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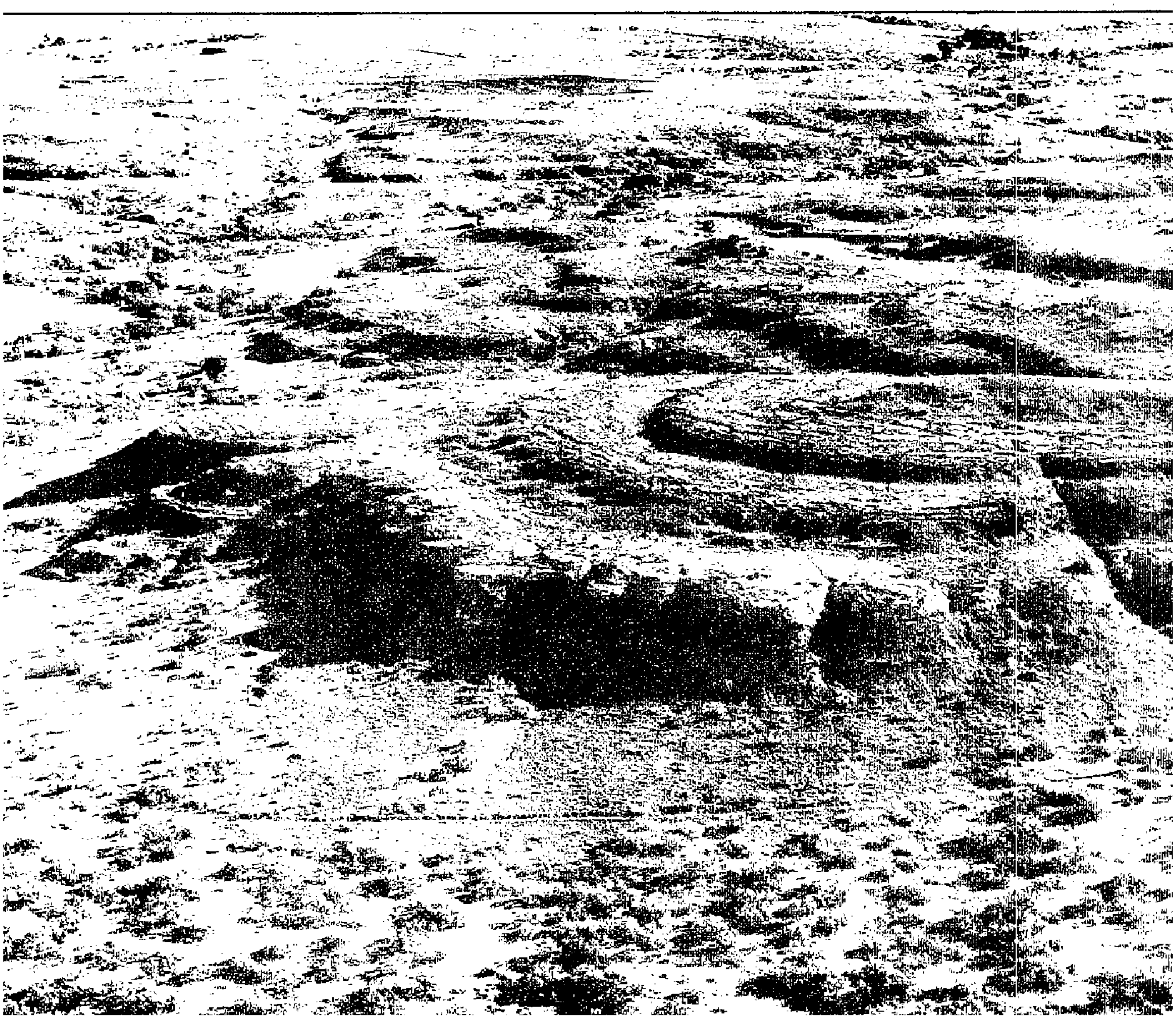

On the cover—

Permian Beds of Gypsum and Shale

Aerial photograph showing outcrops of scarp-forming Permian gypsum beds of the Blaine Formation in southwestern Oklahoma. Three benches, each capped by white gypsum beds 15–25 ft thick, are conspicuous in the central part of the photo. Gypsum beds are interbedded with red-brown shales, each 10–15 ft thick, and they overlie ~150 ft of red-brown Flowerpot Shale in the escarpment. The scarp face, located in sec. 19, T. 8 N., R. 21 W., Beckham County, is ~60 ft high: view looking to the northeast.

The Blaine Formation and Flowerpot Shale are widespread evaporite and red-bed units in western Oklahoma and adjacent parts of Texas and Kansas. The Blaine gypsum beds are mined for making wallboard, plasters, and portland cement at about 14 open-cut mines in western Oklahoma. The Flowerpot Shale is mined at two places, for making brick and for lining earthen pits of waste-disposal facilities; the Flowerpot also is the host rock for a hazardous-waste disposal facility in northwestern Oklahoma.

Kenneth S. Johnson
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OKLAHOMA GEOLOGICAL SURVEY

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OKLAHOMA GEOLOGY

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OKLAHOMA
GEOLOGICAL
SURVEY

VOL. 53, NO. 5

OCTOBER 1993

MOUNTAINS, STREAMS, AND LAKES OF OKLAHOMA[1]

Kenneth S. Johnson[2]

Introduction

Mountains and streams define the landscape of Oklahoma. The mountains consist mainly of resistant rock masses that were folded, faulted, and thrust upward in the geologic past (Fig. 1), whereas the streams have persisted in eroding less-resistant rock units and lowering the landscape to form broad valleys, hills, and plains throughout most of the remainder of Oklahoma (Fig. 2). All the major lakes and reservoirs of Oklahoma are man-made, and they are important for flood control, water supply, recreation, and generation of hydroelectric power. Natural lakes in Oklahoma are limited to oxbow lakes along major streams and to playa lakes in the High Plains region of the west.

Mountains

The three principal mountain systems (Wichitas, Arbuckles, and Ouachitas) occur in southern Oklahoma, although other mountainous and hilly areas extend across many parts of the State (Fig. 2). Oklahoma's mountains result from geologic processes that acted upon the State in the past, and they are very important areas because they expose much of the mineral wealth needed for the State's growth and industrial development. Areas to be discussed in this section are the Wichita, Arbuckle, and Ouachita Mountains, and mountains of the Arkansas Valley, followed by discussions of the Ozark Plateau, Glass Mountains, and Black Mesa.

Wichita Mountains

The Wichita Mountains in southwest Oklahoma (Figs. 1,2) consist mainly of granite, rhyolite, and other igneous rocks emplaced during the Cambrian Period of geologic time, about 525 mya (million years ago). They are flanked, on the northeast, by thousands of feet of folded and steeply dipping marine limestones and other sedimentary rocks deposited during Late Cambrian and Ordovician time (515–425 mya). The mountains were created during the Pennsylvanian Period (330–290 mya) due to 20,000 ft of local uplift of the Earth's crust; the uplift was accompanied by weathering and erosion, so the mountains probably never towered more than 3,000–5,000 ft above the surrounding plains and seaways that had covered Oklahoma. At present, the relief (the difference in elevation between hilltops or mountain summits and the nearby lowlands or valleys) generally ranges from 400 to 1,100 ft, and the highest elevation is about 2,475 ft above sea level on an unnamed

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[1]Reprinted, and expanded, from *Oklahoma Almanac, 1993–1994,* Oklahoma Department of Libraries, p. 554–557.

[2]Oklahoma Geological Survey.

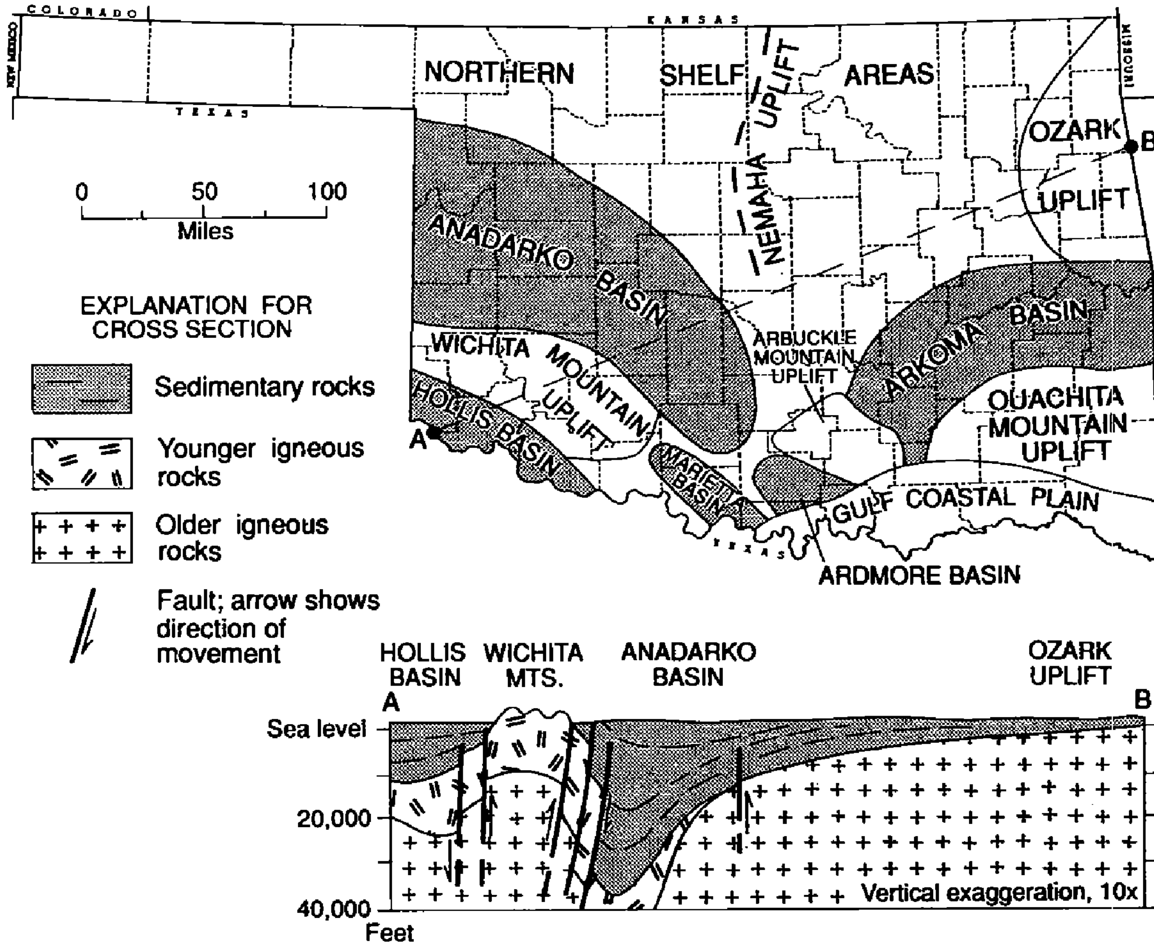
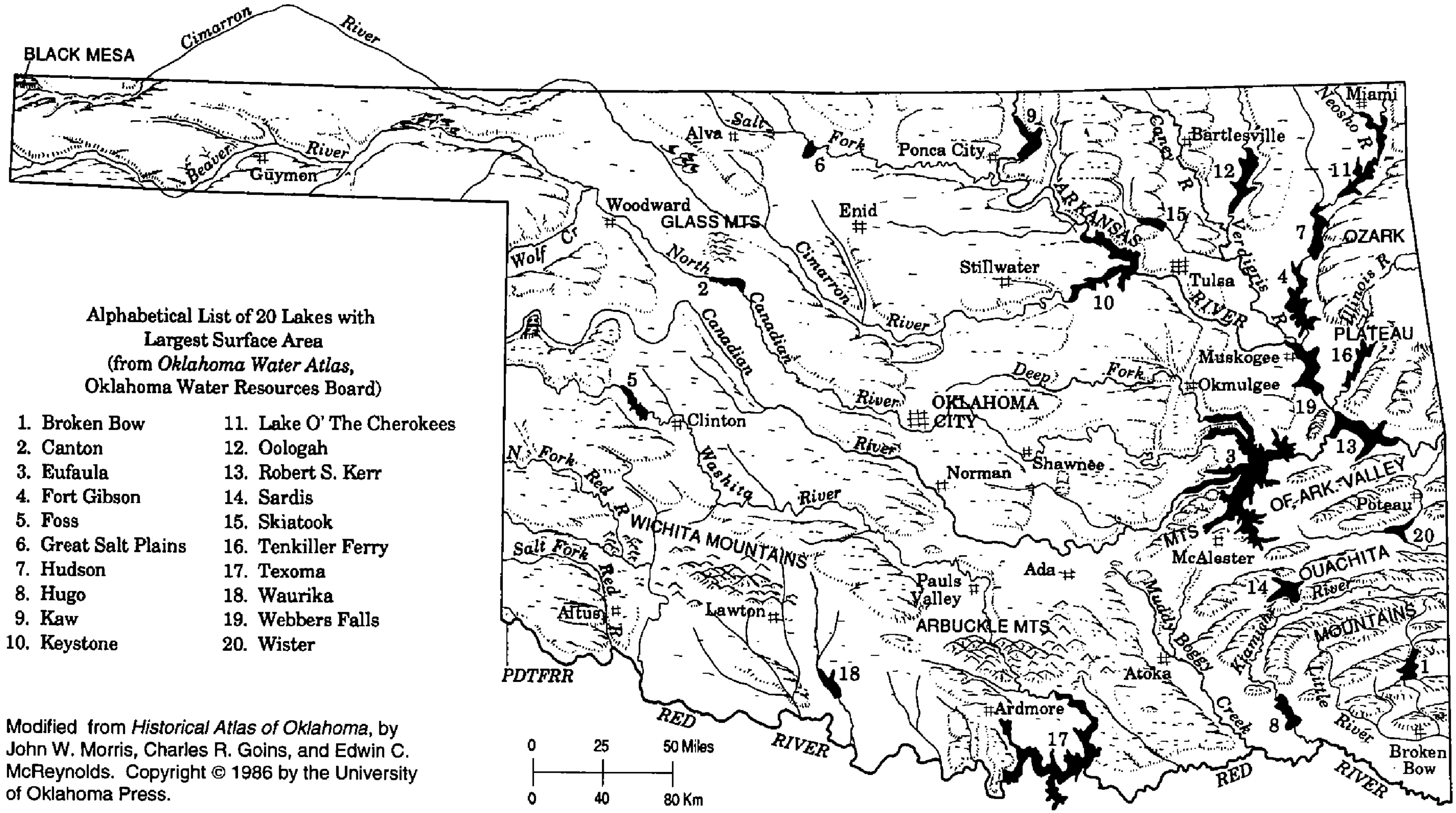


Figure 1. Major geologic provinces of Oklahoma.

peak 4 mi east–southeast of Cooperton. Mt. Scott is the best-known peak; its summit (2,464 ft), which can be reached by car or bus, commands the most spectacular view of the Wichita Mountains. Much of the mountain area is in the Wichita Mountains National Wildlife Refuge and the Fort Sill Military Reservation; other significant sites in the Wichitas are Quartz Mountain State Park and Great Plains State Park. Important mineral resources produced in the area are granite, limestone, and sand and gravel. The mountains have been prospected (with only limited success) for gold, silver, copper, lead, zinc, aluminum, and iron ores; oil and gas have been produced from sedimentary rocks that surround the mountain area.

