)L. 42, NO. 2 APRIL 1982

OKLAHOMA GEOLOGY NOTES

OKLAHOMA GEOLOGICAL SURVEY, THE UNIVERSITY OF OKLAHOMA

On the cover—

Photomicrograph of Granite Porphyry Northeastern Oklahoma

The cover illustration shows a sample of micrographic granite porphyry taken from an outcrop of the Spavinaw Granite Group near Spavinaw, sec. 15, R. 22 N., R. 21 E., Mayes County, Oklahoma. Phenocrysts of plagioclase and perthite are set in a delicately micrographic groundmass of quartz–perthite.

Iron oxides are common, and all original femic minerals have been converted to chlorite. The sample yielded an Rb/Sr age of 1,326 ± 58 million years. Zircons from this outcrop area gave a U/Pb age of 1,370 ± 20 million years. Plane-polarized light; field width, 1.6 mm.

This photomicrograph is figure 2 of plate 4 of recently published OGS Circular 84, *Basement Rocks in Northeastern Oklahoma*, by Rodger E. Denison. A description of the publication is given on pages 60–61 of this issue.

Oklahoma Geology Notes

Editor: Connie Smith
Editorial Staff: Elizabeth A. Ham, William D. Rose

Oklahoma Geology Notes, ISSN 0030-1736, is published bimonthly by the Oklahoma Geological Survey. It contains short technical articles, mineral-industry and petroleum news and statistics, reviews, and announcements of general pertinence to Oklahoma geology. Single copies, $1; yearly subscription, $4. All subscription orders should be sent to the Survey at 830 Van Vleet Oval, Room 163, Norman, Oklahoma 73019.

Short articles on aspects of Oklahoma geology are welcome from contributors. A set of guidelines will be forwarded on request.

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Contents

This publication, printed by The University of Oklahoma Printing Services, Norman, Oklahoma, is issued by the Oklahoma Geological Survey as authorized by Title 70, Oklahoma Statutes 1971, Section 3310, and Title 74, Oklahoma Statutes 1971, Sections 231–238. 1,800 copies have been prepared for distribution at a cost to the taxpayers of the State of Oklahoma of $2,704.

OKMULGEE COUNTY COAL BED YIELDS EXOTIC QUARTZITE COBBLE

LeRoy A. Hemish[1]

A large, rounded, somewhat flattened, spheroidal cobble weighing 17 pounds and 12 ounces recently was given to the Oklahoma Geological Survey by Mr. Ken Rogers. Rogers reported that the specimen was collected from the Morris coal bed in a mine operated by MANCO Coal Co., near Bald Knob, Okmulgee County, Oklahoma (fig. 1). The property, in the SW¼ sec. 3, T. 14 N., R. 14 E., is owned by Rogers' mother.

Figure 2 shows the rock, which measures 7⅞ inches by 7¾ inches by 5½ inches. It reportedly was found embedded in a 16-inch-thick coal seam called the Morris coal. On the basis of mapping completed in northeastern Oklahoma, I have tentatively correlated the Morris coal with the Mineral coal, named in Kansas by Pierce and Courtier (1937, p. 69–70). The coal is of Pennsylvanian (middle Desmoinesian) age and is hvAb (high-volatile A bituminous) in rank.

Figure 3 shows fragments of bright, hard coal adhering to the rock, as well as pieces of black, coalified plant compressions welded to its exterior surface. The plant fragments are parts of the ribbed trunk of *Calamites* (L. R. Wilson, Norman, Oklahoma, oral communication, 1982), a scouring rush (sphenopsid) that grew as tall as 40 feet in the Pennsylvanian coal swamps.

The exterior of the exotic rock is stained dark gray (N 3, Geological Society of America Rock Color Chart), owing to the extended period of burial within the coal bed. Exterior discoloration of exotics also has been observed by other writers. Gresley (1896, p. 332) noted that "most erratics found in or in contact with coal are stained black on the outside." The contrast in color between the exterior and the interior of the Okmulgee County exotic is well shown in figure 4. The interior is light brownish gray (5 YR 6/1, Geological Society of America Rock Color Chart).

A slab has been sawed from one end of the cobble for petrographic examination and thin sectioning (figs. 4, 5). Figure 4 is a frontal view of the cut surface, showing simple, low-angle, small-scale, graded cross-stratification, according to terminology suggested by McKee and Weir (1953). Examination clearly shows that the rock originated as a part of an arenaceous sedimentary deposit. The size of the clasts ranges from less than $\frac{1}{16}$ mm (silt) to 1½ mm (coarse sand), according to the Wentworth (1922) grade scale.

[1]Geologist, Oklahoma Geological Survey, Norman.

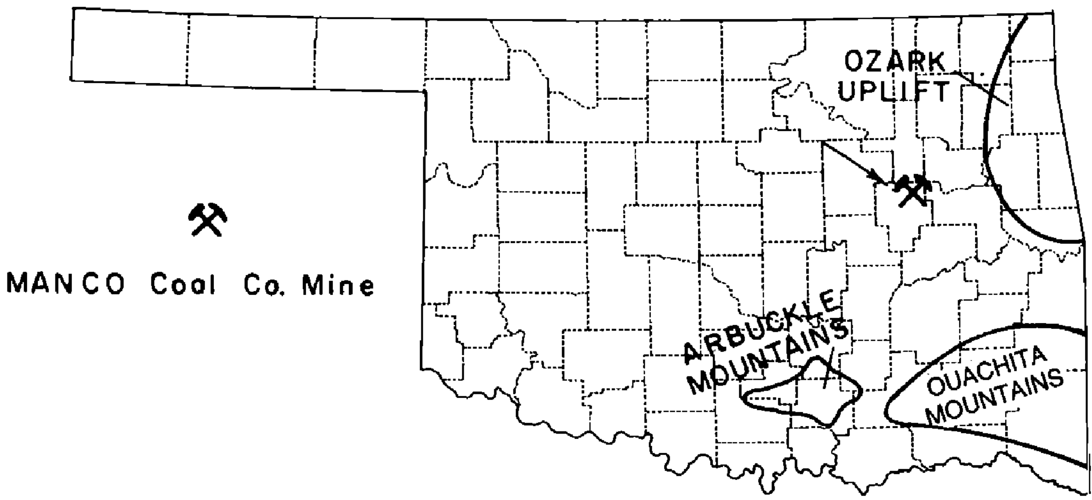

Figure 1. Map of Oklahoma showing location of discovery of exotic cobble in Okmulgee County, Oklahoma.

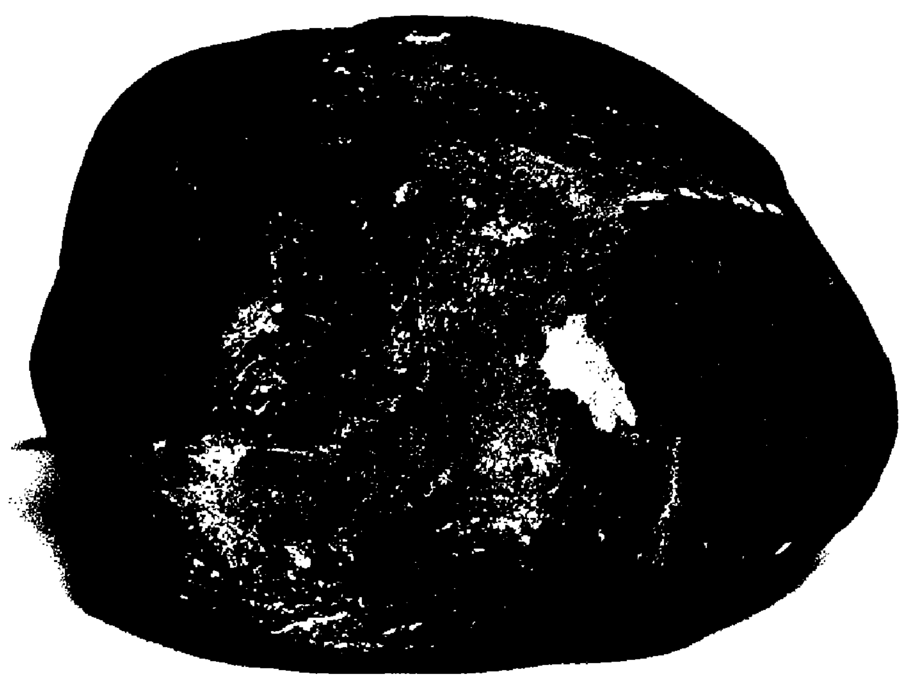

Figure 2. Exotic cobble found embedded in Morris coal seam, SW¼ sec. 3, T. 14 N., R. 14 E., Okmulgee County, Oklahoma.

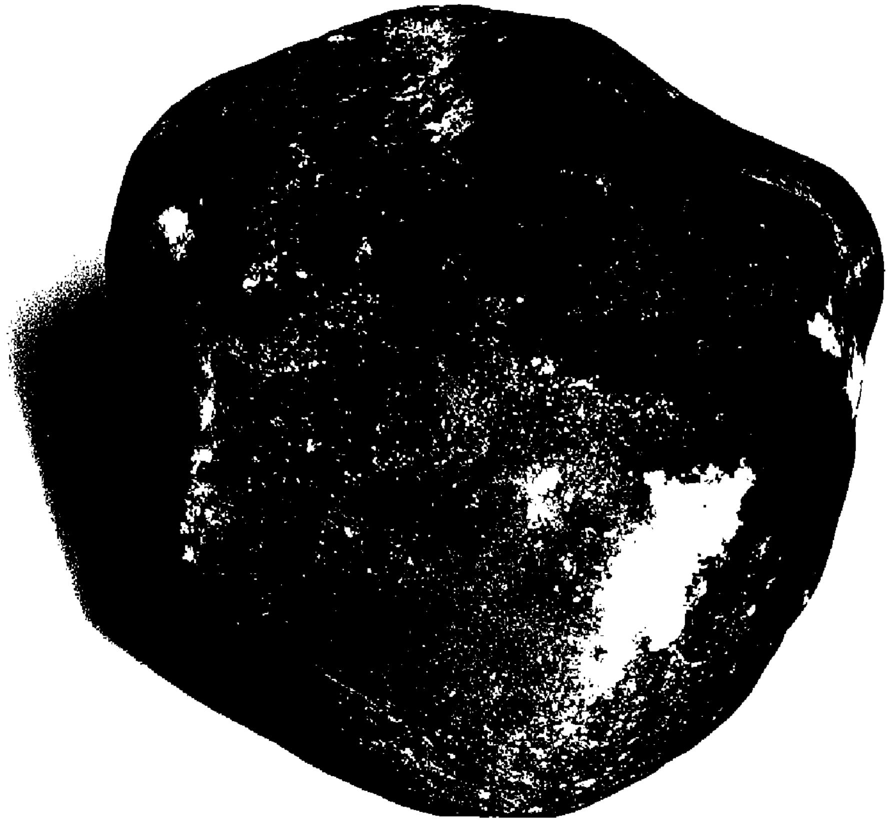

Figure 3. View of exotic cobble showing coal fragments and plant compressions adhering to its surface. Faceted surface is also well shown on left side of photograph.

Another feature of particular scientific interest is a flat, naturally faceted surface that has been cut perpendicular to the bedding plane (figs. 3, 5). This phenomenon is discussed further in a later section of this article.

A thin section was prepared, and optical properties of the mineral constituents of the rock were studied using a petrographic microscope. According to the classification system recommended by Folk (1968), the exotic is an orthoquartzite (quartzarenite) that is compositionally mature but texturally submature, with sand grains that are poorly sorted and not well rounded.

The relative abundance of minerals in the rock was estimated by the author as follows:

Quartz	80.0%
Chert	16.0%
Muscovite and sericite	2.5%
Magnetite (with minor alteration to hematite)	1.0%
Apatite, tourmaline, zircon, unidentified	0.5%

Quartz types are diverse, including, for example, igneous quartz, metamorphic quartz, and reworked sedimentary quartz. Some grains are

Figure 4. View of exotic cobble showing color contrast between interior and exterior as well as cross-stratification on cut face.

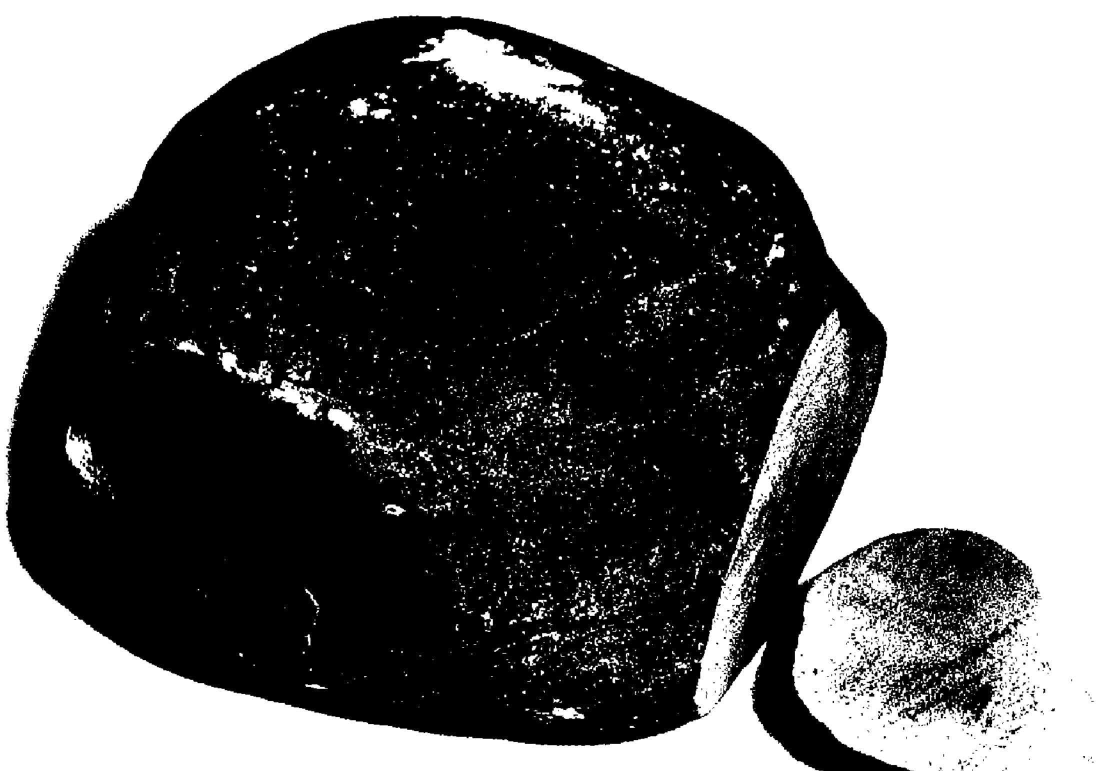

Figure 5. View of exotic cobble showing sawed portion. Note faceted surface at lower left side of rock in this view.

rounded, others are angular, some contain microlites, many show strain shadows, and some include vacuoles. Boundaries are irregular, and adjoining grains are interlocked. The quartz grains are cemented by a siliceous secondary overgrowth that completely fills the pore spaces. Overgrowths having sharp crystal faces are rare.

The detrital chert contains minor impurities in the form of clay minerals. A small amount of sericite is associated with the muscovite as an alteration product.

Accessory minerals are of minor importance volumetrically. Apatite was observed only as microlites occurring in quartz grains. The tourmaline and zircon grains are rounded, and probably recycled.

