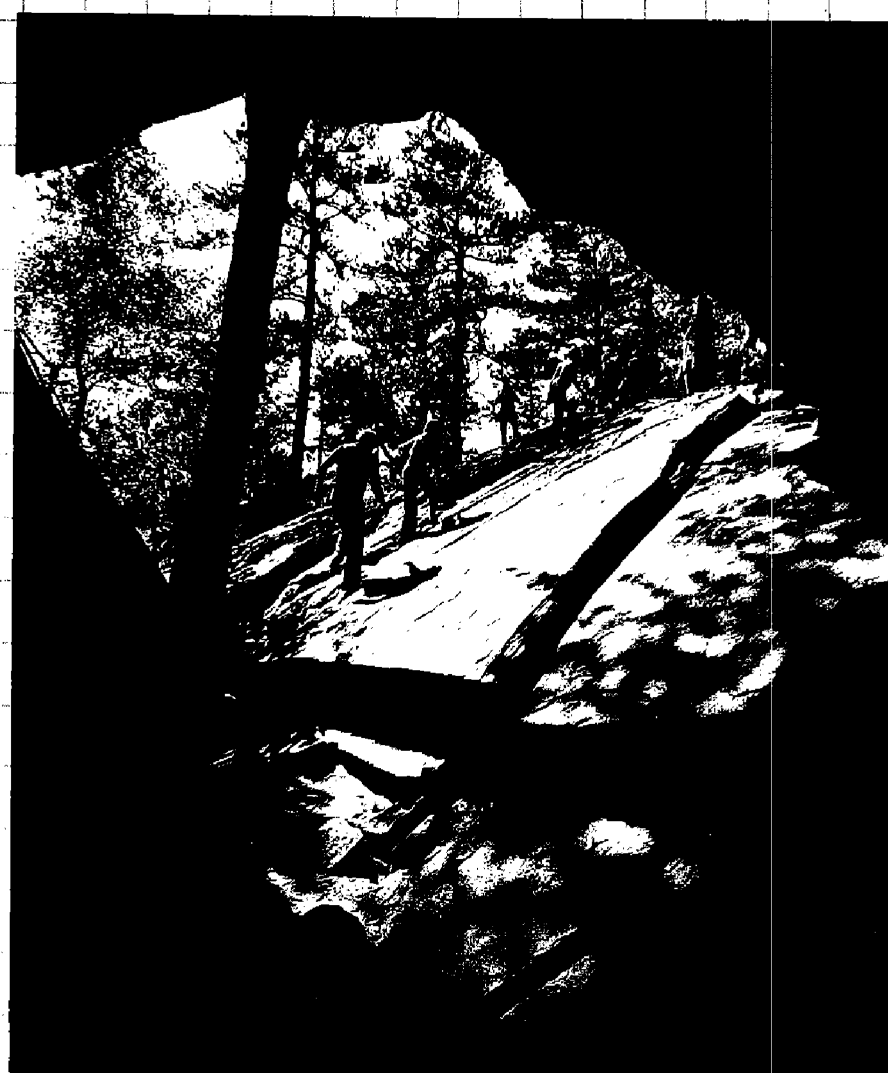
Oklahoma Geology Notes

OKLAHOMA GEOLOGICAL SURVEY / VOL. 46, NO. 2 — APRIL 1986



On the cover—

Guide to Robbers Cave State Park Published

The cover photo shows the view from Robbers Cave, the focus of an extensively updated and revised *Guide to Robbers Cave State Park,* issued recently by the Oklahoma Geological Survey as Guidebook 22. In addition to the revised material on the geology of the area, a section on botany was added to help visitors enjoy and appreciate the park, located near Wilburton in southeastern Oklahoma.

The section on geology discusses the origin of the caves and rocks, the geologic history, paleontology, topography, and structural geology of the area. Maps showing the location of the park, locations of available facilities, and routes of major highways are included, along with a columnar section and a table showing the geologic time scale compared to a calendar year. Six color photos give readers a glimpse of the beauty of the cave area and nearby Lake Carlton. A geologic map of the park is included in a pocket.

The botany section is complete with a key to the woody plants, a list of plants, and detailed ink drawings of leaves of many types in the vicinity.

Authors Arthur J. Meyers, Dearl T. Russell, George J. Goodman, and Cheryl A. Lawson have put together an informative and enjoyable guide that will be most useful on springtime outings to this state park.

