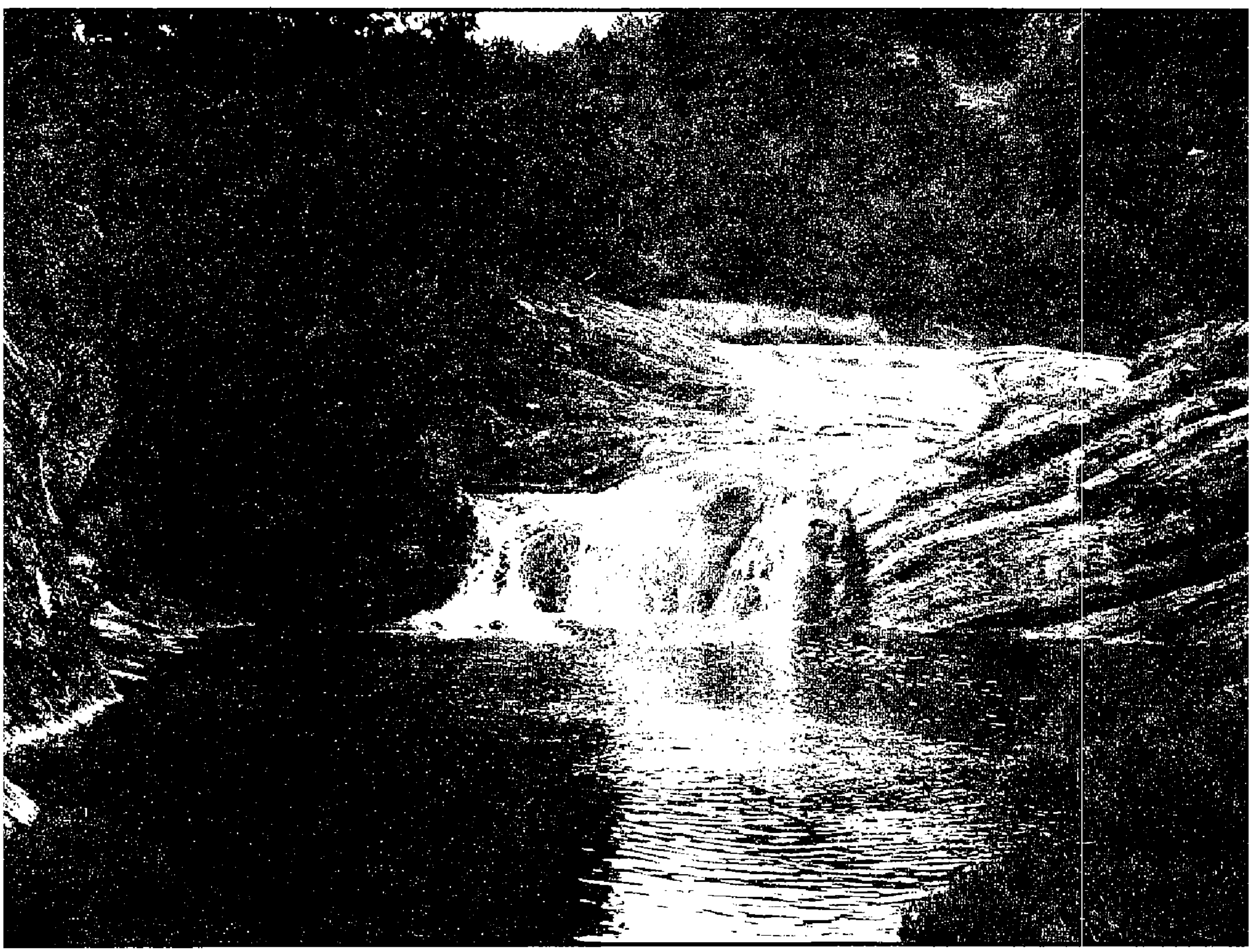
OKLAHOMA GEOLOGY



April, 1994
Vol. 54, No. 2

On The Cover —

Cedar Falls on the Lazy S Ranch, Carter County, Oklahoma

Cedar Falls on the Lazy S Ranch in Carter County, Oklahoma (SW¼SW¼ sec. 36, T. 2 S., R. 2 E.). Cool Creek forms this falls as it cuts through the resistant cherty, nodular limestones (Welling Formation) of the upper Viola Group, Upper Ordovician. Note that we are looking down section and as the units are dipping away from the viewer, this section is overturned. This area is on the southern flank of the Arbuckle anticline, south of the Washita Valley fault and west of the Washita River.

M. Charles Gilbert
University of Oklahoma

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OKLAHOMA GEOLOGY

Notes

50
Cedar Falls on the Lazy S Ranch, Carter County

52
Revenue from Public and Indian Lands in the United States and Oklahoma
Charles J. Mankin

57
Oklahoma Earthquakes, 1993
James E. Lawson, Jr., and Kenneth V. Luza

69
Mineral Industry of Oklahoma, 1993

72
New OGS Publication:
- Catalog of Fossil Vertebrate Specimens, OMNH

73
AAPG Annual Convention
Denver, Colorado, June 12–15, 1994

78
Notes on New Publications

79
Upcoming Meetings

80
Oklahoma Abstracts

VOL. 54, NO. 2

Revenue from Public and Indian Lands in the United States and Oklahoma

Charles J. Mankin[1]

Public lands are an important source of revenue to the federal government, as shown by the fact that the Minerals Management Service (MMS) is the second largest collector of public revenue, after the Internal Revenue Service. Revenue from onshore public lands is shared with the state in which it originates, and is an important source of funds for those states with large tracts of public lands. All of the revenue from Indian lands goes to the Indian tribe or allottee that owns the producing property. In many instances, the revenue generated from Indian lands is the largest source of funding to tribes and individual allottees.

Use of public and Indian lands in the United States has been, and continues to be, a focus of controversy. In particular, the concept of multiple land use for public lands has spawned much heated debate. During the past two decades, large tracts of public land have been converted from multiple uses to single-purpose use, primarily as wilderness areas. In addition, most of the outer continental shelves in the United States are under moratoria from petroleum development as the result of congressional response to environmental concern. Arguments continue to be advanced for the "preservation" of public lands for future generations, but little mention is made of the importance of public lands as a current source of public revenue and of jobs that are created through the development of their natural resources.

[1]Director, Oklahoma Geological Survey.

Much of that public revenue is shared with the state from which it is collected and provides an important source of operating funds for state government. Where public lands are a significant part of the total land area in a state, the state share of revenue from those lands is a critical component of the state operating budget. Restricting the development of natural resources on those public lands places an extra burden on the development of natural resources held by the state and private owners in order to support the state's economy.

Unfortunately, revenue from public and Indian lands is in sharp decline. In 1992, income from rents, bonuses, and royalties from public and Indian lands in the United States amounted to $3.7 billion in the U.S., exclusive of revenue to the Osage Nation in Oklahoma (Fig. 1).

Osage County revenue is not included in MMS data because treaty arrangements provide that the Osage Tribal Council will manage the mineral estate for Osage County, Oklahoma. The decline in revenue from public and Indian lands in 1992 was about $200 million below that of the 1991 income and almost $7 billion below the 1983 revenue (MMS, 1993). In 1992, more than 90% of this income was from royalty payments, compared with about 40% in 1983, making it apparent that income from mineral leases and bonus bids from leasing has declined markedly during the past decade (Fig. 1). It is likely that mineral revenue from public and Indian lands will continue to de-

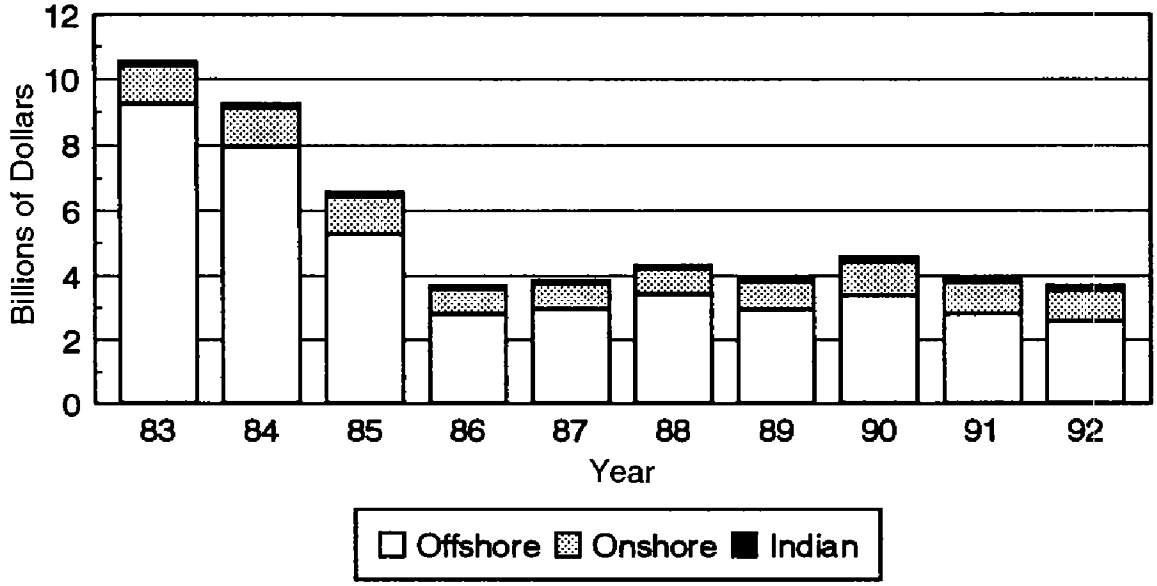

Figure 1. Total revenue from public and Indian lands in the United States. The Indian lands in this figure do not include revenue to the Osage Nation from oil and gas production in Osage County, Oklahoma. Source: MMS (1993).

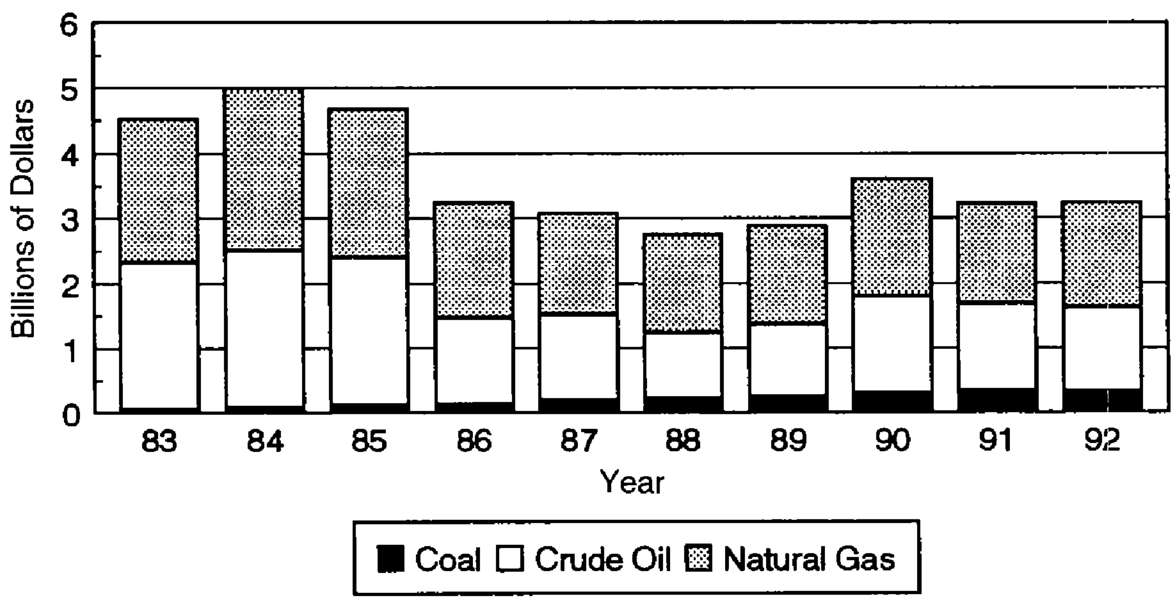

Figure 2. Royalty income from public and Indian lands in the United States. The royalty income from the Indian lands portion in this figure is less than 4% of each year's total royalty revenue. Revenue from Osage County, Oklahoma, is not included. Source: MMS (1993).

cline as the productivity of current leases decreases and fewer new leases are developed. The primary decline in revenue is from offshore public lands, where congressional moratoria have prevented new lease sales for most of these holdings. Oil and gas continue to dominate the royalty income from public and Indian lands in the nation, but both have been in general decline during the past decade (Fig. 2). Coal, although still less than 10% of the royalty income, has increased from $62 million in 1983 to $325 million in 1992.

The mineral value from public and Indian lands in Oklahoma is a relatively small, but important, part of total value generated by oil, gas, and other mineral production in the State. The gross value for all mineral production in Oklahoma for 1992 was $5.36 billion. That portion derived from public and Indian lands (including Osage County) in Oklahoma was about $260 million; Indian lands accounted for more than 80% of that amount (Fig. 3).

Osage County is an important source of oil and gas production in Oklahoma. More than half of the total value of mineral production from Indian lands in the State is from Osage County (Fig. 4). Unfortunately, because of declining production, especially of crude oil, the gross value of mineral production from Indian lands in the State is in sharp decline. From 1990 through 1992, the value has declined at an annual rate of $25 million, or about 10%, each year. According to preliminary information for 1993, the decline is continuing at the same rate.

As the gross value of mineral production on public and Indian lands in Oklahoma has declined, so has the revenue (rents, bonuses, and royalties) from that production. It should be noted that most of the decline is from Indian lands and is associated with declines in both the production and the value of crude oil and, to a lesser extent, of natural gas. This decline is of particular concern because this revenue is an important source of funds for Oklahoma's Indian tribes and allottees. The revenue from public and Indian lands in Oklahoma is shown in Figure 5; the revenue goes to the State and to the Indian tribes or allottees.

The State's share of revenue from mineral production on public lands is shown in Figure 6. The average annual income to the State for the past 10 years has been about $1.9 million (MMS, 1993). In 1992, Oklahoma's share of public-land revenue was only 0.3% of the total United States distribution of $432 million. Wyoming received $179 million, the largest revenue share, fol-

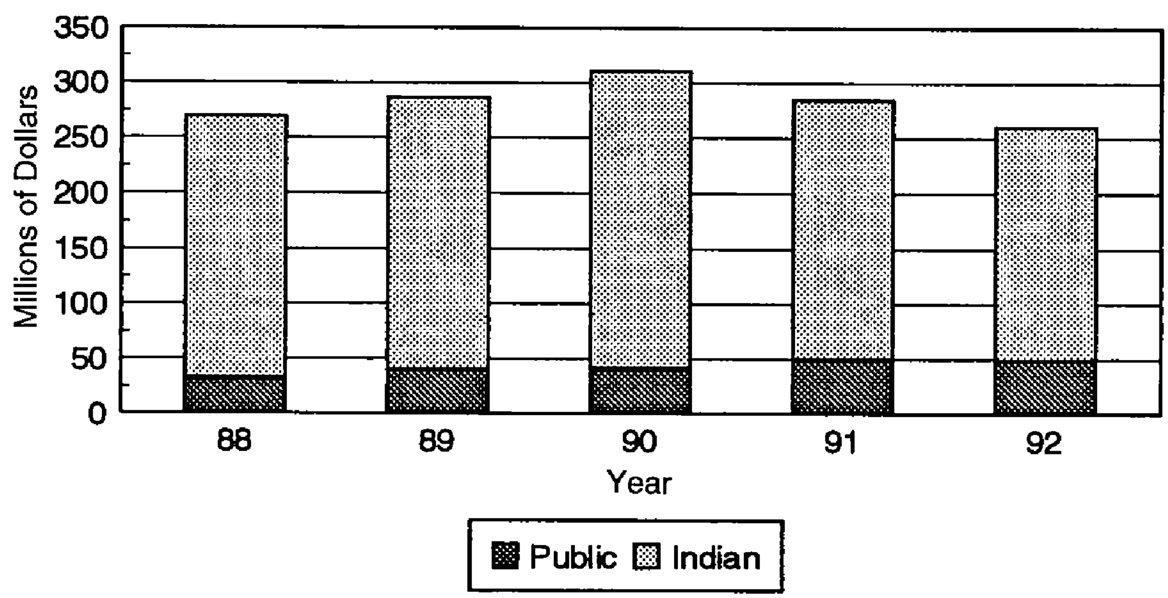

Figure 3. Gross value of mineral production from public and Indian lands in Oklahoma. Data from Osage County are included in the Indian lands total. Value of Osage County oil and gas production was determined using State average oil and gas prices for each year. Source: MMS (1993); Osage County, personal communication (1994).

