OKLAHOMA GEOLOGY

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On the cover—

Fossil Linguoid Ripple Marks in Sandstone of the Savanna Formation

Well-preserved sedimentary structures classified as linguoid ripple marks are shown in the cover photo. Formed in Pennsylvanian-age sandstone, the specimen was collected from the Savanna Formation in the San Bois Mountains of Latimer County, southeastern Oklahoma.

Pettijohn (1949, p. 131) stated that linguoid (tongue-shaped) ripples are formed by low-velocity water currents on the bottoms of shallow streams. Conversely, Conybeare and Crook (1982, p. 252) said that linguoid ripples form where currents are strong, such as in the tidal channels of estuaries. The form of the ripples shown in the cover photograph indicates the current direction was from right to left.

As soon as movement of sand grains begins in a channel, the bed material is molded into a number of bed forms, initially, current ripples. Figure 1 is a diagram showing current-ripple-mark terminology. The gently sloping side (upstream) is called the stoss side, and the steep side (downstream) is called the lee side. In profile the typical linguoid ripple is asymmetrical, having a gentle stoss and a steep lee slope. In most examples both the crests and the troughs are broadly rounded (Blatt and others, 1972, p. 125). Figure 2 is a plan view showing the shape of idealized linguoid ripples.

(continued on p. 155)

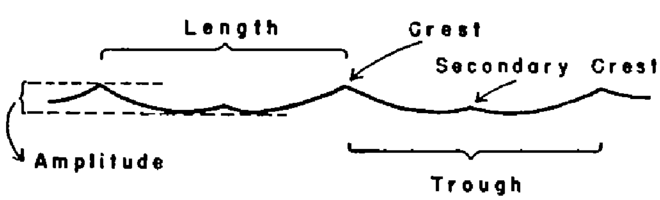

Figure 1. Ripple-mark terminology (from Pettijohn, 1949, fig. 40).

OKLAHOMA GEOLOGICAL SURVEY

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NOTES

OKLAHOMA GEOLOGY

C O N T E N T S

OKLAHOMA GEOLOGICAL SURVEY

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RE-EVALUATION OF JACKFORK GROUP TYPE SECTION ALONG INDIAN NATION TURNPIKE, OKLAHOMA

Neil H. Suneson[1]

Introduction

In 1989, as part of the Mid-Continent Section meeting of the American Association of Petroleum Geologists, and again in 1991, as part of the annual meeting of the AAPG, Jock Campbell and I led a field trip to the western Ouachita Mountains in southeastern Oklahoma. The purpose of stop 12 of the 1989 field trip was to examine the Jackfork Group at the west end of Jackfork Mountain along the Indian Nation Turnpike (Suneson, 1990). Pitt and others (1982) considered this outcrop to be part of the type section of the Jackfork Group. Several of the 1989 field-trip participants commented that part of the section was "unusual" Jackfork. Campbell and I agreed.

Prior to leading the 1991 field trip, I mapped the area near the reported Jackfork Group "type section." At the north end of the outcrop, a transverse (or "tear") fault of unknown displacement and not recognized by Pitt and others (1982) juxtaposes Stanley Group sandstone and shale to the west against Jackfork Group sedimentary rocks to the east.

The purpose of this paper is to review the history of Jackfork Group nomenclature and document that the "type section" reported by Pitt and others (1982) is faulted and is partly Stanley Group. The recognition of the fault is important because the previously published Jackfork type section (Harlton, 1938) is not readily accessible, whereas the exposure along the turnpike is. In addition, the tuffaceous sandstone and underlying black siliceous shale suggested by Pitt and others (1982) to be part of the Jackfork are, in fact, within the Stanley. Furthermore, some of the sandstones exposed in the outcrop are oil stained; these are within the Stanley and are not part of the Jackfork.

History of Nomenclature

The Jackfork Sandstone was originally named by Taff (1902) for exposures on Jackfork Mountain in the western part of the Ouachita Mountains in what was then the Choctaw Nation, Indian Territory. At the time, Taff did not specifically designate a type section. Later, Taff (1909) reported that the Jackfork was Carboniferous, 5,000 ft thick, and was underlain by the Standley (his spelling) Shale and overlain by the Caney Shale.

Honess (1924) recognized the Jackfork Sandstone in the northern and central parts of the Ouachita Mountains on Windingstair Mountain and in the Lynn Mountain and Boktukola synclines in southern Le Flore, northern McCurtain, and eastern Pushmataha Counties. He identified a zone near the middle of the Jackfork that

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[1]Oklahoma Geological Survey.

contained an abundant Morrowan mold fauna similar to fossils contained in the Wapanucka Limestone. Miser and Honess (1927) mapped that part of the "Jackfork" above the fossiliferous zone as Atoka Formation. Cline (1960, p. 82) noted that the sandstone containing the Morrowan mold fauna was within the Johns Valley Formation and that similar fossiliferous zones were present as low as the Markham Mill Formation and as high as the lower part of the Atoka Formation. Legg and others (1990) interpreted the fossiliferous sandstone zone as a basal Atoka channel-fill eroded into the Johns Valley Shale and correlated it to the Spiro sandstone in the Arkoma basin. Clearly, the top of the Jackfork in the Boktukola syncline area is difficult to identify, partly because the overlying Johns Valley Formation, if it is present, does not contain olistoliths. Similarly, the Jackfork in that area has not been correlated with the type Jackfork of Harlton (1938).

Major advances *and* misconceptions in understanding the Jackfork were introduced with the work of Harlton (1934,1938,1959). Harlton (1938) elevated the rank of the Jackfork to group status and described it as containing four formations, each separated from the underlying formation by a widespread siliceous shale. These formations are, from bottom to top, the Wildhorse Mountain, Prairie Mountain (including the Prairie Hollow member), Markham Mill, and Wesley (Fig. 1). The type section of the Wildhorse Mountain Formation is on the southeast edge of the

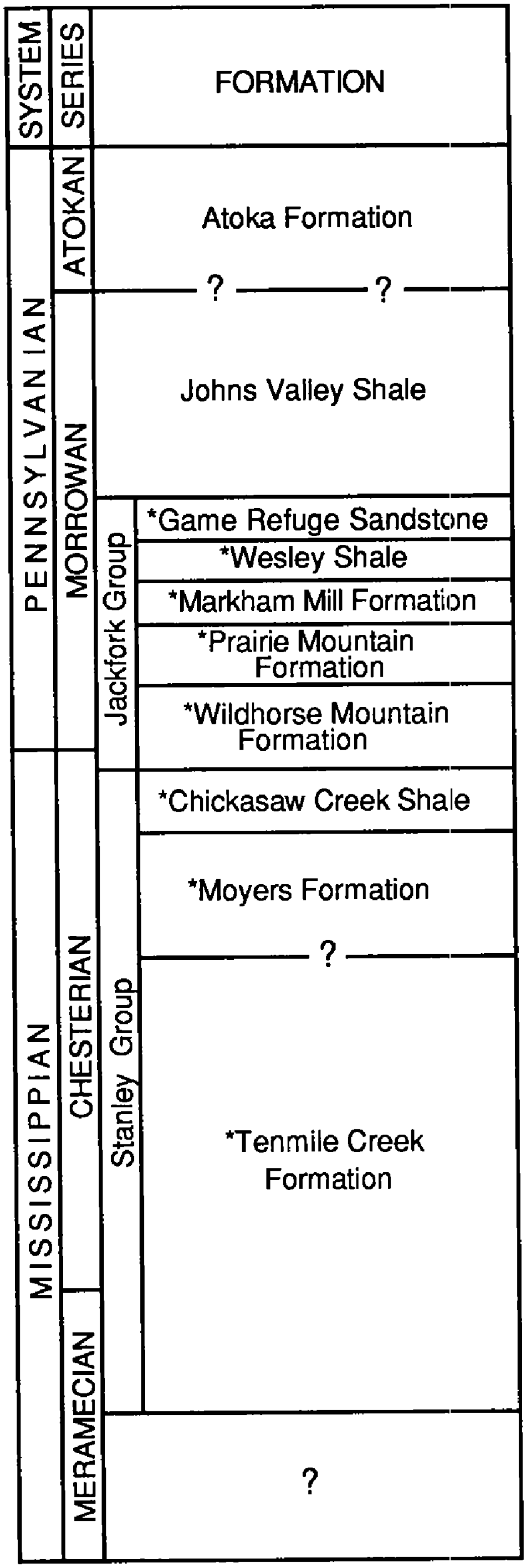

Figure 1 (right). Stratigraphy of Carboniferous formations in the Ouachita Mountains, southeastern Oklahoma (from Gordon and Stone, 1977). An asterisk in front of the formation name indicates its formal adoption by the U.S. Geological Survey.

Tuskahoma syncline in T. 2 S., R. 16 E. The type section of the Prairie Mountain Formation is on the northwest limb of the Round Prairie syncline in T. 1 S., R. 12 E.; that of Markham Mill is on the northwest limb of the Farris syncline (T. 2 S., R. 14 E.); and that of the Wesley is near the village of Wesley (T. 1 N., R. 13 E.). Harlton (1938) did not include the immediately overlying sandstones in his Jackfork, as did Taff (1902), preferring instead to correlate them with the Union Valley Sandstone. Nor did he include the underlying Chickasaw Creek Formation of the Stanley Group in his Jackfork. Later, the name "Union Valley" was withdrawn and a new name, "Game Refuge Sandstone," was included at the top of the Jackfork Group by Harlton (1959) (Fig. 1). Harlton (1934,1938,1959) included the Jackfork Group in his "Pushmataha Series" of the "Bendian System," which was between the Mississippian and Pennsylvanian. Later workers rejected Harlton's chronostratigraphic subdivisions.

Hendricks and others (1947) mapped the Jackfork Sandstone throughout the frontal and central belt of the western Ouachita Mountains in Oklahoma. He mapped four widespread siliceous shale beds within the Jackfork as well as a maroon shale member, but did not use Harlton's terminology. Later workers suggested that he did this because he could not recognize the different formations in the highly folded and faulted frontal belt of the Ouachitas. Hendricks and others (1947) indicated that the Jackfork (and underlying Stanley) were Pennsylvanian.

Cline (1956,1960) and Cline and Moretti (1956) suggested several changes in the age and nomenclature of the Jackfork Group. Cline (1956) believed that the lower part of the Johns Valley Formation was Mississippian, insisting that the black "Caney" Shale at the base of the formation was in place; this required that the underlying Jackfork also be Mississippian. He also pointed out that since the type Union Valley Formation was Morrowan, Harlton's (1938) correlation was incorrect. Harlton (1959) accepted this and changed the name of the sandstone immediately overlying the Wesley Formation to "Game Refuge" and included it within the Jackfork Group. Harlton (1938) approximately located a type(?) section of the Game Refuge but did not describe it nor specifically identify it as such. Cline and Moretti (1956) generally agreed with Harlton's (1938) subdivision of the Jackfork Group, but included the Prairie Hollow Shale Member in the Wildhorse Mountain Formation. Cline (1960) suggested that the age of the Jackfork was Meramecian and Chesterian and included five formations: Wildhorse Mountain, Prairie Mountain, Markham Mill, Wesley, and Game Refuge.

In 1959, Harlton made several changes to the nomenclature he proposed in his 1938 paper. He agreed with Cline and Moretti (1956) that the Prairie Hollow Shale Member is within the Wildhorse Mountain Formation of the Jackfork Group. He added the Game Refuge Formation above Wesley Formation. He continued to insist that the entire Jackfork Group (including the underlying Stanley and overlying Johns Valley) were part of the Pushmataha Series of the Bendian System.

