OKLAHOMA GEOLOGY

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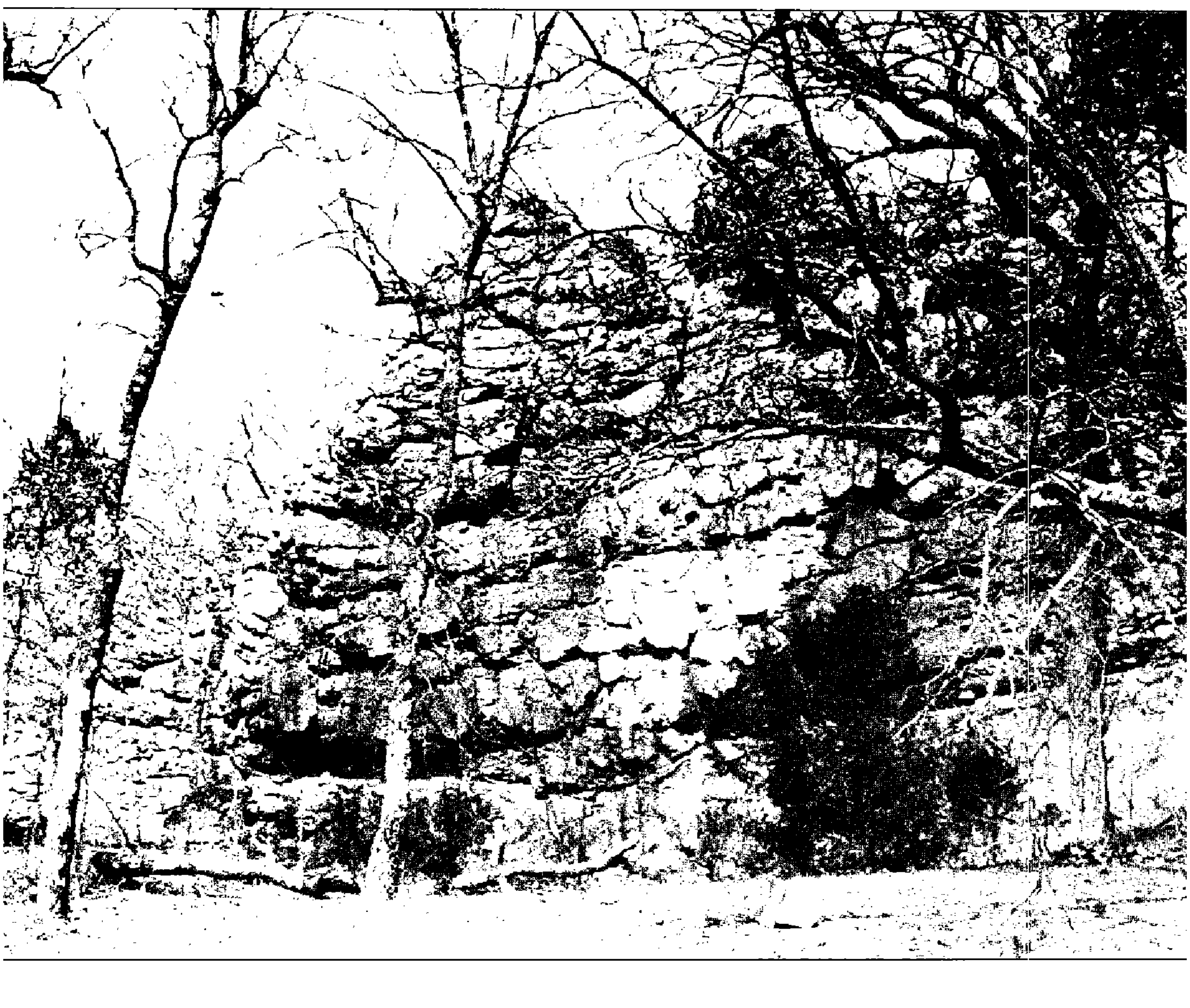


On the cover—

Trough Cross-Bedding in Sandstone of the Savanna Formation

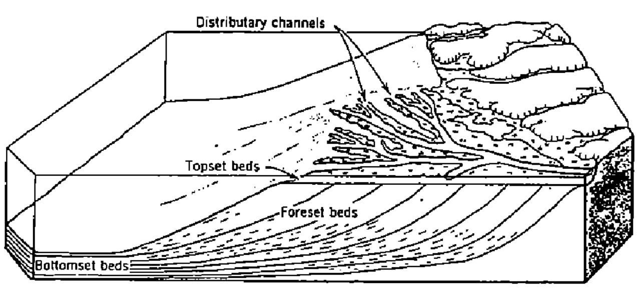
Sandstone of the Pennsylvanian Savanna Formation is well exposed in the Sans Bois Mountains, in the NE¼SW¼NE¼NE¼ sec. 36, T. 6 N., R. 19 E., Latimer County, Oklahoma. This unit is present continuously throughout the mountain range and is the same sandstone in which Robbers Cave occurs ~5 mi to the northwest in Robbers Cave State Park.

In the cover photograph, the beds display trough cross-bedding. The lower bounding surface is trough- or scoop-shaped, and the beds are inclined with respect to a thicker stratum in which they occur.

The depositional environment is interpreted by the writer as a delta front. The view in the cover photo is toward the landward or upstream direction. Because of the steep inclination of the beds and the distinctness of the stratification, it is believed that the sediments were deposited in deep offshore waters.

The accompanying diagram shows an idealized delta.

LeRoy A. Hemish



Idealized delta. Inclination of foreset beds is identical with slope of delta front, shown in phantom view through the water. The shallower the water offshore, the gentler the slope and the less distinct the stratification. (After Longwell and others, 1969, Physical Geology: John Wiley and Sons, New York, 685 p.)

OKLAHOMA GEOLOGICAL SURVEY

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OKLAHOMA GEOLOGY

CONTENTS

OKLAHOMA EARTHQUAKES, 1989

James E. Lawson, Jr.,[1] *and Kenneth V. Luza*[2]

Instrumentation

A statewide network of 12 seismograph stations was used to locate 62 earthquakes in Oklahoma for 1989 (Fig. 1). The Oklahoma Geophysical Observatory (OGO) station, TUL, located near Leonard, Oklahoma, in southern Tulsa County, operates seven seismometers, three long-period and four short-period. The seismic responses at TUL are recorded on 12 paper-drum recorders. Accurate timing is assured by a microprocessor clock that is continuously locked to the National Bureau of Standards cesium-beam clocks by low-frequency radio transmissions broadcast by WWVB (Lawson, 1980). Seven semipermanent volunteer-operated seismograph stations and three radio-telemetry seismograph stations complete the Oklahoma Geological Survey's seismic network. The operation and maintenance of 10 of the stations is partially supported by the U.S. Nuclear Regulatory Commission (Luza, 1978).

Each of the seven volunteer-operated seismograph stations consists of a Geotech S-13 short-period vertical seismometer; a Sprengnether MEQ-800-B unit, including amplifier, filters, hot-stylus heat-sensitive-paper recording unit, and a clock; and a Kinemetrics time-signal-radio receiver for high-frequency WWV time signals. Each radio-telemetry system consists of one Geotech S-13 seismometer and one radio-telemetry unit. The telemetry unit amplifies the seismometer output and uses this output to frequency-modulate an audiotone. The signals are transmitted to Leonard in the 216- to 220-MHz band with 500-mW transmitters and 11-element beam antennas, giving an effective radiated forward power of 12.9 W. Transmission path lengths vary from 50 to 75 km. Seismograms from the radio-telemetry stations are recorded at the Oklahoma Geophysical Observatory.

Station OCO, which contains equipment similar to the volunteer-operated stations, is located at the Omniplex museum in Oklahoma City. Omniplex staff members change the seismic records daily as well as maintain the equipment. Oklahoma Geophysical Observatory staff help interpret the seismic data and archive the seismograms with all other Oklahoma network seismograms.

Station LNO consists of two Geotech 23900 seismometers placed near the bottom of a 770-m-deep borehole located on Observatory property. The responses from the borehole seismometers are digitally recorded at 200 samples/sec near the well bore. Also, the responses are continuously recorded on analog seismograms at the Observatory.

[1]Oklahoma Geophysical Observatory, Leonard.
[2]Oklahoma Geological Survey.

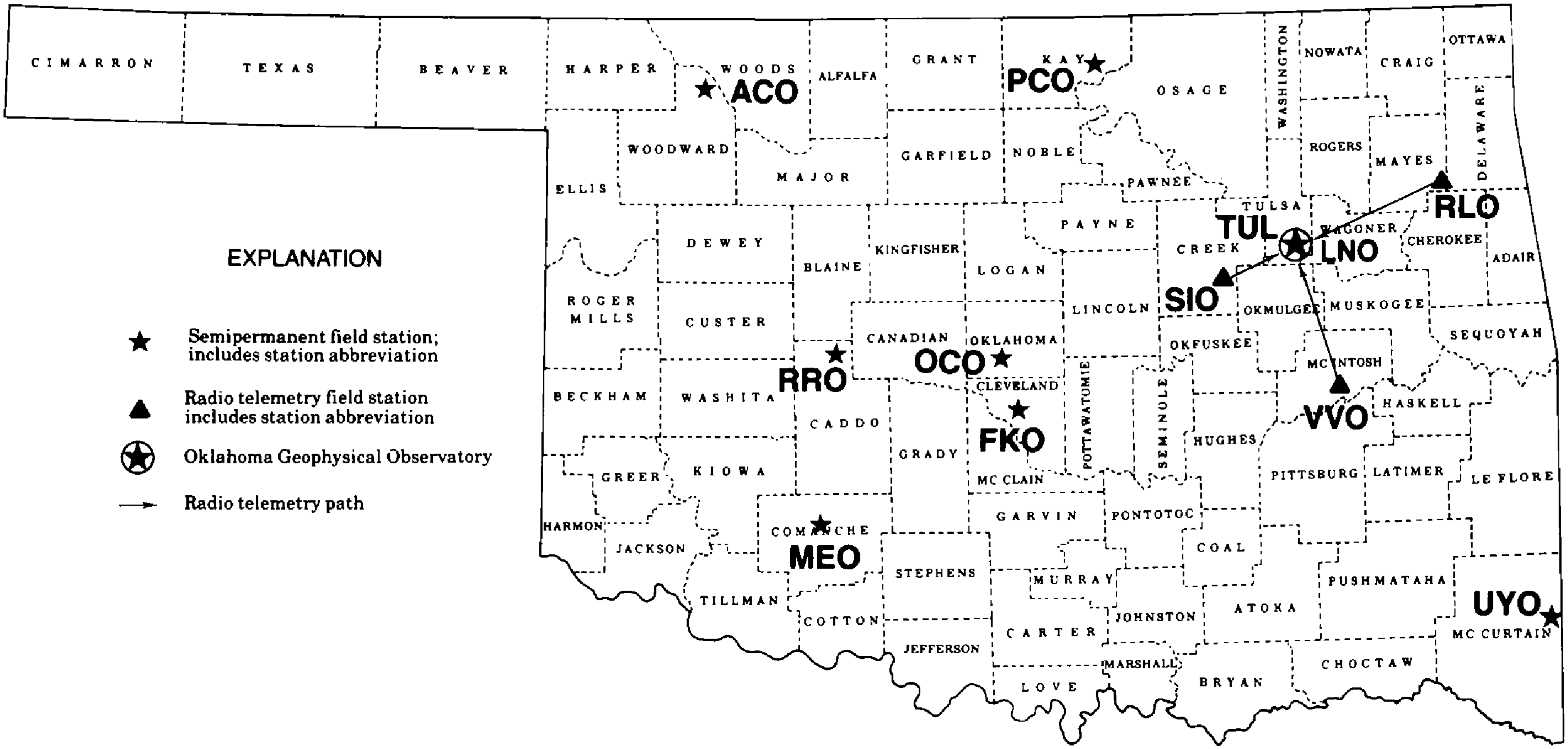

Figure 1. Active seismographs in Oklahoma.

