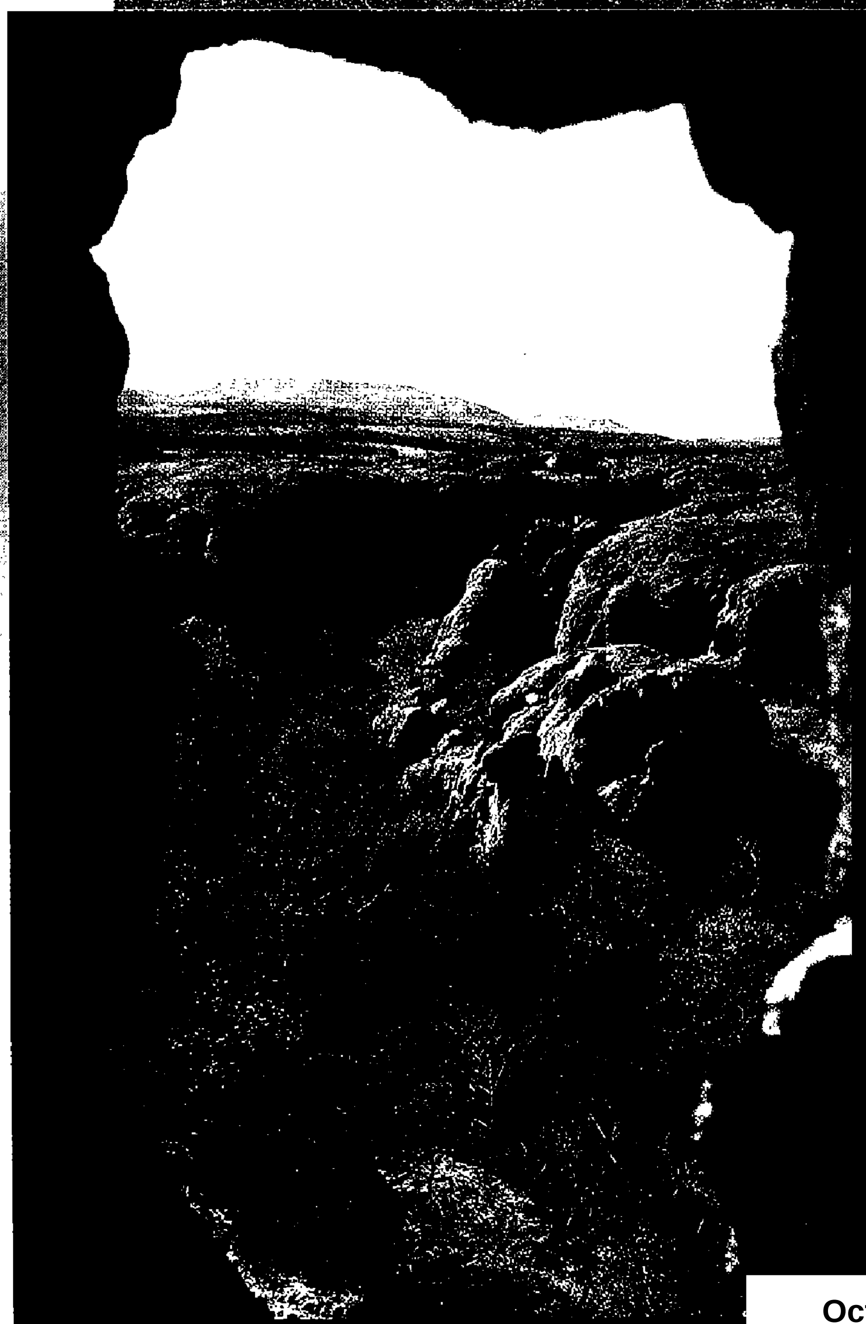
LAHOMA GEOLOGY Notes



October 1999

Vol. 59 No. 5

On The Cover —

Window on the Wichita Mountains, Southwestern Oklahoma

The picture on the cover was photographed through a small natural bridge of Quanah Granite near the intersection of Quanah Creek and a tributary, Cow Creek—not far south of Lake Quanah Parker, in the Wichita Mountains National Wildlife Refuge. The view is to the west–northwest, across the central lowland of the eastern Wichitas. Elk Mountain, one of the most prominent peaks in the area (2,250 feet elevation; about 650 feet relief) is visible about 4 miles away. It is a favorite of climbers and hikers because of the huge granite blocks and craggy pinnacles that adorn its top and sides, and the rather challenging southwest face with steep topographic drops and views across Charons Gardens and plains to the southwest and west.

The flat surface between the camera location and Elk Mountain is an ancient erosion surface. The Quanah Granite, which forms the surface, originated as magma that intruded and crystallized deep in the Earth's crust about 525 million years ago. Much later, in Pennsylvanian time, the area was uplifted and deeply eroded, exposing the granite and generating this topographic scene during the Permian.

About 280 million years ago—still during the Permian—delta-plain sediments known as the Post Oak Conglomerate buried this topography. In the last few million years, erosion has again stripped this area of Permian and younger overlying rocks, exposing a topography formed long ago. Thus, the Wichita Mountains have become a geologic museum where features that formed hundreds of millions of years ago are on display.

M. Charles Gilbert
School of Geology and Geophysics
University of Oklahoma

OKLAHOMA GEOLOGICAL SURVEY

CHARLES J. MANKIN
Director

KENNETH S. JOHNSON
Associate Director

OKLAHOMA GEOLOGY NOTES

Editor
Christie Cooper

Associate Editor
Tracy Peeters

Cartography
T. Wayne Furr, *Manager*
James H. Anderson
Charlotte Lloyd

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OKLAHOMA GEOLOGY

Notes

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Generalized Geological Time Scale

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

the GEE(*whiz!*) OLOGY of Oklahoma

compiled by
Neil H. Suneson
Oklahoma Geological Survey

INTRODUCTION

Did you know that when Oklahoma became the 46th State, in 1907, it was the largest oil-producing entity in the world? That is but one of a myriad facts about the geology and resources of this extraordinary young State. Although today Oklahoma does not have an active volcano, a sandy beach, or a towering mountain range, in the geologic past it had all those. Even now, the geology of our State and the resources derived from that geology rival those of many other places on Earth.

Oklahoma contains the Anadarko basin, which is one of the most prolific oil and gas provinces and also North America's deepest sedimentary basin. Our State has four geologically different uplifts—the ancient mountain ranges we call the Arbuckles, Ouachitas, Ozarks, and Wichitas. Some of the oldest rocks (1.4 billion years) in the southern Midcontinent are exposed here—as well as some of the youngest, for selenite crystals are forming today in river sediments in the northern part of the State. The State Rock—red barite rose—occurs in few other places in the world.

The geology of Oklahoma has made it a major producer of oil and gas; its reserves of gypsum could sustain current production through the next millenium; and it is the only producer of iodine in the United States, now filling about 25% of national demand. Crushed stone, sand and gravel, and coal also contribute to the economy of Oklahoma and the Nation.

Through more than a century of geological studies that began with the Territorial Geological Survey and continue in this 91st year of the Oklahoma Geological Survey, many scientific and economic observations and interpretations have been made about the geology and natural resources of Oklahoma. These studies were conducted by a large number of geoscientists who worked in academia, state and federal surveys, and industry. As a result of their efforts, few other states can match our three-dimensional view of Oklahoma's geology. And new discoveries continue to be made, to the benefit of current and future generations.

In 1998, Governor Frank Keating proclaimed the second week in October as Earth Sciences Week in the State of Oklahoma. October 10–16, 1999, marked the second annual celebration. As a contribution to this event, the Oklahoma Geological Survey has compiled this list of notable—even amazing—facts about the geology of Oklahoma, its resources, and some of its geologists.

We hope you enjoy reading these facts about Oklahoma geology. If you think of others, let us know and we will consider them for a future edition. Write to us at 100 E. Boyd St., Rm. N-131, Norman, OK 73019, or call (405) 325-3031. You also can contact us through our website at http://www.ou.edu/special/ogs-pttc/.

Geology and Oklahoma's Environment

➤ Granite exposed in the Arbuckle Mountains in Johnston County is about 1.4 billion years old. It is the oldest rock exposed between the southern Appalachians and the Rocky Mountains.

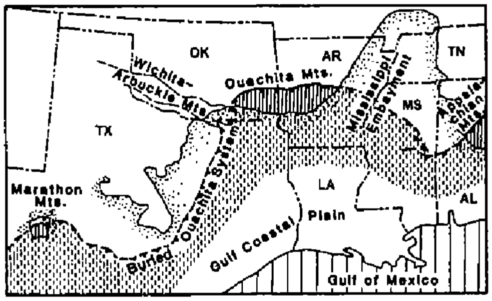

Figure 1. Map of Ouachita Mountains, most of which are buried by younger rocks and sediments.

➤ Oklahoma once had a mountain system very much like the Colorado Rockies. During the Pennsylvanian period, the Wichita and Arbuckle Mountains were connected to the Rockies. Ever since, Oklahoma's mountains have been eroding but the Rockies were uplifted a second time, beginning about 70 million years ago. Today, the Wichitas and the Arbuckles are less striking than the modern-day Rockies, but their roots sink just as deeply into the Earth's crust.

➤ The Ouachita Mountains in southeastern Oklahoma are part of a mountain belt that extends from Alabama to Mexico. In the United States, the only parts of this great belt not buried by younger rocks are the Ouachita Mountains in Arkansas and Oklahoma and the Marathon Mountains in West Texas. *(Fig. 1.)*

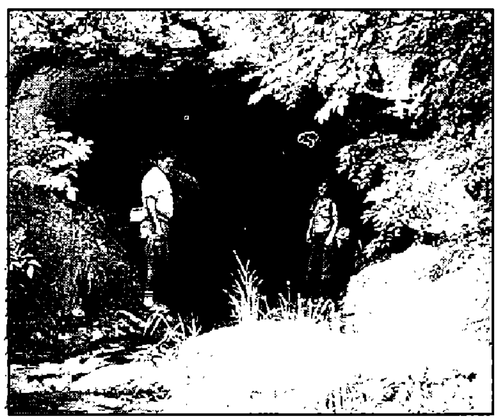

Figure 2. Entrance to Jester Cave, the longest gypsum cave in the world outside of Russia.

➤ Virtually all the lakes and reservoirs in Oklahoma are artificial; their water is impounded by dams. The only natural lakes in the State are oxbow lakes scattered along the flood plains of major rivers and the playa lakes in the High Plains of northwestern Oklahoma and the Panhandle.

➤ The longest gypsum cave in the world, outside Russia, is Jester Cave in Greer County. More than 33,000 feet of passageways have been mapped in the cave. And Alabaster Caverns, in Woodward County, is the largest commercial gypsum cave in North America. *(Fig. 2.)*

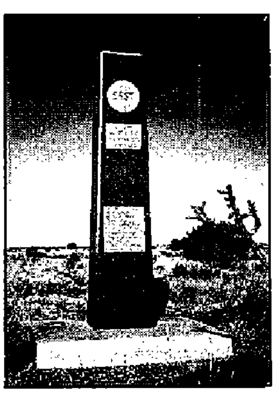

Figure 3. Monument marking the highest point in Oklahoma, in Black Mesa State Park.

➤ The highest point in Oklahoma, at 4,973 feet above sea level, is in Black Mesa State Park in Cimarron County. The mesa is capped by a basalt lava flow less than 5 million years old. The lava flowed from a volcano in southeastern Colorado. *(Fig. 3.)*

- About 2,500 tons of dissolved salt (table salt, or $NaCl$) is carried down the Cimarron River every day from the Big Salt Plain, near Plainview in Woods County.

- A 1,400-acre area just north of the Cimarron River, near Waynoka in Woods County, contains so many sand dunes that it is known as Little Sahara. The dunes consist of sand grains blown from the flood plain of the Cimarron by the prevailing southwesterly winds. The area, which attracts numerous dune-buggy drivers and cyclists, has been designated Little Sahara State Park. *(Fig. 4.)*

Figure 4. Sand dunes at Little Sahara State Park.

- The barite rose, found in only a few places worldwide, is the State Rock of Oklahoma. It received its official status in March 1968. Norman and Noble in Cleveland County have become world famous for rose rocks, where they are found in the Garber Sandstone (Permian age). *(Fig. 5.)*

Figure 5. Oklahoma's State Rock, the rose rock.

Ancient Life in Oklahoma

did you know

- The largest trilobite fossils west of the Mississippi River are found in Oklahoma. Trilobites of the genus *Isotelus* occur in the Bromide Formation (Ordovician age) in the Criner Hills in Carter County and in the eastern Arbuckle Mountains near Bromide, in Johnston County. *(Fig. 6.)*

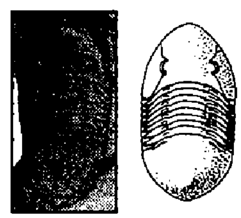

Figure 6. Trilobite *Isotelus*, (actual size 2.4 inches long).

- One of the largest known stumps of the world's oldest tree is on display on the campus of East Central University in Ada, Pontotoc County. *Archaeopteris* (extinct) was moderately abundant in Devonian time, and its petrified remains occur in the Woodford Formation near Ada and in the Arbuckle Mountains. *(Fig. 7.)*

Figure 7. *Archaeopteris* stump on the East Central University campus, Ada.