According to characterizations of Folk (1968, p. 137), the origin of the clasts composing the orthoquartzite was most likely from an older sedimentary source, probably in an orogenic environment. He characterized orthoquartzites derived from older sedimentary sources as having low maturity, with many textural inversions (such as a lack of correlation between roundness and size, with a mixture of angular and rounded grains within the same size, or small round grains plus large angular ones). Orogenic sediments are poorly sorted. Because they are derived from erosion of many previous formations, quartz types are diverse, and some reworked overgrowths may be found. Abundant chert is the chief diagnostic material, with very little feldspar and mica. Suites of heavy minerals characteristically include recycled, rounded tourmaline and zircon. The color of these rocks is usually dirty white or shades of light gray with dark specks (chert).

Though unusual, finds of exotic rocks in coal beds are not rare. Knechtel (1949, p. 46) reported that well-rounded erratic cobbles had occasionally been found by miners in Oklahoma in the upper part of the Lower Hartshorne coal bed. A dark-gray quartzite and a quartz monzonite were discovered in the same coal seam. Branson and Merritt (1963) examined the quartz monzonite exotic in detail and reported the results, but were unable to determine its source or the means of transport into the swamp. Until the discovery of the exotic cobble in the Morris coal bed, no other finds had been reported in the State. The rock described in this report is the largest known to have been found in Oklahoma coals to date.

Branson and Merritt (1963, p. 237–238) thoroughly searched the literature for reports of other occurrences of exotic rocks in coal. For those readers who may not have ready access to this reference, the results of their findings are quoted below:

> The first instances reported were by Binney (1951) and by Phillips in 1855 (p. 220). The latter stated that "quartz and hard sandstone" boulders had been found in Upper Carboniferous coal at Newcastle and at Norbury, near Stockport.
>
> Spencer (1887, p. 734–735) reported a 6-pound boulder in the Gannister coal near Bacup, Lancashire, 180 feet below the ground surface. It and other boulders and pebbles of the area are isolated, are waterworn and rounded, and are of granite, quartz, and quartzite.
>
> Gresley (1885, p. 553–555) reported five boulders of quartzite entirely embedded

in the Lount Nether coal at the Coleorton colliery in Leicestershire. The coal is 4½ feet thick and the boulders were about 20 inches from the top. They weighed 6¾ ounces to 11½ pounds. Four were within a space of 20 yards and one was 500 yards away. All were rounded. The coal has many "horses," or gaps, where sandstone or shale occurs in place of the coal. Gresley also noted a waterworn pebble of lead ore at the top of a coal seam in Shropshire, and a sandstone boulder and quartzite pebbles in the underclay of the Little Coal seam of Derbyshire.

A summary of known occurrences was given by Stur (1885), and he described exotics from Moravian coals.

Roemer (1864) described the occurrence of boulders of gneissic rock in the Caroline coal bed near Kattowitz in Upper Silesia. The three boulders were in the coal itself and were spheroidal, the largest 11 inches in greatest dimension.

In 1923, Stutzer (1940, p. 273–277) summarized reported occurrences of exotic rocks in coal. In a French coal seam, 300 boulders of varied rock types and ages were collected, and a total of 1,073 such boulders was assembled from the region. Similar occurrences have been described in Belgium, Bohemia, Westphalia, Silesia, and at several places in England.

Cobbles have been found in coal at few places in the United States. Andrews (1871, p. 78) reported a gray quartzite boulder in the Nelsonville coal bed at Zaleski, Vinton County, Ohio. The boulder was 17 inches long, 12 inches in least dimension, and was rounded. The boulder was half embedded in the coal.

Newberry (1874, p. 174–175) reported a 4-inch boulder of talcose slate in an ironstone parting of Coal No. 1 at Mineral Ridge, Mahoning County, Ohio.

Gresley (1896, p. 332) mentioned a quartzite boulder taken from the Mammoth seam at Mt. Carmel, Pennsylvania, and a limestone boulder from the fireclay over the workable part of the Pittsburgh coal.

The largest boulder known is the 400-pound quartzite mass taken from the Middle Kittanning seam at Shawnee, Perry County, Ohio (Orton, 1892). Scores of cobbles were found in the mine at Zaleski, Ohio, in the same seam. A 10½-pound cobble was found embedded in the Sharon coal at Mineral Ridge, Mahoning County, Ohio. The specimen was angular and showed no signs of wear.

The Sewell coal of Greenbrier County, West Virginia (equivalent to the Sharon coal), in the New River Group of the Pottsville, yielded 40 exotics ranging from less than an ounce to 161½ pounds (Price, 1932). These are mainly of quartzite, but some are vein quartz, sandstone, and conglomerate. Two are of igneous rocks. A quartzite boulder had earlier been reported from the New River coal field of West Virginia (White, 1915).

A boulder of metarhyolite was found in a coal seam in the Etna coal mines near Chattanooga, Tennessee (McCallie, 1903). The waterworn specimen of some 20 or 30 pounds is of a rock type not known to occur in the region. Dana (1895, p. 664) stated that F. H. Bradley had found a quartzite boulder in coal along Coal Creek in eastern Tennessee.

Of particular interest is a means by which exotic rocks are carried into the coal swamps. Several hypotheses have been advanced concerning probable means, but few writers agree. Again, Branson and Merritt (1963, p. 239) researched the various theories in considerable detail. Their condensed report is quoted below:

Theories on the origin of the boulders and on the means of transport are varied. Binney (1851) thought that three quartzite boulders he observed were meteorites. Stur (1885) considered the boulders in the coal of Moravia to be pseudomorphs after ironstone concretions. Many of the British coals are channeled, and the boulders in the coal would seem to have been transported by streams that later cut and filled channels. Gurich (1891), Gresley (1896), and Savage and Griffin (1928), explained the presence of exotics by river transport in contemporary streams. Price (1932, p. 71) concluded that the exotics of Greenbrier County, West Virginia, were carried 60 miles from the Blue Ridge by a Pennsylvanian river. He considered that the rafting could have been accomplished in ice, by rafting of trees with cobbles held in their roots, by prior stream deposition and elevation of the cobbles upward into the bog in root pads of trees. Newberry (1874) and Schmitz (1894) thought that cobbles were held in the roots of floating trees. Ball (1888) and Schmitz (1894) thought that the exotics were transported in rafts of marine plants.

Potonié (1920) considered that cobbles could be transported into the bogs by waves moving the rocks by aid of attached seaweeds. Several authors considered that transportation was in ice floes (Spencer, 1887; Gresley, 1887; Andrews, 1871).

Although no positive statement can be made concerning the sequence of events that brought the Oklahoma exotic to its resting place in Okmulgee County approximately 270 million years ago, I am offering the following suggestions—based on geologic evidence and judgment—as possibilities. The geologic history of the events could be construed to have happened as follows:

1. Grains of predominantly quartz sand were derived from an unknown source and deposited by currents of water, most likely in a marine environment, in a subsiding basin, probably similar to the Gulf of Mexico.
2. Following burial, and during an extended period of diagenesis, the detrital quartz and chert grains were cemented by silica to form sandstone, and were further cemented by siliceous secondary overgrowths to form an orthoquartzite.
3. The formation was uplifted during a tectonic episode, with concurrent fracturing and fragmenting of the rock unit.
4. In the newly uplifted mountain range, a broken piece of the rock was detached from its parent formation, and with the aid of forces of nature, such as gravity and running water, was carried into a mountain stream. It was then moved along the stream bed as part of the bed load, where mechanical wear of rock on rock caused by friction and impact between particles rounded and smoothed its surface.
5. The waterworn cobble was next deposited with other material in a body of alluvium, probably in a terrace, or in a fan built where the stream emerged from a highland valley onto a nearly level plain.
6. At this stage, the faceted surface could have been cut by the action of wind-driven sand and silt as the stone lay partially buried in barren ground.
7. In time, probably with a change to more humid conditions, vegetation began growing on the alluvial deposit, and the stone may have become entangled in the root mass of a tree.
8. Subsequent shifting of the stream channel brought the tree near to the stream bank until undermining by currents caused it to topple into the water.
9. The entire tree, with root pad and exotic rock intact, was floated

downstream and transported into the coal swamp, either by flood waters or, possibly, by tidal currents.

10. The tree became waterlogged and sank to the bottom of the swamp, where it was subjected to physical and chemical changes during the long process of coalification. Other than the staining of its surface, the entrapped orthoquartzite cobble would have been little altered during this extended period of burial.
11. The cobble was exhumed and discovered during the mining of the coal bed approximately 270 million years after burial.

An alternate explanation for part of the sequence of events is that during step 4, some of the shaping of the cobble may have resulted from glacial action. Several authors have considered glacial transport or ice rafting as a means of accomplishing the movement of exotics into coal swamps (Andrews, 1871; Gresley, 1887; Spencer, 1887; Price, 1932). These hypotheses have been considered invalid where Oklahoma is concerned (Branson and Merritt, 1963, p. 239), because plant types found in Desmoinesian coal seams could have survived only in a warm climate. Analyses of fossilized plant remains from Oklahoma's coal beds and associated strata provide evidence that during the Pennsylvanian, Oklahoma's climate was tropical, with humid, warm conditions prevailing (Dott and Batten, 1971, p. 311).

Although it seems unlikely that ice was the means for rafting the exotic cobble into the coal swamp, it is conceivable that glaciers could have existed during the Pennsylvanian in the cratonic mountains of southeastern Oklahoma. Dott and Batten (1971, p. 321) said that the mountains "must have been a few thousand meters high" (15,000 to 18,000 feet?). Table 1 lists three present-day mountains in Africa, located virtually on the equator

TABLE 1.—GLACIATED AREAS IN EASTERN AFRICA
(Modified from table 26–A of Flint, 1971, p. 698)

	Highland	Latitude (approx.)	Longitude (approx.)	Altitude (approx.)	Existing glaciers
1.	Ruwenzori (Margherita Peak), Uganda	0°24′N	29°54′E	5,119 m (16,794 ft)	Down to 4,400 m (14,435 ft)
2.	Mt. Kenya, Kenya	0°10′S	37°18′E	5,501 m (18,047 ft)	Down to 4,900 m (16,076 ft)
3.	Kilimanjaro, Tanzania	3°05′S	37°22′E	5,897 m (19,389 ft)	Down to 4,550 m (14,928 ft)

and ranging in height from 16,794 to 19,389 feet, that have existing glaciers as low as 14,435 feet.

Therefore, it is possible that sometime during transportation of the orthoquartzite cobble down the mountain, it could have been carried part of the distance by a moving highland glacier. It would have been during this time that most of the shaping of the clast occurred. According to Flint (1971, p. 165), clasts are altered most readily at the base of glaciers. Facets are made by grinding as the clasts are carried forward in the sole of the glacier in contact with underlying bedrock. Rounding of the stone could have occurred either before incorporation in or after release from the ice through wearing in meltwater streams.

The shape characteristics of the Oklahoma cobble are nearly those of the ideal form of a glaciated clast (Flint, 1971, p. 166): It has a roughly pentagonal shape; the "base" is broad at one end and narrow at the other; it is slightly convex in both the transverse and longitudinal directions; and its sides and top are relatively smooth, rounded, and faceted. Striations are not evident, but these probably would have disappeared during stream transport down the lower part of the mountain.

Other than modifying step 4 and eliminating step 6 in the history of geologic events, the sequence would remain the same. In my opinion, the most plausible explanation for the rafting of the exotic into the coal swamp is that it was floated to the site entangled in the roots of a tree.

Figure 6 shows a modern-day tree, its roots partially exposed by erosion, growing in coarse-grained alluvial material. The drawing gives a cross-sectional view of the sediments in the cutbank of a stream in east-central Oklahoma. Several clasts of sandstone are entangled in the root mass. One of the cobbles has been almost totally surrounded by the growth of the woody part of a thick root. It is apparent that further undercutting of the stream bank during times of high water will eventually cause the tree, with its root mass intact, to topple into the stream. This situation provides a present-day analog to hypothesized events that occurred during Pennsylvanian time and shows how exotics could be trapped in the roots of trees, then floated into coal swamps.

The source of the exotic cobble cannot be positively identified, although one of the Paleozoic arenaceous formations from the newly uplifted ancient Ouachita Mountains seems the most likely probability. According to Wanless and others (1970, p. 234), the principal sources of Pennsylvanian sediments for the Midcontinent were tectonic uplifts in southern Oklahoma, particularly the upland resulting from deformation of the Ouachita Basin, and, later in the Pennsylvanian, the Arbuckle Mountains area. Wanless and others (1970, p. 234) believed that "very little sediment was derived from . . . such uplifts within the Midcontinent region as the Nemaha Ridge, Central Kansas Uplift, and the Ozarks."

The orogenic source of the sediment composing the orthoquartzite is purely speculative, but the ancient (now deeply buried) mountains of Llanoria in eastern Texas are one possibility. Miser (1929, p. 10) said: "Most of the clastic sediments for the Paleozoic rocks of the Ouachita Mountains

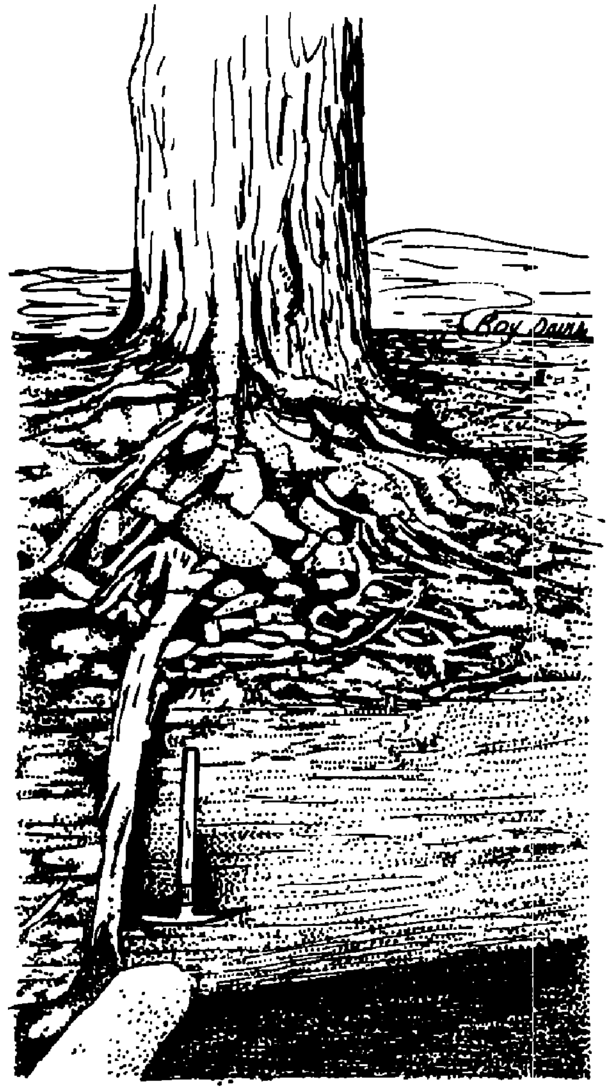

Figure 6. Tree roots partly exposed by erosion. Note entangled cobbles. Drawing was made from a photograph of a tree in cutbank of stream channel in NW¼ sec. 23, T. 10 N., R. 12 E., Okfuskee County, Oklahoma.

had a southern source." The diagenetic processes involving chemical and physical changes of the sediments to an orthoquartzite would have occurred during burial of the clasts in the Ouachita Basin (prior to the Ouachita orogeny).