On April 15, a new station, UYO, was opened near Union Valley, Oklahoma, in McCurtain County (Fig. 1). The seismometer is located in a 10-m-deep hand-dug well. Station UYO is operated by Steven Due.

Data Reduction and Archiving

Arrival times from all visible teleseisms (phases from distant earthquakes) at TUL, RLO, MEO, VVO, SIO, and OCO are sent to the U.S. National Earthquake Information Service and the International Seismological Centre in England. P-wave and surface-wave amplitudes from TUL, plus selected arrival times from ACO and all arrival times from MEO and UYO, are also included. These reduced seismic data are sent to more-specialized agencies such as the USAF Technical Applications Center, which monitors underground nuclear tests worldwide.

From station TUL, at the OGO near Leonard, five short-period vertical seismograms (with differing frequency responses) and one short-period vertical seismogram from the LNO borehole seismometer signal are searched exhaustively for local and regional earthquake phases. Also searched are two TUL short-period horizontal seismograms; two short-period vertical seismograms from each of RLO, SIO, and OCO; and one short-period vertical seismogram from each of the seven other stations.

Twelve daily TUL seismograms, as well as 11 daily seismograms from the remote stations, are permanently archived at the OGO.

Earthquake Distribution

All Oklahoma earthquakes recorded on seismograms from three or more stations are located. In 1989, 62 Oklahoma earthquakes were located (Fig. 2; Table 1). No earthquakes were reported felt. The felt and observed effects of earthquakes are generally given values according to the Modified Mercalli intensity scale, which assigns a Roman numeral to each of 12 levels described by effects on humans, man-made constructions, or natural features (Table 2).

Earthquake-magnitude values range from a low of 1.1 (MDUR) in Okfuskee County to a high of 3.1 (m3Hz) in Major County. An unusually high number of counties, 31, experienced earthquakes in 1989 (Fig. 2). In July a swarm of 15 earthquakes occurred near the Major–Woodward county line. Five earthquakes were located in Cleveland County. McClain and Garvin Counties, one of the most active areas in the State since 1979, experienced four and three earthquakes, respectively. Pontotoc County experienced three earthquakes; and Ellis, Haskell, Johnston, Logan, McIntosh, and Okfuskee Counties each contained two locatable earthquakes.

Catalog

A desk-top computer system, including linked HP-9825T and HP-9835-A computers, hard and flexible disks, and printers, is used to calculate and catalog local earthquake epicenters. Any earthquake within Oklahoma or within about 100–

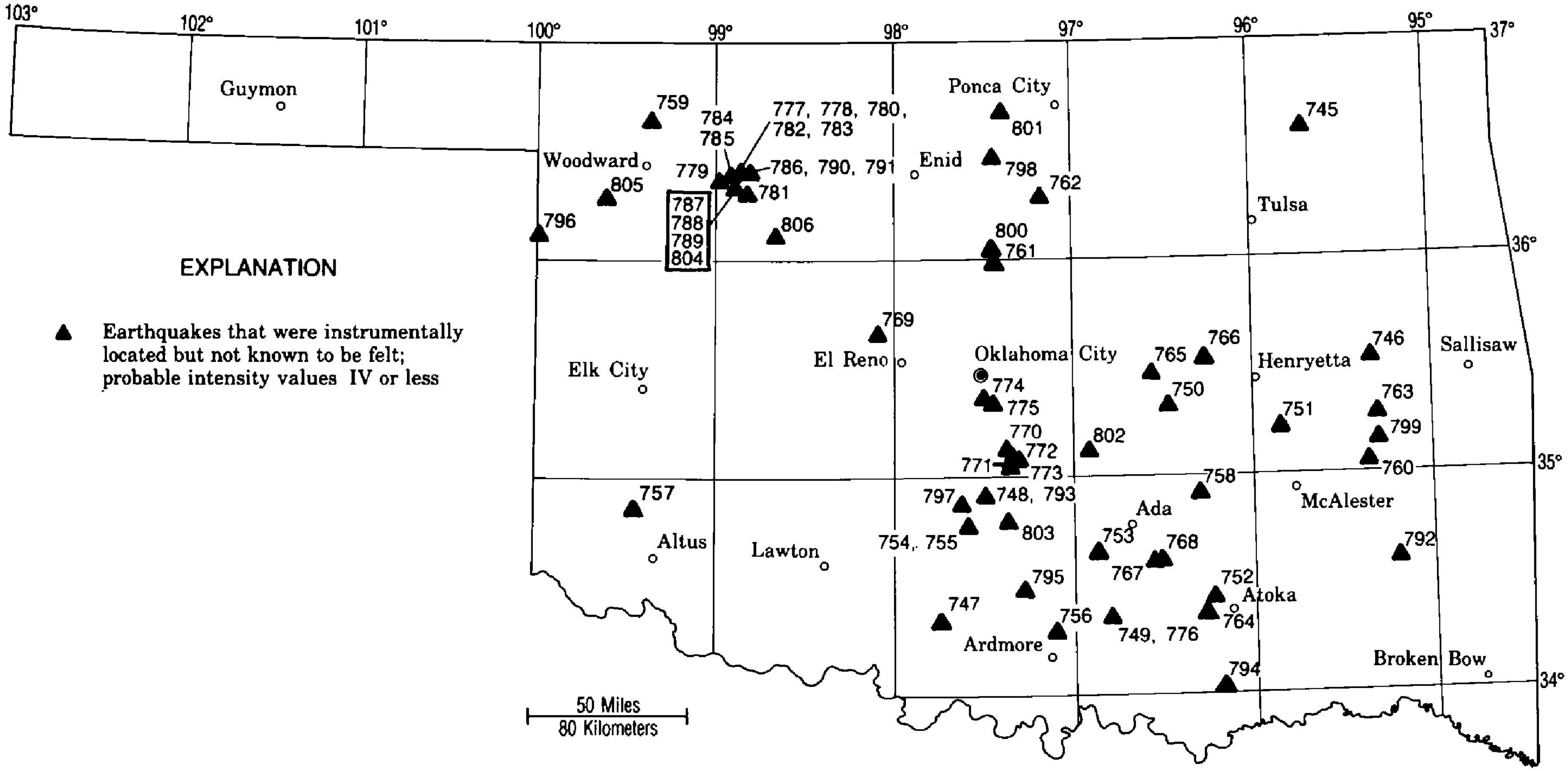

Figure 2. Distribution of Oklahoma earthquakes for 1989. Numbers correspond to event numbers in Table 1.

TABLE 1.—OKLAHOMA EARTHQUAKE CATALOG FOR 1989

Event Number	Date and Origin Time (UTC)[1]		County	Intensity MM[2]	Magnitudes 3Hz	bLg	DUR	Latitude deg N	Longitude deg W	Depth (km)[3]
745	JAN 5	064846.15	ROGERS				1.8	36.575	95.707	5.0R
746	JAN 24	001903.36	McINTOSH				1.7	35.511	95.364	5.0R
747	JAN 31	225839.91	STEPHENS				2.0	34.361	97.775	5.0R
748	JAN 31	231506.39	McCLAIN			2.5	2.6	34.918	97.472	5.0R
749	FEB 7	222246.67	JOHNSTON		2.1	2.0	2.2	34.386	96.831	5.0R
750	FEB 20	115918.01	SEMINOLE		2.0		2.1	35.324	96.464	5.0R
751	FEB 23	004355.66	McINTOSH				1.4	35.212	95.862	5.0R
752	MAR 8	003129.99	COAL		2.5	2.3	2.5	34.431	96.253	5.0R
753	APR 2	072040.27	PONTOTOC		2.0		1.9	34.664	96.859	5.0R
754	APR 14	035743.34	GARVIN				1.8	34.778	97.562	5.0R
755	APR 14	065304.03	GARVIN				2.0	34.774	97.562	5.0R
756	APR 19	200636.95	CARTER				1.7	34.313	97.089	5.0R
757	MAY 3	012158.12	GREER		2.1		2.2	34.912	99.475	5.0R
758	MAY 3	055300.45	HUGHES				1.5	34.910	96.317	5.0R
759	MAY 3	070954.89	HARPER		1.9		2.3	36.665	99.408	5.0R
760	MAY 15	092503.42	PITTSBURG				1.5	35.048	95.386	5.0R
761	MAY 18	112927.61	LOGAN				1.8	35.984	97.414	5.0R
762	MAY 29	225532.21	NOBLE		2.0		2.0	36.271	97.193	5.0R
763	JUN 2	094846.38	HASKELL				1.6	35.275	95.345	5.0R
764	JUN 12	142047.58	ATOKA		2.2		1.8	34.355	96.261	5.0R
765	JUN 20	030726.30	OKFUSKEE				1.4	35.480	96.585	5.0R
766	JUN 22	080856.46	OKFUSKEE				1.1	35.485	96.276	5.0R
767	JUN 30	055324.79	PONTOTOC				1.4	34.589	96.557	5.0R
768	JUL 6	045639.36	PONTOTOC				1.8	34.585	96.517	5.0R
769	JUL 9	181239.62	CANADIAN				1.9	35.667	98.108	5.0R
770	JUL 16	051751.48	CLEVELAND				1.3	35.109	97.354	5.0R
771	JUL 16	053353.13	McCLAIN				1.4	35.029	97.355	5.0R
772	JUL 16	055408.73	CLEVELAND				1.6	35.064	97.332	5.0R
773	JUL 16	064132.11	CLEVELAND		1.9	1.8	2.0	35.052	97.320	5.0R
774	JUL 16	081718.54	CLEVELAND		1.8	1.8	1.9	35.355	97.490	5.0R
775	JUL 16	104259.71	CLEVELAND				1.8	35.326	97.453	5.0R
776	JUL 19	015143.27	JOHNSTON		1.8		1.7	34.373	96.824	5.0R
777	JUL 19	101158.13	MAJOR		1.3		1.7	36.360	98.883	5.0R
778	JUL 19	144919.35	MAJOR		2.3		2.1	36.360	98.883	5.0R
779	JUL 19	153931.83	WOODWARD		2.1		2.1	36.360	98.977	5.0R
780	JUL 19	202912.09	MAJOR				1.7	36.360	98.883	5.0R
781	JUL 19	205458.60	MAJOR		2.2		1.9	36.311	98.824	5.0R
782	JUL 20	023208.26	MAJOR		1.6		1.8	36.360	98.860	5.0R
783	JUL 20	024949.89	MAJOR		2.7	2.2	2.6	36.360	98.883	5.0R
784	JUL 20	031654.51	MAJOR		2.3		2.1	36.362	98.946	5.0R
785	JUL 20	035233.33	MAJOR		1.9		2.0	36.364	98.938	5.0R
786	JUL 20	060751.54	MAJOR		3.1	2.5	2.8	36.382	98.818	5.0R
787	JUL 20	102108.81	MAJOR		2.1		2.2	36.347	98.931	5.0R
788	JUL 20	110651.96	MAJOR		2.0		2.0	36.337	98.923	5.0R
789	JUL 21	042216.43	MAJOR		2.1		2.0	36.351	98.865	5.0R
790	JUL 22	182736.49	MAJOR				1.8	36.382	98.818	5.0R
791	JUL 22	213224.74	MAJOR				1.9	36.382	98.818	5.0R
792	JUL 26	085855.53	PUSHMATAHA		2.1	1.8	2.2	34.593	95.208	5.0R
793	AUG 7	075406.68	McCLAIN		2.4		2.2	34.918	97.507	5.0R
794	AUG 29	235817.70	BRYAN				1.9	34.012	96.146	5.0R
795	SEP 16	010348.53	MURRAY				1.9	34.503	97.314	5.0R
796	SEP 27	071223.40	ELLIS		2.5	2.5	2.3	36.127	99.995	5.0R
797	SEP 29	034919.13	McCLAIN		2.2	2.0	2.2	34.871	97.652	5.0R
798	OCT 4	131925.63	GARFIELD		2.0		1.6	36.425	97.464	5.0R
799	OCT 5	060516.45	HASKELL		2.2	1.5	2.1	35.139	95.326	5.0R
800	OCT 12	053322.54	LOGAN		1.9		1.9	36.061	97.437	5.0R
801	OCT 14	013129.25	KAY		1.6		1.9	36.653	97.404	5.0R
802	NOV 3	064858.69	POTTAWATOMIE		1.9		1.8	35.109	96.932	5.0R
803	NOV 22	115354.62	GARVIN		1.8		1.8	34.800	97.380	5.0R

TABLE 1.—*Continued*

Event Number	Date and Origin Time (UTC)[1]		County	Intensity MM[2]	Magnitudes 3Hz	bLg	DUR	Latitude deg N	Longitude deg W	Depth (km)[3]
804	DEC 09	181735.20	MAJOR		2.0		2.1	36.339	98.892	5.0R
805	DEC 15	224228.10	ELLIS		2.5		2.4	36.335	99.634	5.0R
806	DEC 27	043148.09	DEWEY		1.5		1.9	36.104	98.709	5.0R

[1]UTC refers to Coordinated Universal Time, formerly Greenwich Mean Time. The first two digits refer to the hour on a 24-hour clock. The next two digits refer to the minute, and the remaining digits are the second. To convert to local Central Standard Time, subtract 6 hours.
[2]Modified Mercalli (MM) earthquake-intensity scale (see Table 2).
[3]The hypocenter is restrained (R) at an arbitrary depth of 5.0 km, except where indicated, for purposes of computing latitude, longitude, and origin time.