- White Mound in southeastern Murray County is world famous for its Early Devonian invertebrate fossils. These fossils include ostracodes, trilobites, brachiopods, corals, cephalopods, crinoids, gastropods, and sponges. Well-preserved trilobite specimens from the Haragan Formation at White Mound are found in museums around the world.

Ancient Life in Oklahoma *(continued)*

Figure 8. Prepared slab of numerous specimens of trilobite *Homotelus.* Slab is 6 inches long and 4 inches high.

- The trilobite *Homotelus* is found in great abundance in only a few layers of the Bromide Formation (Ordovician) in the Criner Hills of Carter County. Specimens occur by the thousands in seven distinct layers, each only a few inches thick. Museums and other collections from around the world prize these fossils. *(Fig. 8.)*

- Asphalt-impregnated limestone in the Deese Group (Pennsylvanian age) near Sulphur in Murray County contains some of the world's oldest fossils that retain their original shell material. Most fossils are imprints or casts of shells, or the original shell material, which consists of aragonite and magnesian calcite, has been replaced by another mineral. The Deese fossils are pristine, retaining their original iridescence.

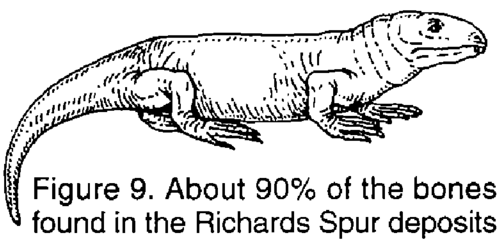

Figure 9. About 90% of the bones found in the Richards Spur deposits are of the Permian reptile *Captorhinus aguti.* This reconstruction is of a specimen about 1 foot long.

- The Dolese Brothers limestone quarry at Richards Spur in Comanche County contains the richest deposit of Early Permian reptile and amphibian fossils in Oklahoma, and is one of the richest in the world. The fossils occur in fissures and solution cavities in the Kindblade Limestone (Ordovician age); these openings in the rock were later filled with Early Permian sediment—and bones. *(Fig. 9.)*

- During the Mesozoic era (the "Age of Reptiles"), many kinds of dinosaurs roamed what is now Oklahoma. *Apatosaurus, Barosaurus, Camptosaurus, Diplodocus, Saurophaganax,* and *Stegosaurus* bones have been found near Black Mesa in Cimarron County. Other dinosaurs (described below) lived in southeastern Oklahoma.

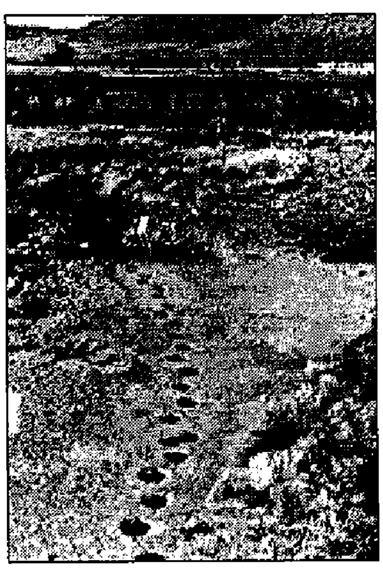

Figure 10. Tracks of a medium-sized ornithopod dinosaur near Kenton in Cimarron County.

- Just north of Kenton in Cimarron County, 28 fossil footprints of an ornithopod dinosaur can be seen preserved in sandstone of the Morrison Formation (Jurassic age). The dinosaur was probably about 6 feet tall at the hip and about 17 feet long. *(Fig. 10.)*

➤ One of the largest of all the Early Cretaceous carnivorous dinosaurs lived in what is now southeastern Oklahoma. *Acrocanthosaurus atokensis* ("high-spined lizard from Atoka") was first described in 1940 from two specimens found in the Antlers Formation (Early Cretaceous age) in Atoka County. The North Carolina State Museum of Natural Sciences paid $3 million for another, nearly complete, 40-foot-long skeleton of *Acrocanthosaurus* discovered near Eagletown in McCurtain County. A complete cast made from the original skeleton can be seen at the Goddard Children's Museum at Lake of the Arbuckles, in Murray County. *(Fig. 11.)*

Figure 11. Skeleton of *Acrocanthosaurus.* Note the prominent spines that extend upward from the dinosaur's back.

➤ Bones of the raptor dinosaur *Deinonychus* were discovered with bones of its presumed prey, the ornithopod dinosaur *Tenontosaurus,* in the Antlers Formation in Atoka County. They are being excavated and studied by paleontologists from the Sam Noble Oklahoma Museum of Natural History in Norman. The lightly built, agile *Deinonychus* was a close relative of the velociraptors featured in the movie *Jurassic Park* and may have hunted in packs. *(Fig. 12.)*

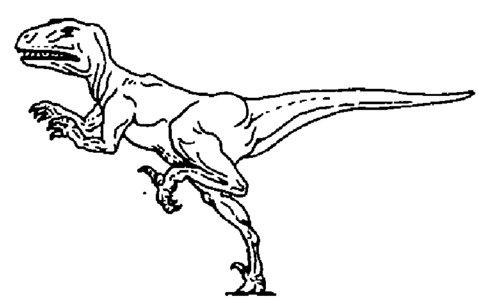

Figure 12. Reconstruction of *Deinonychus* ("terrible claw"). Adults were about 3 feet tall and nearly 10 feet long from head to tail.

➤ A fossil bed consisting almost entirely of Cretaceous-age ammonite fossils can be found around parts of Lake Texoma, in southern Oklahoma. These fossils, some as large as 2 feet in diameter, are popular with local collectors and look like giant snails. In fact, they are extinct cephalopods and are related to the squid, octopus, and chambered nautilus. The fossils are in the lower part of the Duck Creek Member of the Caddo Formation. *(Fig. 13.)*

Figure 13. Large ammonite *Eopachydiscus*, typical of those found along the shores of Lake Texoma.

➤ During Miocene time, Oklahoma was home to rhinoceroses, camels, ancient elephants, ground sloths, three-toed horses, bone-eating dogs (with hyena-like jaws), and saber-toothed cats. About the same time, alligators lived in present-day Beaver County. *(Fig. 14.)*

Figure 14. Reconstruction of the extinct gomphothere *Platybelodon,* an ancient elephant whose bones have been found in Beaver County.

did you know

Geological Resources of Oklahoma

ENERGY SOURCES

Coal

➤ Coal has been mined continuously on a commercial scale in eastern Oklahoma ever since the first reported production in 1873. Mining was begun primarily to fire the steam engines of railroad locomotives. At first, most of the coal was mined underground. Most miners were European immigrants, and many of their descendants still live in the coal belt of eastern Oklahoma. Today, almost all Oklahoma coal is strip-mined, with overlying soil and rock being removed by heavy earth-moving equipment. Only one mine, in Le Flore County, is still worked underground. *(Fig. 15.)*

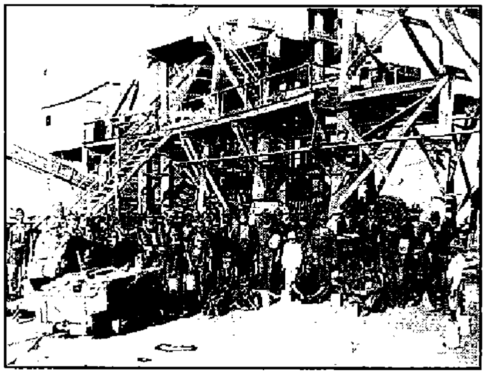

Figure 15. Coal miners pose in front of the head frame of a shaft to a coal mine in Indian Territory, 1902.

➤ Since 1873, about 275 million tons of coal has been produced in Oklahoma. For the past few years, about 1.7 million tons of bituminous coal has been mined annually in eastern Oklahoma and burned to generate electricity and to furnish process heat for industrial use. This is enough coal to supply more than 650,000 people with electricity. Oklahoma has about 1.6 billion tons of bituminous-coal reserves (reserves are the economically recoverable part of coal resources), of which about 342 million tons is available for surface mining. *(Fig. 16; also see map of nonpetroleum mineral resources, p. 181.)*

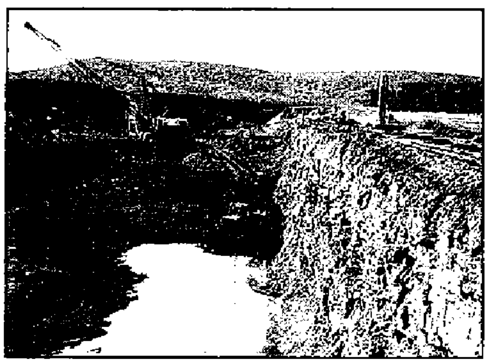

Figure 16. Wister coal mine in Le Flore County, with dragline, headwall, and drill rig used for drilling shotholes. This mine is typical of Oklahoma strip mines.

➤ About 70–80% of the electricity generated and used in Oklahoma now comes from six coal-burning power plants in the State. These plants burn a total of 20 million tons of coal per year. Almost 95% of the 20 million tons is shipped by rail from Wyoming because Wyoming coal contains less sulfur than Oklahoma coal and thus burns more cleanly. *(Fig. 17.)*

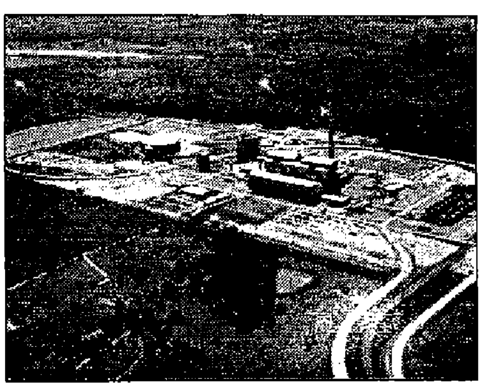

Figure 17. AES Shady Point coal-fired power plant near Poteau.

➤ Bituminous coal in Oklahoma is the source of a kind of natural gas known as coalbed methane. Since 1988, more than 700 wells have been drilled into Oklahoma coal beds to produce methane. (Coalbed methane is burned just like any other natural gas.)

Oil and Gas

- The Ames structure, in the Ringwood field, Major County, produces oil and gas from an ancient meteorite crater formed in Early Ordovician time. Much of the production is from rock shattered by the meteorite and later buried by 10,000 feet of sedimentary deposits. *(Fig. 18.)*

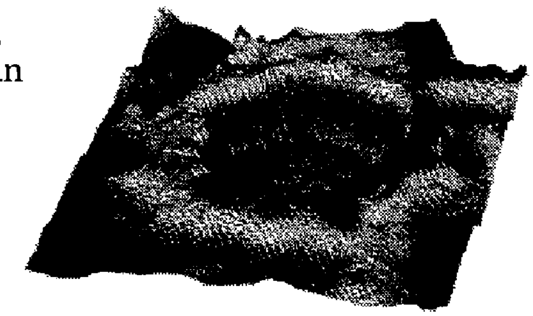

Figure 18. Three-dimensional, computer-generated illustration of the Ames structure, which now is deeply buried by sedimentary rocks.

- In Oklahoma, a shallow oil or gas well, about 3,000 feet deep, can be drilled in a few days; a deep gas well, about 15,000 feet deep, takes 2 to 4 months to drill. A shallow well might cost about $150,000, and a deep well about $1.3 million. To drill and complete a very deep well (over 25,000 feet deep) would cost more than $10 million.

- Although many of Oklahoma's oil wells had an initial production of hundreds or even thousands of barrels of oil per day, the daily average for all producing wells is now about 2 barrels. That's because the original reservoir pressure that drives the oil in most fields has fallen as the oil and gas were produced; also, most of the mobile oil, the easiest to remove, has already been extracted.

- Since 1891, Oklahoma has produced about 14 billion barrels of oil and 83 trillion cubic feet of natural gas. Gasoline refined from that much oil would enable a car that averages 20 miles per gallon to make almost 22 million round trips to the Moon.

- More than 460,000 wells have been drilled for oil and gas in Oklahoma since 1915, the year the State began keeping records. (That total includes producing wells and dry holes.) If earlier wells are counted, the total probably would be closer to 500,000. At the end of 1998, there were about 88,000 producing oil wells and 30,000 producing gas wells. *(See map of oil and gas production, p. 181.)*

- Oil, coming from deep in the ground, must be discovered through long and costly exploration. Then it must be pumped, transported (sometimes half way around the world), and refined. Even after adding taxes, it still sells for about half of what we pay for bottled water in a grocery store.

INDUSTRIAL MINERALS

➤ In 1997, Oklahoma produced a number of industrial, or nonfuel, minerals worth about $411 million. Leading nonfuel commodities in 1997 were crushed stone (worth $134 million), portland and masonry cement ($131 million), sand and gravel ($33 million), glass sand ($27 million), iodine ($24 million), and gypsum ($18 million). *(See map of nonpetroleum mineral resources, p. 181.)*

➤ Oklahoma is the only state in the country producing iodine, an important constituent in animal feed, disinfectants, photography, and pharmaceuticals. In northwestern Oklahoma, three companies have drilled wells 7,000–10,000 feet deep and pumped out brine yielding nearly 3 million pounds of iodine annually, about 25% of all U.S. consumption. And in 1998, 10% of all the iodine produced in the world came from Oklahoma.

Figure 19. Gypsum quarry at Fletcher, Comanche County, operated by Temple-Inland Products Corporation.

