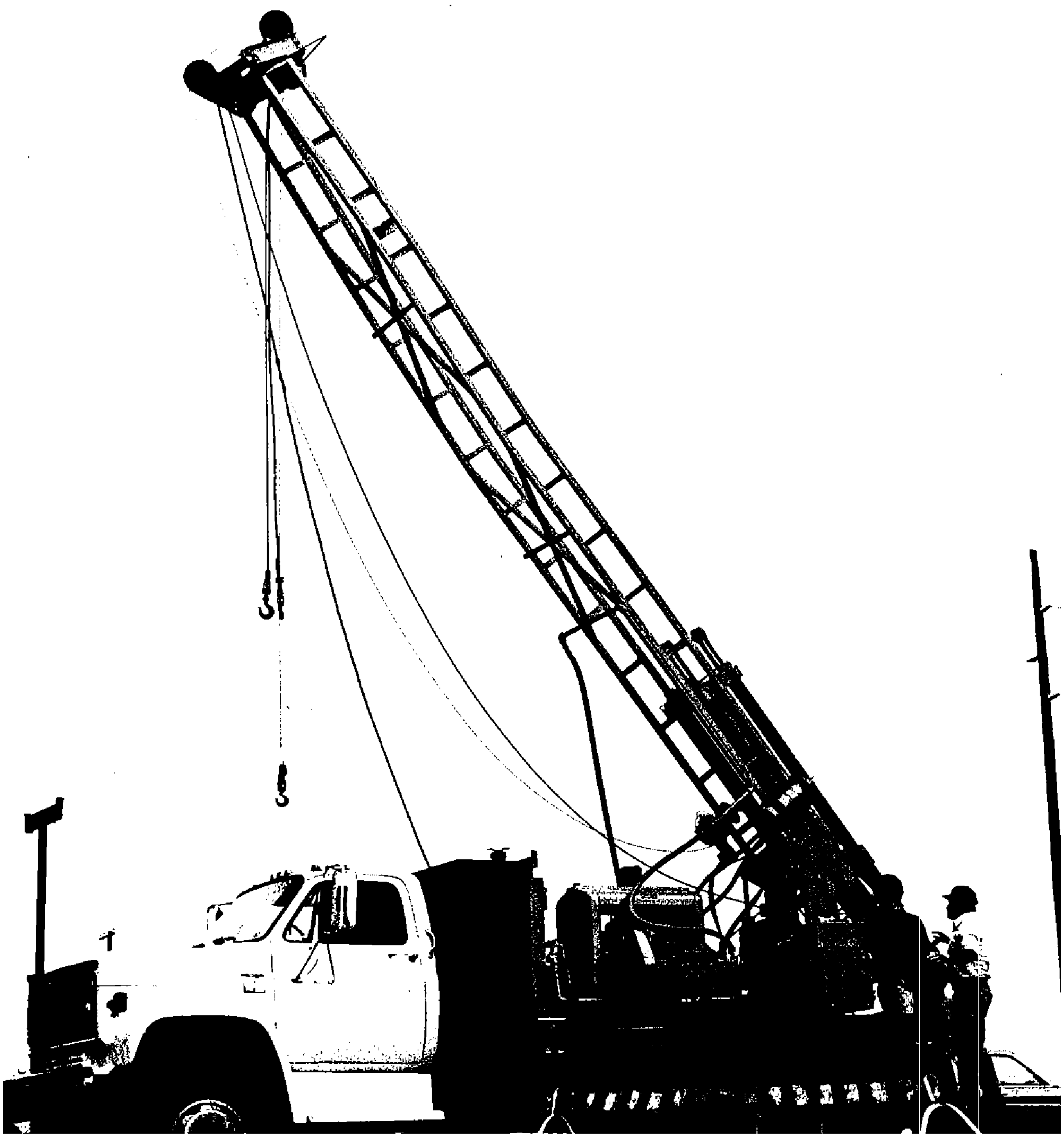
VOL. 41, NO. 5 OCTOBER 1981

OKLAHOMA GEOLOGY NOTES

OKLAHOMA GEOLOGICAL SURVEY / THE UNIVERSITY OF OKLAHOMA



On the cover—

Survey Purchases Drilling Rig

The cover photo captures the initial raising of the 24-foot mast of the Oklahoma Geological Survey's new core-drilling rig that was tested recently in the park surrounding the Duck Pond, just east of the main OU campus in Norman.

While factory representatives were teaching OGS geologists William E. Harrison, Kenneth V. Luza, and M. Lynn Prater to operate the rig, several interested spectators gathered to see the first cores of Hennessey Shale. The machine has the capacity to drill and recover cores to a depth of 1,200 feet, although such depth was not reached in the initial tests.

The new tool is a combined auger/wire-line core-drilling rig with associated tooling equipment mounted on a 1981 2½-ton flat-bed Chevrolet truck. The rotary drillhead has two speed ranges and is hydraulically fed. The motor is a four-cylinder, watercooled, 12-volt, electrically starting White model D 2300. Core barrels in lengths of 5 to 10 feet will catch the cores drilled.

The brightly colored "OSU-orange" and white rig will be a valuable asset for assessing all types of hydrocarbon deposits—including coals—as well as some nonfuel minerals.

The rig's first practical applications will come this fall in Harrison's tar-sands and heavy-oil project in the Arbuckle Mountain region, as well as in other work on a geothermal-gradient investigation.

Oklahoma Geology Notes

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

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

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

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OKLAHOMA GEOLOGICAL SURVEY, THE UNIVERSITY OF OKLAHOMA

Contents

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OKLAHOMA EARTHQUAKES, 1980

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

Introduction

Oklahoma is part of a geologic region referred to as the Stable Central Province (King, 1951; Hadley and Devine, 1974). This province extends from the western margin of the Appalachian Plateau to the eastern edge of the Rocky Mountain Uplift and from the Gulf Coastal Plain to south-central Canada. Compared to other tectonic provinces, such as the Appalachian Province, the Stable Central Region has displayed little tectonic activity since Late Pennsylvanian time. The historical seismological record has been limited, with a notable exception being the New Madrid, Missouri, area and adjacent regions in Kentucky, Tennessee, and Illinois.

The New Madrid earthquakes of 1811 and 1812 are probably the earliest historical earthquake tremors felt in Oklahoma (then Arkansas Territory) by early residents in southeastern Oklahoma settlements. The earliest documented earthquake in Oklahoma occurred near Jefferson, Grant County, on December 2, 1897. 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 approximately 362,000 square km (Docekal, 1970; Kalb, 1964; von Hake, 1976). From 1900 through 1979, 278 earthquakes have been located in Oklahoma (Lawson and others, 1979; Lawson and Luza, 1980).

Instrumentation

A statewide network of 11 seismograph stations is recording seismological data in Oklahoma (fig. 1). The Oklahoma Geophysical Observatory station, TUL, has been recording earthquake data since December 1961. The Observatory, located near Leonard, Oklahoma, in southern Tulsa County, operates seven seismometers, three long period and four short period, which are installed in a vault detached from the main building. The seismic responses at TUL are recorded on 14 paper-drum recorders; 16 seismograms are recorded on 16-mm film. Seven semipermanent, volunteer-operated seismograph stations and three radio-telemetry stations constitute Oklahoma's regional network. The installation and maintenance of these