TABLE 2.—MODIFIED MERCALLI (MM) EARTHQUAKE-INTENSITY SCALE (ABRIDGED) (MODIFIED FROM WOOD AND NEUMANN, 1931)

I Not felt except by a very few under especially favorable circumstances.

II Felt only by a few persons at rest, especially on upper floors of buildings. Suspended objects may swing.

III Felt quite noticeably indoors, especially on upper floors of buildings. Automobiles may rock slightly.

IV During the day felt indoors by many, outdoors by few. At night some awakened. Dishes, doors, windows disturbed. Automobiles rocked noticeably.

V Felt by nearly everyone, many awakened. Some dishes, windows, etc., broken; unstable objects overturned. Pendulum clocks may stop.

VI Felt by all; many frightened and run outdoors.

VII Everybody runs outdoors. Damage negligible in buildings of good design and construction. Shock noticed by persons driving automobiles.

VIII Damage slight in specially designed structures; considerable in ordinary substantial buildings; great in poorly built structures. Fall of chimneys, stacks, columns. Persons driving automobiles disturbed.

IX Damage considerable even in specially designed structures; well-designed frame structures thrown out of plumb. Buildings shifted off foundations. Ground cracked conspicuously.

X Some well-built wooden structures destroyed; ground badly cracked, rails bent. Landslides and shifting of sand and mud.

XI Few if any (masonry) structures remain standing. Broad fissures in ground.

XII Damage total. Waves seen on ground surfaces.

200 km of Oklahoma's borders is considered a local earthquake. A catalog containing date, origin time, county, intensity, magnitude, location, focal depth, and references is printed in page-sized format. Table 1 contains 1989 Oklahoma earthquake data displayed in a modified version of the regional earthquake catalog. Each event is sequentially numbered and arranged according to date and origin time. The numbering system is compatible with the system used for the *Earthquake Map of Oklahoma* (Lawson and others, 1979) and subsequent additions (Lawson and Luza, 1980–89).

The date and time are given in UTC. UTC refers to Coordinated Universal Time, formerly Greenwich Mean Time. The first two digits refer to the hour on a 24-hour clock. The next two digits refer to the minute, and the remaining digits are the seconds. To convert to local Central Standard Time, subtract 6 hours.

Earthquake magnitude is a measurement of energy and is based on data from seismograph records. There are several different scales used to report magnitude. Table 1 has three magnitude scales, which are mbLg (Nuttli), m3Hz (Nuttli), and MDUR (Lawson). Each magnitude scale was established to accommodate specific criteria, such as the distance from the epicenter, as well as the availability of certain seismic data.

For earthquake epicenters located 11 km to 222 km from a seismograph station, Otto Nuttli developed the m3Hz magnitude scale (Zollweg, 1974). This magnitude is derived from the following expression:

$$\text{m3Hz} = \log(A/T) - 1.63 + 0.87 \log(\Delta),$$

where A is the maximum center-to-peak vertical-ground-motion amplitude sustained for three or more cycles of Sg waves, near 3 Hz in frequency, measured in nanometers; T is the period of the Sg waves measured in seconds; and Δ is the great-circle distance from epicenter to station measured in kilometers.

In 1979, St. Louis University (Stauder and others, 1979) modified the formulas for m3Hz. This modification was used by the OGO beginning January 1, 1982. The modified formulas had the advantage of extending the distance range for measurement of m3Hz out to 400 km, but also had the disadvantage of increasing m3Hz by about 0.12 units compared to the previous formula. Their formulas were given in terms of log(A) but were restricted to wave periods of 0.2 sec to 0.5 sec. In order to use log(A/T), we assumed a period of 0.35 sec in converting the formulas for our use. The resulting equations are:

(epicenter 10–100 km from a seismograph)

$$\text{m3Hz} = \log(A/T) - 1.46 + 0.88 \log(\Delta)$$

(epicenter 100–200 km from a seismograph)

$$\text{m3Hz} = \log(A/T) - 1.82 + 1.06 \log(\Delta)$$

(epicenter 200–400 km from a seismograph)

$$\text{m3Hz} = \log(A/T) - 2.35 + 1.29 \log(\Delta)$$

Otto Nuttli's (1973) earthquake magnitude, mbLg, for seismograph stations located between 55.6 km and 445 km from the epicenter, is derived from the following equation:

$$\text{mbLg} = \log(A/T) - 1.09 + 0.90 \log(\Delta).$$

Where seismograph stations are located between 445 km and 3,360 km from the epicenter, mbLg is defined as:

$$\text{mbLg} = \log(A/T) - 3.10 + 1.66 \log(\Delta)$$

where A is the maximum center-to-peak vertical-ground-motion amplitude sustained for three or more cycles of Sg waves, near 1 Hz in frequency, measured in nanometers; T is the period of Sg waves measured in seconds; and Δ is the great-circle distance from epicenter to station measured in kilometers.

The MDUR magnitude scale was developed by Lawson (1978) for earthquakes in Oklahoma and adjacent areas. It is defined as:

$$\text{MDUR} = 1.86 \log(\text{DUR}) - 1.49,$$

where DUR is the duration or difference, in seconds, between the Pg-wave arrival time and the time the final coda amplitude decreases to twice the background-noise amplitude. Before 1981, if the PN wave was the first arrival, the interval between the earthquake-origin time and the decrease of the coda to twice the background-noise amplitude was measured instead. Beginning January 1, 1982, the interval from the beginning of the P wave (whether it was Pg, P*, or Pn) to the decrease of the coda to twice the background-noise amplitude was used.

The depth to the earthquake hypocenter is measured in kilometers. For most Oklahoma earthquakes the focal depth is unknown. In almost all Oklahoma events, the stations are several times farther from the epicenter than the likely depth of the event. This makes the locations indeterminate at depth, which usually requires that the hypocenter depth be restrained to an arbitrary 5 km for purposes of computing latitude, longitude, and origin time. All available evidence indicates that no Oklahoma hypocenters have been deeper than 15 to 20 km.

Earthquake detection and location accuracy have been greatly improved since the installation of the statewide network of seismograph stations. The frequency of earthquake events and the possible correlation of earthquakes to specific tectonic elements in Oklahoma are being studied. It is hoped that this information will provide a more complete data base that can be used to develop numerical estimates of earthquake risk, giving the approximate frequency of the earthquakes of any given size for various regions of Oklahoma. Numerical risk estimates could be used for better design of large-scale structures, such as dams, high-rise buildings, and power plants, as well as to provide the necessary information to evaluate insurance rates.

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SEPM MIDCONTINENT SECTION PLANS FIELD TRIP

"Sequence Stratigraphy of the Mississippian System in North Arkansas" is the topic of a two-day field conference for the 1990 SEPM Midcontinent Section Annual Meeting, scheduled for October 19–21 in Fayetteville, Arkansas. The University of Arkansas at Fayetteville, Department of Geology, will host the meeting.

Current plans call for assembly Friday evening, October 19, in Fayetteville, for dinner and pre-field trip discussions.

The trip will begin October 20 and conclude in Fayetteville October 21. Participants will examine two Mississippian depositional sequences in outcrops across north Arkansas—the St. Joe–Boone Lower Mississippian sequence and the Hindsville–Batesville–Pitkin Upper Mississippian sequence. Trip leaders and chairmen are Robert Handford (ARCO) and Walt Manger (University of Arkansas).

For more information contact Robert Handford, ARCO Oil and Gas Co., 2300 West Plano Parkway, Plano, TX 75075; (214) 754-6869.

SEPM 1926

MINERAL INDUSTRY OF OKLAHOMA, 1989

The estimated value of nonfuel minerals produced in Oklahoma in 1989 was $221 million, compared with $220 million in 1988. The State ranked 36th in the nation and accounted for 0.7% of the total value of nonfuel mineral production. Crushed stone output, worth more than $78 million in 1989, continued to contribute the greatest dollar amount to the State's total nonfuel mineral production. Other nonfuel minerals produced were, in decreasing order of value, portland cement, $54 million; construction sand and gravel, $19 million; and 11 other commodities.

Employment—Total unemployment in the State continued the favorable trend, falling from 6.4% to 5.0% between October 1988 and October 1989. Total nonfuel mining employment, however, decreased from an estimated 2,200 to 2,100 persons in that same period.

Environment—The American Exchange Bank found itself liable for hazardous waste cleanup that could reach $15,000 when it foreclosed on a property northwest of Norman. The site had been used by the Flynt Mining Co. to recover silver from photographs and X-rays, using a cyanide solution. Waste water from the processing, which contained traces of silver and cyanide, was dumped into a pond on the site, drawing complaints from neighbors. Because the Oklahoma State Department of Health began its investigation into the problem after the bank had foreclosed on the property, the bank became responsible for the cleanup. The Federal Superfund law (Comprehensive Environmental Response, Compensation, and Liability Act of 1980, Public Law 96-510) gave State and Federal environmental officials wide latitude in determining who shall pay for cleaning up a hazardous waste site.

Kerr-McGee Corp. settled 13 lawsuits concerning the accidental release in January 1986 of toxic fumes at its Sequoyah Fuels uranium processing plant near Gore.

The Abandoned Mine Land program of the Oklahoma Conservation Commission began, in April, filling up 169 old coal mine shafts, tunnels, and seep holes near Lake Eufaula.

Exploration—NERCO Minerals Co., Newmont Exploration Ltd., and American Copper & Nickel Co. entered into a 5-year joint venture exploration project in southwestern Kiowa County. Drilling began in 1989 on targets developed by NERCO during the previous 2 years.

Legislation and Government Programs—In October, the President signed a law enabling the transfer of a 190-acre site near Keys to a public trust. The trust was formed for the sole purpose of taking possession of the U.S. Bureau of Mines-built and -owned helium plant and surrounding land in Cimarron County. The Keys Helium Plant was built in 1959 and closed in 1985. Cimarron Industrial Park Authority was expected to take possession on September 30, 1990.

The U.S. Bureau of Land Management announced in September that it would lift mining restrictions for coal production firms that supply coal to the Applied Energy Services cogeneration plant at Shady Point, Le Flore County. The agreement took effect October 11. The elimination of a 250-ton limit on how much coal may be mined for test burns was part of the agreement that let the State regulate surface mining operations on Federal leases and issue the required permits. Oklahoma expected to begin issuing the Federal coal mining permits by the summer of 1990. National Wildlife Federation officials protested that the agreement violates the Surface Mining Control and Reclamation Act of 1977, the Federal Coal Leasing Amendments Act of 1976, the Administrative Procedure Act, and the National Environmental Policy Act.