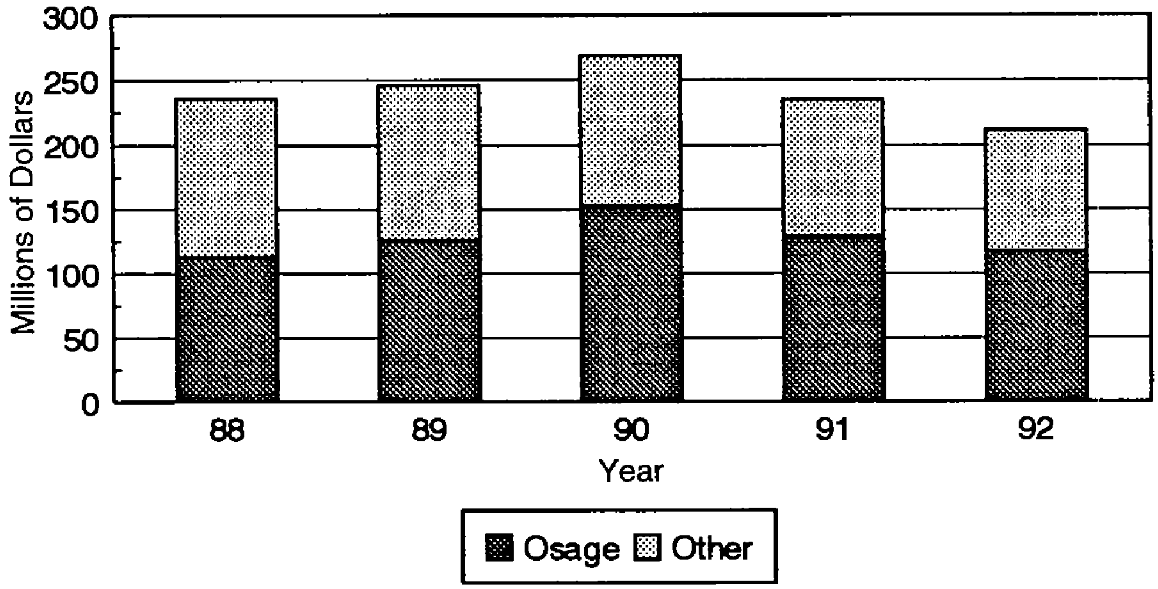

Figure 4. Gross value of mineral production from Indian lands in Oklahoma. Value from Osage County is more than half of the total for all Indian lands in the State. Source: MMS (1993); Osage County, personal communication (1994).

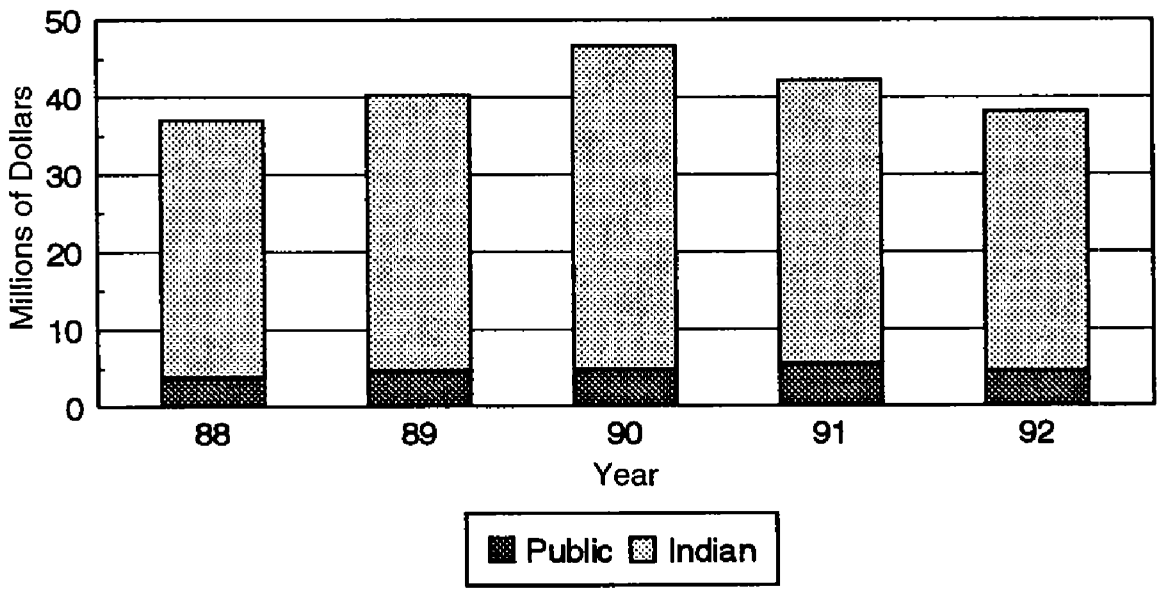

Figure 5. Revenue from crude oil, natural gas, coal, and other commodities on public and Indian lands in Oklahoma, including Osage County. Sources: MMS (1993); Osage Tribal Council, personal communication (1994).

lowed by New Mexico, which received $108 million.

The amount of public land in Oklahoma is small, and some of that land is in areas where crude oil, natural gas, or other economic deposits of minerals are unlikely to occur. Except for coal and a minor amount of industrial-mineral production, the use of public land in the State for mineral development is not a major issue. However, mineral production does occur on public land in Oklahoma, and there are additional tracts of public land in the State that

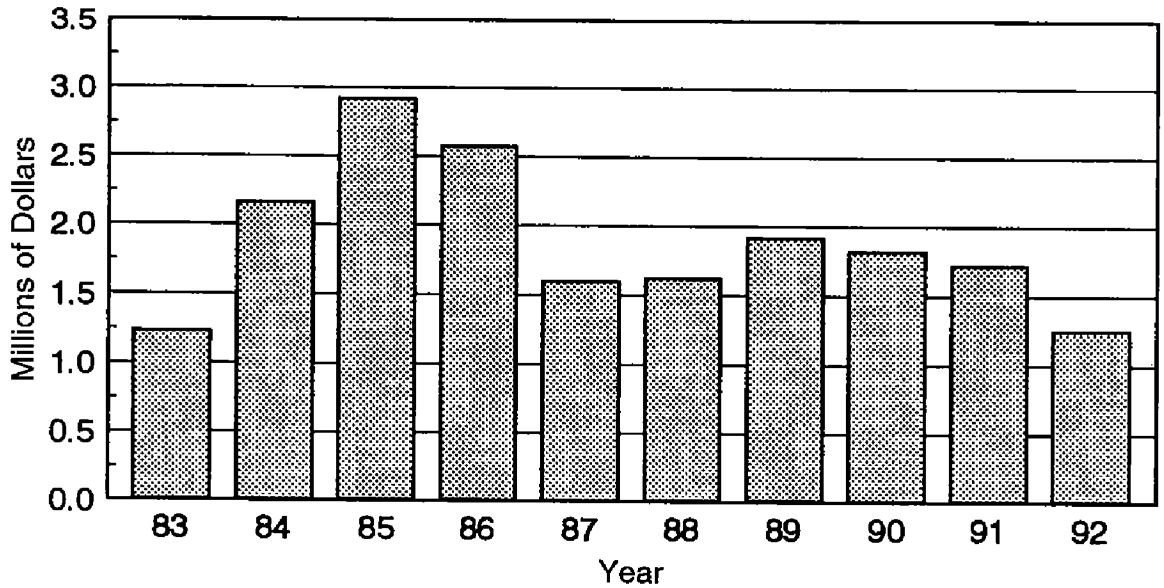

Figure 6. Revenue from public lands in Oklahoma allocated to the State under the federal government's revenue-sharing requirement. Source: MMS (1993).

have potential for mineral production. The economic benefits from royalty payments and from the jobs created by the production of these natural resources are important, and these benefits should be given serious consideration when proposals to restrict public lands from multiple use are evaluated.

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Minerals Management Service, 1993, Mineral revenues 1992; report on receipts from federal and Indian leases: U.S. Department of the Interior, Minerals Management Service, 126 p.

Oklahoma Earthquakes, 1993

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

Introduction

More than 930,000 earthquakes occur throughout the world each year (Tarbuck and Lutgens, 1990). Approximately 95% of these earthquakes have a magnitude of <2.5 and are usually not felt by humans (Table 1). Only 20 earthquakes, on average, exceed a magnitude 7.0 each year. An earthquake that exceeds a magnitude 7.0 is considered to be a major earthquake and serious damage could result.

Earthquakes tend to occur in belts or zones. For example, narrow belts of earthquake epicenters coincide with oceanic ridges where plates separate, such as in the mid-Atlantic and east Pacific Oceans. Earthquakes also occur where plates collide and/or slide past each other. Although most earthquakes originate at plate boundaries, a small percentage occur within plates. The New Madrid earthquakes of 1811–12 are examples of large and destructive intraplate earthquakes in the United States.

The New Madrid earthquakes of 1811 and 1812 are probably the earliest historical earthquake tremors felt in Oklahoma (Arkansas Territory) by residents in

TABLE 1. — ESTIMATED NUMBER OF WORLDWIDE EARTHQUAKES PER YEAR BY MAGNITUDE
(Modified from Tarbuck and Lutgens, 1990)

Magnitude	Estimated number per year	Earthquake effects
<2.5	>900,000	Generally not felt, but recorded
2.5–5.4	30,000	*Minor to moderate earthquakes* Often felt, but only minor damage detected
5.5–6.0	500	*Moderate earthquakes* Slight damage to structures
6.1–6.9	100	*Moderate to major earthquakes* Can be destructive in populous regions
7.0–7.9	20	*Major earthquakes* Inflict serious damage if in populous regions
≥8.0	1–2	*Great earthquakes* Produce total destruction to nearby communities

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

southeastern Oklahoma settlements. The earliest documented earthquake in Oklahoma occurred near Jefferson, Grant County, on December 2, 1897 (Stover and others, 1981). The next oldest known Oklahoma earthquake happened near Cushing in December 1900. This event was followed by two additional earthquakes in the same area in April 1901 (Wells, 1975).

The largest known Oklahoma earthquake occurred near El Reno on April 9, 1952. This magnitude-5.5 (mb) earthquake was felt in Austin, Texas, as well as Des Moines, Iowa, and covered a felt area of ~362,000 km^2 (Docekal, 1970; Kalb, 1964; von Hake, 1976). From 1897 through 1993, more than 1,015 earthquakes have been located in Oklahoma.

Instrumentation

A statewide network of 11 seismograph stations was used to locate 73 earthquakes in Oklahoma for 1993 (Fig. 1). The Oklahoma Geological Survey Observatory station, TUL, located near Leonard, Oklahoma, in southern Tulsa County, records 15 continuous seismic signals from sensors located at five stations. The data are recorded, analyzed, and archived on a GSE digital seismic system provided by the Defense Advanced Research Projects Agency/Nuclear Monitoring Research Office.

Signals are digitized by two Geotech RDAS (Remote Data Acquisition System) units at either 36,000 or 1,200 24-bit samples per second. The RDAS then applies digital anti-alias filtering to eliminate frequencies too high for the final sampling rate. After one to three digital filter and resampling stages, the RDAS produces 40, 60, or 10 24-bit samples per second. The samples are time-tagged by RDAS clocks locked to very low-frequency Omega Navigation/Time signal receivers. The signals are passed by RS422 serial links to an AST 386/25 RTDS (Real Time Data Server) computer, which has a Lynx™ real-time Unix-like operating system. The partially processed signals are passed by ethernet to a Sun Sparc 1+ Unix workstation with 40 megabytes of memory, two 660-megabyte disks, and two 2.3-gigabyte Exabyte™ tape drives. All of the data from the most recent two to three days are retained on disk. Each day, data from the preceding day (167 million bytes) are automatically archived onto Exabyte™ tape. All Oklahoma earthquakes, and other selected events, are placed in named dearchive directories on a 900-megabyte disk attached to a Sun 3/50 computer belonging to Lawrence Livermore National Laboratories. The dearchive directories are remote mounted, by way of the ethernet, by the Sun Sparc 1+ workstation. An Oracle™ data base on the Sun Sparc 1+ keeps track of every second of data on the permanent archive tapes, the last two or three days' data on disk, and data in the dearchive directories.

Data analysis is done by Teledyne-Geotech and Science Applications International Corp. software on the Sparc 1+ workstation.

The digital system signals are from six sensors in the Observatory vault (international station abbreviation TUL); from three sensors in a borehole on the Observatory property (station LNO); and from single sensors located at Rose Lookout (RLO) in Mayes County, at the Bald Hill Ranch near Vivian (VVO) in McIntosh County, and at the Jackson Ranch near Slick (SIO) in Creek County.

TUL has three (vertical, north–south, east–west) Geotech GS-13 seismometers which produce 40-sample-per-second short-period channels. Three Geotech BB-13 seismometers produce 10-sample-per-second broadband channels; three one-

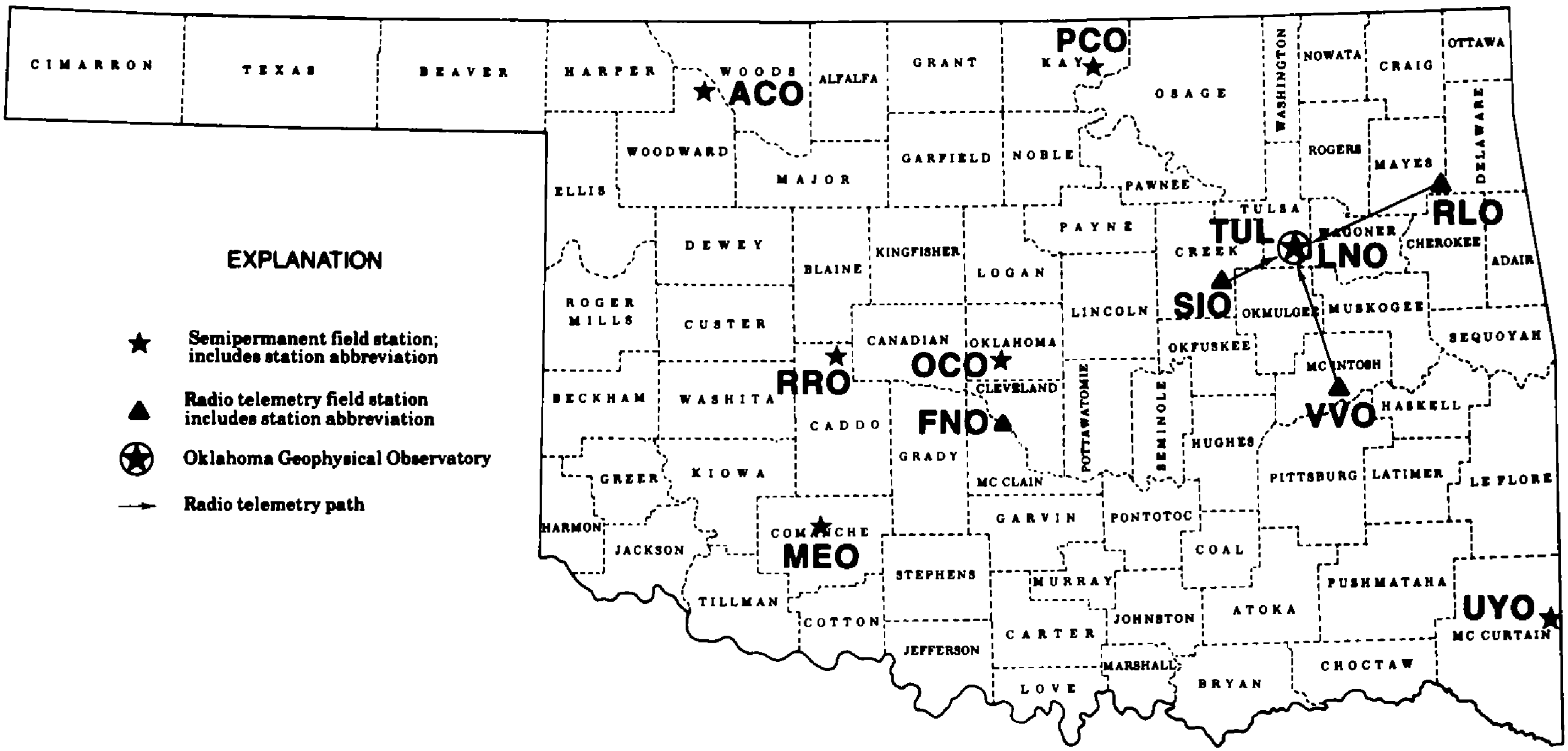

Figure 1. Active seismographs in Oklahoma.

sample-per-second long-period channels are derived by the workstation from the broadband channels. The broadband channels are seldom used in the study of Oklahoma earthquakes; the long-period channels are never used. The short-period signals are particularly useful in calculating the direction of arrival of waves by digital calculation of polarization.