➤ Gypsum, a mineral with many uses in agriculture, construction, food processing, and in the manufacture of pharmaceuticals, is an $18-million-per-year industry in Oklahoma. Gypsum resources in western Oklahoma are estimated at 48 billion tons, enough to supply the United States for 1,500 years at the present rate of consumption. *(Fig. 19.)*

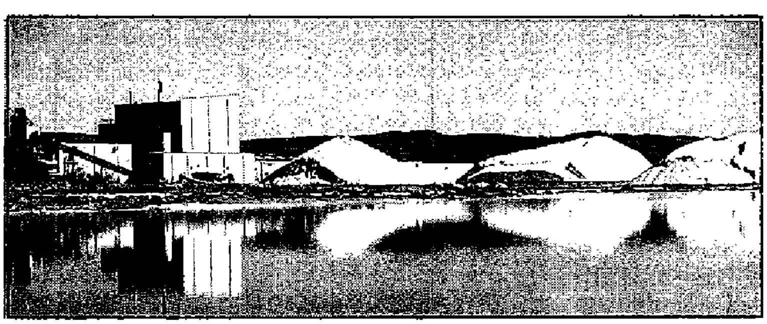

Figure 20. Cargill Salt Company salt-mining operation in northwest Oklahoma.

➤ Resources of common salt (NaCl) in western Oklahoma are estimated at more than 21 trillion tons, enough to meet the current rate of use in the United States for 500,000 years. Most of the salt occurs as buried geologic formations. About 200,000 tons of salt was produced in Oklahoma in 1998, all evaporated from brine in Woods County. *(Fig. 20.)*

- Volcanic ash was once mined for abrasives in Beaver, Hughes, and Okfuskee Counties. Some of the ash was blown by the wind from Mount Mazama (in Oregon, where only Crater Lake now remains of the volcano) and from volcanoes in Yellowstone National Park, Wyoming, and northern New Mexico. The volcanoes erupted thousands to hundreds of thousands of years ago.

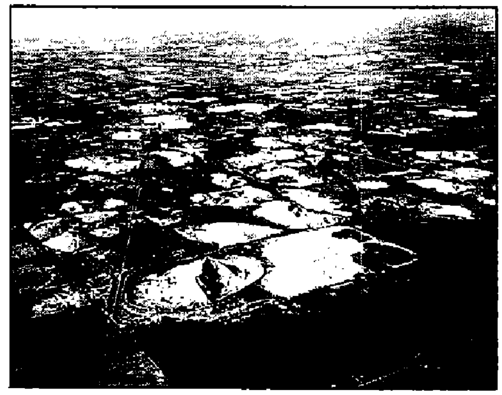

Figure 21. Aerial photograph of Picher mining district. Chat (waste) piles are now quarried for roadbed material.

METALS

- Almost every year from 1918 to 1945, Oklahoma led the country in zinc production. More than 5.2 million tons of zinc (and 1.3 million tons of lead) were produced from the Picher Field in Ottawa County from 1891, when mining began, to 1970, when operations ceased. Because about 20 pounds of zinc is used in every car, Oklahoma could have supplied the zinc for more than half a billion cars. *(Fig. 21.)*

Figure 22. Oblique aerial photograph looking northwest of Eagle-Picher copper strip mine at Creta. Highwall on left side of pit is about 40 ft high.

- Copper was mined in Oklahoma between 1965 and 1975. In that period Eagle-Picher Industries strip-mined its Creta copper deposit in Jackson County and produced more than 1.5 million tons of ore with an average grade of about 1.90% copper. The ore was chalcocite, a copper sulfide, which occurred in a shale bed 6 to 12 inches thick in the Flowerpot Shale (Permian age). *(Fig. 22.)*

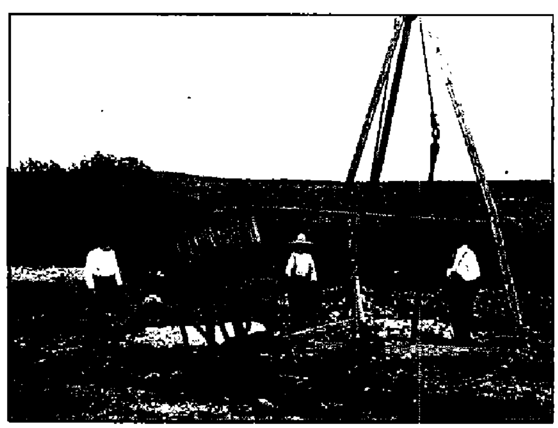

Figure 23. Cable-tool rig used to explore for zinc in the Southwest Davis zinc field. Gertrude Sober in center. Photo taken in 1909.

- The Southwest Davis zinc field, in the Arbuckle Mountains in Murray County, was discovered by Gertrude Selma Sober. She began prospecting in 1907 and discovered the small field in 1909. Although her involvement in mining did not last long, she pursued other interests in geology and in 1933 received her B.S. degree from the University of Oklahoma at the age of 63. In 1988, Sober was inducted posthumously into the National Mining Hall of Fame in Leadville, Colorado. *(Fig. 23.)*

Geology and History of Oklahoma

did you know

- The builders of Spiro Mounds in eastern Oklahoma (1,000–800 years ago) made paint by mixing clay or grease with galena (lead sulfide) for gray, with limonite (hydrated iron oxide) for yellow, malachite (hydrated copper carbonate) for green, hematite (iron oxide) for red, and azurite (another hydrated copper carbonate) for blue.

- As early as 1850, copper ore was mined near present-day Byars in McClain County, by Col. Randolph B. Marcy, the first person on record to trace the Red River to its source.

Figure 24. Rock Mary, landmark for emigrants traveling through Oklahoma during the California gold rush.

- Rock Mary, an isolated sandstone butte near Red Rock Canyon State Park in Caddo County, was a landmark for California-bound emigrants. Rock Mary was named in 1849 for 17-year-old Mary Conway, who was one of the emigrants and the daughter of a governor of Arkansas. The butte consists of Rush Springs Sandstone (Permian age), which also forms Red Rock Canyon. *(Fig. 24.)*

- The first well to produce oil in Oklahoma was drilled in 1859, but not to find oil. It was drilled in a search for salt at a saline spring on the Neosho River, probably near Salina, in Mayes County. It is said to have produced about 10 barrels of oil per day for about a year.

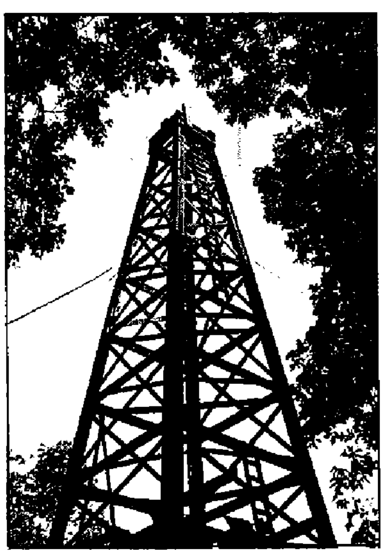

Fig. 25. Reconstruction of the No. 1 Nellie Johnstone well near Bartlesville.

The first well specifically seeking oil in Oklahoma was drilled in 1872 near an oil seep (an "oil spring") in the Cherokee Nation; its exact location is unknown. Two other exploratory wells were drilled (also near oil seeps) in 1883 on Clear Boggy Creek near Atoka, Atoka County, and in 1886 near Chelsea, Rogers County. These recovered subcommercial quantities of oil, the Atoka well in 1888 and the Chelsea well in 1889. The small amount of oil they produced commonly was used by local ranchers as tick-dip.

The first commercial oil well in Oklahoma was the No. 1 Nellie Johnstone, drilled in 1897 on the banks of the Caney River near Bartlesville, Washington County. However, commercial production did not begin until 1904, when transport to markets became feasible. *(Fig. 25.)*

➤By 1906, Tulsa was known as the Oil Capital of the World. In 1909, more than 300 oil companies were chartered in Oklahoma.

➤Oklahoma produced more oil than any other state in the country from 1907 (the year of statehood) to 1923. In 1927, oil production in Oklahoma reached an all-time annual high of 278 million barrels.

➤In 1913, Henry Kendall College (now Tulsa University) offered the first petroleum geology course in the Midcontinent. In 1915, the University of Oklahoma offered its first course in petroleum geology.

➤Some of the largest and most widely known oil and gas companies had their beginnings in Oklahoma, including Champlin Petroleum Company, Cities Service Company, Continental Oil Company (Conoco), Kerr-McGee Corporation, Phillips Petroleum Company, Sinclair Oil and Gas Company, and Skelly Oil Company.

➤A graduate of the University of Oklahoma developed the seismic-reflection method, which is one of the most valued techniques in petroleum exploration today. John Clarence Karcher formed a small company that first tested his method in 1921 near Belle Isle in Oklahoma City. His first company failed, but through his efforts a second company, Geophysical Services, Inc., continued to refine the method. This second company led to another, called Texas Instruments. *(Fig. 26.)*

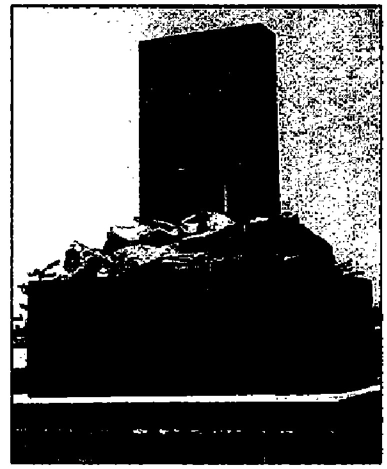

Figure 26. Monument near Belle Isle reads "Birthplace of the Reflection Seismograph. Field tests which confirmed the validity of the reflection seismograph method of prospecting for oil were conducted near this spot on June 4, 1921. The shot has virtually echoed around the world. This monument was erected on the golden anniversary, 1921–1971, by the Geophysical Society of Oklahoma City to commemorate the event."

➤The largest professional organization for petroleum geologists in the world, the American Association of Petroleum Geologists (AAPG), was founded in Oklahoma. Members first met formally in Norman in 1916; the headquarters office has been in Tulsa since 1926. *(Fig. 27.)*

Figure 27. Headquarters of the American Association of Petroleum Geologists in Tulsa.

➤In 1930, during the early years of the Oklahoma City oil field, the drilling of a well later called the "Wild Mary Sudick" encountered very high pressure that resulted in a blow out. Oil was blown into the air and carried by the wind as far as Norman, about 12 miles away.

Geology and History of Oklahoma *(continued)*

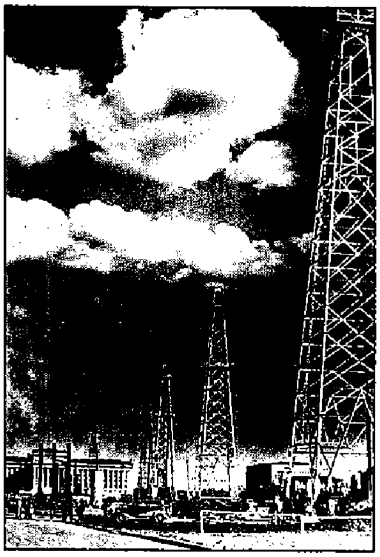

Figure 28. Oil derricks in front of the Capitol Building.

Figure 29. U.S. oil-field crew in England breaking for tea, early 1940s.

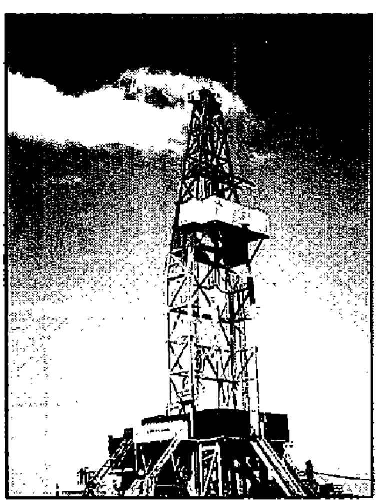

Figure 30. Drilling rig for the Lone Star No. 1 Bertha Rogers well, Washita County.

➤ Oklahoma's State Capitol is the only one in the country that once had producing oil wells on its grounds. The wells are now inactive. *(Fig. 28.)*

➤ Noble Drilling Company, of Ardmore, Carter County, was instrumental in developing an oil field in the legendary Sherwood Forest in England in the early 1940s. It was a significant contribution to the defense of Britain during World War II, because aviation fuel was badly needed for fighter planes of the Royal Air Force. Drilling crews worked in near-darkness at night because of the blackout. They also had to live on 1,200 calories a day, because food was scarce. *(Fig. 29.)*

➤ The deepest well ever drilled anywhere for oil and gas is in Washita County. It is the Lone Star Producing Company No. 1 Bertha Rogers. On April 13, 1974, drillers reached a total depth of 31,441 feet, only 239 feet short of 6 miles. The temperature at that depth was so high that sulfur in liquid form occurred at the bottom of the well. (It solidified as it circulated out of the hole.) The total cost of the well was $5.9 million (in 1974 dollars) and it took almost 2 years to drill and complete. The well discovered gas at 13,000 feet. *(Fig. 30.)*

➤ The second deepest natural-gas producing well in the world is the Leede Oil and Gas Company No. 1-29 McCall, in Beckham County. It was completed in 1985, producing gas from the Henryhouse Formation (Late Silurian age) at a depth of 24,763 feet to 25,000 feet. (The deepest gas producer in the world is in Pecos County, Texas.)