The Department of the Interior in December granted Oklahoma $925,025 to administer the State's abandoned coal mine lands reclamation program.

The Oklahoma Geological Survey began compiling a directory of all coal and nonfuel mining companies permitted in the State. The directory is to include a list of known minerals and the counties in which they have been found.

Review By Nonfuel Mineral Commodities—Crushed stone production fell nearly 6% from that of the last canvass in 1987. Average price per short ton decreased about $0.20 to $3.30 and total value fell 15%.

Masonry and portland cements were produced in the State at higher estimated tonnages and total values than in 1988. Portland cement output and total value rose about one-quarter and price per short ton increased from $29.42 to $30.

Estimated output and value of construction sand and gravel fell nearly 14% and 17%, respectively, from figures for 1988, when the last canvass was compiled. The average price was $2.35, down from $2.44 per short ton in 1988.

Oklahoma clay pits were the source of common clay and shale. Estimated output was down 155,935 short tons to 598,119 tons, and total value fell 15% to $1.5 million.

Feldspar production increased by 15% and value rose nearly 10%, but the estimated average price fell $3.10 per short ton. The State was one of only seven that produced feldspar in 1989; production came from Muskogee County. Feldspar was used in glass- and pottery-making.

Crude gypsum output was unchanged from that of 1988, but total value rose an estimated 5% and average price was up $0.33 to $6.49 per short ton. The estimated output and total value of calcined gypsum in the State rose nearly 4%. One of the State's principal producers was United States Gypsum Co.'s Southard plant in Blaine County. The calcining plant required rock that was 96% pure, and the best quality gypsum was taken from the Nescatunga Gypsum Member of the Blaine Formation. In June, the firm installed a rock beneficiation system/log washer unit to cleanse dirt and clay from the gypsum. About 200 gypsum products were made at the Southard plant. Most sales were made to customers in Oklahoma, Arkansas, Kansas, and Texas and some products were shipped as far as the north slope of Alaska and to Colombia and Venezuela.

Three companies produced iodine from brines in northwestern Oklahoma: IOCHEM Corp. near Vici, North American Brine Resources near Dover, and Woodward Iodine Corp. at Woodward. The addition of IOCHEM's operation in late 1988 helped increase annual output to 2.9 million pounds. The estimated price of iodine was $7.74 per pound. Oklahoma brines are the nation's sole domestic source of iodine.

Lime production increased slightly but total value fell insignificantly from figures for 1988. In June 1989, a new Cimprogetti 3-stage hydrator was started up at St.

Clair Lime Co.'s plant near Sallisaw, Sequoyah County. The $1 million Italian-made hydrator was, according to company officials, to be the first of its kind installed in North America. It processed both bulk and bagged hydrated limes from quicklime produced in two adjacent coal-fired rotary kilns. About 2 tons of limestone were used to make 1 ton of lime, which was 52% to 54% CaO. The underground room and pillar mine was at a shallow depth beneath the surface. Two levels were worked in 1989; pillars were between 45 and 50 feet high and measured 35 by 35 feet at the base. The recovery rate in the mine was 70%, and about one-third of the production was sold as lime. A major customer for the lime was the nearby Grand River Dam Authority coal-fired power plant, which used it to neutralize SO_2 in the scrubber system.

NONFUEL MINERAL PRODUCTION IN OKLAHOMA

Commodity	1988 Quantity[b]	1988 Value (thousands)	1989[a] Quantity[b]	1989[a] Value (thousands)
Cement:				
Masonry (thousand short tons)	—	—	—	—
Portland (thousand short tons)	1,432	$42,131	1,800	$54,000
Clays (short tons)	754,054	1,803	598,119	1,530
Gemstones	—	18	—	—
Gypsum (thousand short tons)	2,173	13,393	2,174	14,099
Iodine (pounds)	2,238,152	—	2,935,000	22,715
Sand and gravel:				
Construction (thousand short tons)	9,273	22,654	8,000	18,800
Industrial (thousand short tons)	1,268	17,381	1,260	19,000
Stone:				
Crushed[d] (thousand short tons)	26,300[c]	92,000[c]	23,700	78,300
Dimension (short tons)	7,746[c]	785[c]	7,940	1,123
Combined value of feldspar, lime, salt (1987–88), stone (crushed dolomite), tripoli (1987–88)	—	29,972	—	11,470
Total	—	$220,137	—	$221,037

Source: USBM Denver Regional Office of State Activities in cooperation with the Oklahoma Geological Survey.
Dashes indicate data not available, withheld to avoid disclosing company proprietary data, or not applicable.
[a]Preliminary figures.
[b]Production as measured by mine shipments, sales, or marketable production (including consumption by producers).
[c]Estimated.
[d]Excludes certain stones; kind and value included with "Combined value" data.

UPCOMING MEETINGS

Soil and Water Conservation Society, Annual Meeting, July 29–August 1, 1990, Salt Lake City, Utah. Information: Tim Kautza, SWCS, 7515 Northeast Ankeny Road, Ankeny, IA 50021-9764; (515) 289-2331.

Chemical Modeling of Ground Waters, August 7–10, 1990, Dallas, Texas. Information: National Water Well Association, 6375 Riverside Dr., Dublin, OH 43017; (614) 761-1711.

CONSERV 90: The National Conference and Exposition Offering Water Supply Solutions for the 1990s, August 12–16, 1990, Phoenix, Arizona. Information: CONSERV 90, 6375 Riverside Dr., Dublin, OH 43017; (614) 761-1711.

SEPM Research Conference, "Cretaceous Resources, Events and Rhythms," August 20–24, 1990, Denver, Colorado. Information: Michael A. Arthur, Graduate School of Oceanography, University of Rhode Island, Narragansett, RI 02882-1197; fax (401) 792-6160.

Oil and Gas Waste Management, International Meeting, September 10–13, 1990, New Orleans, Louisiana. Information: U.S. Environmental Protection Agency Oil and Gas, GRCDA, Box 6126, Silver Springs, MD 20906; (301) 585-2898; fax (301) 589-7068.

Society of Petroleum Engineers, Annual Technical Conference and Exhibition, September 23–26, 1990, New Orleans, Louisiana. Information: Meetings Dept., Society of Petroleum Engineers, Box 833836, Richardson, TX 75083-3836; (214) 669-3377.

Society of Exploration Geophysicists, Annual Meeting, September 23–27, 1990, San Francisco, California. Information: Convention Dept., SEG, Box 702740, Tulsa, OK 74170-2740; (918) 493-3516.

Association of Engineering Geologists, 33rd Annual Meeting, October 1–5, 1990, Pittsburgh, Pennsylvania. Information: 33rd AEG Meeting, MEMS, One Northgate Sq., Suite 211, P.O. Box 270, Greensburg, PA 15601; (412) 836-6813; fax (412) 836-6817.

NEW OGS PUBLICATIONS

CIRCULAR 91. ***Hydrology of the Arbuckle Mountains Area, South-Central Oklahoma,*** by Roy W. Fairchild, Ronald L. Hanson, and Robert E. Davis. 112 pages. Clothbound, $18; paperbound, $13.

Authors' abstract:

Rocks that make up the Arbuckle–Simpson aquifer crop out over ~500 mi^2 in the Arbuckle Mountains province in south-central Oklahoma. The aquifer consists of limestone, dolomite, and sandstone of the Arbuckle and Simpson Groups of Late Cambrian to Middle Ordovician age and is about 5,000–9,000 ft thick. The rocks

were subjected to intensive folding and faulting associated with major uplift of the area during Early to Late Pennsylvanian time.

Water in the aquifer is confined in some parts of the area, while in other parts it is unconfined. The average saturated thickness of the aquifer is ~3,500 ft in the outcrop area. Water levels measured in wells fluctuated from 8 to 53 ft each year, primarily in response to recharge from rainfall.

Recharge to the aquifer is estimated at ~4.7 in./yr.

The average storage coefficient of the aquifer is estimated at 0.008, and the average transmissivity is estimated at 15,000 ft^2/day. Based on an average saturated thickness of ~3,500 ft and a storage coefficient of 0.008, the volume of ground water contained in the 500-mi^2 outcrop area is ~9 million acre-ft. An undetermined amount of fresh water probably exists in the aquifer around the periphery of the aquifer outcrop.

Base flow of streams that drain the aquifer accounts for ~60% of the total annual runoff from the outcrop area and is maintained by numerous springs. The close hydraulic connection between streams in the outcrop area and the aquifer is shown by a close correlation between base flow in Blue River and the fluctuation of ground-water levels in five wells in the Blue River basin. This correlation also exists between the discharge by Byrds Mill Spring and the fluctuation in water level in a nearby observation well; increase and decrease in spring discharge correspond to rise and fall of the water level in the well.

The chemical quality of water from the Arbuckle–Simpson aquifer is suitable for most industrial and municipal uses. The water is hard and of the bicarbonate type; the average hardness is ~340 mg/L, and the average dissolved-solids concentration is ~360 mg/L. Because springs issue from the aquifer and discharge to streams in the area, the quality of water from springs and base flow in streams is similar to that of ground water. The average dissolved-solids concentration of stream water is slightly less than that of water from wells and springs.

GEOLOGIC MAP GM-31. ***Geologic Map and Sections of the Arbuckle Mountains, Oklahoma,*** by William E. Ham, Myron E. McKinley, and others; revised by Kenneth S. Johnson. 1 sheet, scale 1:100,000. Price: $4, folded in envelope.

The well-known and widely used *Geologic Map and Sections of the Arbuckle Mountains, Oklahoma,* by William E. Ham and Myron E. McKinley was originally released by the OGS in 1954 and went out of print about five years ago. The four-color map has been redrafted, at reduced scale and with minor revisions, and now is available as OGS Map GM-31. The new map is at a scale of 1:100,000, and has been set upon a composite base map consisting of U.S. Geological Survey planimetric sheets for the Ada, Ardmore, Pauls Valley, and Tishomingo 30′ × 60′ maps.

Some of the stratigraphic nomenclature has been updated from the earlier map and it is largely consistent with terminology adopted in the COSUNA project. Mine, pit, and quarry data have been updated through 1987. Map reduction, adjustments, revisions, stratigraphic nomenclature, and new mine, pit, and quarry data have been provided by Kenneth S. Johnson. Patrick K. Sutherland provided information on the Atoka and Wapanucka Formations; Rodger E. Denison provided mapping and subdivision of Precambrian units; Robert O. Fay provided data on stratigraphic nomenclature and on thrusting along major faults.

In addition to its release as GM-31, the map also will be included in the new OGS Circular 91, *Hydrology of the Arbuckle Mountains Area, South-Central Oklahoma,* by R. W. Fairchild, R. L. Hanson, and R. E. Davis. The map in Circular 91 is identical to GM-31, except that it contains an outline of the area underlain by the Simpson–Arbuckle aquifer.

SPECIAL PUBLICATION 90-3. ***Hazardous-Waste Disposal in Oklahoma—A Symposium,*** edited by Kenneth S. Johnson. 87 pages. Price: $5.