The LNO station has a Geotech 20171A seismometer in a 4.5-m-deep borehole and two Geotech 23900 (a deep-hole version of the 20171A) seismometers at 432- and 748-m depth in a borehole that is 1 m away from the 4.5-m-deep hole. The LNO equipment is provided and partially supported by Lawrence Livermore National Laboratories. The three LNO channels are digitized by a second RDAS near the borehole and recorded and archived at 60 samples per second. This allows recording of higher frequency waves than is possible with the 40-sample-per-second data. The higher frequencies are particularly prominent in nearby (Oklahoma and adjacent areas) earthquakes. At frequencies above 10 Hz, the high-frequency background noise produced by wind and cultural activity is almost absent at the 748-m-deep sensor. It is particularly important for recording signals from smaller Oklahoma earthquakes, which are very difficult to see on seismograms from near-surface seismometers.

RLO, VVO, and SIO have Geotech S-13 seismometers in shallow tank vaults. The seismic signals are amplified and used to frequency modulate an audio tone that is transmitted to Leonard with 500-mW FM transmitters at various frequencies in the 216–220-mHz band. The signals are received by antennas on a 40-m-high tower at Leonard, the tones are discriminated to produce a voltage which is proportional to the remote seismometer voltage, and the voltages are digitized at 40 samples per second by the vault RDAS. The operation of RLO, VVO, and SIO are partially supported by the Nuclear Regulatory Commission.

A fourth radio-telemetry station, FNO, was installed in central Oklahoma on April 28, 1992. The seismometer, Teledyne Geotech S-500, is located at the bottom of a 30-m-deep borehole, ~7 km northeast of the Oklahoma Geological Survey's (OGS) building. A discriminator converts the audio-signal frequency fluctuations to a voltage output. The voltage-output is amplified and recorded by a Sprengnether MEQ-800 seismograph recorder (located in an OGS display case) at 60 mm/min trace speed.

In the Leonard vault, seven additional seismometers produce analog (wiggly-line) recordings on paper-drum recorders. Eleven such recordings are produced, five of which are the proper frequencies to record some aspect of nearby earthquakes. One paper recording is produced from each of RLO, VVO, and SIO. There are no LNO paper records. The paper records are used as a digital system backup, and to scan for earthquakes faster than is possible on computer screens.

In addition to the digital and analog seismograms at the OGS Observatory, there are six volunteer-operated seismographs. Each consists at a Sprengnether S-13 short-period vertical-motion-sensing seismometer in a shallow tank vault, or in an abandoned mine shaft (station MEO) or large-diameter, hand-dug, shallow water well (station UYO). The seismometer signal runs through 200–1,800 ft of cable in surface PVC conduit to the volunteer's house or other building. The volunteer has a Sprengnether MEQ-800B timing system amplifier-filter-drum recorder, which records 24 hours of seismic trace at 1 mm/min in a spiral path around the paper on the drum. The times are set by a time signal radio receiver tuned to the National Institute of Standards and Technology and high-frequency radio station WWV. The volunteers mail in the seismograms weekly, or, more often, upon request.

Data Reduction and Archiving

Seismic traces from the TUL vault vertical seismometer (TUL sz), the deepest borehole short-period vertical seismometer of station LNO (LNO/sz1) and one radiotelemetry site (usually VVO) are displayed on a 19-in. monitor on the Sun Sparc 1+. The traces are band passed through 0.4–4.0-Hz digital filters and are displayed in 90-min segments. A fourth, long-period vertical trace is displayed, but it records only waves from distant earthquakes. The 90-min traces are fuzzy lines with spikes showing signals above the noise. Distant earthquakes of magnitude ≥5.0 are usually identifiable by the shape of the spike and the following long-period surface waves. Other spikes represent local or regional earthquakes or surface-mine blasts. There are from 10 to 30 recordable surface-mine blasts each weekday, two to five on Saturday, and one or two on Sunday.

The monitor display is zoomed on a 60-sec segment surrounding each spike, and the event is identified by its appearance. If it is a P-wave from a distant earthquake, the display is zoomed to 15 sec and the arrival time, frequency, amplitude, and polarization (direction) are measured, calculated, and recorded for transmission to international data centers.

If a spike is identified as a possible near or regional earthquake, nine traces are displayed on the monitor (TUL sz, sn, se; LNO sz1, sz2, sz3; RLO sz; VVO sz; SIO sz). They are then filtered and unfiltered repeatedly to enhance and identify the phases. One set of filters, developed at NORESS (Norwegian Experimental Seismic System) is described by Mykkeltveit and others (1990). Using the time interval between phases, the distance can be determined; the direction is determined from polarization (using the TUL vault vertical, north–south, and east–west signals). The distance and direction give an approximate location, which is then improved by incorporating arrival times from remote sites RLO, VVO, and SIO. At this point, a short press release is issued from the OGS offices at Norman. Paper seismograms are also searched for regional and local earthquakes. At times, a small earthquake may initially be spotted on only the digital system or only on paper seismograms.

The next stage is dearchiving digital data from the nine short-period signals (listed in the preceding paragraph). These are put in a permanent named disk file and indexed in the on-line Oracle™ data base.

Each quarter, paper seismograms from all volunteer stations and from Observatory seismograms are carefully searched for local earthquakes. Arrival times are measured and added to those already determined from the digital system. As many as two or three additional earthquakes may be found. These are dearchived from Exabyte™ tapes for digital system analysis.

Arrival times, signal durations, and various signal amplitudes are entered into a location program running on a Hewlett-Packard 9825T computer. After each location is finalized, it is entered into an Oklahoma earthquake catalog maintained by Hewlett-Packard 9825T and linked 9835A computers. This catalog is used to produce lists (by date, by county, by latitude–longitude rectangle, and several other choices), and to produce maps with a six-color Hewlett-Packard 7975A plotter.

Earthquake Distribution

All Oklahoma earthquakes recorded on seismograms from three or more stations are located. In 1993, 73 Oklahoma earthquakes were located (Fig. 2; Table 2). Three earthquakes were reported felt (Table 3). The felt and observed effects of

TABLE 2. — OKLAHOMA EARTHQUAKE CATALOG FOR 1993

Event no.	Date and origin time (UTC)[a]		County	Intensity MM[b]	Magnitudes 3Hz	bLg	DUR	Latitude deg N	Longitude deg W	Depth (km)[c]
945	JAN 11	044619.61	McClain	—	1.6	—	1.5	34.929	97.463	5.0R
946	JAN 14	170610.19	Alfalfa	—	3.2	3.1	2.7	36.663	98.283	5.0R
947	JAN 21	074908.38	Hughes	—	2.1	—	2.0	34.894	96.268	5.0R
948	JAN 21	081903.94	Hughes	—	2.5	—	2.1	34.886	96.270	5.0R
949	JAN 30	044253.63	Love	F	1.8	2.0	2.0	34.052	97.084	5.0R
950	FEB 13	194503.36	Garvin	—	—	—	2.3	34.716	97.541	5.0R
951	FEB 13	205724.55	Garvin	—	—	—	2.2	34.748	97.573	5.0R
952	FEB 14	231238.00	Garvin	—	—	—	1.9	34.790	97.456	5.0R
953	MAR 11	011501.08	McIntosh	2	—	2.7	2.4	35.230	95.932	5.0R
954	MAR 11	020550.39	McIntosh	—	—	—	1.8	35.301	95.949	5.0R
955	MAR 17	172125.68	Garvin	—	2.3	2.2	2.2	34.820	97.557	5.0R
956	MAR 24	103729.06	Garvin	—	2.2	2.2	2.1	34.835	97.666	5.0R
957	MAR 26	025217.17	Garvin	—	2.1	2.0	2.0	34.773	97.401	5.0R
958	APR 6	075603.78	McClain	—	2.3	2.3	2.2	34.911	97.514	5.0R
959	APR 13	181520.31	McClain	—	2.1	1.8	1.9	34.913	97.494	5.0R
960	MAY 7	164135.42	Garvin	—	2.6	—	2.3	34.593	97.463	5.0R
961	MAY 7	175037.70	Garvin	—	2.4	2.1	2.1	34.738	97.541	5.0R
962	MAY 9	225211.19	McClain	—	2.8	2.6	2.3	34.898	97.533	5.0R
963	MAY 19	202226.87	Le Flore	—	2.2	2.0	1.5	34.698	94.912	5.0R
964	MAY 26	092159.55	Pittsburg	—	1.3	—	1.6	34.850	95.602	5.0R
965	MAY 26	093933.27	Pottawatomie	—	—	—	1.3	34.941	96.897	5.0R
966	JUN 10	115900.56	Garvin	—	2.3	2.3	2.0	34.792	97.428	5.0R
967	JUN 18	225752.18	Le Flore	—	2.2	—	1.9	34.952	94.529	5.0R
968	JUL 9	041849.86	Lincoln	—	—	—	1.0	35.938	96.799	5.0R
969	JUL 9	042818.78	Garvin	—	—	—	1.9	34.854	97.460	5.0R
970	JUL 9	213849.44	McClain	—	2.0	1.9	1.9	34.913	97.463	5.0R
971	JUL 14	002615.84	Love	—	2.4	2.7	2.2	34.038	97.158	5.0R
972	JUL 16	032143.79	Garvin	—	1.9	—	1.7	34.716	97.516	5.0R
973	JUL 16	032300.18	Garvin	—	2.1	—	1.8	34.807	97.557	5.0R
974	JUL 16	033716.51	Garvin	—	1.9	—	1.8	34.709	97.552	5.0R
975	JUL 16	035339.63	Garvin	—	1.8	—	1.7	34.623	97.508	5.0R
976	JUL 16	041216.14	Garvin	—	2.1	1.4	2.0	34.726	97.510	5.0R
977	JUL 16	042430.56	Garvin	—	2.0	—	2.0	34.718	97.526	5.0R
978	JUL 16	050844.55	McClain	—	—	—	1.6	34.938	97.630	5.0R
979	JUL 16	065843.10	Garvin	—	1.4	—	1.8	34.791	97.589	5.0R
980	JUL 16	082059.89	Garvin	—	1.7	—	2.0	34.749	97.502	5.0R
981	JUL 16	112827.98	Garvin	—	2.3	2.2	2.2	34.729	97.530	5.0R
982	JUL 17	095046.75	Garvin	—	2.0	—	2.0	34.734	97.526	5.0R
983	JUL 18	135801.24	Garvin	—	1.7	1.5	2.0	34.743	97.559	5.0R
984	JUL 20	175023.55	Murray	—	2.0	2.4	2.0	34.488	97.256	5.0R
985	JUL 22	023524.22	Pittsburg	—	1.6	1.5	1.9	35.173	95.925	5.0R
986	AUG 8	060327.36	McClain	—	1.6	1.4	2.0	34.937	97.463	5.0R
987	AUG 10	211713.15	Garvin	—	1.7	—	1.9	34.765	97.408	5.0R
988	AUG 12	152640.38	Garvin	—	2.1	2.2	1.8	34.550	97.190	5.0R
989	AUG 29	091051.79	Grady	—	—	—	1.3	35.045	97.850	5.0R
990	AUG 30	073002.01	Grady	—	1.5	—	1.9	34.941	97.733	5.0R
991	SEP 2	052802.73	McClain	—	—	—	1.7	34.913	97.494	5.0R
992	SEP 6	050636.25	Garvin	—	—	—	1.4	34.713	97.663	5.0R
993	SEP 6	061821.60	Garvin	—	—	—	1.3	34.819	97.436	5.0R
994	SEP 6	122709.63	Logan	—	—	—	1.7	36.070	97.383	5.0R
995	SEP 17	100002.40	McClain	—	2.0	1.9	1.9	34.933	97.447	5.0R
996	SEP 18	101803.07	Noble	—	1.6	—	1.7	36.507	97.184	5.0R
997	SEP 28	073141.07	McClain	—	1.5	—	1.9	35.062	97.365	5.0R
998	OCT 5	054546.53	Pittsburg	—	1.8	—	1.6	34.692	95.816	5.0R
999	OCT 13	084403.15	McClain	—	2.1	2.0	1.9	34.874	97.424	5.0R
1000	OCT 14	191438.91	Grady	—	2.5	2.6	1.8	34.859	97.713	5.0R
1001	OCT 15	092632.71	Garvin	—	2.0	1.9	1.8	34.849	97.643	5.0R
1002	OCT 15	154154.23	McClain	—	1.9	—	1.8	34.908	97.422	5.0R

1003	OCT 19	165952.41	Alfalfa	F	3.1	2.8	2.5	36.546	98.173	5.0R
1004	OCT 24	063223.75	McClain	—	1.6	1.5	1.7	34.937	97.518	5.0R
1005	OCT 30	015443.96	Garvin	—	2.9	2.7	2.3	34.847	97.436	5.0R
1006	NOV 11	213704.74	Woods	—	—	—	1.9	36.898	98.849	5.0R
1007	NOV 22	214619.80	Caddo	—	2.0	—	1.4	35.284	98.538	5.0R
1008	NOV 27	002103.51	McClain	—	1.8	1.7	1.7	34.998	97.503	5.0R
1009	NOV 29	030232.84	Woods	—	1.9	—	2.3	36.894	99.209	5.0R
1010	DEC 3	212942.08	Logan	—	—	—	1.8	36.091	97.557	5.0R
1011	DEC 3	213656.06	Logan	—	2.0	2.0	1.9	36.091	97.557	5.0R
1012	DEC 3	214010.90	Logan	—	—	—	1.6	36.091	97.557	5.0R
1013	DEC 6	040729.91	Garvin	—	2.5	2.3	2.0	34.839	97.401	5.0R
1014	DEC 7	033538.50	Kingfisher	—	—	—	1.6	35.934	98.005	5.0R
1015	DEC 7	033943.40	Kingfisher	—	—	—	2.4	35.934	98.005	5.0R
1016	DEC 20	172040.40	Garvin	—	2.4	—	2.2	34.648	97.502	5.0R
1017	DEC 20	174355.40	Garvin	—	—	—	1.9	34.524	97.456	5.0R

[a]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.

[b]Modified Mercalli (MM) earthquake-intensity scale (see Table 4).

[c]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 3. — EARTHQUAKES THAT WERE REPORTED FELT IN OKLAHOMA, 1993

Event no.	Date and origin time (UTC)[a]		Nearest city	County	Intensity MM[b]
949	JAN 30	044253.63	E Overbrook	Love	felt
953	MAR 11	011501.08	Vernon	McIntosh	II
1003	OCT 19	165952.41	Goltry	Alfalfa	felt

[a]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.

[b]Modified Mercalli (MM) earthquake-intensity scale (see Table 4).