➤ The Kinta natural gas field is about 70 miles long and extends across five counties—Haskell, Latimer, Le Flore, Pittsburg, and Sequoyah. *(See map of oil and gas production, p. 181.)*

➤ The greatest number of well completions in Oklahoma was achieved in 1982, when 12,012 wells began producing oil or gas or both. Large numbers of wells in the State were completed in the "oil boom" years of the 1970s and early 1980s. Before that time, the highest number of well completions was in 1913, at 9,131, during Oklahoma's original "Black Gold Era" (1908–1928).

- Oklahoma has deposits of solid hydrocarbons, which are rare in the geologic record. Most of them are in the Ouachita Mountains. They occur as veins formed when oil filled fractures in the rock and later turned into a solid that looks like coal. One solid hydrocarbon, impsonite, is named for Impson Valley in western Pushmataha County. Near Page, in Le Flore County, impsonite was mined for fuel before 1911, and during World War I it was burned to recover vanadium from the ash. (Vanadium is used in making steel.) *(Fig. 31.)*

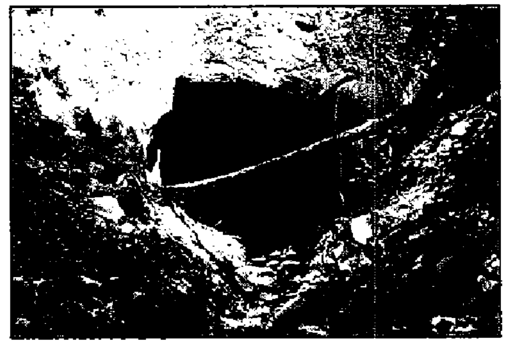

Figure 31. The Page impsonite mine in 1945.

- In 1915, the University of Oklahoma had the largest class in paleontology in the United States, taught in the attic of Old Science Hall.

- Between 1935 and 1942, John W. Stovall, then director of the Oklahoma Museum of Natural History, in Norman, opened 17 dinosaur-bone quarries near Black Mesa in Cimarron County under the Works Progress Administration (later the Works Project Administration). About 6,000 bones were collected from those quarries, all in the Morrison Formation (Jurassic). Many of the bones are only now being properly curated and studied, and among them new species are being discovered. One of the quarries can be visited near Oklahoma Highway 325, about 8 miles east of Kenton. *(Fig. 32.)*

Figure 32. John W. Stovall (1891–1953) examining a fossil *Tenontosaurus* skull.

- The deepest coal mined in Oklahoma came from the Carbon No. 5 mine east of McAlester, in Pittsburg County. The coal, 1,600 feet below the surface, was produced in the early 1960s.

Earthquakes in Oklahoma

did you know

- The earliest well-documented Oklahoma earthquake occurred near present-day Jefferson, Grant County, in 1897.

- Oklahoma counties with the most earthquakes recorded during 1977 through 1998 were Garvin (290), Grady (188), McClain (125), and Canadian (82). Fourteen Oklahoma counties had only one or two earthquakes, and Washington, Nowata, Jackson, Craig, Cimarron, and Adair Counties had none.

Earthquakes in Oklahoma *(continued)*

- In the 22 years from 1977 through 1998, the Oklahoma Geological Survey detected and located 1,429 earthquakes in the State. Of those, 67 were felt by Oklahomans. In 1997, an earthquake of magnitude 4.4 was felt from Durant (Bryan County) to Spavinaw (Mayes County). Another, of magnitude 4.2, occurred in 1998 and was felt from Pawnee (Pawnee County) to North Dallas, Texas.

Earthquake Rocks Entire State; Capitol Office Building Cracked

Figure 33. Front-page headline from the *Norman Transcript,* April 9, 1952.

- The largest (magnitude 5.5) well-documented earthquake centered in Oklahoma was felt throughout the State and in parts of seven others. It occurred on April 9, 1952, and is known as the El Reno earthquake for its epicenter in Canadian County. It caused a 50-foot-long crack in the State Capitol Office Building in Oklahoma City. An earthquake of similar magnitude occurred in the Indian Territory in 1882. *(Fig. 33).*

Figure 34. Meers fault scarp (escarpment). View looking north.

- One of the best examples of a Recent fault (with movement in the last 10,000 years) east of the Rocky Mountains is found in Oklahoma. It is the Meers fault, which is exposed in northern Comanche County for about 18 miles. The maximum relief along the fault is 15 feet. Movement along the fault last occurred about 1,100 to 1,500 years ago. *(Fig. 34).*

ACKNOWLEDGMENTS

This compilation tapped the knowledge of many geoscientists throughout the State. Many are on the staff of the Oklahoma Geological Survey; others are as noted: Richard D. Andrews, Colin Barker (University of Tulsa), Tom L. Bingham, Raymon L. Brown, Roger J. Burkhalter (Sam Noble Oklahoma Museum of Natural History), Jock A. Campbell, Brian J. Cardott, James R. Chaplin, Nicholas J. Czaplewski (Sam Noble Oklahoma Museum of Natural History), Robert O. Fay, Samuel A. Friedman, M. Charles Gilbert (University of Oklahoma), A. Allen Graffham (Geological Enterprises, Inc.), LeRoy A. Hemish, Kenneth S. Johnson, James E. Lawson, Jr., Kenneth V. Luza, Charles J. Mankin, Neil H. Suneson, and Jane L. Weber. Credit for figures follows.

FIGURE CREDITS

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19–22. Kenneth S. Johnson, Oklahoma Geological Survey.

23. Courtesy Western History Collections, University of Oklahoma Libraries.

24, 25. Fred W. Marvel, Oklahoma Department of Tourism and Recreation.

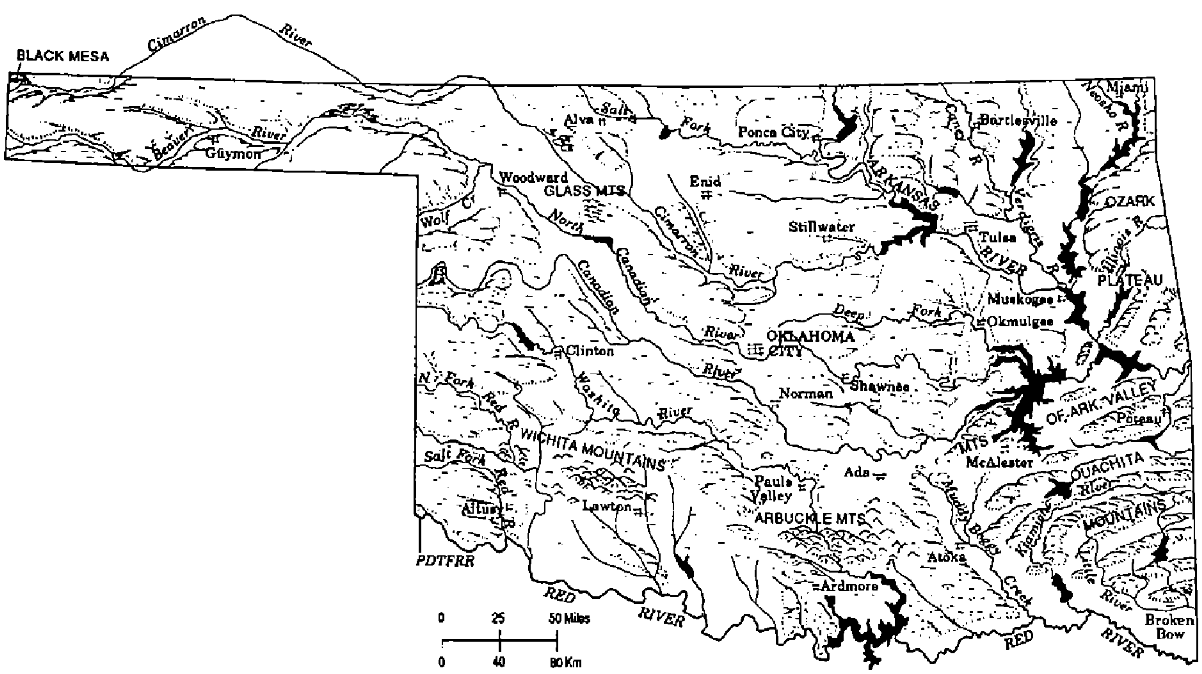
26. Kenneth S. Johnson, Oklahoma Geological Survey.
27. Courtesy American Association of Petroleum Geologists.
28. Courtesy Western History Collections, University of Oklahoma Libraries.
29. From Woodward, G. H.; and Woodward, G. S., The Secret of Sherwood Forest: University of Oklahoma Press, Norman, p. 156. Photo courtesy BP-Amoco, Inc.
30. Kenneth S. Johnson, Oklahoma Geological Survey.
31. M. C. Oakes and J. O. Beach, courtesy Western History Collections, University of Oklahoma Libraries.
32. Courtesy Sam Noble Oklahoma Museum of Natural History, University of Oklahoma.
33. Norman Transcript, April 9, 1952, p. 1, top headline.
34. Kenneth V. Luza, Oklahoma Geological Survey.

did you know

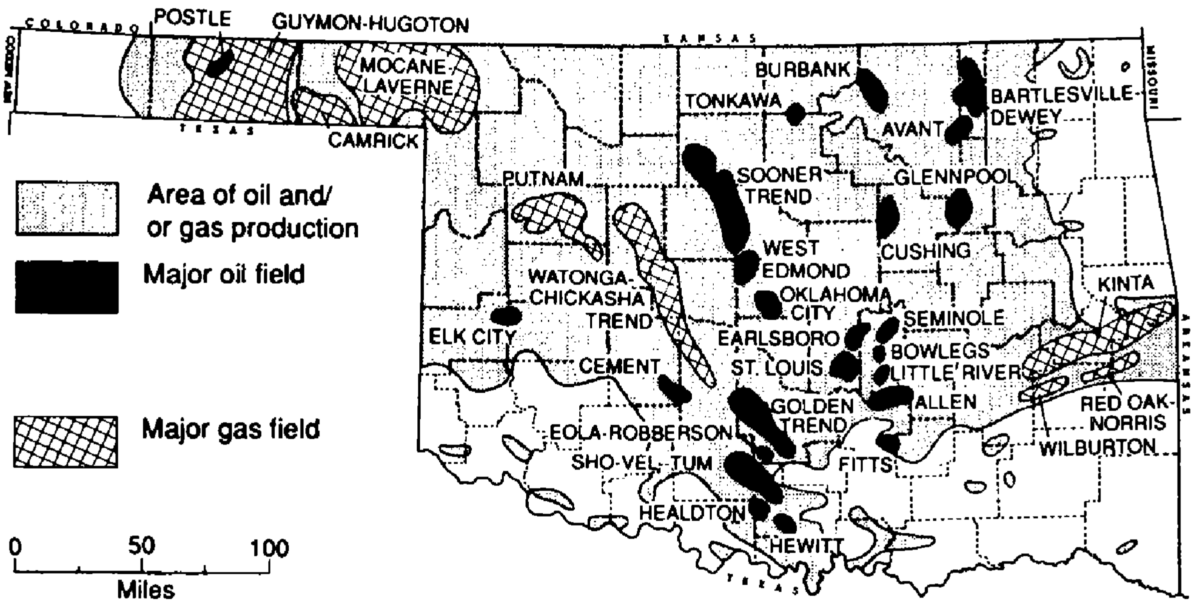
Helpful Maps

Counties of Oklahoma

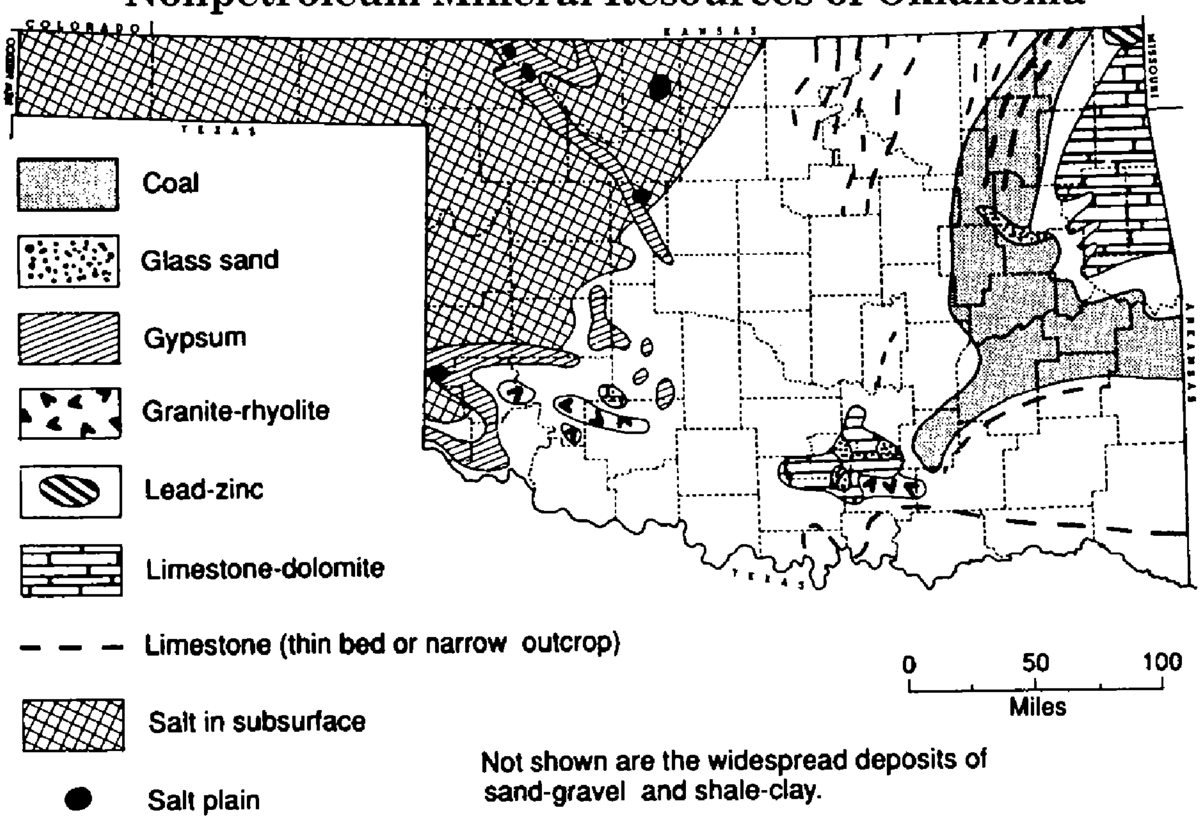
Landforms of Oklahoma



Major Oil and Gas Fields of Oklahoma and Areas of Lesser Petroleum Production



Nonpetroleum Mineral Resources of Oklahoma



Earth Science Activities for Teachers Made the Grade

As part of the "Partners for Earth Science" teacher outreach program, the Oklahoma City Geological Society (OCGS) and the Oklahoma Geological Survey (OGS) cosponsored a workshop and a field trip to the Arbuckles for earth science teachers in September 1999.