Arbuckle Mountains

The Arbuckle Mountains are an area of low to moderate hills in south-central Oklahoma (Figs. 1,2). They contain a core of Precambrian granite and gneiss formed about 1,300 mya; in the western Arbuckles, Precambrian rocks are overlain by at least 5,000 ft of Cambrian rhyolites formed about 525 mya. Most of the Arbuckles consist of 15,000 ft of folded and faulted limestones, dolomites, sandstones, and shales deposited in shallow seas from Late Cambrian through Pennsylvanian time (515–290 mya). Folding and uplift of the mountains occurred during several mountain-building episodes in the Pennsylvanian Period. The complex mountain



Modified from *Historical Atlas of Oklahoma*, by John W. Morris, Charles R. Goins, and Edwin C. McReynolds. Copyright © 1986 by the University of Oklahoma Press.

Figure 2. Mountains, streams, and principal lakes of Oklahoma.

area probably was never more than several thousand feet above the surrounding plains and seaways. Relief in the area now ranges from 100 to 600 ft, and the highest elevation, about 1,415 ft, is in the West Timbered Hills, about 9 mi west–southwest of Davis. Although the relief in this mountain area is low, it is still impressive because it is six times greater than any other topographic feature between Oklahoma City and Dallas, Texas. Two significant features in the mountains are the deep road cuts on Interstate 35, and the "tombstone topography." The road cuts are as much as 156 ft deep and provide spectacular exposures of rock units that are of strong interest to geologists, partly because they yield great amounts of oil and gas and other mineral and water resources throughout the southwestern United States. "Tombstone topography," which looks like rows of tombstones in a field, results from differential weathering and erosion of alternating layers of hard and soft limestone. Important scenic sites in the Arbuckle Mountains are the Chickasaw National Recreation Area, Turner Falls, Price Falls, and the Arbuckle Wilderness Park. The Arbuckles contain the most diverse suite of mineral resources in Oklahoma: limestone, dolomite, glass sand, granite, sand and gravel, shale, cement, iron ore, lead, zinc, tar sands, and oil and gas; all these minerals are, or have been, produced.

Ouachita Mountains

The Ouachita (pronounced "Wa-she-tah") Mountains of southeast Oklahoma and western Arkansas make up an arcuate belt of forested mountain ridges and subparallel valleys (Figs. 1,2). The Ouachitas are the central part of a great chain of mountains that include the Appalachian Mountains of eastern United States and the Marathon Mountains of West Texas and northern Mexico. Connections between these three exposed mountain systems are buried beneath thousands of feet of younger rock and sediments in the Mississippi embayment (to the east) and Texas (to the south and west). Rocks making up the Ouachitas are mostly thick units of sandstone and shale, with lesser amounts of chert and novaculite (a fine-grained silica rock, like flint), deposited in a deep sea that covered the area from Late Cambrian through Early Pennsylvanian time (515–315 mya). The area was then folded and faulted in such a manner that resistant beds of sandstone, chert, and novaculite now form long, sinuous mountain ridges that tower 500–1,500 ft above adjacent valleys formed in easily eroded shales. The highest elevation is 2,666 ft, on Rich Mountain. Major prominent ridges within the Ouachita system are Winding Stair, Rich, Kiamichi, Blue, Jackfork, and Blackjack Mountains. The Ouachita National Forest covers a large part of the mountain area; other important scenic sites in the Ouachitas include the McCurtain County Wilderness Area, and state parks at Beavers Bend, Hochatown, Pine Creek, McGee Creek, Talimena, and Clayton Lake. Mineral resources that are, or have been, produced in the Ouachitas include limestone, quartzite, sand and gravel, asphaltite, lead, and oil and gas.

Mountains of the Arkansas River Valley

Another group of mountains are scattered in the Arkansas River Valley of east-central Oklahoma (Fig. 2). They include Sans Bois, Cavanal, Sugar Loaf, Poteau, Beaver, Hi Early, and Rattlesnake Mountains, among others, in parts of Le Flore, Latimer, Pittsburg, Haskell, Sequoyah, Muskogee, and McIntosh Counties. The mountains typically are broad features capped by thick and resistant sandstones that stand 300–2,000 ft above the wide, hilly plains formed on thick shale units. These sandstones and shales were deposited in shallow seas and coastal areas that covered eastern Oklahoma in Early and Middle Pennsylvanian times (330–310 mya), and this area was broadly uplifted and gently folded during the Middle and Late Pennsylvanian uplift of the Ouachita Mountains. The largest mountain area is the Sans Bois Mountains, north of Wilburton and Red Oak. The highest summit is Sugar Loaf Mountain, 8 mi east of Poteau; it is 2,568 ft high and rises about 2,000 ft above the surrounding plains. Sites of interest include Heavener Runestone, Wister, Robbers Cave, Arrowhead, Fountainhead, and Spiro Mounds State Parks; also, the Sequoyah Wildlife Refuge at Robert S. Kerr Reservoir. Principal mineral resources of the area are coal, oil and gas, shale, clay, building stone, sand and gravel, and volcanic ash.

Ozark Plateau

The Ozarks of northeast Oklahoma (Figs. 1,2) are best described as a deeply dissected plateau. Bedrock units in the area are mostly flat-lying limestones and cherts deposited in shallow seas during the Mississippian Period (365–330 mya). Southern and southwestern parts of the Ozarks include outcrops of sandstones and shales deposited in shallow seas and coastal areas during Early Pennsylvanian time (330–315 mya); this area embraces the Brushy Mountains or Boston Mountains. Broad and gentle uplifting of the area during, and since, Pennsylvanian time has caused streams to be incised into the bedrock. Relief in the Ozarks typically is 50–400 ft, and the highest elevation, about 1,745 ft, is on Workman Mountain, 8 mi east–southeast of Stilwell. The beauty of the Ozarks and the abundant clear-water lakes have spawned many state parks, including Beaver Spring, Twin Bridges, Bernice, Honey Creek, Little Blue–Disney, Cherokee, Spavinaw, Upper Spavinaw, Snowdale, Salina, Rocky Ford, Sequoyah, Sequoyah Bay, Adair, Cherokee Landing, Greenleaf, Tenkiller, Sallisaw, and Brushy Creek State Parks. Important mineral resources include limestone, shale, cement, tripoli, and sand and gravel; minor amounts of oil and gas have also been produced. In the north is the world-famous Tri-State lead/zinc mining district (in the Miami/Picher area), which led the United States in zinc production almost every year from 1918 to 1945; the last of these mines finally was closed down in 1970.

Glass Mountains

The Glass Mountains are in north-central Major County, about 6 mi west of Orienta, in an area of badlands topography (Fig. 2). Outcropping rocks are red-brown shales and siltstones capped by a bed of resistant white gypsum; all these strata were deposited during the Permian Period (about 270 mya). The red-brown bluffs and slopes are littered with crystals and fragments of gypsum that weather out of the shale. Much of the gypsum looks like glass fragments, and hence the name "Glass Mountains." It is a misnomer to call these "mountains"; they are, however, prominent mesas, buttes, and escarpments. The local relief generally ranges from 150 to 200 ft, and the elevation at the top of the high buttes is about 1,585 ft. The Glass Mountains are a prominent feature of the Blaine escarpment that extends southeast to northwest across northwest Oklahoma. Flat-lying beds of caprock gypsum and underlying shales originally extended far to the north and east, but the

Blaine escarpment is being eroded back to the south and west. Once the protective caprock is eroded, the underlying shale is rapidly worn down into irregular badlands features.

Black Mesa

Black Mesa, in the northwest corner of the Oklahoma Panhandle (Fig. 2), is the highest point in the State; it has an elevation of 4,973 ft. It is not a mountainous area, but is a plateau that rises about 600 ft above the adjacent Cimarron River and North Carrizo Creek. The Oklahoma portion of Black Mesa is 0.5–1 mi wide and 3 mi long; it is the erosional remnant of a finger-like basaltic lava flow extruded from a volcano in southeast Colorado. The lava flow occurred during late Tertiary (Pliocene) time, about 2–4 mya, and it occupied what was then a broad valley. Since Tertiary time, the local topography has been reversed; less-resistant sandstone and shale uplands that were adjacent to the basalt flow have been deeply incised by the Cimarron River system, whereas the resistant basalt, that once occupied a valley, now stands high above the surrounding terrain. Black Mesa and Black Mesa State Park are located 3 mi northwest of Kenton and about 30 mi northwest of Boise City.

Streams and Lakes

The term "stream" refers to any body of running water, great or small (from large rivers down to small rills), that flows under the influence of gravity to progressively lower elevations in a relatively narrow, but clearly defined, channel. Each major drainage system in the State consists of a principal river, with a large number of smaller tributary rivers, streams, and creeks that funnel water to the main river.

Oklahoma's stream systems of today are temporary (in terms of geologic time) as to location and flow rates. In time, the streams will cut deeper and will cut laterally into their banks, their tributaries will erode nearby uplands, and their positions will thereby be shifted. Major drainage systems of today were initiated during the Pleistocene Epoch of geologic time (the last 2 million years, or so). Streams had flowed across Oklahoma for many millions of years prior to that time, of course, but they finally began carving out today's major drainage basins during the Pleistocene. The shifting early positions of these streams within their drainage basins are now marked by old alluvial deposits that were left as terraces, high above the current flood plains, as the streams eroded deeper into the Earth.

The Pleistocene Epoch is characterized as a time of erosion in Oklahoma. Rocks and loose sediments at the land surface have been weathered to soil, and the soil particles are then carried away to the streams. In this way, mountains, hills, and plains are being worn down, and sediment is transported to the Gulf of Mexico or is temporarily deposited on the banks and in the bottoms of streams and lakes. Sand, silt, clay, and gravel deposits associated with Pleistocene and Holocene (the last 10,000 years) rivers and lakes typically are unconsolidated and are 25–100 ft thick. Finding Pleistocene terrace deposits 100 ft to >300 ft above modern flood plains attests the great amount of erosion and downcutting performed by major rivers in the past 2 million years.

All of the major streams in Oklahoma are characterized by broad, sand-filled channels, with the active water courses occupying only a small portion of the river bed or flood plain. These broad, sand-filled channels reflect the large changes in discharge (floods) that have occurred through time. With the development of many man-made dams on the major streams and their tributaries, the frequency and magnitude of flooding is decreasing, causing a gradual stabilization of the active water courses within the broad stream beds.

There are a great many lakes and reservoirs in Oklahoma. Most of them are man-made and were created by constructing dams across streams. They were made mainly for flood control, water supply, recreation, fish, wildlife, and hydroelectric power. Lakes on the Arkansas and Verdigris Rivers also aid in maintaining navigation along the McClellan–Kerr Navigation System. Major lakes in Oklahoma have been constructed by the U.S. Army Corps of Engineers, U.S. Bureau of Reclamation, and the Grand River Dam Authority; other large lakes are owned and operated by various state and federal agencies, by cities, and by other entities. Additionally, a great number of smaller lakes and ponds have been built by farmers and other landowners.

The only natural lakes in Oklahoma are a series of oxbow lakes and playa lakes (Oklahoma Water Resources Board, 1990). Oxbow lakes, which typically are crescent-shaped lakes in abandoned channels (oxbows) of a meandering stream, occur mainly in floodplains of major rivers, such as the Red, Arkansas, Washita, North Canadian, and Verdigris Rivers in eastern and central Oklahoma. Oklahoma has 62 oxbow lakes that cover at least 10 acres, and the largest, near Red River in McCurtain County, is 272 acres (Oklahoma Water Resources Board, 1990).

Playa lakes form in shallow, saucer-like depressions that are scattered across the semiarid High Plains region of northwestern Oklahoma and the Panhandle. They are characterized by internal drainage and have no outflow: they hold water during and after rainy seasons, and most of them lose all their water through evaporation and/or infiltration into the ground. These intermittent or ephemeral playa lakes number about 600 following thunderstorms, but only a few of them last year-round (Oklahoma Water Resources Board, 1990).

Oklahoma is totally embraced within two major drainage basins, the Red and Arkansas River basins (Fig. 2). These two rivers, and their many tributaries, flow into Oklahoma from all six of the State's neighbors; however, all the surface water leaving the State flows into Arkansas, via the Red, Arkansas, and Little Rivers, and Lee Creek. Major rivers and their tributaries flow mainly to the east and southeast across Oklahoma. Among the special aspects of Oklahoma's rivers are its six scenic rivers in the east and the several natural salt plains and saline rivers in the west. The following data on major streams and lakes in the Red and Arkansas River basins are mainly from the Oklahoma Water Resources Board (1990).