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 4).

The felt areas for the three earthquakes listed in Table 3, Love County earthquake (event no. 949), McIntosh County earthquake (event no. 953), and Alfalfa County earthquake (event no. 1003), are probably restricted to a few tens of square kilometers away from the epicentral location. The McIntosh County earthquake produced intensity-MM II effects. However, no damage was reported.

Earthquake-magnitude values range from a low of 1.0 (MDUR) in Lincoln County to a high of 3.2 (m3Hz) in Alfalfa County. Forty-four earthquakes occurred in Garvin and McClain Counties, one of the most active areas in the State since 1979. Four earthquakes were located in Logan County; Grady and Pittsburg Counties experienced two earthquakes; Hughes, Love, Le Flore, Woods, and Kingfisher Counties experienced two earthquakes.

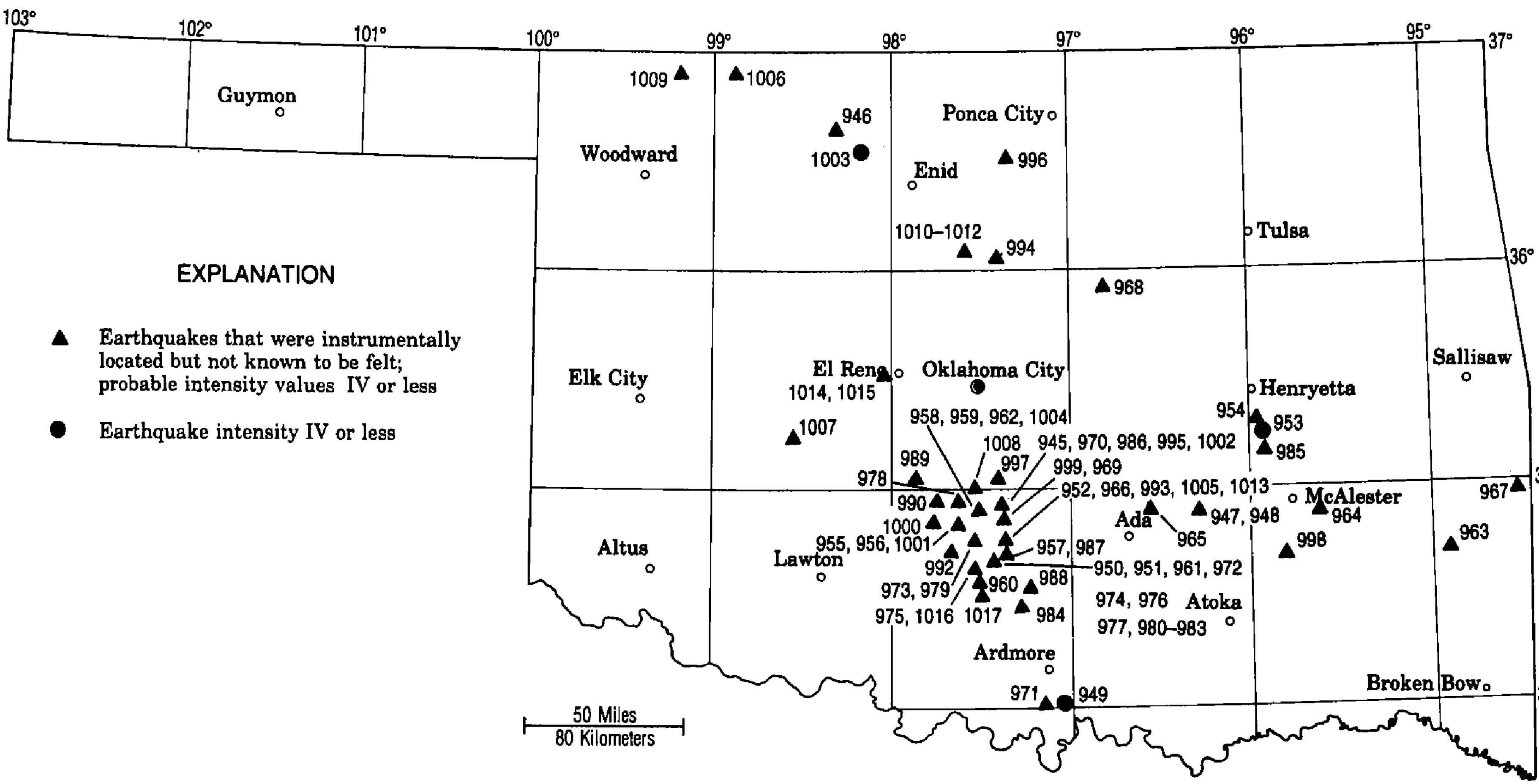

Figure 2. Distribution of Oklahoma earthquakes for 1993. Numbers correspond to event numbers in Table 2.

TABLE 4. — 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	Damaged 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.

Catalog

A desktop computer system, including linked HP-9825T and HP-9835A computers, hard and flexible disks, and printers, is used to calculate and catalog local earthquake epicenters. Any earthquake within Oklahoma or within about 100–200 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 2 contains 1993 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, 1980–90,1993; Lawson and others, 1991,1992).

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 2 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 11–222 km from a seismograph station, Otto Nuttli developed the m3Hz magnitude scale (Zollweg, 1974). This magnitude is derived from the following expression:

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

where A is the maximum center-to-peak vertical-ground-motion amplitude sustained for three or more cycles of Lg waves, near 3 Hz in frequency, measured in nanometers; T is the period of the Lg 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 OGS Observatory 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 0.2–0.5 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)

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

(epicenter 100–200 km from a seismograph)

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

(epicenter 200–400 km from a seismograph)

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

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

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

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

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

where A is the maximum center-to-peak vertical-ground-motion amplitude sustained for three or more cycles of Lg waves, near 1 Hz in frequency, measured in nanometers; T is the period of Lg 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:

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

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 15–20 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.

Acknowledgments

Shirley Jackson, Ruth King, and Todd McCormick maintained the OGS Observatory at Leonard. Volunteer seismograph-station operators and landowners at various locations in Oklahoma make possible the operation of a statewide seismic network.

This work was funded directly by the Oklahoma Geological Survey, with partial funding by the Nuclear Regulatory Commission. The GSE digital seismic system, provided by the Defense Advanced Research Projects Agency/Nuclear Monitoring Research Office, considerably enhanced the OGS's ability to analyze Oklahoma earthquakes. A borehole seismic system, a joint project with the Lawrence Livermore National Laboratories, was useful in recording Oklahoma earthquakes. The Observatory exists because of building and land-purchase gifts from Jersey Production Research Co. (now merged into Exxon) and the Sarkeys Foundation.

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MINERAL INDUSTRY OF OKLAHOMA, 1993

The value of nonfuel mineral production in Oklahoma was estimated by the U.S. Bureau of Mines, Department of the Interior, to be nearly $282.5 million in 1993. This was an almost $30 million increase over the $252.6 million produced in 1992. Sales increased or remained the same in 1993 for most mineral commodities produced in the State. Increases in masonry cement, portland cement, salt, and construction sand and gravel production were the most substantial, followed by crude gypsum, feldspar, crushed stone, dimension stone, and lime. Crushed stone continued as the State's leading mineral commodity, accounting for more than 39% of the total nonfuel mineral value. Combined values for crushed stone, portland cement, construction sand and gravel, and crude iodine accounted for nearly 77% of the estimated total mineral value produced in 1993. Oklahoma ranked 34th nationally in nonfuel mineral value and continued as the nation's leading producer of iodine.

Employment

Employment in the mining industry in September 1993, the last month for which data are available, totaled 35,100 workers, a 0.9% increase from the 34,800 employed in September 1992. The number of workers in the oil and gas extraction sector increased 0.6%, from 32,800 in September 1992 to 33,000 in September 1993. The stone, clay, and glass products sector of the manufacturing industry decreased 1.1%, from 9,500 in September 1992 to 9,400 in September 1993. The primary metals sector decreased by 100 workers to 4,800 in 1993. Employment in the mineral-related construction industry increased by 100 employees to 39,400.

Environment

The State received more than $1.1 million from the Office of Surface Mining, Reclamation, and Enforcement for abandoned mine lands stabilization and cleanup. Funds for such grants are derived from coal production fees, charged at a rate of 35¢ per ton for surface-mined coal and 15¢ per ton for coal mined underground.

The U.S. Bureau of Indian Affairs joined the Osage tribe in protesting a proposed landfill west of Ochelata in Osage County. Phibro Resources Corp. planned to purchase the site from a private individual to dispose of soil from the Zinc Corp. of America smelter site in Bartlesville. The soil is contaminated with lead and cadmium. The tribe owns the mineral rights to the land, but because the landfill would be lined with plastic barriers and clay, drilling for oil and gas beneath the landfill would not be possible.

The U.S. Environmental Protection Agency (EPA) considered placing the Zinc Corp. of America smelter at Bartlesville on its National Priorities List of Superfund sites. Bartlesville officials were given until May 1994 to propose an alternate cleanup plan. In September, after receiving a reprieve from Superfund site listing until May 1994, the company laid off more than half of its employees for one year. The layoff would allow the company to replace or upgrade equipment and complete an environmental retrofit to bring the operation into compliance with EPA standards.

Soil contaminated with lead from the abandoned Blackwell Zinc smelter apparently posed no unusual threat to children in the area. Blood samples from area children were tested and did not show high lead levels.

NONFUEL MINERAL PRODUCTION IN OKLAHOMA

Mineral	1992 Quantity[b]	1992 Value (thousands)	1993[a] Quantity[b]	1993[a] Value (thousands)
Cement (portland) (thousand short tons)	1,026	$39,280	1,545	$59,172
Clays (common) (thousand metric tons)	622	3,296	538	2,945
Gemstones	—	1,863	—	280
Gypsum (crude) (thousand short tons)	2,603	14,915	2,720	15,570
Iodine (crude) (thousand kilograms)	1,995	20,877	1,921	20,117
Sand and gravel:				
Construction (thousand short tons)	9,904	24,204	10,700	27,300
Industrial (thousand short tons)	1,071	19,011	1,016	18,222
Stone:				
Crushed[c] (thousand short tons)	27,500[d]	105,300[d]	28,000	110,600
Dimension (short tons)	5,182[d]	706[d]	5,275	658
Tripoli (metric tons)	—	—	—	—
Combined value of cement (masonry), feldspar, lime, salt, stone (crushed dolomite [1991], crushed granite [1992–93], and dimension sandstone [1991])	—	23,144	—	27,603
Total	—	252,596	—	282,467

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]Excludes certain stones; kind and value included with "Combined value" data.
[d]Estimated.

Legislation and Government Programs

House bill 1002 and related Senate bill 361 transferred a number of programs, responsibilities, and funds into the new Department of Environmental Quality (DEQ), formed as a result of legislation enacted in 1992 that reorganized the State environmental agency structure. Provisions of the bills address agency overlap and duplication of effort, public confusion about agency regulatory responsibilities, lack of timeliness and definitive response to questions and complaints, the elimination of dual water discharge permits from both the State and federal governments, and hazardous waste.

House bill 1167 defines the terms "geology" and "geologist." A geologist is defined in terms of specific course work, degrees earned, and/or work experience. This legislation has nothing to do with any condition of certification in the State.

House bill 1409 gave the Oklahoma Department of Mines jurisdiction over borrow pits on property where commercial mining operations are conducted. The bill also provided that mine operators could apply for a permit for the life expectancy of the operation rather than renewing every five years.

Senate bill 295 promotes and encourages recycling of used batteries and motor oil by requiring vendors to post signs identifying the location of the nearest recyclers. Other bills address solid wastes, landfills, water rights, and air quality, particularly with respect to meeting recent federal and State environmental regulations.

The Oklahoma Geological Survey and Oklahoma Department of Mines jointly compiled and published a directory for the mining industry.

Fuels

Senate bill 165 provides a tax credit of $1 per ton for each ton of Oklahoma-mined coal purchased for use by any corporation. A variety of other legislation provides for the deduction of a portion of lease operating expenses for secondary and tertiary oil and gas recovery projects, and establishes guidelines for environmental cleanup and remediation of historic oil and gas pollution. Representatives of private industry are included on the Oklahoma Energy Resources Board, and the use of alternative fuels is defined and encouraged.

Transok Inc. began construction of a $15 million intrastate natural-gas pipeline extension project in south-central Oklahoma. The 41-mi-long pipeline was expected to be completed by April 1994. Transok is a subsidiary of Central Southwest Corp., of Dallas, Texas.

The Applied Energy Services (AES) Shady Point cogeneration plant formed its own company, Cavanal Minerals Inc., as an independent power producer to sell electricity to Oklahoma Gas and Electric Co. When one of Cavanal's major coal suppliers declared bankruptcy, the company decided to manage two Oklahoma subsidiaries, Mountain Minerals Inc. and Coal Creek Minerals Inc., rather than use out-of-state coal.

Review by Nonfuel Mineral Commodities

Crushed stone continued as the State's leading nonfuel mineral commodity, accounting for more than 39% of the total nonfuel mineral value in 1993. Oklahoma remained the only state producing crude iodine, which constituted about 7% of the State's total nonfuel mineral value. Production of crude gypsum increased about 4.5% from 1992 production and value, as a result of increased construction in the Southwest, improvements in the economy, and increased wallboard prices.

Boral Bricks reopened its brick plant in Union City, Canadian County. The plant, closed for more than two years, reopened because of increased home construction.

After continued problems and violations, the Sequoyah Fuels Corp. uranium processing plant at Gore closed in July, after fulfilling contracts for uranium tetrafluoride. By August the decommission and cleanup plans were approved by EPA. The company had operated since 1970, producing uranium hexafluoride, a part of the process of making reactor fuel, and uranium tetrafluoride, used in armor-piercing bullets. Cleanup could take as much as 12 years and is expected to cost $86 million.

NEW OGS *Publication*

SPECIAL PUBLICATION 94-1. ***Catalog of Type and Figured Fossil Vertebrate Specimens, Oklahoma Museum of Natural History,*** by Nicholas J. Czaplewski, Richard L. Cifelli, and Wann Langston, Jr. 35 pages. Price: $2.

From the authors' introduction:

The vertebrate paleontology collection of the Oklahoma Museum of Natural History (OMNH) constitutes a major U.S. holding and is one of the most complete existing records of vertebrate history in the southern plains. The collection includes specimens from various places in the U.S.A. (particularly the Western Interior) and a number of foreign countries, but the vast majority of the specimens were collected in Oklahoma. As might be predicted from the distribution of terrigenous sedimentary rocks within the State, the collection includes well-represented series of lower tetrapods and fishes from Upper Pennsylvanian and Lower Permian units; dinosaurs and other Mesozoic reptiles from Upper Jurassic and Lower Cretaceous units of the Panhandle and southeastern Oklahoma, respectively; and mammals from Ogallala Group rocks of western Oklahoma. The most significant holdings from other areas include Cretaceous vertebrates from Texas, New Mexico, Utah, and Montana. The majority of the collection was amassed during a short interval earlier in this century (1930–42), under the direction of J. Willis Stovall, at that time a faculty member of the Department of Geology, University of Oklahoma. Several independent specimen catalogs were begun at various times, but they include many duplications of numbers and other errors. The majority of the collection was never curated. After several decades of inactivity and a number of moves (with attendant specimen disassociation, breakage, and loss), the collection became functionally inaccessible. In 1988, under sponsorship of the National Science Foundation, we initiated a recovery program to restore the utility of the collection as a research resource in the earth and life sciences.

Cataloging is not yet complete, but the collection includes an estimated 50,000 specimens; the most recent survey of North American collections ranks it 15th in the U.S.A. In spite of relatively limited use during its long and somewhat checkered career, the collection is known to include 34 type specimens (holotypes and cotypes), seven paratype specimens, and an additional 550 figured specimens.

The primary purpose in publishing this catalog is to present, in organized fashion, critical data on important specimens in the collection, in order to foster and facilitate research based on this resource. [Until now], no catalog of the collection has been published.