[1] Geophysicist, Oklahoma Geophysical Observatory, Leonard.
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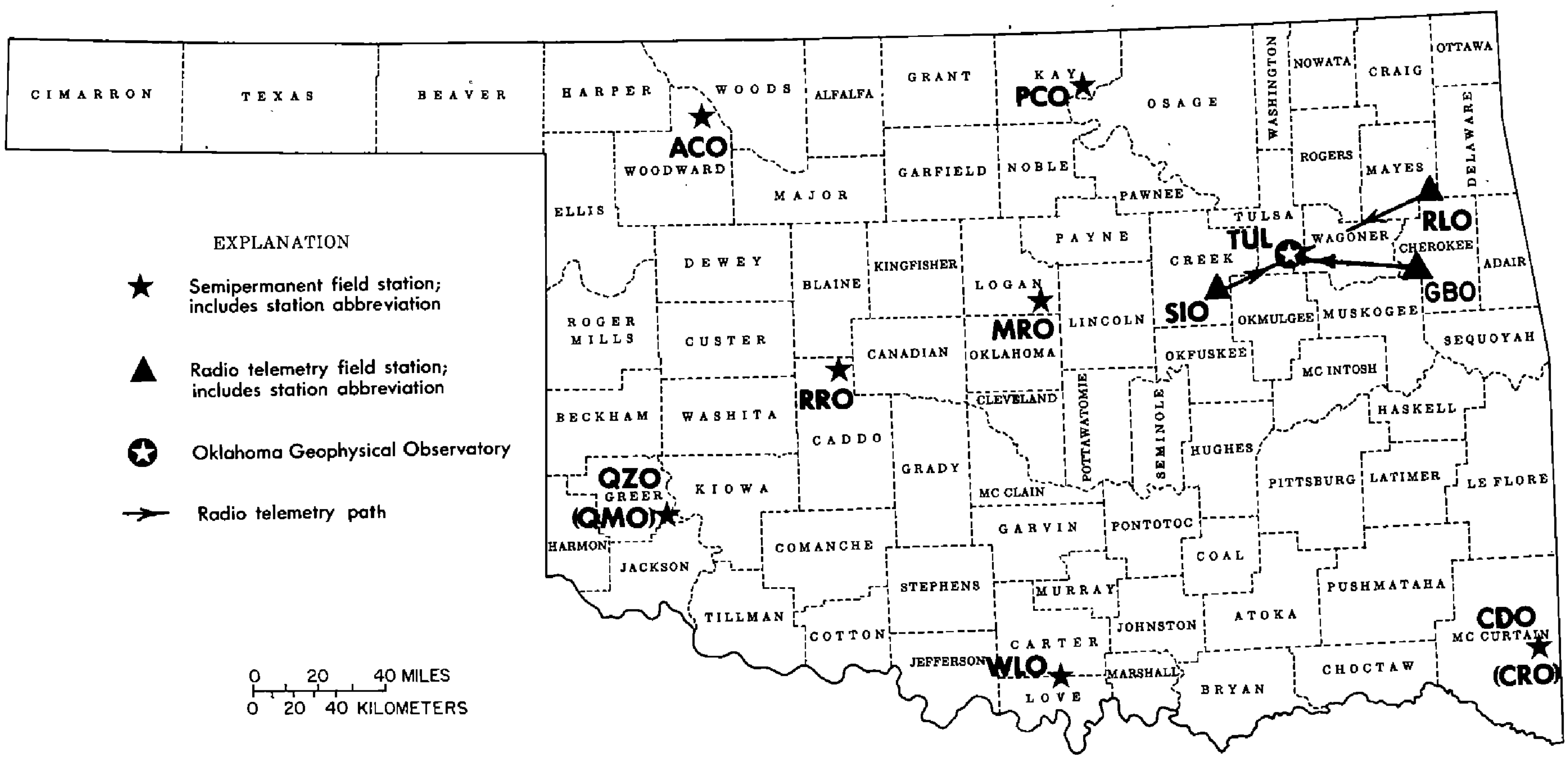

Figure 1. Active seismograph stations in Oklahoma.

stations are being supported by the U.S. Nuclear Regulatory Commission (NRC) (Luza, 1978). The regional seismograph network supplements the existing seismological capability at the Oklahoma Geophysical Observatory by providing more accurate location and detection of earthquake activity in Oklahoma.

Each of the seven volunteer-operated seismograph stations consists of a Geotech S-13, short-period, vertical seismometer; a Sprengnether MEQ-800-B unit, including amplifier, filters, ink-recording unit and a clock; and a Kinemetrics time-signal-radio receiver for high-frequency WWV time signals. Each radio-telemetry system consists of one Geotech S-13 seismometer and one Monitron and/or Emheiser Rand telemetry unit. The telemetry unit amplifies the seismometer output and uses this output to frequency-modulate an audiotone. A 500-milliwatt, crystal-controlled transmitter limits the line-of-sight transmission to 80 km. Seismographs from the radio-telemetry stations are recorded at the Oklahoma Geophysical Observatory.

From January 1, 1980, to December 31, 1980, station coverage was relatively uniform. The Carnasaw Mountain Station, CRO, was closed July 23, 1980. A new station was installed near Cedar Creek, CDO, in McCurtain County on August 1, 1980.

Earthquake Distribution

In 1980, 49 Oklahoma earthquakes were located (fig. 2) by the Oklahoma Geophysical Observatory staff. Magnitude values range from a low of 0.9 (mbLg) in Kay County to a high of 3.0 (mbLg) in Canadian County. The listing represents only those earthquakes that could be located by using three or more seismograph records. Six earthquakes were reported felt by people living in the vicinity of an earthquake epicenter. A summary of these events is listed in table 1.

TABLE 1.—EARTHQUAKES THAT WERE REPORTED FELT IN OKLAHOMA, 1980

Event no.	Date and origin time (UTC)		Nearest City		County	Intensity (MM)[2]
282	Feb 5	043235.45	NE	Orr	Love	III
308	Nov 1	052613.85	SW	Yukon	Canadian	III
309	Nov 2	100049.03	N	Mustang	Canadian	V
321	Dec 4	012316.96	SW	Reck	Carter	Felt
322	Dec 4	234843.22	NW	Burneyville	Love	Felt
323	Dec 5	000726.29	N	Dunbar	Love	Felt

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

[2] Modified Mercalli (MM) earthquake-intensity scale (see table 2).

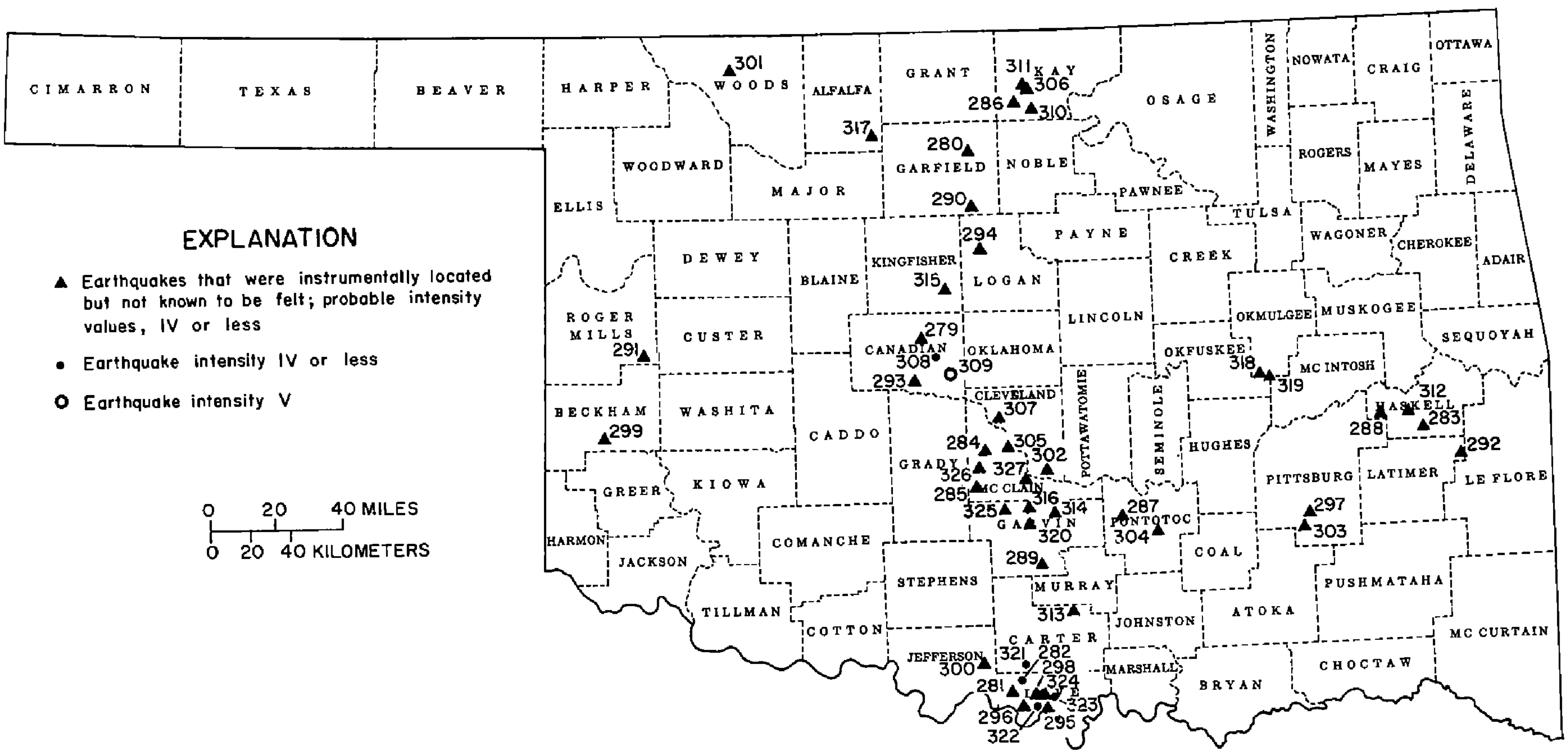

Figure 2. Distribution of Oklahoma earthquakes for 1980. Numbers correspond to event numbers in table 3.

The felt areas for the above earthquakes are probably restricted to a few tens of square kilometers away from the epicentral location. The felt and observed effects of earthquakes are generally given values according to the Modified Mercalli intensity scale, which assigns a Roman numeral to each of 12 levels described by effects on humans, man-made constructions, or natural features (table 2).