Red River Basin

Red River and its tributaries drain essentially the southern third of the State (Fig. 2), and the basin's total drainage area in Oklahoma is about 23,000 mi^2. The westernmost headwaters of Red River is a small tributary (Frio Draw) that begins in eastern New Mexico, about 30 mi south of Tucumcari. The main stem of the river flows across the Texas Panhandle through Palo Duro Canyon, and marks Oklahoma's southern border (517 river-miles long) with Texas. It then flows through Arkansas and into Louisiana, where it joins the Atchafalaya River before entering Atchafalaya Bay and the Gulf of Mexico.

At the southwest corner of Oklahoma, the main stem is called Prairie Dog Town Fork Red River (PDTFRR); 2 mi to the east it is joined by Buck Creek, and from that point eastward it officially is called Red River. Lake Texoma is the only reservoir on the main stem of Red River in Oklahoma: it holds the largest volume of water (>2.6 million acre-ft) in the State, and has the second largest surface area (88,000 acres). The tributaries to Red River have many other important lakes and reservoirs (such as, from west to east, Altus, Foss, Ellsworth, Waurika, Arbuckle, McGee Creek, Sardis, Hugo, Pine Creek, and Broken Bow), and four of them are among the 20 largest lakes in the State (Fig. 2).

Major Oklahoma tributaries to Red River (from west to east) include Salt Fork Red River, North Fork Red River, and Washita River, all of which contribute flow into Lake Texoma (Fig. 2); others are Muddy Boggy Creek, and Kiamichi and Little Rivers. All of these rivers have their own tributary systems, and there are many other rivers and creeks that flow directly into Red River. The lowest elevation in Oklahoma (287 ft) is where Little River enters Arkansas, some 20 mi north of the southeast corner of the State (at the southeast corner of the State, Red River has an elevation of 305 ft).

Arkansas River Basin

Arkansas River and its tributaries drain the northern two-thirds of Oklahoma (Fig. 2), with a drainage area in Oklahoma of nearly 47,000 mi^2. The source of Arkansas River is near the town of Leadville, in the Rocky Mountains of central Colorado. The river flows eastward across southeast Colorado and through western and central Kansas. It then turns southeast, entering Oklahoma in Kay County, north of Ponca City, and crosses northeast Oklahoma to leave the State at Fort Smith, Arkansas. Arkansas River continues southeastward through Little Rock to its confluence with the Mississippi River, which then flows south through New Orleans to the Gulf of Mexico. The river's name is pronounced "Ar-Kansas" in the State of Kansas, but is pronounced "Arkansas" (the same as the State) in Colorado, Oklahoma, and Arkansas.

Much of Arkansas River has a series of locks and dams (McClellan–Kerr Navigation System) that link Oklahoma with barge traffic from the Port of Catoosa (on the Verdigris River, northeast of Tulsa) down to the Mississippi River, and then to ocean-going vessels at New Orleans. Major lakes and reservoirs on the main stem of Arkansas River include (from the southeast): Robert S. Kerr, Webbers Falls, Keystone, and Kaw, each of which is among the 20 largest lakes in Oklahoma. Eufaula Lake, on the Canadian River in eastern Oklahoma, has the largest surface area (105,500 acres) and the second largest volume (>2.3 million acre-ft) in the State. Tributaries to Arkansas River have many other important lakes and reservoirs (such as, from west to east, Canton, Great Salt Plains, Hefner, Overholser, Thunderbird, Carl Blackwell, Hulah, Skiatook, Oologah, Fort Gibson, Hudson, Tenkiller Ferry, and Wister), and 10 of them are among the 20 largest in the State (Fig. 2).

Major tributaries to Arkansas River (from southwest to northeast) include Canadian River, North Canadian River (called Beaver River in the Panhandle, west of Wolf Creek), and Deep Fork, all of which flow into Eufaula Lake (Fig. 2); others are Cimarron, Salt Fork, Caney, Verdigris, Neosho (Grand), and Illinois Rivers. There are tributary systems to each of these rivers, and many other rivers and creeks flow directly into Arkansas River. The lowest elevation along Arkansas River (385 ft) is where it flows into Arkansas at Fort Smith.

Scenic Rivers

Six of Oklahoma's free-flowing streams have such exceptional beauty and recreational value that they have been officially designated as "scenic rivers," protected by the State Legislature. One scenic river is in the Red River system—the upper part of Mountain Fork, which flows into Broken Bow Lake in McCurtain and Le Flore Counties, in the Ouachita Mountains. The other five scenic rivers are in the Arkansas River system, and are located in Adair, Cherokee, Delaware, and Sequoyah Counties, in the Ozark Plateau; they include parts of the Illinois River, and parts of Flint, Baron Fork, Lee, and Little Lee Creeks.

Salt Plains Saline Rivers

Natural dissolution of bedded salt (deposited during the Permian Period, about 270 mya) occurs at shallow depths in several parts of northwest and southwest Oklahoma. The resultant high-salinity brine seeps to the surface, creating a series of small to large, natural salt plains or salt flats in some of the State's rivers. In the Arkansas River drainage, Great Salt Plains on Salt Fork covers about 25 mi^2 and is the largest salt flat. Others in northwest Oklahoma are Big Salt Plain and Little Salt Plain, on Cimarron River, and Ferguson Salt Plain, just north of Watonga in Blaine County. In the Red River drainage, the Chaney, Kiser, and Robinson Salt Plains are on Elm Fork in northern Harmon County, south of Erick. All Oklahoma salt plains, and others along Red River tributaries in Texas, discharge brines to the Arkansas and Red River systems, thus degrading the river waters and making them unusable in parts of western and central Oklahoma. The saline river waters are diluted by freshwater inflow downstream from the salt plains, and thus the water is largely usable for water-supply, livestock, and industrial purposes by the time it reaches Keystone Lake and Lake Texhoma.

References Cited

Morris, J. W.; Goins, C. R.; and McReynolds, E. C., 1986, Historical atlas of Oklahoma: University of Oklahoma Press, Norman.

Oklahoma Water Resources Board, 1990, Oklahoma water atlas: Oklahoma Water Resources Board Publication 135, 360 p.

UPCOMING MEETINGS

New Developments Regarding the K/T Event and Other Catastrophes in Earth History, February 9–12, 1994, Houston, Texas. Information: Lita Holley, Lunar and Planetary Institute, 3600 Bay Area Blvd., Houston, TX 77058; (713) 486-2149, fax 713-486-2160.

Society for Mining, Metallurgy, and Exploration, Annual Meeting, February 14–17, 1994, Albuquerque, New Mexico. Information: Meetings Dept., SME, P.O. Box 625002, Littleton, CO 80162; (303) 973-9550, fax 303-979-3461.

Breakthroughs in Karst Geomicrobiology and Redox Geochemistry, February 16–19, 1994, Colorado Springs, Colorado. Information: Arthur Palmer, Earth Sciences Dept., State University of New York, Oneonta, NY 13820; (607) 436-3064, fax 607-436-2107.

V. E. McKelvey Forum on Mineral Resources, February 22–25, 1994, Tucson, Arizona. Information: Warren C. Day, U.S. Geological Survey, Box 25046, MS 905, Federal Center, Denver, CO 80025; (303) 236-5568, fax 303-236-5603.

Geological Society of America, South-Central Section, Annual Meeting, March 21–22, 1994, Little Rock, Arkansas. *Abstracts due November 30, 1993.* Information: Philip L. Kehler, Dept. of Earth Sciences, University of Arkansas, 2801 S. University Ave., Little Rock, AR 72204; (501) 569-3546, fax 501-569-8020.

19th International Mineral Processing Congress, October 22–27, 1995, San Francisco, California. *Abstracts due December 1, 1993.* Information: Meetings Dept., Society for Mining, Metallurgy, and Exploration, P.O. Box 625002, Littleton, CO 80162; (303) 973-9550, fax 303-979-3461.

Simpson/Viola Workshop Set for March 29–30

The Oklahoma Geological Survey will sponsor a two-day workshop on "Simpson and Viola Groups in the Southern Midcontinent." The workshop will be held March 29–30, 1994, in Norman, Oklahoma, and will have 200–300 attendees.

The Simpson and Viola Groups (Ordovician in age) are major sandstone and carbonate reservoirs that have already yielded large volumes of oil and gas, and they have a great potential for yielding additional hydrocarbons by the use of advanced-recovery technologies. The workshop will present discussions and reports on surface or subsurface studies dealing with the geologic setting, depositional environments, and diagenetic history of these strata and/or reservoirs, as well as reservoir characterization and the engineering factors that influence hydrocarbon accumulation or hydrocarbon production.

If you wish to contribute a paper or poster, please contact Kenneth S. Johnson, Oklahoma Geological Survey, 100 E. Boyd, Room N-131, Norman, OK 73019; phone (405) 325-3031, fax 405-325-7069, as soon as possible.

Geologic Map GM-34. *Pre-Woodford Subcrop Map of the Anadarko Basin, Western Oklahoma and Texas Panhandle,* by Thomas W. Amsden and James E. Barrick. 2 sheets, scale 1:500,000, with accompanying text. Price: $8, folded in envelope.

This report is based on the result of intense drilling in the Anadarko basin during the late 1970s and early 1980s. New core and sample data containing lithostratigraphic and biostratigraphic information on middle Paleozoic strata in the basin indicated the need for some revision of earlier biostratigraphic interpretations, especially for Silurian strata in the western areas. GM-34 includes a pre-Woodford subcrop map and a series of stratigraphic cross sections showing lithology, biostratigraphy, and correlation of the Hunton Group and equivalent rocks throughout the Anadarko basin. The accompanying 20-page appendix includes brief drilling statistics and a summary of the pertinent geological information for the wells which provided the core and/or sample data for the map and cross sections.

Special Publication 93-3. *Guidebook for Selected Stops in the Western Arbuckle Mountains, Southern Oklahoma,* by Brian J. Cardott and James R. Chaplin. 55 pages. Price: $4.

From the authors' preface:

This guidebook has been prepared for the 10th annual meeting of The Society for Organic Petrology (TSOP) field trip to the western region of the Arbuckle Mountains on October 13, 1993. Organic petrology is the branch of earth science dealing with the origin, occurrence, thermal maturity, composition, and utilization of sedimentary organic matter. Organic petrology includes coal petrology, kerogen petrology, organic geochemistry, petroleum geochemistry, palynology, and paleobotany. Therefore, the emphasis of this field trip is the organic petrology of selected rock units in the western Arbuckle Mountains.

The Arbuckle Mountains uplift geologic province, named for Brigadier General Matthew Arbuckle, is located in south-central Oklahoma as part of the Osage Plains of the Central Lowland physiographic province. The formations that comprise the Arbuckle Mountains have been extensively studied for hydrocarbon source rock and reservoir rock characteristics that can be applied to the subsurface in the adjacent Anadarko and Ardmore basins. The western Arbuckle Mountains region is an important petroleum region in its own right. More than 17,000 oil and gas wells have been drilled in each of Stephens and Carter Counties.

Special Publication 93-4. *Hunton Group Core Workshop and Field Trip,* edited by Kenneth S. Johnson. 212 pages. Price: $9.

From the editor's preface:

The Late Ordovician–Silurian–Devonian Hunton Group is a moderately thick sequence of shallow-marine carbonates deposited on the south edge of the North

American craton. This rock unit is a major target for petroleum exploration and reservoir development in the southern Midcontinent. The workshop is being held to display cores, outcrop samples, and other reservoir-characterization studies of the Hunton Group and equivalent strata throughout the region. The field trip is organized to complement the workshop by allowing examination of excellent outcrops of the Hunton Group in the Arbuckle Mountains.

The core workshop and the field trip cover such topics as: petroleum-reservoir characterization; deposition, diagenesis, facies, sequence stratigraphy, paleokarst, and petroleum production; and interpretation of Hunton Group geology based upon petrologic, petrographic, and innovative subsurface studies. To facilitate the exchange of information on these important topics, the Oklahoma Geological Survey (OGS) and the Bartlesville Project Office of the U.S. Department of Energy (BPO–DOE) are co-sponsoring this workshop and field trip. The ultimate goal of this program is to increase activity in the search for, and the production of, our oil and gas resources.

GM-34, SP 93-3, and SP 93-4 can be obtained over the counter or by mail from the Survey at 100 E. Boyd, Room N-131, Norman, OK 73019; phone (405) 325-3031. Add 10% to the cost of publication(s) for mail orders, with a minimum of 50¢ per order.

OKLAHOMA CITY GEOLOGICAL SOCIETY ELECTS NEW OFFICERS

Officers of the Oklahoma City Geological Society for the 1993–94 term are:

President: David G. Bryant, Bryant & Associates

President Elect: Robert A. Northcutt, Consulting Petroleum Geologist

Past President: Thomas E. Davis, Viersen & Cochran

Vice President: William M. Smith, Bracken Energy

Treasurer: Gerard J. Medina, Medina-Pierce Oil and Gas Co.

Secretary: Guy M. Decker, Petrocorp

Library Director: M. Stuart Kirk, Triump Investments

Shale Shaker Editor: Kathleen S. Fowler, Target Reservoir Analysis

1st Presidential Appointee: Lindell C. Bridges, Bogo Energy Corp.

2nd Presidential Appointee: James R. Howell, Independent Geologist

AAPG Delegate: Carroll Kinney, Mewbourne Oil Co.

Midcontinent Representative-at-Large: Kathy Lippert, Southwestern Energy Production Co.

NOTES ON NEW PUBLICATIONS

Water Resources Data—Oklahoma, Water Year 1992

Records on both surface water and ground water in Oklahoma are contained in this two-volume report by R. L. Blazs, D. M. Walters, T. E. Coffey, D. K. White, D. L. Boyle, and J. F. Kerestes. Specifically, it includes (1) discharge records for 136 streamflow-gaging stations and 61 partial-record or miscellaneous streamflow stations, (2) stage and content records for 31 lakes or reservoirs, (3) water-quality records for 50 streamflow-gaging stations, and (4) water-level records for 28 observation wells. Data for the Arkansas River basin are given in volume 1 (524 pages), and data for the Red River basin are given in volume 2 (239 pages).