Interpretations concerning the geologic history of the exotic cobble cannot be any more complete than those suggested herein. If, in the future, additional exotics are discovered in the coal beds of Oklahoma, perhaps more exact conclusions can be reached.

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AAPG CONVENTION OFFERS "RESOURCE ROUNDUP"

Calgary, Alberta, Canada, will be the site of the 1982 annual convention of the American Association of Petroleum Geologists and its divisions, the Society of Economic Paleontologists and Mineralogists (SEPM), the Energy Minerals Division, and the Division of Professional Affairs. The meeting will be held June 27–30.

Appropriate to this cattle and oil city of the great northern plains—not too far removed in time or spirit from its frontier days—is the "Resource Roundup" western theme chosen for this year's convention. Serving as hosts for the gathering, the Canadian Society of Petroleum Geologists and general chairman James S. MacDonald, of Dome Petroleum Co., have extended a warm welcome to AAPG members and guests.

In line with the theme, technical sessions will include papers on frontier oil plays and case histories of selected oil fields, as well as numerous papers on petroleum exploration and various disciplines that encompass all phases of geology. The program of the Energy Minerals Division will cover oil shales, tar sands, nuclear resources, and geothermal energy. The Division of Professional Affairs will offer a session on professionalism and ethics.

SEPM will present 15 research colloquia and two short courses on sedimentology, stratigraphy, geochemistry, and paleontology. Other short courses offered at the meeting will cover geophysics, Canadian giant reservoirs, concepts in stratigraphy, carbonate diagenesis, and techniques for preparing and presenting technical papers. A variety of poster sessions will be on display throughout the meeting.

Twelve pre- and post-meeting field trips have been scheduled, to examine the geology of the Northern Rocky Mountains and their adjacent plains.

For further information on this meeting, contact the AAPG Convention Department, P.O. Box 979, Tulsa, OK 74101, or phone (918) 584–2555.

HARRISON, MANKIN, AND TAYLOR TO FILL IOCC POSITIONS

William E. Harrison, petroleum geologist and geochemist with the Oklahoma Geological Survey, has been appointed by Governor George Nigh to serve as a new member of the Interstate Oil Compact Commission (IOCC).

Charles J. Mankin, Survey director, has received reappointment to the commission.

John Allen Taylor, OU graduate and Oklahoma City independent petroleum geologist and civic leader, was named Nigh's official voting representative to the commission.

IOCC was formed in 1935 following a demoralizing period for the oil industry, when resources were overproduced and underconsumed, natural gas was vented into the air, and oil was wasted in earthen tanks. It is a cooperative advisory body made up of representatives from oil-producing states with the purpose of conserving oil and gas by the "prevention of physical waste." It functions through established state agencies and at present represents 36 states.

BASEMENT ROCKS DESCRIBED IN NEW OGS CIRCULAR 84

A new publication describing the *Basement Rocks in Northeastern Oklahoma* has been issued by the Oklahoma Geological Survey as Circular 84. The 84-page volume was authored by Rodger E. Denison, consulting geologist of Dallas, Texas.

The report covers the igneous rocks that underlie all or parts of 29 counties in northeastern Oklahoma, encompassing approximately one-third of the State. These rocks, probably the oldest in Oklahoma, have been dated at about 1,300 million years. They comprise four geologic units: the Washington Volcanic Group, the Spavinaw Granite Group, the Osage Microgranite, and the Central Oklahoma Granite Group.

With the exception of one small area near Spavinaw, in Mayes County, where the Spavinaw Granite is exposed in five small hills, all the rocks under discussion occur only in the subsurface. Depths of burial are variable, ranging to 9,000 feet, with deepening toward the southern part of the area where the basement surface dips under the Arkoma Basin. The author states that much of the variation results from the rugged topography of the basement surface, rather than from structural movement, with later modifications caused by movements in late Paleozoic times. Depths to basement, as determined from examination of the records of approximately 400 wells, are presented in tabular form in a 43-page appendix, and are also shown on a plate containing a structure map and a geologic map of the Precambrian surface. The maps are at a scale of 1:750,000.

Petrographic descriptions of the many well cores and cuttings used in interpretations for preparation of the geologic map also are given in the appendix. Other data incorporated into the report include results of chemical analyses; magnetic, density, and isotopic-age determinations; and modal compositions.

Circular 84 can be obtained from the Oklahoma Geological Survey at the address given inside the front cover. The price is $12 for a hardbound copy, and $8 for a paperbound copy.

TWO SEISMICITY MAPS FOR OKLAHOMA

U.S. Geological Survey Miscellaneous Field Studies Map MF-1352, *Seismicity Map of the State of Oklahoma*, compiled by C. W. Stover, B. G. Reagor, S. T. Algermissen, and J. E. Lawson, Jr., is one of a series of state seismicity maps being published by the federal survey.

Maps for states north, south, and west of Oklahoma have been published with the exception of a map of New Mexico, which has been compiled but will not be issued until those of its border states have been completed.

MF-1352 locates epicenters of selected earthquakes that have occurred in the State, gives the dates and Mercalli intensities of the occurrences, and indicates the number of disturbances at each location. A table on the map sheet contains a chronological listing of earthquakes from 1897 through 1979, with available information on time, latitude and longitude, magnitude, and intensity of tremors. A list of sources of information is included, as is a description of the significance of Mercalli measurements.

More detailed and comprehensive information on Oklahoma earthquakes can be found in Oklahoma Geological Survey Map GM-19 (1979), compiled by Lawson, chief geophysicist with the OGS; Robert L. DuBois, professor and associate director of the OU School of Geology and Geophysics; Paul H. Foster, geophysicist with the Observatory; and Kenneth V. Luza, engineering geologist with the OGS.

OGS GM-19 locates and gives time and intensity for all earthquakes (182) that have occurred in Oklahoma between 1900 and 1978. An accompanying 15-page booklet describes the tectonic setting of Oklahoma, the statewide seismograph network used in acquiring data, measurements used in determining magnitude, and meanings of earthquake-phase nomenclature. An earthquake catalog is included.

Lawson, in discussing the two seismicity maps, states that "I see

GM-19 and MF-1352 not as competing maps but as complementary maps, one being a very complete map for Oklahoma and one being part of a uniform national series."

USGS Map MF-1352 can be obtained for $1.25 from Distribution Branch, U.S. Geological Survey, Box 25286, Federal Center, Denver, CO 80225. OGS Map GM-19 is available from the offices of the Oklahoma Geological Survey at the address given inside the front cover. The price is $5.

COAL-RECLAMATION PROJECTS FUNDED FOR OKLAHOMA

Two Oklahoma projects are included among 31 major coal-reclamation projects in 13 states, Interior Secretary James Watt announced recently.

The nearly $10 million needed for the projects will come from the federal share of fees collected from active coal-mining operations under the Surface Mining Control and Reclamation Act of 1977. The fund is administered by the Interior's Office of Surface Mining.

The Oklahoma projects, the Keota Park and Fowler Estep projects, will cost an estimated $400,000.

OSM Director James R. Harris said, "This funding is aimed at correcting abandoned mine lands where the health and safety of people are threatened."

USGS HYDROLOGIC ATLASES RELEASED

Two hydrologic atlases covering the High Plains aquifer in parts of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming have been issued by the U.S. Geological Survey. Each atlas contains two map sheets, at a scale of 1:2,500,000, with accompanying reports. Atlas HA-648 describes the bedrock geology, altitude of base, and 1980 saturated thickness in the area. HA-652 details water-level and saturated thickness changes, predevelopment to 1980.

The High Plains aquifer, which consists principally of the Ogallala Formation of Tertiary age, is the main source of water for all uses in the eight-state area covered. Underlying approximately 177,000 square miles and containing several billion acre-feet of water, this supply is crucial to the irrigated farming that is basic to the economy of the region.

In 1978 the USGS began a 5-year study to determine the effects of continued ground-water development on the aquifer. Data presented in HA-652 show that, although net depletion of the aquifer is small, withdrawal has seriously affected ground-water supplies in local areas, with decreases ranging from 0 to more than 50 percent.

These maps can be obtained for $5 per set from the Western Distribution Branch, U.S. Geological Survey, Box 25286, Federal Center, Denver, CO 80225. Orders must include the report number (HA-648 or HA-652) and checks or money orders payable to the U.S. Geological Survey.

Samuel A. Friedman (left), OGS coal geologist, and Laxman Phadke, of Northeastern Oklahoma State University's physics department, discuss the OGS "Coal Resources of Oklahoma" exhibit on display recently at OU.

POSTER SESSION OUTLINES OU ENERGY RESEARCH

Energy research at The University of Oklahoma was the focus of a poster session held February 19 in the Oklahoma Memorial Union. Representatives of energy-related companies in Oklahoma and the region, as well as OU students, faculty, and staff members, toured the exhibits to ask questions and gain a broader understanding of the wide variety of research being conducted at OU.

The Oklahoma Geological Survey sponsored four exhibits: "Geothermal Resources of Oklahoma," by William E. Harrison, petroleum geologist; "Tar-Sand Potential of South-Central Oklahoma," also by Harrison; "Coal Resources of Oklahoma," by S. A. Friedman and L. A. Hemish; and "Geochemical Prospecting for Stratigraphic Traps," by Harrison.

Robert H. Arndt, director of the Oklahoma Mining and Minerals Resources Research Institute at OU, and geologist with the Survey, coordinated the OGS exhibit.

The entire session proved to be a highly popular method of showcasing the work of various departments and groups.

"Our objectives were to make the private sector aware of the variety of energy-related research under way at OU and to help on-campus faculty to know what one another is doing in the energy area," explained Kenneth R. Hoving, dean of the OU Graduate College and vice provost for research administration.

Faculty and staff involved in energy-related research used 4- by 5-foot posters presenting the investigations on which they are working, the procedures and techniques that they are using, the results they have obtained to date, and any conclusions that can be drawn.

Other OU departments and the research they presented were:

School of Aerospace, Mechanical and Nuclear Engineering—Davis Egle and Akhtar Khan, "Determining Stresses in Pipelines"; S. R. Gollahalli, "Combustion of Synthetic Fuels"; Tom Love, "Energy from Artificial Geothermal Wells"; and John Purcupile, "Oil Shale Research."

Department of Botany and Microbiology—Michael McInerney, "The Use of Microorganisms in Enhanced Oil Recovery."

School of Chemical Engineering and Materials Science—Carl Locke, "Corrosion by Drilling Fluids"; John Scamehorn, "Enhanced Oil Recovery by Surfactant Flooding"; Kenneth Starling and Lloyd Lee, "Energy System Fluid Properties."

Department of Chemistry—Gordon Atkinson, "The Thermodynamics of Brine Completion Fluids"; John Burr, "High Temperature Hydrogenolysis of Bibenzyl"; Sherril Christian and Ed Tucker, "The Characterization of Surfactant Micelles by Precise Vapor Pressure and Calorimetric Techniques"; Roger Frech, "Spectroscopic Studies of Fast Ion (Superionic) Conductors"; Arnulf Hagen, "High Pressure Interactions: In–Situ Coal Mining and Preparation of an Asphalt Extender"; David Marten, "Organoiron Dimers as Models in Fischer-Tropsch Synthesis."

School of Civil Engineering and Environmental Science—Larry Canter, "Ground Water Implications of Energy Development"; Edwin Klehr, "The Use of Transport/Transformation Matrices to Study the Behavior of Contaminant Released to the Environment from Energy Development"; Joakim Laguros, " 'Flyash' Waste-Resource Material as an Energy Problem"; Michael Schnornlick and Leale Streebin, "Management of an Energy Industry's Hazardous Wastes"; Leon Wang, "Protective Design of Energy Transportation Systems Under Adverse Environments."

Department of Economics—Larry Eubanks and Michael Mueller,"Economics of Sedentary Oil Recovery with Ground Water in Competition with Irrigation."

School of Electrical Engineering and Computer Science—John Fagan, "The Great Hurricane Chase"; Leon Zelby, "Energy Alternatives: Possible, Probable, Practical."

Energy Resources Center—Kenneth MacDonald, "The Petroleum Data System."

School of Geology and Geophysics, Judson Ahern, "Thermal History and Hydrocarbon Maturation, Williston Basin (North Dakota)"; Douglas Elmore, "Asphalt Sediment, Zagros Mountains, Iran"; Cary McConnell, "Well Log Techniques to Determine Salinity for Enhanced Oil Recovery"; John

Pigott, "Indonesian Production, Past and Future"; Patrick Sutherland, "Potential Stratigraphic Traps in the Arkoma Basin"; John Wickham, "Fracture Intensity in Geologic Structures"; Richard Wilson, "Paleotemperature and Organic Maturation in the Arkoma Basin"; and Jiri Zidek, "Ichthyoliths as Stratigraphic and Maturation Indicators."

NEW THESES ADDED TO OU GEOLOGY LIBRARY

The following M.S. theses have been added to The University of Oklahoma Geology and Geophysics Library:

The Depositional and Diagenetic History of the Oswego Lime, Aline–Lambert Field Area, North-Central Oklahoma, by Timothy John Drexler. 149 p., 19 ill., 1980 [1981].

Geology Along a Cross Section Through the Frontal Ouachita Mountains in Pittsburg, Atoka, and Pushmataha Counties, Oklahoma, by David Scott Rippee. 90 p., 18 ill., 1981.

Calcareous Foraminifers and Algae from the Type Morrowan (Lower Pennsylvanian) Region of Northwestern Arkansas and Northeastern Oklahoma, by John R. Groves. 158 p., 10 plates, 1981.

Subsurface Analysis, "Cherokee" Group (Desmoinesian), Portions of Lincoln, Pottawatomie, Seminole, and Okfuskee Counties, Oklahoma, by Lura Ellen Rosewitz. 57 p., 4 figs., 19 plates, 1981.

OKLAHOMANS INCREASE GASOLINE USAGE

Despite a national trend to use less gasoline, with the amount consumed throughout the United States during the first eight months of 1981 being 2.7 percent less than the same period last year, Oklahoma increased its gasoline consumption during the same period by 3.4 percent.

Besides Oklahoma, nine states reported an increase in the periods of comparison. Two states with higher increases than Oklahoma were Alaska, with an increase of 4.9 percent, and Utah, where consumption was up 3.8 percent.

The gasoline-consumption figures are available from the U.S. Department of Transportation, Federal Highway Administration, in the report *Monthly Motor Gasoline Reported by States*, issued in November.

MINERAL-DEPOSITS MAP PUBLISHED

A map showing more than 4,000 ore deposits of North America on a geologic background, compiled from information furnished by most of the individual countries on the continent, has been published by the U.S. Geological Survey. Two companion reports identify the deposits and list mineral commodities and coordinates.

The 14-color map, *Preliminary Metallogenic Map of North America*, depicts the geology and ore deposits from Greenland to Panama, including the islands of the Caribbean. Published at a scale of 1:5,000,000 (1 inch = about 80 miles), the 5- by 6-foot map is printed in four sheets.

"The map constitutes a benchmark of our present knowledge of the mineral endowment of the continent and provides an overview that has never before been available," said Philip Guild, geologist at the USGS National Center, Reston, VA, and chief compiler of the map.