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

I	Not felt except by a very few under especially favorable circumstances.
II	Felt only by a few persons at rest, especially on upper floors of buildings. Suspended objects may swing.
III	Felt quite noticeably indoors, especially on upper floors of buildings. Automobiles may rock slightly.
IV	During the day felt indoors by many, outdoors by few. At night some awakened. Dishes, doors, windows disturbed. Automobiles rocked noticeably.
V	Felt by nearly everyone, many awakened. Some dishes, windows, etc. broken; unstable objects overturned. Pendulum clocks may stop.
VI	Felt by all; many frightened and run outdoors.
VII	Everybody runs outdoors. Damage negligible in buildings of good design and construction. Shock noticed by persons driving automobiles.
VIII	Damage slight in specially designed structures; considerable in ordinary substantial buildings; great in poorly built structures. Fall of chimneys, stacks, columns. Persons driving automobiles disturbed.
IX	Damage considerable even in specially designed structures; well-designed frame structures thrown out of plumb. Buildings shifted off foundations. Ground cracked conspicuously.
X	Some well-built wooden structures destroyed; ground badly cracked, rails bent. Landslides and shifting of sand and mud.
XI	Few if any (masonry) structures remain standing. Broad fissures in ground.
XII	Damage total. Waves seen on ground surfaces.

Eleven earthquakes occurred in a 35 kilometer-wide zone that extends between Norman and Maysville, through Cleveland, McClain, and northern Garvin Counties. Most of these earthquakes had magnitude values between 1.8 and 2.2 mbLg. Only four earthquakes were located in Canadian County in 1980. Of these, one earthquake near Yukon and one earthquake near Mustang were felt. The Mustang event, the largest 1980 earthquake, had an MM V intensity and a magnitude of 3.0 (mbLg). Nine earthquakes occurred in the Love and Carter County region. Of these, four were reported felt.

The 1980 earthquake epicentral data, when combined with previous earthquake data, produced at least four seismic trends worthy of discussion.

One trend is located in north-central Oklahoma (fig. 3). The pre-1977 earthquake data (circles) and the 1977–80 earthquake data (triangles) are shown in figure 3. There appears to be a 40-km-wide and 145-km-long earthquake zone that extends northeastward from near El Reno toward Perry (Noble County). Most of the earthquakes within this zone have occurred in the vicinity of the El Reno–Mustang area, which has been the site of numerous earthquakes since 1908. Six of the 1980 earthquakes plot within this zone. Prior to installation of the statewide earthquake-station network, more than one-half of the known Oklahoma earthquakes occurred in the vicinity of El Reno. However, after the El Reno earthquake of 1952, magnitude 5.5 (mb), no earthquakes were reported for this region until 1978.

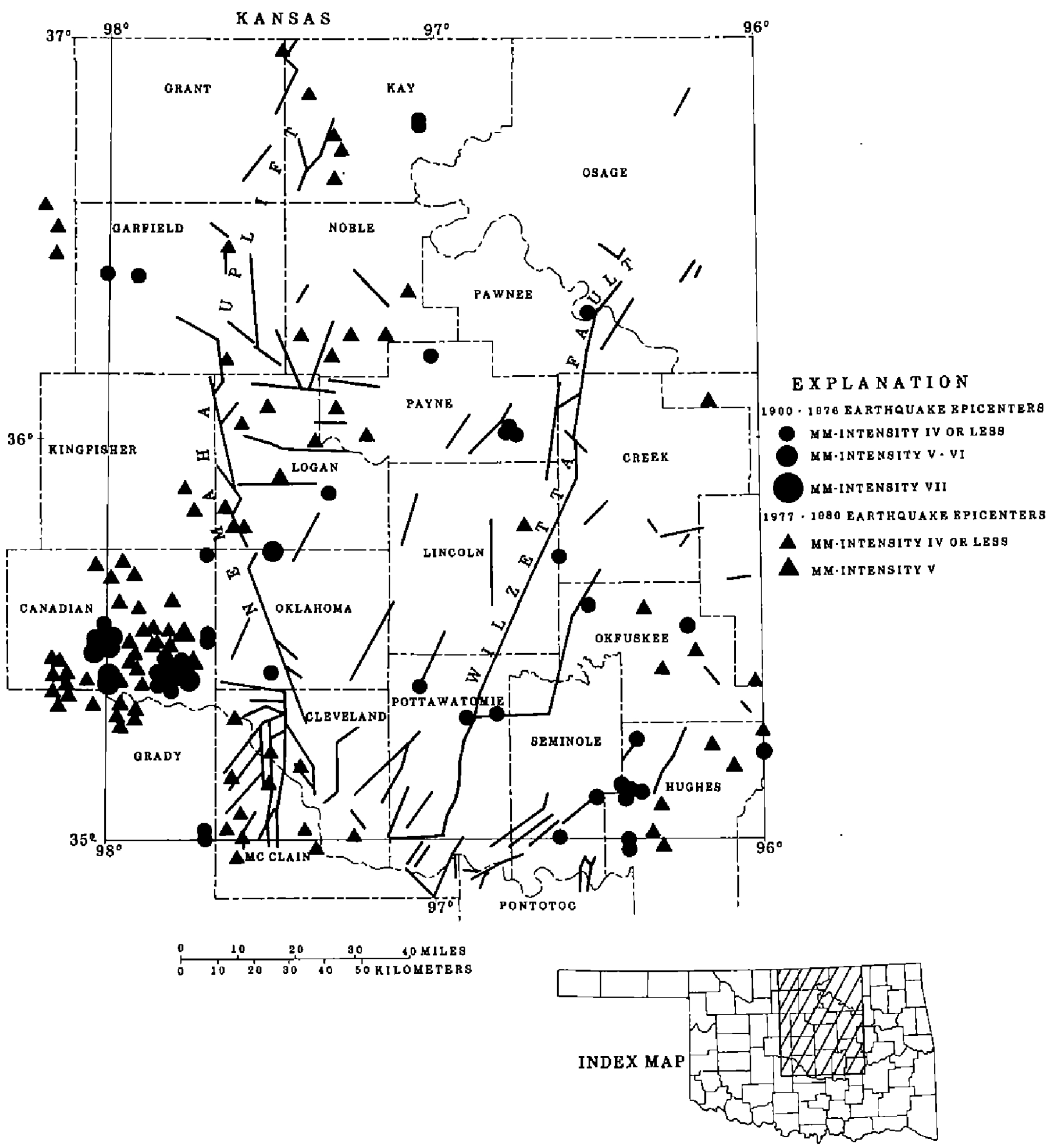

Figure 3. Distribution of faults that cut pre-Pennsylvanian strata, and earthquake epicenters for north-central Oklahoma (Wheeler, 1960; Jordan, 1962; unpublished reports).

The correlation of historical and recent earthquake activity to known structural features remains unclear. Some fault features that cut pre-Pennsylvanian rocks, which are compiled from Jordan (1962), Wheeler (1960), and unpublished reports, are shown in figure 3. The El Reno–Perry trend appears to cut diagonally across the Nemaha Uplift structures at about a 30° angle. The southern end of this trend appears to be more active than the middle and northern parts. The recent as well as the historic earthquake data seem to support this observation. A three-seismograph-station array was installed in December of 1980 southeast of El Reno. It is hoped that additional earthquake data, such as focal-depth determinations, will give us a better understanding of this feature.

A second trend is situated between Norman and Pauls Valley. Eleven earthquakes were instrumentally located in this region. This trend closely parallels the McClain County fault zone which is about 40 km wide and 60 km long. Perhaps this very complex fault zone, which contains numerous subparallel faults, is the southernmost extension of the Nemaha Uplift.

In south-central Oklahoma, earthquakes are concentrated in the Wilson area, Carter and Love Counties. Nine earthquakes, of which four were felt, were located in this region in 1980. In the past, this area has also been the site of numerous small earthquakes. A fourth general area of earthquake activity is located along and north of the Ouachita front (Arkoma Basin) in southeastern Oklahoma. Eight earthquakes, with (DUR) magnitudes that range from 1.4 to 2.7, were instrumentally detected in this region.

Catalog

An HP-9825T desk-top computer system is used to calculate local earthquake epicenters. A catalog containing date, origin time, county, intensity, magnitude, location, focal depth, and references is printed in page-size format. Table 3 contains 1979 Oklahoma earthquakes 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).