Significant improvements have been made to the 1992 report. These include:

- Statistics of monthly mean data for the current period of record include the mean flow for the period, and maximum and minimum flow for the period of record, with year of occurrence.
- Summary statistics for all surface-water stations have been expanded. The statistics now include totals for the 1991 calendar year, the 1992 water year, and summary for the current period of record (including only those statistics following streamflow regulation). Statistics prior to regulation are included as footnotes to the table.
- A hydrograph of the current water year has been included, which provides a quick graphic display of data on the facing page.
- Hydrographs for continuous-record ground-water wells have been included. These show a five-year period of record.

Order USGS Water-Data Report OK-92-1 from: U.S. Geological Survey, Water Resources Division, 202 N.W. 66th St., Bldg. 7, Oklahoma City, OK 73116; phone (405) 231-4256. A limited number of copies are available free of charge.

Land-Use and Ground-Water Data, Cheyenne–Arapaho Tribes, Concho Reserve, Canadian County, Oklahoma

The USGS, in cooperation with the Cheyenne and Arapaho Tribes, conducted this study to determine the vulnerability to contamination of ground water beneath tribal lands within the 3,991-acre Concho Reserve in Canadian County, Oklahoma. The report gives the results of field reconnaissance observation, provides a compilation of hydrologic data from USGS files, and includes data on ground-water hydrology and geology of the area within and immediately surrounding the Concho Reserve. Current land use and potential sources of contamination of ground water are identified. Tables of water-quality data from 1943 through 1980 have been compiled from USGS files. This report, by D. L. Bergman and M. E. Savoca, is printed on two sheets at a scale of 1:24,000.

Order OF 93-110 from: U.S. Geological Survey, Water Resources Division, 202 N.W. 66th St., Bldg. 7, Oklahoma City, OK 73116; phone (405) 231-4256. A limited number of copies are available free of charge.

OKLAHOMA ABSTRACTS

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

Plocezyga Microgastropod Biostratigraphy of the Mid-continent Pennsylvanian

JOHN R. ANDERSON, II, Science Dept., Dekalb College, Dunwoody, GA 30338; and DARWIN R. BOARDMAN, II, School of Geology, Oklahoma State University, Stillwater, OK 74078

The microgastropod genus *Plocezyga* has been found to be biostratigraphically useful within the Pennsylvanian, Desmoinesian to Virgilian, strata of the United States. A biostratigraphic zonation of the Pennsylvanian of North-Central Texas was established using first occurrence species-level range zones of the genus *Plocezyga*. This zonation was used to correlate from North-Central Texas into the Appalachian Basin.

Recent work has focused on the Desmoinesian–Missourian boundary of Oklahoma and the Missourian–Virgilian boundary of Kansas. The Desmoinesian–Missourian boundary has been recognized based on the first occurrence of *Plocezyga (P.) costata*. The Desmoinesian strata below the Desmoinesian–Missourian boundary has the assemblage of *Plocezyga* species observed in the Desmoinesian strata of North-Central Texas, whereas the Missourian above the boundary has the assemblage of *Plocezyga* species found in the Missourian of North-Central Texas. Stratigraphically around the Missourian–Virgilian boundary, in Kansas, the first occurrence of *Plocezyga (P.) obscura* has been observed which in North-Central Texas is slightly above the Missourian–Virgilian boundary.

Reprinted as published in the Geological Society of America *Abstracts with Programs, 1993,* v. 25, no. 1, p. 2.

Morphologic Variation, Maturity, and Sexual Dimorphism in an Upper Carboniferous Ammonoid from the Midcontinent

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A collection of sixty-nine well preserved Upper Carboniferous ammonoids belonging to the goniatite genus *Glaphyrites* has been recovered from the Wewoka Formation in Okmulgee County, Oklahoma. This collection contains many mature individuals presenting an opportunity to study mature morphologic variation, modification, and sexual dimorphism in one population.

In addition to standard measurements of conch height, width, diameter, and umbilicus, sections were made to determine body chamber lengths, coiling, and the

possible relationship of shell constriction to sutural approximation. The specimens were also examined for indications of mature modification including the following: changes in coiling, whorl section, ornament, and shell deposition; development of apertural constriction, shell thickening, and peristome; sutural approximation and simplification, thickening of the last septum and the presence of muscle scars.

Six of these mature modifications were observed in the Wewoka population, including septal approximation and simplification, accompanied by thickening of the last septum, muscle scars following the terminal septum, shell constriction, and a change in coiling. A unique type of runzleschicht at the terminal aperture of one of the specimens is of great interest. Here the runzelshicht, a rugose deposit on the dorsal whorl surface, changes from a smooth pustulose pattern into a spiny form pointing toward the aperture. This may be a new form of modification.

Morphologic measurement on specimens displaying mature modifications indicates that there is a wide variation in size at maturity. Thus, sexual dimorphism expressed as micro- and macro-conch variation is not present in this population.

Reprinted as published in the Geological Society of America *Abstracts with Programs, 1993,* v. 25, no. 2, p. 67.

Bryozoans as Epizoans on *Meristella Atoka* (Brachiopoda Athyridacea) from the Haragan Formation (Lower Devonian), South-Central Oklahoma

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Of 1270 specimens of *Meristella atoka* from the Haragan Fm at White Mound (Arbuckle Mountains), 403 are encrusted by 430 bryozoan colonies; 3 common species (*Fistuliporella quinquedentata*-188, *Cyphotrypa corrugata?*-122, *Cyclotrypa mutabilis*-54) and 3 rare species (66) are identified. The spatial distribution of each bryozoan species on *M. atoka* was determined by estimating the percentage of 5 marginal sectors and 1 postero-median sector (of each valve) that is covered by each colony.

These data demonstrate that all bryozoan species considered together: (1) more extensively encrust each of the marginal sectors as compared to the postero-median sector (of both valves), and that this trend is more pronounced on the pedicle valve; and (2) overall less extensively encrust the pedicle valve. These data also yield several species-specific trends. *C. corrugata?* (encrusting sheet-like trepostome) exhibits the most significant preference to more extensively encrust marginal sectors of both valves. *F. quinquedentata* and *C. mutabilis* (dome-like fistuliporoids) exhibit (1) a significant tendency to more extensively encrust marginal sectors of the pedicle valve only and (2) a tendency to more extensively encrust right-hand than left-hand sectors of the brachial valve.

These trends are interpreted to be the result of three interacting factors: brachiopod feeding currents, bryozoan colony form, and brachiopod living orientation.

Bryozoans more extensively encrust marginal sectors adjacent to the commissure to utilize the brachiopod's feeding currents. Thin sheet-like colonies would benefit more than dome-like colonies by being closer to the feeding currents throughout life and thus exhibit greater preference to encrust these sectors. Bryozoans exhibit greater preference to encrust the brachial valve and marginal sectors of the pedicle valve because the adult brachiopod was oriented with the postero-median portion of the pedicle valve resting on the sediment.

Reprinted as published in the Geological Society of America *Abstracts with Programs, 1993,* v. 25, no. 3, p. 14–15.

Possible Ancestor to the Late Carboniferous/Early Permian Teguliferiniid Brachiopods in the Middle Carboniferous of Oklahoma, U.S.A.

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Abundant silicified specimens of a brachiopod characterized by a conical pedicle valve anchored by rhizoid spines and an operculiform brachial valve occur in the Jolliff Formation, in the Ardmore Basin of southern Oklahoma. These brachiopods form small bioherms up to 0.70 m in diameter. The specimens occur in growth position and form closely packed small clusters resting on top of earlier clusters and all are attached by rhizoid spines. The Jolliff Formation is of Middle Carboniferous (Early Pennsylvanian; Morrowan) age, as indicated by the *Idiognathodus sinuosis* conodont zone.

The Jolliff brachiopod species is closely similar to the earliest occurring, typical species of the genus *Teguliferina* from strata of Late Carboniferous (Late Pennsylvanian) in west Texas. The Jolliff form is more primitive and forms the ideal ancestor to the Late Pennsylvanian species. The new fossil occurrence has important evolutionary implications. It is believed to dispell the hypothesis that the appearance of *Teguliferina* in the Upper Pennsylvanian represents an evolutionary punctuation. The apparent absence of such brachiopods in the Middle Pennsylvanian is probably due either to the rarity of shallow reef environments during the cyclic terrigenous deposition that was so widespread or to the incompleteness of the preserved rock record.

Reprinted as published in XI[e] Congrès International de Stratigraphie et de Géologie du Carbonifère Beijing 1987, Compte Rendu, v. 2, 1989, p. 355.

Unembellished Graphic Correlation: An Example from the Ordovician of North America

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The graphic method, as originally described by Shaw, has now been applied in the correlation of Ordovician rocks in sections at 125 localities in the United States and Canada. These sections, related to one another by the well-controlled distribution of 318 species of conodonts, form the basis for a chronostratigraphic framework that currently permits recognition in all major component sections of the equivalents of divisions 6 m thick in the Standard Reference Section. The latter is a graphically assembled composite of long sections in Nevada, Oklahoma, and the Cincinnati Region of Indiana, Kentucky, and Ohio.

To demonstrate the graphic method, correlation of Middle and Late Ordovician rocks in New York, Minnesota, and Tennessee will be illustrated. Sections considered include stratotypes of the 7 or 8 stages into which the Mohawkian and Cincinnatian Series have traditionally been divided. Graphic assembly clearly documents the now well-known overlap between the upper "Trentonian" Cobourgian Stage of New York and strata typical of the Edenian and lower Maysvillian stages in the typical Cincinnatian sequence of Ohio, Indiana, and Kentucky.

Reprinted as published in the Geological Society of America *Abstracts with Programs, 1993,* v. 25, no. 2, p. 82.

Taxonomy, Morphology, and Biostratigraphic Position of Topotype Material of *Cordylodus Proavus* from the Upper Signal Mountain Limestone, Arbuckle Mountains, Oklahoma

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K. J. Müller described the conodonts *Cordylodus proavus* and *C. oklahomensis* in 1959 from material collected at 6, 10, and 20 m below the top of the Signal Mountain Limestone on the Chapman Ranch, Arbuckle Mountains, southern Oklahoma. We resampled these stratigraphic levels from approximately the locality where Müller's material was collected, and we regard our several hundred cordylodan specimens as near-topotype material. Trilobite studies by J. H. Stitt indicate these strata are within the *Missisquoia typicalis* Subzone of the *Missisquoia* Zone. The presence of *Fryxellodontus inornatus* and *Hirsutodontus rarus* in these samples indicate that these strata are referrable to the *F. inornatus* Subzone of the *Cordylodus proavus* Zone. The trilobite and conodont biostratigraphic data are consistent with relationships elsewhere and indicate a level within the lower Ibexian (or Canadian) Series (lowest Ordovician of North American usage) but from below the Tremadocian Series (and thus Cambrian in Acado–Baltic usage). Müller's two species of *Cordylodus* are now considered to be parts of the multielement species *C. proavus,* the name-giver of a biozone that is recognized worldwide.

R. S. Nicoll recently proposed a 7-element apparatus for *C. proavus* that includes M, Sa, Sb, Sc, Sd, Pa, and Pb elements. Our abundant material is slightly older than the samples from Texas studied by Nicoll. Our S elements (Müller's form-species *C. proavus,* or rounded elements in previous multielement usage) are highly variable and are more than three times as common as elements that Nicoll assigns to the Pb position (Müller's form-species *C. oklahomensis,* i.e., compressed elements in previous usage). Most of the S elements are slightly asymmetrical and may have either sharp or rounded anterior edges below the distal half of the main denticle. Also numerous are symmetrical S elements; these also may be sharp or rounded along the anterior edge. We would not distinguish separate Sb and Sd elements as defined by Nicoll. Pa elements (sensu Nicoll) are about ⅓ as common as Pb elements. We found no M elements of the type illustrated by Nicoll for *C. proavus,* and we assume that Nicoll's illustrated specimen is from a younger species. About half of our Pb elements show morphology deemed characteristic of M elements, and if Nicoll's model is assumed, both M and Pb elements can be recognized within the collections at hand. These collections include a few other elements that do not fit any model of *C. proavus,* and the minor presence of aberrant morphotypes or other taxa is a possibility.

Reprinted as published in the Geological Society of America *Abstracts with Programs, 1993,* v. 25, no. 3, p. 68.

Desmoinesian Conodont Biostratigraphy of the Deese Group, Ardmore Basin, Oklahoma

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The Deese Group consists of up to 7,500 feet of interbedded shale, sandstone, thin limestone, and locally thick conglomeratic units overlying the Pumpkin Creek Limestone, the uppermost member of the Dornick Hills Group. Repetitive lithologies within the Deese record episodic basin subsidence and uplift along the basin margin. These events established and controlled the distribution of environments that range from non-marine through marginal-marine to locally more open-marine conditions. Most of the variable lithologic units are unnamed or informally designated. The named members include (in ascending order) Devils Kitchen, Arnold, Rocky Point, Campground, and Natsy. All of the named units are impure limestones except for the Devils Kitchen and Rocky Point, which are locally thick, non-marine, conglomeratic sandstone successions.

165 samples collected from the Pumpkin Creek–Natsy were processed, but only 92 of these yielded conodonts. In general, the carbonate lithologies produced the best faunas. Most samples yielded small numbers, and low diversity faunas characterized by *Cavusgnathus* and *Idiognathodus.* Locally, *Idioprioniodus, Ellisonia, Neognathodus, Hindeodus,* and *Diplognathodus* are present in those samples presumed to represent less-restricted environments.