SP 94-1 can be purchased over the counter or by mail from the Survey at 100 E. Boyd, Room N-131, Norman, OK 73019; phone (405) 325-3031, fax 405-325-7069. Add 10% to the cost of publication(s) for mail orders, with a minimum of 50¢ per order.

AAPG ANNUAL CONVENTION
Denver, Colorado, June 12–15, 1994

"Analogs for the World" is this year's convention theme, in recognition of the increasingly global arena of hydrocarbon exploration and development.

Emphasis will be on new technical and scientific advances in geology and geophysics related to the domestic and international petroleum industry. A large part of the program will also focus on the most recent discoveries in emerging areas of interest internationally. It will cover a broad range of topics, including application of high-resolution sequence stratigraphy in reservoir development, risk analysis in international ventures, environmental petroleum hazards, and the role of eustacy vs. tectonics impassive continental margins.

In addition to an excellent technical program, there will be several thought-provoking debates. And a broad array of pre- and post-meeting field trips will provide convention participants with a unique opportunity to examine extraordinary exposures in classic geologic provinces in the western U.S.

Short courses and workshops have also been designed to complement the technical program by providing state-of-the-art techniques and concepts for the practicing petroleum geologist.

Denver'94

AAPG ANNUAL MEETING

Analogs for the World

AAPG Annual Convention Agenda

Technical Program

June 13

AAPG Geology and Exploration in South America
SEPM Stratigraphic Patterns: Sequences in Siliciclastic Continental Margin Facies and the Role of Eustacy
AAPG/SEPM High-Resolution Sequence Stratigraphy Applied to Development
AAPG/SEPM Structural Development in Collisional Orogens
SEPM Thermal Maturity in Sedimentary Basins: Uses and Abuses of Vitrinite Reflectance
SEPM Global Analysis of Carbonates
EMD Future of Energy—An Energy Minerals Perspective
Global Interests *(film presentations)*
AAPG/SEPM Geology and Exploration in South America
SEPM Stratigraphic Patterns: Local and Global Patterns in Other Times and Facies, and the Question of Global Controls
AAPG "See in 3-D": 3-D Seismic Case Histories
AAPG/SEPM Hydrocarbon Occurrence in Basement-Involved Foreland Orogens
AAPG/SEPM Organic Geochemistry-Application of Biomarkers to Exploration and Production
AAPG International Reserve Evaluation
AAPG/SEPM Geology and Exploration in West Africa
AAPG/SEPM Unconformities in Carbonates: Recognition and Porosity Development
AAPG Hydrocarbon Reservoirs of the West Siberian Basin and Caspian Sea Region
Exploration: A Search for Order *(film presentations)*

June 14

DEG Worldwide Environmental Petroleum Concerns
AAPG/SEPM Geology and Exploration in the Former Soviet Union (C.I.S.)
SEPM Research Symposium—Sequence Correlatability and Sea-Level Behavior Over Time: Alternative Views
AAPG/SEPM Computer Applications—Computer Modeling: Stochastic, 3-D, Knowledge-Based, and Data
AAPG Quantification of Reservoirs for Field Development
SEPM/AAPG Structural Styles in Rift Basins: An Around-the-World Tour
SEPM Diagenesis and Basin Evolution: Regional Aspects
AAPG Astrogeology: Impact Structures and Hydrocarbon Habitat
Recent Advances in Exploration Technology (film presentations)
DPA Going International: So You Like the Rocks, Now What?
AAPG/SEPM Geology and Exploration in the Middle East/North Africa
SEPM/AAPG Computer Applications—Modeling Basins and Fluid Flow

AAPG Evaluation of Traps and Seals
SEPM/AAPG Sedimentation and Rifting: Global Perspective, Cambrian to Modern, Marine and Continental
SEPM Diagenesis and Basin Evolution: Concepts and Techniques
Impact and the Fossil Record: Extinction at the Cretaceous–Tertiary Boundary *(debate)*
The Environment *(film presentations)*

June 15

AAPG Natural Gas: Realities of the Resources Base, Geology, and Economics
AAPG/SEPM Geology and Exploration in Southeast Asia
AAPG New Concepts in Exploration and Development—Concepts and Methods
SEPM Allocyclic Controls on Nonmarine Stratigraphy: Introduction and Valley Fills
AAPG Evaluating and Predicting Fracture Reservoir Properties
SEPM Cyclostratigraphy: Deciphering the Depositional Harmonic
AAPG Lessening Risk in International Exploration and Development Ventures
AAPG New Developments in Structural Geology: Some Old Ideas and New Data Threaten to Overturn Some Standard Concepts
Global Warming: Case Closed? *(debate)*
Practical Applications in Oil and Gas Exploration (film presentations)
AAPG Natural Gas: Realities of the Resource Base, Geology and Economics
AAPG/SEPM Geology and Exploration in China
AAPG New Concepts in Exploration and Development—Examples
SEPM Allocyclic Controls on Nonmarine Stratigraphy: From Coastal Plain to Intermountain Basin
AAPG Creating the Future Through Petroleum Migration Modeling and Prediction Technology
SEPM Recent Advances in Facies and Sequence Stratigraphy: Analogs from the Western Interior
DEG/EMD Environmental Impact of Energy Minerals Production and Use
AAPG/SEPM Organic Matter Burial and Global Change
From Dinosaurs to Space Travel *(film presentations)*

Short Courses

RMAG Surface Modeling in Two and Three Dimensions—An Overview of Computer Mapping Techniques, *June 11*
RMAG Exploration Petrophysics (Or How to Predict Performance Ahead of the Bit), *June 11*
RMAG Fractal Geometry and Its Application in Earth Sciences, *June 11–12*
RMAG Comparative Anatomy of Subandean Foreland Basins and Related Fold/Thrust Belts and Geological Processes in Their Development, *June 11–12*
RMAG Geomechanics for Reservoir Management, *June 11–12*
RMAG Applications of Outcrop Gamma-Ray Logging, *June 12*
RMAG Unconformity-Related Hydrocarbon Trapping—A Core Workshop, *June 12*

AAPG Creative Petroleum Exploration Workshop, *June 10–12*
AAPG Sequence Biostratigraphy Workshop, *June 11–12*
AAPG Siliciclastic Sequence Stratigraphy Applied to Petroleum Exploration and Field Development, *June 11–12*
DEG Fundamentals of Federal Environmental Regulations—Impact on the Petroleum Industry, *June 11–12*
DEG Transition to Hydrogeology: Broadening Your Geologic Base for Career Enhancement, *June 12*
DEG Environmental Considerations of Enhanced Oil Recovery Projects, *June 16*
DEG Phase I and Phase II Site Assessment Methodology, *June 16*
DPA Lease Acquisition for the Independent Geologist, *June 11*
EMD Geostatistics in the Search for Energy, *June 12*
EMD Trace-Elements in Coal: A Clean Air Act Perspective, *June 12*
AAPG/SC The Practicing Hydrogeologist, *June 12*
SEPM Organic Geochemistry of Sediments and Sedimentary Rocks, *June 10–11*
SEPM Luminescence Microscopy and Spectroscopy: Quantitative and Qualitative Applications, *June 11*
SEPM Systematics of Fluid Inclusions in Diagenetic Minerals, *June 12*
SEPM Geologic Log Interpretation, *June 11*
SEPM Lacustrine Reservoirs and Depositional Systems, *June 12*
DWLS Russian Log Interpretation, *June 12*
SEG Geophysical Applications of Remote Sensing and Digital Image Processing, *June 11–12*
SEG Introduction to Reflection Seismic Interpretation, *June 11–12*

Field Trips

RMAG Grand Canyon Geology Via the Colorado River, Arizona, *June 3–11*
RMAG High-Resolution Sequence Stratigraphy: Reservoir Description and Geologic Setting of the Giant Aneth Oil Field, Paradox Basin, SE Utah, *June 8–11*
RMAG Contrasting Sandbody Geometries of Fluvial Reservoirs: Outcrop Analogs in Meandering and Braided Systems, *June 8–11*
RMAG A New Look at the Laramide Orogeny in the Shirley Mountains, Freezeout Hills, and Hanna Basin, South-Central Wyoming Foreland, *June 9–12*
RMAG Sedimentology, Sequence Stratigraphy and Relation to Late Cretaceous Tectonism: Campanian Mesaverde Group, SE Wyoming, *June 9–12*
RMAG Permian Reef Geology Trail, McKittrick Canyon, Guadalupe Mountains: Facies, Depositional Models, and Sequence Stratigraphy, *June 9–12*
RMAG Depositional Environments, Sequence Stratigraphy, and Petroleum Geology of the Northern Denver Basin, *June 10*
RMAG Sequence Stratigraphy and Petroleum Geology of the Central Denver Basin, *June 11*
RMAG Sequence Stratigraphy, Paleotectonics, and Reservoir Geology of Selected Upper Paleozoic Carbonate Reservoirs, Bighorn and Wind River Basins, Wyoming, *June 9–11*

RMAG The K/T Boundary Claystone in the Southern Raton Basin, New Mexico and Colorado—Evidence of Asteroid Impact, *June 11–12*

RMAG Sequence Stratigraphy of the Gallup and Tocito Sandstones, San Juan Basin, New Mexico, *June 15–18*

RMAG Development Issues in Fractured Reservoirs, *June 15–17*

RMAG Sedimentology and Ichnology of Coarse-Grained Delta Deposits in the Fountain Formation (Pennsylvanian) near Colorado Springs, *June 16*

RMAG The Cordilleran Thrust Belt in Western Wyoming, Eastern Idaho, and Northern Utah, *June 16–18*

RMAG Sequence Stratigraphy, Facies Architecture, and Permeability Structure of Fluvial-Deltaic Reservoir Analogs: Upper Cretaceous Ferron Sandstone, Central Utah, *June 16–19*

RMAG Petroleum Geology and Sequence Stratigraphy of Devonian Carbonates of Eastern Nevada, and the Catastrophic Alamo Breccia, *June 16–20*

RMAG High-Resolution Stratigraphic Analysis, Source Rock Potential, and Fracture Porosity of the Niobrara Formation, Lyons, Colorado, *June 17*

RMAG Laramide Thrust Tectonics of the Eastern Front Range, Colorado, *June 12*

DEG Divide Creek Field—A Model for Environmentally Responsible Oil and Gas Operations, *June 10–11*

DEG Environmental Cleanup at Rocky Mountain Arsenal, Commerce City, Colorado, *June 16*

DEG Underground Storage Tank (UST) Seminar, *June 16*

DEG Environmental Field Trip at Rocky Flats, Golden, Colorado, *June 17*

EMD Sequence Stratigraphy of the Upper Cretaceous Strata of the Kaiparowits Plateau, Utah, *June 8–12*

EMD Relation of Basin Development and Architecture to Oil and Gas Resources of the Piceance Basin, Colorado, *June 10–12*

RMS/SEPM Models for the Stratigraphy of Ramp Margins: Sequence Stratigraphy and Facies Architecture of the Desert and Castlegate, Book Cliffs, Utah and Colorado, *June 8–11*

RMS/SEPM Valley-Fill, Estuarine and Shelf-Ridge Sandstones, Mid-Cretaceous Frontier Formation, Central Wyoming, *June 15–18*

SEPM Modern and Ancient Eolian Deposits as Analogs for Hydrocarbon Exploration and Production, *June 9–11*

SEPM Pennsylvanian and Permian Depositional Systems and Cycles in the Eagle Basin, Northwest Colorado, *June 16–17*

WGA Dinosaurs of Wyoming, *June 16–19*

AAPG/SC Influence of Tectonism and Eustacy on Deposition of the Pennsylvanian Minturn Formation of North-Central Colorado, *June 11*

For further information about the annual meeting, contact AAPG Convention Dept., P.O. Box 979, Tulsa, OK 74101-0979; (918) 584-2555, fax 918-584-2274. The preregistration deadline is May 13.

Oklahoma, A Summary of Activities of the U.S. Geological Survey, Water Resources Division, in Fiscal Years 1991–92

Compiled by John S. Havens, this 38-page USGS open-file report summarizes current and recently completed projects in the State of Oklahoma.

Order OF 94-38 from: U.S. Geological Survey, Water Resources Division, 202 N.W. 66th St., Bldg. 7, Oklahoma City, OK 73116; phone (405) 231-4256, fax 405-843-7712. A limited number of copies are available free of charge.

Quaternary Geologic Map of the Wichita 4° × 6° Quadrangle, United States

This USGS miscellaneous investigations series map was edited and integrated by G. M. Richmond and A. C. Christiansen. Prepared in cooperation with the Kansas Geological Survey, Oklahoma Geological Survey, and Texas Bureau of Economic Geology, the map contains state compilations by J. E. Denne, K. V. Luza, G. M. Richmond, K. M. Jensen, W. D. Fishman, and E. G. Wermund, Jr. Latitude 36° to 40°, longitude 96° to 102°. Scale 1:1,000,000 (1 inch = ~16 miles). Color sheet measures 52 × 41 inches.

Order I-1420 (NJ-14) from: U.S. Geological Survey, Map Distribution, Box 25286, Bldg. 810, Federal Center, Denver, CO 80225. The price is $4; a $1 handling charge is applied to orders of less than $10. Add 25% to the price for foreign shipment.

Ground-Water-Quality Assessment of the Central Oklahoma Aquifer, Oklahoma: Geochemical and Geohydrologic Investigations

Written by David L. Parkhurst, Scott Christenson, and George N. Breit, this report provides a comprehensive description of the major elements of the geochemistry and geohydrology of the Central Oklahoma aquifer. The 111-page report describes the geohydrologic units that are part of the aquifer; the mineralogy of the geologic units; the geochemical reactions that affect the major-ion composition of water in the aquifer; recharge; discharge; hydraulic properties; flowlines; and the age of ground water. Most of the discussion is directed toward the Permian bedrock geologic units in the study area, and only a brief discussion of the Quaternary alluvium and terrace deposits is included. The scope of the work included petrographic analysis of core material, measurements of water levels and stream flows, sampling wells for a large variety of chemical constituents, analyses of aquifer tests, age dating of ground water, numerical flow modeling, and geochemical modeling.

Order OF 92-642 from: U.S. Geological Survey, Water Resources Division, 202 N.W. 66th St., Bldg. 7, Oklahoma City, OK 73116; phone (405) 231-4256, fax 405-843-7712. A limited number of copies are available free of charge.

UPCOMING *Meetings*

EPA's Robert S. Kerr Environmental Research Laboratory, Ground-Water Seminar, June 1–3, 1994, Oklahoma City, Oklahoma. Information: Jerry N. Jones, (405) 436-8593.

SEPM Core Workshop, "Lacustrine Depositional Systems," June 12, 1994, Denver, Colorado. Information: Society for Sedimentary Geology, P.O. Box 4756, Tulsa, OK 74159; (918) 743-9765.

Geological Society of America Penrose Conference, "Fractured Unlithified Aquitards," June 15–20, 1994, Racine, Wisconsin. Information: David M. Mickelson, Dept. of Geology and Geophysics, University of Wisconsin, 1215 W. Dayton St., Madison, WI 53706; (608) 262-7863, fax 608-262-0693.

Dinosaurs of Wyoming, Field Meeting, June 16–19, 1994, Casper, Wyoming. Information: Walter R. Merschat, Box 356, Casper, WY 82602; (307) 266-4409, fax 307-266-1113.

SPWLA Annual Logging Symposium, June 18–22, 1994, Tulsa, Oklahoma. Information: Jay Patchett, Amoco Production Research, P.O. Box 3385, Tulsa, OK 74102; (918) 660-3386.

American Quaternary Association Meeting, "Data and Models in Quaternary Research," June 19–22, 1994, Minneapolis, Minnesota. Information: Linda Shane, Geology and Geophysics, Limnological Research Center, 310 Pillsbury Dr., S.E., Minneapolis, MN 55455; (612) 626-7889, fax 612-625-3819.

American Nuclear Society, Annual Meeting, June 19–24, 1994, New Orleans, Louisiana. Information: ANS, 555 N. Kensington Ave., La Grange Park, IL 60525; (312) 352-6611.