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 3 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 from 11 km to 222 km from a seismograph station, Otto Nuttli developed the m3Hz magnitude scale (Zollweg,

TABLE 3.—OKLAHOMA EARTHQUAKE CATALOG FOR 1980

Event number	Date and origin time (UTC)		County	Intensity (MM)	Magnitudes 3Hz	bLg	DUR	Latitude (°N.)	Longitude (°W.)	Depth (km)[1]
279	JAN 5	071131.21	CANADIAN		1.9	1.7	1.7	35.586	97.894	5.0R
280	JAN 12	071256.45	GARFIELD		1.7		1.4	36.453	97.642	5.0R
281	FEB 3	004630.05	LOVE		2.2	1.9	2.0	33.994	97.463	5.0R
282	FEB 5	043235.45	LOVE	3	2.1	2.3	1.9	34.046	97.451	5.0R
283	MAR 9	035710.56	HASKELL		1.2	1.4	1.4	35.100	95.100	5.0R
284	MAR 17	140231.21	MC CLAIN		2.3	2.2	1.9	35.047	97.566	5.0R
285	MAR 19	225057.93	MC CLAIN		2.4	2.4	2.0	34.980	97.644	5.0R
286	MAR 23	074901.56	KAY			1.4	1.4	36.655	97.391	5.0R
287	APR 1	211632.26	PONTOTOC		1.9	1.8	1.8	34.726	96.762	5.0R
288	APR 8	191806.93	HASKELL		2.1		2.1	35.165	95.301	5.0R
289	APR 29	195951.18	GARVIN		2.0	2.4	1.8	34.578	97.285	5.0R
290	MAY 28	040545.65	GARFIELD		1.8			36.168	97.602	5.0R
291	MAY 30	074402.72	ROGER MILLS		3.0	2.6	2.5	35.512	99.390	5.0R
292	JUN 3	214150.31	LATIMER		2.3	2.1	1.7	35.000	94.932	5.0R
293	JUN 6	013127.86	CANADIAN		2.6	2.3	2.2	35.402	97.983	5.0R
294	JUN 6	031812.45	LOGAN		1.5			36.039	97.570	5.0R
295	JUN 8	233334.30	LOVE		2.1	1.9	1.7	33.940	97.323	5.0R
296	JUN 9	055042.20	LOVE			1.8	1.4	33.940	97.417	5.0R
297	JUN 15	125051.95	PITTSBURG				1.2	34.728	95.778	5.0R
298	JUL 8	013444.01	LOVE		2.3	2.5	2.4	34.002	97.354	5.0R
299	JUL 18	142946.88	BECKHAM			3.2	2.8	35.180	99.698	5.0R
300	AUG 5	171332.96	JEFFERSON				2.2	34.096	97.588	5.0R
301	AUG 10	101002.58	WOODS		2.3	2.2		36.843	98.871	5.0R
302	SEP 7	015014.23	CLEVELAND		1.9		2.2	34.953	97.258	5.0R
303	SEP 7	080620.87	PITTSBURG		1.6	1.4	1.8	34.680	95.840	5.0R
304	OCT 4	090220.56	PONTOTOC		2.2	1.8	2.1	34.694	96.612	5.0R
305	OCT 8	083305.97	MC CLAIN		1.9	1.9	2.1	35.084	97.405	5.0R
306	OCT 21	090255.01	KAY		1.7	0.9		36.707	97.318	5.0R
307	OCT 28	050304.99	CLEVELAND		1.7	1.8	1.8	35.225	97.495	5.0R
308	NOV 1	052613.85	CANADIAN	3	1.9	2.0	2.0	35.472	97.836	7.5R
309	NOV 2	100049.03	CANADIAN	5	3.0	3.0	2.8	35.429	97.777	7.5R
310	NOV 7	004633.07	KAY		2.1	1.7	2.0	36.638	97.326	5.0R
311	NOV 7	005011.34	KAY		1.7	1.6	1.7	36.716	97.326	5.0R
312	NOV 13	002339.10	HASKELL		1.5		1.7	35.196	95.235	5.0R
313	NOV 13	235548.18	CARTER		1.8	1.8	1.8	34.367	97.077	5.0R
314	NOV 15	120659.08	GARVIN		1.7	1.8	1.7	34.820	97.187	5.0R
315	NOV 20	095039.73	KINGFISHER		1.5		1.6	35.871	97.733	5.0R
316	NOV 21	102553.61	GARVIN		1.9	1.9	1.9	34.857	97.359	5.0R
317	NOV 22	033410.24	ALFALFA		2.3	1.8	2.1	36.527	98.146	10.1
318	NOV 22	193502.77	OKMULGEE		2.7	2.5	2.7	35.379	95.995	5.0R
319	NOV 22	200430.13	OKMULGEE		1.8	1.4	1.7	35.356	95.987	5.0R
320	NOV 30	234401.99	GARVIN		2.3	1.8	2.2	34.795	97.360	5.0R
321	DEC 4	012316.96	CARTER	F	1.9	1.8	1.7	34.096	97.401	5.0R
322	DEC 4	234843.22	LOVE	F	2.1		2.1	33.942	97.352	5.0R
323	DEC 5	000726.29	LOVE	F	2.6	2.4	2.4	33.909	97.284	5.0R
324	DEC 5	095323.98	LOVE		2.2	2.0	2.0	34.002	97.323	5.0R
325	DEC 17	124945.46	GARVIN		2.8	2.9	2.8	34.855	97.464	5.0R
326	DEC 21	140555.45	MC CLAIN		2.2	2.1	2.2	35.017	97.592	5.0R
327	DEC 30	151752.59	MC CLAIN		1.8		1.7	34.953	97.362	5.0R

1974). This magnitude is derived from the following expression:

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

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

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

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

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

$$mbLG = \log(A/T) - 3.10 + 1.66\log(\Delta),$$

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

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

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

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. If the Pn wave is the first arrival, the interval between the earthquake-origin time and the decrease of the coda to twice the background-noise amplitude is measured instead.

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

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

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WATT NAMES MANKIN TO COMMISSION

Secretary of the Interior James G. Watt has named Charles J. Mankin to a five-member blue-ribbon commission charged with the investigation of accounting systems used to collect the billions of dollars paid annually for federal oil and mineral royalties.

Mankin, director of the Oklahoma Geological Survey and the OU Energy Resources Center, will be on the panel along with retired U.S. comptroller general Elmer Staats; Houston oilman Michel Halbouty; David F. Linowes, founder of Leopold and Linowes national accounting firm; and Mary Gardiner Jones, vice-president with Western Union. Jones was formerly a commissioner for the Federal Trade Commission.

Problems with royalty accounting procedures have resulted in allegations that the federal government is now losing millions of dollars due it each year from various oil and mineral royalty agreements.

"The allegations suggest that several hundred million dollars annually aren't being collected," Mankin said. "If this is true, the amount could grow substantially in the next several years if the problem is not corrected."

Mankin said that, along with meetings of the committee, four or five public hearings will be held in an attempt to obtain more information on the royalty-collection process.

"I think it is a do-able task, but not an easy job because it is a complicated issue. I can anticipate there is no single solution—and that makes it difficult."

The panel will examine a new accounting system being proposed by the U.S. Geological Survey, the agency in charge of royalty collection for public and some Indian lands.

"Last year, the USGS collected over $4 billion in royalty income. A decade ago, that was on the order of *millions* of dollars annually," Mankin noted.

"Over a period of a very few years, this income has increased in both dollar amount and volume of business."

The outdated and understaffed system of collection is now becoming unable to keep up with the flow of paperwork, statistics, and money, he said.

Besides investigating the losses and updating the accounting system itself, the committee will also study allegations of actual physical theft of oil from federal lands.

The committee is expected to report to secretary Watt by January of 1982, Mankin said.

L. R. WILSON AWARD ANNOUNCED

Because of the generosity of OU professor emeritus Dr. Leonard R. Wilson, the American Association of Stratigraphic Palynologists (AASP) Outstanding Student Paper award will now include a substantial cash award. The award, which will henceforth be known as the "L. R. Wilson Award," will also include an inscribed plaque as well as 2-years free membership in AASP.

The monetary part of the award will be drawn from the interest generated from a $3000 donation made to AASP by Dr. Wilson. The amount anticipated to be available for the award is approximately $300. The AASP expects this amount to be exceeded in the coming years.

Papers authored and presented by students at the 1981 annual AASP meeting in New Orleans will be eligible for this award.

The L. R. Wilson Award will be in recognition of, and thus should help to encourage, the highest level of professional accomplishment by students in conducting and presenting the results of their research in palynology.

Students wishing to compete for this award can request more information from Dr. Robert T. Clarke, Mobil Research and Development Corp., Research Lab, P. O. Box 900, Dallas TX 75221.

NEW FLOOD-PRONE AREA MAPS ISSUED

The U.S. Geological Survey has released 13 new maps designating areas in Oklahoma that are susceptible to flooding. The maps are based on 7.5-minute USGS topographic quadrangle maps, i.e., at a scale of 1:24,000, with flood boundaries delineated on the basis of data obtained from information on past floods.

Over half of Oklahoma is now covered by these flood-prone area maps, with new quadrangles mapped including: Carney, Cogar Northeast, Fort Reno, Fort Reno Northeast, Fort Reno Southwest, Foyil, Pearson, Perkins, Pocasset, Porcupine Butte, St. Louis, Tate Mountain, and Wolf.

Copies of these maps and an index map indicating which quadrangles are completed are available for inspection at the Oklahoma Geological Survey. Maps can be obtained free on request as available from the U.S. Geological Survey, Water Resources Division, Room 621, 215 Dean A. McGee Avenue, Oklahoma City, OK 73102.