Three broad, generalized conodont intervals are recognized. The lower interval is characterized by *Idiognathodus delicatus, Neognathodus medadultimus,* and *N. medexultimus.* In the middle interval, carinate platform morphotypes of *I. delicatus,* and *N. roundyi* appear; *N. medexultimus* and *N. medadultimus* are also present. Carinate morphotypes of *I. delicatus* persist into the upper interval, which is distinguished on the basis of the occurrence of terminal *Neognathodus.* Relating these broad subdivisions to previous zonations is difficult. However, the general outline of Merrill zonation can be recognized. In contrast, Deese morphotypes of *Idiognathodus* do not show the ordering of *Idiognathodus* spp. 1–6 established for Desmoinesian cyclothems by Swade.

Reprinted as published in the Geological Society of America *Abstracts with Programs, 1993,* v. 25, no. 3, p. 73.

Middle Whiterockian Conodonts of the Pruitt Ranch Member (Oil Creek Formation), Southern Oklahoma

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The Pruitt Ranch Member, which is exposed in the Criner Hills of southern Oklahoma, consists of 27 meters of fossil-poor, pelsparite and burrowed micrite. It overlies an oolitic facies of the middle Oil Creek Formation and is overlain by fossiliferous limestone assigned to the McLish Formation. The Pruitt Ranch represents a regressive phase of sedimentation during which oolite shoals were overridden by tidal-flat sediments.

Pruitt Ranch conodonts include species of *Leptochirognathus, Parapanderodus,* and *"Scandodus"* which indicate a middle Whiterockian age. Conodont collections recovered from above and below the Pruitt Ranch are more diverse and contain representatives of *Neomultioistodus, Paraprioniodus, Pteracontiodus, Histiodella,* and *Oistodus.*

Conodont frequency and diversity in Oil Creek and lowermost McLish samples reflect changing paleoenvironments. Faunas derived from oolitic and shallow subtidal facies are more diverse and were generated by paleoecologic factors and mechanical transport. The Pruitt Ranch conodont fauna is relatively low in diversity and is probably an accurate representation of the impoverished biocoenosis living in highly stressed, peritidal environments.

Reprinted as published in the Geological Society of America *Abstracts with Programs, 1993,* v. 25, no. 3, p. 5.

Carboniferous Conodont Biofacies and Bizarre Geochemistry

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Perhaps the most strikingly bizarre geochemical signatures that we have seen are in the Carboniferous of central Texas where not fewer than five thin intervals are enriched in iridium to approximately "Gubbio" levels. These intervals contain the other siderophiles in abundance along with rare earths, uranium, thorium, and arsenic. These intervals include the base of the Barnett Shale (Mississippian, Meramecian or Chesterian), near the middle (?) of the Barnett (Chesterian), the very top of the Barnett where it is Mississippian (Chesterian) as well as where it is Pennsylvanian (Morrowan), near the base of the Marble Falls (Morrowan) and the base of the Strawn (Pennsylvanian, Desmoinesian). The thicknesses (up to a metre) and stratigraphically widespread distribution of these geochemical spikes argues that, whatever the ultimate origin of the iridium and its associates may be; cosmic, volcanic, or other, their presence and abundances in these rocks are the result of sedimentary processes. The conodonts indicate quite slow rates of sedimentary accumulation with reduced pH and moderate restriction. Each of the intervals with these

geochemical spikes is rich in glauconite and phosphorite. We have sampled and analyzed other phosphatic and glauconitic rocks from the same interval and region such as the bulk of the Barnett (phosphate only) and limestones in the Strawn (glauconite only) and they contain enrichments in some of the elements listed above, but not iridium and the other platinum group metals; they only occur where both minerals are present. Illinois Basin Pennsylvanian black shales, rich in phosphate but lacking glauconite, also have only parts of the geochemical suite. They are highly enriched in U, Th, Pb, and Zn.

Similar geochemistry has been noted in rocks of other ages. Two deeply weathered clay partings in the Ordovician of Oklahoma (Viola Springs) are rich in phosphate and apparently in glauconite as well and have nearly identical geochemistry to our Carboniferous samples. The famous K-T boundary clay at Gubbio (as well as several iridium-bearing clays below it) has been described as being glauconitic. Our work suggests that it might be phosphatic as well.

Reprinted as published in the Geological Society of America *Abstracts with Programs, 1993,* v. 25, no. 3, p. 67.

A Discussion of the Controversy Surrounding the Depositional Environment and Silica Sources of Novaculite in Arkansas and Oklahoma

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There has been considerable research and speculation concerning the depositional environment and the silica sources of the Arkansas Novaculite in the Ouachita Mountains. Stratigraphically the Arkansas Novaculite conformably overlies the Missouri Mountain Shale and underlies the Mississippian Stanley Shale group, both of deep-marine deposition origin.

Stratigraphic, paleontologic and sedimentologic information described from the literature and field work was compiled to determine the probable depositional environment and silica source for the Lower, Middle and Upper Novaculite for the Broken Bow, Oklahoma and the Magnet Cove, Arkansas regions. Stratigraphic evidence presented by Viele and Thomas (1989, Tectonic synthesis of the Ouachita orogenic belt, *DNAG* F-2) suggest that the Arkansas Novaculite represents a sequence of deep-water marine deposition. Thin sections from samples of Upper Novaculite in the Broken Bow and the Magnet Cove regions were examined for remains of siliceous organisms. Cooper (1931, Jour. Paleo. 5, 142–151), Henbest (1935, Jour. Paleo. 10, 77–78), and many others discovered such fossils as conodonts, graptolites, sponge spicules and radiolaria in all layers of the novaculites from Arkansas to Oklahoma. Extensive alteration and deformation of the region during Late Mississippian to Pennsylvanian time was not conducive to the preservation of radiolaria remains. Although all of these fossils can be found in either shallow or deep marine environments, modern-day radiolaria live only in open ocean environments; graptolites also lived in the open ocean, and conodonts are rarely found in sediments inferred to have been deposited outside of the bathyal zone. Although non-siliceous, the paleoecological range of these fossil conodonts was used to constrain the water depth at which the silica sources for the novaculites were deposited. From this information a paleobathymetry chart of the novaculite taxa was created.

When considering the amount of silica required for deposition of massive and relatively pure silica-rich novaculite the following factors must be taken into account: (1) the source of the silica; (2) the kind of environment that will support silica-based marine life; and (3) the environmental conditions that would account for thick, clean chert beds. Great quantities of silica may be derived from several sources. One source may have been volcanic ash derived from volcanic activity associated with a collision with the suspect clastic wedge. Structural evidence in the Ouachita mountains supports a continent-continent collision and/or island arc subduction involving the continental margin of North America during Late Mississippian, after the novaculite sequence (Thomas, 1989, Appalachian–Ouachita orogenic beneath the eastern gulf coastal plain, *DNAG* F-2). Abundant fossil evidence from the literature suggest that a large portion of the silica may have been provided by graptolites, radiolaria and sponge spicules.

Metamorphic activity was important in converting silica rich sediments to fine grained novaculites. Fossil evidence, the lack of stratigraphic evidence pointing to a shallowing of the sea and subsequent metamorphic activity strongly suggest that the depositional environment for the Novaculite was marine subsequent to deep basin, and the siliceous sediments were subjected to metamorphism producing the novaculite.

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Conodont Biochronology and Its Implications on the Mid-Carboniferous Lithostratigraphy of the Frontal Ouachita Mountains, Oklahoma

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Conodont biostratigraphic data from the Ouachita Mountains indicates Carboniferous lithostratigraphic units are apparently diachronous and time transgressive, although, formation boundaries have been considered both lithostratigraphic and chronostratigraphic. Six conodont assemblages are recognized from the fauna studied in the Ouachitas: two Mississippian (Meramecian?–Chesterian) and four Pennsylvanian (Morrowan–Atokan). The distribution of these assemblages suggests modifications of previous biostratigraphic assignations of the lithostratigraphic units.

Some stratigraphic miscorrelations result from similar facies present in different formations: the Caney, "Springer," and Johns Valley Formations' black shale facies; the "Springer" and Johns Valley Formations' olistostromes; and the Jackfork and Atoka Formations' similar successions of turbidites and shales. Equating the Caney and "Springer" Formations to the chronostratigraphic subdivisions Mississippian and Pennsylvanian is unwarranted because conodont data indicate the Caney Forma-

tion is partly Pennsylvanian. Conodonts recovered from the Johns Valley Formation indicate a Pennsylvanian designation slightly older than workers previously estimated. Lithofacies transition across the frontal Ouachitas is unmistakable in the late Morrowan Wapanucka and early Atokan "Spiro" Formations. Gradation of isochronous Wapanucka limestone to Chickachoc Chert develops southward to Pine Mountain Fault, where pinchout of the "Spiro" sand also occurs. South of this fault the Wapanucka and "Spiro" Formations are no longer recognized and application of the term "Spiro" south of Pine Mountain fault is unjustified. Considering the limited number of depositional settings developed at the mid-carboniferous basin-to-margin transition, lithostratigraphic and chronostratigraphic relationships become more important with increased exploration in the Arkoma basin and Ouachita Mountains.

Reprinted as published in the American Association of Petroleum Geologists, *1993 Annual Convention Official Program*, p. 199.

Lower Ordovician Conodonts of the Mazarn Formation, Ouachita Mountains, Arkansas

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University of Missouri, Columbia, MO 65211

Conodonts from the Mazarn Formation were recovered in outcrops in the Ouachita Mountains of Arkansas (Mount Ida, Crystal Springs, Hamilton, and McGraw Mountain 7.5′ quadrangles). Samples were collected from thin subordinate limestone units, typically interbedded with thick shales and sandstones, interpreted as having been deposited in a slope environment. Little or no stratigraphic context for the samples is available due to poor exposure and the structural complexities of the Ouachita Orogen.

The conodonts obtained from the Mazarn include both North American Midcontinent Province forms and North Atlantic Province forms. The numerically dominant Midcontinent Province species include: *Eucharodus parallelus, Glyptoconus quadraplicatus, Diaphorodus delicatus,* and *Tropodus comptus*. Numerically dominant forms typical of the North Atlantic Province (NAP) include: *Oepikodus evae, Drepanodus arcuatus,* and *Paracordylodus gracilis.* The shallow-water Midcontinent forms probably were carried by turbidity currents to the slope environment where the Mazarn shales were accumulating and interred there with the indigenous deep-water NAP fauna.

The conodonts demonstrate Lower Ordovician (Ibexian/Arenigian) age of the Mazarn. Conodonts allow the Mazarn to be correlated in North America with the Shallow Bay Formation (Cow Head Group; Newfoundland), the Cool Creek, Kindblade, and West Spring Creek Formations (Arbuckle Group; Oklahoma), and the Jefferson City Formation (Missouri). In addition, intercontinental correlations can be made with the San Juan Formation (Argentina), the Horn Valley Siltstone (Australia), and the Djupvik and Kopingsklint Formations (Sweden).

Reprinted as published in the Geological Society of America *Abstracts with Programs, 1993,* v. 25, no. 3, p. 12.

Hydrothermally, Color-Altered Conodonts from MVT Tri-State Mines

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Goebel, E. D., Thompson, T. L., and Waugh, T. C. (1968) reported the conodont biostratigraphic zones of the Tri-State Mississippi Valley Lead and Zinc District of Missouri, Kansas and Oklahoma. Those conodonts were collected from known MVT ore zones principally in the Picher Field.

Work by Rejebian, V. A., Harris, A. G., and Huebner, J. S. (1987) set the standards for conodont color-alteration indices (CAIs) for hydrothermally altered conodonts. Observed color alteration and physical characteristics of the Tri-State Picher Field conodont collections match well with CAI indices of 2 and less. This CAI Range of color alteration is prevalent over much of Missouri and Kansas where trace MVT mineralization occurs in Paleozoic rocks. At some locations CAIs of 3 have been measured. Geothermometric fluid inclusion data on sphalerite from the same host rock specimens that yielded the conodonts in the Picher Field, in general, corroborate CAIs of the ore zone conodonts.

Visitors to this poster session display are invited to view the conodont collection from the mines, as well as selected examples of anamolous CAI occurrences.

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Tri-State Lead–Zinc Mining District of Missouri, Kansas, and Oklahoma

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From 1848 through 1971, when the last mines shut down, the Tri-State Mining District of Missouri, Kansas, and Oklahoma had produced about 12 million tons of zinc and nearly 3 million tons of lead. Although no crude ore tonnages or grade figures are available from discovery (appx. 1850) through 1906, about 2 million tons of zinc and 0.6 million tons of lead were recovered. From the period 1907–1964, average recoverable grade of ore was 2.26% Zn and 0.56% Pb from over 400 million tons of crude ore.

The orebodies occur in Mississippian limestones. Depth to ore-bodies ranges from surface exposures at the eastern end of the district to about 450 ft at the western end, beneath Pennsylvanian-age shales. The mining district occurs where the underlying Devono–Mississippian Chattanooga Shale is absent, and the near-basal Mississippian silty Northview Shale is less than 10 ft thick.

In southwest Missouri, the major sub-districts (i.e., Joplin, Oronogo–Webb City, Alaba–Neck City) appear to be related to northwest structural trends. The largest and richest sub-district, the Picher Field of Oklahoma and Kansas, occurs around the junction of the northwest trending Bendelari Monocline with the northeast–

southwest trending Miami Fault. Farther west, and just north of the Chattanooga Shale pinchout, another large lead–zinc mineralized area exists near Oswego, Kansas. It was prospected by mining companies in the mid-1970's and early 1980's, but has not been mined.

Two types of orebodies occur: (1) the richer, run-type orebodies are in more massive, cherty limestones that have been subjected to fracturing, solutioning, brecciation, dolomitization, and silicification. The highest grade ore is around the dolomite–jasperoid contact; (2) the thin, lower-grade "sheet-ground," or blanket-type, orebodies cover many acres, and dolomite is not a controlling factor. Jasperoid replaces limestone in the thinly interbedded limestone–chert sequence. The ore occurs disseminated in the jasperoid and is in open spaces.