Based on his work in the eastern part of the Lynn Mountain syncline, Briggs (1973) reassigned the Chickasaw Creek Formation to the Jackfork Group as had originally been done by Taff (1902). Based on work later published by Gordon and Stone (1977), he reassigned the Jackfork to the Pennsylvanian, as had originally been done by Hendricks and others (1947). Briggs (1973, p. 8) noted that the siliceous shales used by Harlton (1938) to subdivide the Jackfork in the western Ouachita Mountains pinch out eastward. In Arkansas, the Jackfork is divided into the Iron Forks Mountain Formation and the overlying Brushy Knob Formation (Morris, 1971).

In 1977, Gordon and Stone clearly demonstrated the uppermost Chesterian age of the Chickasaw Creek Formation. They also showed that most of the Jackfork Group was Morrowan, with perhaps only the lowest part of the Wildhorse Mountain Formation being Mississippian. This age designation was corroborated by Whiteside and Grayson (1990).

In 1982, Pitt and others proposed that the type section of the Jackfork Group be along the east side of the Indian Nation Turnpike at the west end of Jackfork Mountain in sec. 19, T. 1 N., R. 15 E. They did not suggest why the previously established type sections of the formations in the Jackfork Group (Harlton, 1938) were unacceptable. Pitt and others (1982) probably wanted to establish a type section on Jackfork Mountain, following Taff (1902), and one that was accessible. The only available geologic map of the area (Hendricks and others, 1947) indicated that all of the new road cut along the turnpike should expose Jackfork Group strata (Fig. 2). Obviously, Hendricks did not have the benefit of a fresh road cut to accurately locate the north-striking fault, which he mapped at the base of Jackfork Mountain.

Geology of the Area

Following the 1989 field trip, the geology of the area near the Jackfork "type section" was remapped (Fig. 3). A fault, probably high-angle and clearly oblique to the overall northeast-trending structural grain of the area, juxtaposes Stanley Group shale and minor sandstone to the west against Jackfork Group sandstone and minor shale to the east at the road level on both sides of the turnpike. The slightly steeper dips and more northerly strike of the Stanley compared to the Jackfork suggests the fault is high-angle and has a significant component of left-slip movement. The fault is west of the first "bench" cut into the outcrop on the east side of the highway during construction; therefore, Jackfork Group strata are exposed continuously along this "bench." Sandstone beds exposed along the "bench" cannot be traced down to the road level. The fault is not well exposed on the east side but is marked by a concentration of vegetation. On the west side of the turnpike, the approximate position of the fault is marked by vegetation-covered Jackfork strata to the east against relatively bare Stanley strata to the west.

The tuffaceous sandstone and dark-gray to black siliceous shale (Markham Mill Formation?) described by Pitt and others (1982, p. 80) appear to be west of the fault and within the Stanley Group. Between them is a sandstone with conspicuous bottom marks; this sandstone is partly saturated with dead oil, which is typical of some Stanley sandstones in McGee Valley. The recognition that these beds are within the Stanley Group and not the Jackfork is important; tuffaceous sandstone beds and oil-saturated sandstones have never been identified in Jackfork Group strata in Oklahoma. Dark, organic-rich(?) shales are rare in the Jackfork. However, the road cut does expose a siliceous-shale bed in the Jackfork exactly where Hendricks and others (1947) mapped it.

This is not the first interpretation that Stanley Group strata are present in this outcrop. Leding (1986), a student of R. C. Morris, correctly interpreted the geology of the Indian Nation Turnpike exposure.

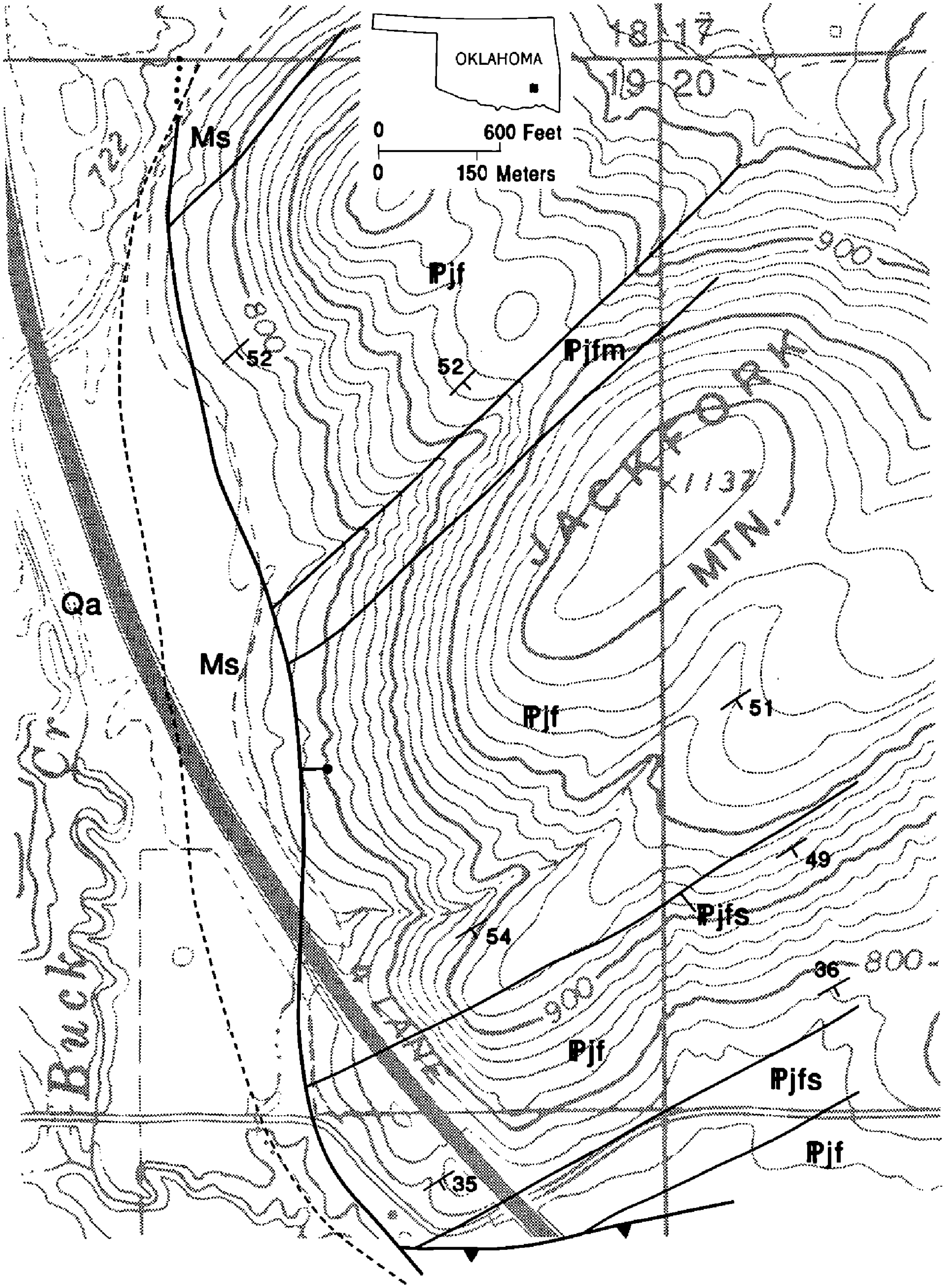

Figure 2. Geology of west end of Jackfork Mountain according to Hendricks and others (1947). Ms—Stanley Shale; Pjf—Jackfork Sandstone; Pjfm—Maroon Shale Member; Pjfs—Siliceous Shale in Jackfork Sandstone; Qa—Alluvium.

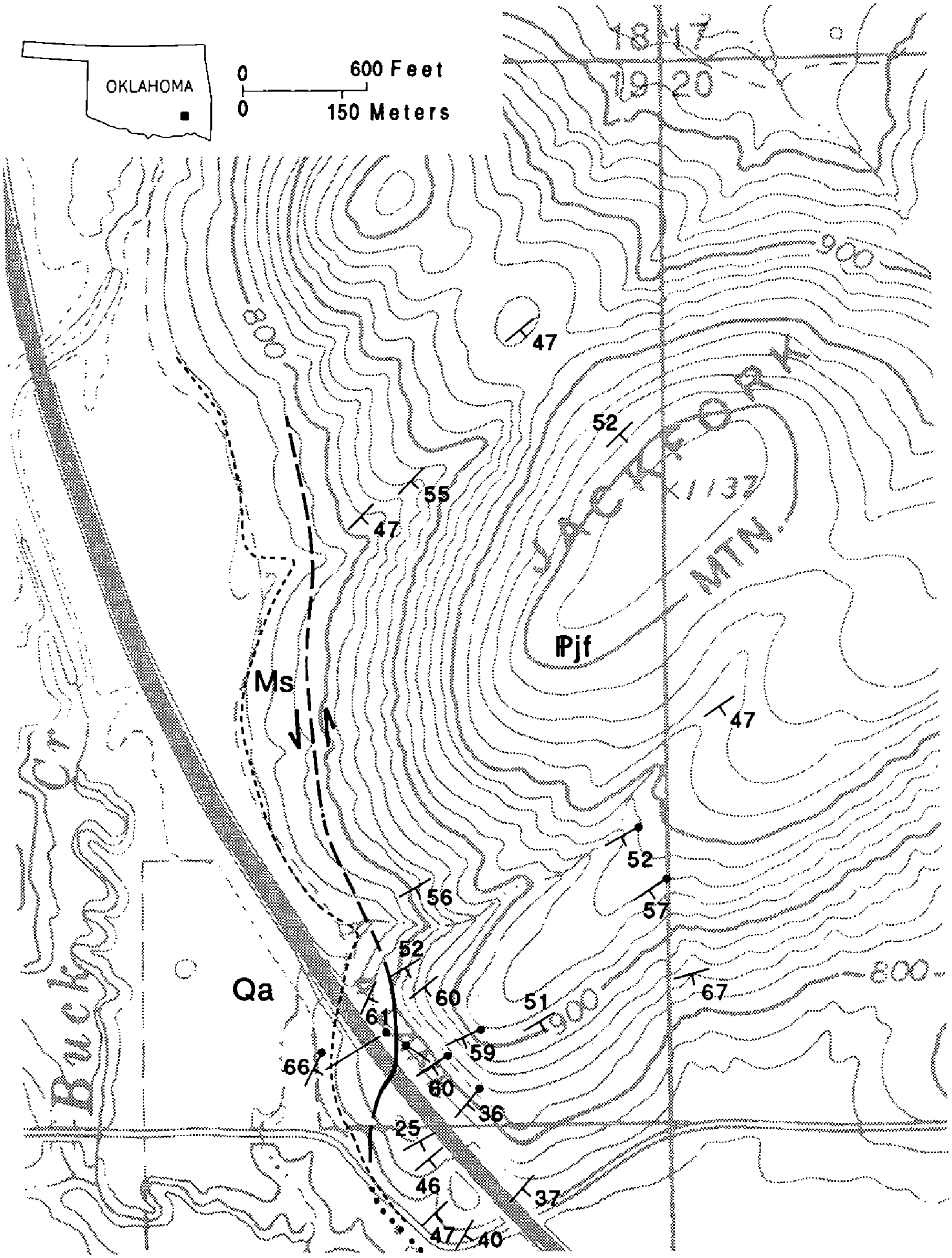

Figure 3. Geology of west end of Jackfork Mountain based on mapping by Suneson. Ms—Stanley Group; Pjf—Jackfork Group; Qa—Alluvium.