IRRIGATED-CROPLAND MAPS AVAILABLE

Maps showing irrigated cropland in 15 counties in eight states of the High Plains aquifer region, stretching from South Dakota to New Mexico, have been prepared by the U.S. Geological Survey, Department of the Interior.

The maps are part of a five-year project started in 1978 by the USGS to develop a ground-water-flow computer model of the Ogallala aquifer and associated water-bearing sediments that underlie about 177,000 square miles of the High Plains region. Once developed, the model can be used to evaluate alternative ground-water-management methods and proposals in the region.

Ground-water levels have been falling in most parts of the region since pumping for irrigation of farm lands began increasing shortly after World War II. Most of the irrigation water is being pumped from the Ogallala aquifer.

The nine irrigated-cropland maps, showing 15 counties, depict Cherry County, Nebraska; Chase, Dundy and Perkins Counties, Nebraska; Todd County, South Dakota; Cheyenne and Sherman Counties, Kansas; Laramie County, Wyoming; Kit Carson, Phillips and Yuma Counties, Colorado; Texas County, Oklahoma; Hockley and Lamb Counties, Texas; and Curry County, New Mexico.

Copies of the maps of the counties in Wyoming, Colorado, New Mexico and Texas may be purchased from the Rocky Mountain National Cartographic Information Center, U.S. Geological Survey, Box 25046, Federal Center, Mail Stop 504, Denver, CO 80225, telephone (303) 234-2326. The Open-File Report identification numbers are 80-638 for Laramie County, Wyoming; 80-639 for Kit Carson, Phillips and Yuma Counties, Colorado; 80-169 for Curry County, New Mexico; and 80-168 for Hockley and Lamb Counties, Texas.

Copies of the maps of the counties in South Dakota, Nebraska, Kansas and Oklahoma may be purchased from the Mid-Continent National Cartographic Information Center, U.S. Geological Survey, 1400 Independence Road, Rolla, MO 65401, telephone (314) 341-0851. The Open-File Report identification numbers are 79-1627 for Todd County, South Dakota; 79-1626 for Cherry County, Nebraska; 80-641 for Chase, Dundy and Perkins Counties, Nebraska; 80-640 for Cheyenne and Sherman Counties, Kansas; and 80-170 for Texas County, Oklahoma.

Prices: $2.25, paper copy; $12.50 film diazo copy; $26 stable-base-film-positive copy. Orders must specify map identification number and include checks or money orders payable to the U.S. Geological Survey.

WATER-DATA REPORTS PUBLISHED BY USGS

Two new statistical reports on water resources in Oklahoma for water year 1979 have been issued by the U.S. Geological Survey. The data are presented in two volumes, with the first covering the quantity and quality of surface and subsurface waters in the Arkansas River Basin and the second offering similar detailed information for the Red River Basin. The streams, lakes, and ground water of the entire State are contained in these two river basins, which are considered to be parts of the larger Lower Mississippi River Basin.

The reports, U.S. Geological Survey Water-Data Report OK–79-1, *Water Resources Data for Oklahoma, Volume 1. Arkansas River Basin,* and *U.S. Geological Survey Water-Data for Oklahoma, Volume 2. Red River Basin,* can be purchased from the National Technical Information Service, Springfield, VA 22161. A limited number of copies are available free on request from the U.S. Geological Survey, Water Resources Division, Room 621, 215 Dean A. McGee Avenue, Oklahoma City, OK 73102.

NEW THESES ADDED TO OU GEOLOGY LIBRARY

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

Strain Analysis of a Low Amplitude Fold in North-Central Oklahoma Using Calcite Twin Lamellae, by Carla Maria Gasteiger. 90 p., 21 figs., 1980.

Correlation of Landsat Lineaments with Geologic Structures, North-Central Oklahoma, by Robert C. Shoup. 123 p., 27 figs., 5 plates, 1980.

An Explanation for the Lineation in Production on the Southern Portion of the Central Oklahoma Platform, by Timothy J. Nagengast. 90 p., 18 figs., 13 plates, 1981.

NOTES ON NEW PUBLICATIONS

Nonmarine Depositional Environments: Models for Exploration

This recent publication by the Society of Economic Paleontologists and Mineralogists (SEPM) contains the results from a symposium sponsored by the SEPM Rocky Mountain Section as well as results of recent studies on nonmarine depositional environments with emphasis on applications to uranium, coal, oil and gas, and ground water exploration and environmental concerns.

The book, which covers the geologic range from Paleozoic to Holocene, contains 19 papers by 32 authors.

Order from: SEPM, P.O. Box 4756, Tulsa, OK 74104. Price: $20 to AAPG and SEPM members, $25 to non-members. Tulsa orders add 5 percent. Add 2 percent for other Oklahoma orders.

When the Earth Moves

The U.S. Geological Survey has recently released "When the Earth Moves"—a new film on natural hazards. This color-sound motion picture describes such hazards as earthquakes, floods, and landslides, and relates some of the methods now being practiced to avoid or lessen their destructive impact on the United States.

The film uses animation and film footage of actual events to describe the hazards and associated dangers. In addition, case studies show how appropriate land-use, engineering techniques, and building regulations can reduce harmful effects to lives and property. Interviews with planners, government officials, engineers, geologists, and community residents emphasize the importance of making earth-science information available to the public.

"When the Earth Moves" is intended for a broad audience, which might include land-use planners, government officials, and members of the building industry, as well as students and teachers from intermediate through college levels and the general public.

"When the Earth Moves" is available for short-term loan, free of charge, or may be purchased by writing to: Modern Talking Picture Service, Inc., 5000 Park Street, North, St. Petersburg, FL 33709.

Geology and Recognition Criteria for Sandstone Uranium Deposits of the Salt Wash Type, Colorado Plateau Province

The authors of this report are: John K. Thamm, of Thamm, Mickle & Co., Grand Junction, Colorado; Anthony A. Kovschak, Jr., Union Carbide Corp., Grand Junction; and Samuel S. Adams, Samuel S. Adams & Associates, Boulder, Colorado. They state that the difference between Salt Wash deposits and other sandstone uranium deposits are significant but have been underemphasized by many investigators. The Salt Wash deposits are unique among sandstone deposits in that they are dominantly vanadium deposits with accessory uranium. The main objective of this study has been to identify the geologic characteristics, or recognition criteria, that are most diagnostic for the occurrence of Salt Wash-type vanadium/uranium deposits, for use in exploration and resource studies.

Order report number GJBX-6(81) from: Bendix Field Engineering Corp., P.O. Box 1569, Grand Junction CO 81502.

Price: $3.50 microfiche, $5 printed. Add $2 per report to cover postage.

Offshore Geologic Hazards

This short course, coordinated by Arnold Bouma, covers slope stability, foundation mechanics, and the problems of submarine siting. The course notes volume contains 504 plates.

Order from: AAPG, P.O. Box 979, Tulsa, OK 74101. The catalog number is 892. Price: $12; $10 for 10 or more copies.

Sample Examination Manual

Roger G. Swanson, of the Shell Company Exploration Training Department, is the author of this new manual which explains how to take samples, shows different techniques for examining them, and provides a standardized lithologic legend for sample description.

The *Sample Examination Manual* is available from: AAPG, P.O. Box 979, Tulsa, OK 74101. The catalog number is N. 603. Price: $18 members, $22 nonmembers.

Geothermics: Use of Temperature in Hydrocarbon Exploration

Author Peter Gretener stresses an understanding of temperature and thermal gradients and their application to petroleum exploration in this course notes publication of 164 pages.

Order from: AAPG, P.O. Box 979, Tulsa, OK 74101. The catalog number is 891. Price: $8; $7 per copy for orders of 10 or more.

Organic Geochemistry for Exploration Geologists

Douglas W. Waples' recent publication provides essential information for professionals in the field.

Background information for those with little or no knowledge of organic geochemistry is provided in the first chapter. The author proceeds with descriptions of the composition of specific fossil fuels, the formation and migration of oil and gas, and evaluation of samples and data acquired. The text also includes data interpretation problems and solutions to give the reader an opportunity to apply the theoretical concepts examined in the book.

Order from: CEPCO Division—Burgess Publishing Co., 7108 Ohms Lane, Minneapolis, MN 55435. Price: $21.95 cloth, $17.95 paper.

Deltas: Processes and Models for Exploration

This monograph is used by author James M. Coleman to accompany his popular short courses given to oil companies, government agencies, and professional societies.

The book covers deltaic processes, characteristics of deltaic subenvironments, and the variability of deltaic facies. An important feature of the new second edition is the updated section on the subaqueous portion of deltaic facies.

Order from: CEPCO Division—Burgess Publishing Co., 7108 Ohms Lane, Minneapolis MN 55435. Price: $21.95 cloth, $16.95 paper.