"Among other uses, the map shows where chemical elements are known to have been concentrated to ores by geologic processes, and by analogy, where as-yet undiscovered deposits may exist," Guild added. "Thus the map should provide a basis for planning research to guide exploration for additional deposits."

Colors and patterns on the map depict North America's sedimentary and volcanic rocks by age and structural or metamorphic state (unfolded or folded, low or high metamorphic grade) and the igneous intrusive rocks by their chemical nature (alkaline, granitic, mafic, or ultramafic). The granitic rocks are further distinguished by their ages relative to the tectonic development of regions in which they occur.

The location, metal and mineral content, relative size, host-rock environment, igneous-rock association, type, and geologic age of 4,215 ore deposits and districts are shown on the map by colored symbols superimposed on the geology. Chemical symbols or letters indicate the metals or minerals present, give their order of abundance or value, and show the general mineralogic class such as oxide, sulfide or silicate. Numbers keyed to computer-prepared lists in the companion reports identify the deposits.

This first edition of the map is considered "preliminary" because it was reproduced quickly by electronic scanning of hand-colored copy rather than by normal map color-separation methods, and because the individual contributors have not yet had the opportunity to check the map in detail.

Copies of the map (in four sheets) can be purchased for $10 a set from Branch of Distribution, U.S. Geological Survey, 1200 South Eads Street, Arlington, VA 22202; or Branch of Distribution, U.S. Geological Survey, Box 25286, Federal Center, Denver, CO 80225. Orders must specify the map by name and include a check or money order payable to the U.S. Geological Survey. Copies of the companion reports, USGS Circular 858-A, *Preliminary Metallogenic Map of North America: A Numerical Listing of Deposits*, and USGS Circular 858-B, *An Alphabetical Listing of Deposits*, are free upon application to Text Products Section, Branch of Distribution, U.S. Geological Survey, 604 South Pickett Street, Alexandria, VA 22304.

NOTES ON NEW PUBLICATIONS

Synthetic Fuels and Alternate Energy Directory

Listings for over 1,500 companies active in the alternate-energy field, with descriptions of projects, key personnel, names, titles, addresses and phone numbers, are available in this new directory.

Order from: PennWell Directories, P.O. Box 21278, Tulsa, OK 74121. Price: $35.

In Situ Mining Research, Proceedings: Bureau of Mines Technology Seminar, Denver, Colo., August 5, 1981

An overview of the *in-situ* mining research currently being carried out by the U.S. Bureau of Mines is available in these proceedings.

This publication is free and can be obtained from: Section of Publications, Bureau of Mines, U.S. Department of the Interior, 4800 Forbes Avenue, Pittsburgh, PA 15213.

Land Use and Land Cover and Associated Maps for Perryton, Texas, Oklahoma, Kansas

The four maps which come with this report are keyed to the 1° × 2° U.S. Geological Survey Perryton topographic map at a scale of 1:250,000 and include information on land use and land cover, political units, hydrologic units, and county subdivisions. One positive of the cultural base for Perryton is also included.

Contact USGS, Mid-Continent Mapping Center (NCIC-M), 1400 Independence Road, Rolla, MO 65401, for information on availability and price. Order number, 81-001.

1982 U.S.A. Oil Industry Directory

Over 25,000 listings from every major integrated oil company, major independent, pipeline company, drilling fund, and major marketing firm in the United States are in this 475-page directory. Listings for government agencies and associations connected with the oil industry are also included.

Order from: PennWell Directories, P.O. Box 21278, Tulsa, OK 74121. Price: $55.

Bibliographies

The Geological Information Library of Dallas has announced the following Bibliographies in its series of GILD Publications pertaining to the literature of various geologic basins over a span of a hundred years (1881–1981).

The Bibliographies follow the GILD style of numbered alphabetical Author Index with Subject Index listing numbers referring to Authors. The series includes:

GILD Publication No. 2: Annotated Bibliography of the Fort Worth Basin Area, Texas, revised 1981 Edition covering 40 counties and containing 666 citations, including 124 master's theses and Ph.D. dissertations. Price is $25.

GILD Publication No. 3: Annotated Bibliography of the Arkoma Basin Area, Arkansas-Oklahoma, covering 43 counties and containing 1,729 citations, including 302 theses and dissertations. Price is $35.

GILD Publication No. 4: Annotated Bibliography of the Palo Duro Basin Area, with Hardeman and Hollis Basins, New Mexico-Texas-Oklahoma, covering 25 counties and containing more than 700 citations, with 31 theses and dissertations. Price is $25.

GILD Publication No. 5 is in Press: Annotated Bibliography of the Ardmore and Marietta Basins Area covering 5 counties with more than 700 citations. Advanced orders are $25.

Order from: GILD Publications, Geological Information Library of Dallas, Suite 100, One Energy Square, 4925 Greenville Avenue, Dallas, TX 75206. Orders from within Texas should include 5 percent tax.

Petroleum Development Geology

This second edition of Parke A. Dickey's book includes new chapters on applying development geology, oil fields in carbonate reservoirs, drill-stem and transient testing, fluid behavior in reservoirs, and evaluation of an oil discovery to locate second, third, and fourth wells.

The book discusses the tools of the petroleum geologist, including the utilization of samples, mud logs, cores, and wire-line logs. Different types of sand bodies are described, and the chemistry of oil, gas, and oil-field waters is briefly discussed. Also included is a review of fluid behavior and a set of case histories giving actual examples of geology applied to waterflooding and EOR operations.

Order from: PennWell Books, P.O. Box 21288, Tulsa, OK 74121. Price: $30. Alabama, California, Oklahoma, Texas, and Washington, D.C., residents must add sales tax.

OKLAHOMA ABSTRACTS

AASP Annual Meeting
New Orleans, Louisiana, October 7–10, 1981

The following abstracts are reprinted from Programs and Abstracts from the 14th Annual Meeting of the American Association of Stratigraphic Palynologists. Page numbers are given in brackets below the abstracts. Permission of the authors and of Vaughn M. Bryant, Jr., managing editor of the AASP, to reproduce the abstracts is gratefully acknowledged.

A 5200+ Year Record from Ferndale Bog, Southeastern Oklahoma

LOIS E. ALBERT, Oklahoma Archeological Survey, University of Oklahoma, Norman, OK 73019

Evidence of climatic fluctuations has been found in 5,200 + dated core from a southeastern Oklahoma peat bog. Ferndale Bog is located near the forest/savanna transition and is, therefore, in a sensitive location. The earliest date in the 160 cm core is 5,170 ± 80 B.P. (WSU – 2434) from 145–150 cm. The sediments below this level appear to be from the terminal portion of the Altithermal; the pollen assemblage is that of an oak savanna. A period of increased deposition, increased deciduous trees and decreased grasses is seen around or before 2,700 B.P. The vegetation of this period is probably an open-hickory forest (moister). An increase in pine is noted around 1,700 B.P. The forest may be more closed and is probably an oak–hickory–pine forest. Fluctuations in the percentage of pine and of the AP/NAP ratio are seen, one somewhat before 550 B.P., which may indicate periods of drought. [10]

OKLAHOMA ABSTRACTS is intended to present abstracts of recent unpublished papers relating to the geology of Oklahoma and adjacent areas of interest. The editors are therefore interested in obtaining abstracts of formally presented or approved documents, such as dissertations, theses, and papers presented at professional meetings, that have not yet been published.

Upper Ordovician (Lower Richmondian) Acritarchs and Chitinozoans from Southeastern Indiana, U.S.A.

MERRELL A. MILLER, Amoco Production Co., Research Center, P.O. Box 591, Tulsa, OK 74102; REED WICANDER, Department of Geology, Central Michigan University, Mt. Pleasant, MI 48859

A diverse and well-preserved acritarch and chitinozoan assemblage has been recovered from the upper part of the Arnheim Formation and from the overlying Waynesville Formation at Bon Well Hill, one mile northeast of Brookville, Indiana. Both of these classical Cincinnatian units are now included in the Dillsboro Formation, a lithostratigraphic unit that encompasses all Maysvillian and pre-Saluda Richmondian strata in southeastern Indiana. This section, from the upper part of the Dillsboro Formation—the Richmondian part—is from the type area of the Richmondian and correlative to part of the upper Ashgill. The Cincinnatian Series includes, from youngest to oldest, the Richmondian, Maysvillian, and Edenian stages.

Preliminary analysis of nineteen samples indicates representatives of the following acritarch genera are present: *Actinotodissus, Aremoricanium, Axisphaeridium, Baltisphaeridium, Carminella, Dicommopalla, Eupoikilofusa, Fractoriconula, Holothuriadeigma?, Leiofusa, Leiosphaeridia, Micrhystridium, Multiplicisphaeridium, Navifusa, Ordovicidium, Orthosphaeridium, Peteinosphaeridium, Polygonium, Veryhachium,* and *Villosacapsula*. Chitinozoan genera present are: *Ancyrochitina, Conochitina, Cyathochitina, Desmochitina,* and *Hercochitina*.

The acritarchs from the Arnheim and Waynesville formations are generally comparable to Richmondian assemblages from the Sylvan Shale of Oklahoma and Maquoketa Shale of the Kansas subsurface. Many of the acritarch genera from the Richmondian of Indiana appear to range through the Cincinnatian Series and are present in the Edenian; however, there appear to be sufficient differences at the species level to allow differentiation of Richmondian from Edenian. Acritarchs from the intervening Maysvillian Stage have not been examined from Indiana.

Chitinozoans from the Richmondian of Indiana show some similarity to Upper Ordovician assemblages from Oklahoma and Anticosti Island but differ by having *Cyathochitina hyalophrys* Eisenack 1959, an apparent Cincinnati area endemic species. [34]

Palynology of Upper Dakota Formation Lignites from Northwestern Iowa and Northeastern Nebraska

ROBERT L. RAVN, Amoco Production Co., New Orleans, LA; DONALD L. WHITLEY, Amoco Production Co., 6425 Bankside No. 2113, Houston, TX 77096

The upper portion of the Dakota Formation in its type area of northwestern Iowa and northeastern Nebraska contains lignites and lignitic clays that yield well-preserved pollen and spore assemblages of early Cenomanian

age. Two Iowa lignites from the uppermost Dakota localities of Sergeant Bluff and Stone State Park near Sioux City produced particularly rich assemblages, dominated quantitatively by *Gleicheniidites* spp. and *Dictyophyllidites* spp. The Sergeant Bluff seam contains abundant schizaeaceous fern spores of numerous species of *Cicatricosisporites* and *Appendicisporites*. Stratigraphically significant less common taxa present include *Microreticulatisporites uniformis, Lycopodiumsporites expansus, Trilobosporites purverulentus, Triporoletes laevigatus, Cicatricosisporites crassiterminatus, Klukisporites pseudoreticulatus, Undulatisporites undulapolus, U. pannuceus, Equisetosporites virginiaensis, Stephanocolpites tectorius, Artiopollis indivisus* and rare *Corollina (Classopollis) torosus*.

The Stone Park lignite assemblage was equally well preserved but less diverse, nearly lacking *Cicatricosisporites* spp. and having only rare specimens of *Appendicisporites potomacensis* and *A. tricornitatus*. Lignitic shales from several localities produced sparse miospores generally dominated by *Gleicheniidites* and *Dictyophyllidites*. Angiospermous pollen is of minor importance in all samples examined, and consists of reticulate and scabrate monocolpate, tricolpate and extremely rare tricolporate forms, further suggesting an early Cenomanian age.

The miospore flora of the upper Dakota in Iowa and Nebraska is comparable in most respects to those reported from the Dakota in Arizona and Utah, the Woodbine Formation of Oklahoma, and the Tuscaloosa Formation of the Gulf Coast. The presence of an early Cenomanian assemblage near the top of the Dakota suggests the possibility that the lower part of the formation, which consists mainly of sandstone, may be Albian. [39]

A Paleoecological Interpretation of the Francis Shale Formation (Missourian) Based upon Palynology and Invertebrate Paleontology

L. R. WILSON, School of Geology and Geophysics, University of Oklahoma, Norman, OK 73019; WILLIAM A. EDWARDS, Deceased

From a 40-foot section of Francis Shale (Pennsylvanian–Missourian) near Ada, Pontotoc County, Oklahoma, 63 species in 39 genera of palynomorphs have been identified. The following four environments are represented in the assemblage: (1) an "upland" vegetation consisting of species of *Illinites, Platysaccus, Leuckisporites, Potonieisporites* and other mono- and bisaccate forms, (2) a low-land coastal element consisting of *Calamospora, Punctatisporites, Triquitrites*, and others, (3) a marine biota of acritarchs, i.e. *Baltisphaeridium*, etc. and (4) recycled forms from the Devonian such as *Tasmanites*, and from the Mississippian, the genera *Densosporites, Vallatisporites*, and *Discernisporites*. The recycled palynomorphs are from sources that were exposed to erosion during Missourian time in the Arbuckle Mountains south of the Francis area of deposition. An analysis of the Francis Shale palynomorph assemblage reveals the following percentages of plant groups: Gymnospermae 68.9, Psilopsida 14.9, Lycopsida 5.5, Sphenopsida 4.5, Filicinae 2.9 and unknowns 3.2. *Potonieisporites* is the most abundant genus with 44.1 percent, *Punctatisporites* 8.7 and *Perisaccus* 7.2. The invertebrate fossils consist of an abundant marine assemblage of foraminifera, ostracodes, crinoids, and brachiopods all of which confirm the conclusion of shallow marine deposition and Missourian age of the Francis Shale. [47]

GSA Annual Meeting
Cincinnati, Ohio, November 2–5, 1981

The following abstracts are reprinted from *Abstracts with Programs* of the Geological Society of America, v. 13, no. 7. Page numbers are given in brackets below the abstracts. Permission of the authors and of John C. Frye, executive director of GSA, to reproduce the abstracts is gratefully acknowledged.

Interpretation of Proterozoic Basement in the Midcontinent

M. E. BICKFORD and W. R. VAN SCHMUS, Department of Geology, University of Kansas, Lawrence, KS 66045; and I. ZIETZ, Phoenix Corp., Reston, VA 22102

Geochronologic and petrographic study of Proterozoic rocks in the midcontinent region, along with compilation of regional aeromagnetic data, has resulted in the following interpretations: The oldest terrane is the 1.85 b.y. old Penokean suite of the Lake Superior region. Rhyolite and epizonal granite formed 1.76 b.y. ago in southern Wisconsin and are associated with widespread quartzite. 1.63–1.65 b.y. old granite and rhyolite in southwestern Wisconsin, northern Missouri, and northeastern Kansas suggests that a major igneous (orogenic?) belt extends from southeastern Arizona and southern New Mexico across the midcontinent to the Great Lakes region. Numerous 1.47 b.y. old granites intrude older rocks in the midcontinent and are part of a major belt of anorogenic plutons of similar age that extends from southern California to Labrador. Rhyolite and epizonal granite of this age underlie southeastern Missouri and may comprise much of the basement in Illinois and Indiana. A similar terrane formed about 1.37 b.y. ago in southwestern Missouri, southern Kansas, and Oklahoma, and distinctive plutons 1.34–1.36 b.y. old occur in eastern Kansas and western Missouri. Many of the terranes have distinctive magnetic anomaly signatures, aiding in their mapping.