The 48-page Guidebook 22 is available from the Survey at the address given below. The price is $5.

Oklahoma Geology Notes

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Oklahoma Geology Notes, ISSN 0030-1736, is published bimonthly by the Oklahoma Geological Survey. It contains short technical articles, mineral-industry and petroleum news and statistics, reviews, and announcements of general pertinence to Oklahoma geology. Single copies, $1.50; yearly subscription, $6. 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.

Oklahoma Geology Notes

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Contents

This publication, printed by the Transcript Press, Norman, Oklahoma, is issued by the Oklahoma Geological Survey as authorized by Title 70, Oklahoma Statutes 1981, Section 3310, and Title 74, Oklahoma Statutes 1981, Section 231–238. 1,800 copies have been prepared for distribution at a cost of $1,239 to the taxpayers of the State of Oklahoma. Copies have been deposited with the Publications Clearinghouse of the Oklahoma Department of Libraries.

OKLAHOMA EARTHQUAKES, 1985

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

Instrumentation

A statewide network of 11 seismograph stations was used to locate 54 earthquakes in Oklahoma for 1985 (fig. 1). The Oklahoma Geophysical Observatory (OGO) station, TUL, located near Leonard, Oklahoma, in southern Tulsa County, operates seven seismometers, three long-period and four short-period. The seismic responses at TUL are recorded on 14 paper-drum recorders and one digital recorder. Accurate timing is assured by a microprocessor clock that is continuously locked to the National Bureau of Standards cesium-beam clocks by low-frequency radio transmissions broadcast by WWVB (Lawson, 1980). Seven semipermanent volunteer-operated seismograph stations and three radio-telemetry seismograph stations complete the Oklahoma Geological Survey's seismic network. The operation and maintenance of 10 of the stations is partially supported by the U.S. Nuclear Regulatory Commission (Luza, 1978).

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

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

A rapid buildup of cultural noise in the vicinity of station GBO, Fort Gibson, made this site less desirable. Therefore, this station was closed