Geology and Recognition Criteria for Sandstone Uranium Deposits in Mixed Fluvial-Shallow Marine Sedimentary Sequences, South Texas

This report was authored by Samuel S. Adams, Samuel S. Adams and Associates, Boulder, Colorado; and R. B. Smith, R. B. Smith and Associates, Austin, Texas. The authors conclude that the uranium deposits in south Texas are classical roll-type deposits that formed at the margins of tongues of altered sandstone by the encroachment of oxidizing, uraniferous solutions into reduced aquifers containing pyrite and, in a few cases, carbonaceous plant material.

Order from: Bendix Field Engineering Corp., P.O. Box 1569, Grand Junction, CO 81502. Ask for report GJBX-4(81). Price: $5.50 microfiche, $13 printed. Add $2 per report to cover postage.

Geology and Recognition Criteria for Vein-Like Uranium Deposits of the Lower to Middle Proterozoic Unconformity and Strata Related Types

The authors of this report are: Franz J. Dahlcamp, consulting geologist, Bonn, West Germany; and Samuel S. Adams, Samuel S. Adams and Associates, Boulder, CO. The report reviews the geology, genesis and controls of the Lower to Middle Proterozoic vein-like uranium deposits for the purpose of identifying those geologic observations, or recognition criteria, which seem most useful for the evaluation of areas with potential new deposits.

Order report GJBX-5(81) from: Bendix Field Engineering Corp., P.O. Box 1569, Grand Junction CO 81502. Price: $5.50 microfiche, $16 printed. Add $2 per report to cover postage.

Directory of the Geologic Division, U.S. Geological Survey

Available from the AGI, this directory gives addresses, phone numbers, current projects, and research specialties for personnel in Reston, Flagstaff, Denver, Menlo Park, and other localities.

Order from: American Geological Institute, 5205 Leesburg Pike, Falls Church, VA 22041. Price: $6.

International Petroleum Encyclopedia 1981

This new, 14th edition was prepared by representatives from the staffs of *Oil and Gas Journal*, *Offshore*, and *Petroleo Internacional*. The encyclopedia provides maps and information on petroleum operations worldwide as well as information on new areas of exploration, petrochemicals, and synthetic fuels.

Order from: Pennwell Publishing Co., IPE/81, P.O. Box 1260, Tulsa, OK 74101. Price: $52.50.

Irrigated Cropland, 1978, Texas County, Oklahoma

The cultural-base component of this map, by Bruce Wright, was derived from parts of the USGS Dalhart (NJ 12–13) and Perryton (NJ 14–10) 1:250,000-scale topographic maps.

For information on price and availability, write to: USGS Mid-Continent Mapping Center, 1400 Independence Road, Rolla, Missouri 65401.

ZINC-MINE WATER EXAMINED

A study of the *Chemical Quality of Water in Abandoned Zinc Mines in Northeastern Oklahoma and Southeastern Kansas* has been completed by the U.S. Geological Survey's Water Resources Division in cooperation with the Oklahoma Geological Survey, and results of the investigation have been issued by the OGS as Circular 82. The authors of the report are Stephen J. Playton and Robert E. Davis, hydrologists with the USGS, and Roger G. McClaflin, USGS hydrologic technician.

The study area lies in northern Ottawa County, Oklahoma, and Cherokee County, Kansas, where increasing demands for water have resulted in decreased water levels in the over-pumped aquifers of the Ordovician-age Roubidoux Formation. However, water in the abandoned zinc mines of the Tri-State area of Oklahoma, Kansas, and Missouri—which at one time accounted for more than half the total zinc production of the United States—has been rising rapidly since exhaustion of the deposits of zinc and lead. By mid-1976 the mines contained an estimated 100,000 acre-feet of water. This figure represented an average rise of 1.5 feet per month. The water from the Mississippian-age Boone Formation appeared to hold great potential for an alternative source of water. It was essential, however, to determine the quality of this supply.

Playton, Davis, and McClaflin conducted a water-sampling program from seven mine shafts over a period of more than a year, and samples were analyzed for physical properties and chemical constituents. Results of these analyses are shown in 19 tables in the circular.

The authors concluded that their analyses show water in the mine shafts to be unsuitable for public supply, for irrigation, or for industrial cooling without treatment. In their report, they state that even when treated, "The inability of current domestic water-treatment practices to remove toxic metals, such as cadmium and lead, precludes use of the water for a public supply."

OGS Circular 82 can be obtained from the Oklahoma Geological Survey at the address given inside the front cover. The price is $9 for a hardbound copy or $5 for a paperbound copy.

OKLAHOMA ABSTRACTS

GSA Annual Meeting, North-Central Section
Ames, Iowa, April 30–May 1, 1981

The following abstracts are reprinted from Abstracts with Programs of The Geological Society of America, v. 13, no. 6. Page numbers are given in brackets below the abstracts. Permission of the authors and of John C. Frye, executive director of GSA, to reproduce the abstracts is gratefully acknowledged.

Conodont- and Ammonoid-Based Correlations of the Mississippian–Pennsylvanian Boundary in North America with the Namurian of Europe

J. F. BAESEMANN and H. R. LANE, Research Center, Amoco Production Company, P.O. Box 591, Tulsa, Oklahoma 74102

Correlation of late Mississippian–early Pennsylvanian strata in North America with their European Namurian counterparts has been based on ammonoid sequences in Arkansas and the British Isles, even though they have no species in common. The Arkansas succession has been interpreted to be less complete than the British, having a major break at the Mississippian–Pennsylvanian contact that includes the Chokierian and Alportian Stages. This interpretation places the base of the Pennsylvanian in Arkansas at or near the base of the Kinderscoutian of Britain. Incorporation of conodont occurrences into this framework requires discordant ranges for species common to North America and Europe. For example, it requires the oldest occurrence of *Neognathodus symmetricus* in Europe to correlate with the base of the Pennsylvanian, a much earlier occurrence than is known in North America. *Rhachistognathus primus* and *R. muricatus*, important in North America, have not been found in Europe. The assumption is that they are restricted to North America. These differences vanish, however, if the European succession has a major hiatus separating the Arnsbergian and Chokierian. This hiatus is equivalent to at least part of the late Mississippian *unicornis* and *muricatus* Zones, the early Pennsylvanian *primus* Zone and part or all of the *sinuatus* Zone. Our studies of the genera

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

Rhachistognathus, Declinognathodes, Idiognathoides and *Neognathodus* show that *R. minutus*, a cryptogen that occurs at the base of the Chokierian in Europe, appears in a phyletic sequence near the top of the *primus* Zone in North America. Palynologic information from both regions reinforces our conclusions. [270]

Integrated Analyses and Preliminary Interpretations of Uppermost Cherokee Rocks (Desmoinesian) in Eastern Kansas

ROBERT L. BRENNER, Department of Geology, The University of Iowa, Iowa City, Iowa 52242

Uppermost Cherokee rocks above the widespread Verdigris Limestone in Eastern Kansas form a genetic package consisting of irregularly distributed lenses of sandstone in a sequence containing mudrocks, coals and thin limestones. Both the bounding Verdigris Limestone at its base and the basal beds of the Ft. Scott Limestone at its top are recognizable in surface exposures and in geophysical well-logs. Data used in this study include: 1) outcrops in Crawford, Cherokee and Labette Counties, Kansas and Craig County, Oklahoma; and 2) core and geophysical well-log data from Kansas counties east of the Nemaha Uplift. Well-logs were collected from a grid of wells in order to provide a three-dimensional stratigraphic and sedimentologic framework. Outcrop lithologic relations were used along with core data to determine the well-log signatures of various lithologies. Sandstone bodies in the lower-to-middle portion of the package appear to have channel affinities and may represent fluvial and/or deltaic distributary channel systems. Sandstone units in the upper portion of the package also have abrupt bases, but appear to be more marine in nature and may represent delta-front deposition. Future work in this area will delineate more precisely the distributions and characteristics of sandstone units within the uppermost Cherokee as well as evaluate their reservoir characteristics. In addition, the diagenetic histories of lithic facies will be determined through the use of various petrographic techniques. The combining of stratigraphical, sedimentological, geophysical and petrological information will yield a geologic model from which evaluations of petroleum, coal and water resources can be made. [272]

The Tectonic History of the Transcontinental Arch and Nemaha Uplift and their Relationship to the Cretaceous Rocks of the Central Midcontinent Region

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Laramide tectonism has modified the original depositional fabric of Cretaceous rocks in the northern Great Plains states. Studies of the Phanerozoic history of many of the tectonic features in the midcontinent region show that they have experienced episodic deformation since the Precambrian. These periods of tectonic activity correspond with regional cratonic unconformities as defined by Sloss (1963). Laramide orogenic events reactivated many of these

older midcontinent features that were active during the Paleozoic. The Nemaha Uplift of southeast Nebraska and northeast Kansas has shown a history of recurrent activity, having had its origins in pre-Middle Ordovician time (Southeast Nebraska Arch). Structural mapping of the Greenhorn Limestone in the central midcontinent indicates that Laramide orogenic events reactivated the Nemaha Uplift. Overstepping of Tertiary sediments on regionally truncated Cretaceous rocks can be recognized in eastern Nebraska and northwestern Iowa as the crest of the Nemaha Uplift is approached. [272]