The decrease in age from north to south and the apparent scarcity of mafic rocks indicate that intracratonic rifting was not a likely cause for the formation of these rocks. Nor is plate motions over hotspots an attractive possibility. These terranes probably formed during successive events on the southeastern margin of the growing Proterozoic continent. A possible model is that convergent plate events formed calcalkaline suites about 1.85

and 1.65 b.y. ago. Following each of these, melting of tectonically thickened crust, possibly with some extensional stress, produced large volumes of high-silica granitic magma. [410]

Origin of Middle Proterozoic Granitic and Rhyolitic Rocks in the Midcontinent Region of North America

M. E. BICKFORD and W. R. VAN SCHMUS, Department of Geology, University of Kansas, Lawrence, KS 66045

A major question in Proterozoic evolution of North America is the origin of the floods of rhyolitic to dacitic rocks and associated epizonal plutons that characterize the midcontinental region. The St. Francois Mountains of southeastern Missouri are a major window on this mostly buried terrane that extends from northern Ohio across the midcontinent and into the Texas Panhandle. In this terrane, bounded on the north by the 1850–1880 m.y. old calcalkaline suite of the Penokean region, granite and rhyolite formed 1760 m.y. ago in southern Wisconsin, 1610–1650 m.y. ago in Iowa and northern Missouri and Kansas, 1450–1480 m.y. ago in Illinois and southeastern Missouri, and 1360–1380 m.y. ago in southwestern Missouri, southern Kansas, and Oklahoma. Rocks of the 1450–1480 m.y. old suite, apparently emplaced as isolated plutons in older rocks, occur in central Wisconsin, central Missouri, and Kansas. Similar rocks, formed 1420–1450 m.y. ago, occur in Colorado and the southwestern U.S. A distinctive suite of 1340–1360 m.y. old plutons occurs in western Missouri and eastern Kansas. The decrease in age from north to south and the scarcity of mafic rocks indicate that intracratonic rifting is not a likely setting for these rocks. Nor is their wide distribution easily reconciled with "hotspots" and plate motions. The terranes probably formed by successive events on the margins of the continent, but the rock assemblages are not similar to those of younger collisional plate margins. A possible model is that collisional events formed calcalkaline suites about 1880 and 1650 m.y. ago and, following each, crustal melting produced floods of rhyolite magma. [410]

Evolution of Eostaffellid Foraminifers in Late Chesterian (Late Mississippian) Strata of the North American Midcontinent

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Calcareous foraminifers of the Family Eostaffellidae, assignable to the genera *Eostaffella, Paramillerella, Millerella* and other as yet undescribed taxa, appeared and/or proliferated in late Chesterian strata within the Midcontinent. *Eostaffella* originated in the Eurasian realm during the early Visean but became widespread in North America only following the extinc-

tion of ecologically competitive *Eoendothyranopsis* in the late Meramecian. On the other hand, the earliest representatives of *Paramillerella, P. tortula* (Nodine-Zeller) and *P. designata* (Nodine-Zeller), apparently derived from an *Endostaffella discoidea* (Girty) ancestry in Glen Dean time and gave rise to *P. advena* (Thompson) (=*Millerella cooperi* Nodine-Zeller) during the deposition of the Kinkaid Limestone and equivalent strata. Primitive specimens of *Millerella* also appeared in Kinkaid time, or possibly earlier, following their evolution from paramillerellids or intermediate forms. They gave rise to more advanced species such as *M. pressa* Thompson in the overlying Morrowan (Early Pennsylvanian). The changes in the paramillerellid/millerellid lineages, in conjunction with the occurrences of other types of calcareous foraminifers, provide a biostratigraphic capability for subdivision of the late Chesterian in the Midcontinent. Similar eostaffellid successions have been reported recently from the southeastern United States, and elements of the fauna occur in the Cordilleran region although details of their stratigraphic distribution are yet to be determined. Furthermore, specimens illustrated from Japan, the Soviet Union and Great Britain suggest that these areas contain similar sequences which, when fully understood, may provide another means of intercontinental correlation. [416]

COCORP Seismic Reflection Traverse Across the Southern Oklahoma Aulacogen

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COCORP deep seismic profiles have been recorded across the Southern Oklahoma Aulacogen, from the Hardeman Basin in the south, through the Wichita Mountains and into the Anadarko Basin in the north. The data reveal new and surprising aspects of the basement structure and sedimentary cover deformation that require a revision of ideas about the history of this aulacogen.

An important Precambrian history to the area is indicated by distinctive layering in the basement south of the Wichita Mountains (to depths of about 13 km). The layering may be due, among other possibilities, to a Proterozoic Basin apparently pre-dating the aulacogen. The southerly and westerly extent of this inferred basin is unknown. The Precambrian layering is truncated on the south side of the Wichita Mountains, probably by Precambrian faulting (rejuvenated during the Pennsylvanian) and/or granitic intrusions. While some remnants of the layering may extend underneath the mountains, there is no evidence that it exists further north under the Anadarko Basin.

Compressional structures associated with Pennsylvanian deformation are very pronounced in the Anadarko Basin. The Wichita Mountains overlap the basin by up to 8–9 km along a moderately dipping thrust fault. Sedimentary rocks in the basin are deformed into anticlines which in some cases may be related to listric thrust faults.

Thus the Wichita Mountains lie on the northern boundary of what may be a Proterozoic basin, and on the southern boundary of the Anadarko Basin. The Precambrian structures revealed by these data may have influenced the early evolution of the aulacogen. Present structures within the aulacogen suggest a large component of compressional deformation in Pennsylvanian times. [416]

Thin Black Pennsylvanian-Age Shales of the Mid-Continent U.S.—A Neglected Metallic Resource?

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Spectrographic analyses (AA, ICAP, XRF), fire assays and colorimetric techniques show certain thin (≤ 1m), organic-rich, black shales from Mid-continent Pennsylvanian-age cyclothems to be relatively enriched in metals of economic interest. For example, over hundreds of square miles, portions of the Mecca Quarry and Logan Quarry shales of Illinois and Indiana contain 3–10,000 ppm Zn, 1–5,000 ppm V, 5 ppm Ag, and, in the vicinity of ancient shorelines, ≥ 1000 ppm Mo and ≥ 150 ppm U. In Missouri, Kansas and Iowa similar shales of Pennsylvanian age, such as the Hushpuckney shale of the Kansas City group, also contain anomalously high quantities of heavy metals. In all of these shales some heavy metals occur as discrete mineral grains (*e.g.* Zn as sphalerite), whereas others seem to be dispersed within organic matter or absorbed on clays (*e.g.* Mo?).

In the past, organic-rich Pennsylvanian-age shales were considered to be sub-economic, in part because of the costs of mining such extremely thin units. Now, however, many such shales are routinely excavated from the overburden of coal seams. Hence, in view of present-day mining practices and the pervasive nature of their heavy metal mineralization, such units now warrant renewed investigation as possible sources of metals for critical national needs. (Moreover, there may be possible fringe benefits in the realm of pollution control which would tend to partly offset the costs of mining.) Nevertheless, both extraction tests and additional field studies in search of particularly enriched areas are sorely needed in order to form an adequate basis for determining the true economic worth of these units. [432]

Diagenesis of Pennsylvanian Fan-Delta Sandstones and Interbedded Shelf Carbonates, Texas Panhandle

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Fan deltas prograded from the Amarillo Uplift onto a shallow shelf in the southern Anadarko Basin during Late Pennsylvanian (Missourian) time. The mineralogy of the fan-delta sandstones—lithic arkoses and arkosic litharenites—reflects the composition of the Precambrian granites and granodiorites that were exposed in the nearby source area. Shallow marine carbonates were deposited between periods of clastic influx, and older distal-fan sandstones were commonly reworked into high-energy grainstone environments such as oolite shoals.

The interbedded terrigenous clastics and carbonates underwent a complex, interrelated diagenetic history with increasing burial. 1) The establishment of a freshwater, phreatic environment in the sediments soon after deposition caused solution of aragonitic fossils and oolites and precipitation of equant calcite cement in the carbonates and fossiliferous sandstones. Neomorphism of micrite to microspar occurred at this time. In unfossiliferous sandstones, the earliest cement was pore-lining, authigenic chlorite, which probably formed during early burial. 2) At greater burial depths minor quartz and feldspar overgrowths precipitated on exposed grains, including terrigenous oolite nuclei within oomoldic porosity. Chlorite cement probably inhibited quartz precipitation, but the low volume of quartz overgrowths (< 1%) suggests that the silica source was also limited. 3) Late-stage Fe-calcite and ankerite cements filled much of the remaining porosity and partially replaced feldspars and calcite in calcareous sandstones and carbonates. Unfossiliferous sandstones contain less of these late cements and generally retain higher porosity. 4) Solution and kaolinization of feldspars continued after carbonate cementation. Rare anhydrite and celestite were the last authigenic cements to precipitate.

[1]Publication authorized by Director, Bureau of Economic Geology, University of Texas at Austin, Austin, Texas.

Variations in Scale and Mechanism of Deformation in a Polyphase Fold System: Environment of Deformation and Deformation Mechanisms Noted in Some Mesoscopic Folds from the Core Area, Ouachita Mountains, Arkansas

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Evidence of cataclastic flow, fracturing, interlayer slip, and pressure solution is seen in tightly folded rocks exposed in the core area of the Ouachita Mountains. These rocks underwent several phases of deformation. The dominant deformation mechanisms differed during each of the phases, depending on the state of the rock and the environmental conditions at the time of deformation. An overburden pressure of 414 MPa and a temperature of 380° C are calculated, assuming normal lithostatic and geothermal

gradients; these are reasonable estimates of the pressures and temperatures at the time of deformation.

Intergranular flow was the dominant mechanism during the formation of the oldest folds. Many of the folds probably represent soft sediment deformation structures which formed during, or soon after, deposition. Pressure solution facilitated the development of a slaty cleavage associated with the folds. The second and third deformation phases involved flexural slip and flexural flow folding. Flexural slip folding is observed in chert, siliceous shale and clayey shale sequences where the ratio of chert to shale thickness is at least 7:1. Cataclastic flow and fracturing are seen in the folds, indicating rocks behaved in a semi-brittle fashion. Flexural flow folds formed in interbedded shale and chert section with a shale to chert thickness ratio of at least 2:1. Both chert and shale beds show thickening at the hinges of the folds and thinning on the limbs without evidence of much fracturing.

The difference in deformation mechanisms between the different deformation phases indicate a change from a ductile regime to more brittle conditions as the Ouachita orogeny progressed. [455]

High "Homogenization" Temperatures for Sphalerite Fluid Inclusions from Southwestern and Southern Kansas

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Minor occurrences of metallic sulfides are common and widespread in Paleozoic carbonate rocks in the Mid-Continent area (Goebel 1966). As shown by Coveney and Goebel (1981), where specimens of these are recovered as insoluble acetic acid residues from carbonate rock cores, or from un-heated cuttings, they are useful (especially clear sphalerite) in fluid inclusions homogenization temperature determination.

Homogenization temperatures measured in sphalerite specimens from D. L. Evans' (1962) Ordovician occurrences in southwest Kansas are uniformly high, but extremely erratic, ranging mostly from 150–270° C. As far as can be determined, after the cuttings from which these specimens were recovered, the cuttings were washed, then dried in gas ovens at extremely high temperatures. Our observed high temperatures are most likely artifacts, caused by induced leakage and stretching of the fluid inclusions during the drying operation. Therefore, fluid inclusion workers should be aware of the post-recovery heating history of specimens from oil and gas explorational borehole drilling.

Known ore districts characteristically have homogenization temperatures greater than 100° C. We have measured filling temperatures of from 90–120° C from un-heated surface samples of sphalerite from Pennsylvanian-aged rocks located in southern Kansas far to the west of the Tri-State District. Our measured temperatures are well within the range of temperatures common in the Tri-State District. This area of high temperatures in

Elk and Montgomery Counties, Kansas, may be indicative of nearby undiscovered ore-grade deposits. [460]

Calcareous Microfossils from the Type Morrowan (Lower Pennsylvanian) Region of Northwestern Arkansas and Northeastern Oklahoma

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Type Morrowan (Lower Pennsylvanian) rocks of northwestern Arkansas and northeastern Oklahoma are distinguished from underlying late Chesterian strata by the appearance of the calcareous foraminifers *Millerella marblensis, M. pressa, Planoendothyra spirilliniformis, P. evoluta, Eostaffella pinguis,* and *Monotaxinoides transitorius* and the algae *Archaeolithophyllum missouriense, Cuniephycus texana* and *"Cribroporidium"* (*nom. nud.*). *Millerella pressa, M. marblensis* and *Monotaxinoides transitorius* may prove to be reliable indices at the Mississippian–Pennsylvanian boundary across North America.

The appeareance of *Hemigordius harltoni* in the upper Brentwood Limestone (northwestern Arkansas) and at the base of the Brewer Bend Limestone (northeastern Oklahoma) provides the basis for an informal local two-fold chronostratigraphic subdivision of the Morrowan Series. The appearance of *H. harltoni* in the type Morrowan region coincides closely with the base of the *Idiognathodus sinuosis* Conodont Zone, and falls within the *Branneroceras branneri* Ammonoid Zone and the *Plicochonetes*? *arkansanus* Brachiopod Zone. *Hemigordius harltoni* appears slightly below the base of the *I. sinuosis* Zone in Nevada (Bird Spring Fm.) and within the *I. sinuosis* Zone in Texas (Marble Falls Fm.), yet its interregional chronostratigraphic integrity is still largely untested. Future studies aimed at critically evaluating Morrowan foraminiferal successions are urgently needed.

The primitive fusulinids *Eoschubertella, Pseudostaffella* and *Profusulinella* were not recovered from type Morrowan rocks. Thus, there is no local evidence supporting a Morrowan age for any portion of the ranges of those taxa. Use of the appearance of *Eoschubertella* and *Pseudostaffella* by many workers to indicate the base of the Atokan Series is consistent with knowledge of the type Morrowan succession. [465]

Tectonic Influence on Foreland Basin Sedimentation: the Hartshorne Formation of the Arkoma Basin

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The Desmoinesian Hartshorne Formation of the Arkoma Basin was deposited in an elongate, west-plunging, peripheral foreland basin during Ouachita suturing. Geometry of fluvial and deltaic channel deposits and

paleocurrent data indicate that detritus entered the eastern portion of the basin from the north, south, and possibly east. Major channels merged near the eastern axis of the basin and flowed longitudinally westward through the basin. Petrographic data support these inferences; sands derived from the south (Ouachita orogen) are rich in slate rock fragments and plagioclase and deficient in chert relative to sands derived from the north (North American craton).

Within the basin, Hartshorne detritus was deposited in a tidally-influenced, high-constructive deltaic system. Facies characteristics which suggest a fundamental structural influence on sedimentation include elongate distributary channel geometries within facies packages otherwise suggestive of a lobate delta, longitudinal orientation of major channel facies within the basin, evidence of multiple delta lobe progradations longitudinally westward within the basin, vertical stacking of distributary channel facies in superjacent lobes, and the presence of a major coal split which defines a hinge line on the cratonic side of the basin.

Longitudinally-oriented deltaic facies tracts in the Hartshorne Formation contrast markedly with the transverse orientation of similar facies tracts in other foreland basins and probably reflect the influence of diachronous, westward-migrating Ouachita suturing on foreland basin sedimentation.