Recommendations

The Jackfork "type section" published by Pitt and others (1982) should be abandoned. With more careful study, particularly in the poorly exposed lower part of the Jackfork east of the turnpike, it could be considered a supplementary reference section (NACSN, 1983). The section along Highway 259, south of Big Cedar in Le Flore County, described by Cline and Moretti (1956) and modified by Briggs (1973), should be recognized as a principal reference section for the Jackfork Group. Despite their relative inaccessibility, the type sections of the Wildhorse Mountain, Prairie Mountain, Markham Mill, and Wesley Formations (Harlton, 1938) should be retained, with the exception that the Prairie Hollow Shale Member be included in the Wildhorse Mountain rather than the Prairie Mountain (Cline and Moretti, 1956). The nature of the Game Refuge Sandstone (Harlton, 1959) and its relation to the Johns Valley Formation, basal Atoka Formation (Spiro sandstone?), and Morrowan mold fauna sandstones, particularly in the Boktukola syncline area, are unresolved.

Acknowledgments

The author gratefully acknowledges the thoughtful reviews of an early version of this paper by Jock A. Campbell and LeRoy A. Hemish. Robert O. Fay critically reviewed a later draft of this paper and made many helpful comments.

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CALL FOR PAPERS: WORKSHOP ON STRUCTURAL STYLES IN THE SOUTHERN MIDCONTINENT

Papers and posters are requested on structural styles, structural development, and tectonic evolution within the region, as well as on the effects of structural development upon sedimentation, reservoir characteristics, hydrocarbon accumulation, and hydrocarbon production. The report needs to cover work done in (or applicable to) some part of the southern Midcontinent, which includes all of Oklahoma and adjacent parts of contiguous states. If you have been doing studies on any of these topics, we welcome your contribution to the workshop, to be held March 31–April 1, 1992. The ultimate aims of this program are a better understanding of the style, age, and development of large and small structures in the region, as well as improving our ability to search for and produce our oil and gas resources.

Please submit a tentative title for your presentation by October 1, 1991, to Kenneth S. Johnson, Oklahoma Geological Survey, 100 E. Boyd, Room N-131, Norman, OK 73019; (405) 325-3031.

OGS HOSTS COAL FORUM

Samuel A. Friedman [1]

Hosted by the Oklahoma Geological Survey, the 15th Annual Forum of Coal Geologists of the Western Interior Coal Basin was held May 15–16 in Norman at the new OU Energy Center. Samuel A. Friedman chaired two sessions and led a field trip to study the coal geology at the new Wister strip mine of Heatherly Mining Co. in Le Flore County.

Participants were William V. Bush, Arkansas Geological Commission; Lawrence L. Brady and Dan Hoffman, Kansas Geological Survey; Joy L. Bostic, Missouri Division of Geology and Land Survey; Brian J. Cardott, Samuel A. Friedman, LeRoy A. Hemish, and Michelle J. Summers, Oklahoma Geological Survey; and M. Devereux Carter and Harold Ganow, U.S. Geological Survey.

The first session was devoted to presentations and discussions of the 1990 coal industry and coal production of each state and production predictions for 1991.

Brady reported that in 1990, 720,581 tons of coal were produced in Kansas at three strip mines—a 16% decrease from 1989. Three bituminous-rank coals were mined and contained an average of 3.8% sulfur (as mined), but the sulfur was reduced to an average of 3% at two coal-washing plants. Most Kansas coal production was shipped to electric-power-generating plants. The Kansas plants used 44%, and Missouri plants used 56% of this coal. Of the 17.5 million tons of coal consumed in Kansas in 1990, 90% was shipped from the Powder River basin, Wyoming; 2% was mined in Kansas; 7% was shipped from Illinois; and <1% originated in Colorado and Oklahoma. Brady predicted that >425,000 tons of coal would be mined in Kansas in 1991.

Bostic reported that in 1990 in Missouri, six strip mines produced 2,595,741 tons of bituminous-rank coal from six coal beds in five counties—a 22% production decrease from 1989. About 90% of the 1990 coal production was cleaned at two preparation plants; 10% was crushed, mine-run (raw) coal. The average sulfur content of the total coal production was 3.5%. Two of the six mines were closed by the end of 1990. Bostic expects 2.6 million tons of coal to be mined in Missouri in 1991. Bostic said that Alternate Fuels purchased P&M's walking dragline and walked it 25 miles across country, following a victory in a federal law suit filed by Interior's OSMRE to prevent the walk. The mining company will use the dragline at a new mine to remove overburden from an estimated 300,000 tons of Weir-Pittsburg coal in 1991.

Bush estimated that Arkansas low-volatile bituminous coal production in 1990 will equal the 1989 production, which was ~107,000 tons from surface mines. Arkansas ranks 27th of the 27 coal-producing states. Low-sulfur Lower Hartshorne coal was produced in eight of the nine strip mines in Arkansas in 1990. Virtually all the coal was used for activated charcoal manufacture. A new underground mine in the Lower Hartshorne coal is expected to be developed in 1991. Coal production in Arkansas in 1991 will probably be 100,000 tons, according to Bush.

Friedman cited Oklahoma Depart-

[1]Oklahoma Geological Survey.

ment of Mines data showing 1,636,760 tons of coal production in 1990 in Oklahoma. This was the smallest coal production in Oklahoma since 1968, although 14 mining companies operated 23 mines with 25 pits in nine coals in nine counties in eastern Oklahoma. The weighted average sulfur content of the coal production was 2.4%; the Btu/lb averaged 13,000, and coal thickness averaged 1.4 ft. Most of the 1990 Oklahoma coal production was used in five electric-power-generating plants in Oklahoma. Approximately 15 million tons of subbituminous coal was shipped by unit train from the Powder River basin in Wyoming to these Oklahoma power plants in 1990. These plants generated ~60% of the electric power consumed in Oklahoma in 1990. Friedman expects 1.6 million tons of coal to be mined in Oklahoma in 1991.

During the second session, forum participants reported on their recent coal research projects, publications, and liaison activities.

Bostic reported that she traveled to Washington D.C. to encourage four U.S. congressmen to sponsor a bill which would provide $4.6 million for four years to be spent by the geological surveys of Missouri, Kansas, Iowa, and Nebraska and by the U.S. Geological Survey, for the purpose of evaluating coal-bed methane resources and reserves in the Forest City basin.

Ganow indicated that the U.S. Geological Survey is included in the grant proposal, because it will supply necessary drilling rigs and two staff members. The Mulky, Cainsville, and Riverton coals have been targeted for (1) methane desorption testing of cores, (2) coal-quality analysis, (3) water-quality analysis, and (4) coal thickness and structure-contour mapping. The proposed funding includes cost of publishing the results of the research.

Bush reported that although no bituminous coal research took place in Arkansas, 9 billion tons of lignitic coal to 150 ft in depth in the Arkansas part of the Gulf Coal Province had been determined, based on drilling data generated by the Arkansas Geological Commission and the Arkansas coal industry. The industry has estimated that 270 million tons of lignite resources are under lease for surface mining.

The Arkansas 10%-coal-use law has become useless, as the utilities are not buying any coal mined in the state. These utilities continue to use subbituminous coal shipped from Wyoming, as do all the states represented at the 15th Coal Forum.

Carter summarized the NCRDS program. The computer system was down recently for nine months, but GARNET would soon be available again. The 22 state geological agencies participating in the NCRDS program received grants from the U.S. Geological Survey totaling $300,000 annually and averaging $13,600 each. Missouri has been receiving NCRDS funds for 17 years; Iowa, 14 years; Kansas, 13 years; and Oklahoma, five years (1983–88). Oklahoma's NCRDS coal data was scheduled to be digitized soon by the USGS.

Brady reported that the Kansas and Missouri Surveys had cooperated in mapping the coal resources of the Joplin 1° × 2° Quadrangle (scale 1:250,000). The map will show thickness and depth of coal resources by standard reliability categories; it will also show mined surface and underground areas in parts of three counties in southeastern Kansas and six counties in southwestern Missouri. As part of the USGS's CUSS-MAP Project, the Joplin Quadrangle will be published in the USGS Miscellaneous Map Series. Brady also noted that he had authored the Kansas parts of a guidebook for the 1990 annual field trip of the Coal Geology Division of the Geological Society of America in conjunction with the GSA convention in Dallas.

Brady was supervising Dan Hoffman's master's thesis on the south end of the Forest City basin in Kansas. Hoffman showed detailed stratigraphic cross sections in which Middle Pennsylvanian coal beds were correlated in the Cherokee basin and along the Bourbon Arch.

Friedman reported authoring three sections and co-editing *Coal Geology of the Interior Coal Province, Western Region*, a guidebook privately published by Environmental and Coal Associates of Reston, Virginia. This book was distributed to participants of the GSA Coal Geology Division annual field trip, which traversed parts of Kansas, Missouri, and Oklahoma in conjunction with the GSA convention in Dallas, October 1990. Cardott's paper, "Petrology of Five Principal Commercial Coal Beds of Oklahoma," was published in the guidebook, as was Hemish's paper, "Coal Geology of the Senora Formation (Pennsylvanian) in Northeastern Oklahoma." Bostic co-authored "Geology of the Southern Part of the Southwest Coal Field, Missouri" and "Beneficiation and Desulfurization of Missouri Coal," as well as "Overview of Missouri Coal," all of which were published in the guidebook. Friedman noted that his paper, "Developments in Coal in 1989" (published in the AAPG *Bulletin*, October 1990, p. 359–731), indicated a 2.7% increase in coal production in the Interior Coal Province, but showed an 11% decrease in coal production in the Western Region, the area represented by the Coal Forum states. In 1989, these states produced only 0.7% of the total coal production in the United States. This coal was bituminous in rank and contained 11,500–14,500 Btu/lb.

Friedman also published a cover photograph of the Secor coal and a description of the depositional history of this coal in Pittsburg County in the December 1990 issue of *Oklahoma Geology Notes*, p. 193–194.

Hemish's recently published *Coal Geology of Tulsa, Wagoner, Creek, and Washington Counties, Oklahoma* (OGS Geologic Map GM-33) includes a full topographic base (scale 1 in. = 1 mi) and an update of the identified coal resources and recoverable reserves of coal in these counties. Hemish reported on the stratigraphy of the lower part of the Boggy Formation, Krebs Group, Desmoinesian Series in the Beland–Crekola area, Muskogee County. Hemish stated that the Secor, Secor rider, Peters Chapel, and Bluejacket are clearly separate coal beds in this area. Hemish published the results of this study in *Oklahoma Geology Notes*, December 1990, p. 196–217. Hemish published a previous structural and stratigraphic study of the lower Boggy Formation in northwestern Muskogee and southwestern Wagoner Counties, Oklahoma (*Oklahoma Geology Notes*, December 1986, p. 168–187). He completed mapping the surface geology of the Red Oak and Leflore 7.5′ topographic quadrangle map areas in Latimer and Le Flore Counties as part of a USGS COGEOMAP project. The northern one-third of these maps includes stratigraphic sequences of the Hartshorne, McAlester, Savanna, and Boggy Formations.

Cardott reported on a cooperative project between Exxon Corporation and the OGS, initiated by H.-B. Lo of Exxon in 1990. The project delineated the weathering profile of the McAlester coal at the Red Oak mine of Farrell-Cooper Mining Co. in Latimer County, Oklahoma. Preliminary results of the organic geochemical analyses by Exxon and vitrinite-reflectance analysis by Cardott indicate near-surface changes in the coal properties due to weathering. Such detailed results have never before been documented in Oklahoma coal.