Distribution and Significance of Allochthonous Conodonts in Early Pennsylvanian Rocks of Eastern Oklahoma

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Allochthonous conodonts ranging from Ordovician through earliest Pennsylvanian age occur in Lower Pennsylvanian rocks exposed in south-central Oklahoma. The exposures from the south toward the northeast are located in the Ardmore Basin, Mill Creek Syncline and Arkoma Basin. The geographic and stratigraphic distribution of allochthonous condonts reflect late Paleozoic deformation resulting from continent-continent collision. The Ardmore Basin sequence contains abundant reworked Ordovician to earliest Pennsylvanian-aged conodonts in rocks ranging from middle Morrowan (*Neognathodus symmetricus* Zone) to late Atokan (*Idiognathoides noduliferus* Zone) age. The Arkoma Basin, Atoka Formation, contains reworked Mississippian (Chesterian) through earliest Pennsylvanian (Morrowan) species in a narrow interval of late Atokan age (*Idiognathoides noduliferus* Zone). The Mill Creek sequence produces a reworked fauna that consists entirely of earliest Morrowan conodonts also from a single zone (*Diplognathodus orphanus*) of latest Morrowan or earliest Atokan age. This distributional pattern suggests that deformation began in the Ardmore Basin area in middle Morrowan time and migrated northeastward toward Mill Creek and the Arkoma Basin while decreasing in intensity from latest Morrowan to Atokan time. [279]

New Evidence Concerning the Structural Framework of the Arkoma Basin

JOHN H. MC BRIDE, Department of the Geophysical Sciences, University of Chicago, Chicago, Illinois 60637

An analysis and geologic interpretation of potential field (gravity and magnetic) data provide a better understanding of the relation of surface structural geology to the igneous basement configuration of the Arkoma basin of Northwest Arkansas. The deduced subsurface nature of large scale photolineaments gives new insight into their genetic association with Arkoma basin tectonics. Gross basin geometry can also be quantitatively described from potential field data.

Major east-trending normal faults, which characterize the Arkoma basin on the north, are found to be geometrically related to steeply dipping basement faults having a significant amount of displacement. From potential field modeling, basement graben structures are concluded to be associated with some of the major basin faults. Such structural features presumably developed from tensional forces as the basin subsided and the Ozark dome remained positive. In some cases, the axial traces of folds are parallel to and closely associated with the strike lines of major normal faults. This configuration could well have originated from the compaction of Atoka sediment on the downthrown side of large basement fault blocks in response to northward-directed compressional forces provided by the Ouachita orogeny. Gravity data also indicate that certain anticlines correlate well with horsts in the lower part of the sedimentary section. Photo-lineaments are shown to be related to Precambrian basement fracture zones which are superimposed on the local system of deformation, suggesting that they are not necessarily associated with stresses that formed the basin. Finally, potential field evidence is presented for a basement surface sloping southward at a regional dip of approximately 3°. [309]

Lower Permian (Wolfcampian) Crinoids from the North American Midcontinent

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Recent field work has yielded important assemblages of inadunate crinoids from Nebraska, Kansas, Oklahoma, and Texas, that show strong provincialism. The Nebraska–Kansas fauna is characterized by a blothrocrinid–pachylocrinid assemblage; the Oklahoma province contains a catacrinid–stellarocrinid assemblage; and the Texas province contains a pirasocrinid–catacrinid assemblage. These faunas contrast sharply with Wolfcampian crinoids from Nevada reported by Lane and Webster (1966) which contain large numbers of cromyocrinids.

In Nebraska and Kansas, crinoids from the Hughes Creek Shale member (Foraker Formation) are associated with the fusulinid *Triticites secalicus* and crinoids from the Grant Shale occur about 35 meters above the highest known occurrence of *T. ventricosus* in the Florena Limestone. In Texas, crinoids in the Thrifty Formation occur with *Schubertella* and *Triticites; Schwagerina* first appears in the Waldrup No. 2 Limestone; and *Pseudoschwagerina* first occurs in the Santa Anna Shale (Moran Formation).

Crinoids in the Watts Creek Shale (Moran Formation) and the Camp Creek Shale (Pueblo Formation) in Texas occur with the ammonoid, *Artinskia;* the Admiral Formation contains crinoids associated with the ammonoids *Metalegoceras, Properrinites, Akmilleria,* and *Almites;* and the Ivan Limestone (Thrifty Formation) has a crinoid fauna associated with the ammonoids *Schistoceras* and *Agathiceras.* [312]

Early and Middle Proterozoic Evolution of the Midcontinent Region of North America

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

The Proterozoic basement of the midcontinent consists of volcanic, metasedimentary, and plutonic rocks of varying age and composition. In the Great Lakes area the Penokean Orogeny occurred about 1820–1860 m.y. ago, followed by an extensive terrane of rhyolite and epizonal granite 1760 m.y. ago in southern Wisconsin. The Proterozoic basement of the southwestern U.S. represents two distinct periods of orogeny, 1690–1780 m.y. ago to the north and 1610–1680 m.y. ago to the south, but units of Penokean age are apparently absent. In the northern midcontinent the basement consists of gneissoid granitic rocks and small amounts of metasedimentary and metavolcanic rocks. Some of these may be coeval, perhaps correlative, with either the older terrane in the west or the Penokean terrane to the east (or both), but precise ages are lacking. Some of the plutonic rocks in Kansas and Missouri formed about 1625 m.y. ago and are coeval with younger plutons in Ariz. and N.M. Metamorphism of that age also occurs in the Penokean, indicating that the 1610–1680 m.y. activity extended that far east. A younger terrane of rhyolite and epizonal granite extends from Ohio across Ind., Ill., Mo., Kan., Okla., and into Texas. Most, if not all, of these rocks formed in two events, 1440–1490 and 1360–1400 m.y. ago, but precise ages are lacking east of the Mississippi R. To the south and east is the 1100 m.y. old Grenville terrane. [320]

AAPG–SEPM–EMD Annual Meeting
San Francisco, California, May 31–June 3, 1981

The following abstracts are reprinted from the May 1981 issue, v. 65, no. 5, of the *Bulletin* of the American Association of Petroleum Geologists. Page numbers are given in brackets below each abstract. Permission of the authors and of Myron K. Horn, AAPG editor, to reproduce the abstracts is gratefully acknowledged.

Uraniferous Pyrobitumens from Southwestern Oklahoma

SALMAN BLOCH, Oklahoma Geological Survey, Norman, OK; JOSEPH A. CURIALE and JANINA R. BLOCH, The University of Oklahoma, Norman, OK; and others

Pyrobitumen nodules from the northern flank of the Wichita Mountains, Kiowa County, Oklahoma, contain unusually high concentrations of uranium (2,235 to 10,112 ppm), while the thorium content is low (0.1 to 2.0 ppm). The nodules are surrounded by a halo of gray dolomitic siltstone in a

Permian (Hennessey Group) red dolomitic siltstone matrix. Microscopic examination indicates that the nodules consist of at least two phases of distinctly different reflectivity. Surprisingly, the uranium is associated with the low reflectance phase, in which it ranges up to 10% by weight.

Stable carbon isotope ratios of the uraniferous nodules show a consistent decrease from −31.2 ppt in the center of the nodule to −31.6 ppt at the outer edge (all values relative to PDB). This isotopic lightening at the edge of the nodule is also reflected in the surrounding siltstones. The carbon of the carbonate within the gray siltstone immediately surrounding the nodule is always lighter than that in the adjacent red siltstone by 0.3 to 0.8 ppt. Atomic H/C ratios of whole nodules average 0.83, while atomic O/C ratios of the nodules average 0.15, indicating that the nodules are extremely oxidized.

The presence of petroliferous rocks in the subsurface of the study area and zones of reduction along cracks and faults in the red siltstone suggest that the pyrobitumens are secondary, that is, alteration products of crude oil. This interpretation is further supported by microscopic examination revealing fracture-infilling by bituminous material. Finally, uranium was provided by ground waters rather than by concentration due to the oil-pyrobitumen transition. [903]

Petrologic Factors Controlling Internal Migration and Expulsion of Petroleum from Source Rocks: Woodford–Chattanooga of Oklahoma and Arkansas

J. B. COMER, The University of Tulsa, Tulsa, OK, and H. H. HINCH, Amoco Production Co., Tulsa, OK

Upper Devonian–Lower Mississippian Woodford–Chattanooga black shales are oil source beds throughout Oklahoma and much of western Arkansas. Diagenesis in the Woodford–Chattanooga source section proceeded through the following relative time sequence: (a) silicification, chiefly by recrystallization of radiolarians, which probably followed the reaction conversion of amorphous opal-A to opal-CT to chert; (b) dolomitization of deep-basin opal or chert and shallow-platform carbonate laminae; (c) tectonic faulting, folding, and associated fracturing and stylolitization predominantly associated with the late Paleozoic Arbuckle and Ouachita orogenesis; (d) late silicification and mineralization along fractures contemporaneous with (e) generation and expulsion of petroleum.

