished M.S. thesis.

Garden, A. J., 1973, Geology of western Payne County, Oklahoma: Oklahoma State University unpublished M.S. thesis.

Gilluly, James, Waters, A. C., and **Woodford, A. O.,** 1950, Principles of geology: San Francisco, W. H. Freeman, 527 p.

Greig, P. B., 1959, Geology of Pawnee County, Oklahoma: Oklahoma Geological Survey Bulletin 83, 188 p.

Ham, W. E., and **Merritt, C. A.,** 1944, Barite in Oklahoma: Oklahoma Geological Survey Circular 23, 42 p.

Heine, R. R., 1975, Geochemistry and mineralogy of the Permian redbeds and related copper deposits, Payne, Pawnee, and Noble Counties, Oklahoma: Oklahoma State University unpublished M.S. thesis.

Johnson, K. S., 1969 [1970], Mineral map of Oklahoma (exclusive of oil and gas fields): Oklahoma Geological Survey Map GM-15, scale 1:750,000.

———, 1971, Introduction, guidelines, and geologic history of Oklahoma, *Book 1 of* Guidebook for geologic field trips in Oklahoma: Oklahoma Geological Survey Educational Publication 2, 15 p.

———, 1972, Northwest Oklahoma, *Book 2 of* Guidebook for geologic field trips in Oklahoma: Oklahoma Geological Survey Educational Publication 3, 42 p.

Johnson, K. S., Branson, C. C., Curtis, N. M., Jr., Ham, W. E., Marcher, M. V., and **Roberts, J. F.,** 1972, Geology and earth resources of Oklahoma—an atlas of maps and cross sections: Oklahoma Geological Survey Educational Publication 1, 8 p. (Maps and cross sections of Oklahoma in color at a scale of 1:2,000,000.)

Jordan, Louise, and **Vosburg, D. L.,** 1963, Permian salt and associated evaporites in the Anadarko basin of the western Oklahoma–Texas Panhandle region: Oklahoma Geological Survey Bulletin 102, 76 p.

Kitts, D. B., 1965, Geology of the Cenozoic rocks of Ellis County, Oklahoma: Oklahoma Geological Survey Circular 69, 30 p.

Miser, H. D., and others, 1954, Geologic map of Oklahoma: Oklahoma Geological Survey and U.S. Geological Survey, scale 1:500,000.

Mogg, J. L., Schoff, S. L., and **Reed, E. W.,** 1960, Ground water resources of Canadian County, Oklahoma: Oklahoma Geological Survey Bulletin 87, 112 p.

Moore, R. C., Frye, J. C., Jewett, J. M., Lee, W., and **O'Connor, H.,** 1951, The Kansas rock column: Kansas Geological Survey Bulletin 89, 132 p.

Myers, A. J., 1962, A Middle Pleistocene stream channel: Oklahoma Geology Notes, v. 22, p. 224–229.

Myers, A. J., Gibson, A. M., Glass, B. P., and **Patrick, C. R.,** 1969, Guide to Alabaster Cavern and Woodward County, Oklahoma: Oklahoma Geological Survey Guide Book 15, 38 p.

Naff, J. D., 1977, Selenite crystals effects assessment, Ark.–Red River Basin chloride control, Ark. River Basin: U.S. Army Corps of Engineers, Special Publication DA CW 56–76–C–0184.

Oakes, M. C., 1959, Geology and mineral resources of Creek County, Oklahoma: Oklahoma Geological Survey Bulletin 81, 134 p.

Powers, Sidney, 1928, Age of the folding of the Oklahoma Mountains—the Ouachita, Arbuckle, and Wichita Mountains of Oklahoma and the Llano-Burnet and Marathon uplifts of Texas: Geological Society of America Bulletin, v. 39, p. 1031–1071.

Ries, E. R., 1954, Geology and mineral resources of Okfuskee County, Oklahoma: Oklahoma Geological Survey Bulletin 71, 120 p.

Ross, J. S., 1972, Geology of central Payne County, Oklahoma: Oklahoma State University unpublished M.S. thesis.

Shelton, J. W., 1973, Models of sand and sandstone deposits: a methodology for determining sand genesis and trend: Oklahoma Geological Survey Bulletin 118, 122 p.

Tanner, W. F., 1956, Geology of northeastern Osage County, Oklahoma: Oklahoma Geological Survey Circular 40, 76 p.

Travis, Abe, 1930, Geology of Oklahoma: University of Oklahoma M.S. thesis, 46 p.

Vosburg, D. L., 1954, Geology of the Burbank-Shidler area, Osage County, Oklahoma: University of Oklahoma unpublished M.S. thesis, 110 p.

Wood, P. R., and **Burton, L. C.,** 1968, Ground-water resources in Cleveland and Oklahoma Counties, Oklahoma: Oklahoma Geological Survey Circular 71, 75 p.