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

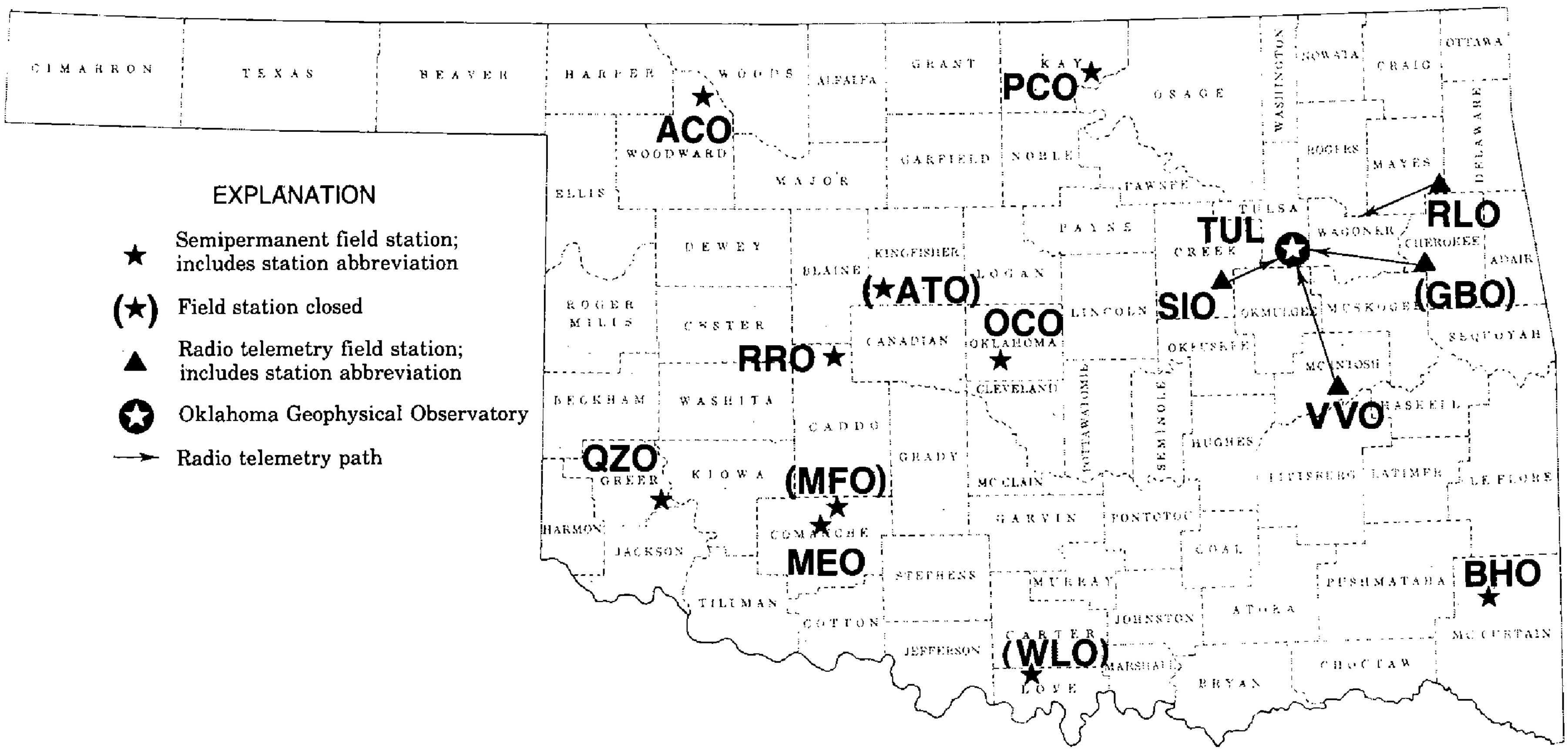

Figure 1. Active seismographs in Oklahoma.

in January. A new location was found near Vivian in McIntosh County. In September, the radio-telemetry equipment formerly at GBO became operational at the Vivian site, station VVO. Station MFO, the Meers Fault station, was closed in May. A new station, MEO, was opened on June 11. This station is located at the store in Meers, 3.9 km southwest of the Meers Fault. In July, station WLO was temporarily closed due to severe noise created from nearby oil-field activity. Station ATO was permanently closed on September 19, 1985.

Data Reduction and Archiving

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

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

Fourteen to 16 daily TUL seismograms, as well as 13 daily seismograms from the remote stations, are permanently archived at the OGO.

Earthquake Distribution

All Oklahoma earthquakes recorded on seismograms from three or more stations are located. In 1985, 54 Oklahoma earthquakes were located (fig. 2; table 1). Four of these earthquakes were reported felt (table 2). 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 3).

The felt areas for most of those earthquakes listed in table 2 are probably restricted to a few tens of square kilometers away from the epicentral location. No damage was reported from any of the felt earthquakes. On May 3, a magnitude-2.5 (mbLg) earthquake occurred 5 km north of Foster, Oklahoma. Intensity-MM IV effects were reported 5 km west-northwest of Foster. Two earthquakes were felt in Garvin County on May 5. The first earthquake, event number 537, occurred 7 km northwest of Foster. The second earthquake, event number 538, was located 3 km northwest of Maysville. A magnitude-2.3 (mbLg) earthquake occurred in McClain County on May 6 approximately 11 km west-southwest of Purcell.