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Influence of Ozark Uplift on Pennsylvanian Sediment Dispersal Patterns

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The Ozark uplift exerted a significant, though mostly passive, influence on sediment dispersal patterns in the midcontinent during the Pennsylvanian. Following withdrawal of shallow marine waters near the end of the Mississippian, the Ozarks remained a low-lying positive element where regional truncation of Mississippian through Cambrian, mostly carbonate strata occurred in a humid, tropical climate that promoted karstification. Chert weathered from the carbonate strata and quartz eroded from thin sandstone formations (e.g., St. Peter) constituted the primary terrigenous clastic sediment derived from weathering of the uplift. With some of this siliciclastic sediment locally trapped in karst depressions, only a modest volume of chert and quartz sand was eroded from the Ozarks and deposited in adjacent basins.

Significant volumes of siliciclastic sediment began entering the midcontinent during early to middle Pennsylvanian, a reflection of tectonic uplift in the central Appalachians (Morrowan and later) and along the Ouachitas (Atokan and later). During the Morrowan, the greatest volume of sand entered the region from the Appalachians and was dispersed southward through the Illinois basin into the Mississippi embayment, with the Ozarks blocking sand dispersal to the west. This dispersal system persisted during the Atokan, and a large volume of sand was also derived from the rising Ouachitas and dispersed westward through the Arkoma basin, with the Ozark uplift acting as the northern margin of the basin. Quartzose sand apparently derived from the craton was deposited along the northwestern margin of the uplift (Forest City basin) during the Atokan.

During the Desmoinesian, the general patterns of sand dispersal established during the Atokan prevailed on all sides of the Ozark uplift. Significantly, Desmoinesian and Missourian sandstones along the northern and western margins of the uplift record a transition from quartzose, craton-derived sands to lithic, orogen-derived sands, indicating that the Illinois basin was overflowing with sediment and

that sand derived from the Appalachians was diverted around the north and west sides of the Ozark uplift. This observation suggests that the southern end of the Illinois basin was no longer open as the primary route of sand dispersal, probably the result of either uplift of the Pascola "arch" or sediment damming caused by influx of detritus from the Ouachita orogen. With continued sediment influx and basin-filling, the Ozark uplift was progressively onlapped during the late Pennsylvanian, but whether the uplift was ever completely buried by Pennsylvanian or younger strata remains unclear.

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In the Absence of a Regional Thermal Gradient, Does the Viburnum Trend Fit into a Common Regional Hydrologic Flow Model with Other Ozark Region MVT Deposits?

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A popular misconception is that a regional thermal gradient (deduced from fluid inclusions in sphalerite) exists among the MVT districts of the Ozark region, apparently linking them to a common regional hydrologic flow model with an Arkoma Basin fluid source. Examination of *all* available data indicates that there is no thermal gradient in the Ozark region MVT deposits.

Means and ranges of T_h data for fluid inclusions in sphalerite from the Northern Arkansas (NA), Tri-State (TS) and Viburnum Trend (VT) districts are statistically indistinguishable from one another. The Central Missouri (CM) district has a narrower range of T_h and is cooler than the other districts. This does not indicate a gradient, but shows that one small district is cooler than three other large MVT districts which formed at similar, higher temperatures.

The values from sphalerite in NA, TS and VT appear bimodal. Unimodal Th values for Cm appear to correspond to the lower T_h mode of the other districts. It is notable that the lower T_h mode for the VT represents Early and Late Stage sphalerite, whereas the higher T_h mode represents Main Stage sphalerite. This pattern illustrates that variations of Th data exist for multiple sphalerite generations within individual districts which may complicate comparisons of Th values among districts and that Main Stage sphalerite of the VT is anomalous and cannot be correlated thermally with other districts, especially CM.

In the absence of a regional thermal gradient in the Ozark region, the most useful tools to link (or separate) MVT districts are geochemical data. There may be a connection among the NA, TS and CM districts, based on similarities of ore and gangue mineralogy and geochemistry, including trace element data for sphalerites, K/Cl and Ca/Mg ratios of inclusion fluids, and lead and sulfur isotopes. Minor, Late Stage mineralization in the Viburnum Trend district also shows geochemical similarities to the other districts. However, predominant, Main Stage mineralization in the Viburnum Trend is anomalous in its mineralogy and geochemistry.

In the absence of a regional thermal gradient, does the Viburnum Trend fit easily into a common regional hydrologic flow model with other Ozark region MVT deposits? No.

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Tectonic History and Analysis of Structures in Eastern Kansas and Western Missouri

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Orogenic events in and around the midcontinent in Proterozoic time were responsible for the formation of the dominant master set of younger northeast- and older northwest-trending faults that dominate the structure of the area today. Reactivation of these faults throughout geologic time gave rise to tectonic zones consisting of sets of anastomosing faults or other complex patterns. These zones are likely important in helping to determine the configuration of major uplifts and basins that involve the crust.

The Nemaha tectonic zone defines the western boundary of both the Forest City and Cherokee basins, while a structural block delineated by the Chesapeake and Bolivar–Mansfield regional faults coincides with the approximate position of the Bourbon Arch, which is reflected in the thickness of Mississippian carbonate rocks.

Rocks of the Ozark uplift began to be uplifted by the end of Maquoketa time. The uplift has historically been described as a landform, rather than a geologic structure. Hence, the extent and the boundaries of the uplift are ill-defined. The northeast-trending line forming the contact between Mississippian and Pennsylvanian rocks is commonly regarded as the western boundary. This boundary coincides with a major tectonic zone, extending northeastward from Oklahoma through Kansas and Missouri into at least southern Iowa. In the Tri-State area of Kansas, Oklahoma, and Missouri the zone is referred to as the Miami trough and features prominently in the localization of major ore deposits. This zone may then also be regarded as the eastern boundary of the Forest City and Cherokee basins.

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Principal Elements of Ozark Uplift During the Pennsylvanian

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The Pennsylvanian history of the Ozark uplift is complex reflecting major late Mississippian or earliest Pennsylvanian reactivation along prominent NW-trending tectonic zones (TZ), followed by regional baseleveling, repeated phases of regional uplift, and a number of lesser episodes of reactivation along principal tectonic zones and intra-zonal faults. Pre-Pennsylvanian baseleveling resulted in a complex paleogeologic substrate.

During the Pennsylvanian, movement along principal tectonic zones defined large elements of Ozark uplift *provisionally* identified as *Trans-Ozark arch; Northeast Missouri graben; Lincoln fold system; St. Francis Mtn. core;* and *Tri-State platform,* incorporating both *Spavinaw arch* and *Arkansas–Missouri shelf/platform.* The suggested definitions and nomenclature follow an important concept developed by Searight and Searight (1961) in a little-publicized paper.

Lincoln fold system may reflect a tectonic zone with its extension to the southeast offset along Cap-Au-Gres fault. *Mississippi River arch* served to link the obliquely faulted northeastern area of the uplift with southwestern elements of Wisconsin uplift. *Spavinaw arch,* including *Seneca fault zone* along its axis, is associated with and may in fact dominate the Tri-State platform. Both became clearly defined during early(?) Atokan time and served to define an eastern boundary of early Desmoinesian Cherokee "basin." *Miami "Trough,"* reflecting a significant NE-trending TZ, bounds Tri-State platform to the west–northwest. *Trans-Ozark arch,* a horst-dominated feature including the area between Bolivar–Mansfield TZ and Grand River TZ, incorporates Central Missouri TZ as the most important of several associated features.

Regional expression of elements of Ozark uplift changed during Pennsylvanian time in the course of successive TR events coupled with the influence of continuing tectonic activity.

The definitions and nomenclature provide for better communication in the suggested resolution of stratigraphic and tectonic problems. Further, the potential for utilization in paleohydrologic and mineral resource studies is anticipated.

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Re-Examination of Models for the Origin of Granite–Rhyolite Provinces in the Midcontinent Region, U.S.A.

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New isotopic data for the 1.47 Ga Eastern Granite–Rhyolite Province and the 1.37 Ga Southern Granite–Rhyolite Province require re-examination of models for the origin of these suites of rock. For the most part, εNd(t) values for the granite–rhyolite provinces and A-type plutons intrusive into adjacent Early Proterozoic basement are compatible with origin through melting of 1.8 Ga continental crust (Nelson and DePaolo, 1985). However, new data (Bowring et al., 1992) show that southeastern parts of the granite–rhyolite provinces yield positive εNd(t) values, which can only be explained by derivation from 1.5 Ga continental crust. The transition from older substrate (1.8 Ga) to younger substrate (1.5 Ga) occurs along a NE–SW line from Detroit, MI to eastern Oklahoma; it probably represents the edge of the pre-1.6 Ga craton. A further variation in εNd(t) data in an E–W trending belt of intermediate values in northern Oklahoma; εNd(t) data south of this belt, in S. Oklahoma, are equivalent to that in Kansas and Nebraska, reflecting ca. 1.8 Ga lower crust.

The granite–rhyolite provinces are not related to any well defined tectonic event, and they have commonly been referred to as "anorogenic." The thermal event re-

sponsible for producing the silicic melts may have been associated with an extensional regime, in view of the A-type character of the granites. However, the 1.5 Ga crust underlying the SE parts of the granite–rhyolite provinces suggests that there may be a 1.5 Ga magmatic arc accreted to the margin of the 1.6 Ga craton. Formation of this arc must have been followed within a few tens of m.y. by a major rise in the geotherm which melted not only its lower crustal regions, but also Early Proterozoic crust throughout the U.S. A similar event must have followed about 100 m.y. later, affecting the south-central region. The intermediate εNd(t) values in Oklahoma may denote an E–W zone of crustal extension in which melts formed from 1.8 Ga crust with a significant contribution from 1.37 Ga mantle-derived magmas (fractional crystallization of mafic magmas at the base of the crust?). The heat for the regional 1.47 Ga magmatism is problematical, but the presence of a continental margin along the SE edge of the craton suggests a tectonic regime similar to that which produced voluminous felsic volcanic suites of the Cordillera (shallow subduction of delamination of continental lithosphere?). Restriction of melting to Early Proterozoic provinces resulted either because the Archean craton was not fertile enough to produce A-type melts, or because a deeper keel to the Archean craton prevented an influx heat.

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2.8–0.57 Ga Individual Detrital Zircons from Carboniferous Rocks of the Ouachita Orogen, Arkansas: A Northern or Southern Source?

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The Late Paleozoic Ouachita orogen developed in response to collision of the North American craton with an unknown, now rifted, land mass. Rocks of the orogen are composed chiefly of synorogenic sediments that were imbricated in northwest vergent thrust sheets. In order to address the question of ages of source rocks, we dated individual zircons from turbiditic sandstones of the Mississippian Stanley Group and from the Pennsylvanian Atoka Formation.

The samples are fine-grained, poorly sorted sublitharenites composed of subrounded quartz, plagioclase, untwinned feldspar, white mica, zircon, titanite, and epidote. Lithic fragments include shale, slate, phyllite, and chert. The heterogeneous color and morphology of extracted zircons implies derivation from multiple sources and their subrounded to well-rounded character suggests a multicycle history.

Zircon U–Pb ages are concordant to moderately discordant. Stanley Group zircons are 0.57, 0.59, 0.92, 0.93, 1.73, and 2.81 Ga whereas those from the Atoka Formation are 1.03, 1.06, 1.08, 1.32, 1.74, 2.50, and 2.75 Ga. These ages are comparable to known U–Pb ages of the North American basement. We note, however, the absence of 1.35–1.40 Ga zircon ages that characterize the midcontinent

Granite–Rhyolite terrain. The range of zircon ages is not inconsistent with derivation from Central American and South American sources, but the lack of well-constrained basement ages in these regions preclude direct correlations.

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Pennsylvanian Tectonic and Depositional History, Southern Ozark Dome, Arkansas and Missouri

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Pennsylvanian strata of the southern Ozarks comprise only the Morrowan and Atokan Series, although beds of Desmoinesian age occur in the Arkoma Basin. Significant, regional unconformities occur at the Mississippian–Pennsylvanian boundary, within the upper Morrowan Series, and at the Morrowan–Atokan boundary.

The Mississippian–Pennsylvanian boundary is an angular unconformity, representing the first loading of the crust by the rising Ouachitas. Beds of the basal Morrowan Series (Hale Formation) onlap progressively older Mississippian (Chesterian) units (Pitkin Limestone or older Fayetteville Shale) from south to north across the southern Ozarks.

An intraformational unconformity occurs in the type Morrowan succession of northern Arkansas at the base of the Dye Member, Bloyd Shale. It is associated with a pronounced facies change from shallow carbonates in northeastern Oklahoma, to coal-bearing shales in the type region (Washington County, Arkansas), to massive sandstones representing braided streams in north-central and northeastern Arkansas. The duration of the unconformity increases with the facies change eastward, involving units as old as Mississippian. Tectonism is not indicated; the break appears to be entirely eustatic, probably related to glaciation.

The Morrowan–Atokan boundary exhibits some regional tilting associated with an off-lapping depositional sequence. An emergent Ozark Dome is indicated by detrital ore minerals in basal Atokan strata of the Arkoma Basin and Atokan chert breccias. Ouachita orogenic movement deformed all Pennsylvanian strata of the Arkoma Basin and raised the Ozark Dome, never allowing the coverage of the Ozarks by epicontinental seas again.

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Base Line Sequence Stratigraphy, Arkoma Basin to Chautauqua Arch

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Use of sequence stratigraphy concepts requires some caution, especially if these are based almost solely on theoretical models enhanced by a computer data base or by seismic records where lithologic interpretations are assumed rather than observed. Optimum input for sequence models is obtained from actual stratigraphic data from outcrops, cuttings and cores across sedimentary strike, such as those from the Arkoma Basin northward to the Chautauqua Arch along the Oklahoma–Kansas border area. Sequence stratigraphy involving Pennsylvanian data indicates a major northward shift of the Arkoma Basin paleobathymetric axis from the southern Ouachita Mountains to southern Kansas with some occasional backward and forward motion. This long base line is also needed to ascertain the total number of parasequences (transgressive-regressive cycles), their geometric succession, and interrelationship of low-stand, shelf-margin, transgressive high-stand, and condensed system tracks. The first two system tracts are important for productive reservoirs, whereas the latter three usually serve as prime source beds.