At the half-day workshop on Friday, Sept. 17, four presenters demonstrated activities designed to help teachers become more comfortable with the subject of earth science. Twenty teachers and six geologists attended the meeting, which was at the Kerr McGee Auditorium in Oklahoma City.

Debbie Jensen, a middle-school teacher from Woodward and Oklahoma's representative to the National Earth Science Teachers Association, showed participants inexpensive activities they can do to teach mineral identification and other classroom activities using minerals and rocks.

Mindy Stitt from the Oklahoma Energy Resources Board used a loaf of bread and gummy candy fish (to represent fossils) to demonstrate how sedimentary rocks are deposited as layers, how sediments are compressed over time to form sedimentary rocks, how different objects make different impressions (fossils) in the sediment, and how fossils contribute to the formation of oil and gas.

John Samuel from the Oklahoma Conservation Commission explained "Project Wet," an interdisciplinary educational program addressing all aspects of water. Oklahoma Project Wet is cosponsored by the Oklahoma Conservation Commission, the Department of Environmental Quality, and the Oklahoma Water Resources Board. The program is intended to supplement individual schools' existing curriculum. Project Wet offers teachers a curriculum and activity guide with more than 500 pages of lesson plans, activities, cross references, and background material.

Jim Chaplin, a geologist with the OGS, updated participants on the Survey's outreach program for Earth Science teachers.

The OGS is preparing a variety of materials for K–12 teachers, including an Oklahoma geologic time scale, and learning activities for students, including numerous crossword puzzles, word searches, word scrambles, "geodetective" puzzles, and matching. The materials have an Oklahoma focus and will acquaint students with oil trivia, geology of State parks, fuel and nonfuel resources, earthquakes, minerals and rocks, water resources, and dinosaurs. In addition, mineral, rock, and fossil kits will be available soon for all Oklahoma earth science teachers.

On Saturday, Sept. 25, geologists from the OCGS and OGS led a one-day geologic field trip to the Arbuckle Mountains for earth science teachers. Thirty teachers and seven geologists participated. Field trip leaders included John Gatchell, Ralph Espach, Paul Pipes, and John Shenk from the OCGS and Jim Chaplin from the OGS.

The geological concepts and principles demonstrated on the field trip included the laws of superposition and cross-cutting relationships, and the principles of original horizontality and lateral continuity. The group discussed the relation of rock types to topographic landforms, geologic contacts, reading topographic maps, and dipping beds. Teachers were shown how to determine the attitude of beds (strike and dip) using a Brunton compass.

Some of the geological features observed and studied on the field trip included karst features, anticlines, synclines, faults, and unconformities. Participants also visited a shale pit, limestone quarry, and natural asphalt quarry, where they collected samples to use in their classrooms and discussed the economic resources as well as the geologic significance of the sites.

One of the highlights of the day was a visit to the world-famous site for collecting Early Devonian fossils in the Hunton Group (Haragan Formation) at White Mound in southeastern Murray County. There the teachers collected trilobites, brachiopods, corals, bryozoans, crinoid stems, gastropods, and bivalves for use with their students.

Geologists John Shenk, Ralph Espach, and John Gatchell show earth science teachers how to determine the attitude (strike and dip) of beds using a Brunton compass on a dipping bedding plane of the Woodford Shale, Sept. 25, Arbuckles field trip.

Based on their comments on the evaluation form distributed after the field trip, the teachers found the day's activities exciting and worthwhile:

- "I will use the rocks I picked up to give hands-on experience."
- "The tour satisfied my long-standing curiosity and interests."
- "It was informative, educational, and enjoyable."
- "Now I'll be able to lead a field trip to the sites myself."
- "Having so many geologists really made this trip informative—especially with their varied experiences."
- "Everything we did and saw was fabulous."
- "I now have some rock samples to show along with the handouts to help make them more real."
- "I now have a greater understanding of terms and concepts, and new ideas for hands-on demonstrations and laboratories."

Besides field trips and workshops, the "Partners for Earth Science Program" also involves a commitment by the OCGS and OGS to provide professional geologists to talk to students about a variety of geological topics. Classroom presentations are designed to help K–12 teachers enhance their skills and knowledge in the area of earth science. Speakers often are requested for such subjects as plate tectonics, minerals, rocks, fossils, earthquakes, volcanoes, dinosaurs, and natural hazards.

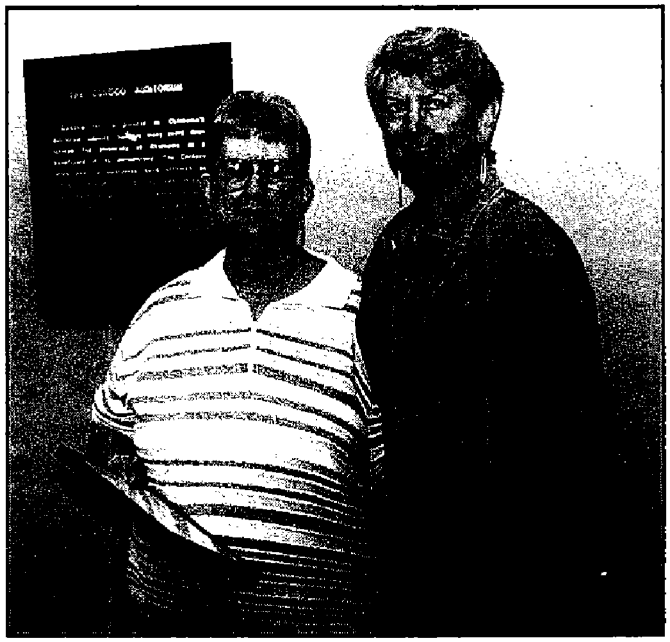
—James R. Chaplin

Future Activities

A field trip to the Arbuckles for earth science teachers will take place in November, and another workshop is being planned for spring. For more information about these activities or about having a professional geologist speak to a classroom, contact the Oklahoma City Geological Society, 227 W. Park Ave., Oklahoma City, OK 73102, (405) 236-3436; or James R. Chaplin, Oklahoma Geological Survey, 100 E. Boyd, Room N-131, Norman, OK 73019, (405) 325-3031.

OU Geology Library's Carolyn Powell Receives Outstanding Staff Award

Carolyn Powell, library technician at the University of Oklahoma's Laurence S. Youngblood Energy Library (usually called "the Geology Library"), is this year's recipient of the University Libraries' "Outstanding Classified Staff Award."



Carolyn Powell, left, and Geology Librarian Claren Kidd.

The Geology Library, in the Sarkeys Energy Center, houses the collections of the Oklahoma Geological Survey and is jointly supported by the OGS and the University of Oklahoma. It contains almost 100,000 cataloged volumes, 146,000 map sheets, and 279,800 Oklahoma well-completion cards.

Carolyn has worked in this library throughout her 38 years with the University of Oklahoma Libraries, and has received certificates of honor signed by four of the seven university presidents during that time. She has worked with four different geology librarians, and was in charge of the library for several extended periods.

"Users appreciate her substantial knowledge of the formats and organization of the geoscience books, journals, maps, completion cards, and electronic media," Geology Librarian Claren Kidd wrote in her letter of nomination for the award.

Carolyn has attended several computer-training courses to improve her ability to use the library's computer technology, and also has taken classes in Russian, German, and Spanish to help her understand the literature written in those languages that the library holds.

Carolyn plans and supervises the activities of the library's student assistants. She also initiates and carries out projects that benefit library users, including adding bibliographic records of the library's maps to their entries in the online catalog. "Her attention to detail in these projects, and in all her work, is outstanding," Claren's nomination said.

Congratulations, Carolyn! We're happy to be able to work with you!

NEW OGS *Publications*

CIRCULAR 102. *Proceedings of the 34th Forum on the Geology of Industrial Minerals, 1998,* edited by Kenneth S. Johnson. 364 pages, 50 contributions. Paperbound. Price: $15.

In May 1998, Norman, Oklahoma, was the host city for the annual Forum on the Geology of Industrial Minerals, a conference that addresses issues involved in the exploration, evaluation, and development of deposits of such nonmetallic resources as cement, stone, gypsum, sand, gravel, salt, granite, and iodine.

The 1998 meeting, organized and supported by the Oklahoma Geological Survey, the U.S. Geological Survey, the Oklahoma Department of Mines, and the Oklahoma Mining Commission, drew 177 representatives from industry, government, and academia.

Contained in this volume are 45 papers and 5 abstracts based on 32 talks and 18 posters contributed to the meeting. Papers are organized into the following categories: Oklahoma, Arkansas, Kansas, Colorado and Wyoming, Gulf of Mexico, other states, United States and general topics, marketing and transportation, international, and presentations as abstracts.

Volume editor Kenneth S. Johnson, associate director of the OGS, served as the general chair of the meeting. This was the second forum chaired by Johnson and cohosted by the OGS; the first was held in Norman in May 1977. The proceedings of that meeting were published as OGS Circular 79, *Thirteenth Annual Forum on the Geology of Industrial Minerals.*

SPECIAL PUBLICATION 99-1. *Two and Three-Dimensional Seismic Methods: Effective Application Can Improve Your Bottom Line,* by Deborah K. Sacrey and others. 84 pages. Bound in 3-ring notebook. Price: $14.

Most areas of Oklahoma are "friendly" to seismic data, and as a result, both structure and stratigraphy can be studied by seismic methods—a real boon to those involved in petroleum exploration and production in the State. But seismic studies are expensive and costs can vary greatly depending on the type of seismic data being provided, the area worked, and many other factors. Two-dimensional (2-D) seismic costs can run upwards from $700 per line mile, while some three-dimensional (3-D) work can be as much as $50,000 per square mile. It would help anyone considering such an investment in data to have some understanding of seismic procedures and their applications.

To address this issue, the Oklahoma Geological Survey, in cooperation with the Petroleum Technology Transfer Council (PTTC), presented a workshop in Oklahoma City on July 29, 1999. Contained in SP 99-1 is the material covered in this workshop. The workshop and book are part of a series designed to provide information and technical assistance to small oil and gas operators.

The material is geared toward people who do not specialize in seismic work, and who may come from a nontechnical background. The book introduces geophysical theory, explains the differences between 2-D and 3-D seismic information, looks at a number of specific examples from Oklahoma, and examines the economics and methods of acquiring seismic data. The publication contains more than 100 figures, including some full-color illustrations.

The authors of the publication are Deborah K. Sacrey of Auburn Energy in Houston; Raymon L. Brown, OGS geophysicist; Bob Springman, an independent geophysicist from Oklahoma City; George Burris, Morris E. Stewart Oil Company, Oklahoma City; and Ernie R. Morrison of the Kansas Geological Survey in Wichita, Kansas.

SPECIAL PUBLICATION 99-2. *Petroleum Core Catalog, Oklahoma Geological Survey—September 1999*, compiled by Water C. Esry and Larry T. Austin. 295 pages. Price: $13 for paper copy; data also available on 3.5-in. floppy disks for $13.

Listed in this catalog are the petroleum cores, the largest and most-used group of materials contained in the OGS Core and Sample Library. The library, established in 1936 by Robert H. Dott, former director of the OGS, is used by petroleum company personnel, geoscientists, and students throughout the United States.

The petroleum group consists of cores from more than 4,400 wells drilled in Oklahoma, contained in an estimated 113,904 boxes. This information has been computerized and incorporated in the Natural Resources Information System (NRIS) of Oklahoma, which is a group of interrelated data bases that together provide a wide range of information on the State's oil and gas resources. NRIS is being constructed to respond to the growing need for access to information on the State's natural resources.