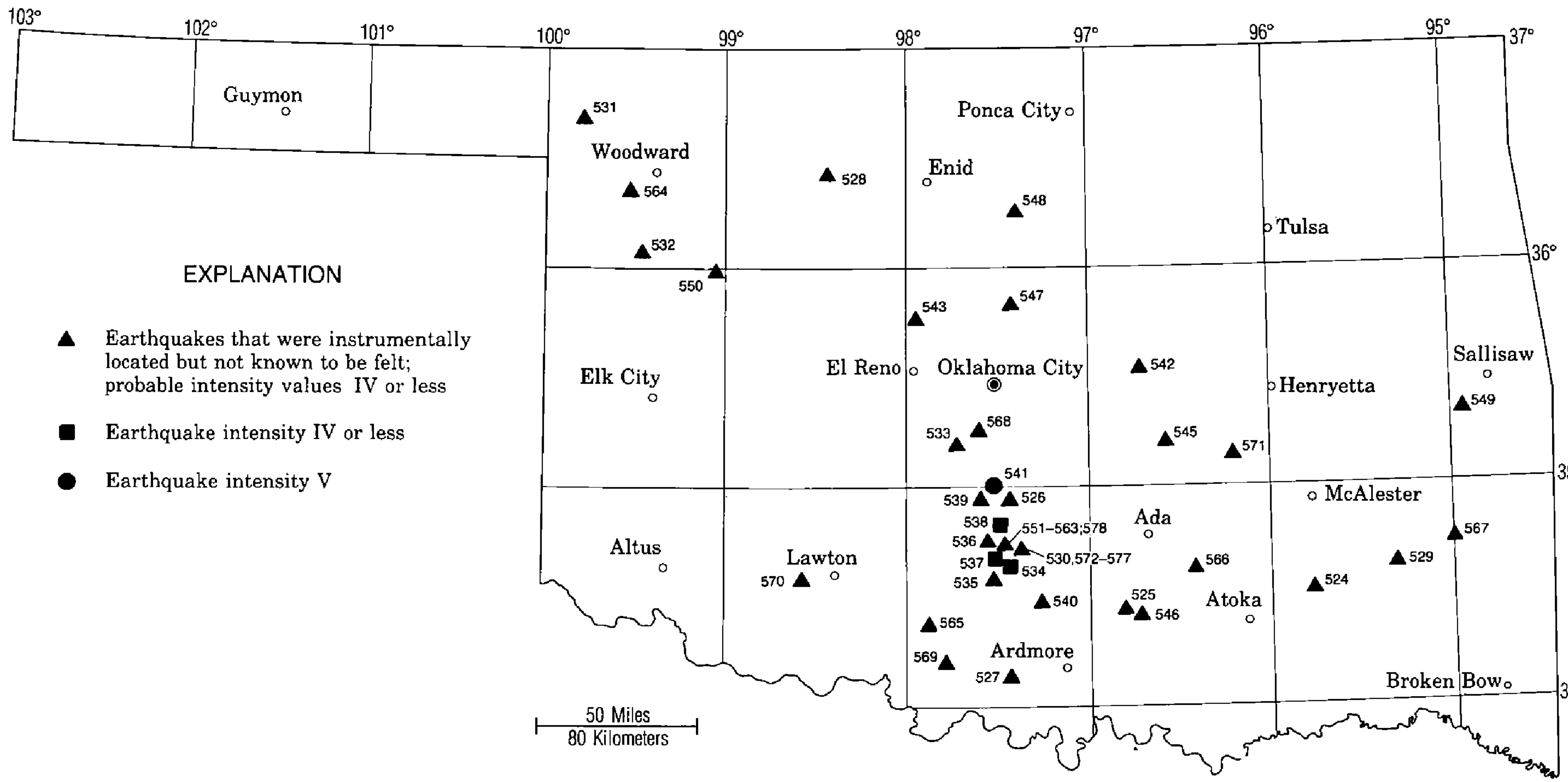

Figure 2. Distribution of Oklahoma earthquakes for 1985. Numbers correspond to event numbers in table 1.