Usually not all parasequences are present at any one place along an established base line or transect. The low-stand or shelf-margin parasequences are usually absent on the craton or on interbasinal or intrabasinal arches such as the Chautauqua Arch, whereas the transgressive and high-stand parasequences commonly thin basinward into condensed sequences or disappear through downlapping.

Actual Pennsylvanian outcrop data commonly differ from the standard sequence stratigraphy model of Exxon and Peter Vail. Sequence boundaries based on unconformities may occur at any place within a parasequence (transgression stillstand or regression) and may change places along the baseline. Hiatuses that are tectonic rather than eustatic are of irregular durations and occurrences.

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Pennsylvanian History of the Chautauqua Arch

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Westward extension of the Ozark Uplift known as the Chautauqua Arch is concealed by a Pennsylvanian cover. This cover provides an insight into its later tectonic history subsequent to its major Late Devonian uplift and truncation. Part of this arch was episodically uplifted during Pennsylvanian time in an area extending west from southwestern Missouri along the Kansas–Oklahoma border to western Montgomery County. Recent stratigraphic mapping in that county indicates moderate Late Desmoinesian to Missourian tectonism. Some strata present on both flanks of the arch are either comparatively thin or missing owing to unconformity truncation or non-deposition. Stratal loss involves the Lenapah Limestone, the Hepler and Lost Branch Formations, the Cherryvale Shale and the Hertha, Drum, Dewey, Stanton and Wyandotte Limestones. Earlier movements also account for the truncation of Morrowan, Atokan and possibly some Early Desmoinesian beds over the arch. Between tectonic episodes along the arch there were periods of relative tectonic quiescence accompanied by shelf-edge carbonate banks, condensed sequences and siliciclastic sedimentation.

West of Montgomery County in Chautauqua County, the widespread Late Pennsylvanian Virgilian outcrops show practically no tectonism. Therefore, the name Chautauqua Arch seems inappropriate for this Pennsylvanian arch, and the name Tri-State Arch is proposed. This arch is bounded on the north by the Cherokee Basin and on the south by the northern rise of the Arkoma Basin. Although this arch is

commonly omitted on many tectonic maps, it is a stronger gravity feature than the Bourbon Arch about 50 miles northward.

Both tectonic and sedimentary structures have produced much oil and gas entrapment along this arch. For example, an east–west fault south of Independence, aligned with buried Proterozoic hills, has been especially productive.

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Geometry of Surface Fractures along the Mervine Anticline in Kay County, North Central Oklahoma

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Surface fractures in the Lower Permian Barneston Formation are well exposed at three quarries in Kay County, north central Oklahoma. The three quarries are located along the Mervine Anticline which is a broad, asymmetric, low amplitude drape-like fold over a N20E trending subsurface fault. The most northerly of the three quarries is at the axial surface trace of the anticline. The second quarry is one mile to the west and the third quarry is one-quarter mile to the east of the axial surface trace.

In each quarry, a representative area of about 7850 square feet was chosen for detailed mapping of the surface fractures. In each representative area, we divided the surface fractures into what we termed as "primary" and "secondary" fractures. Traverse and area sampling methods were used to collect quantitative data on the joint orientation and frequency. The primary fractures are orthogonal and have a visible opening, while the secondary fractures have little or no opening. The primary fractures, the orthogonal sets, strike N30W and N75E. The secondary fractures show a slight preferred orientation along N65E although the overall distribution is random.

These observations suggest to us that a similar fracture geometry exists in all three quarries. However, in one quarry we have observed that fracture surfaces of the N30W striking set are inclined and their formation may have been influenced by movement along the proposed subsurface fault in the area.

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Phosphate and the Condensed Section in Pennsylvanian Cratonic Sequences

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Early diagenetic phosphate is common in the condensed section in Upper Desmoinesian–Virgilian cyclic deposits from Texas to Ohio. Regional variations in

petrography and chemistry may enhance the precision of sequence-stratigraphic correlation.

In Ohio, the phosphate occurs as reworked clasts in thin marine limestone that marks maximum transgression in that region. In Iowa, most phosphate consists of discontinuous laminae within dark colored shale, whereas in the outcrop belt extending from eastern Kansas to northern Texas, unreworked nodular phosphate is common in addition to laminae.

Nodular phosphate varies petrographically from northeastern Kansas to central Oklahoma. Septarian nodules are common in central Oklahoma. In northeastern Oklahoma and Kansas, the nodules lack septaria, and consist of aggregates of radiolarians and/or peloids cemented by early phosphate which is sometimes followed by calcite and quartz cement.

Rare earth elements (REE) vary regionally from northeastern Kansas to northeastern Oklahoma. A major control on the REE signature in the phosphate appears to be the ratio of the amount fecal material to the amount of detrital material immediately surrounding the phosphate. The REE signature of the phosphate varies somewhat from cycle to cycle, probably reflecting the fecal/detrital balance. This may be developed into a useful tool for correlation when only small samples (e.g., cores) are available.

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Glacial-Eustatic Sea-Level Fluctuation Curve for Carboniferous–Permian Boundary Strata Based on Outcrops in the North American Midcontinent and North-Central Texas

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Based on lithologic and faunal analysis of uppermost Carboniferous through Lower Permian strata (Wabaunsee through lower Chase groups) exposed from southeastern Nebraska through north-central Oklahoma, a preliminary glacial-eustatic sea-level fluctuation curve is presented herein. This sea-level curve is the upward extension of earlier published curves (Heckel, 1986; Boardman and Heckel, 1990) that included only the basal part of the Wabaunsee Group. Black fissile shales that were characteristic of upper Desmoinesian–middle Virgilian cyclothems are exceedingly rare in Carboniferous–Permian boundary strata. Instead most cyclothems are represented by maximum highstand deposits consisting of either gray to dark gray clay slightly phosphatic shales characterized by high conodont abundances or by glauconitic carbonates (highly fossiliferous wackestones) also with high conodont abundances. Lowstand deposits are characterized by subaerially exposed carbonates, paleosols, fluvial complexes, and incised valley fills. Highstand or near highstand deltaic deposits that characterize many of the Oklahoma Desmoinesian–middle Virgilian cyclothems are noticeably rare in the Wabaunsee through lower Chase groups. Additionally, uppermost Carboniferous–Permian cyclothems are characterized by under-utilization of accommodation space caused by exceptionally rapid transgressions as well as equally rapid regressions without significant

highstands, contrasted to upper Desmoinesian through middle Virgilian cyclothems that were typically characterized by rapid transgressions followed by slow complex regressions that resulted in more accommodation space being utilized.

In addition to the sea-level curve presented for the Midcontinent region, one for coeval outcropping strata (middle and upper Cisco Group) of the Eastern Shelf of the Midland Basin is also presented based on similar criteria. This sea-level curve is derived from new field studies as well as a refinement of earlier curves presented by Harrison (1973) and Boardman and Malinky (1985). The conclusions on the nature of the Carboniferous–Permian boundary strata cyclothems in the Midcontinent is mirrored by the results of that from North-Central Texas.

Each of the primary biostratigraphically based picks for the Carboniferous–Permian boundary coincide with either intermediate or major cycles in both study areas. Utilization of a glacial-eustatic maximum transgressive event for the Carboniferous–Permian boundary should result in a more correlatable level for intercontinental correlation.

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Sequence Stratigraphy of Lower Missourian (Lowermost Upper Pennsylvanian) Cyclothems in the Midcontinent, U.S.A.

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The sequence-stratigraphic analysis of midcontinent lower Missourian cyclothems differs in several important ways from traditional "Vailian" sequence stratigraphy. These differences are largely because these cyclothemic units were deposited mainly during complex (i.e., staggered) relative sea-level falls; traditional sequence-stratigraphic concepts were generated from and have been applied primarily to successions deposited mostly during complex relative sea-level rises.

Lower Missourian strata deposited on the relatively stable midcontinent shelf from Iowa to Oklahoma consist of cyclically alternating, mixed carbonate and siliciclastic successions. Updip these cyclothems are relatively simple, 3- to 10-m-thick, carbonate-dominated, asymmetric transgressive-regressive depositional sequences bounded by well-developed paleosols and other features indicative of prolonged subaerial exposure, with the deepest-water lithofacies occurring near the base of each sequence. Transgressive deposits generally consist of a single thin, deepening upward succession, whereas the regressive strata are thicker, more complex, and include numerous small-scale cycles that occur in both deep-water and shallow-water units. The dominant control on deposition of these sequences was likely high-amplitude (100+ m), high-frequency (100–400 ka) glacial eustasy, with relative sea-level curves very possibly analogous to those that typified the latest Quaternary (< about 700 ka), which consist of rapid rises and longer, relatively complex falls.

An important consequences of this "inverse motif" is the existence of surfaces herein termed "basinward-shift surfaces." These occur in late-highstand systems tract deposits and reflect the abrupt juxtaposition of shallow-water lithofacies over deeper-water rocks during periods of especially rapid relative sea-level fall; they can be considered the mirror image of parasequence boundaries sensu Van Wagoner.

In addition, true lowstand systems tracts are not present in most of these sequences in the midcontinent, probably occurring only in areas that are basinward of the downdip limit of subaerial exposure.

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Possible Allocyclic Units in the Lower Marmaton, Northern Midcontinent

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Recent studies (Suchy, 1987; Roth, 1991) of the interval from the top of the Mulky Coal to the top of the Hux–Higginsville limestone identified seven lithologic "packages." In most cases, the boundaries between these seven "packages" are subtle sedimentologic and/or biologic changes. Perhaps the most subtle such boundaries occur within the two major limestone units and are, in this case, marked by chaetetid epiboles (West et al., in press). These boundaries are recognized in outcrops in southeastern Kansas and northeastern Oklahoma, and there is evidence to suggest that they are also recorded by the gamma ray and neutron signatures from subsurface boreholes. These aspects are currently being tested using full hole cores and the electric logs of these core holes.

Combined sedimentological and biological aspects of these "packages" can be explained by a series of smaller than cyclothem scale transgressions and regressions, but they can also be explained by climatic fluctuations. Wetter climates would provide a greater input of siliciclastics and could "push" carbonate production to a more offshore position. Conversely, drier climates would be recorded by an increase in nearshore carbonate production with a corresponding decrease in siliciclastic input. A relative water depth curve and a climate curve for this interval are extremely similar. If causally related, the combined affects of climate and eustatic change could act to amplify or diminish the effects of either mechanism acting alone.

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Sequence-Stratigraphic Implications of Glacial-Eustatic Pennsylvanian Cyclothems in North America

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Only glacial eustasy accounts for all characteristics of Pennsylvanian northern Midcontinent cyclothems that consist of transgressive limestone, offshore ("core") shale, regressive limestone, and variable nearshore to terrestrial shale. Because of the rapidity of glacial eustatic fluctuations of sea level relative to tectonic movements of the shelf or to sediment filling of the large accommodation space provided by sea-level highstand, sequence-stratigraphic concepts and terminology require modification for these cyclothems. It is mainly the condensed intervals of sedimentstarved, phosphate- and conodont-rich core shales that represent true highstand deposits on the mid to lower shelf (which is all that is presently preserved). The regressive limestone and local overlying deltaic deposits are better termed regressive systems tracts because they were deposited during sea-level fall, which greatly reduced the highstand accommodation space available and ultimately led to widespread subaerial exposure, with local erosion, terrestrial deposition and paleosol formation prior to the next marine flooding. The basic cyclothem was modified in Texas and Illinois by detrital overwhelming of regressive limestone deposition from nearer sources, but similar widespread condensed intervals still represent most of highstand. Higher shelf deposits are preserved in the Appalachian basin where phosphate- glaucony- and conodont-rich Conemaugh marine limestones represent highstand deposits in shallower water. These are penetrated locally eastward by deltaic clastics, which also represent highstand as well as early regression. Later regression involved greater fluvial incision, local terrestrial deposition and widespread paleosol formation, which continued through lowstand and early transgression. Late transgression produced widespread coal swamps, migrating ahead of inundation as a result of rising water table and increasing source of rainfall. Coal formation continued at highstand in detrital-free coastal areas, where coals record marine highstand in "nonmarine" coal-bearing cyclothems that dominate parts of the Appalachian succession.

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Sequence-Stratigraphic Context of Pennsylvanian (Desmoinesian–Missourian) Siliciclastics: Cleveland Formation and Marmaton Group, Western Anadarko Basin, Texas Panhandle

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Upper Desmoinesian and lower Missourian siliciclastic strata of the western Anadarko Basin compose a Midcontinent cyclothemic succession that was influenced by both eustatic variation and local, pronounced tectonism during deposition. Mostly westerly sourced fluvial and deltaic/strandplain systems of this interval accumulated in coastal plain, marine-shelf, and proximal shelf-slope settings within the western Anadarko Basin of the northeastern Texas Panhandle.

The study interval consists of three probable fourth-order sequences. Sequence 1 is characterized by landward- and seaward-stepping facies patterns on well logs and in cores that define (in ascending order) Marmaton lowstand-wedge and transgressive systems tracts (TST) and a lower Cleveland highstand systems tract. A regionally correlative, organic-rich, and phosphatic black shale (condensed section) at the top of the Marmaton TST represents a eustatic maximum at the end of the Desmoinesian. A relative sea-level drop with the onset of Sequence 2 deposition initiated development of a sand-rich incised-valley system that traversed the Cleveland coastal plain and depositional shelf for more than 135 km and extended basinward of an irregular, north–south-trending Cleveland shelf break. Subsequent coastal onlap by thin deltaic systems of the overlying TST marks the start of de-

creased sediment influx during late Cleveland time, resulting in thinning of parasequences and an increase in carbonate beds in upper Sequence 2 and Sequence 3.