The petroleum core data base presented in this catalog consists of information on section, township, range, well location, county, operator, well name and number, formation name, cored depth interval, "catalog" interval number, number of boxes, diameter of the core, condition, representation, total feet cored, average feet per box, and the library file number.

Although not included in the Petroleum Core Catalog, the library also contains samples (well cuttings) and nonpetroleum cores related to coal, minerals, and special stratigraphic studies. These items are listed in a separate card file at the library.

SPECIAL PUBLICATION 99-3. *Geological Perspectives of Reservoir Engineering: A Waterflood Workshop*, by Kurt Rottmann. 101 pages. Bound in 3-ring notebook. Price: $10.

This volume presents the material covered in a one-day workshop held by the Oklahoma Geological Survey in cooperation with the Petroleum Technology Transfer Council on October 20, 1999.

Designed to acquaint geologists and engineers with the geological pitfalls that can jeopardize the potential success of a waterflood candidate, the workshop was geared toward regional producers, many of whom are on a limited budget and are producing oil from old fields in an era of depressed prices.

The workshop and publication address how to answer these fundamental questions: Is there enough oil to make a waterflood project profitable, and approximately how much oil will be produced from secondary recovery? The workshop volume contains 148 figures, including numerous relevant mathematical formulas.

"Geologists must have a basic knowledge of a reservoir's rock and fluid properties for three reasons: First, to be able to do an initial evaluation of a reservoir's primary and secondary reserve potential; second, to be able to communicate with the engineering department about the rock and fluid properties of a waterflood candidate; and third, to understand how those properties affect the origination, migration, and entrapment of hydrocarbons," says Kurt Rottmann. Rottmann was the coordinator and principal presenter of the workshop, as well as the main author of the publication.

David R. Crutchfield, a consulting petroleum reservoir engineer in Oklahoma City, assisted with the workshop and also contributed to the publication.

The workshop on geological perspectives of reservoir engineering complemented a waterflooding workshop held last year. That workshop addressed the topics of determining reservoir data, deciphering production data, determining and isopaching net pay, sand geometry boundaries, coring and core results, distinguishing natural and induced fractures, water-supply evaluation, and permitting. (The workshop publication, OGS SP 98-3, is still available.)

Rottmann, a consultant geologist based in Oklahoma City, also was a presenter at several of the workshops on fluvial-dominated deltaic oil reservoirs held by the OGS from 1995 to 1997.

SPECIAL PUBLICATION 99-4. ***Morrow Gas Play in the Anadarko Basin and Shelf of Oklahoma***, by Richard D. Andrews. 133 pages. Paperbound. Price: $18.

Based on an entirely new study, this publication contains the material covered in a workshop held on Nov. 10, 1999, by the OGS in cooperation with the Petroleum Technology Transfer Council. It includes regional maps of various Morrow sandstone zones from the upper Morrow chert conglomerate in the deep basin to the more shallow lower Morrow and Primrose sandstones along the eastern and northern play boundaries. Other regional materials include shelf-to-basin cross sections, a map showing fields that have production from the Morrow Formation, a Morrow structure map, and a production allocation map based on current stratigraphic interpretions by IHS Energy Group in Oklahoma City.

The report also features three field studies that represent typical Morrow parameters. It contains photos of Morrow core along with interpretations of important reservoir characteristics and environments of deposition.

Richard D. Andrews, the author of the publication and principal presenter, also was a presenter for the workshop on the Hartshorne gas play last year and for a number of workshops on fluvial-dominated deltaic oil reservoirs. Walter J. Hendrickson of the IHS Energy Group also contributed to the workshop and publication.

The Morrow gas play workshop and publication are part of a continuing series that provides information and technical assistance to Oklahoma's oil and gas operators.

OGS Circular 102, SP 99-1, SP 99-2, SP 99-3, and **SP 99-4** can be purchased by mail from the Survey at 100 E. Boyd, Room N-131, Norman, OK 73019; fax 405-325-7069. To mail order, add 20% to the cost for postage, with a minimum of $1 per order.

All OGS publications can be purchased over the counter at the OGS Publication Sales Office, 1218-B W. Rock Creek Road, Norman; phone (405) 360-2886, fax 405-366-2882.

Notes ON NEW PUBLICATIONS

Summary of Floods in the United States, January 1992 through September 1993

Edited by C. A. Perry and L. J. Combs, this water-supply paper contains a summary of the flooding in the upper Mississippi and Missouri River basins during the spring and summer of 1993 and 36 articles describing severe, widespread, or unusual flooding in the United States from January 1, 1992, to September 30, 1993. Each article in the 286-page publication includes one or more maps showing the general area of flooding and the sites for which data are presented, and most articles include tables that compare the described flood with past floods. The article on Oklahoma pertains to floods on May 8–14 and September 25–27 and was written by D. M. Walters and R. L. Tortorelli.

Order W 2499 from: U.S. Geological Survey, Information Services, Box 25286, Federal Center, Denver, CO 80225; phone (303) 202-4210. Cost is $18, plus $3.50 per order for handling.

National Water Summary on Wetland Resources

Compiled by J. K. Fretwell, J. S. Williams, and P. J. Redman, this 431-page National Water Summary on Wetland Resources documents wetland resources in the United States. It presents an overview of the present status of knowledge of wetlands—what they are, where they are found, why they are important, and the controversies surrounding them, with an emphasis on their hydrology. The six-page section on Oklahoma wetland resources was written by B. D. Jones.

Order W 2425 from: U.S. Geological Survey, Information Services, Box 25286, Federal Center, Denver, CO 80225; phone (303) 202-4210. Cost is $49 , plus $3.50 per order for handling.

Bibliography Pertaining to the Ozark Mississippi Valley-Type Metallogenic Province, Missouri, Arkansas, Kansas, and Oklahoma, USA, Covering 1785 to February 1998

Compiled by Craig McClung, Dorinda Bair, and David Leach, this 84-page USGS open-file report also is now available on CD-ROM.

Order OF 98-0238 from: U.S. Geological Survey, Information Services, Open-File Reports, Box 25286, Federal Center, Denver, CO 80225; phone (303) 202-4210. Cost is $21.25 for a paper copy, $5 for microfiche, or $32 for a CD-ROM (order OF 98-0238-B), plus $3.50 per order for handling.

Hydrogeology and Water Quality of the North Canadian River Alluvium, Concho Reserve, Canadian County, Oklahoma

C. J. Becker prepared this 27-page report in cooperation with the Cheyenne and Arapaho Tribes of Oklahoma.

Order OF 97-0657 from: U.S. Geological Survey, Information Services, Open-File Reports, Box 25286, Federal Center, Denver, CO 80225; phone (303) 202-4210. Cost is $5 for a paper copy and $5 for microfiche, plus $3.50 per order for handling.

OGS to Host Workshop on Coalbed Methane

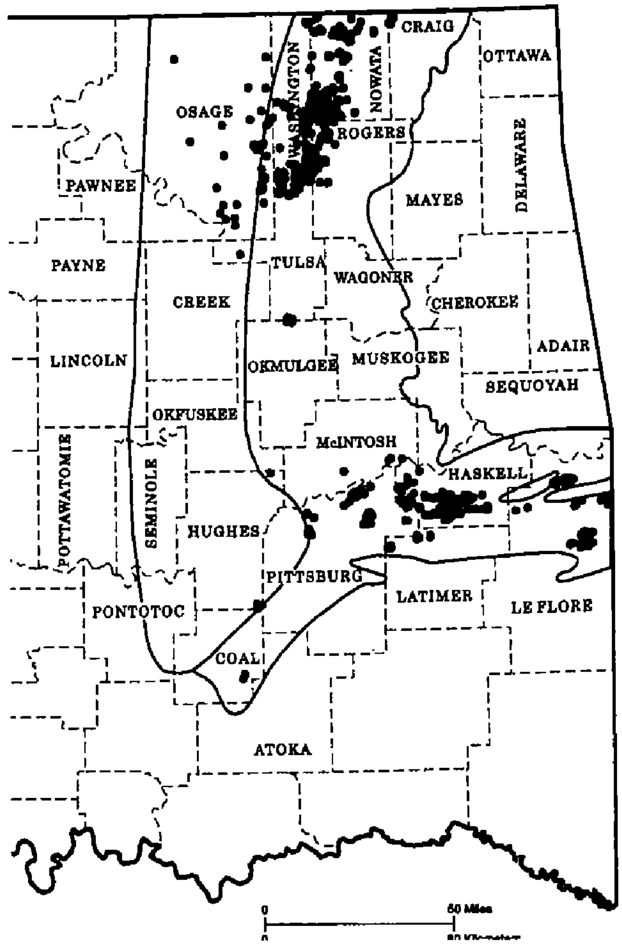
The Oklahoma Geological Survey, in cooperation with the Petroleum Technology Transfer Council (PTTC), will present "Oklahoma Coalbed-Methane Workshop," a day-long program, on Dec. 1 at the Moore-Norman Technology Center, 4701 12th Ave. N.W., in Norman.

The workshop will present both an overview of coalbed methane and applications to the Oklahoma coal field. The overview will address a wide range of topics on the unique properties of coal as a source rock and a reservoir for natural gas, including: how gas is generated and stored in coal; the influence of rank, water, and mineral matter, and how to estimate the gas content.

Applied topics include: a history of the coalbed-methane industry in Oklahoma; how natural fractures in the Oklahoma bituminous coal control permeability; an evaluation of favorable completion techniques; and factors that determine an economic prospect.

Topics and presenters include:

- Changing perceptions of coalbed methane, David Hill, Gas Research Institute, Chicago, Ill.
- Coalbed methane producibility model, Andrew R. Scott, Bureau of Economic Geology, Austin, Tex.
- Effects of coalbed-reservoir property analysis methods on gas-in-place estimates, Charles Nelson, Gas Research Institute, Chicago, Ill.
- Coalbed methane activity in Oklahoma, Brian J. Cardott, OGS
- Oklahoma coal cleat, Samuel A. Friedman, OGS (retired)
- Coalbed methane completion practices in Oklahoma, Brad Wilkins, Wilkins Engineering, McAlester, Okla.



Coalbed methane completions in Oklahoma.

- Economic analysis of coalbed methane from the Hartshorne coal, Arkoma basin, Oklahoma, Matthew A. Biddick, Fractal Oil Company, Norman, Okla.

The registration fee for the workshop is $35. The cost includes lunch, breaks, and a copy of the workshop publication, *Oklahoma Coalbed-Methane Workshop* (OGS Open-File Report 6-99).

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

The Oklahoma Geological Survey thanks the American Association of Petroleum Geologists and the Geological Society of America for permission to reprint the following abstracts of interest to Oklahoma geologists.

Removed Overburden and Maturation Analysis of the Arkoma Basin and Ouachita Foldbelt, Oklahoma and Arkansas

GARY LAWYER, Consultant, St. George, UT; and *ALAN P. BYRNES*, Kansas Geological Survey, 1930 Constant Ave., Lawrence, KS 66047

Removed overburden analysis and calculations of thermal maturity, using burial and thermal history reconstruction, were performed for 115 wells across the Arkoma Basin and Frontal Ouachita Foldbelt. Results indicate that maturity in this region can be explained using models that are largely controlled by depth of burial and paleo-geothermal gradients similar to present-day gradients. Increasing maturation from west to east across the basin can be explained by increasing Atokan and Desmoinesian strata overburden and subsequent Mesozoic and Cenozoic surface erosion and does not appear to be due to Mesozoic intrusions or hydrothermal fluid migration. Removed overburden increases from 5,000 ft on the north flank of the basin to 15,000 ft along the southern basin axis. As much as 25,000 to 40,000 ft have been removed from the core of the Ouachita Foldbelt. Analysis indicates that most of the basin is over-mature for oil production from intervals below the Spiro Sandstone except to the north and northwest on the Oklahoma Platform. Except for the basal Arbuckle Group, all formations were immature prior to burial by northeastward prograding depocenters of Mississippian- and Morrowan-age sediments in the Ouachita Foldbelt of Oklahoma and by the Atokan- and Desmoinesian-age sediments over most of the Arkoma Basin. In most areas, strata entered the oil generation window during or immediately after Atokan deposition. In most areas, these same strata entered the dry gas window with 1 to 10 million years after onset of oil generation. Producing gas appear to have been emplaced as oil, cracked to gas, and trapped during this brief time period.

Reprinted as published in the American Association of Petroleum Geologists *1999 Annual Convention Official Program*, v. 8, p. A78.

Submarine Channel Sandstones in the Jackfork Group—SE Oklahoma

DAVID A. PAULI, Weyerhaeuser Mineral Resources, Federal Way, WA 98003

The Jackfork Group in SE Oklahoma consists of over 6,500 feet of sedimentary rocks that have historically been interpreted as deep marine turbidites deposited in a distal submarine fan setting. Jackfork sedimentary features such as Bouma cycles, sole markings and trace fossils have previously been used to infer a turbidite origin. An eastern sediment source for the Jackfork has been interpreted from paleocurrent data and the presence of proximal submarine fan facies (i.e., submarine channels) in Arkansas.

Less well-documented are the presence of thick submarine channel facies in the Jackfork Group in SE Oklahoma. Sand-rich submarine channel sandstones are exposed in Oklahoma in the Lynn Mountain Syncline, well beyond the distal submarine fan facies proposed in older depositional models for the Jackfork sedimentary sequence.