On the second day of the meeting, Friedman led a field trip to the Wister Mine of Heatherly Mining Co. on the south side of Cavanal Mountain, Le Flore County (see photograph below). The company sells the Secor coal produced there to the Applied Energy Services (AES) Shady Point fluidized bed, cogeneration power plant. Heatherly

Photo by M. J. Summers

An exposure of the Secor coal, 4-ft-thick, medium-volatile bituminous in rank (maturity), high in sulfur content (±4%) and Btu/lb (±14,000) sampled by S. A. Friedman and B. J. Cardott at the Wister strip mine of Heatherly Mining Co. (view is toward the east).

has developed a second strip mine in the Secor coal on the north side of Cavanal Mountain, near Calhoun. The medium-volatile bituminous, high-sulfur, high-Btu coal bed averages four ft thick and contains clay-shale partings in these mines. The Secor coal bed contains millions of tons of recoverable coal reserves and billions of cubic feet of methane (gas) in Cavanal Mountain. The coal is amenable to both underground and surface mining.

The field-trip participants examined the Secor coal bed and clay-shale bed conformably overlying the coal. The shale contains numerous, compressed brachiopods of a few species, indicating a marine environment of deposition. This marine environment commonly is identified in strata immediately overlying high-sulfur coal, such as the Secor coal in Le Flore County.

The Secor coal in Le Flore County contains closely spaced cleat (vertical fractures) formed during coal maturation, and cleavage fractures induced by structural deformation (folding) probably in Middle and Late Pennsylvanian times, and probably related to tectonic activity in the adjacent Ouachita Mountains. The fracture patterns in the coal bed identify and control the anisotropic direction of maximum permeability, which must be considered during coal-bed methane exploration and production.

Coal-bed methane is an important unconventional gas resource in the Arkoma basin part of Le Flore County. Although coal-bed methane exploration in Le Flore County has increased recently, no commercial production has been reported yet; however, it is anticipated by the end of 1991.

The 10 participants in the 15th Coal Forum accepted Joy Bostic's invitition to meet next year in Missouri.

ARBUCKLE GROUP CORE WORKSHOP/FIELD TRIP Norman, Oklahoma, October 29–31, 1991

The Oklahoma Geological Survey and the Bartlesville Project Office of the U.S. Department of Energy will co-sponsor a major core workshop and field trip that will focus on the Cambrian–Ordovician Arbuckle Group in the southern Midcontinent. The workshop will be held in Norman, Oklahoma, Tuesday, October 29, 1991, and the field trip will examine excellent outcrops in the Wichita and Arbuckle Mountains October 30–31. It will be possible to attend the workshop, the field trip, or both events.

The Arbuckle Group is a thick sequence of shallow-marine carbonates in the southern Midcontinent. It consists mainly of limestone in the deep-basin area of the southern Oklahoma aulacogen, and is mainly dolomite in the shelf areas. The unit has been of major interest as a target for oil and gas exploration in the last three years, since discovery of oil and gas in the prolific Cottonwood Creek and Wilburton fields. This workshop is intended to help in the exchange of information about this important petroleum reservoir.

Below is a tentative program for the workshop presentations:

- **Comparison of Core and Outcrop in Evaluation of Stratigraphic Sequences within the Arbuckle Group,** by James Lee Wilson, Richard D. Fritz, and Pat Medlock, MASERA Corp., Tulsa, OK
- **Paleokarstic Features and Thermal Overprints Observed in Some of the Arbuckle Cores in Oklahoma,** by Mark Lynch, Union Oil Company of California, Oklahoma City, OK, and Zuhair Al-Shaieb, Oklahoma State University, Stillwater, OK
- **Comparison of Arbuckle at Wilburton Field, Latimer County, with Home-Stake Royalty Corp. Susie Pi-Hoodle No. 1, Alden Field, Caddo County, Oklahoma,** by Bruce N. Carpenter, Consulting Geologist/Log Analyst, Edmond, OK, and Michael C. Evans, Home-Stake Royalty Corp., Tulsa, OK
- **Sedimentology and Diagenesis of the Arbuckle Group in Outcrops of Southern Oklahoma,** by R. Nowell Donovan, Texas Christian University, Fort Worth, TX, and Deborah Ragland, Conoco, Ponca City, OK
- **Study of Arbuckle Brown Zone Diagenesis and Karst Development in Healdton Field, Carter County, Oklahoma,** by R. T. Waddell, Conoco, Lafayette, LA, Huaibo Liu and J. M. Forgotson, Jr., University of Oklahoma, Norman, OK
- **Results of a Deep Cambrian–Ordovician Drilling Program, Northern Fort Worth Basin, Texas,** by Bill McCommons and Joseph R. Whiteside, McCommons Oil Company, Dallas, TX
- **Karst-Controlled Reservoir Characteristics in the Ellenburger of West Texas,** by Charles Kerans, Texas Bureau of Economic Geology, Austin, TX
- **Lithology, Stratigraphy, and Age of the Arbuckle Group in the Amoco Shads No. 4 Core,** by James R. Derby, Consulting Geologist, Tulsa, OK,

Henry Hinch, Amoco Production Company Research, Tulsa, OK, and John R. Repetski, U.S. Geological Survey, Reston, VA

- **Deformation Characteristic of Arbuckle Rock,** by James Bryan Tapp, University of Tulsa, Tulsa, OK
- **Stratigraphy and Exploration of the Knox Group in the Appalachian Fold and Thrust Belt and Black Warrior Basin in Alabama,** by Dorothy E. Raymond and W. Edward Osborne, Geological Survey of Alabama, Tuscaloosa, AL
- **Petrophysical Character of the Arbuckle Dolostone (Cambro–Ordovician) of the Wilburton Field, Latimer County, Oklahoma, Based on One Core,** by Liang Chuanmao and Gerald M. Friedman, Northeastern Science Foundation, Inc., Troy, NY
- **Study of the Knox Group in the Black Warrior Basin of Mississippi,** by Kevin Henderson and S. Cragin Knox, Mississippi Office of Geology, Jackson, MS
- **Dolomitization–Diagenetic History of Ordovician Carbonates, Texas and Oklahoma: Burial Modification of Dolomite and Chert,** by Lynton S. Land, Guoqiu Gao, and Julie A. Kupecz, University of Texas, Austin, TX

For further information on the program, contact Ken Johnson, Workshop Coordinator. Copies of the final program and registration form can be requested from Tammie Creel, Registration Co-Chair, or from the OGS receptionist at (405) 325-3031.

OKLAHOMA CITY GEOLOGICAL SOCIETY ELECTS NEW OFFICERS

Officers of the Oklahoma City Geological Society for the 1991–92 term are:

President: Steve D. Bridges, Consultant
President Elect: Thomas E. Davis, Viersen and Cockran
Past President: Kathy Gentry, Consultant
Vice President: Mark D. Orgren, Southwest Energy Production Company
Treasurer: Raymond Dale Shipley, Greenleaf Energy Corporation
Secretary: Danna Kay Johnson, Kerr-McGee
Library Director: Stewart Kirk, Triump Investments, Inc.
Shale Shaker Editor: Kathleen Fowler, Consultant
Social Chairman: Michael W. Schmidt, Oklahoma Corporation Commission
Public Relations: David G. Bryant, Mobil Oil Corporation
AAPG Delegate: Terry Hollrah, Consultant

NEW OGS PUBLICATION

CIRCULAR 92. *Late Cambrian–Ordovician Geology of the Southern Midcontinent, 1989 Symposium,* edited by Kenneth S. Johnson. 227 pages, 31 contributions. Price: Paperbound, $10.

From the editor's preface:

Rocks of Late Cambrian and Ordovician age in most parts of the southern Midcontinent are a thick sequence of shallow-marine carbonates, interbedded with thinner marine sandstones and shales. They grade laterally into deep-water black shales, cherts, and sandstones in the Ouachita trough. These strata preserve a nearly continuous record of sedimentation in the Oklahoma basin and the Ouachita trough, and they are of considerable economic importance as sources of oil and gas, non-fuel minerals, and ground water, as well as disposal zones for liquid wastes.

To provide a forum for open discussion of research on Late Cambrian and Ordovician geology of the southern Midcontinent, the Oklahoma Geological Survey sponsored this symposium October 18–19, 1989. The symposium was held at the Oklahoma Center for Continuing Education, The University of Oklahoma, in Norman, and this volume contains the proceedings of that conference. Research reported upon at the symposium includes petroleum exploration and development, structure, sedimentation, diagenesis, petrography, geochemistry, biostratigraphy, dolomitization, and paleokarst. We hope that the symposium and these proceedings will bring such research to the attention of the geoscience community, and will help foster exchange of information and increased research interest by industry, university, and government workers. Seventeen papers were presented orally at the symposium, and an additional 15 reports were given as posters. All 17 of the oral papers are presented here as full papers or abstracts, and 14 of the poster presentations are given as short reports or abstracts. About 300 persons attended the symposium.

Circular 92 can be obtained over the counter or by mail from the Survey at 100 E. Boyd, Room N-131, Norman, OK 73019; phone (405) 325-3031. Add 10% to the cost of publication(s) for mail orders, with a minimum of 50¢ per order.

AAPG MID-CONTINENT SECTION MEETING
Wichita, Kansas, September 22–24, 1991

On behalf of the Kansas Geological Society and Geologists' Wives Association, I invite you to Wichita to attend the 1991 Mid-Continent Section Meeting of the American Association of Petroleum Geologists.

The timely theme of this meeting is "The Three Rs of Geology—Revival, Reappraisal, and Recommitment," with an underlying theme of "Back to the Basics . . . With Tools of the Future." Revival: the renewal of one's spirit and zest, the resurgence of the importance of the role of the geologist in exploration and exploitation, and the "geologist-aid" for the resuscitation of the industry. Reappraisal: to re-assess one's career and position in this industry, to re-evaluate old fields and producing areas, and to re-examine frontiers abandoned in the '80s. Recommitment: to re-pledge one's expertise and dedication to the profession of geology as it relates to the AAPG, and to encourage managers, company leaders, and investors to prioritize capital and energy to the discovery and development of hydrocarbons.

Back to the Basics . . . With Tools of the Future: links the important relationship of fundamental geology with other disciplines and sophisticated tools. Geologists must continue to enhance their necessity in successful exploration and exploitation projects in the wake of increasing reliance on geophysics, engineering, and computers and other technologies. The geologist should continue to learn to cooperate with these other disciplines and tools and incorporate them into his or her methods, not compete with them.

1991 may be a time of renaissance for our profession and our industry. Now is the time to energize ourselves, our companies, and our investors—the time to grow in the knowledge of geology and the use of those tools which aid our endeavors—so come to Wichita!