Because of its distinctive faunal assemblage, the top-of-Marmaton condensed section can be correlated with the Nuyaka Creek black shale bed of the Midcontinent shelf; this bed represents a major eustatic transgressive phase. This correlation and the systems-tract framework of the Marmaton/Cleveland interval provide a starting point for developing a more detailed interregional sequence-stratigraphic tie between the Anadarko Basin and Midcontinent shelf.

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Geologic Controls and Resource Potential of Natural Gas in Deep Sedimentary Basins, United States

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Deep portions of sedimentary basins in the United States contain large volumes of natural gas. Deep reservoirs (>15,000 ft) have accounted for 7% (50 trillion cubic ft-Tcf) of the total gas production in the United States (698 Tcf by 1989). Our study quantifies the distribution and character of undiscovered, deep gas accumulations. Findings as follows:

1) Internally sourced hydrocarbons (HCs) contribute to porosity preservation at depth in the Anadarko basin and in Rocky Mountain basins. An empirical framework for predicting the porosity variations of sandstones as a function of vitrinite reflectance (R_0) was developed and broadly applied to deep sandstones.

2) Measurements of stress-sensitive capillary pressure suggest that small pore throats (<0.1 micrometer), common in fine-grained clastic rocks, are a factor in controlling gas productivity. Natural fractures also are an important factor in flow rates.

3) In some Rocky Mountain basins, structural partitioning prior to thrusting and sequential northeastward breakup of the foreland during the Late Cretaceous and the Paleocene, may have strongly affected the volume and distribution of deep natural-gas accumulations.

4) In flanking basins of the Midcontinent Rift and the Grand Canyon region, Middle Proterozoic source rocks, active HC seeps, and favorable thermal maturities for generating and preserving natural gas, indicate a potential for economic gas accumulations.

5) Methane generation by thermal decomposition of C_{15} + HCs takes place at high maturation ranks. Significant amounts of CO_2 and the presence of H_2S indicate that thermochemical sulfate reduction and simultaneous oxidation of HCs to CO_2 may be the dominant control on non-HC gas composition in deep carbonate reservoirs. Quartz-vein systems in convergent, transpressive plate-margin basins may act as conduits for migration of natural gas.

6) Where geologic information is available concerning known or suspected accumulations of deep gas, a "deposit simulation" based on a geologic model of reservoir volumes is the most appropriate assessment methodology.

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The Red Fork Sandstone of the Deep Anadarko Basin—A Submarine Fan

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Active exploration and development drilling for the upper Pennsylvanian Red Fork sandstone has been going on since 1979 in the western part of the Anadarko Basin of Oklahoma. The fine grained, low permeability, gas and gas condensate reservoir produces at depths ranging from 12,000 to 14,000 feet from stratigraphic traps. Though drilling has generally been continuous through the years, the Red Fork play is very sensitive to gas price because of drilling depths and reservoir characteristics. The play is now mature but because of the complexity of the depositional environment, it is still difficult to predict the good quality reservoir sandstone.

Isopach maps, log curve shapes, lithologic information and seismic data are all utilized to define the facies within a submarine fan. In the Red Fork most of the sand was deposited in the middle fan with the best reservoirs found in narrow channels of the supra-fan lobes. Quality of the reservoir rock in the levee facies deteriorates significantly away from the channel. The gross morphology of the interpreted supra-fan lobes in the Red Ford is similar to those seen in the modern Mississippi River submarine fan and the ancient Tabernas Basin fan in southeast Spain.

Utilizing 2-D and 3-D seismic data to map the supra-fan lobes and channel systems has proved to be very challenging in the Red Fork. However, careful integration of all the well information with the seismic data will yield the best interpretation. Changes in amplitude are used to help define the presence or absence of sandstone and the relative quality of the reservoir.

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Temporal Variation in Carbonates and Mississippian Oolite Reservoirs in the United States

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Oolitic limestone reservoirs of Mississippian age represent an important domestic petroleum resource because: (1) significant hydrocarbon production from oolitic rocks of Meramecian and Chesterian occurs in four areas in North America—Illinois, Anadarko (including the Hugoton embayment), and Appalachian basins, and,

to a lesser extent, the Williston basin; (2) exploration potential for these reservoirs is high even at relatively shallow depths in densely drilled basins because they occur in areally small stratigraphic traps; and (3) oil recovery from these reservoirs tends to be efficient because their primary porosity is commonly preserved and dolomitization is generally lacking.

The abundance of oolitic rocks and their tendency to perform well as hydrocarbon reservoirs can be related to the temporal variations of major factors affecting carbonate sedimentation and diagenesis. Four times in the Phanerozoic are known for peak oolite deposition: the late Cambrian, later Mississippian, late Jurassic, and Holocene. Each time corresponds to a first-order rise or fall of sea level, rather than a highstand or lowstand. Other temporal variations contributing to widespread oolitic deposition during the Mississippian include the relative absence of framework-building organisms that occupy the same high-energy niche; and (2) tectonic events during the Meramecian and Chesterian time that produced broad expanses of shallow water at low paleolatitudes with little terrigenous clastic input. The fall in sea level during Mississippian time was followed by a period of maximum emergence, which was unfavorable for subsequent widespread dolomitization.

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Measured and Modeled Vitrinite Reflectance—Comparisons in Diverse Basins

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Thermal maturity data and burial history reconstructions are commonly combined to assess the maturation of kerogen and the timing of petroleum generation, migration, and preservation. Other applications have come to include modeling of basin development, thermal regimes, heat transport, reservoir diagenesis, and porosity evolution. Laboratory measurements of thermal maturity include vitrinite reflectance, bitumen reflectance, thermal alteration index, and data drawn from Rock-Eval pyrolysis. These measurements are commonly correlated to one another and expressed as a vitrinite reflectance equivalent. Kinetic and time-temperature (TTI) methods have also been developed that calculate equivalent vitrinite reflectance.

The present study compares equivalent vitrinite reflectance (R_{oe}) as determined from laboratory measurements with, R_{oe} from both kinetic and TTI models and investigates their internal consistency using examples from basins of diverse ages and geologic histories. Cases presented include Paleozoic rocks of the Anadarko and Williston Basins, Jurassic strata of the eastern Gulf Coast, Cretaceous rocks of the Piceance and Wind River Basins, and Tertiary formations of the Uinta Basin.

For the Upper Devonian–Lower Mississippian Woodford Shale between 5,000 and 25,000 ft (1,500 and 7,600 m) in the Anadarko Basin of Texas and Oklahoma, R_{oe} as determined from TTI is 1.3 to 2.0 times higher than both measured and kinetic-modeled R_{oe}. For example, for the Woodford at a depth of 21,500 ft (6,553 m), R_{oe} (measured) is 3.0 percent, R_{oe} (kinetic) is 2.70 percent, and R_{oe} (TTI) is 5.3 percent. For the Upper Jurassic Norphlet Formation of southwestern Alabama and vicinity at depths of 10,000 to 22,000 ft (3,050 to 6,700 m) R_{oe} as determined from TTI is 1.3 to 1.7 times higher than both measured and kinetic-modeled R_{oe}. For example, at Hatter's Pond Field at a depth of about 18,400 ft (5,600 m), R_{oe} (measured) is 1.62 percent, R_{oe} (kinetic) is 1.68 percent, and R_{oe} (TTI) is 2.73 percent. As a third example, for the Upper Cretaceous Mesaverde Formation in the Wind River Basin of Wyoming, R_{oe} as determined from TTI is 1.4 to 1.5 times higher than both measured and kinetic-modeled R_{oe}. For the Mesaverde at a depth of 13,000 ft (3,960 m) in the northwestern part of the basin, R_{oe} (measured) is 1.10 percent, R_{oe} (kinetic) is 1.10 percent, and R_{oe} (TTI) is 1.60 percent.

For all of our examples, thermal and burial histories are fairly well constrained. TTI modeling consistently over-predicts R_{oe} as determined from laboratory measurements, but R_{oe} trends determined from kinetic modeling and laboratory measurements are generally in excellent agreement. We conclude, therefore, that in areas where burial and thermal histories are not well constrained, it is reasonable to vary parameters such as amounts of erosion, heat-transport, paleogeothermal gradients, surface temperatures, etc., until kinetic-modeled R_{oe} and measured R_{oe} trends are brought into agreement.

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Formation Resistivity as an Indicator of Oil Generation—Bakken Formation of North Dakota and Woodford Shale of Oklahoma

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With the onset of oil generation in organic-rich, low porosity shales, nonconductive hydrocarbons begin to displace conductive pore water. As this process continues, formation resistivity increases from the low levels typical of water saturated shales and can reach hundreds of ohm-m if sufficient oil is generated. In this study, formation resistivity of selected organic-rich shales is compared with geochemical indicators of hydrocarbon generation and thermal maturity in order to quantify relationships between resistivity and oil generation.

The upper and lower shale members of the Bakken Formation (Upper Devonian and Lower Mississippian) of the Williston Basin, North Dakota, and the Woodford Shale (Upper Devonian and Lower Mississippian) of the Anadarko Basin, Oklahoma are used here as illustrative examples. An increase of volatile hydrocarbons (Si) in core samples indicates that a resistivity of about 35 ohm-m marks the onset of observable oil generation in these three organic rich shales. This resistivity value is used to map regions of the study areas where the Woodford Shale and the Bakken Formation have generated oil and where free oil might possibly be produced from fracture systems.

Crossplots of formation resistivity versus vitrinite reflectance (R_o) indicate that the level of thermal maturation required for oil generation is about $R_o = 0.44\%$ in the upper Bakken Formation, $R_o = 0.50\%$ in the lower member of the Bakken Formation, and $R_o = 0.57\%$ in the Woodford Shale of the study area.

Crossplots of formation resistivity versus Lopatin's time-temperature index of thermal maturity (TTI) indicate that the level of time-temperature exposure required for oil generation is about TTI = 11 in the upper Bakken Formation, TTI = 23 in the lower member of the Bakken Formation, and TTI = 33–48 in the Woodford Shale of the study area. Such crossplots provide a direct empirical link between initiation of oil generation and mathematical measures of time-temperature exposure, thereby circumventing problems of indirect calibrations.

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Tectonic Controls on Deposition and Source-Rock Properties of the Woodford Shale, Anadarko Basin, Oklahoma—Loading, Subsidence, and Forebulge Development

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The Woodford Shale (Late Devonian–Early Mississippian) is an organic-rich, highly compacted black shale that is a significant hydrocarbon source rock in the Anadarko Basin of Oklahoma. The Woodford can be subdivided into lower, middle, and upper informal members based on geophysical-log character. Depositional patterns of these three members were shaped by the tectonic evolution of the Southern Oklahoma Aulacogen.

Depositional patterns of the Woodford Shale reveal a positive paleotopographic feature, parallel with and about 75 mi (120 km) north of the Amarillo–Wichita Uplift, that divided the Woodford into northeast and southwest depocenters and was a hinge line separating areas of differential basement movement during Woodford time. Three lines of evidence suggest that the paleotopographic high was tectonically rising before and during a Late Devonian (pre-Woodford) episode of regional erosion and throughout Woodford time: (1) erosional channels on the pre-Woodford unconformity do not cross the axis of the paleotopographic high; (2) the Late Devonian Misener Sandstone, which was deposited on the pre-Woodford unconformity in topographic lows, is not present along the axis of the paleotopographic high; and (3) Woodford sediments thicken from the paleotopographic high toward both the southwest and northeast.

The paleotopographic high can be explained as a forebulge that developed on the basin margin as the direct result of loading and subsidence along the central trough of the Southern Oklahoma Aulacogen. The ratio of basin subsidence to uplift of the paleotopographic high is in reasonable agreement with a theoretical forebulge model. The distance between the paleotopographic high and the load axis of the Southern Oklahoma Aulacogen is comparable to that between the Goodman Swell (a forebulge of the Midcontinent Rift System) and its nearest load axis.

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Some Mineralogical and Geochemical Aspects of Middle and Upper Pennsylvanian Marine Black Shales in Part of the Midcontinent Region

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This study assesses the regional variations in mineralogy and metal content of thin (<1 m) marine black shales of Middle (Desmoinesian) and Upper (Missourian and Virgilian) Pennsylvanian age in the midcontinent region. It can be inferred that the ratios of illite to kaolinite, albite to potassium feldspar, frequency of occurrence of gypsum, and frequency of occurrence of apatite are probably a function of distance from shoreline or are related to proportion of detrital contributions. The distribution of kaolinite, potassium feldspar, and gypsum seem to reflect a detrital origin, whereas the distribution of illite, albite, and iron-rich chlorite indicates an authigenic or diagenetic origin.

Although the relative positions with regard to shoreline are given, it is very well known that these black shales were deposited in deep water during maximum stands of sea level in the midcontinent region; thus those referred to as nearer shoreline were probably several hundred kilometers from the shoreline.

For Middle Pennsylvanian marine black shales the samples from Iowa have lower ratios of illite to kaolinite and a higher proportion of gypsum than do samples from farther south and west, in Missouri, Kansas, and Oklahoma. This is apparently due to the detrital origin of kaolinite and gypsum from a shoreline or nearshore source to the northeast or north of Iowa. The Iowa samples also have a lower ratio of albite to potassium feldspar than do samples from farther south, in Missouri and Oklahoma, because of the detrital origin of potassium feldspar.

The concentrations of both molybdenum and vanadium are much greater in the samples from Iowa than in the samples from the areas to the south and southwest. This is consistent with previous suggestions that these metals tend to be more concentrated in areas closer to shoreline. The concentration of nickel, in most cases, seems to be related more to the content of organic matter than to any other factor.

For the Upper Pennsylvanian (Missourian) Stark Shale Member of the Dennis Limestone, the patterns of ratios of illite to kaolinite and albite to potassium feldspar and the frequency of occurrence of gypsum are similar to the patterns shown by the Middle Pennsylvanian black shales. The average concentrations of both molybdenum and vanadium in the Stark Shale Member are higher in samples from Iowa and northeastern Kansas than in those from western Kansas and in northern Oklahoma.

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