They consist predominantly of friable, medium-grained quartz arenite. Sedimentary features include both tabular-planar and trough-like crossbedding, ripple bedding, scoured contacts, and southward-directed paleocurrent indicators. Sole marks are rare and Bouma cycles are absent.

A revised depositional model is proposed for the Jackfork Group. The model incorporates the presence of proximal submarine fan facies in SE Oklahoma and a significant northern sediment source.

In outcrop, Jackfork submarine channel sandstones appear to have good reservoir potential. The Jackfork currently produces natural gas from channel sandstones and other submarine fan facies in the Frontal Ouachita Thrust Belt in Latimer County, Oklahoma.

Reprinted as published in the American Association of Petroleum Geologists *1999 Annual Convention Official Program*, v. 8, p. A105.

Simple-Shear Conjugate Rift Margins of the Argentine Precordillera and the Ouachita Embayment of Laurentia

WILLIAM A. THOMAS, Dept. of Geological Sciences, University of Kentucky, Lexington, KY 40506; and *RICARDO A. ASTINI*, Cátedra de Estratigrafía y Geología Histórica, Universidad Nacional de Córdoba, Av. Vélez Sársfield 299 C.C. 395, 5000 Córdoba, Argentina

The Argentine Precordillera rifted from the Ouachita embayment of Laurentia during Early Cambrian time. In plate reconstructions, the western margin of the Precordillera is conjugate to the Ouachita rift margin of the Texas promontory of Laurentia, and the northern Precordillera shares the Alabama–Oklahoma transform margin with the Ouachita embayment of Laurentia. Subsidence profiles demonstrate post-rift cooling, and contrasts in subsidence history between the conjugate margins are consistent with low-angle simple-shear rift models.

Along the Ouachita rifted margin of the Texas promontory of Laurentia, a narrow zone of transitional crust, a lack of synrift rocks, and a thin passive-margin succession (which rests with local paleotopographic relief directly on basement) indicate slow and limited post-rift subsidence, characteristic of the upper plate above a low-angle detachment. Stratigraphic data from the western Precordillera suggest more extensive synrift sediment accumulations and document a thick passive-margin succession, indicating more rapid and relatively greater post-rift subsidence than along the Ouachita margin of Laurentia. Passive-margin deposition began in latest Early Cambrian time around the Precordillera, but it did not begin before latest Middle Cambrian time around the Ouachita embayment. The earlier beginning and greater magnitude of post-rift subsidence of the Precordillera are consistent with thinner, more extended continental crust and early cooling characteristic of a lower-plate margin.

A locally thick carbonate succession along the Southern Oklahoma (transform) fault system reflects initial thermal subsidence followed by load-induced subsidence in response to dense synrift mafic rocks emplaced at shallow crustal levels along a leaky transform. Similarities of Lower Cambrian strata in the northern Precordillera and the Birmingham graben (southern Laurentia) suggest comparable locations adjacent to opposite sides of the Alabama–Oklahoma transform fault. A Middle Cambrian change in stratigraphic polarity in the Precordillera carbonate shelf suggests an initial north-to-south gradient away from the northern transform boundary followed by an east-to-west gradient over the extended crust of the lower-plate western rifted margin of the Precordillera.

Reprinted as published in the Geological Society of America *1998 Abstracts with Programs*, v. 30, no. 7, p. A-175.

Cambrian Rifting and Subsequent Structures in Eastern Texas

WILLIAM A. THOMAS, Dept. of Geological Sciences, University of Kentucky, Lexington, KY 40506; and *G. RANDY KELLER*, Dept. of Geological Sciences, University of Texas at El Paso, El Paso, TX 79968

The margin of Precambrian continental crust (Laurentia) in eastern Texas was originally framed by a Cambrian rift (Ouachita rift). An early stage of Mesozoic rifting that led to opening of the Gulf of Mexico followed approximately the same rift outline. The Cambrian rift ends northward at the Alabama–Oklahoma transform fault, outlining the Ouachita embayment in Precambrian crust. Crustal structure models show an abrupt boundary between continental crust and transitional to oceanic crust along the transform. Adjacent to the Cambrian continental margin (Ouachita rift) in eastern Texas, the post-rift thermal subsidence history of the Texas promontory of Laurentia is consistent with an upper-plate setting in a simple-shear low-angle detachment model for continental rifting. Such a setting has specific implications for crustal structure which can be tested by models based on a compilation of geological and geophysical data. Although available data outline the general structure of the rifted margin, more specialized geophysical surveys are needed to confirm structures of sub-regional scale. Important outstanding questions include (1) the magnitude of rift-stage faults; (2) possible fault reactivation that might have affected Cambrian-Ordovician passive-margin carbonate deposition; (3) possible reactivation or inversion of rift-stage faults during the late Paleozoic Ouachita orogeny, both beneath the Ouachita allochthon and in the Fort Worth basin and Llano uplift of the Ouachita foreland; (4) and reactivation or reuse of Cambrian rift-stage faults during Mesozoic extension. Cambrian rift-stage structures in basement (upper crust) rocks probably controlled subsequent compressional and extensional structures and related sedimentary accumulations. Resolution of the history of these structures has important implications for exploration targets throughout the Paleozoic and lower Mesozoic stratigraphy of eastern Texas.

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An Integrated Geophysical and Geological Analysis of Lithospheric Structure Across the Southern Margin of Laurentia

G. RANDY KELLER, Dept. of Geological Sciences, University of Texas at El Paso, El Paso, TX 79968; *W. A. THOMAS*, Dept. of Geological Sciences, University of Kentucky, Lexington, KY 40506; and *KEVIN L. MICKUS*, Dept. of Geography, Geology, and Planning, Southwest Missouri State University, Springfield, MO 65804

The southern margin of Laurentia was created by Neo-Proterozoic to Cambrian age rifting. The resulting continental margin was relatively stable until the Ouachita-Appalachian orogeny which involved a complicated series of collisional events followed by Mesozoic rifting. However, in the case of the Ouachita region, this margin is well preserved since the orogeny did not pervasively deform it. We have compiled geological and geophysical data along the Ouachita portion of this margin and have created updated models of lithospheric structure across and along it. One model starts on the craton in Tennessee, crossing the Black Warrior foreland basin, the Ouachita thrust belt, the Mississippi salt basin, and the Wiggins arch before ending in the Gulf of Mexico. The most prominent features on this model are the crustal-scale block associated with the Wiggins arch and the crustal thinning under the Mississippi salt basin. Another N–S trending model, located to the west of the first, shows another crustal scale block which

extends across much of western Louisiana. On both of these models, the continental margin is narrow, suggesting the presence of transform faulting. In central Texas, no crustal block is found outboard of the Laurentian margin and the transition from continental to oceanic crust is broad, which may reflect the effects of both Cambrian and Mesozoic rifting. The cratonal region adjacent to the margin has been significantly deformed, creating large structures such as the Southern Oklahoma aulacogen, the Reelfoot rift, and a series of foreland basins, all of which represent significant modification of the crust. In spite of subsequent events, it seems clear that the formation of the Laurentian margin created the structural framework of the region that has lasted to the present.

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Pennsylvanian Incised Valley-Fill Systems of the Southern Midcontinent

ARTHUR W. CLEAVES, School of Geology, Oklahoma State University, Stillwater, OK 74078

Incised valley-fill systems preserved in the Pennsylvanian stratigraphic record of the southern Midcontinent furnish striking evidence as to the significance of glacial-eustatic sea level change in generating siliciclastic reservoir facies. In North-Central Texas, 29 of 30 major upper Desmoinesian through Virgilian cyclic genetic units contain incised valley-fill accumulations within the outcrop zone. Many of these fluvial systems have been directly superimposed on highstand river-dominated, wave-modified delta lobes. Individual channels are typically comprised of large-scale, trough cross-bedded chert-arenite conglomerate. They were components of a sediment transport pathway less than 100 km long. An uncertain, but probably similar, proportion of age-equivalent Oklahoma fluvial-deltaic complexes have also been modified by lowstand fluvial incision of the coastal plain and shelf followed by transgressive systems tract backfilling of the stream valley. Few of these deposits are chert-rich, however, because they lacked a short-distance sediment dispersal system emanating from the Ouachita Mountains, as is seen farther to the south in Texas. Sediment dispersal systems for the Bartlesville, Red Fork, Prue, and Tonkawa sandstone units all had a northerly, cratonic source area more than 400 km distant from the principal deltaic depocenters.

The pattern of forced regression noted on the Eastern Shelf of the Midland Basin likely involved the basinward extension of one or more distributaries in the youngest active lobe of a given highstand delta system. Headward erosion of the trunk stream into the alluvial fan apron fringing the Ouachita Mountains gave rise to a short-distance dispersal system that transported conglomeratic detritus out onto the exposed lowstand shelf, but not as far as the delta plain of perched, lowstand delta lobes. The feeder channel that connected the two deltaic fairways down cut to adjust for the higher gradient, thus converting a highstand distributary into an incised-channel system of the lowstand coastal plain. Oklahoma short-distance sediment dispersal systems equivalent to those in North-Central Texas include the Calvin Sandstone and the Seminole Formation of the Arkoma Basin.

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Structural and Stratigraphic Transect Across the Arkoma Foreland Basin of Western Arkansas

ERIC W. JAMISON, JAMES SLOAN, and *DOY ZACHRY*, Dept. of Geosciences, University of Arkansas, Fayetteville, AR 72701

The Arkoma foreland basin of western Arkansas is an east-trending feature that lies between the Ozark uplift to the north and the Ouachita orogenic belt to the south. It is

characterized by an asymmetric sedimentary fill of Paleozoic age that ranges in thickness from less than 1,000 meters at the northern margin to over 7,000 meters adjacent to the Ouachita Mountains, a distance of approximately 80 kilometers. Surface structures include east-trending normal faults and poorly defined folds in the northern part of the basin and tight asymmetrical anticlines separated by broad open synclines in the southern part.

Four seismic lines and 85 mechanical logs were used to construct a north to south cross-section across the axial region of the Arkoma basin. Prominent seismic reflectors correlated with well log data allowed the subdivision of the Arkoma succession into six seismic units, four of which are basin wide. The basal unit includes mainly carbonate strata from Cambrian to Mississippian in age and rests directly on a basement of Precambrian igneous rock. Successive seismic units include the Morrowan (Pennsylvanian), and the lower, middle and upper parts of the Atoka Formation.

East-trending normal faults displaced early and middle Paleozoic strata of the basal seismic unit initiating basin subsidence. The faults developed in progression from south to north successively effecting sediment dispersal patterns in strata of Morrowan, early Atokan and middle Atokan age. Maximum subsidence occurred during middle Atokan time, accommodating over two kilometers of sandstone and shale. Subsidence and accumulation of large volumes of sediment continued into late Atoka time but normal faulting ceased. North-verging thrust faults caused by orogenesis in the Ouachitas displaced Pennsylvanian strata in the southern part of the basin. Large, asymmetrical anticlines with vertical or overturned northern limbs were produced as surface and near surface expressions of the thrusts. Middle Atoka sandstone and shale units from slope and basin environments were moved northward and positioned adjacent to sandstone units from coastal environments.

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Stable Isotope Geochemistry of Quartz Veins and Their Metasedimentary Host Rocks from the Paleozoic Ouachita Orogenic Belt, Arkansas and Oklahoma

IAN J. RICHARDS, Stable Isotope Laboratory, Dept. of Geological Sciences, Southern Methodist University, Dallas, TX 75275; *JEFFREY B. CONNELLY*, Dept. of Earth Sciences, University of Arkansas–Little Rock, Little Rock, AR 72204; and *ROBERT T. GREGORY*, Stable Isotope Laboratory, Dept. of Geological Sciences, Southern Methodist University, Dallas, TX 75275

Oxygen isotope analyses of quartz veins from within the metasedimentary rocks of the Ouachita orogenic belt provide an opportunity to study fluid-rock interaction associated with deformation and low-grade regional metamorphism. Vein quartz spans a range in $\delta^{18}O$ values from 16.3 to 26.4‰ (SMOW). Coexisting host rocks span a slightly broader range with $\delta^{18}O$ values between 13.2 and 27.9‰. Vein quartz-host rock $\Delta^{18}O$ fractionations are near 0 in chert, novaculite and siliceous shale, are typically +2 to +3 in sandstone and shale and are +6 in some sandstones where veins are associated with euhedral quartz crystals. At the outcrop scale (a few m), independent of vein orientation or relative age, quartz is extremely homogeneous in composition with traverses along and across veins (up to 20 cm in size) exhibiting less than 0.4 ‰ variation. Within large (greater than 200 m) continuous outcrops, bedding perpendicular, parallel and oblique veins are much more uniform (range of 1‰) than their host rocks (range of 3‰). This same relationship also exists on a much larger scale (100's km), where the same lithology within individual formations usually has a 5‰ range in $\delta^{18}O$ values, while the veins

in this lithology only have a 3‰ range. Oxygen isotope data from both regional- and local-scale fault zones indicates that faults were not sites of large-scale focused fluid flow, as quartz vein–host rock relationships within fault zones are the same as those in less deformed rocks away from the faults. Quartz vein–host rock oxygen isotopic systematics indicate that the fluid flux rate was low relative to the chemical and isotopic reaction rates. This implies that the rocks had limited permeabilities such that fluid movement was on the scale of 100's of m and not several km. Thus, there was only limited flow of fluids during deformation and low-grade regional metamorphism, with vein formation occurring as a result of local advection and diffusion of fluids.