History of the Earth Sciences Society, 3rd Annual Meeting, July 7–9, 1994, Troy, New York. Information: Gerald M. Friedman, Northeastern Science Foundation, Inc., Rensselaer Center of Applied Geology, P.O. Box 746, Troy, NY 12180; (518) 273-3247, fax 518-273-3249.

SEPM Research Conference, "Clastic Deposits of the Transgressive Systems Tract: Facies, Stratigraphy, and Reservoir Character," July 10–14, 1994, Long Beach, Washington. Information: Society for Sedimentary Geology, P.O. Box 4756, Tulsa, OK 74159; (918) 743-9765.

Earthquake Engineering, 5th U.S. National Conference, July 10–14, 1994, Chicago, Illinois. Information: Claudia Cook, Newmark Civil Engineering Laboratory, University of Illinois, 205 N. Mathews, Urbana, IL 61801; (217) 333-0498.

Society of Petroleum Engineers: Forum Series in North America, July 10–August 5, 1994, Snowmass Village, Colorado. Information: Society of Petroleum Engineers, Box 833836, Richardson, TX 75083; (214) 952-9393, fax 214-952-9435.

5th Annual Archie Conference, November 30–December 3, 1994, The Woodlands, Texas. *Abstracts due June 1.* Information: Education Dept., American Association of Petroleum Geologists, P.O. Box 979, Tulsa, OK 74101; (918) 584-2555, fax 918-584-0469.

Oklahoma ABSTRACTS

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

Granite Platforms in the Wichita Mountains, Oklahoma: Pediment Outliers of the Southern High Plains in Texas and New Mexico

JAMES A. HARRELL, Dept. of Geology, University of Toledo, Toledo, OH 43606

Well-developed granite platforms exist near the summits of four of the highest hills in the Lake Altus area of the western Wichita Mountains in southwest Oklahoma. These features had previously been interpreted as wave-cut benches of Permian age. New evidence indicates that they are Pliocene pediments cut at the level of the Southern High Plains, which originally extended into western Oklahoma. During the late Pliocene and early Pleistocene, this surface retreated 180 km to its present position in the Texas Panhandle.

Reprinted as published in the *Journal of Geology*, v. 101, p. 397, May 1993.

The Role of Fluorine in Crystallization of A-Type Sheet Granite, Wichita Mountains, Oklahoma

JOHN P. HOGAN and *M. CHARLES GILBERT*, School of Geology and Geophysics, University of Oklahoma, Norman, OK 73019

Fluorine played an important role in determining the primary mineral assemblage and pluton morphology of A-type granites of the Wichita granite group. Wichita granites crystallized at near surface conditions from H_2O-poor, high-T magmas to form a series of thin (≤0.5 km) but laterally extensive (≈20–55 km length) sheets. Individual granite-sheets can be remarkably homogeneous. The Mount Scott granite-sheet is characterized by a distinctive petrography and chemical signature (i.e., SiO_2 71.0–73.6; CaO 1.0–1.5; Rb/Sr ≈1.3) recognizable over a distance of at least 55 km. Other granite-sheets display more variability. Minor and accessory minerals (e.g., amphibole, biotite, magnetite, titanite, *fluorite*, zircon, ±apatite) commonly occur as multi-mineral aggregates. Segregation of these aggregates into layers, exhibiting patterns similar to cross-bedding, is observed near some contacts. Fluorite is present as subhedral-euhedral inclusions in amphibole and biotite and is interpreted as magmatic. Titanite and fluorite exhibit antipathetic modal variation consistent with reaction $CaTiSiO_5 + F_2 = CaF_2 + TiO_{2(melt)} + SiO_2 + \frac{1}{2}O_2$. Similarly, evolved granites characterized by magnetite + fluorite suggest amplibole/biotite may have been consumed by the reaction Amp/Bio + F_2-rich melt = $CaF_2 + SiO_2 + Fe_3O_4 + H_2O$. Such changes are diagnostic of increasing F_2 activities during crystallization. F_2 contents of ferro-edenitic amphibole (≈1.40 wt% @Fe/Fe+Mg+Mn= 0.7) and annitic biotite (≈1.30 wt% @Fe/Fe+Mg+Mn=0.8) are elevated in comparison with other granite types. Fluorine may have promoted early crystallization of

amphibole from relatively "dry" melts. Partition coefficients for F_2 between biotite and granitic melt (see Icehower and London, this session) indicate F_2 contents of Wichita granite magmas were approximately 0.8 wt%. We suggest elevated F_2 contents lowered the viscosity and solidus of these magmas, enhancing their crystallization at high crustal levels as relatively well-mixed sheet-like magma bodies.

Reprinted as published in the Geological Society of America *Abstracts with Programs, 1993*, v. 25, no. 6, p. A-372.

Fractal Dimensions of Drainage Networks as Expressions of Recent Intraplate Tectonics

GEORGE W. SHURR, CHARLES L. NELSON, IVAN W. WATKINS, and *REBECCA J. REID*, Dept. of Earth Sciences, St. Cloud State University, St. Cloud, MN 56301

Recent earth movements in the interior areas of major lithosphere plates are subtle, but do have expression in the density of tributaries within a drainage network. Drainage networks in areas of uplift generally have more numerous tributaries than networks in areas of subsidence. Fractal dimensions can be used to describe tributary density: high-density, rejuvenated networks on uplifted blocks have larger fractal dimensions than those on down-dropped blocks. These generalizations are documented in several areas of the "stable" craton of North America, as well as in areas of active neotectonics.

Fractal dimensions were calculated for 20 drainage networks mapped on topographic quadrangles, along the Missouri River from central South Dakota to northern Nebraska. The fractal dimensions were calculated using commercial software and were all less than a value of 2. Areas of uplift and subsidence are identified using structural datums in Cretaceous units. Areas of uplift consistently have higher fractal dimensions than areas of subsidence. Pairs of networks from opposite sides of two Precambrian fault zones in Minnesota and Iowa show similar variation in fractal dimension. Preliminary work in the New Madrid area, along the Meers Fault in Oklahoma, on several subtle structures in the Gulf Coast, and along obvious recent fault scarps in Death Valley suggests that the generalization also applies in these areas.

Reprinted as published in the Geological Society of America *Abstracts with Programs, 1993*, v. 25, no. 6, p. A-344.

Structural/Stratigraphic Reconstruction of Frontal "Choctaw" Triangle Zone within Oklahoma Atoka Trend—Early Controls (Prethrusting) on Deposition of Deep-Water Clastic Reservoirs

DAN COX, Consulting Geophysicist, 200 N. Shelby, Carthage, TX 75633; and *RON FOSHEE*, Seagull Mid-South Inc., Shreveport, LA 71105

A structural and stratigraphic study in southwestern Oklahoma encompassing approximately 30 townships in Atoka, Coal, and Pittsburg counties, was done using several hundred wells, surface geologic maps, and more than 400 mi of 1980 seismic data. Isopach maps of six Atokan sands covered various areas, all within a deep-water fan setting. Structural balancing, done on numerous geologic cross sections of 6 mi or less, allowed correlation of logs of the various reservoirs and structural details within the frontal "Choctaw" triangle zone. Two regional cross sections were made based, respectively on 12 and 16 mi of recent high-fold common-depth-point seismic lines, with a minimum of one-well-per-mile control, diameter data, and surface geology. These cross sections were reconstructed by line balancing to illustrate the amount of thrust-

ing in the section and the pre-Pennsylvanian normal faulting that subtly controlled the Atoka sands depositional framework. The thickest and most channelized sands are found downthrown to these earlier faults, with this past relationship now obscured by post-Atokan thrusting.

Reprinted as published in the American Association of Petroleum Geologists *Bulletin*, v. 77, p. 1584, September 1993.

Diagenetic Pressure Seal Analysis Using Fluid Inclusions and Stable Isotopes, the Simpson Group (Middle Ordovician), Anadarko Basin, Oklahoma

DAVID B. MITCHELTREE, Dept. of Geosciences, University of Tulsa, Tulsa, OK 74104; and *DAVID I. NORMAN*, Dept. of Geosciences, New Mexico Institute of Mining and Technology, Socorro, NM 87801

Multi-layered diagenetic quartz, calcite and dolomite mineralization in the Simpson Group have formed a pressure seal at depth in the Anadarko Basin, Oklahoma. Drill core from the Weaver Unit No. 1 well was selectively sampled from the depths of 11,014 to 12,067 ft (3,376 to 3,657 m). Fluid and hydrocarbon inclusions were microthermometrically analyzed in a variety of diagenetic features (cements, fractures, void-fill, vug and stylolitic) for each type of mineralization. $\delta^{18}O$ and $\delta^{13}C$ stable isotope values were determined for some of the diagenetic carbonate mineralization. The $\delta^{18}O$ water (SMOW) values were constrained by fluid inclusion temperatures of homogenization (Th).

Fluid and hydrocarbon inclusion Th values indicate that diagenetic mineralization occurred with a thermal gradient at or greater than that currently present. But, less than the maximum paleo-thermal gradient for the Anadarko Basin indicated by vitrinite reflectance data. The diagenetic mineralization occurred at depth, over a broad temperature range, from fluids of highly variable density and lower salinity than that of current formation waters. Mineral oxygen and carbon values (PDB) for carbonates are light, indicating higher temperatures of mineral precipitation than expected for a purely marine water source. The $\delta^{18}O$ water values (SMOW) straddle that of standard mean ocean water with later diagenetic mineralization apparently becoming lighter (more negative). The occurrence of potentially mobile hydrocarbon phases (gas and condensates) was late in the diagenetic time frame for quartz, calcite and dolomite.

Reprinted as published in the Geological Society of America *Abstracts with Programs, 1993*, v. 25, no. 6, p. A-151.

Reservoir Framework and Exploration Potential of the Cleveland Formation (Western Anadarko Basin) Using a Sequence-Stratigraphic Model

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The Upper Pennsylvanian (lower Missourian) Cleveland Formation has yielded more than 435 bcf of natural gas and more than 18.2 MM bbl of oil from a seven-county tight-gas area in the northeastern Texas panhandle. Regional study of the Cleveland and underlying Desmoinesian Marmaton Group siliciclastics established the sequence-stratigraphic framework to clarify the vertical and areal occurrence of Cleveland reservoirs, seals, and source rocks.

Regionally distinctive facies stacking patterns in the study interval compose a sequence-stratigraphic framework of several westerly sourced systems tracts and three

depositional sequences. Sequence 1 (S1) is characterized by landward- and seaward-stepping deltaic/strand-plain cycles (parasequences), deposited on the top-of-Oswego type 1 sequence boundary, that define (in ascending order) Marmaton late-stage lowstand-wedge and transgressive systems tracts (TST) and a lower Cleveland highstand systems tract (HST). A regionally correlative, organic-rich marine-condensed section at the top of the Marmaton TST, equivalent to the Nuyaka Creek black shale bed of mid-continent cyclothems, represents maximum flood conditions during eustatic rise. A relative sea level drop with the onset of S2 deposition initiated development of a sand-rich incised-valley system (LST:iv) in the middle Cleveland that extended basinward of the lower Cleveland shelf break. Subsequent coastal onlap by thin deltaic systems of the overlying TST marks the start of decreased sediment influx during late Cleveland deposition, resulting in thinning of parasequences and an increase in carbonate beds in upper S2 and S3.

Stratigraphic traps and pinch out of reservoir facies within small, southeast-plunging anticlines compose most traps in the producing area. Proximal delta-front and fluvial sandstones of the Cleveland upper HST and overlying LST:iv, respectively, are the primary reservoirs. The high-TOC, top-of-Marmaton marine-condensed section and thick prodeltaic and lower distal delta-front shales within the lower Cleveland HST are the probable source rocks. Distal deltaic shales of the middle Cleveland TST form most reservoirs seals. Potential new reservoirs should be targeted at the updip terminations of systems tracts, at lapout positions of individual sand-rich HST and TST parasequences, and along LST:iv valley-margin stratal terminations.

Reprinted as published in the American Association of Petroleum Geologists *Bulletin*, v. 77, p. 1573–1574, September 1993.

Upstream Source Systems and Downstream Trap Systems

WILLIAM H. ROBERTS, III, Hydrexco, Houston, TX

In this paper, I try to apply common sense to the relationship of petroleum sources and accumulations by looking at some functional aspects of fluid transfer between the two. The actual physical linkage between petroleum sources and geochemically correlated petroleum accumulations is very uncertain. Basic geology, hydrology, and fluid mechanics may help.

The terms "upstream" and "downstream" are useful in referring to sources and reservoirs in a basin-wide, three-dimensional fluid continuum; however, one should avoid the ambiguous term "fluid." It is critically important to know specifically what is deemed to be moving, from where to where, and why. In the porous media of typical petroliferous basins, water is estimated to be the dominant fluid by five to ten orders of magnitude. In such an essentially aqueous continuum, the upstream and downstream positions are defined by the level of energy potential in relation to the earth's gravitational field. Gas and oil accumulations usually are found downstream. In such a water-dominant, water-soaked system, the independent natural movement of gas or oil via discrete channels or conduits seems unlikely.

Field evidence of the association of gas and oil traps with downstream hydrologic situations occurs both at the surface and in the subsurface. The data of interest include all geological, geochemical, and geophysical information obtained at many different levels, from satellite imagery to deep surface. Mid-continent examples of these observations include the Anadarko basin at large and specific references to such fields as Hugoton, Healdton, Cement, and Velma.

Reprinted as published in the American Association of Petroleum Geologists *Bulletin*, v. 77, p. 1576–1577, September 1993.

Simpson Opportunities in the North Mid-Continent

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Many production opportunities in Simpson sand (Middle Ordovician) still exist today in South Kansas, North Oklahoma, Colorado and Nebraska. Simpson tests are relatively sparse because of difficulty drilling (400′ to 500′ of hard Mississippi lime) in earlier days and undependability of seismic surveys more recently. Many oil fields with recoveries exceeding 3,000,000 barrels have been discovered at depths less than 6,000′.

The sand was deposited over most of Kansas by seas advancing northward from what is now the Anadarko Basin. The great thickness of the Oklahoma Simpson diminishes to a pre-Chattanooga (Woodford) pinchout in the North Mid-Continent. This wedge edge is responsible, along with many pre-Pennsylvanian age structures, for excellent Simpson sand reserves.

Detailed isopachous, lithofacies and structural studies will result in significant Simpson discoveries. These studies are easier to accomplish today because of more geological control (open hole logs, cores and good sample descriptions) in the study area.

The Salina and Forest City Basins in Northeast Kansas, Southeast Nebraska and parts of Iowa and Missouri have Simpson production, but the potential is barely "scratched."

The wedge edge from the Ozark Dome (Chautauqua arch area) westward across the Pratt anticline and into the Hugoton embayment produces Simpson oil in large quantities, but many favorable areas remain to be tested—talk about opportunity! The area has the added serendipity feature of four or more possible pays above the Simpson.

Presented structure, isopachous, lithofacies and production maps substantiate the belief that much Simpson oil is yet to be found at economic costs.

Reprinted as published in the American Association of Petroleum Geologists *1993 Annual Convention Official Program*, p. 129.

COCORP Studies of Crustal Evolution: The Return to the Midcontinent

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Ithaca, NY 14853

COCORP profiles of the Phanerozoic orogenic belts in the Cordilleria and Appalachians reveal major architectural elements such as thrust detachments and ramps, terrane sutures, extensional detachments, and regional variation in Moho depth and character. In recent years, however, COCORP profiles are increasingly addressing the structure and evolution of the craton hidden beneath the Phanerozoic platform cover of the U.S. midcontinent, both to identify the structures associated with accretion and stabilization of Precambrian continental crust, and to explore the structural underpinnings for the Phanerozoic intra-cratonic basins and their fundamental mechanisms of formation. COCORP profiles and reprocessed industrial reflection data indicated that large parts of the midcontinent (i.e., southern Indiana and Illinois, western Ohio, and southwest Oklahoma and adjacent Texas) are underlain by layered Precambrian rocks that may represent essentially unexplored sedimentary/volcanic sequences. The Grenville Front and its characteristic deeply penetrating zone of E-dipping reflections, as well as structures within the 1.1 Ga Grenville province like the Coshocton Zone, can be correlated over hundreds of kilometers. New COCORP profiles across the Williston Basin and early Proterozoic Trans-Hudson orogen beneath eastern Montana and North Dakota reveal an arched zone of crustal scale reflections that dip toward or beneath both the Archean Wyoming and Superior provinces to the west and east, a pattern that is remarkably similar to that observed across the Trans-Hudson orogen farther north in Canada on new Lithoprobe profiles. It is increasingly clear that major crustal structures and tectonic boundaries are recognizable and traceable for great distances beneath the midcontinent.