[476]

Basement–Allochthon Interactions, Eastern Overthrust Belt (Texas to Quebec)

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In the Appalachian Mountains, from the Marathons to the Gaspé Peninsula, Devonian to Permian thrusting exhibits four style elements, from oldest to youngest: (1) basement-involved sheets, transported 50 to 250 km over cratonic sediments, (2) thin-skinned thrust sheets of cratonic sediments and foredeep fill, (3) imbricates of basement beneath earlier sheets (elements 1 & 2), and (4) late imbricates in the earlier basement-involved sheets (element 1). Style differences, evident in map view and in sediment thickness, are also apparent in the strain contributed by each element. Timing and habitat of mesofabrics and the interaction between thin-skinned and basement tectonics constrain thrusting models and plate tectonic scenarios.

Basement shows four styles: (1) elastic downwarp of craton, edge-loaded by cooling oceanic crust and Airy-loaded by sediments, (2) elastic-plastic downwarp, with normal faults soling in [intracrustal] décollements, (3) low-angle thrusting, (4) higher-angle thrusting and folding. Downwarp and detachment of type (2) originate by subduction or by underthrusting beneath type (4) massifs, in both cases as early stages of type (3) thrust slabs. Thin-skin externides contain décollements, ramps, and blind thrusts. Branch thrusts, folds, and spaced cleavage shorten and thicken the thrust wedge, whose surface slope interacts with foredeep sedimentation.

Transport prograded downward and forward; retrogression locally produced fold-discordant thrusts. Correlation of low-angle thrusting between basement and externides is good, but the structural response of the externides upon the rise of type (4) massifs is unknown. Strain rates, the ages of Piedmont plutons, and the 110 m.y. timespan (Devonian to Permian) of deformation are consistent with thrusting antithetic (conjugate) to a subduction zone dipping beneath the craton. [539]

Cambrian Denudation Rate—Evidence from the Reagan Sandstone, Oklahoma

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The rate of denudation during Cambrian time in the Wichita Mountains of Oklahoma is estimated to be in the range of 600 to 1200 millimeters per thousand years. Petrographic examination of the Reagan Sandstone reveals the presence of unaltered plagioclase and potassium feldspars in the upper portion of the formation. The influx of locally derived feldspars results from the erosion of the Carlton Rhyolite and the subsequent exposure of the Raggedy Mountain Gabbro and Wichita Granite. The removal of the rhyolite capping the core area of the Wichita Mountains is recorded by the appearance of abundant feldspar in the Reagan strata. The denudation rate is calculated by dividing the thickness of the Carlton Rhyolite by the time interval between the rhyolite formation and the deposition of upper Reagan strata. The calculated denudation rate is comparable to modern mountainous regions of considerably greater relief, suggesting that a combination of high weathering rates resulting from a tropical paleolatitude location, and the lack of land plants enhanced erosion rates on the low relief highlands of the Cambrian Wichita Mountains. [549]

Paleoecologic Response and Cyclothemic Phase of *Neochonetes granulifer* from the Midcontinent Pennsylvanian

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Neochonetes granulifer collected from late Desmoinesian to late Missourian rocks in Kansas, Missouri, and Oklahoma were subjected to multiple discriminant function analysis using 14 external shell characters. The position of groups and characters within multidimensional space are displayed by embedding them with a sine-cosine function. The plotted display of groups indicates that morphologic adaptations to paleoenvironments present during various phases of the Kansas-type cyclothem are distinct from one another. This is especially true for those paleoenvironments represented by core shales and adjacent portions of underlying and overlying limestones (offshore, deep, quiet waters) and outside shales (nearshore, shallow water). These findings support similar studies for two other species of brachiopods (*Chonetinella alata* and *C. flemingi*) and are in close agreement with Heckel and Baesemann's (1975) view of large scale oscillations for Pennsylvanian cyclothemic development.

Specimens from shallow water shales tend to exhibit characteristics suitable for stabilization in relatively firm substrates with comparatively high flow regimes. Specimens from core shales exhibit adaptations toward very soft substrates and quiet water conditions, thought to have existed during the maximum transgression phase of a Kansas-type cyclothem. Those from middle and upper limestones, situated respectively on either side of a core shale, exhibit characteristics of an intermediate nature, depending upon proximity to the core shale and maximum transgression. [559]

Pseudomonocyclic and Pseudodicyclic Crinoids: New Problems in Crinoid Classification

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The contrast between crinoid cups with one circlet of plates below the radials (monocyclic) vs. two circlets of plates (dicyclic) has long been a major morphologic difference used to classify crinoids. Paleozoic inadunate and camerate crinoids are both subdivided into monocyclic and dicyclic groups which are considered as separate orders within these subclasses. It is unlikely that these crinoids could easily change from true monocyclic to true dicyclic or vice versa; this statement might be termed Warn's Rule. This classification is reasonable as long as pseudomonocyclic crinoids (derived from dicyclic ancestors by loss of infrabasals) or pseudodicyclic crinoids (derived from monocyclic ancestors by development of infrabasals) are rare or nonexistent. However, two examples of these unusual designs have recently been discovered in the Middle Ordovician Bromide Formation of Oklahoma.

One and perhaps both species of *Hybocrinus* from the Bromide are pseudomonocyclic with stem pentameres centered below the basals; this may imply that all hybocrinids (seven genera total) are pseudomonocyclic. Hybocrinids are now classified in the Order Hybocrinida and allied with the monocyclic Order Disparida, which they do not closely resemble. If they were derived from dicyclic ancestors by the loss of infrabasals, they should instead be allied with the dicyclic Order Cladida. This origin would explain many of the unusual features seen in hybocrinids, which show many similarities to some early large-calyx cladids.

A new rhomb-bearing camerate crinoid from the Bromide is the first pseudodicyclic crinoid ever described. This unusual crinoid has a nearly square stem with tetrameres centered below the infrabasals, four infrabasals and basals, respiratory rhombs between nearly all cup plates, and apparently non-pinnulate arms. It was probably derived from a monobathrid ancestor and should perhaps be classified with this group, even though it does not closely resemble any other camerate crinoid. [559]

An Approach to the Interpretation of Spring Water Geochemistry

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In order to access the factors affecting spring water, 91 springs from a 130 X 140 km area west of Hot Springs National Park, Arkansas to the Oklahoma border and precipitation at a site north of the springs have been analyzed and compared. Precipitation, the recharge water, has its concentration altered by (1) concentration by evapo-transpiration, (2) addition of elements, mainly from solution of rocks, and (3) absorption-desorption equilibria with soil and rock. Process (1) evapo-transpiration increases the concentration of all elements. Thus in order to interpret the effect of processes (2) and (3), it is necessary to first remove the effect of evapo-transpiration (1) which may be done by normalizing all element concentrations to chloride. Based on elemental/Cl^- ratios, Na and Mg have been added to the recharge water by processes (2) and (3), K has been removed (2) and about equal numbers of springs have had Ca added (2) or removed (3). About one-third of the springs have dissolved significant amounts ($1.5 \times$ median values) of Fe, Mn and Zn from the rocks (2).

Variation of ground water temperature causes chemical differences among the springs. Six anomalously warm springs (temperature $> 21.1°$ C) generally contain more electrolytes, particularly Ca, than the other springs. Springs supersaturated with chalcedony contain more Ca, Na, K and Mg, and have higher specific conductivity than less saturated springs. The higher silica content of these 13 supersaturated springs is a reflection of their higher reservoir temperatures despite the cooling of the ground water as it travels to the surface. [560]

Geologic Applications of Upper Pennsylvanian Ichthyoliths from the Midcontinent Region

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Ichthyoliths (microscopic fish skeletal debris comprised mainly of teeth, dermal denticles and mucous membrane denticles) are abundant and diverse in a wide range of lithologies and often occur in horizons which are otherwise unfossiliferous. In addition, they undergo color alterations which are time and temperature dependent, making them useful in geothermometry. However, very few studies have dealt with Upper Paleozoic ichthyoliths.

In the present study I have attempted to assess the various geologic applications of Upper Pennsylvanian (Virgilian) ichthyoliths from the Midcontinent region with regard to their biostratigraphy, geothermometry and paleoecology. This study indicates a definite potential of Paleozoic ichthyoliths for various geologic applications. Many have short stratigraphic ranges and are not subject to facies changes. In addition, the reactions of ichthyoliths to high temperatures indicate that they will be most valuable for predicting the grade of hydrocarbon if present in the same unit in a manner similar to that of conodonts and palynomorphs. The color variations may also be used to recognize reworking of an assemblage since zonations of Paleozoic ichthyoliths have not yet been established. This study indicates that correlation by ichthyoliths is possible for rock units at least as fine as members and that their potential in biostratigraphy exceeds the limits of conodont biostratigraphy. This is due to the fact that the geologic range of ichthyoliths encompasses nearly the entire Phanerozoic and that they are not restricted to marine depositional environments. [570]

Aeromagnetic Signature of Ouachita Folded Belt

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A new aeromagnetic map of the United States in preparation by the U.S. Geological Survey shows several features related to the Ouachita folded belt. In Tennessee, Alabama, and Mississippi a series of southwest-bearing magnetic highs and lows, coincident with gravity highs and lows, is cut off abruptly at the approximate position of the Ouachita tectonic front. In Arkansas, a general decrease in intensity contours parallels the east west trending frontal margin of the Ouachitas. In Oklahoma and Texas, sharply-defined magnetic lineaments, paralleling the Arbuckle province, end southeastward at the Ouachita front. Farther south in Texas, a general decrease in intensity contours parallels the front, although here definition is not as clear. On the Gulf side of the Ouachita folded belt, the map shows little variation in magnetic intensity, whereas much variation in intensity is shown on the cratonal side.

To us, the aeromagnetic map indicates that the Ouachitas constitute a fundamental suture joining two plates. The difference in variation of magnetic intensity may indicate a continental basement seaward of the Ouachitas fundamentally different from that of the North American craton. The abrupt truncation of North American cratonal patterns may indicate limited subduction of cratonal rocks beneath the Ouachitas, and thus, the line of truncation may mark the Paleozoic continental margin. [573]

Aeromagnetic Coverage of the Mid-Continent U.S.A.

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A cooperative between the U.S. Geological Survey and the Society of Exploration Geophysics is underway to compile an aeromagnetic map of the

United States at a scale of 1:2,500,000. The earth's main field (IGRF) has been removed to emphasize the anomalous features of the upper part of the earth's crust.

There are many "first order" features which are apparent on the map, a few of which will be listed below:

1) The mid-continent feature, a probable rift of Keweenawan age extending from Minnesota to Kansas and containing as much as 40,000 feet of high density basalts. 2) The New York-Alabama lineament of King and Zietz which we now believe to be a major suture of Grenvillian age. 3) A surprising northwesterly grain in the magnetic basement rocks extending from western Montana in the Great Plains just east of the Rocky Mountain front to where it terminates at the New York–Alabama lineament in eastern Kentucky. It passes thru the transform fault in Kansas of the midcontinent feature and also is on line with the Ste. Genevieve fault. 4) In the northern Great Plains, the edge of the Superior Province as outlined by Green et al in Canada can be extended as far south as South Dakota. Similarly the granite/greenstone belt of Green et al can be extended from the Flin Flon area in a southerly direction to southern South Dakota. 5) In eastern Montana and western North Dakota a long linear anomaly extends in a northwesterly direction and cuts across the NACP anomaly of Camfield and Gough, suggesting that the latter is not a suture as proposed by Peterman. 6) In Arkansas and Mississippi a major lineament can be seen separating a highly magnetic crust to the north from a uniform non-magnetic crust to the south. It would appear that this lineament marks the edge of the North American craton which strengthens the conclusions of Viele and others, that it is the approximate location of a possible suture. [588]

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Clay Mineralogy and Depositional Environments of Upper Cherokee (Desmoinesian) Mudrocks, Eastern Kansas, Western Missouri, and Northeastern Oklahoma

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The Desmoinesian (Middle Pennsylvanian) rocks in Kansas, Missouri, and Oklahoma comprise alternating formations of limestones with shales and lenticular sandstones. The Cherokee Group (which includes the Lagonda interval) constitutes the lower part of the Desmoinesian Series, and principally consists of interstratified shales and sandstones with minor thin limestones and coals which are common as part of a regressive sequence of Pennsylvanian cyclic sedimentation.

During the Middle Pennsylvanian, eastern Kansas, western Missouri, and northeastern Oklahoma became an area of subsidence in both the Cherokee and Forest City basins. As regression occurred, prodeltaic muds followed by delta-front shales and sands were deposited.

Analyses of samples from outcrops and subsurface well-cores by petrographic methods including x-ray diffraction, has produced maps and cross-sections which illustrate clay mineral distributions. These data suggest that the Lagonda deltaic sequences prograded in a general westward direction, and they delineate the areal extent of deltaic lobes.

Clay minerals present in the Lagonda interval include kaolinite, chlorite, illite, and degraded illite. Their relative abundances on a time-stratigraphic plane reflect both source area and environment of deposition, while vertical changes demonstrate deltaic evolution through time. Microfossils support this observation by their presence or absence, and by their diversities and abundances. [105]

Early and Middle Paleozoic History of the Anadarko Basin

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The Anadarko Basin is a sedimentary–structural basin with the sediments dipping and thickening southwards to the Wichita Uplift. The Wichita Fault Zone has a stratigraphic throw of some six miles, and no post–Early Ordovician to pre–Late Pennsylvanian sediments are presently known from the uplift. Blocks of Hunton–Woodford strata within the fault system show evidence of late Paleozoic erosion, suggesting that the Wichita Fault System was quiescent during early and middle Paleozoic time, with movement starting after Woodford deposition, probably in late Mississippian–Early Pennsylvanian time. The lithofacies–lithostratigraphic characteristics of Ordovician through Devonian strata in the basin are similar to those in the Arbuckle Mountains, although the thickness has increased substantially. The paleoenvironmental pattern and regional distribution of these strata point to deposition in a widespread, shallow seaway which inundated the present Wichita Uplift. The depocenter of the basin during this time is inferred to have been in the position of the present Wichita Uplift. Hunton strata were affected by at least two periods of erosion, one in the Early Devonian (pre-Frisco, pre-Sallisaw), and a second in the Middle Devonian (pre-Woodford). Both uplifts were concentrated mainly on the margins of the basin, and deposition in the central part was probably continuous or nearly continuous. [105]

Evolution of the Ouachita Mountains

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The preponderance of deep water sediments (shales, cherts, turbidites) over "typical" miogeoclinal and paralic foredeep sedimentation in the exposed thrust belt not only requires a special tectonic depositional setting but also results in a distinct disharmonic structural style. Scarcity of reliable data in the subsurface portion of the Ouachita system still makes a reconstruction of Paleozoic events along the southern margin of North America a speculative undertaking.

After the opening of the Proto-Atlantic (Iapetus) ocean in late Precambrian normal passive margin subsidence was probably accelerated in Early Ordovician by down-to-south faulting creating a deep water terrace or plateau on which carbonate-deficient slope sediments of the Lower Ouachita facies were deposited (graptolitic and in part euxinic shales, cherts, turbidites). Closure of the Iapetus (from Mid-Ordovician to Permian) along a postulated northwest dipping Benioff zone did not noticeably affect sedimentation until Mississippian when accelerated subsidence and a massive influx of clastics initiated the flysch sedimentation that characterizes the Upper Ouachita facies in a back-arc setting. North vergent orogeny related to the beginning continental collision of Gondwana and North America can first be documented in the Atokan in the subsurface south of the Ouachita Mountains, although radiometric evidence points to an otherwise undocumented earlier Acadian (?) event. Flysch sedimentation continued, now in a foredeep setting, of a northward migrating orogenic front which reached the Arkoma basin by Mid-Desmoinesian. Final collision and removal of the Iapetus occurred in Late Pennsylvanian and Permian; this phase was accompanied by the basement uplift of the core areas (e.g., Waco–Broken Bow–Benton uplifts) accompanied by a pervasive thermal event, massive quartz invasion and south overturning of previously north vergent structures. [105]

Stratigraphic Analysis of the Cheyenne Sandstone Member of the Purgatoire Formation (Lower Cretaceous), Northwestern Cimarron County, OK

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Previous interpretations of the Cheyenne Sandstone are controversial and problematical. Depositional processes cited include fluvial and marine.