From the editor's preface:

> The management and disposal of hazardous wastes is one of the major problems being addressed in Oklahoma and throughout the nation. Oklahoma has taken a number of specific steps to deal with these issues, and the purpose of this symposium was to bring together people knowledgeable about various hazardous-waste activities in the State and discuss the issues in a public forum. This goal was well met, and this symposium-proceedings volume is a further attempt to disseminate information to the concerned public.
>
> In the Spring of 1989, the Oklahoma Geological Survey (OGS) proposed to the Executive Committee of the Oklahoma Academy of Science (OAS) that a one-day symposium on hazardous-waste disposal in Oklahoma be presented under the sponsorship of OAS at the next annual technical meetings, held at Central State University in Edmond. It was proposed that the Geology Section of OAS would organize the session, and that it be held on November 9, 1989, the day before the OAS technical meeting. This was agreed to, and the final program was offered under the cosponsorship of the OAS, OGS, Oklahoma State Department of Health (OSDH), Oklahoma Department of Wildlife Conservation, and Oklahoma Wildlife Federation. All these organizations were instrumental in the success of the symposium.
>
> The success of the program can be measured in part by the number and diversity of attendees. About 275 people attended the symposium, including representatives of industry, government (city, state, and federal), academia (faculty and students), environmental organizations, and the general public.

The 13 technical papers presented in this volume include: Hazardous Wastes Generated and Disposed of in Oklahoma; History of Oklahoma's Regulatory Responsibility; Geologic and Hydrologic Siting Criteria; Aquifer Protection and Contamination Monitoring; Impacts and Citizen Concerns; Relation of Waste Disposal to Industrial and Economic Development; Surface Disposal of Hazardous Wastes; Class I Hazardous-Liquid-Waste Disposal Wells; Transportation of Hazardous Wastes; The Superfund Program; Program for Removal of Chemicals from Schools; Closure of Hazardous-Waste Facilities; and Alternative Strategies for Managing Hazardous Wastes.

Circular 91, GM-31, and SP 90-3 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.

GSA ANNUAL MEETING
Dallas, Texas, October 29–November 1, 1990

Geology is alive and well in Dallas. Join us to experience the excitement of current, relevant science at the Dallas Annual Meeting. No longer just for the oil geologist, Dallas is a desirable destination for all geologists.

Dallas has a strong base in other areas besides geology. Beyond recognition for oil and cattle, Dallas is known as the Silicon Prairie; Dallas ranks among the top five cities in computer and microelectronic manufacturing employment in the United States. Dun and Bradstreet also reports that Dallas has one of the largest concentrations of million-dollar corporations, the nation's second leading fashion and apparel center, and the world's largest wholesale trading complex.

And when the business day ends, people don't ride off into the sunset, because Dallas lights up with night life dedicated to good times that go well beyond calico and cowboy boots. Today's Dallas lets you kick up your heels at the most sophisticated nightspots. Boasting more restaurants per capita than New York City, Dallas offers culinary delights ranging from French to Thai to Tex-Mex. Every night in Dallas over 100 live performances are staged including opera, ballet, and improvisational entertainment.

DALLAS: a prime destination for geologists open to the latest in science. And after a long day in sessions, these same geologists can be revived by the cuisine and night life offered with a warm Texas welcome.

—GSA

DALLAS

GSA Annual Meeting Agenda

Technical Program

Symposia

Sea Floor Hydrothermal Mineralization: New Developments
Geologic Setting and Generation of Very Large Volcanic-Hosted Massive Sulfide Deposits
The Origin of Animals
Active Tectonics in the Mid-Continent
Extinction and Recovery of Plankton from the K/T Boundary Event
Thermodynamic Mixing Properties of Petrologically Important Minerals
Geoscience Organizations: Their Efforts and Impact on Geoscience Education
Geochemistry of Metalliferous Black Shales
Transient Responses to Global Change: The Geomorphic and Hydrologic Record
Oxygen and Carbon Isotopes in Paleozoic and Early Mesozoic Marine Sediments: Toward a Global Isotope Stratigraphy
Geology of Venus
The Effects of Scale on Archaeological and Geological Perspectives
Geological Societies and Information Transfer in the Electronic Age
Salt Tectonics
The Effects of Past Global Change on Life
Eustasy: The Ups and Downs of a Major Concept
Practical Applications of Coal Geology
Structure, Tectonics, and Geophysics of the Southern Margin of North America

Theme Sessions

Strontium Isotopes and Sedimentary Geology
Mesozoic Tectonic Evolution of Mexico and the Gulf of Mexico
Problems and Solutions to Monitoring Ground Water in Karst Terranes
Cretaceous/Tertiary Boundary Sections in the Southern United States
Hydrogeology of Arid Regions
Erosional Landscapes of the South-Central United States
Oxygen and Carbon Isotopes in Paleozoic and Early Mesozoic Marine Sediments: Toward a Global Isotope Stratigraphy
Geologic Effects of Hurricane Hugo
Environmental and Engineering Studies for Radioactive Waste
Isolation: Experience Based on the Waste Isolation Pilot Plant (WIPP) Project, SE New Mexico
Effects of the Loma Prieta Earthquake
Amino Acid Geochemistry: Applications in Stratigraphy and Geochronology
Metageology: Expanding Geologic Awareness
The Late Proterozoic Evolution of Organisms and Environments
Regulatory Geology: Site and Performance Evaluations in the Face of Geological Uncertainty
Salt Domes: Geotechnology, Energy, and Economic Significance
Paleosois and Subaerial Exposure Surfaces in Carbonate Sequences
Upper Cretaceous Stratigraphy and Paleontology, U.S. Gulf Coastal Plain and Adjacent Regions

Isotope Fractionations in Organic Matter: Biosynthetic and Diagenetic Processes
Calibration of Controls on Stratigraphic Sequences
Geoscience Transects
Applications of Organic Matter Biomarkers in Sedimentary Geology
Salt Tectonics
Tectonostratigraphic Correlation of Late Cretaceous–Early Tertiary Island-Arc Rocks in the Caribbean Region
Geological Resources, Hazards and Population
Friction Melting Processes and Products in Geologic Materials
Writing Assignments: A Tool for Teaching and Learning Geology
Geochemistry and Global Change
Microcomputer Management of Databases in Petrology and Geochemistry
Practical Applications of Coal Geology
Granites/Rhyolites: Interrelations, Processes, Geometries, Geochemistries
Water and Volcanoes
Transient Responses to Global Change: The Geomorphic and Hydrologic Record
Opportunities for Scientific Drilling in the Continental Crust: Shallow- to Intermediate-Depth Projects

Field Trips

Premeeting Trips

Sedimentation and Diagenesis of Middle Cretaceous Platform Margins, East-Central Mexico, *October 24–28*
Hydrogeology of Trans-Pecos Texas, *October 25–28*
Petrologic Evolution of the Southeast San Juan Volcanic Field: Oligocene Intra-Continental Arc Magmatism, *October 25–28*
Remote Sensing Techniques Applied to Structural Geology and Oil Exploration in South-Central Oklahoma, *October 25–28*
Geology, Geochemistry, and Structure of Low-Pressure Sheet Granites, Wichita Mountains, Oklahoma, *October 25–28*
Coal Geology of the Western Region of the Interior Coal Province in Parts of Kansas, Missouri, and Oklahoma, *October 25–28*
Carbonate and Siliciclastic Sedimentation in Late Pennsylvanian Cycles, North-Central Texas, *October 27–28*
Nearshore Clastic-Carbonate Facies and Dinosaur Trackways in the Glen Rose Formation (Lower Cretaceous) of Central Texas, *October 27*
Dinosaur Tracks in the Cretaceous Glen Rose Formation of Central Texas, *October 28*
Geology, Hydrogeology, and Engineering Aspects of the Superconducting Super Collider Side, Ellis County, Texas, *October 28*
Archaeological Geology of the Upper Trinity River Drainage Basin, Texas, *October 28*
Clastic and Carbonate Shelf Deposition, Late Albian–Early Cenomanian, North Texas, *October 28*

Postmeeting Trips

Structure and Stratigraphy of the Marathon Basin, Big Bend Park and Vicinity, Trans-Pecos Texas, *November 1–4*

Geological and Hydrological Studies of Evaporites in the Northern Delaware Basin for the Waste Isolation Pilot Plant (WIPP), *November 1–4*
Hydrogeology of the Blaine Gypsum-Dolomite Karst Aquifer, Southwestern Oklahoma, *November 1–3*
Structure and Stratigraphy of the Arbuckle Mountains, Southern Oklahoma, *November 1–3*
NOAM-CARIB Plate Boundary in Guatemala, *November 2–8*
Reefal Development in a Terrigenous Province—The Reefs of Veracruz, Mexico, and Eocene–Miocene Analogues of the Tampico–Misantla Basin, Mexico, *November 2–6*
The Lampasas Cut Plain—Evidence for the Cyclic Evolution of a Regional Landscape, Central Texas, *November 2–3*
Carboniferous Geology and Tectonic History of the Southern Fort Worth (Foreland) Basin and Concho Platform, *November 2–3*
Engineering and Urban Geology of the Dallas–Fort Worth Metroplex, *November 2*
Hydrogeology of the Jewett Lignite Mine, East Texas, *November 2*
Lower Cretaceous Vertebrates in Central Texas, *November 2*

SEG-Sponsored Trip

Non-Metallic Mineral Resources of the Delaware Basin, Texas and New Mexico, *October 25–27*

Short Courses/Workshops/Forums

Mineral-Water Interface Geochemistry, *October 26–28*
Site Selection for Critical Facilities—The Earth Science Perspective, *October 27*
Coastal Land Loss, *October 27–28*
Contaminant Hydrogeology: Practical Monitoring, Protection, and Cleanup, *October 27–28*
Creating Geological Applications with Macintosh HyperCard, *October 27–28*
Metamorphic Pressure-Temperature-Time Paths, *October 27–28*
Phanerozoic Plate Tectonic Reconstructions, *October 27–28*
Quantitative Sedimentary Basin Modeling, *October 27–28*
Seismic Expression of Structural Styles, *October 27–28*
Computer Modeling of Cyclic Carbonate Sequences, *October 28*
Marine and Terrestrial Radiations of the Arthropods, *October 28*
Practical Tracing of Ground Water, with Emphasis on Karst Terranes, *October 28*
Recent Sediments of the Northwest Gulf Coast Region, *October 28*
Geology and Public Policy Forum: The Future for Fossil Fuels, *October 30*
GeoRef Beginners Workshop, *October 30*
GeoRef Advanced Workshop, *October 31*
GIS Database Forum, *November 1*

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 28.

NOTES ON NEW PUBLICATIONS

Reprocessing of the COCORP Data Recorded across the Wichita Mountain Uplift and the Anadarko Basin in Southern Oklahoma

Written by W. F. Agena, M. W. Lee, and J. A. Grow, this USGS open-file report contains 20 pages.

Order OF 89-0357 from: U.S. Geological Survey, Books and Open-File Reports, Federal Center, Box 25425, Denver, CO 80225; phone (303) 236-7476. The price is $4 for microfiche and $3.50 for a paper copy; add 25% to the price for shipment outside North America.

The New Madrid Earthquake

The original scientific work on the New Madrid Earthquake was published by the USGS in 1912 as Bulletin 494. It has been out of print most of the time since. Written by Myron L. Fuller, this 120-page book is the essential starting point for all seismologic, geologic, and historic research on this topic. Since it is such an important and fundamental work regarding this unparelleled series of earthquakes, the Center for Earthquake Studies at Southeast Missouri State University plans to keep it in print as long as there is demand.

Order from: Center for Earthquake Studies, Southeast Missouri State University, One University Plaza, Cape Girardeau, MO 63701-4799; phone (314) 651-2000. The price is $10.95 postpaid.

Water Quality in Gaines Creek and Gaines Creek Arm of Eufaula Lake, Oklahoma

Written by Joanne K. Kurklin, this 97-page USGS water-resources investigations report characterizes the water quality in Gaines Creek near the site of the proposed Higgins reservoir and in the Gaines Creek arm of Eufaula Lake, with emphasis on the suitability of the water for municipal use.

Order WRI 86-4169 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.

A Statistical Processor for Analyzing Simulations Made Using the Modular Finite-Difference Ground-Water Flow Model

Jonathon C. Scott prepared this 218-page water-resources investigations report to aid ground-water modelers in their understanding of the results of ground-water flow simulations made using the Modular Three-Dimensional Finite-Difference Ground-Water Flow Model (Modular Model) by McDonald and Harbaugh.