Table 1.—Oklahoma Earthquake Catalog For 1985

Event Number	Date and Origin Time (UTC)[1]		County	Intensity MM[2]	Magnitudes 3Hz	bLg	DUR	Latitude deg N	Longitude deg W	Depth (km)[3]
525	JAN 23	003948.68	JOHNSTON		2.1	2.1	2.2	34.352	96.826	5.0R
526	JAN 24	121242.40	MC CLAIN		2.5	2.5	2.5	34.924	97.427	5.0R
527	FEB 1	090724.89	CARTER		1.8	2.0	2.1	34.143	97.449	5.0R
528	FEB 10	141552.21	MAJOR		3.0	2.8	2.7	36.433	98.412	5.0R
529	FEB 28	175657.73	PUSHMATAHA		2.4	2.3	2.3	34.661	95.339	5.0R
530	MAR 15	052209.32	GARVIN		1.7	1.9	2.1	34.758	97.437	5.0R
531	APR 14	071905.41	HARPER		1.6		1.8	36.691	99.806	5.0R
532	APR 17	053949.06	ELLIS		2.0		2.2	36.141	99.495	5.0R
533	APR 24	103158.77	GRADY		1.9		2.0	35.101	97.710	5.0R
534	MAY 3	073340.40	GARVIN	IV	2.5	2.5	2.6	34.656	97.484	5.0R
535	MAY 3	113547.06	GARVIN		2.1	1.9	2.1	34.647	97.540	5.0R
536	MAY 4	120519.00	GARVIN		2.0	2.0	2.3	34.807	97.549	5.0R
537	MAY 5	013930.78	GARVIN	felt	3.0	2.9	2.8	34.664	97.529	5.0R
538	MAY 5	021602.65	GARVIN	felt	2.4	2.2	2.3	34.836	97.455	5.0R
539	MAY 5	202747.26	MC CLAIN		1.8	1.8	1.9	34.910	97.541	5.0R
540	MAY 5	212915.95	MURRAY		1.3		1.6	34.508	97.323	5.0R
541	MAY 6	021116.16	MC CLAIN	V	2.2	2.3	2.4	34.969	97.482	5.0R
542	MAY 7	172204.91	LINCOLN		2.3	1.9	2.4	35.496	96.727	5.3
543	MAY 26	100049.96	KINGFISHER		2.1	1.7	2.1	35.731	97.963	5.0R
544	JUN 3	071334.47	ATOKA		2.1		2.1	34.500	95.851	5.0R
545	JUN 6	115018.80	SEMINOLE		1.8		1.6	35.188	96.608	5.0R
546	JUN 22	140155.05	JOHNSTON		2.1	1.9	2.0	34.345	96.760	5.0R
547	JUL 12	043537.76	LOGAN		1.8	1.7	2.2	35.863	97.421	5.0R
548	JUL 27	200008.29	NOBLE		2.2		1.8	36.240	97.405	5.0R
549	AUG 6	194414.58	HASKELL		2.4	2.5	2.0	35.378	95.008	5.0R
550	AUG 11	101623.22	DEWEY		2.7		2.6	35.964	99.037	5.0R
551	AUG 20	181738.35	GARVIN				1.7	34.759	97.482	5.0R
552	AUG 20	183153.24	GARVIN				1.6	34.759	97.482	5.0R
553	AUG 20	193740.77	GARVIN				1.7	34.759	97.482	5.0R
554	AUG 20	194331.33	GARVIN				1.5	34.759	97.482	5.0R
555	AUG 20	194951.81	GARVIN				1.4	34.759	97.482	5.0R
556	AUG 20	195035.10	GARVIN		2.6	2.3	2.2	34.751	97.498	5.0R
557	AUG 20	203446.14	GARVIN				1.4	34.759	97.482	5.0R
558	AUG 20	223014.92	GARVIN		2.5	2.5	2.2	34.759	97.468	5.0R
559	AUG 20	230346.94	GARVIN		2.6	2.3	2.4	34.732	97.476	5.0R
560	AUG 21	003733.32	GARVIN				1.5	34.759	97.482	5.0R
561	AUG 21	014613.31	GARVIN				2.1	34.759	97.482	5.0R
562	AUG 21	021257.04	GARVIN				2.4	34.759	97.482	5.0R
563	AUG 21	085638.97	GARVIN				1.7	34.759	97.482	5.0R
564	AUG 22	090652.20	WOODWARD		1.7		1.9	36.386	99.537	5.0R
565	AUG 28	023151.12	STEPHENS				2.1	34.382	97.844	5.0R
566	SEP 17	095844.10	COAL		1.8	1.8	1.8	34.618	96.471	5.0R
567	SEP 23	010344.10	LE FLORE		3.3	2.9	2.6	34.725	95.059	5.0R
568	OCT 24	121219.98	MC CLAIN		2.1	1.8	2.0	35.232	97.607	5.0R
569	NOV 7	083533.76	JEFFERSON		1.8	2.0	2.2	34.181	97.790	5.0R
570	DEC 10	005906.04	COMANCHE		2.2	2.1	2.2	34.577	98.549	5.0R
571	DEC 28	101137.92	HUGHES		2.1		2.2	35.118	96.232	5.0R
572	DEC 31	181530.90	GARVIN				1.8	34.703	97.459	5.0R
573	DEC 31	182726.12	GARVIN		3.0	2.7	2.5	34.703	97.459	5.0R
574	DEC 31	192038.52	GARVIN				1.9	34.703	97.459	5.0R
575	DEC 31	192126.80	GARVIN				1.8	34.703	97.459	5.0R
576	DEC 31	193149.15	GARVIN				1.7	34.703	97.459	5.0R
577	DEC 31	214803.77	GARVIN		2.3	2.3	2.2	34.704	97.460	5.0R
578	DEC 31	224503.76	GARVIN		2.4		2.2	34.766	97.490	5.0R

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

[2]Modified Mercalli (MM) earthquake-intensity scale (see table 3).