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Sequence Stratigraphy and Depositional Dynamics, Atoka Formation (Middle Pennsylvanian), Southern Ozarks, Northeastern Oklahoma and Northwestern Arkansas

EDWARD J. VALEK and *WALTER L. MANGER*, Dept. of Geology, University of Arkansas, Fayetteville, AR 72701; *T. A. (MAC) McGILVERY* and *DANIEL L. PEARSON*, Phillips Petroleum Corp., Bartlesville, OK 74004

Deposition of the Atoka Formation (Middle Pennsylvanian) in the northern Arkoma Basin and adjacent shelf is characterized by an alternation of sandstones and shales. The sequence represents successive packages of fluvial-deltaic systems that prograded and aggraded across the Arkoma shelf just prior to, and during its flexural down bending into the Arkoma foreland basin. Sand-rich facies are attributed to channel and delta front subenvironments and mud-rich facies represent delta plain interdistributary bay and marine shelf settings. The distinction between the two mud-rich facies is made on the basis of color, palynofacies, and lateral persistence. Composite deltaic systems are constructive and coalesce along strike yielding an apparent sheet-like geometry. High frequency sequences within these complexes are the result of the interplay between sediment supply, autocyclic lobe switching and tectonic subsidence. Genetic stratigraphic sequences are bounded by maximum flooding surfaces defined by black, prodeltaic shales in outcrop and high gamma-ray log signatures in the subsurface. Correlation of outcrops along the northern Arkoma Basin linked to log motif in wells from producing gas fields to the south provides an outstanding surface-subsurface analog for application of high frequency sequence stratigraphy and recognition of productive, sand-rich depositional facies.

Reservoir quality is preserved in sandstone intervals that possessed high initial porosities related to the energy of their environmental setting. Traps are either stratigraphic or anticlines resulting from normal faulting. The Atoka Formation is internally sourced from shales that produce mostly dry methane.

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Microfacies Analysis of Early Pennsylvanian Microproblematica *Donezella* Bioherm

SUK-JOO CHOH, Dept. of Geological Sciences, University of Texas at Austin, Austin, TX 78712

Donezella emerged as an important bioherm builder in the middle Carboniferous, after the demise of many Cambrian to Devonian reef-building algae such as the *Epi-*

phyton–Renalcis assemblages. The biologic affinity of *Donezella* is still poorly understood. It was considered to be a rhodophyte, chlorophyte, codiacean, or an encrusting foraminifera. *Donezella* is capable of building small, oncoid-type colonies as well as spectacular carbonate buildups more than 30 m thick and 200 m long.

The primary objective of this study is to provide a detailed petrographic and sedimentologic analysis of *Donezella*-bearing formations by means of microfacies analysis. This will allow recognition of the specific depositional environments and an understanding of the mechanism of *Donezella* carbonate buildup development.

Four stratigraphic sections from the Wapanucka Formation (southeast Oklahoma), Marble Falls Formation (central Texas), and Magdalena Formation (west Texas) will be investigated. In order to aid the rapid determination of the microfacies, a new method of digitizing thin sections is being developed. Integration of microfacies analysis and meter-scale shallowing-upward cycle analysis allows for detailed interpretation of depositional environments of *Donezella* bioherms and associated facies.

Initial results from the Wapanucka Formation indicate that the *Donezella*-bearing interval is generally underlain by open marine, siliceous spicule-rich microfacies and overlain by shoal and lagoonal deposits. This may indicate that *Donezella* probably occupied a facies belt between the open marine and shoal area near the carbonate platform margin.

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Sequence Stratigraphic Significance of Meter-Scale Shallowing-Upward Cycles, Wapanucka Formation (Morrowan), Oklahoma

SUK-JOO CHOH and *BRIAN E. LOCK*, Dept. of Geology, University of Southwestern Louisiana, Lafayette, LA 70504

Detailed petrographic studies of 370 hand specimens and 400 thin sections from two measured sections through the Wapanucka Formation permitted recognition of nine microfacies. These have been interpreted in terms of water depth during deposition, and multiple meter-scale shoaling-upward cycles were identified. Cycles range from 30 cm to 6 m thick, and include environments from open shelf, through oolite shoals to back-shoal/lagoon. Each cycle terminates with an abrupt return to relatively deeper water.

The two measured sections are both within the northernmost thrust sheet of the Frontal Ouachitas, near Hartshorne. They are about 15 km apart, and are essentially along depositional strike from one another. Based on one-dimensional cycle analysis, one pronounced cycle boundary is correlated between sections with confidence. Section A contains 20 meter-scale cycles, averaging 1.4 m thick, with 7 cycles below and 13 cycles above the correlation surface. Section B comprises 18 meter-scale cycles, averaging 2.4 m in thickness, with 8 cycles below and 10 cycles above the correlation surface.

The principal concern of this study was to determine whether the individual meter-scale cycles and microfacies could be correlated from section to section. Presence of nearly equal number of cycles in both sections suggests the possible near equivalency of individual cycle. A few short concealed intervals may explain the slight difference in cycle numbers. Lateral facies and thickness variations clearly occur, and individual cycles may be locally absent due to non-deposition or erosion. The Wapanucka meter-scale cyclicity might be explained by eustatic control or lateral migration of local environments.

Reprinted as published in the American Association of Petroleum Geologists *1999 Annual Convention Official Program*, v. 8, p. A24.

Blind-Thrust Spiro Play—A Case History, Western Arkoma Basin, Oklahoma

CURTIS L. DITZELL, Ocean Energy Inc., 410 17th St., Suite 1400, Denver, CO 80202, and *DOUGLAS B. OSTBY*, Barrett Resources Corp., 1515 Arapahoe, Suite 1000, Denver, CO 80202

This paper presents a case history of the in-fill development of a portion of the Hartshorne South gas field (100+ Bcf), located in the western Arkoma Basin of southeastern Oklahoma, USA. Development primarily targets the Basal Atoka "Spiro" sandstone where thrust faulting compartmentalized the Spiro into separate, gas-charged reservoirs at 12,000′ to 15,000′. Having no surface expression, the "blind thrusted" Spiro fault blocks require detailed subsurface imaging to identify and define drilling targets. Although the Hartshorne South gas field was successfully developed during the mid 1980s to early 1990s using 2D seismic for structural imaging, the increased subsurface illumination of a 50 square mile 3D seismic survey was required to locate the undrilled and potentially undrained structures targeted by our in-fill development program.

Interpretation of the 3D volume, integrated with well control and production performance data, identified a previously untested structure that, due to its structural orientation, was largely invisible to the existing, predominately north-south oriented, 2D seismic data. Amplitude analysis, of reservoir continuity, aided in the selection of a drill site at the optimum structural location. The Barrett Resources Watts Ranch #1-25 wellbore successfully encountered a productive and originally pressured "blind-thrust" Spiro reservoir.

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An Economic Evaluation of the Hartshorne Coalbed Methane Play in Oklahoma

MATTHEW A. BIDDICK, Fractal Oil Co., 330 W. Gray, Suite 305, Norman, OK 73069

The effort to produce coalbed methane (CBM) from the Hartshorne coal in the Arkoma Basin of Oklahoma may or may not make economic sense. Geologic, technical, and serendipitous factors must be matched to have a profitable CBM well.

CBM production in Oklahoma began in 1926 with documented production in Pittsburgh and Haskell Counties. Modern CBM production as a result of concerted efforts began in 1988 at the Kinta anticline in Haskell County. Since then, more than 250 wells have tested the profitability of Hartshorne CBM production. Some of the best wells have produced at rates in excess of 200 MCFGPD for over a year. Rates of 25 to 75 MCFGPD are more common. The effort at the Kinta Anticline has been a commercial success, however, certain unique attributes of the coal and the operator, Bear Productions, Inc., were present. Since 1988, Bear Productions has produced in excess of 4 BCFG from 54 wells with current production in excess of 1,000 MCFGPD. The more recent CBM projects are probably still in the process of "paying out" with a distinction drawn between projects (multi-section, multi-wells) and "hit and miss" efforts (perforating the coal when a good show is observed). In 1998 for the first time in Oklahoma, a few horizontal holes have been drilled into the Hartshorne coal with some good and some poor results. Horizontal drilling may be the future of Oklahoma CBM.

The Arkoma Basin's ample endowment of CBM resources has attracted an initial investment. Has "scratching the surface" determined it is wise to "plunge in"?

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Oklahoma Coalbed Methane: From Mine Explosion to Gas Resource

BRIAN J. CARDOTT, Oklahoma Geological Survey, 100 E. Boyd, Room N-131, Norman, OK 73019

Once an explosion hazard in eastern Oklahoma underground coal mines, coalbed-methane (CBM) has become a valuable resource. Mine explosions from gas and dust caused more than 500 deaths in mining disasters from 1885–1945. There have been more than 600 CBM completions in Oklahoma since 1988.

CBM well information is in the coalbed-methane completions table of the Oklahoma Coal Database. Each record in the table includes the operator, well name, completion date, location information (township grid system and latitude-longitude), county, coal bed, producing depth interval, initial potential gas and produced-water rates, and comments. A searchable version of the table is available as a link from the Oklahoma Geological Survey web page.

The CBM play began in 1988 with 7 wells in the Hartshorne coal bed at depths of 611–716 ft. A maximum of 68 wells were drilled in 1992, followed by a decline to 26 wells in 1994. Through 1993, CBM production was exclusively from the Arkoma basin. Activity on the northeast Oklahoma shelf began with 3 wells in 1994. More than 140 CBM wells were drilled in 1997, of which more than 100 were on the shelf. Since 1988, depths of producing intervals ranged from 216–1,689 ft on the shelf to 598–3,748 ft in the basin. Initial potential gas rates ranged from a trace to 125 thousand cubic feet of gas per day (MCFGPD) on the shelf and from a trace to 595 MCFGPD from a horizontal CBM well in the basin.

Low initial gas rates and minimal initial increase in gas production during dewatering are often attributed to formation damage caused by well stimulation, including the generation of coal fines that plug permeability. Present industry emphasis is on matching the completion technique to the specific coal bed.

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Coal Geology and Underground-Mine Degasification Applied to Horizontal Drilling For Coal-Bed Methane

SAMUEL A. FRIEDMAN, Oklahoma Geological Survey, 100 E. Boyd, Room N-131, Norman, OK 73019

In eastern Oklahoma's Arkoma Basin in 1998 at least three energy companies drilled coal-bed methane wells 700–2,000 feet deep that eventually penetrated 700–800 feet horizontally into the 4–6-feet-thick Hartshorne coal, but also drilled through shale, mudstone, and interlaminated shale and sandstone. Those well segments in shale and mudstone may collapse, leading to well abandonment. Obviously coal will not be penetrated if the bit drifts into strata overlying or underlying the coal bed. Coal may be missing if the bit intersects a normal fault, a thick non-coal parting, or a channel-fill sandstone.

Coal geology studies, including coal characterization *before* drilling begins, should help in lease selection and hold down costs. Also, data should be tabulated and maps constructed showing net coal-bed thickness, cleat frequency and orientation, coal-bed structural contours, faults and secondary coal fractures, cleat-filling minerals, coal-rank isocarbs, inherent moisture, vitrinite reflectance, and lithology of strata overlying or underlying the coal bed. Most of these items, in addition to the laws of gas movement, affect or control the permeability and porosity of the coal-bed methane reservoir and the flow of gas to the well.

Twenty-three horizontal, open-hole, experimental boreholes 300–2,200 feet long, were drilled by a coal company into the 4-feet-thick Hartshorne coal in an underground mine in Oklahoma in the middle 1970s, removing great quantities of 97%-methane gas without hydraulic fracturing.

Therefore, detailed geological evaluation combined with information from the history of horizontal drilling to drain gas from coal beds in underground mines, should be applied to maximize success in coal-bed methane drilling, production, and profit.

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Reservoir Characterization Integrating Sequence Stratigraphy, Neural Networks, and Production Data in Red Oak Gas Field, Arkoma Basin, Oklahoma

TERRILYN M. OLSON, Amoco Production Co., P.O. Box 4381, Houston, TX 77210; *DONNA S. ANDERSON*, Colorado School of Mines, Golden, CO 80401; and *STANLEY W. KLEINSTEIBER*, Amoco Production Co., P.O. Box 4381, Houston, TX 77210

New techniques from various disciplines can be used to improve our ability to characterize hydrocarbon reservoirs. Some common problems in building geologic models to be used in reservoir modeling are addressed by techniques from sequence stratigraphy, artificial neural networks, and production decline type curve analyses. Integrating results from these applications provides a useful model of reservoir architecture and plumbing systems. These techniques are illustrated with data from Red Oak Gas Field in the Arkoma Basin of Oklahoma. Production comes from deep marine Red Oak formation sandstones of highly variable reservoir quality.

Correlations based on stratigraphic sequences form the basis for determining flow units and predicting lateral sandstone connectivity. Permeability is predicted from well logs (gamma ray, induction, and density curves) using neural networks. These predictions are compared with kh from production decline type curve analyses; resulting values are displayed with the sand body correlations to illustrate permeability connectivity. Cross sections can now be constructed that illustrate permeability connectivity, flow units, appropriate model layers, and stratigraphic barriers. Maps and, ultimately, 3D models show the distribution of reservoir and non-reservoir lithologies as well as lateral reservoir connectivity.

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