Order WRI 89-4159 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 Geological Society of America and the authors for permission to reprint the following abstracts of interest to Oklahoma geologists.

The Northwest Extention of the Meers Fault, Oklahoma

HASAN CETIN, Dept. of Geology, Texas A&M University, College Station, TX

The geology of southwestern Oklahoma is dominated by the Wichita Uplift. The uplift is bounded to the north–northeast by the Anadarko Basin and to the south by the Hollis–Hardeman Basin and is composed primarily of the Cambrian Wichita granite complex and Precambrian Raggedy Mountain gabbro complex.

The uplift is separated from the Anadarko Basin by the Frontal Fault Zone which extends for 200 mi in a northwest to southeast orientation. The zone, ranging from 7 to 10 mi in width, has faults whose strike is roughly parallel to the dominant trend directions.

There are three faults dominating the fault zone: the Meers (originally Thomas), Blue Creek Canyon, and Mountain View Faults. The Meers Fault is a capable fault moved within the last 35,000 years and may cause strong earthquakes in the future.

Substantial deflection of stream alignments, buried A-Horizons, oil-coated gravels deposited and coated by seeping oil from the fault zone, and A-Horizon and shale fragments eroded from the upthrown block soon after the last displacement in Quaternary suggest that the Meers Fault has an active northwestern continuation of about 20 mi. The fault splits in Sugar Creek area. This suggests re-evaluation of present building construction codes and careful assessment of seismic risk for critical facilities in the area.

Reprinted, with author corrections, from the Geological Society of America *Abstracts with Programs*, v. 22, no. 1, p. 3.

Late Quaternary Displacements on the Meers Fault, Southern Oklahoma

K. I. KELSON, F. H. SWAN, and J. R. WESLING, Geomatrix Consultants, One Market Plaza, San Francisco, CA

The N60W-striking Meers fault is part of the complex Frontal Wichita fault zone along the northern margin of the Southern Oklahoma aulacogen. Detailed geologic mapping and trenching at four sites along the central and northwestern part of the 26- to 37-km-long active Meers fault indicate down-on-the-south left-oblique slip on a vertical to steeply northeast-dipping fault. Offset buried late

Holocene channels indicate a ratio of lateral to vertical slip components of between about 1.3:1 and 1.4:1. Total lateral separation of the channels is about 4 m and total vertical separation is about 3 m. Cumulative late Holocene net slip ranges from 3.9 ± 1.4 m to 4.4 ± 1.2 m.

Much of the late Quaternary vertical separation resulted from folding within 20 m on both sides of the fault. The ratio of brittle to ductile deformation among the sites ranges from about 3:1 to about 1:2, indicating that generalizations on the relative amounts of brittle and ductile deformation cannot be made based on our data.

Two surface-rupture events occurred along the faults within the past 6,000 years, based on 29 radiocarbon dates from displaced and undisplaced alluvium and scarp-derived colluvium exposed in trenches. Along the northwestern part of the fault, these events occurred at about 1100 yr BP and about 2800 yr BP, but data from the central part of the fault indicate displacements occurred at about 1100 yr BP and about 3200 yr BP. These data reflect either uncertainty in sample ages or different rupture histories on adjacent fault segments. Net slip per event ranges from 2.0 ± 0.8 m to 2.3 ± 1.2 m. At the southeasternmost site, vertical separation of a Holocene fluvial terrace is similar to that of a higher terrace estimated to be middle Pleistocene based on relative soil-profile development. Temporal clustering of surface-rupture events is indicated, with the recent episode of Holocene events preceded by a period of tectonic quiescence of about 10^4 to 10^5 yr.

Reprinted as published in the Geological Society of America *Abstracts with Programs*, v. 22, no. 1, p. 10–11.

Hydrogeology of the Shallow Brine Aquifers, Cimarron River Basin, Northwest Oklahoma

GEORGE J. HALL, P.G., P.E., Chief Geologist, Tulsa District, Corps of Engineers, P.O. Box 61, Tulsa, OK

The Corps of Engineers performed hydrogeologic studies in the Cimarron River Basin near Freedom, Oklahoma, as a part of the Arkansas River Chloride Control Study. The regional geologic and hydrogeologic setting is discussed as a prelude to discussion of 4 aquifer pumping tests performed to define site-specific conditions. Conclusions are drawn from the aquifer pumping tests and a hypotheses is presented regarding the events leading to the formation of the present-day aquifer system. The major conclusions include: (1) the aquifer is not homogeneous or isotropic, (2) the aquifer system is dynamically evolving as solutioning progresses, (3) most flow occurs along preferential flow paths, and (4) dewatering can cause consolidation of the aquifer skeleton and change the aquifer's properties. A simplified block model is presented to diagrammatically illustrate the mechanics of salt dissolution and aquifer evolution. The model is supported by results from the pumping tests and other side explorations. Engineering considerations are presented regarding construction of major structures above the brine aquifer.

Reprinted as published in the Geological Society of America *Abstracts with Programs*, v. 22, no. 1, p. 8.

Current Hydrogeologic Studies of the Permian Blaine Aquifer in the Hollis Basin of Southwestern Oklahoma

KENNETH S. JOHNSON, Oklahoma Geological Survey, Norman, OK

The Permian Blaine Formation consists of 200–250 ft of laterally persistent, cyclic interbeds of gypsum, dolomite, and shale in southwestern Oklahoma. Typically, each of the 9 thick gypsum beds is underlain by a thin dolomite and is overlain by a thin to thick red-brown shale: individual gypsum beds are 10–30 ft thick, dolomite beds are 0.1–5 ft thick, and shale beds are 1–25 ft thick. Gypsum and dolomite beds have been partly dissolved by circulating ground waters, thus creating the karstic aquifer that yields water in 1,000 sq. miles making up the Hollis–Duke irrigation district. Karst features include sinkholes, caves, disappearing streams, springs, and underground water courses. In addition to natural recharge, the Blaine aquifer is recharged artificially by diverting storm runoff into sinkholes and into wells drilled through the cavernous rocks.

A hydrogeologic study of the Blaine aquifer is being carried out by the U.S. Geological Survey, the Oklahoma Water Resources Board, and the Oklahoma Geological Survey. The regional flow of water in the Blaine aquifer is from northwest to southeast. Irrigation wells completed in the aquifer typically are 50–300 ft deep and they commonly yield 250–2,000 gpm. Depth to water in the Blaine ranges from about 5–90 ft below land surface. The water has high concentrations of calcium sulfate (derived from the gypsum), and it has an average of about 3,100 mg/L total dissolved solids; this is suitable for irrigation, but not for drinking water.

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Design Methodology for a Long-Term Groundwater Withdrawal and Treatment System, Garber–Wellington Aquifer, Central Oklahoma

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The Corps of Engineers performed hydrogeologic studies in the Garber–Wellington Aquifer as part of the environmental restoration studies at Tinker Air Force Base. A pumping test was performed to obtain aquifer parameters for cleanup of contaminated groundwater beneath a portion of the base. The pumping test was conducted by simultaneously pumping from 3 distinct aquifer units, and monitoring the drawdown and recovery of these 3 aquifers. Analysis of this data was accomplished using the microcomputer program "WHIP," and solving for drawdowns from several observation wells simultaneously. The methods of analysis of the time-drawdown data is discussed, and hydrographs of some typical wells are presented. A report was prepared that recommended well spacings, screen depths, and pumping rates for the groundwater withdrawal system to operate over an antic-

ipated 30 year life. Complicating factors include: (1) the interaction of the 3 aquifers pumping simultaneously, (2) the long time span over which the system must operate, (3) a large percentage of the area is covered by concrete, asphalt, or buildings, (4) the necessity to guarantee a constant inflow rate regardless of the current aquifer recharge state, and (5) the lack of design guidance for long-term groundwater withdrawal systems. The design methods used to conservatively estimate well yields, required spacing, and groundwater chemistry, are discussed.

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Siderite Occurrences in the Atoka Formation, Oklahoma and Arkansas, and their Hydrochemical, Diagenetic and Paleomagnetic Implications

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Siderite occurs in sandstone sequences of the upper Atoka Formation near Pocola, Oklahoma, and Hackett, Arkansas. Eight types of bedded or redistributed siderite are defined, each a result of specific responses to bioturbation, to physical erosion during and after deposition, and to dissolution, hydrochemical dispersion and redistribution. Interpretations based on sedimentary structure, texture, and mineralogy of the sediments intimately associated with siderite occurrences suggest that iron-rich organic material accumulated in a quiet tidal-flat environment of a southward prograding fluvial-deltaic system, creating localized microenvironmental reducing conditions with bacterial action converting iron to its ferrous state and combining with abundant bicarbonate to form siderite soon after deposition. Occasionally, strong bottom currents eroded, broke up and redistributed the newly formed siderite.

The shallow ground-water environment below the sediment-water interface would behave as a geochemical cell with a high Fe^{+2}:Ca^{+2} ratio and low SO_3^{-2} in solution. Such a geochemical cell would invade subsurface regions and would account for the observed siderization of calcareous materials within marine sediment located at some distance and time down the paleohydraulic gradient from the source siderite zones. We have initiated a reevaluation of the siderite samples taken from outcrop in 1975 and have resampled the original sites. Preliminary investigations suggest that this type of siderite does not alter readily although studies on their chemical make-up and remanent magnetism have not been completed at the date of this status report. Further investigations on the "in-place" siderite zones may provide additional insights to diagenetic mechanisms. In addition, the bedded siderite zones may prove to be useful in paleomagnetic investigations if the remanent magnetism has persisted through time and sampling.

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Hydrogeologic Effects on Variations in Shallow Ground-Water Quality

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A comprehensive monitoring program was established at a field site in Stillwater, Oklahoma, to relate observed variations in shallow ground-water quality to controlling hydrogeologic factors.

Rainfall amounts, fertilizer application rates, ground-water levels, moisture content in the unsaturated zone, and chemical quality of water samples from the unsaturated zone and upper portion of a fine-grained, alluvial aquifer were measured between March and December, 1988. The monitoring program was supplemented by two tracer experiments, through unsaturated soil at the site under both "wet" and "dry" antecedent soil-moisture conditions.

Minimal variability in water quality was observed in the lower portion of the unsaturated zone and upper part of the aquifer between successive sampling event. This suggests that large quantities of rain water and regularly measured ionic constituents do not move rapidly from land surface to the water table. Although tracer experiments demonstrated that small percentages of rain water and surface applied contaminants may quickly migrate to ground water by direct infiltration when the soil is initially very moist and the water table is elevated, temporal changes in ground-water quality are probably more heavily influenced by other processes. These processes include flushing of water and solutes from the unsaturated zone in the aquifer, underflow, soil-water interactions, and microbial activity.

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Southern Midcontinent–Texas Transect: Overview and Statement of the Tectonic Problems

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This transect is along the line from a point on the Kansas–Oklahoma state boundary, latitude 37° N, longitude 98° W, through the point lat 34° N, 99° W, to the Llano uplift in south-central Texas, lat 31° N, 99° W, a distance of about 700 km. The lithospheric geology and tectonic history of a 200 km-wide strip, 100 km deep, along the transect are being constructed. This transect focuses on a section which will elucidate one aspect of the southern edge of the North American plate. It is west of and subparallel to the paleozoic Nemaha Uplift, and west of and subparallel to the Ouachita Front. The lower crust of this transect is apparently Proterozoic; however, the basement varies in age from 1.35–1.4 by in the north, across a strip 0.55 by, to 1.1–1.2 by in the south. The northern basement is the granite-rhyolite terrane of the southern Midcontinent, mostly known from well data outside the transect area. The southern basement is the Texas craton consisting of a lithologically more diverse suite of igneous and metamorphic rocks, variably tectonized, as exposed at the surface in the Llano region. The placement and character of the boundary or suture (Grenville front equivalent?) between these two crustal types, the interpretation of the late Proterozoic basin with pronounced horizontal seismic layers discovered by Brewer and others (which lies between the two basement types and possibly along part of the suture), and the full crustal characterization of the Southern Oklahoma Aulacogen (SOA), a Cambrian extensional terrane, are major objectives.