— M. Bradford Rine
General Chairman

WICHITA 91

REVIVAL

REAPPRAISAL

RECOMMITMENT

BACK TO THE BASICS ...WITH TOOLS OF THE FUTURE

AAPG Mid-Continent Section Meeting Agenda

Technical Sessions

September 23

Exploring the Wichita Mountain Front—With New Parameters
Regional Structure and Stratigraphic Framework in Kansas and Relationship to Oil and Gas Accumulation
Petroleum Exploration and Production in Nebraska: Historical and Geological Patterns
The Wilburton–Ouachita Trend—A Gas Giant for the 1990s
Comparative Evolution of Pennsylvanian Platform Margins in Oklahoma and North-Central Texas
Lopatin Analysis of Maturation and Petroleum Generation in the Illinois Basin
Geochemical Surface Anomaly Distribution above Active Hydrocarbon Source Beds: Anadarko Deep Example
Estimated Diffusion Rates of Inorganic Gases from Southeastern Colorado Reservoirs
Geological Applications of the Spectral Gamma-Ray Logging Tool in Kansas
Present and Future Geologic Applications of Petrographic and Other Image Analysis
Measurement of "Rock Properties" in Coal for Coal-Bed Methane Production

September 24

An Analysis of the Kansas Hugoton Infill Drilling Program
Reservoir Characterization with Limited Information
Secondary Recovery from the Burbank Field, Northeastern Oklahoma, is Environmentally Attractive and Economically Feasible
Formation Evaluation in Pressure Depleted Reservoirs
Seismic Support Leading to Discovery and Development of Strahm South Field, Forest City Basin, Northeastern Kansas
Mississippian Facies Relationships, Eastern Anadarko Basin, Oklahoma
Fracture Zones: Rare Oil Reservoirs in Central Kansas
Development and Implementation of a Reservoir Management Plan
Old Geologists, Old Fields, New Ideas, New Techniques—New Reserves
Stockholm SW Field, Southeastern Colorado
Probable Reservoir Facies of the Wapanucka Limestone (Morrowan), Frontal Ouachita Mountains, Southeastern Oklahoma
Sea-Level Fluctuations and Ooid Diagenesis in the Round Top Palo Pinto Field, Fisher County, Texas
Tectonics and Sedimentology along the Monkey River and Big Creek, Southern Belize, Central America: Modern Analog of Select Morrow Sands
Description and Quantitative Modeling of Oolitic Reservoir Analogs within the Lower Kansas City Group (Pennsylvanian), Southeastern Kansas
Tidal Influence within Pennsylvanian Sandstones
Oolite Shoals of the St. Louis Formation, Gray County Kansas: A Guide for Oil and Gas Exploration
Prediction of Reservoir Geometries in the Morrow of Southeastern New Mexico
The Use of Expected Monetary Values in the Reappraisal of Mature Petroleum Provinces
Horizontal Drilling: Overview of Geologic Aspects and Opportunities
Risk Assessment of Petroleum Prospects in Kansas

Short Courses

Geological Applications of Reservoir Engineering Tools, *September 21*
Mud Logging in the Mid-Continent, *September 22*
Integrated Studies of Petroleum Reservoirs in the Mid-Continent, *September 22*

Field Trip

Back to the Basics . . . An Exposed Analog to Known Hydrocarbon Reservoirs, *September 21*

For further information about the Mid-Continent Section Meeting, contact AAPG, Convention Dept., P.O. Box 979, Tulsa, OK 74101; (918) 584-2555. The preregistration deadline is August 21.

SEPM MIDCONTINENT SECTION PLANS FIELD TRIP

The 1991 SEPM annual field conference will be devoted to an examination of Morrowan reservoir units in outcrop on the northern margin of the Arkoma basin in Johnson, Newton, and Madison Counties, Arkansas. Hosted by the Department of Geology, University of Arkansas at Fayetteville, and led by Doy L. Zachry, the field trip will originate from Ft. Smith on Saturday, October 26, and from Ozark, Arkansas, on Sunday, October 27.

Morrowan strata include reservoir units that are widely productive of natural gas in the northern part of the Arkoma basin of Arkansas. These units are extensively exposed in the Boston Mountains immediately north of the basin, only a few miles from the Batson and Ozone fields of Johnson County, where they contain significant gas reserves. The field conference will afford an opportunity to examine surface equivalents of the Lower, Middle, and Upper Hale, Brentwood, and Cannon sandstone units within the Hale and Bloyd Formations adjacent to producing areas.

Morrowan sandstone units accumulated in a variety of marine to fluvial depositional environments that influenced the distribution of reservoir quality strata in the Arkoma basin. Reservoir quality was also strongly influenced by diagenetic processes acting on the depositional framework, especially in calcareous sandstone units of the Hale Formation. Outcrops examined during the conference will emphasize both depositional and diagenetic aspects.

For additional information contact Doy L. Zachry, Dept. of Geology, University of Arkansas, Fayetteville, AR 72701; (501) 575-6603 or 575-3355.

UPCOMING MEETINGS

Integrating Geographic Information Systems and Environmental Modeling, International Conference, September 15–18, 1991, Boulder, Colorado. Information: GIS/Modeling Conference Secretariat, NCGIA, University of California, Santa Barbara, CA 93106; (805) 893-8224.

Association of Engineering Geologists, Annual Meeting, October 1–4, 1991, Chicago, Illinois. Information: Theodore R. Maynard, Bureau of Engineering, Dept. of Public Works, 320 N. Clark St., Room 700, Chicago, IL 60610; (312) 744-3530.

Clay Minerals Society, Annual Meeting, October 5–10, 1991, Houston, Texas. Information: Dave Pevear, Program Services/CM 91, Lunar and Planetary Institute, 3303 NASA Road 1, Houston, TX 77058; (713) 965-4452.

Society of Exploration Geophysicists, Annual Meeting, November 10–14, 1991, Houston, Texas. Information: Convention Dept., SEG, Box 702740, Tulsa, OK 74170; (918) 493-3516.

Petroleum Hydrocarbons and Organic Chemicals in Ground Water: Prevention, Detection, and Restoration, November 20–22, 1991, Houston, Texas. Information: National Water Well Association, 6375 Riverside Dr., Dublin, OH 43017; (614) 761-1711.

Third Conference on Environmental Problems in Karst Terranes and Their Solutions, December 4–6, 1991, Nashville, Tennessee. Information: Education Dept., National Water Well Association, 6375 Riverside Dr., Dublin, OH 43017; (614) 761-1711.

American Geophysical Union, Fall Meeting, December 9–13, 1991, San Francisco, California. Information: AGU, 2000 Florida Ave., N.W., Washington, DC 20009; (202) 462-6900.

Society for Mining, Metallurgy, and Exploration, Annual Meeting and Exhibit, February 24–27, 1992, Phoenix, Arizona. Information: Meetings Dept., SME, P.O. Box 625002, Littleton, CO 80162; (303) 973-9550.

American Association of Petroleum Geologists, Southwest Section, Annual Meeting, April 12–14, 1992, Midland, Texas. *Abstracts due December 1, 1991.* Information: West Texas Geological Society, P.O. Box 1595, Midland, TX 79702; (915) 683-1573.

AAPG International Conference and Exhibition, August 2–5, 1992, Sydney, Australia. *Abstracts due November 1, 1991.* Information: Convention Dept., American Association of Petroleum Geologists, P.O. Box 979, Tulsa, OK 74101; (918) 584-2555.

Oklahoma Geological Survey and U.S. Department of Energy, Workshop on Structural Styles in the Southern Midcontinent, March 31–April 1, 1992, Norman, Oklahoma. *Abstracts due November 1, 1991.* Information: Kenneth S. Johnson, OGS, 100 E. Boyd, Room N-131, Norman, OK 73019; (405) 325-3031.

Society of Economic Paleontologists and Mineralogists, Annual Meeting, June 21–24, 1992, Calgary, Alberta, Canada. *Abstracts due October 15, 1991.* Information: Susan Green, SEPM, P.O. Box 4756, Tulsa, OK 74159; (918) 743-9765.

GSA ANNUAL MEETING
San Diego, California, October 21–24, 1991

The Annual Meeting of the Geological Society of America will be held October 21–24, 1991, in San Diego's spectacular new convention center. You must come, and we'll tell you why. First, we are planning one of the finest combinations of technical sessions and field trips ever offered at a GSA meeting—reason enough.

Of even greater importance, the habitat of humankind is in danger, and it's time that earth scientists step forward boldly to be heard. A special keynote session, "The Global Challenge," will be one of the Monday morning sessions. The special session will be followed during the week by theme sessions on global change, natural disasters, and the limits of natural resources. There will be an open discussion on Monday evening, and a concluding rapporteur session summarizing the events of the week and challenging us to take the next steps in meeting our global obligations.

We should meet not just to exchange data, but to interpret our science to everyone. We should let the world know what we have learned, and how it applies to us all. We want you to come to San Diego to help us focus on Earth as a whole, and to be part of the solutions to our major environmental problems.

— R. Gordon Gastil
General Chair

San Diego
GLOBAL PERSPECTIVES

GSA Annual Meeting Agenda

Technical Program

Symposia

Archaeological Geology of the Archaic Period (8–3 ka) in North America
Coalbed Methane: Geology, Recovery Technology, and Resources
Georisk Assessment
Depositional Environments and the Development of Aquifers
Geology of the Pacific Rim
Geologic Evidence of Late Quaternary Aridification in Western North America: Great Plains, Desert Southwest, and Great Basin
Fluvial Response to Base-Level Changes: Eustatics vs. Tectonics—Part I
Strike Slip Faulting: Geological and Geophysical Perspectives
The Global Climate Transition from the Late Paleocene to Early Eocene
Lithospheric Contrasts in Northwestern North America: Vestiges of Archean and Proterozoic Crustal Growth
International Initiatives in Geosciences Information—A Global Perspective
Contact Metamorphism
New Approaches to Introductory Geology Courses
Biotic Turnover Examined in a Phylogenetic Context
Applications of Micro-Analytical Techniques to Economic Geology
Crustal-Scale Controls on Ore Deposits
Organic Matter Survivable at High Temperatures: Implications for Life
Enhancing Geologic Education through the Arts—A Metageologic Approach
Continental Drift, Plate Tectonics, and Biogeography: The History of a Synthesis of Two Cultures
Venus and Earth: Tectonic and Volcanic Evolution
Geophysics of the Southwestern Cordillera—USA and Mexico
Pangia: Ice-House Processes and Events on a Super Continent

Theme Sessions

Global Challenge: Predicting Our Future, How Good Are the Models?
Resources: The Costs and Consequences of Use
Global Climate Changes—I: The Geologic Record of Climate Dynamics
Global Climate Changes—II: The Past, a Key to the Future
Global Warming and Geologic Evidence of Aridification During Late Quaternary Time
Fluvial Response to Base-Level Changes: Eustatics vs. Tectonics—Part II
Processes Controlling the Composition of Siliciclastic Sediments
Global Sedimentary Geology of the Phanerozoic
Approaches to Sequence Stratigraphic Analysis—Examples from the Tertiary
The K-T Boundary—I: Late Cretaceous Extinctions: Catastrophes or Not?
The K-T Boundary—II: Nonmarine Fossil Record at the Cretaceous–Tertiary Boundary
Actinide-Series Disequilibria in Igneous and Geothermal Processes
Solution Mass Transfer and Volume Strain in Crustal Rocks
Site Characterization Studies Related to Ground-Water and Surface-Water Contamination at Sites Operated by the U.S. Department of Energy
Geology, Hydrogeology, and Tectonics of Southern Nevada in Relation to the Potential Storage of High-Level Nuclear Waste
Characterization and Monitoring of Ground-Water Contamination at Hazardous Waste Sites: Research and Case Histories

Urban Geologic Hazards
Soil and Ground-Water Remediation Techniques
Contamination of Fractured Bedrock Aquifers: Investigation Techniques and Case Histories
Geologic Controls on Multi-Phase Fluid Flow in Porous Media
Geophysical Exploration for Ground Water in Arid and Semi-Arid Regions
Multivariate Statistical Methods in the Geosciences
Failure Mechanisms of Megaslides
Active Margin of Antarctica Proterozoic to Holocene
Cenozic Extension in the Cordillera: Geometry, Timing, Mechanisms, and Regional Controls
Mesozoic Stratigraphic and Structural Evolution of Northwestern Mexico
Jurassic Magmatism and Tectonics of the North American Cordillera
Tectonics of Modern and Ancient Accretionary Prisms
Landscapes of Tectonically Active Strike-Slip, Normal, and Reverse Faults
New Views of the Moon: The Lunar Frontier Revisited
Southern California Areal Mapping Project—Accomplishments, Work-in-Progress, Goals
Baja California: Geologic History of the Peninsula and Gulf of California
Geology of the Future—Now
Earth Scientists and Science Educators: Common Ground