[3]The hypocenter is restrained (R) at an arbitrary depth of 5.0 km, except where indicated, for purposes of computing latitude, longitude, and origin time.

TABLE 2.—EARTHQUAKES THAT WERE REPORTED FELT IN OKLAHOMA, 1985

Event no.	Date and origin time (UTC)		Nearest city	County	Intensity (MM)
534	May 3	073340.40	N Foster	Garvin	IV
537	May 5	013930.78	NW Foster	Garvin	felt
538	May 5	021602.65	NW Maysville	Garvin	felt
541	May 6	021116.16	W Purcell	McClain	V

TABLE 3.—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.

Intensity-MM V effects were reported 2 km north-northwest of Story and 5 km west-northwest of Maysville.

Earthquake-magnitude values range from a low of 1.3 (m3Hz) in Murray County to a high of 3.3 (m3Hz) in Le Flore County. More than half of the earthquakes, 30, occurred in McClain and Garvin Counties. This region has been one of the most active areas since 1979. For the second year in a row, the Canadian County area contained no locatable earthquakes. The northern shelf area (west of the Nemaha Ridge) and the Arkoma Basin region experienced a few low-magnitude earthquakes.

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-sized format. Table 1 contains 1985 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, 1981, 1982, 1983, 1984, 1985).

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

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

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

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

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

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

(epicenter 10 to 100 km from a seismograph)

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

(epicenter 100 to 200 km from a seismograph)

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

(epicenter 200 to 400 km from a seismograph)

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

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 Hz in frequency, measured in nanometers; T is the period of Sg waves measured in seconds; and Δ is the great-circle distance from epicenter to station measured in kilometers.

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

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

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. 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) and the decrease of the coda to twice the background-noise amplitude was used.

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

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

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NEW GEOREF THESAURUS AVAILABLE

The fourth edition of the *GeoRef Thesaurus and Guide to Indexing*, edited by Crystal S. Palmer, is now available. The Thesaurus section, with some 15,000 terms and cross-references, shows how related terms are used in the GeoRef (Geological References) data base. Understanding these relationships guides searchers to choose terms that will give them the best search results.

Over 1,000 terms are new to the fourth edition. These include geographic place names, systematic terms (rocks, fossils, minerals, etc.), and non-systematic terms (geologic features, processes, properties, materials, methods, techniques, etc.). The largest groups of new terms are U.S. county names, rock formation names (mostly North American), geophysical methods and techniques, and geographic terms.

Changes have also been made in entries for existing terms. For example, the area denoted by some geographic terms has been adjusted, and the scope of some common fossil names has changed. Those searching the data base for materials published before 1967 will be helped by the addition of explanatory scope notes and cross-references for more than 300 of the principal index terms that are no longer valid.

The American Geological Institute wishes to acknowledge the contribution of the GeoRef Advisory Committee's Vocabulary Task Force members: Barbara Pearson (chair), Exxon Production Research Co.; Ann Coppin, Chevron Oil Field Research Co.; Dorothy McGarry, University of California, Los Angeles; Unni Rowell, Exmin Corp.; Patricia Sheahan, Konsult International, Inc.; and Marilyn Stark, Colorado School of Mines. The Task Force reviewed new terms for this edition, suggested additional new terms, and recommended changes in the front matter.

The *GeoRef Thesaurus and Guide to Indexing*, 4th ed., 1986, Crystal S. Palmer, editor, is available from the American Geological Institute, Customer Service Dept., 4220 King St., Alexandria, VA 22302. Soft cover, paper, 510 p., $65; microfiche $25.

NEW USGS TOPOGRAPHIC MAPS NOW AVAILABLE AT SURVEY

Seven new USGS 7.5-minute-quadrangle topographic maps of areas in Oklahoma are now available at the Oklahoma Geological Survey. The maps are for the Eagle City, Fay, Putnam, Putnam NW, Rough Creek, Squaw Creek, and Webb quadrangles. These areas were covered previously only in the 15-minute-quadrangle map series.