Later Paleozoic structures crossed by the transect are (1) the Anadarko Basin, a compound cratonic and foreland basin; (2) the Wichita–Criner–Amarillo Uplift, the igneous floor of the SOA; (3) the Hollis–Hardeman Basin, part of the original early Paleozoic ancestral Anadarko Basin; (4) the Red River Uplift; and (5) the Bend Arch–Llano Uplift. Other questions addressed in the transect include: (1) nature of the southern Midcontinent lithosphere and of the Texas craton lithosphere; (2) why is the Llano block a longstanding crustal high; (3) what is the significance of the large wide gravity low cutting E–W across the Bend Arch; (4) is the Red River–Matador Arch a suture zone; (5) can the Midcontinent Rift be followed to the SOA; and (6) implication for lithospheric structure of the SOA.

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Southern Midcontinent–Texas Transect, Surface Bedrock Geology

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Within the context of the Transect a Surface Bedrock map covering an area of approximately 87,000 square miles is under construction. In general the map depicts the geology of a strip approximately 100 miles wide on either side of the transect line. The philosophy used in the construction of the map is that only tectonically significant boundaries (i.e., those that result in angular unconformities of regional significance) are depicted. In consequence lithological changes which record fluctuation in the relative height of sea level (and which form the basis of conventional lithostratigraphy) are ignored.

The following unconformities are incorporated into the map:

sub Ogallala
sub Cretaceous
sub Garber–Wellington
sub Vanoss
sub Lower Paleozoic

Additional features incorporated into the map are major structural trends, generalized isopachs to basement and paleogeographic generalizations. The resulting map highlights regions of Upper Paleozoic structural complexity: the Wichita uplift and Frontal fault zone, the Arbuckle and Criner uplifts and the Llano region. The surface geology of adjacent basins, mostly filled with Permian and Pennsylvanian strata, is characteristically simple and reflects the lack of Mesozoic and Tertiary tectonic activity in the area.

As constructed the map has considerable areas of surficial blandness above the Cretaceous and Penn–Permian unconformities (recording long-lived platform stability). Such bland areas permit us to incorporate relevant lineament roses and localized cross sections depicting the complexities of the sedimentary cover drawn to basement. These sections allow us to explore the age of the rocks above the basement, variations in thickness of key elements in the section and the details of structurally complex areas. The following sections are under construction: (a) above the Tulsa Hills; (b) through the Nemaha ridge; (c) across the Wichita uplift; (d) the northern flank of the Llano uplift.

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Basement Rocks Along the Southern Midcontinent–Texas Craton Transect

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The southern midcontinent–Texas craton transect traverses rocks of five main basement terranes and provinces. These are, from north to south, the mesozonal and eipizonal granites of the anorogenic granite-rhyolite terrane of southern Kansas and northern Oklahoma, the igneous rocks of the Wichita province of southwestern Oklahoma, the Tillman Metasedimentary Group of southwestern Oklahoma and adjacent northern Texas, a proposed late Proterozoic basin with pronounced deep horizontal seismic layering along the Oklahoma–Texas border, and a diverse suite of igneous and metamorphic rocks of the Llano province of Texas. Radiometric ages from these rocks are as follows: granite-rhyolite terrane, 1,340–1,400 Ma; Wichita igneous province, 520–550 Ma; Tillman Metasedimentary Group, 1,000–1,380 Ma; and Llano province, 1,050–1,300 Ma. A prominent Proterozoic boundary is the Llano front (Grenville front equivalent, Mosher, in press) which follows a linear array of gravity and magnetic anomalies and separates rocks of contrasting age and lithology.

The diverse basement tectonic elements that occur along the transect suggest that the region had a complex Proterozoic history that included anorogenic magmatism, basinal sedimentation, and two or more periods of compressional orogenesis. The geology and structure of the basment has been further complicated by a number of major Paleozoic structures that cross the transect. These are the Cambrian-age southern Oklahoma aulacogen and the Paleozoic Anadarko–Ardmore Basin, the Wichita Uplift, the Hollis–Hardeman Basin, the Red River Uplift, the Bend Arch, and the Llano Uplift.

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Southern Midcontinent–Texas Transect: Crustal Structure from Seismic and Gravity Studies

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Seismic data which provide constraints on crustal structure are sparse in Oklahoma and northern Texas. The available data indicate a regional crustal thickness of approximately 40 km. However, more detailed results are available in southwestern Oklahoma in the vicinity of the Wichita Uplift because of recent efforts by COCORP and a U. T. Dallas–U. T. El Paso joint study. These studies establish that this uplift is associated with a deep-seated anomaly in crustal structure. Gravity data are available throughout the region and provide a basis on which to extrapolate from the seismic control. The large gravity high centered on the Wichita Uplift is flanked by nearly symmetrical gravity lows. The structure, however, is very asymmetrical with the northern gravity low being due to the Paleozoic Anadarko basin and the southern gravity low being due to a Proterozoic feature.

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Geology, Geochemistry, and Platinum-Group Element Mineralization of the Glen Mountains Layered Complex, Southwestern Oklahoma

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The Cambrian-age Glen Mountains Layered Complex is composed of several cyclic units. The cycles are ideally characterized by a plagioclase-olivine cumulate layer (POc) overlain by plagioclase-olivine-pyroxene (POAc), plagioclase-pyroxene (PAc), and plagioclase cumulate (Pc) layers.

POc, POAc, and PAc portions of cycles are moderately to strongly adcumulate and characterized by an upward decrease in the amount of olivine and upward increase in the amount of pyroxene and oxide. Defined cyclic units often contain a number of vertically and laterally variable rythmic layers of POc, POAc, and PAc that may represent primary magma (liquid) stratification. Olivine varies from Fo_{60} to Fo_{74} and exhibits both magnesium and iron enrichment within some cycles while orthopyroxene varies from En_{65} to En_{77} and shows an overall iron enrichment trend.

Pc layers are orthcumulate with poikilitic ilmenomagnetite and oikocrystic clinopyroxene. Some Pc layers contain laterally continuous sulfide horizons parallel to phase layering and plagioclase lamination. Platinum-group element mineralization is associated with Pc layers with disseminated sulfide (<2%) horizons or adjacent to discontinuous POc layers within Pc layers. Sulfides include pyrite, chalcopyrite, pyrrhotite, and pentlandite in order of abundance.

Whole-rock ^{18}O and ^{34}S values range respectively from +1.9 to +7.2 per mil and −1.8 to +2.9 per mil. Eighty-five percent of the samples have ^{18}O values between 5.7 and 7.2 per mil, typical of "normal" gabbroic and anorthositic rock types. Evidence for substantial crustal contamination of parent melts is not indicated, based on either S or O isotopic values. Fifteen percent of the analyzed samples are characterized by depletion in ^{18}O, with ^{18}O values between 1.9 and 3.6 per mil. These values occur in plagioclase cumulates adjacent to cross-cutting felsic (Cold Springs) intrusions, and are thought to be caused by isotopic exchange with groundwaters heated during emplacement of the felsic intrusions at shallow crustal levels.

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The World's Oldest Stalagmite? Recent Discoveries in a Permian Cave System in the Slick Hills, Southwestern Oklahoma

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The landscape of the Slick Hills in southwestern Oklahoma has long been recognized as an exhumed Permian inheritance in which hills of up to 500 feet of relief were buried beneath a veneer of the Leonardian Post Oak Conglomerate. A cave system on the slopes of Bally Mountain has previously been dated on the basis of a Permian reptile fauna. Speleothems in the caves are noteworthy in that they contain abundant hydrocarbon inclusions and seepages. Our analysis of the joint patterns within the Lower Ordovician Kindblade Formation shows two principal joint modes, oriented 055 and 135 respectively. Joint formation appears to have predated tilting of the sequence to the northeast. Karst development has utilized master joints within the two principal modes, particularly the 045 orientation. Most of the cave systems are linear fissures, rarely more than three feet wide. The largest cavern is approximately ten feet high and six feet wide. In places the caves are completely closed by vadose and phreatic speleothems. Elsewhere the final infill of the cave involved clastics-calcreted conglomerates in the upper parts and delicately laminated green and brown clays of lacustrine origin in the lower parts of the system.

Intermingled with these clastics are numerous bone fragments. These tend to fine downwards in size and may be concentrated in extraordinary numbers at the base of clay deposits—we estimate that two such concentrations contain as many as 20,000 such fragments each. So far we have identified abundant *Captorhinus* (an anaspid reptile), *Thrausmosaurus* and cf. *Mycterosaurus* (varanopseid pelycosaurs), a new caseid pelycosaur, close to *Cotylorhyncus*, cf. *Labidosaurus* (a captorhinid) and an unknown reptile whose tiny bladed teeth have accessory cuspules along the blade edge.

Detailed timing of events in the evolution of the system is difficult. For example conglomerates in the upper parts of the present system contain reworked speleo-

them fragments along with bones and limestone fragments, indicating that the overlying hill was being gradually reduced in relief as the cave system evolved. The most extraordinary evidence of landscape reduction is the presence of a large (14 inch high) stalagmite, completely entombed in lake clays, which presently lies at the bottom of a twenty foot deep sinkhole, i.e., the roof of the cavern which once nourished this remarkable speleothem has been removed.

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The Application of D.C. Resistivity as a Method of Determining the Karstic Nature of the Blaine Gypsum Formation in SW Oklahoma

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In 1986, the Ground Water Division of the Oklahoma Water Resources Board submitted a proposal to The United States Bureau of Reclamation to scientifically observe the ground-water recharge mechanism occurring within the Blaine Gypsum Formation, near Hollis, Oklahoma. The karstic formation provides the sole irrigation water for several hundred miles of farming on the High Plains.

It was necessary to determine adequate monitoring locations which were located over the ground-water filled caverns. Projected drilling costs were excessive; therefore, there was a real need for a low-cost, effective method to determine lithology, depth to water, and the cavernous nature of the Blaine existed. The D.C. Surface Resistivity technique was used based on the knowledge that the technique has been sucessfully used to aid in defining carbonate karst terraines; however, the technique has not been reportedly used to describe gypsiferous karst.

The Blaine aquifer typically is 50 to 65 meters thick and consists of a sequence of laterally persistent gypsum, dolomite, and shale interbeds. Gypsum and dolomite beds have been partly dissolved by circulating ground water which has created some 2,500 square kilometers of karst. Karst features include sinkholes, caves, disappearing streams and springs. Therefore, ground-water flow paths occur in a variety of vertical and horizontal directions.

Three sites were selected for examination by D.C. resistivity, in June, 1989. Each site was offset by a well or a test hole which had been logged total depth by either geophysical or grab-sample methods. Each site was examined with a Bison Model 2350 Earth Resistivity Meter using the Lee Modification of the Wenner Configuration. Resistivity Plots were correlative with the lithology, caverns, and ground-water levels within the first thirty meters. Resistivity response to the occurrence of caverns was similar to that found in carbonate terraines. Ground-water levels were particularly obvious because of the highly mineralized ground water.

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Borehole Logging Techniques Used to Verify Monitoring Well Construction—A Case Study

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A procedure is proposed for verifying important details of monitoring well construction using borehole geophysics. Interpretive logs of drill cuttings have routinely been adjusted to geophysical logs for an estimated fifty years or more. Maher (1964) described a procedure for constructing the composite interpretive log which is useful for groundwater monitoring wells, especially deeper wells and wells for which installation records are unclear or in doubt. However, the literature provides only a few well-documented examples of log responses in monitoring wells constructed with plastic casing.