Field Trips

Premeeting Trips

Mesozoic and Cenozoic Geologic Evolution of the Mojave Desert Block and Environs, *Oct. 16–20*
Active Faulting and Volcanism in the Trans-Mexican Volcanic Belt, *Oct. 16–20*
High-Resolution Sequence Stratigraphy of Coal-Bearing Delta Complexes, Ferron Sandstone (Cretaceous), Western Interior, and Optional Geological Overflight Over the Southwestern United States, *Oct. 17–19*
Lower Cambrian Depositional and Sequence Stratigraphic Framework of the Death Valley and Eastern Mojave Desert Regions, *Oct. 17–20*
Quaternary Geomorphology and Geochronology of Owens Valley, California, *Oct. 17–20*
Miocene to Holocene Extensional Tectonics and Volcanic Stratigraphy, Northeast Baja California, Mexico, *Oct. 18–20*
Igneous and Metamorphic Features of the Smartville Complex, Northern California, *Oct. 18–20*
Gem-Bearing Pegmatites of San Diego County, *Oct. 18–20*
Active Folding and Reverse Faulting in the Western Transverse Ranges, Southern California, *Oct. 18–20*
Ground-Water Basins Along the Eastern Sierra Nevada: Tectonics, Water, and Politics, *Oct. 18–20*
Archaeological Geology of the Point Conception—Vandenberg Areas, California, *Oct. 18–20*
Upper Cretaceous Submarine-Fan Deposits, San Diego, *Oct. 19*
Mesozic Evolution of Basement Terranes in the San Gabriel Mountains, Southern California, *Oct. 19–20*
Modern Eolian Processes of the Algodones Dune Field, California, *Oct. 19–20*
Geologic Hazards in San Diego, *Oct. 20*

Half-Day Mini Trips (held during the meeting)

Geology of San Diego, *Oct. 22* or *Oct. 23*
The Downtown San Diego Blob, *Oct. 23*

Postmeeting Trips

Geological Overflight of Southern California, *Oct. 25*
Remote Sensing and Planetology at JPL, *Oct. 25*
Eocene Depositional Systems in San Diego, *Oct. 25–26*
Landslides in the Peninsular Ranges, Southern California, *Oct. 25–26*
Zoned Plutons of the Eastern Peninsular Ranges, Baja California Norte, *Oct. 25–26* or *Oct. 25–29*
The Catalina Schist: Metamorphic and Fluid-Flow Processes in a Paleo-Subduction Zone, *Oct. 25–27*
A Petrologic and Structural Transect Across the Peninsular Ranges Batholith, *Oct. 25–27*
Geologic Structure, Transpression, and Neotectonics of the San Andreas Fault in the Salton Trough, California, *Oct. 25–27*
Late Cenozoic Sedimentation and Tectonics Along the Western Margin of the Salton Trough, California, *Oct. 25–27*
A Hydrogeologic Overview of the Regional Ground-Water Flow System in Relation to Yucca Mountain, Nevada, *Oct. 25–27*
Low-Angle Detachment Faulting and Rapid Uplift of Mid-Crustal Mylonitic Rocks in the Whipple Mountain Metamorphic Core Complex, *Oct. 25–27*
Mesozoic Geology of Cedros Island, Baja California, Mexico, *Oct. 25–28*

SEG-Sponsored Field Trips

Industrial Mineral Deposits of the Mojave Desert, *Oct. 18–19*
Active and Fossil Rhyolite-Hosted Epithermal Systems, *Oct. 18–19*
Active and Fossil Hydrothermal Mineralization in the Salton Trough Rift, *Oct. 25–26*

Short Courses/Workshops/Forum

Description and Analysis of Fluid-Mineral Equilibria Using SUPCRT91, *Oct. 18–19*
Concepts, Strategy, and Software for Practical Three-Dimensional Contaminant Transport Modeling, *Oct. 18–20*
Contact Metamorphism, *Oct. 18–20*
Sequence Stratigraphy and Biostratigraphic Patterns: An Integrated Approach to Defining Basin History, *Oct. 19*
Deformation and Kinematics of High Strain Zones, *Oct. 19–20*
Fractals and Their Use in Earth Sciences, *Oct. 19–20*
Quantitative Sedimentary Basin Modeling, *Oct. 19–20*
Thermochronology: Applications to Tectonics, Petrology, and Stratigraphy, *Oct. 19–20*
Analytical Paleontology, *Oct. 20*
Assessing the Mobility of Chemicals in the Vadose Zones, *Oct. 20*
Computer-Aided Illustration in Geology, *Oct. 20*
Geosciences Information on CD-ROM Workshop, *Oct. 20*
Earthquakes and Earthquake Preparedness, *Oct. 20*
Hydrogeologic and Environmental Applications of Stable Isotopic Systems, *Oct. 20*
GeoRef Workshop, *Oct. 23*
Applications of Radar Remote Sensing: Terrestrial and Planetary, *Oct. 25*
Contaminant Hydrogeology: Practical Monitoring, Protection, and Cleanup, *Oct. 25–26*
Sedimentary Basin Systems, *Oct. 25–26*

For further information about the annual meeting, contact GSA, Meetings Dept., P.O. Box 9140, Boulder, CO 80301; (303) 447-2020 or 1-800-472-1988. The preregistration deadline is September 20.

Water Type and Concentration of Dissolved Solids, Chloride, and Sulfate in Water from the St. Francois Aquifer in Missouri, Arkansas, Kansas, and Oklahoma

The St. Francois aquifer, which extends throughout the Ozark Plateaus Province, crops out and is used as a source of domestic and municipal drinking water near the St. Francois Mountains in southeastern Missouri. J. L. Imes and J. V. Davis prepared the maps at a scale of 1:750,000 (1 in. = ~12 mi), showing water type and concentration of dissolved solids, chloride, and sulfate in ground water from the aquifer in and near the outcrop area. Latitude 35° to 39°, longitude 92° to 95°. The color sheet measures 36 × 30 in. The concentration of dissolved solids, chloride, and sulfate in the ground water generally is within recommended limits of the U.S. Environmental Protection Agency for potable water.

Order HA 0711-J from: U.S. Geological Survey, Map Distribution, Federal Center, Box 25286, Denver, CO 80225. The price is $2.40. (A $1 postage and handling charge is applicable on orders of less than $10.)

Water Type and Concentration of Dissolved Solids, Chloride, and Sulfate in Water from the Springfield Plateau Aquifer in Missouri, Arkansas, Kansas, and Oklahoma

The Springfield Plateau aquifer, a permeable limestone unit in the western and southern part of the Ozark Plateaus Province, is used primarily as a source of domestic drinking water. Prepared by J. L. Imes and J. V. Davis, the maps show water type and concentration of dissolved solids, chloride, and sulfate in ground water from the aquifer. The concentration of dissolved solids, chloride, and sulfate in the ground water generally is within EPA-recommended limits for potable water, except along the western and southern flanks of the Ozark uplift, where the mainly fresh-water system contacts surrounding aquifer systems containing saline water. Latitude 35° to 39°, longitude 92° to 95°. Scale 1:750,000 (1 in. = ~12 mi). Two color sheets measure 44 × 34 in. each.

Order HA 0711-L from: U.S. Geological Survey, Map Distribution, Federal Center, Box 25286, Denver, CO 80225. The price is $4.80. (A $1 postage and handling charge is applicable on orders of less than $10.)

Water Resources Data—Oklahoma, Water Year 1989

Records on surface water in Oklahoma are contained in this 522-page report by R. L. Blazs, D. L. Boyle, T. E. Coffey, D. M. Walters, and D. K. White. Specifically, it includes (1) discharge records for 133 streamflow-gaging stations and seven partial-record or miscellaneous streamflow stations, (2) stage and content records for 30 lakes and reservoirs, and (3) water-quality records for 46 streamflow-gaging stations and two lakes.

Order USGS Water-Data Report OK-89-1 from: U.S. Geological Survey, Water Resources Division, 215 Dean A. McGee Ave., Room 621, Oklahoma City, OK 73102; phone (405) 231-4256. A limited number of copies are available free of charge.

Computer Software for Converting Ground-Water and Water-Quality Data from the National Water Information System for Use in a Geographic Information System

This 55-page USGS water-resources investigations report describes software for the conversion of hydrologic data retrieved from the National Water Information System (NWIS) to a geographic information system (GIS). This conversion provides the linkage that integrates the NWIS with the GIS for the display and interpretation of hydrologic data using spatial-data analysis. Author Jonathon C. Scott also describes the procedures to be used for retrieving data from the NWIS and the options available for converting the data for use in the ARC/INFO GIS. The report briefly describes the internal operation of the computer programs that are used in the conversion process.

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Workshop on Application of Structural Geology to Mineral and Energy Resources of the Central Region

Edited by C. H. Thorman, this 17-page USGS open-file report contains the proceedings of a workshop on application of structural geology to mineral and energy resources of the central region. Included is a paper by T. C. Hester, J. W. Schmoker, and H. L. Sahl entitled, "Tectonic controls on deposition and source-rock properties of the Woodford Shale, Anadarko basin, Oklahoma: loading, subsidence, and forebulge development."

Order OF 90-0508 from: U.S. Geological Survey, Books and Open-File Reports Section, Federal Center, Box 25425, Denver, CO 80225; phone (303) 236-7476. The price is $4 for microfiche and $2.75 for a paper copy; add 25% to the price for foreign shipment.

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

This USGS water-resources investigations report by J. S. Havens consists of two over-size sheets at a scale of 1:250,000 (1 in. = ~4 mi).

Order WRI 81-1117 from: U.S. Geological Survey, Water Resources Division, 215 Dean A. McGee Ave., Room 621, Oklahoma City, OK 73102; phone (405) 231-4256. A limited number of copies are available free of charge.

OKLAHOMA ABSTRACTS

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

Biostratigraphic Correlation of Eustatic Cyclothems (Basic Pennsylvanian Sequence Units) from Midcontinent to Texas and Illinois

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The basic Midcontinent Pennsylvanian eustatic cyclothem (transgressive limestone, offshore shale, regressive limestone, nearshore/terrestrial shale/paleosol) has sequence stratigraphic counterparts (major eustatic cycles) in Texas and Illinois, in which the limestone members are poorly developed or localized because of proximity to detrital influx. The gray to black phosphatic facies of the offshore shales in all three areas, however, are characterized by abundant conodont faunas that not only are conspecific at each level across the entire region but also are diagnostic of individual cycles. These faunas, supplemented at several horizons by distinctive fusulinids and ammonoids, allow correlation of up to 16 of the major eustatic cycles at a time scale of about 400,000 years across a large area of North America. This correlation can be refined to perhaps 100,000 years when the intervening minor eustatic cycles are matched between the biostratigraphically diagnostic horizons. Examples of the faunally diagnostic cycles include latest Desmoinesian Lost Branch Formation (Midcontinent), upper East Mountain Shale (Texas), Lonsdale/West Franklin limestones (Illinois); early Missourian Hushpuckney Shale/Swope Limestone (Midcontinent), upper Salesville Shale (Texas), Macoupin Limestone (Illinois); middle Missourian Quivira Shale/Dewey Limestone (Midcontinent), mid-Posideon shale (Texas), Reel Limestone (Illinois); late Missourian Eudora Shale/Stanton Limestone (Midcontinent), upper Winchell/Merriman limestones (Texas), unnamed marine horizon in Charleston core (Illinois); earliest Virgilian Little Pawnee Shale/Cass/Haskell limestones (Midcontinent), lower Colony Creek Shale (Texas), Omega/Bonpas limestones (Illinois); early Virgilian Heebner Shale/Oread Limestone (Midcontinent), Finis Shale (Texas), Shumway Limestone (Illinois); and mid–early Virgilian Queen Hill Shale/Lecompton Limestone (Midcontinent), Necessity Shale (Texas), Bogota Limestone (Illinois). Similar successions of conodont faunas are reported in preliminary work on marine horizons in the Appalachians and in pub-

lished work on the Russian platform augur well for eventual worldwide correlation of eustatic cycles on a time scale within the Milankovitch band of the Earth's orbital parameters during a period of time when glacial eustasy seems to have controlled inundation and withdrawal of the sea over large portions of the continents.