Despite these efforts much of the craton remains unexplored. A systematic program of regional deep profiles is needed to identify, characterize, and map the principle crustal components beneath the midcontinent.

Reprinted as published in the American Association of Petroleum Geologists *1993 Annual Convention Official Program*, p. 115.

Closing of the Midcontinent Rift—A Far-Field Effect of Grenvillian Compression

WILLIAM F. CANNON, U.S. Geological Survey, 970 National Center, Reston, VA 22092

The Midcontinent rift formed in the Laurentian supercontinent between 1,109 and 1,094 Ma. Soon after rifting, stresses changed from extensional to compressional, and the central graben of the rift was partly inverted by thrusting on original extensional faults. Thrusting culminated at about 1,060 Ma but may have begun as early as 1,080 Ma. On the southwest-trending arm of the rift, the crust was shortened about 30 km; on the southeast-trending arm, strike-slip motion was dominant. The rift developed adjacent to the tectonically active Grenville province, and its rapid evolution from an extensional to a compressional feature at ca. 1,080 Ma was coincident with renewal of northwest-directed thrusting in the Grenville, probably caused by continent-continent collision. A zone of weak lithosphere created by rifting became the locus for deformation within the otherwise strong continental lithosphere. Stresses transmitted from the Grenville province utilized this weak zone to close and invert the rift.

Reprinted as published in *Geology*, v. 22, p. 155, February 1994.

Middle Proterozoic Tectonic Activity in West Texas and Eastern New Mexico from Analysis of Gravity and Magnetic Anomalies

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The Precambrian history of west Texas and eastern New Mexico is complex, consisting of four events: Early Proterozoic orogenic activity (1630–1800 Ma), formation of the western granite–rhyolite province (WGRP) (1340–1410 Ma), Grenville age tectonics (1116–1232 Ma), and middle Proterozoic extension possibly related to mid-continent rifting (1086–1109 Ma). Pre-Grenville tectonics, Grenville tectonics, and mid-continent rifting are represented in this area by the Abilene gravity minimum (AGM) and bimodal igneous rocks, which are probably younger. We have used gravity modeling and the comparison of gravity and magnetic anomalies with rock types reported from wells penetrating Precambrian basement to study the AGM and middle Proterozoic extension in this area.

The AGM is an east–northeast-trending, 600 km long, gravity low, which extends from the Texas–Oklahoma border through the central basin platform (CBP) to the Delaware basin. This feature appears to predate formation of the mafic body in the CBP (1163 Ma) and is most likely related to pre-Grenville tectonics possibly representing a continental margin arc batholith.

Evidence of middle Proterozoic extension is found in the form of igneous bodies in the CBP, the Van Horn uplift, the Franklin Mountains, and the Sacramento Mountains. Analysis of gravity and magnetic anomalies shows that paired gravity and magnetic highs are related to mafic intrusions in the upper crust. Mapping of middle Proterozoic igneous rocks and the paired anomalies outlines a 530 km diameter area of distributed east–west-oriented extension. The Debaca-Swisher terrain of shallow marine and clastic sedimentary rocks is age correlative with middle Proterozoic extension. These rocks may represent the lithology of possible Proterozoic exploration targets. Proterozoic structures were reactivated during the Paleozoic, affecting both the structure and deposition in the Permian basin.

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In Search of the Grenville Deformational Front: Fundamental Basement Structure across Southern North America

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Recent work on Precambrian basement rocks exposed in West Texas has revealed a complex history involving an early extension (~1.35 Ga) followed by a collisional event (~1.25–1.0 Ga). The deformational front for these Precambrian events is located near Van Horn, Texas. The distinctive synorogenic sediments in conjunction with large scale structures reflect a two stage collisional history similar to that observed in eastern Canada. The Greville–Van Horn fold belts are assumed, but cannot be proven to be presently connected. The extension of this deformational front eastward towards Canada is hidden by Phanerozoic cover. Geophysical data has provided a tentative projection of this deformational front into central and northern Texas. Well samples provide some indication of the lithological contrast across the boundary. Basement rocks of the Llano region reflect the Grenville age deformation, but are well south of the deformational front. Precambrian rocks of southern Oklahoma are not affected by Grenville age deformation. COCORP data from the Hardeman Basin indicate thick apparently undeformed Proterozoic sediments. It is proposed that a sequence of two or three relatively shallow (~5000′) drill holes located along the Bend Arch of central Texas and/or the Central Basin Platform in West Texas will constrain the location and character of the Grenville deformational front. In doing so, a new perspective about the evolution of the craton could emerge. The potential relationship between Phanerozoic sedimentation and deformation with earlier basement structure can be defined. This data can provide constraints to the various plate reconstructions proposed for the late Proterozoic, including the popular SWEAT hypothesis.

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Factors Controlling Simpson Group Production in Central Oklahoma

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The distribution of oil production from within the Simpson Group has been considered enigmatic because all of the sandstone members are present throughout the study area, but some fields produce from all of the sandstone members and others produce from only one horizon. The Simpson shales are not capable of generating hydrocarbons and the oil produced from the Simpson Group probably originated from the Devonian/ Mississippian Woodford Shale. The McClain County fault juxtaposed the Woodford Shale with the Simpson Group, which enabled lateral oil migration from the Woodford into the Simpson Group sandstones. Also, tortuous migration pathways allowed Woodford oil to ultimately accumulate in Simpson reservoirs, which involve downthrown younger rocks adjacent to upthrown older rocks.

Slight structural movements occurred contemporaneously with the deposition of the Simpson Group, creating semiparallel northeast–southwest-oriented thick and thin trends. Local structural movements were active during part or all of Simpson deposition. This created stratigraphic variations in the individual Simpson Group formations, which cause the apex of a field to migrate (or even vanish) with depth. Consequently, lower Simpson structures may not be reflected by upper Simpson structures, and conversely, upper Simpson structures may not continue with depth. Variations in Viola deposition enhanced the vertical discontinuity of structures within the study area so that mapped Viola structures may not reflect underlying Simpson structures. Furthermore, a dramatic change in the orientation of the structural grain began to appear in the late Ordovician (Viola). Subsequent movements enhanced this later structural orientation, producing two acute structural trends that control the entrapment of oil. This study demonstrates that the dual structural imprint is probably the single most important factor in controlling the distribution and accumulation of hydrocarbons within the study area.

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The Use of ^{129}I in Determining Source Ages and Migration Patterns of Sedimentary Basin Brines

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^{129}I/I ratios have been measured in brines from the Gulf Coast Basin, the Anadarko Basin in Oklahoma and Nevada oil fields. Results indicate that this isotope can be used to identify source formations of I and organic matter, and to track fluid migration from deeper parts of a sedimentary basin to present host formations.

Interpretation of ^{129}I/I ratios measured in brines from sedimentary basins is based on estimation of the relative contributions of cosmogenic and fissiogenic ^{129}I. Ratios measured in brines from the Louisiana Gulf Coast basin can be compared to the decay of cosmogenic ^{129}I to get minimum source ages (when no fissiogenic contribution is included). These minimum ages are significantly older than present host formation ages, indicating migration of brine from older, deeper sources. Some ratios measured in Texas Gulf Coast brines show evidence of a greater fissiogenic component which indicates that the brines have resided in formations with locally high U concentrations. Brines with extremely high I concentrations from a Pennsylvanian host formation in the Anadarko Basin point to the Woodford Shale as the probable source formation, based on comparison of potential fissiogenic contributions from underlying sandstones and shales. Ratios measured in brines from Nevada oil fields are higher than would be predicted for deep sources, and indicate mixing with shallower, younger formation waters.

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Submarine-Fan, Delta Depositional Environment of the Pennsylvania Redfork Sandstone

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Active exploration and development drilling for the Upper Pennsylvanian Red Fork sandstone has been going on since 1979 in the western part of the Anadarko basin of Oklahoma. The fine-grained, low-permeability gas and gas condensate reservoir produces at depths ranging from 12,000 to 14,000 ft from stratigraphic traps. Although drilling generally has been continuous through the years, producing the Red Fork play is very sensitive to gas price because of drilling depths and reservoir characteristics. The play is now mature, but because of the complex submarine-fan depositional environment, it is not easy to predict the good-quality reservoir sandstone.

Isopach maps, log shapes, lithologic information, and seismic data are all used to define the facies within the fan. In the Red Fork, most of the sand was deposited in the middle fan with the best reservoirs found in narrow channels of the suprafan lobes. Quality of the reservoir rock in the levee facies deteriorates significantly away from the channel. The gross morphology of interpreted suprafan lobes in the Red Fork arc compared to and show a similarity with the modern Mississippi submarine fan and suprafan lobes seen in the outcrop.

Using two-dimensional and three-dimensional seismic data to map the suprafan lobes and channel systems has proven very challenging in the Red Fork; however, careful integration of all well information with the seismic data will yield the best interpretation. Changes in amplitude are used to help define the presence or absence of sandstone and the relative quality of the reservoir.

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Depositional Environments of the Red Fork Sandstone in Custer and Roger Mills Counties, Southwestern Oklahoma

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The Desmoinesian Red Fork formation is a prolific, overpressured gas-producing sequence of interbedded sandstones and shales. Total thickness ranges from less than 100 ft (northeast) to more than 1,100 ft (south). Isopach maps suggest that syndepositional faulting controlled major depositional trends.

The lower Red Fork, whose base is defined by a persistent, hot, black shale (sequence boundary?), is mainly deep-marine shale and siltstone. Two major shallowing-upward deltaic sequences separated by a marine transgression are evident in the middle (50–400 ft thick) and upper (30–250 ft thick) Red Fork. The middle Red Fork is marine dominated and was deposited into a relatively deep basin on a steep, unstable delta-front slope. In contrast, the upper Red Fork deltaic sequence is more fluvial dominated and was deposited in shallower water.

The upper Red Fork is overlain by the Pink lime interval, which appears to be shallow-marine/lagoonal black shale. The Pink lime contains fish scales, coffee-ground to branch-size lignitic plant debris, and brackish to shallow-marine ostracodes, linguoid brachiopods, *Tasmanites* algae, and gastropods. Most of the Red Fork has an easterly, possibly Ouachita Mountain area source. The prolific Southwest Leedey field has a different mineral assemblage and diagenetic sequence and may have a northern source.

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Mixing and Evolution of Saline Groundwaters in the Mid-continent, USA: Implications for Carbonate Diagenesis

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Regionally continuous carbonate strata in southeastern Kansas, southwestern Missouri and northern Oklahoma are predominantly marine carbonates and comprise portions of three adjacent large-scale flow systems. Groundwaters collected over the 40,000 sq km study area exhibit an extreme range in geochemical characteristics with salinities from 200 to 250,000 mg/l. δD and (isotope) ^{18}O values range from −106 to −5‰ and −14 to 3‰ (SMOW), respectively. $^{87}Sr/^{86}Sr$ values vary from 0.7088 to 0.7166. Each flow system contains waters of markedly different origins, with distinct geochemical signatures. Fluid mixing processes between these three end members exert a fundamental control on regional groundwater geochemistry. This allows compositions of end member groundwaters associated with each flow system to be tightly constrained and independently evaluates hydrogeologic models. These pore fluids have significant implications for diagenetic studies of ancient carbonate aquifers.

Both end-member and intermediate (i.e., mixed) groundwaters are carbonate-saturated and mixing processes do not create a driving mechanism for water/rock interaction. Based on the carbonate saturation states of the groundwaters and evidence for limited extents of interaction with carbonate aquifer rocks, modeled carbonate cements precipitated from these fluids will reflect both the extreme range of isotopic parameters exhibited by the waters and their gross differences from the aquifer rocks (e.g., measured $^{87}Sr/^{86}Sr$ values for carbonate rocks range from 0.708–0.712).

The relationship between tectonic and hydrologic processes indicates that regional gravity-driven flow systematics may provide an effective mechanism for hydrocarbon migration and MVT ore deposition. The lowest (isotope) ^{18}O values of saline groundwaters in this study reflect far traveled meteoric recharge from high altitude areas to the west of the study area in a gravity driven flow system. Modeled modern carbonate cements associated with these groundwaters may provide an analog for ancient carbonate cements with low (isotope) ^{18}O values, which are common to carbonate sequences. Such low values (−19 to −14‰ PDB) are frequently attributed to cement precipitation during high temperature burial diagenesis or meteoric diagenesis during periods of cold climate. Alternatively, such low (isotope) ^{18}O cement values may reflect meteoric recharge from high altitude areas associated with a gravity driven flow system.

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Mid-Continent Natural Gas Reservoirs and Plays

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Natural gas reservoirs of the mid-continent states of Oklahoma, Kansas, and Arkansas (northern part) have produced 103 trillion cubic ft (tcf) of natural gas. Oklahoma has produced the most, having a cumulative production of 71 tcf. The major reservoirs (those that have produced more than 10 billion ft^3) have been identified and organized into 28 plays based on geologic age, lithology, and depositional environment. The *Atlas of Major Midcontinent Gas Reservoirs*, published in 1993, provides the documentation for these plays. This atlas was a collaborative effort of the Gas Research Institute; Bureau of Economic Geology, The University of Texas at Austin; Arkansas Geological Commis-

sion; Kansas Geological Survey, and Oklahoma Geological Survey.

Total cumulative production from 530 major reservoirs is 66 tcf associated and nonassociated gas. Oklahoma has the highest production with 39 tcf from 390 major reservoirs, followed by Kansas with 26 tcf from 105 major reservoirs. Most of the mid-continent production is from Pennsylvanian (46%) and Permian (41%) reservoirs; Mississippian reservoirs account for 10% production and lower Paleozoic reservoirs, 3%. The largest play by far is the Wolfcampian Shallow Shelf Carbonate–Hugoton Embayment play with 26 tcf cumulative production, most of which is from the Hugoton and Panoma fields in Kansas and Guymon-Hugoton gas area in Oklahoma. A total of 53% of the mid-continent gas production is from dolostone and limestone reservoirs; 39% is from sandstone reservoirs. The remaining 8% is from chert, conglomerate, and granite-wash reservoirs.

Geologically based plays established from the distribution of major gas reservoirs provide important support for the extension of productive trends, application of new resource technology to more efficient field development, and further exploration in the mid-continent region.

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1992 Estimate of Undiscovered Conventional Oil Resources in the Mid-Continent

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In conjunction with a Department of Energy (DOE) sponsored review of recent oil resource estimates, seven AAPG members met in Tulsa, Oklahoma, in August 1992, to evaluate mid-continent undiscovered recoverable conventional oil resources. As a result of this investigation, a major upward revision was made to a 1989 study by the United States Department of the Interior. Mean estimates of undiscovered recoverable conventional oil in the mid-continent are 3.2 billion bbl of oil (no economic parameters) and 2.72 billion bbl of oil ($20.00/bbl, 1992 dollars), 69% and 56% higher, respectively, than the previous study. The mid-continent was subdivided into basin/uplift/shelf areas for this study, and resources assigned to each.

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Reservoir Heterogeneity in a Portion of the Bartlesville Sandstone

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The Bartlesville Sandstone has been one of the most impotent oil-producing intervals in Northeastern Oklahoma, since its discovery in the early 1900s. Many fields have produced from thin sandstone; most are in advanced stages of recovery, and some are faced with possible abandonment. As oil-field maturity increases, reservoir characterization becomes critical.