The principal expulsion mechanism for these Upper Devonian–Lower Mississippian oil source rocks is whole-oil migration through coarser grained matrix pores, stylolites, and fractures, rather than diffusion on a molecular scale. Diffusion migration does occur but appears only to affect internal migration over a few millimeters within the source rock, and thus cannot account for expulsion of large volumes of oil. Preliminary calculations based on source rock extract data indicate that approximately 147 billion bbl of oil have been generated within Woodford shales in the 23,000 sq mi (60,000 sq km) geographic area of southern and western Oklahoma underlain by the Woodford Formation. Minimum relative oil-expulsion efficiency appears to have been approximately 18 to 19% of the oil generated. Thus, at least 27 billion bbl of oil have been expelled from the Woodford into adjacent formations in southern and western Oklahoma while 120 billion bbl of oil remain unexpelled in the source rock. [912]

Origin and Geochemical Correlation of Near-Surface Oil and Asphaltite Deposits of Southeastern Oklahoma

JOSEPH A. CURIALE, The University of Oklahoma, Norman, OK

Three Oklahoma oils and six associated asphaltites were studied and found to have a common source, based on geologic and geochemical criteria. Bulk analyses reveal the following: (1) vanadium and nickel are enriched in the asphaltite relative to the oil by an average factor of 41, although the V/Ni ratio only ranges from 0.5 to 3.5 in most of these samples; (2) the average H/C atomic ratio decreases and the average O/C, N/C, and S/C atomic ratios increase significantly from oil to asphaltite; and (3) stable carbon isotope ratio values show that the ratio of ^{13}C to ^{12}C in the asphaltites is essentially the same as that in the oils, being approximately -29.8 ppt (relative to PDB) in almost all cases. These bulk analyses and analysis of isolated chemical fractions of these materials indicate that the asphaltites and oils are of common origin and have a similar temperature history. These data further indicate that asphaltite is a secondary product after oil and that biodegradation, accompanied by other near-surface effects, is the causal mechanism for asphaltite formation. This conclusion is supported by the geology of the region, insomuch as local listric faults could have served as conduits of migration, bringing deeper oil into the zone of near-surface alteration. [915]

Epigenetic Zoning in Surface and Near-Surface Rocks Resulting from Seepage-Induced Redox Gradients, Velma Oil Field, Oklahoma

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Surface and near-surface Permian sandstone has been drastically altered over the productive part of the structurally complex Velma oil field as a consequence of petroleum microseepage. Buried Permian sandstone along

the northwest-southeast-trending anticline is cemented with abundant pyrite and isotopically anomalous ferroan calcite and ferroan dolomite. At the surface along the anticlinal crest, iron sulfide is scarce; carbonate-cemented sandstone is overlain by sandstone that is massively impregnated by hematite cement. Permian sandstone is normally reddish brown throughout southern Oklahoma, but along the anticlinal flanks it has been bleached yellow and white owing to iron loss; some units contain abundant solid bitumen.

The mineralogy in the vertical section over the anticline follows the calculated stability relations for iron oxides, sulfides, and carbonate along a gradient from strongly reducing conditions at depth to oxidizing conditions at the surface. Reducing conditions were readily provided by seeping hydrocarbons from subsurface reservoirs of this multizone giant field. Production depths range from 120 to 2,180 m. The principal evidence that these are seepage-induced alterations is provided by reports of oil seeps in the early literature, by zones of solid bitumen cements, and by δC^{13} PDB values for carbonate cements that range from -7.8 to -36.7 ppt. [919]

Formation of Diagenetic Alteration Zones by Leaking Reservoir Hydrocarbons over Three Oil Fields in Oklahoma

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Examination of rotary-drill well cuttings from 105 wells within and adjacent to the Eola, Velma, and Chickasha oil fields in southern Oklahoma has revealed diagenetic mineral zonations within Permian sandstones overlying the fields. Permian sandstones which are usually red on outcrop are altered to white over the fields, owing to a change in cementing materials from limonite, hematite, and carbonates to ferroan calcite, ferroan dolomite, and, in some places, pyrite. Bleaching and mineralization were restricted to sandstones and were brought about by the reduction of iron oxides by hydrogen sulfide associated with petroleum and/or generated by a reaction between hydrocarbons and sulfate ions. Hydrogen sulfide reacted with iron oxide to form pyrite, and with oxygen in ground water to form sulfur.

Pyrite cement occurs in zones that overlie pre-Permian faults, oil productive areas, and zones that are elongated along structural trends. Zone boundaries are nearly vertical and extend to the surface. Average pyrite content of mineralized sandstone is 3%. Pyrite occurrences show that petroleum-bearing fluids were introduced into Permian rocks by vertical movement along high-angle normal and reverse faults that cut reservoirs at depth and that intersect unconformities at the base of the Permian section. [924]

Geochemistry of Organic-Rich Shales and Coals from Middle Pennsylvanian Cherokee Group and Lower Part of Marmaton Group, Oklahoma, Kansas, Missouri, and Iowa

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Middle Pennsylvanian rocks have produced substantial quantities of oil in eastern Oklahoma and southeastern Kansas. Initial results (Table 1) of a study of possible petroleum source rocks in these units show that organic-rich shales (> 1% organic C) can be divided into four groups. Group I shales are nonfossiliferous to fossiliferous marine, and commonly pyritic. Groups II, III, and IV shales are laminated, phosphatic, and nonfossiliferous to slightly fossiliferous. Groups III and IV shales are most common in the northern part of the area, which would be closer to the paleo-shoreline. Bulk organic geochemical properties of groups II and III shales are similar to coals, suggesting that most of the organic matter was derived from peat swamps. Reworking of organic matter, particularly in shale groups I and IV, was considerable, as indicated by low inferred hydrogen contents (H index) and relatively high inferred oxygen contents (O index). For types II

Table 1.—*Summary data for rock samples from the Cherokee and Marmaton Groups*

	Shale Class				
	I	II	III	IV	Coal
Number of samples	37	35	15	11	70
Organic Carbon % [1]	3.3	10.5	21.3	8.4	55.8
Hydrogen index[1,2]	45	180	325	26	227
Oxygen index[1,2]	26	9	9	13	7
C vs S slope	.7	.24	.19	.14	—[3]
C vs S intercept % C	.8	1.5	14.4	3.9	—
C vs S correlation (r)	.9	.9	.8	.9	—

[1] mean values; [2] determined by Rock-Eval; [3]—, no data.

and III shales and coals, average H and O indices decrease, and T_{max} (S_2 peak — Rock-Eval) increases from north to south, indicating an increasing maturity of organic matter to the south. This increasing maturity is consistent with changes in coal rank, which increases from high-volatile C bituminous coal in Iowa to high-volatile A and medium-volatile bituminous coal in Oklahoma. Total sulfur-organic carbon plots for the four shale groups do not intercept the sulfur axis, which suggests a lack of H_2S-containing bottom waters; different slopes of these plots suggest variability of sulfate availability, possibly due to salinity differences or rates of sedimentation. [936]

Subtle Porosity and Traps Within Frisco Formation (Devonian, Hunton Group): Geologic-Seismic Waveform Approach, Example from West El Reno Field, Canadian County, Oklahoma

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The Frisco Formation is a Middle Lower Devonian limestone within the Hunton Group (Upper Ordovician-Lower Devonian). In the Anadarko basin, the Frisco Formation consists of skeletal packstones and grainstones, whose main components are pelmatozoans, brachiopods, and, locally, corals. Depositional intergranular porosity has been mostly obliterated through syntaxial cementation on pelmatozoans, and mechanical and chemical compaction. Only minor intrabryozoan primary porosity remains. Secondary porosity, which formed during subaerial exposure of the Frisco Formation during the late Early and Middle Devonian, occurs locally at the top of the formation in the form of partly leached grains, vugs, and solution channels. This secondary porosity is best developed close to areas where the formation was completely eroded; these areas commonly correspond to Middle Devonian paleostructures.

Hydrocarbon accumulations in the Frisco Formation are mainly in stratigraphic traps situated downdip of the areas where the formation has been severely truncated. The Woodford Shale (Upper Devonian–Lower Mississippian) unconformably overlies the Frisco Formation in the study area and provides a source, trap, and seal for Frisco Formation reservoirs.

Geophysical identification of Frisco Formation porosity is possible using Relative Amplitude (RAM) processing. Mapping of porosity and truncated margins, and identification of potential hydrocarbon traps, are facilitated by using these RAM processed seismic sections. The West El Reno field, Canadian County, Oklahoma, produces gas and condensate from an outlier of the Frisco Formation, and provides a template for this technique.[960]