Reprinted as published in the American Association of Petroleum Geologists *Bulletin*, v. 75, p. 592–593, March 1991.

The Distribution of Chonetid Brachiopods in the Lower Permian Wreford Megacyclothem (Nebraska, Kansas, and Oklahoma)

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The Wreford Megacyclothem consists of two partial cyclothems whose rock types are typical of the mid-continent Permian. The Wreford extends geographically from southern Nebraska, through Kansas, into northern Oklahoma, and can be subdivided into 22 stratigraphic horizons.

The chonetid brachiopods of the Wreford include *Neochonetes* and *Quadrochonetes. Neochonestes* is found throughout the Wreford geographically, except in the southernmost exposures. It occurs in 16 of the 22 stratigraphic horizons. It is abundant in calcareous shales of the upper Speiser and lower Havensville, and also occurs in other calcareous shale horizons at many or most Wreford localities. *Neochonetes* is also found in cherty limestone layers at some localities, and more rarely in other limestone types. It is found in the more near-shore localities or rock types. *Quadrochonetes* is much more restricted geographically, lithologically, and stratigraphically, occurring only in the upper Speiser calcareous shale in northern and central Kansas. It is also less abundant than *Neochonetes.*

Immature chonetid specimens were obtained from bulk samples of calcareous shales and brachiopod-molluscan limestones. These are most abundant and widespread geographically in the upper Speiser, but are found in other horizons at a few localities as well.

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Layered Rocks Beneath the Phanerozoic Platform of the U.S. Midcontinent

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A thick sequence of layered rocks lies hidden beneath the Phanerozoic cover of the central U.S. over large regions. A thick sequence of Precambrian layered rocks is imaged on the COCORP transect across southern Illinois and Indiana. The thickness of this layered sequence varies from 1–3 times the thickness of the overlying Phanerozoic section of the Illinois basin. The layered sequence is observed for close to 200 km in an east-west direction. Similar layered reflections are seen on the

COCORP data from Hardeman Co., TX, and neighboring southwest Oklahoma. Both of these known occurrences lie within the region of the middle Proterozoic Granite/Rhyolite province of the U.S. midcontinent, an area within which scattered wells to basement commonly encounter 1.3–1.5 Ga undeformed granite and/or compositionally similar rhyolite. Therefore, these layered assemblages may comprise a thick sequence of silicic volcanic and sedimentary rocks (perhaps also injected by mafic sills) between scattered volcanic-intrusive centers, such as exposed in the St. Francois Mountains of southeast Missouri. However, in places such as Illinois and Indiana, the near absence of deep wells leaves the possibility that the upper portion of these layered rocks may locally be of late Proterozoic or earliest Paleozoic age. The reprocessing of available industry data, analyzed in conjunction with the existing COCORP data, includes extended vibroseis correlation. These industry data are invaluable in our effort to expand the known distribution of these layered rocks (e.g., into north-central Illinois) and to map their structures.

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Paleokarst and Fracture Overprints in Mid-Continent Carbonates in Evaluation of Horizontal Drilling Potential

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The Midcontinent region, especially in Oklahoma and Arkansas, contains thick Paleozoic carbonate sections that are dolomitic and karstic in character. These sections commonly exhibit strong structural overprints, including intense fracturing, due primarily to Pennsylvanian orogenies. Because of their rather wide association with source rocks, these carbonates are thought to represent good potential targets for horizontal drilling.

The Cambro–Ordovician Arbuckle Group, the Ordovician Viola Group, the Siluro–Devonian Hunton Group, and the Mississippian Limestone all contain zones that are locally productive. These stratigraphic units are either uniformly tight or they are heterogenéous with complex porosity profiles. In Karst terranes both types commonly occur together; both require fracturing to increase porosity and permeability.

The Arbuckle Group, for example, was dolomitized very early by peritidal and/ or freshwater mixing processes. Sequences in which intercrystalline porosity was developed with little or no vuggy porosity usually have low permeability and effective porosity; however, these dolomitic sequences are susceptible to fracturing, and they may produce in structural traps. These fractured sequences in the Arbuckle also are susceptible to karstification associated with multiple unconformities.

Both youthful and mature stages of paleokarst are observed in the Arbuckle Group; the best porosity is developed in the youthful stage. These stages can develop microporous, planar porous, or macroporous types of reservoir geometry. All of these may be heterogeneous in nature, requiring fractures to interconnect porous intervals.

Horizontal drilling is yet to be proved as a reliable method for increasing production efficiency in Midcontinent carbonates. An evaluation of diagenetic history, especially karst processes, along with local and regional structural settings, may provide a key for improved understanding of the horizontal drilling potential in these carbonates.

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Potential for Producing Oil and Gas from Woodford Shale (Devonian–Mississippian) in the Southern Mid-Continent, USA

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Woodford Shale is a prolific oil source rock throughout the southern Mid-Continent of the United States. Extrapolation of thickness and organic geochemical data based on the analysis of 614 samples from the region indicate that on the order of 100×10^9 bbl of oil (300×10^{12} ft^3 of natural gas equivalent) reside in the Woodford in Oklahoma and northwestern Arkansas. The Woodford in west Texas and southeastern New Mexico contains on the order of 80×10^9 bbl of oil (240×10^{12} ft^3 of natural gas equivalent).

Tapping this resource is most feasible in areas where the Woodford subcrop contains competent lithofacies (e.g., chert, sandstone, siltstone, dolostone) and is high fractured. Horizontal drilling may provide the optimum exploitation technique. Areas with the greatest potential and the most prospective lithologies include (1) the Nemaha uplift (chert, sandstone, dolostone), (2) Marietta–Ardmore basin (chert), (3) southern flank of the Anadarko basin along the Wichita Mountain uplift (chert), (4) frontal zone of the Ouachita tectonic belt in Oklahoma (chert), and (5) the Central Basin platform in west Texas and New Mexico (chert and siltstone).

In virtually all of these areas the Woodford is in the oil or gas window. Thus, fracture porosity would be continuously fed by hydrocarbons generated in the enclosing source rocks. Reservoir systems such as these have typically produced at low to moderate flow rates for many decades.

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Internal Stratigraphy and Organic Facies of the Devonian–Mississippian Chattanooga Shale in Kansas and Oklahoma

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The Late Devonian–Early Mississippian Chattanooga Shale of the Midcontinent is popularly referred to as a black shale, but it can be gray or green as well. The Chattanooga is a dark gray to black shale in Oklahoma, becoming lighter in color to the north in Kansas. Internal divisions due to differences in organic content account for the variation in color and suggest the presence of several organic facies within the formation.

Three informal subdivisions of the Chattanooga Shale (upper, middle, and lower shale members) were first recognized by examining geophysical logs of the Chattanooga-equivalent Woodford Shale of western Oklahoma (Hester and others, 1988). All three members are commonly present throughout western Oklahoma, but generally only the upper and middle members are found in Kansas (Lambert, in press). The middle member consistently has a higher gamma-ray log response than either the upper or lower members. Density log calculations correlated to organic geochemical analyses led Hester and others (1989,1990) to conclude that this member is the most organic-rich unit within the Woodford.

Total organic carbon (TOC) content within each member decreases northward, but the middle member generally has the highest TOC. Rock-Eval analyses reveal that the upper and lower members commonly contain type III kerogen in Oklahoma, while kerogen in the middle member can be type I or II. In Kansas, the upper member is characterized by type III kerogen and the middle member by either type I, II, or III kerogen.

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Paleoecologic and Taphonomic Controls on Conulariid Distributions: Example from Pennsylvanian Cyclothems of Kansas and Oklahoma

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Representatives of the phylum Conulariida are often cited from dark gray and black shale lithofacies. Traditionally, these organisms have been regarded as allochthonous pelagic fauna, an hypothesis that is consistent with their former interpretation as medusoid cnidarians.

In cyclothems of the North American Midcontinent, conulariids reportedly occur only in core shales. However, presence-absence data from 17 cyclothems of Kansas and Oklahoma show that they are present in approximately the same number of core shales as other marine units. Frequency data show that they tend to be more abundant in some core shales.

New paleoecological evidence from the Midcontinent and elsewhere suggests that conulariids were epibenthic and gregarious as adults, not pelagic as traditionally thought. They were probably minimal organisms: opportunistic suspension-fedders, capable of withstanding low oxygen conditions. Some may have been sysmbiotic with sulfate-oxidizing bacteria. Such a trophic mode would have enabled them to meet nutritional requirements in dysaerobic marine water or adjacent to submarine hydrothermal vents. Some occurrences of Pennsylvanian conlariids in dark gray shales immediately above laminated black shales probably record the position of the exaerobic zone (the dysaerobic/anaerobic boundary). Because conulariids disarticulated rapidly upon death, however, their preservation in these and other situations must also be related to such taphonomic factors as the exclusion of bioturbating and scavenging organisms from oxygen-poor facies, and relatively rapid burial or growth of concretions.

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Trace Element and Isotopic Geochemistry and Petrogenesis of Mafic Igneous Rocks from the Southern Oklahoma Aulacogen

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The igneous basement of the Southern Oklahoma Aulacogen includes a varied suite of Cambrian age (ca. 550 Ma) intrusive mafic igneous rocks. The earliest intrusion, the Glen Mountains Layered Complex (GMLC), comprises a thick sequence of layered troctolitic, gabbroic and anorthositic cumulates. At least four smaller bodies of biotite-bearing gabbros (the Roosevelt Gabbros) intrude the GMLC, and intrusion of a suite of diabase dykes (the Late Diabase Dykes) post-dates both the gabbros and the younger granites and rhyolites.

The plagioclase-rich cumulates of the GMLC have very low incompatible trace element abundances. Whole rocks and plagioclase separates from the GMLC have $\varepsilon_{Nd(550)}$ of +3.8 to +5.6 and $\varepsilon_{Sr(550)}$ −3.8 to −3.4. The Roosevelt Gabbros have moderate abundance of incompatible trace elements, and typically display evidence of internal differentiation. Trace element and isotopic characteristics are consistent between the four Roosevelt Gabbros; they are mildly LREE-enriched (Ce_N/Yb_N 3.3 to 5.4), typically with small positive Eu anomalies (Eu/Eu* 1.10 to 1.46), and have $\varepsilon_{Nd(550)}$ of +4.5 to +7.0 (only one sample above +5.3) and $\varepsilon_{Sr(550)}$ −3.3 to −0.2. The Late Diabase Dykes are high in Fe and Ti (Fe_2O_3 15.7 to 17.2%; TiO_2 3.0 to 4.3%), and generally have higher incompatible trace element abundances than the Roosevelt Gabbros, but similar trace element characteristics (e.g., Ce_N/Yb_N, Zr/Nb ratios). The diabases have $\varepsilon_{Nd(550)}$ of +3.4 to +5.4 and $\varepsilon_{Sr(550)}$ of −5.2 to +5.9 (only one sample above −1.1).