Recent field studies have revealed fining upward sequences and a vertical succession of cross-stratification types from medium scale troughs and a few tabular sets to small scale troughs and a few horizontal sets. Medium scale troughs typically show grain sizes fining upward. These features are tentatively interpreted as indicating a fluvial origin for the Cheyenne Sandstone in northwestern Cimarron County.

The top of the section at most localities is bioturbated suggesting transgression and reworking prior to deposition of the marine Kiowa shale. [106]

Regional Subsurface Analyses of Upper Cherokee (Middle Pennsylvanian) Siliciclastics, Eastern Kansas—A Preliminary Report

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In the past, stratigraphic and sedimentologic analyses of the Desmoinesian Cherokee Group have been concentrated along the outcrop belt of Kansas, Missouri, and Oklahoma. The true three-dimensional nature of these rocks is hidden beneath younger rocks to the west, and can only be determined by combining surface with subsurface data. A grid of geophysical well-log and core data has been gathered and stored in a computer file code-named "WELLGRID." These data have been used to generate a series of maps that suggest that siliciclastic units of the upper part of the Cherokee Group were deposited in fluvial–marginal marine settings, with the bulk of these sediments having been derived from the east and north. Informally referred to as the "Lagonda interval," these units consist of lenses of quartz arenites and subarkoses encased in a variety of mudrocks. Sandstones represent fluvially influenced distributary channels, delta-front bars and thin "destructional" sheets, while mudrocks represent prodeltaic, interdistributary and flood basin deposition. In addition, coal beds representing swamp environments associated with deltaic lobes and fluvial systems, and thin carbonate units formed as concentrations of marine skeletal materials, are scattered within the interval. The post-depositional history of "Lagonda interval" sandstones include calcite and iron-rich carbonate cementation, and partial solution of siliciclastic grains and early carbonate cements. Continuing analyses of geophysical well-logs and core materials in the Forest City and Cherokee basins will allow more detailed stratigraphic and paleogeographic interpretations to be made using expanded versions of "WELLGRID." [106]

COCORP Deep Seismic Reflection Profiling of the Southern Oklahoma Aulacogen

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COCORP deep seismic profiles recorded across the Southern Oklahoma aulacogen reveal new aspects of the style of deformation and the basement structure in this region. The Precambrian basement south of the Wichita Mountains is clearly layered, to depths of about 13 km, probably due to depositional processes that occurred in a Proterozoic basin, although other interpretations, such as layered igneous complexes, are possible. This layering is not seen on data recorded across the Anadarko Basin to the north of the Wichita Mountains, and thus the northern margin of the Proterozoic basin is inferred to underlie the Wichita Uplift. Truncations of deep reflectors in the deepest part of the Anadarko Basin can be interpreted as due to Early Paleozoic normal faults. The Wichita Mountains

thrust over the Anadarko Basin in Pennsylvanian times along a series of moderately dipping (average 30°–40°) faults (Wichita frontal fault system) that can be traced to 20–24 km depth. Sedimentary rocks in the basin responded by shortening along listric thrust faults and forming hanging-wall anticlines.

The Southern Oklahoma aulacogen is interpreted to have reactivated an ancient fault trend. It evolved from a stage of crustal extension (and normal faulting) and culminated in intense crustal shortening (10–15 km based on palinspastic reconstructions). Thus simple models for this aulacogen as related to radial rifting of updomed continental crust may have to be revised. An alternative stress system could have reactivated the ancient fault trend. [106]

Recent Exploration Drilling, Frontal Ouachita Mountains, Oklahoma

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Exploration for gas in the frontal imbricate zone of the Ouachita Mountains in Oklahoma has concentrated on evaluating the reservoir potential of the basal Atokan Spiro Sandstone. Although southward developmental drilling has stalled in the vicinity of the Choctaw Fault, Shell Oil Company recently drilled two wildcats in an attempt to extend Spiro production basinward. Seismic mappability of detailed structural configuration in this complex imbricate zone is difficult due to severe raypath distortion. Seismic data were used primarily to delineate general structural configuration and the presence or absence of Spiro Sandstone/Wapanucka Limestone reflectors.

The Shell, Williams #32–27 (Section 27, T–5–N, R–19–E) tested both a discrete thrust sheet east of the Kinta Fault and the basal, autochthonous Spiro Sandstone. In addition, the shallower Spiro–Wapanucka sheet which outcrops one mile to the north was encountered. The Shell, Retherford #1–24 (Section 24, T–4–N, R–17–E) was drilled three miles south of current production on the upthrown side of the Kinta Fault to test a seismically delineated, allochthonous Spiro–Wapanucka sheet not connected to outcrop. In addition to this basal allochthon, a shallower, thick section of outcropping Spiro Sandstone was encountered with no underlying Wapanucka Limestone. This section was similar to that drilled in the Shell, Mabry #1–9 (Section 9, T–4–N, R–18–E) three miles to the northeast.

The Spiro intervals in both wells were each represented by a minimum of 40 gross feet of very fine to fine-grained clean sand. Minor porosity development was due primarily to calcium carbonate cement with minor amounts of silica cement. The one exception, the shallow, outcropping Spiro Sandstone in the Williams well, contained 106 gross feet of sand, 54 feet of reservoir development, an average porosity of 6.5 percent and a water saturation of 98 percent. [107]

Ouachita Mountain Hydrocarbons

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Four varieties of hydrocarbons occur in the Ouachita Mountains: asphaltites, asphalt saturated rock, liquid oil, and gas. The occurrences increase in number and size from the easternmost in Scott County, Arkansas, to Atoka County, Oklahoma, following an arcuate pattern roughly parallel to the structural grain of the mountains. All known oil fields and seeps are within 30 miles of the southwestern end of the range; all but two are in the Stanley formation. Solid hydrocarbons were discovered in 1890; mining began in 1892. Oil and gas exploration, commencing in 1914, led to the discovery of several small oil accumlations downdip from asphaltic sandstone outcrops. Gas in sizable quantities was first found in 1920 but never produced. In the 1950's several wells reported shows of gas. Southwest Moyers, found in 1960, became the first commercial gas field. The Potato Hills gas field, discovered by Sinclair, also in 1960, was the result of nearly 20 years' geologic exploration by that company. Present activity is in McGee Valley, on the Jumbo anticline, and in the outer belt. Some wells will probably penetrate the thrust plate. Ouachita hydrocarbons originated in the Southern Oklahoma Aulacogen and, subsequent to the cessation of orogeny, migrated from the eastern end of the Arbuckles and the aulacogen. Carrier beds are widespread in the flysch sequence of the Ouachitas, permitting wholesale movement from the source area north and northeastward; thrust faults provided access to older, pre-flysch strata. Every porous rock from the Cambro-Ordovician to the Atokan is a potential petroleum reservoir. [107]

Numerical Simulation of the Alluvium and Terrace Aquifer Along the North Canadian River from Canton Lake to Lake Overholser, Central Oklahoma

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Alluvium and terrace deposits of Quaternary age, which cover an area of about 400 mi^2 along the North Canadian River between Canton Lake and Lake Overholser, locally yield 500 gallons per minute to wells. The deposits are as much as 100 ft thick and consist of varying proportions of clay, silt, sand, and gravel, with sand-sized material dominating. The underlying bedrock is Permian sandstone and shale. During 1980 the amount of water stored in the aquifer was estimated to be 4.00×10^{10} ft^3.

A digital model was used to determine the ability of the aquifer to continue to supply water for irrigation, industry, and domestic use. A block-centered, finite-difference model with 1 mi node spacing was used to project the amount and distribution of water in the aquifer for 1993. The model calibration criteria were the aquifer discharge to the North Canadian River and the difference between computed and measured heads. The model was calibrated using a recharge rate of 1 in/yr, a hydraulic conductivity of 4.5×10^{-4} ft/s and a specific yield of 0.16.

Model simulations using the 1979 pumping rate, a projected pumping rate, and double the projected pumping rate were made to 1993. With the 1979 pumping rate, the volume of water in storage would be 3.88×10^{10} ft^3 and aquifer discharge to the stream would be 10.9 ft^3/s. With the projected pumping-rate increase, the volume of water in storage would be 3.81×10^{10} ft^3 and aquifer discharge would be 6.91 ft^3/s. At double the projected pumping rate, the volume of water in storage would be 3.74×10^{10} ft^3 and the aquifer discharge would be 2.93 ft^3/s. [107]

Siluro-Ordovician Source for Oils of the Western Ouachita Mountains

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Crude oils from Redden, Bald, South Bald and North Daisy fields in Atoka and Pittsburg Counties of southeastern Oklahoma were examined. Stanley through Womble (i.e., Mississippian through mid-Ordovician) rocks were evaluated as potential source rocks for these oils. The following geochemical parameters were determined for both the oils and the extractable organic matter of the rocks: n-alkane, sterane and hopane distributions; stable carbon isotope ratios; vanadium:nickel ratios. Results indicate that the oils are of the same family, and were sourced from Siluro-Ordovician (i.e., Missouri Mountain–Polk Creek–Womble) rocks.

Oil seeps and severely altered oils (solid bitumens) are present throughout the stratigraphic section in the western Ouachitas. Significant vertical migration from source rock to present-day reservoir is implied. The following indirect evidence suggests that migration is accomplished via listric reverse faults in the frontal structural belt of the western Ouachitas. (1) All fields examined are located within 7 km of the surface trace of a major frontal fault, and all produce from depths less than 125 meters. (2) Most of the solid bitumen deposits are also located within 7 km of a major fault. Further, field and laboratory observations suggest that these materials are degraded oils which have accumulated in ancient faults and fissures. It is also relevant that these solid bitumens become less viscous with depth. (3) Oils and solid bitumens are reservoired as far upsection as the Pennsylvanian Jackfork Group, yet are sourced from rocks as old as the (mid-Ordovician) Womble Formation.

The cumulative weight of these observations indicates that oil sourced in the Siluro-Ordovician has migrated vertically along listric reverse faults in the frontal belt of the western Ouachita Mountains. [108–109]

Mississippian Radioactive Marker Beds in West Texas and Their Possible Relationship to the Ouachita Orogeny

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Explosive vulcanism during the Ouachita Orogeny contributed pyroclastic debris to the Mississippian Stanley Group of Arkansas, Oklahoma and East Texas. Gamma log responses within the Mississippian shales of West Texas suggest three, thin widespread radioactive markers that may be distal airfall deposits from an easterly volcanic source, and possible correlatives of three major explosive events documented in the Ouachita Mountains. Another potential source for these possible air fall deposits may be volcanoes in the Marathon part of the Ouachita-Marathon trend.

Regardless of these interpretations relative to the historical geology of the Ouachita Mountains, these highly radioactive markers are excellent rock-stratigraphic keybeds and may also be quasi–time lines. [109]

Basement Framework of the Anadarko Basin

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The location, structural direction and style and sedimentation of the Anadarko Basin are strongly influenced if not totally dependent on the basement framework. The N60°W structural grain, later to be the axis of intense late Paleozoic deformation, is first recognized in 1300–1400m.y. old diabase and granitic dikes in the Arbuckle Mountains.

Although little is known of the basement north of the Wichita–Anadarko trend the best evidence extrapolated from areas well away from the basin suggests that the shelf area is probably underlain by massive 1300–1400m.y. granites. To the south recent COCORP data have revealed an undeformed layered sequence of rocks about 10 km thick. These are probably clastic and rhyolitic rocks deposited and extruded during the interval between 1200 and 1400m.y. These layered rocks are truncated on the south side of the Wichita Mountains.

Extension along a major rift zone parallel to the old dike direction in earlier Cambrian time initiated the Anadarko Basin as we know it. This led to a sequence of basalts and graywackes intruded by large layered gabbroic masses. Following a period of brief but intense uplift and erosion the area was covered by a giant rhyolite field intruded by comagmatic granites. The late Cambrian seas transgressed over this volcanic field and deposited the enormously thick sedimentary rocks of the present Anadarko Basin.

Were it not for a lengthy and complex basement rock history, southern Oklahoma might well look like Kansas. [109]

Metamorphism in Ouachita Rocks

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The first workers in the central Ouachita Mountains recognized significant metamorphism of the sedimentary rocks. The discovery of significant hydrocarbons within Ouachita facies has stimulated a renewed interest in the type and extent of metamorphism affecting these rocks. Older rocks in the core area were subjected to greenschist facies metamorphism with an assemblage that includes muscovite, chlorite, biotite, albite, phlogopite, rutile, sphene, epidote, tourmaline, various iron sulfides and graphite.

The metamorphism increases density of shales, eliminates primary porosity in potential reservoir rocks, causes an erratic magnetic susceptibility to be developed and eliminates any further hydrocarbon potential from organic-rich units.

K/Ar ages on metamorphic mica suggest Early Permian metamorphism but this may be too young. Geologic evidence indicates deformation affects mid-Pennsylvanian rocks. A number of samples along the Ouachita fold belt yield older K/Ar ages suggesting an earlier Silurian–Devonian metamorphic episode. Past regional studies indicate the metamorphism cuts across structural grain and stratigraphy affecting some areas significantly removed from the core areas. A few wells along the trend penetrated foreland rocks beneath metamorphosed Ouachita rocks. In every well the foreland rocks show the same degree of metamorphism as the overlying Ouachita facies. [109]

The Blue Creek Canyon Fault in the Slick Hills, Southwestern Oklahoma

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The Blue Creek Canyon Fault, an important element of the Wichita frontal fault zone, separates the Blue Creek horst to the north and east from the Lawtonka graben to the south and west. The fault is only seen at the surface in Blue Creek Canyon, where it is a north-south trending structure. Elsewhere in the subsurface the fault trends northwest-southeast (in common with other major faults in the region).

In Blue Creek Canyon the fault has previously been interpreted as a normal fault with a downthrow to the south and west. Recent detailed mapping has shown it to be a high-angle reverse fault which has thrust the Carlton Rhyolite, the Timbered Hills Group, and the lower (Cambrian) part of the Arbuckle Group over Ordovician members of the Arbuckle Group. The Ordovician formations (within the Lawtonka graben) are generally folded along northwest–southeast axes. However, adjacent to the fault, fold axes appear to have been rotated by the thrusting movement so that they now trend N20°W and have a consistent plunge in that direction.

The east–west compression indicated by this analysis of the Blue Creek Canyon fault could have generated left-lateral strike-slip movements along major northwest–southeast trending faults in the area. [110]

The Unconformity Between the Timbered Hills Group and the Carlton Rhyolite, Blue Creek Canyon, Slick Hills, Southwestern Oklahoma

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The unconformity between the Cambrian Carlton Rhyolite Group and the overlying late Cambrian Timbered Hills Group is exposed in the folded and faulted terrain of the Blue Creek Canyon area. In the north of the area, where the Carlton Rhyolite consists of tuffaceous sediments, the unconformity is planar. To the southwest, where the Carlton Rhyolite Group consists of lava flows, the unconformity is very irregular. There is an onlap to the southwest of approximately 200 ft in one-half mile. Consequently the Reagan Sandstone Formation is only exposed in the north of the area; in the south of the area the Honey Creek Formation rests against the rhyolite.