A ground-water monitoring well in Oklahoma provided an opportunity to compare open-hole and cased-hole geophysical logs with the hydrogeologist's sample log and field notes. This case history demonstrates the fact that borehole geophysics can be used to reveal final well construction which may differ from the original monitoring well design.

Of the available geophysical logs, the natural gamma ray, guard resistivity and density (gamma gamma) logs proved to be most useful in analyzing well completion. Casing joints and screened intervals were apparent on the guard log. The annular space between casing and borehole was characterized based on the density log. All three logs were used to indicate that the monitoring well "sank" into the borehole approximately four feet after installation. The logs also indicate the presence of voids in the uppermost 70 feet of the annular space.

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Characterization of Input Parameters for Fate and Transport Modeling of Agricultural Chemicals

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Increased demand for water in the Southwest has intensified the need for information on ground-water quality associated with agricultural practices. Such information has a direct bearing on the environmental and economic well being of the area. The objectives of this study were (1) to relate observed changes in chemical content in ground water to land mangement practices, (2) to establish within land resource areas some indicators of expected water quality changes from shifts in management practices such as conservation tillage or fertilization, and (3) to characterize and quantify the transport of applied soluble agricultural chemicals within the saturated and unsaturated zones. Conservation tillage is projected at

nearly 70 percent of U.S. cropland by the year 2000 (USDA–ARS, 1988). This expansion of conservation tillage acreage requires improved understanding of the potential for ground-water quality changes occurring with such management.

Ground-water quality and water levels have been monitored near Perkins, Oklahoma in 11 wells on 7 experimental plots which are cropped to wheat, cotton, beans, and orchard which range from about 0.4 to 5.7 ha in size. Some of the Perkins wells are in paired stacks to monitor water quality above and below an existing silty clay aquitard. An experimental site was selected to represent typical sand soils associated with the terrace alluvium in the Southern Plains. The site has been monitored for a three year period during which precipitation, well hydrograph and tracer test data, soil moisture profile data and water quality data from the unsaturated and saturated zones were obtained. Focus will be placed on the systematic approach used in obtaining these data.

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Middle Pennsylvanian Fusulinid Biostratigraphy in South-Central New Mexico and Southeastern Oklahoma

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The Atokan Series in south-central New Mexico is represented by a 38 m thick fusulinid-bearing, carbonate-dominated sequence (originally described as the Derryan Series by Thompson, 1942). Lithologies range from carbonate mudstone to packstone with interbedded shale intervals. Fusulinids are abundant and well preserved at many horizons. The zones of *Millerella, Eoschubertella, Profusulinella* and *Fusulinella* are recognized within the Derryan type section. The zone of *Beedeina* and the first stratigraphic occurrence of *Wedekindellina* are found above Atokan strata.

The Atokan sequence in southern New Mexico is roughly time equivalent to the Atoka Formation of southeastern Oklahoma. The Atoka Formation reaches over 2,000 m in thickness and is dominated by clastic lithologies. Atoka Formation carbonate units yielding fusulinids tend to be thin, poorly exposed and discontinuous. In addition, fusulinid specimens tend to be abraded or broken. However, Atoka Formation fusulinid faunas include several species found in southern New Mexico.

Fusulinids from southern New Mexico comparable to Atoka Formation species include: *Profusulinella* sp. aff. *P. fittsi* (Thompson), *Fusulinella devexa* (Thompson), *Fusulinella* sp. aff. *F. barnettensis* (Douglass and Nestell) and *Fusulinella famula* (Thompson). Desmoinesian forms similar to species from southeastern Oklahoma include *Beedeina insolita* (Thompson) and *Beedeina* sp. aff. *B. lewisi* (Douglass and Nestell). Fusulinid zonation has been used for biostratigraphic correlation between these markedly different but nearly time equivalent Lower Middle Pennsylvanian sequences.

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Lower and Lower Middle Pennsylvanian Conodonts from the Southern Ardmore Basin: Implications for Boundary Placement and Correlation

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Conodont faunas from the southern Ardmore basin represent an essentially continuous Lower and Lower Middle Pennsylvanian sequence. Three lineages (*Declinognathodus, Idiognathodus,* and *Neognathodus*) exhibit sufficiently rapid evolution to outline a foundation for recognition of nine conodont assemblages. The assemblages are, in ascending order: (1) *Declinognathodus* sp. A; (2) *Neognathodus symmetricus–Declinognathodus* sp. B; (3) *Neognathodus bassleri–Declinognathodus* sp. C (also distinguished by appearance of *Idiognathodus sinuosus* and *Neognathodus* sp. A); (4) *Idiognathodus klapperi–Idiognathoides sinuatus* (with rare *Neognathodus* sp. A); (5) *Neognathodus* sp. B–*Idiognathodus klapperi* (contains appearance of *Diplognathodus* spp.); (6) *Neognathodus* sp. C–*Idiognathodus incurvus*; (7) *Neognathodus atokaensis–Declinognathodus marginodosus*; (8) *Neognathodus "bothrops;"* and (9) *Neognathodus bothrops–N. medadultimus* (with rare specimens of *Declinognathodus* and *Idiognathoides*).

Although chronostratigraphic boundaries cannot be precisely located, the significance and correlation of the assemblages is becoming more certain. Conodont assemblages 1–3 (Morrowan) occur in the "Jolliff" Member of the southern Ardmore basin, and in the Lake Ardmore–Primrose Members of the northern Ardmore basin. Assemblage 4 (late Morrowan) is present in the thick, overlying succession that includes unnamed unit A, Otterville Member, and unnamed unit B. Assemblage 5 spans the Morrowan/Atokan boundary as defined by the appearance of the foraminifer *Profusulinella*. Assemblages 6–8 (Atokan) are present in the Bostwick and unnamed unit C Members, and assemblage 9 (Desmoinesian) occurs in the upper part of unnamed unit C and lower Lester Limestone. Assemblages 4, 7?, 8 and 9 can be recognized in the northern Ardmore basin. The apparent absence, in the northern Ardmore basin, of assemblages 5 and 6 is consistent with the recognized unconformity separating Morrowan and Atokan rocks.

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Confining Layer Integrity Study in the West Edmond Oil Field Area, Oklahoma

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This project was originally one of several studies funded by the Environmental Protection Agency to develop methods of determining confining layer integrity on a regional basis. The study area consistent of 160 square miles centering on the

West Edmond Oil Field just north of Oklahoma City, Oklahoma. Data from over 1,400 oil wells were used to create structure maps on two horizons so that the fault pattern could be identified. Faults were verified by isopach and production trend analysis. Lineament maps were made using Landsat imagery and Color Infrared photographs at scales of 1:120,000 and 1:60,000 respectively. Straight reaches of local streams were also identified on 1:24,000 topographic maps. Using any of the remote sensing media approximately 50% of the faults were identified. However, approximately 35% of the Landsat lineaments and only 12% of the CIR lineaments corresponded to subsurface faults. A conductivity survey was conducted along a reach of a stream where a fault is indicated by subsurface mapping and lineament analysis. Stream water conductivity was lower through the faulted interval. Such surveys could be used to delineate lineaments actually corresponding to pervasive faults.

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Thermal Maturity of Carboniferous Strata in the Ouachita Mountains, Arkoma Basin, and Ozark Dome

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Lateral and vertical trends in vitrinite reflectance (R_o) within Carboniferous strata of the south-central U.S. provide a basis for constraining regional thermal events that influenced the emplacement of ore deposits, the generation and degradation of hydrocarbons, and the diagenesis of sedimentary strata throughout the region.

A map of surface and shallow subsurface R_o reveals a regional pattern that cannot be explained by maximum burial depth, either of stratigraphic or structural origin. In most of the Ouachitas, R_o values decrease from >3% near the core areas to lower values in the frontal thrust belt and southern Ouachita plateau. Anomalously high R_o values (up to 5%) occur in the eastern Ouachitas in the vicinity of Mesozoic intrusions associated with the Mississippi embayment. Northward into the Arkoma basin, R_o contours merge into a pattern that is oriented nearly perpendicular to structural trends, with values increasing from <1% in the west to >2% in the east. With depth, R_o increases in a log-linear fashion that is fairly constant throughout the basin, suggesting that temperature gradients were not severely perturbed by maximum thermal event(s). The north flank of the Arkoma is characterized by R_o values that decrease to <1% toward the northeast Oklahoma platform and to slightly >1% on the south flank of the Ozark dome. Around the circumference of the Ozark dome, R_o values decrease from 1% on the south to <0.5% on the west, but then increase to between 0.5 and 1% on the north. On the east flank of the dome, R_o values increase to >1% but decrease to <1% eastward into the Illinois basin. We suggest two primary mechanisms for thermal maturation. (1) During deposition of Atokan strata, Precambrian basement beneath the Arkoma–

Ouachita basin was faulted as a result of obduction of the Ouachita accretionary prism onto the southern margin of North America. Breakage of crystalline basement probably induced anomalously high heat flow. (2) Sedimentation rates, hydrocarbon generation, and thrust loading within Arkoma–Ouachita flysch may have induced overpressured conditions. Moreover, tectonic uplift of the Ouachitas and Wichitas may have generated gravity driven fluid flow. Individually or together, these events likely caused flow of hot fluids out of the Ouachitas and Arkoma, and that flow probably migrated up depositional dip (eastward) into sand-rich facies in the eastern Arkoma. Within the Arkoma, the juxtaposition across syndepositional normal faults of lower Paleozoic strata, most of which display north–south facies trends, and Atokan strata, most of which display east–west facies trends, likely resulted in divergent flow patterns, northward onto the Ozark dome within lower Paleozoic strata and eastward toward the Mississippi embayment within Atokan and younger strata.

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Structural Styles, Distribution, and Lateral Facies Relationships of the Spiro Formation, Frontal Ouachita Mountains, Southeastern Oklahoma

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The Spiro Formation (Lower Atoka), which is a well known gas reservoir in the Arkoma basin, is exposed only in the frontal Ouachita Mountains. There thrust faulting has produced a narrow outcrop belt that consists of several fault repeated sequences. Differences in thrusting styles between the eastern and western parts of the outcrop belt reflects variations in lateral lithologic character and perhaps subthrust structure. Preliminary palinspastic restoration of thrust sheets establishes a basis to determine paleodepositional trends and geometries.

The Spiro Formation consists of laterally interfingering sandstone, shale, and limestone. The sandstones represent stacked shallow marine shelf bars derived from marine reworking of the Foster channel sands. In the eastern part of the outcrop belt, the Spiro is primarily sandstone with thicknesses up to 150 feet that represents predominantly bar crest and bar margin facies. To the west, the Spiro thins to about 60 feet thick and consists mostly of limestone with lesser amounts of sandstone. There the sandstones exhibit sedimentary characteristics of interbar and bar margin facies. South of the present day Pine Mountain fault, slope and basinal sediments accumulated, whereas to the east of the outcrop belt (within the Ouachita Mountains) the Spiro grades into a shale facies.

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Status of Coal Geology Employment

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Before 1965 most U.S. coal geologists worked for government agencies and universities. In the 1970s the Environmental Protection Agency and the Fuel Use Act opened geologic jobs in exploration for low-sulfur coal reserves. Most of these jobs were taken by sedimentary geologists, who obtained coal expertise from continuing-education seminars. Record numbers joined the Coal Geology Division of GSA and the Energy Minerals Division of AAPG. Most of these new jobs were in business and industry. U.S. coal production increased 64% from 1968–1984. But the economic boom had peaked, and the bust was upon us.

By 1984 most of the re-educated coal geologists had left these jobs, and had resigned from the EMD and the Coal Geology Division. In Oklahoma, coal production decreased 61% from 1978–1988, and full-time coal geology jobs decreased 67%.

In 1990, just as prior to 1965, most full-time coal geology jobs are in government and universities.

If mining companies continue to explore for coal reserves for use in a new breed of electric-power plant, and if gas and oil companies continue to explore for coalbed methane reserves, additional jobs will open for coal geologists in Oklahoma, the United States, and other nations.

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