The Nd and Sr isotopic data indicates that all of the mafic magmas were derived from mantle sources which were depleted in incompatible trace elements, although less so than contemporaneous N-MORB source upper mantle. Limited crustal contamination may explain the slight variations in ε_{Nd} and ε_{Sr} of the mafic rocks. Incompatible trace element ratios such as Zr/Nb, La/Nb, Rb/Nb, etc., are intermediate between those of the depleted upper mantle and typical incompatible trace element enriched hot-spot related magmas. These trace element and isotopic systematics suggest that the mafic magmas of the aulacogen may have been produced through interaction between a hot-spot and asthenospheric and/or lithospheric mantle components.

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Subsidence and Basin Development in the Southern Oklahoma Aulacogen

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Development of the Southern Oklahoma aulacogen was the result of Cambrian tectonism along Proterozoic zones of weakness that caused northwest-trending extensional normal faults related to a rifting event. These faults were reactivated during upper Paleozoic compressional stress with fault patterns indicative of sinistral transpressive and transtensional movement. Mapping in the region has allowed classification of the myriad of faults into six major systems, from north to south: the Washita Valley, Madill–Aylesworth, Caddo, Criner, Horseshoe Bend, and Muenster systems. Development of the fault systems occurred somewhat independently as energy was transferred between them owing to changes in stress from the uneven collision of the Ouachita front. This model may account for the episodic movement recognized by past investigators.

The determination of relative timing of development within these systems has shown that the Madill–Aylesworth and Criner systems were active during the Upper Mississippian. As deformation continued along the Criner system structural activity moved southward to include the Horseshoe Bend and Muenster systems during the Early Pennsylvanian. During the Middle Pennsylvanian, fault development along the southern margin of the aulacogen subsided, and deformation activity was initiated in the northern portions of the Ardmore basin. Late Pennsylvanian deformation involved each of the systems with the most intense activity concentrated along the Washita Valley system.

The amount of horizontal displacement along fault systems in the region is still unresolved. However, by regional mapping along the Criner systems, a minimum of 6 mi left-lateral movement can be documented as having occurred during the Upper Pennsylvanian using models of sediment deposition and transport in strike-slip basins.

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Organic Petrology of Epi-Impsonite at Page, Oklahoma, USA

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Impsonite (asphaltic pyrobitumen) occurs as fracture-filling veins cutting massive sandstone in the frontal Ouachita Mountains near Page, Oklahoma. The Page impsonite formed from low-temperature alteration of crude oil. Mean maximum bitumen reflectance in oil immersion ($\bar{R}_{max}$) of seven samples is 1.41–1.96%. Mean apparent bireflectance of these samples is 0.15–0.54%. The Page deposit classifies at the upper end of epi-impsonite in the generic classification for solid bitumen, based on physical, chemical, and optical characteristics, and as post-oil with unlimited migration in the genetic classification for solid bitumen.

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The Northwest Extension of the Meers Fault, Oklahoma

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Detailed mapping of previously unmapped terrace deposits, a trench, and creek banks along an extended N60W trending line in Kiowa County, Oklahoma strongly suggest that the Meers Fault has an active northwest extension of about 30 km which bifurcates in the Sugar Creek area and continues with a new trend of N80W. Substantial deflection of stream alignments, buried A-soil horizons, gravel coated by seeping oil from the fault zone, shale and A-soil horizon fragments (colluvium) eroded from the upthrown block, and displaced terrace deposits are the evidences for this activity. Bulk soil C_{14} dates on two samples collected from an organic buried A-soil horizon and fragment gave ages of 1090 ±80 BP and 760 ±70 BP years indicating that the Meers Fault must have moved in Late Holocene and may have caused a large earthquake creating a high scarp where well cemented Post Oak Conglomerate outcrops and slope where flexible Hennessy Shale outcrops.

This suggests re-evaluation of present building construction codes and careful assessment of seismic risk for critical facilities in the region and implementation of precautionary safety and educational measures for the local population.

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Geochemical Correlation Between Latest Precambrian–Early Paleozoic Mafic Rocks in Eastern North America and the Southern Rocky Mountains

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Numerous latest Precambrian (~600 Ma) to Cambrian mafic intrusive and extrusive rocks are associated with the ancient eastern North American cratonic margin from Newfoundland to North Carolina and Tennessee. These rocks are interpreted to have formed during the opening of the Iapetus Ocean. Dikes swarms of similar age are present in the Wichita Mountains of Oklahoma, and the Rocky Mountains of southwestern Colorado and northern New Mexico.

Over 30 whole-rock chemical analyses, 20 of which are new analyses, are available for the Rocky Mountain suite. Compositions of these rocks range from quartz-normative basalt to basaltic andesite and are transitional tholeiitic-alkaline; most rocks have gabbroic or diabasic textures, including cumulate textures. At present no extrusive rocks of this age have been identified in the region. Published ages range from 670–500 Ma. The overall whole-rock chemistry indicates normal tholeiitic-type fractional crystallization; however, these rocks have a very distinct high-TiO_2 signature (1.5–3.5%). Additional geochemical characteristics are enrichment in other HFS elements and LREE enrichment [Ce=51–58 ppm and $(Ce/Yb)_n$=3.5].

The Rocky Mountain suite is slightly more silica-rich compared to the eastern North America suite, but they are both enriched in TiO_2 and other HFS elements relative to younger mafic rocks of similar tectonic settings in both regions. For example, TiO_2 contents for lower Mesozoic quartz-normative mafic rocks of eastern North America and the Cenozoic basalts of the northern Rio Grande rift in northern New Mexico and southern Colorado typically range from 0.5–1.5%. Moreover, the older suites in both regions are enriched in LREE, other incompatible elements, and the Fe/Mg ratio relative to younger suites. The magnitudes of these differences cannot be readily explained by simple fractional crystallization and are suggestive of fundamental differences in source compositions, depths of melting, or degree of melting. The widespread homogeneity of rocks within each age group over a large portion of the continent is suggestive of different depth-source controls.

Reprinted as published in the Geological Society of America *Abstracts with Programs, 1991*, v. 23, no. 4, p. 38–39.

Contrasting Crystallizations Styles of Sheet Granites from the Wichita Magmatic Province: Implications for Source Region Heterogeneity

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Cambrian age crustal rifting produced the gabbro-granite/rhyolite terrane of the Wichita Magmatic Province (WMP), the floor of the Southern Oklahoma Aulacogen. Alkali-feldspar granite/granophyre is areally extensive at the surface but volumetrically minor in comparison to gabbroic rocks in the subsurface. The granite/granophyre units can be subdivided into three distinct chemical suites (i.e. Reformatory, Mount Scott, Mountain Park). Field observations suggests that magmas intruded along fissures and spread out laterally as thin (<1 km), sub-horizontal, tabular sheet-like sills, some of which may have exceeded 55 km in length.

In the eastern WMP, the Mount Scott and Mountain Park suites are represented by the Mount Scott and Quanah granite sheets respectively. The Quanah granite (525 Ma, Tilton and others, 1962) intrudes the Mount Scott. Petrographic studies have been used to construct crystallization histories for these two granite sheets. Plagioclase, magnetite, apatite and zircon are near liquidus phases in the Mount Scott followed by quartz, sphene, biotite, hornblende and finally alkali-feldspar. In the Quanah granite quartz appears to be the liquidus phase followed by magnetite and alkali-feldspar. Hornblende and then biotite cystallized near the solidus. Zircon crystallized relatively late in the Quanah granite. Magmatic fluorite is present in both granites. Based on stratigraphic considerations and the presence of miraolitic cavities these magmas are interpreted to have crystallized at a pressure of 10^1–10^2 bars. Crystallization temperatures of 905°C and 898°C were calculated from whole rock Zr concentrations for the Quanah and Mount Scott granites respectively. However, late crystallization of zircon in the Quanah indicates that this is not a liquidus T. Comparison of the crystallization histories to the 1 kb T–xH_2O phase relationships for the Watergums A-Type granite (Clemens and others, 1986) imply an initial T for the Quanah granite in excess of 975°C and xH_2O <2.0 wt.%. Late

crystallization of biotite and vapor saturation near the solidus imply a final T of ~750–720°C and xH_2O of >4.0 wt.%. For the Mount Scott granite, an initial T of 900°C, with plagioclase as the liquidus phase, implies a higher initial xH_2O of ~2.8 wt.%, consistent with the earlier crystallization of hornblende and biotite.

Differences in liquidus temperature and initial H_2O contents of these magmas are compatible with derivation from a single source material that is progressively dehydrated with repeated melting. Alternatively these distinctions may reflect partial meting of distinct source regions. Resolving between these two alternatives will be critical to understanding how partial melting process can affect the intrinsic geochemical signature of granitic magmas and the use of granitic rocks as probes of the lower crust.

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Origin of Late Dolomite Cement by CO_2-Saturated Deep Basin Brines: Evidence from the Ozark Region, Central United States

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Studies of fluid inclusions in regionally extensive late dolomite cement (LDC) throughout the Ozark region show that CO_2 effervescence was widespread during dolomite precipitation. On the basis of quantitative analyses of inclusion fluids, reaction-path modeling shows that LDC with trace amounts of sulfides can be deposited by effervescence of a CO_2-saturated basin brine as it migrates to shallower levels and lower confining pressures. This precipitation mechanism best explains occurrences of LDC in the Ozark region and may account for LDC found in sedimentary basins worldwide.

Reprinted as published in *Geology*, v. 19, p. 348, April 1991.

Fossil Linguoid Ripple Marks—*continued from p. 118*

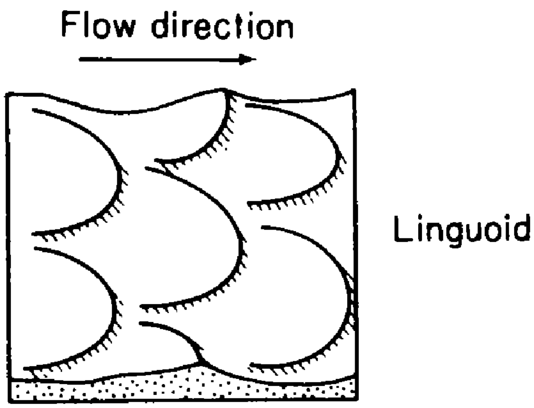

Figure 2. Plan view of linguoid ripples (from Allen, 1968).

The length of the ripples pictured on the cover is ~2 in. and the amplitude is ~0.5 in. The overall length of the specimen (right to left) is ~9 in.

Figure 3, with pencil for scale, shows linguoid ripples exposed on the surface of an in situ bed of sandstone in the Hartshorne Formation (Pennsylvanian). Current direction is from upper right to lower left. The sandstone crops out in the bed of an intermittent stream in the NE¼SE¼SW¼ NE¼ sec. 25, T. 5 N., R. 17 E., Latimer County, Oklahoma. As can be seen in the photograph the linguoid ripple forms are much more irregular than the idealized forms shown in Figure 2, but the term is nevertheless useful for description in the field.

The geometry of a ripple has an important relation to the type of cross-stratification that results from migration of the ripple. Blatt and others (1972, p. 127) said that most small-scale trough cross-lamination probably was formed by migration of linguoid ripples.

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LeRoy A. Hemish

Figure 3. Exposure of Hartshorne Sandstone in creek bed in Latimer County showing linguoid ripples.