In order to characterize reservoir heterogeneities, a roadcut between the cities of Claremore and Pryor was selected for detailed study. The roadcut is 70 ft high and 350 ft long. Twelve wells, penetrating the Bartlesville Sandstone have been drilled, cored and logged behind the roadcut face.

Four levels of heterogeneity are identified at the study site. The first level (largest scale) is represented by multistoried channel fills, plus laterally associated facies. At this level, changes in texture, sedimentary structures and permeability contrasts of 1 to 2 orders of magnitude are found between rocks underlying and overlying erosion surfaces. The second level is the individual "story" or genetic interval represented by a collection of contiguous facies (channel fill, levee, splay). The third level is represented by individual facies such as an individual channel fill. The fourth level for the channel-fill facies contains four subfacies: lower fill, chute-modified lateral accretion bars, complex laminated strata and mud fills. Preliminary results indicate that permeability contrasts are also present among channel fill subfacies.

The outcrop-based model will be used in the definition of reservoir heterogeneities and potential compartments in the prolific Bartlesville Sandstone (Glenn Sand) of Glenn pool field.

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The Ames Astrobleme

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The origin of an unusual structural feature near the town of Ames, in the southeastern part of Major County, Oklahoma, has been subject to much speculation. Maps of subsurface horizons show an intriguing circular closure around a low of some 20 mi^2 in an area approximately centered at the town of Ames. Early drilling revealed an unusually thick, low Hunton section, so an initial characterization was "The Hunton Graben." Subsequent deeper drilling discovered Arbuckle dolomite production on a circular rim around this low. Drilling, mapping, and core studies now indicate the structure is an impact crater, or astrobleme.

Initial Arbuckle dolomite wells were located on the rim of the impact crater. While significant oil and gas discoveries have been found, the prolific oil production from wells located on the crater floor established this structure as possibly the largest known productive astrobleme.

The first crater-floor well, the D. & J. Gregory 1-20 (T21N, R9W), may be the largest oil well established from a single pay in Oklahoma. The pay zone is granite breccia formed as a characteristic central rebound feature in larger astroblemes. Conservatively estimated primary recoveries are over 4 million bbl of oil for this well. Later crater-floor wells have established production from granite wash overlying brecciated dolomite and from solution-enhanced porosity and fracture systems all sealed by Oil Creek shale.

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Vitrain (Cryptotelinite) from the Mississippian Fayetteville Shale, Northwestern Arkansas

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A siltstone/very fine-grained sandstone lense in the Chesterian Fayetteville black shale in northwestern Arkansas contains multiple stringers, approaching one centimeter thick, composed of the coal lithotype vitrain representing fragments of unmacerated tree trunk, probably referable to the Lepidodendrales. The shale represents a near-shore, anoxic marine environment with only a pelagic macrofauna. The siltstone exhibits ripples, low-angle, trough cross-strata, shale partings and contains transported *Stigmaria* fragments and other plant debris, but no fauna. Ammonoids from the black shale belong to the middle Chesterian *Tumulites varians–Cavenoceras fayettevillea* zone that correlates with the Pendleian Stage (E_1), Namurian Series of western Europe.

The coal is brittle, breaks into cubes with smooth surfaces by concoidal fracture, and has a very bright luster. Although resembling impsonite and grahamite megascopically, a woody texture belonging to the coal maceral cryptotelinite is revealed by etching with potassium permanganate and sodium sulfite. Vitrinite is the only maceral group observed in the coal stringers, while vitrinite and inertinite macerals were observed in the siltstone lense. The coal stringers appear to have been sheets of lycopod bark deposited by a single storm event. The cortex of the *Stigmaria* fragments has also been altered to vitrain (cryptotelinite).

Mean maximum vitrinite reflectance is 1.16%, indicating a rank of medium volatile bituminous at the high volatile medium volatile bituminous boundary. Thermal maturity is higher than might be expected for this setting in the southern Ozarks.

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Upper Morrowan Valley-Fill, Sandstone Reservoirs at South Guymon Field, Texas County, Oklahoma—An Integration of Core and Wireline-Log Stratigraphic Studies

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South Guymon field, located in south-central Texas County, Oklahoma panhandle, has produced more than 238 bcf of gas and 430 MBO and condensate from sandstone reservoirs in the Lower Pennsylvanian, Upper Morrow and Lower Morrow formations. The field was developed primarily during the early 1960s, but drilling to extend production and replace damaged wells has continued to date. Upper Morrowan hydrocarbon production in the southern part of south Guymon field is from two conglomeratic sandstone units. The integration of core and wireline-log stratigraphic studies indicates that the two sandstones record valley-fill deposition in two distinct, depositional sequences separated by a major, lowstand surface of erosion unconformity.

During periods of subaerial exposure and erosion associated with Upper Morrowan eustatic drops in sea level, fluvial valleys were incised in older, Upper Morrowan marine shales and previously deposited Upper Morrowan valley-fill sequences. With the initiation of sea level rise, incised valleys began to fill with fluvial sediments. Fluvial deposits in the southern part of South Guymon field are light-gray, medium-scale, cross-stratified and horizontally stratified, coarse-grained sandstones and conglomeratic sandstones. Core study, dipmeter analysis, and detailed mapping of the two Upper Morrowan fluvial sandstone reservoirs in the southern part of south Guymon field suggest these sandstones were deposited by braided and coarse-grained meandering streams.

Continued transgression resulted in marine drowning of the incised valleys and development of restricted quiet-water bays. Bay deposition is recorded by light-gray to gray, wavy parallel-laminated, muddy sandstones and sandy mudstones overlying the coarse-grained, fluvial sandstones. Quiet-water bay deposits contain common, sand-size, uranium-enriched, carbonaceous plant debris that results in high, gamma-ray log values, allowing wire-line log recognition of these deposits. Isopach mapping of the cumulative thickness of fluvial and bay valley-fill deposits shows an approximate width of 0.7 to 3 mi (1 to 5 km), and a north–northeast and west–northwest trend for the Upper Morrowan incised valleys in the southern part of South Guymon field.

During maximum transgression or sea level highstand, offshore marine muds were deposited across the region inside and outside of incised valleys. Offshore marine deposition is recored by black, calcareous, fissile shales with agglutinated forams and negligible siliciclastic sand.

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Preserved Organic Matrix from Pennsylvanian Aged Buckhorn Asphalt Mollusca

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A fundamental component of mollusc shells is the organic matrix that envelops individual crystals of the shell, and serves as the template and seed upon which individual crystallites form. This material, which contains various organic macromolecules including proteins and polysaccharides, may also play an important role in shell degradation. Thus, organic matrix of mollusc shells has both phylogenetic and taphonomic significance.

Pennsylvanian aged organic matrix macromolecules have been identified within fossil mollusc shells of the Buckhorn asphalt deposit in south-central Oklahoma. Using the technique of Clarke (1993, pers. comm.), embedded specimens are polished, etched, critical point dried and examined with a scanning electron microscope. This procedure was carried out on three species of bivalve and one species of nautiloid from the Buckhorn asphalt. For comparative purposes the extant, Texas Gulf coast bivalve *Isognomon bicolor* (Adams) was also analyzed. In all of the specimens examined, the organic matrix was found well preserved and completely intact. The organic matrix consists of two types. Intercrystalline matrix forms a relatively thin envelope which completely surrounds each individual crystal. Additionally, minor amounts of intracrystalline matrix is identifiable within the crystals of the prismatic shell layers. There is a correlation between shell microstructure and relative thickness of the surrounding organic matrix. Nacreous shell layers have a thick organic matrix relative to the thickness of the nacre tablets. Organic matrix of the prismatic shell layer is quite thin relative to the size of the individual prisms, though a fair amount of matrix (intracrystalline) is incorporated within the prisms. The relatively thin organic matrix of the prismatic layer may in part explain the tendency for prismatic shell layers to physically degrade more rapidly than nacreous and crossed lamellar layers.

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Paleoecologic and Evolutionary Significance of Intraspecific Morphologic Variability in *Mesolobus Obsoletus* (Brachiopoda) from the Middle Pennsylvanian of South-Central Oklahoma

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The chonetid *Mesolobus obsoletus* is common in olive-gray shales of "Shale 3" in the Ardmore Basin of south-central Oklahoma. "Shale 3" (uppermost Atokan and basal Desmoinesian) is within the Lake Murray Formation. In a succession of 16 samples of *M. obsoletus* from "Shale 3," the sample means of seven characters, and the diversity of the fauna associated with the chonetids, fluctuate in unison. Specifically, the sample means of width, length, height, mesial fold strength (MF), sulcus strength (SU), and mesial fold width, and the diversity, first decrease, then increase, decrease again, and finally increase. The sample means of length/height ratio (LH) first increase, then decrease, increase again, and finally decrease.

The low-diversity faunas associated with most samples of *M. obsoletus* are dominated by small mollusks. This, plus the presence of ironstone concretions, suggests that the low-diversity faunas lived in dysaerobic or brackish water. Two of the high-diversity faunas are dominated by crinoids, brachiopods, and bryozoans. These groups, plus the presence of limestone lenses, suggest that these high-diversity faunas lived in aerobic or marine water. Thus, the morphologic variability of *M. obsoletus* is interpreted as an ecophenotypic response to oxygen concentration and salinity.

Study of growth sequences of *M. obsoletus* from each sample indicates that three characters exhibited differential development during ontogeny. In any given size-class (~age) from a low-diversity sample, the class means of MF and SU are less, and LH greater, than class means for the same size-class from high-diversity samples. Therefore, adults from dysaerobic/brackish environments resemble juveniles from aerobic/marine environments, and are thus paedomorphic. Furthermore, these paedomorphs resemble *Neochonetes*, the presumed ancestor. This intraspecific heterochrony suggests that evolution of the mesial fold is a modification to enhance feeding in favorable environments rather than an adaptation to permit inhabitation of poor environments. The mesial fold most likely provided better separation of inhalant and exhalant feeding currents.

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Global Iridium Anomaly, Mass Extinction, and Redox Change at the Devonian–Carboniferous Boundary

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Iridium abundance anomalies have been found on a global scale in the Devonian–Carboniferous (D–C) boundary interval, which records one of the largest Phanerozoic mass-extinction events, and event that devastated many groups of living organisms, such as plants, ammonoids, trilobites, conodonts, fish, foraminiferans, brachiopods, and ostracodes. At or very close to the D–C boundary, there exists a geographically widespread black-shale interval, and Ir abundances reach anomalous maxima of 0.148 ppb (Montagne Noire, France), 0.138 ppb (Alberta, Canada), 0.140 ppb (Carnic Alps, Austria), 0.156 ppb (Guangxi, China), 0.258 ppb (Guizhou, China), and 0.250 ppb (Oklahoma). The discovery of global D–C Ir anomalies argues for an impact-extinction model. However, nonchondritic ratios of Ir to other important elements and a lack of physical evidence (shocked quartz, microtektites) do not support such a scenario. The fact that all Ir abundance maxima are at sharp redox boundaries in these sections leads us to conclude that the Ir anomalies likely resulted from a sudden change in paleo-redox conditions during deposition and/or early diagenesis.

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Paleobiology of the Upper Carboniferous Age Gastropod *Amphiscapha (Cyclioscapha) Texana*

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Eighty-five specimens of the Upper Carboniferous age gastropod *Amphiscapha (Cyclioscapha) texana* Yochelson were collected from the Lower Tackett Shale Member of the Coffeeville Formation near Okemah, Oklahoma. Specimens from the genus *Amphiscapha* have been collected from Upper Carboniferous to Middle Permian localities in North America, South America, and Asia, with a large number of specimens recovered from the North American mid-continent. Because large collections of relatively complete specimens of *A. (C.) texana* are rare, this assembly of well-preserved specimens offers a good opportunity to expand the definition of the taxon, as well as to analyze in greater detail some paleobiologic aspects of its life mode.

Amphiscapha (C.) texana is characterized by pseudo-planispiral coiling, transverse color banding, and irregular nodes along the carina. The relative abundance of encrusting epizoans on the nodose side of the gastropod shell as compared to the side without nodes supports the postulation that this taxon lived with the nodose side of the shell in the dorsal position (the frequency of encrustation is six times greater on the proposed dorsal side than on the proposed ventral side). Certain specimens display well preserved transverse color banding parallel to the transverse growth lines of the shell. Some of the irregular markings present are undoubtedly artifacts of preservation. Disruptions of the color bands are also visible, followed by a resumption of normal banding. Some of these disruptions may be in response to environmental pressures, but sublethal encounters (perhaps predation) are probably responsible for the most severe shell interruptions.

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Discovery of the Zonal Index Conodont *Amorphognathus Ordovicicus* in the Richmondian of Indiana: Implications of the Regional Correlation of the North American Upper Ordovician Standard

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Amorphognathus ordovicicus Branson & Mehl, 1933 is a morphologically distinctive, geographically widespread, and biostratigraphically important conodont. Species of *Amorphognathus* form an evolutionary lineage that can be traced back to the Lower Ordovician. Several of these species have been used as zonal indices in the Atlantic conodont zonal scheme in which the youngest Ordovician zone is the *A. ordovicicus* Zone. The ancestor of *A. ordovicicus* is *A. superbus* (Rhodes, 1953) and the evolutionary transition of the latter species to typical *A. ordovicicus* occurs in a very narrow stratigraphic interval in the middle part of the Upper Ordovician. Despite extensive search since the 1960s, prior to the present study no unquestionable specimens of multielement *A. ordovicicus* had been found in the Cincinnatian of the Cincinnati region, the reference standard of the North American Upper Ordovician. Recently, large and closely spaced samples from the uppermost Arnheim and lowermost Waynesville formations near Brookville, Indiana produced typical specimens of *A. ordovicicus* and *A. superbus* as well as transients. This indicates that the base of the *A. ordovicicus* Zone is in the uppermost

Arnheim (lower Richmondian Stage). The establishment of this biostratigraphic key level in the Cincinnatian reference standard has important consequences for the national and international correlation of the Richmondian. For instance, this zonal boundary occurs in the uppermost Dubuque Formation of Iowa–Minnesota; the upper type Cape Limestone of Missouri; the upper Viola Springs Formation of Oklahoma; the lower Cautleyan Stage of the Ashgillian Series in Great Britain; and the upper Fjäcka Shale in the Harjuan Series of Baltoscandia.

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Extent and Definition of the Lower Ordovician (Ibexian) Jeffersonian Stage in North America

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Flower (1957) proposed the Jeffersonian Stage as the penultimate stage for the Lower Ordovician of North America, based upon dolomitic strata and insoluble chert mold faunas of the Jefferson City Formation of Missouri. Flower's proposal, however, lacked the contemporary requirements of boundaries and stratotype.

The Kindblade Formation of southern Oklahoma has yielded a trilobite fauna of 55 species, 11 of which are known from the Jefferson City of Missouri. *Ranasasus brevicephalus, Bolbocephalus missouriensis*, and *"Peltabellia" permaginata* approximate the base of each formation and indicate the base of the Jeffersonian Stage. The top of the Jeffersonian is placed at the base of the succeeding Cassinian Stage. Within the Kindblade this horizon is thought to lie at the lowest occurrence of *Strigigenalis caudata*, based upon trilobite data from Missouri and conodont evidence from the eastern U.S.

Correlations based upon conodont species suggest that the Jeffersonian Stage approximates Ross-Hintze "Zone G" of the Great Basin *Benthamaspis obrepta* is the only trilobite species known to occur from both the "Zone G" strata and Kindblade-equivalent rocks of the mid-continent. Trilobites from the Kindblade, however, occur in a broad region south and east of the Transcontinental Arch (TX, OK–MO, PA).

A lectostratotype is suggested from the base of the Jeffersonian Stage above the base of the Kindblade Formation, at its type section in the Wichita Mountains of Oklahoma. The advantages of increased biostratigraphic resolution within a thick limestone succession justifies removal of the stratotype from Missouri. The unique species-level character of the mid-continent trilobite faunas suggests the utility of the Jeffersonian Stage for correlation east of the Transcontinental Arch in the Lower Ordovician rock of North America.

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