Two distinct facies occur in the Reagan Sandstone Formation: (1) medium-grained, well sorted quartz-rich sandstone characterized by medium- to large-scale cross bedding (possibly of aeolian origin), (2) fine-grained highly glauconitic sandstones characterized by small- and medium-scale cross bedding (possibly a marine shoreline facies). The overlying Honey Creek Formation consists of highly fossiliferous biosparites. Principal fossils are pelmatozoans (largely fragmented) and orthid brachiopods. The broken pelmatozoans form sand bodies characterized by medium-scale cross bedding, whereas the brachiopods appear to have formed partially stabilized banks. The transition zone between the Honey Creek and Reagan Formations is marked by interbedded lime and quartz–glauconite sand layers. [110]

Fusulinids of the Atoka Formation, South-Central Oklahoma

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Fusulinids are found at several horizons in rocks of Middle Pennsylvanian age in the Atoka Formation in the Arbuckle Mountains region west and northwest of Atoka, Oklahoma. Outcrops are poor and the calcareous beds that yield fusulinids are generally thin and discontinuous. The limestones are mostly detrital containing a high percentage of clasts of organic debris. The fusulinids tend to be abraded or broken. The fusulinid-bearing beds all seem to represent the upper part of the Atokan as it is generally understood. Fusulinids of the lineage *Profusulinella copiosa, P. munda*, and *P. decora* are not represented, but they are not found in midcontinent, Illinois basin, or Appalachian basin deposits. The earliest fusiform fusulinid present is a *Profusulinella* related to *P. kentuckyensis* Thompson and Riggs and stratigraphically higher forms are advanced to the *Fusulinella* stage through the development of an inner tectorium in the outer volutions. *Millerella* and several small foraminifera are also present. [110]

Potential Contamination of the Roubidoux Aquifer by Water from Abandoned Zinc Mines, Northeastern Oklahoma

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The Roubidoux Formation (Early Ordovician), a major source of ground water in northeastern Oklahoma, is generally between 500 and 1,500 feet below land surface and consists of a sequence of sandstone and cherty dolomite that averages about 150 feet in thickness.

The Boone Formation (Mississippian), which is about 500 feet above the Roubidoux, consists of chert, limestone, and dolomite, and is 350 to 400 feet thick. Abandoned zinc mines in the Boone Formation contain water with high concentrations of cadmium and lead.

Separating the Boone from the Roubidoux are more than 500 feet of rocks of the Jefferson City and Cotter Dolomites (Early Ordovician). Both formations have a minimal permeability, which may retard downward migration of mine water except where the formations are intersected by fractures.

In the early 1900's, the potentiometric surface of the Roubidoux aquifer was above land surface and wells in the aquifer flowed. Pumping from deep wells has lowered the potentiometric surface more than 450 feet below land surface and in places is as much as 100 feet below the mine floors.

Several deep wells in the mined area developed leaks in the casings that allowed contaminated water from the mines to migrate down the well bore into the Roubidoux Formation. These wells have been repaired or have been plugged. However, the potential for contamination by toxic waters still exists if well casings of other wells develop leaks. The hydraulic properties of fractures in the Jefferson City and Cotter Dolomites are unknown. If these fractures are capable of transmitting water, they represent an additional pathway for potential contamination of the Roubidoux. [110]

The Nemaha Uplift—Tectonic History and a Case for Wrench Fault Tectonics

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One of the most significant tectonic features in the central Mid-Continent is the Central North American Rift System (CNARS). In Kansas and Oklahoma the Nemaha Uplift basement block is located east of, and in inferred fault contact with, the CNARS. The structural evolution of portions of Kansas, Oklahoma, and Iowa can be explained within the context of a wrench-transpression tectonic model.

The CNARS in Kansas is a buried north-northeast trending southern extension of the 1.1 b.y. Keweenawan rift system which crosscuts preexisting Precambrian terrane. Stratigraphic data indicated that uplift of the Nemaha block initiated the separation of the Forest City and Salina basins during the early Osagian Stage (Mississippian). Continued uplift of the Nemaha Anticline and initial development of the Abilene Anticline and Irving Syncline occurred from the late Mississippian–early Pennsylvanian through the Permian(?). Uplift may have occurred in response to left-lateral wrench faulting in the basement complex along the preexisting Humboldt and other northeast-trending zones as a result of north-northwest horizontal compressive stresses related to the Ouachita orogeny. Structural elements are compatible with a 2-layer basement-sediment model.

Cretaceous ultramafic and alkalic intrusions were emplaced along fractures which appear to have opened in response to right-lateral wrenching along northeast-trending fault zones. This opposite sense of movement appears to reflect a reorientation of principal stress axes and reactivation of the fault zone separating the CNARS from the Nemaha Uplift block. Historic seismicity can, in part, be explained by reactivation of these ancient northeast-trending fault zones. [110]

Development of Igneous Basement in the Wichita Mountains

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It is possible that location of the Wichita Uplift is partly controlled by late Proterozoic–Cambrian igneous history. It is probable that much of the structural style of the Uplift and its boundary zones was determined by the character and emplacement geometry of the igneous basement. A consequence is that some of the exposed igneous basement lithologies may not extend beyond the bounding fault zones. Nevertheless, detailed study of exposed basement is necessary to constrain the larger regional picture.

Basement in the best exposed part of the Uplift is a layered, tholeiitic, gabbroic lopolith (Glen Mountains Layered Complex) whose *minimum* areal dimensions are 15 × 65 km. Age is unknown but estimates range from 0.5 to 1.4 b.y. The crust into which it intrudes is not positively identified. It was then cut by a set of smaller, biotite-bearing gabbroic plutons (Roosevelt Gabbros), originating from a hydrous tholeiitic magma. These two units were unroofed and exposed (estimated loss of 1–2 km section, minimum) by Mid-Cambrian. Extruding out on this erosional surface, and extending out over different surrounding basement lithologies were massive amounts of A-type, rhyolitic liquid (Carlton Rhyolite Group), some of which crystallized as the Wichita Granite Group sills. Three chemical classes are recognized but all are probably 525–500 m.y. Late diabasic dikes cut all earlier igneous units and are the last igneous activity.

As this is the type North American aulacogen, integration of igneous timing and chemistry, with recognized succession of rifting, compression and strike-slip structural events, and with the resultant sedimentary record, is important. [111]

Minor Fault Motions in Relation to Late Paleozoic Tectonics of the Wichita–Amarillo Uplift[1]

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The Wichita–Amarillo Uplift of Texas and Oklahoma formed in late Paleozoic time by reactivation of a late Precambrian–early Cambrian rift system. Most of the uplift is buried so that study has been restricted principally to two-dimension techniques, i.e., structure contour mapping and seismic reflection profiling. These two-dimensional restrictions, together with the process of structural reactivation, have made determination of late Paleozoic fault motion directions nearly impossible. Consequently, considerable ambiguity exists as to the origin of late Paleozoic subsidence of the Anadarko Basin: distributed wrenching and crustal thinning vs. vertical adjustments via unknown mechanisms. Exposed late Precambrian–early Cambrian igneous rocks in the Wichita Mountains of Oklahoma allow analysis of the stress history of that area by the study of minor faults. These abundant small-scale shear surfaces have a well-defined relationship to principal stresses. Unfortunately, ambiguities exist as to age, sequence of development and, in most cases, polarity of movement. With these uncertainties in mind, the following stress history is proposed, based on measurement of approximately 300 minor faults: Stage 1; north-south to north-northwest horizontal σ_1 and nearly vertical σ_3, Stage 2; vertical σ_1 and northeast σ_3. Stage 1 is interpreted as the stress system that gave rise to uplift whereas Stage 2 is probably the result of release of confining pressure due to uplift. The Stage 1 stress system would give rise dominantly to reverse motions on the west-northwest trending segment of the uplift and reverse with a right-lateral component on the northwest-trending segment.

[1]Publication authorized by the Director, Bureau of Economic Geology, The University of Texas at Austin, Austin, TX 78712.

[111–112]

Stratigraphic Significance of Pennsylvanian Conodonts from the "Type" Atoka Region, Southeastern Oklahoma

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Conodonts from the important Pennsylvanian sequence in the "type" Atoka region demonstrate their stratigraphic significance. The sequence, from base to top, includes the Wapanucka, Atoka, McAlester and Boggy Formations. Based on conodonts, a latest Morrowan age is indicated for the Wapanucka. Conodonts from the Atoka suggest a middle Atokan age for the formation in its "type" area. The Wapanucka (Morrowan)–Atoka (Atokan) boundary unconformity is an erosional hiatus equivalent to latest Morrowan and early Atokan units exposed in nearby basinal sequences.

Diagnostic conodonts have not been recovered from the Hartshorne, McAlester or Boggy Formations.

The principal factors controlling occurrences of conodont platform taxa are evolution and environment. The exact environmental variables are not known but they correlate with lithology (energy) position in sequence, and sea level movements during deposition of the sequence, either basically transgressive or regressive.

Allochthonous conodonts occur in the Atoka, McAlester, and Boggy Formations. Their distribution records a gradual unearthing of tectonic uplifts associated with Pennsylvanian mountain building. Uplift during latest Morrowan and earliest Atokan time exposed Mississippian and Pennsylvanian strata that sourced Atoka allochthonous conodonts. The Woodford Formation (Devonian) was breached during latest Atokan or Desmoinesian time synchronous with deposition of the McAlester Formation. Tectonic uplift and erosional unearthing exposed Ordovician strata simultaneously with deposition of the Boggy Formation. [112]

Correlation of the Middle Pennsylvanian *Diaboloceras neumeieri* and *D. varicostatum* Zones in the South-Central and Southeastern United States

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Two ammonoid assemblage zones of early Middle Pennsylvanian age are based upon species of the genus *Diaboloceras*. This genus is part of a continuum within the family Schistoceratidae and occurs biostratigraphically between the genera *Branneroceras* below and *Paralegoceras* above. The lower of the two zones, the *Diaboloceras neumeieri* Zone, was described from the Trace Creek Member of the Bloyd Shale in northwest Arkansas, classically part of the type Morrowan section. It has since been recognized as far east as Floyd County, eastern Kentucky, in the Kendrick Shale, and as far west as Pittsburg County, Oklahoma, in the Wapanucka Formation. Ammonoids typical of this zone include *Pseudopronorites arkansiensis* (Smith), *Proshumardites morrowanus* Gordon, *Dimorphoceratoides campbellae* Furnish and Knapp, *Phaneroceras kesslerense* (Mather), *Gastrioceras occidentale* (Miller and Faber), *G.* sp., *Axinolobus* n. sp., and *Diaboloceras neumeieri* Quinn and Carr.

The *Diaboloceras varicostatum* Zone occurs in the lower 300 feet or so of the Atoka Formation as traditionally recognized in northwest Arkansas. This zone has been identified as far west as the Diablo Plateau in Hudspeth County, West Texas, in a black shale containing Smithwick fossils in the Magdalena Limestone. Ammonoids of this zone are present in north-central Texas near Bend, San Saba County, near the base of the Smithwick Shale. Ammonoids of this zone include *Pseudopronorites arkansiensis* (Smith), *Phaneroceras compressum* (Hyatt), *P. kesslerense* (Mather), *Axinolobus* n. sp., and *Diaboloceras varicostatum* Miller and Furnish. Some question now exists as to whether the Morrowan–Atokan boundary should be placed between these two zones, or within or at the base of the lower one. [112]

Calcareous Foraminifers and Conodonts from the Morrowan–"Atokan" (Pennsylvanian) Wapanucka Formation, Southeastern Oklahoma

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Four conodont zones are recognized locally in the Wapanucka Formation of the frontal Ouachita Mountains, southeastern Oklahoma. They are, in ascending order: 1) *Idiognathoides convexus* Zone; 2) *Neognathodus kanumai–Idiognathoides ouachitensis* Zone; 3) *Diplognathodus orphanus* Zone; and 4) *Streptognathodus elegantulus* Zone. Preliminary examination of coincident foraminiferal collections demonstrates that the primitive fusulinids *Eoschubertella* and *Staffella*? appear at least as low as the base of the *D. orphanus* Zone, albeit specimens are exceedingly rare. Exact placement of the Morrowan—"Atokan" boundary within the Wapanucka is impossible owing to inadequacies of the type Atokan as a standard of reference. However, because *D. orphanus* Zone conodonts, *Eoschubertella* and *Staffella*? have not been recovered from unequivocally Morrowan rocks their association in the upper portion of the Wapanucka is confidently interpreted to be post-Morrowan.

The present inability to recognize a definitive Morrowan–Atokan boundary underscores the need to abandon the current faunally undefined boundaries of the type "Atokan." We advocate the selection of boundary stratotypes evaluated by an integrated multi-group approach rather than traditional fusulinid orthochronology. [112]

Buried Trees, Water Table Fluctuations, and Past Climates in Western Oklahoma

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Fifty-seven juniper trees have been recently exhumed by gullying in a small sediment-filled canyon near Carnegie, Caddo County, Oklahoma. Ten of the *in-situ* trees are radiocarbon dated 2600 to 3200 yr B.P. The buried junipers occur in a zone that extends about 2 meters below the present water table. Junipers prefer dry upland soils, and their presence in the canyon means that the water table was at least 4 meters below the present level.

In the same canyon and in a second canyon to the south, near Cyril, a thick azonal paleosol occurs high in the fill sequences 4 to 7 meters above the present water table. Charcoal from the paleosol is radiocarbon dated 1000 to 2000 yr B.P. Within the paleosols are numerous land and freshwater snails, including pelecypods, that indicate moist habitats on the canyon floors and a near-surface water table position. The paleosols also incorporate a considerable amount of carbonate.

If these water table fluctuations were regional, they indicate major climatic change in the south-central Plains: at least 3200 to 2600 yr B.P. the

climate was drier than today; between 2600 and 2000 yr B.P. the climate changed from drier to more moist conditions than that of today; the moist period lasted from 2000 to 1000 yr B.P.; after 1000 yr B.P. the climate changed from moister to the dry conditions that prevail today. The conclusions for a more moist climate 2000 to 1000 yr B.P. are supported by pollen and land snail analyses from northeastern Oklahoma. [113]

Generalized Altitude and Configuration of the Base of the High Plains Regional Aquifer, Northwestern Oklahoma

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The High Plains aquifer in Oklahoma is part of a regional aquifer system extending from South Dakota on the north to Texas and New Mexico on the south. The principal aquifer, the Ogallala Formation of Tertiary age, is hydraulically connected with other unconsolidated deposits, principally of Quaternary age. During 1978, the U.S. Geological Survey began a 5-year study of the High Plains regional aquifer system to provide hydrologic information for evaluation of the aquifer and to develop predictive computer models of it. This report consists of two maps showing the altitude and configuration of the pre-Ogallala bedrock surface, the base of the aquifer. The bedrock surface slopes generally from west to east and is composed of rocks of Permian, Triassic–Jurassic, and Cretaceous age. Altitudes of the aquifer base were determined from drillers' logs and from published and unpublished information. [113]