The maps are available for $2.50 each over the counter at the Survey offices at the address given inside the front cover, or at the same price by mail. The sales office is open from 8 a.m. to noon Monday through Saturday, and from 1 p.m. to 5 p.m. Monday through Friday.

OGS DIRECTOR CHARLES MANKIN LENDS TALENTS TO PBS TV SERIES

A public television show entitled "Gifts from the Earth," which aired this spring, was produced with input from Oklahoma Geological Survey director Charles J. Mankin, who also is professor of geology and executive director of the Energy Resources Institute at the University of Oklahoma.

Mankin co-chaired a committee that put together the episode on earth resources for the television series *Planet Earth*, which was shown by Public Broadcasting System stations nationwide. The series aired on Oklahoma Educational Television Authority (OETA) at 8 p.m. on Sundays and 7 p.m. on Wednesdays.

The *Planet Earth* series, sponsored by the National Academy of Sciences, documents the scientific development of current Earth theories.

The series includes seven films: "The Living Machine," on the scientific development of the theory of plate tectonics; "The Blue Planet," a description of the exploration of the oceans; "The Climate Puzzle," a history of climatology; "Tales from Other Worlds," a film depicting research in planetology; "Gifts from the Earth," a description of the planet's mineral and energy resources; "The Solar Sea," a discussion of the solar system with emphasis on the impact of the sun on the Earth; and "Fate of the Earth," a description of life on Earth. The first segment aired the week of January 26.

A companion book for the series is available through retail bookstores. The book, *Planet Earth*, by Jonathan Weiner, is published by Bantam Books.

EARTH SCIENCES BENEFIT FROM GRANTS

The University of Oklahoma has recently received generous donations from four corporations to be used to further research and education.

The Exxon Education Foundation has awarded OU a $50,000 grant which is being shared by the School of Geology and Geophysics and the Colleges of Business Administration and Engineering. The donation provides $16,000 for geology and geophysics, $10,000 for petroleum engineering, $9,000 for chemical engineering, $6,000 for mechanical engineering, $4,000 for accounting and computer science, $2,500 for electrical engineering, and $1,500 each for business administration and petroleum land management.

The Amoco Corporation has given the University $45,000 for graduate student fellowships in ground-water research in OU's Environmental and Ground Water Institute. The gift will be awarded in three annual installments.

Conoco Oil Company has awarded a scholarship fund of $3,500, through its Financial-Aid-to-Education program, to OU's School of Petroleum and Geological Engineering. Of the total, $2,500 will provide scholarships for students Wade Fouts, Martinsville, Illinois, and Kevin McMillin, Heavener. The remainder will fund the purchase of equipment for the school's instructional laboratories.

The Mobil Foundation has presented the OU School of Geology and Geophysics a $2,000 unrestricted grant, which can be used for anything from new equipment to a graduate program. The school will determine where the grant money is needed most after the budget has been decided.

OGS GEOLOGISTS JOIN STRATIGRAPHIC GROUP

Oklahoma Geological Survey coal geologist LeRoy A. Hemish and OGS bio- and chronostratigrapher James R. Chaplin have accepted appointments to serve on a working group coordinating information on the stratigraphy and sedimentology of Pennsylvanian-age rocks in six states of the central Mid-Continent. The states are Iowa, Kansas, Nebraska, Oklahoma, Missouri, and Illinois. The working group will include representatives from state organizations, academia, and industry.

Still in its initial stages, the program is under the direction of the Mid-Continent Section of the Society of Economic Paleontologists and Mineralogists (SEPM).

Sediments deposited during Pennsylvanian times have undergone a complex history in the central region of the United States, including mountain building that resulted in the formation of the Arbuckle, Wichita, and Ouachita Mountains in Oklahoma. Erosion of these uplifted areas resulted in turn in deposition of thousands of feet of strata in adjacent sedimentary basins.

There are many problems still to be resolved through study of these rocks, and, according to W. Lynn Watney of the Kansas Geological Survey, immediate past-president of the Mid-Continent Section of SEPM, "a working group with a communication link to those in the region might facilitate a quicker and more efficient progression toward a consensus of opinion" on stratigraphic correlations.

Both Hemish and Chaplin are known for their works on rocks of this time period and have an active interest in Pennsylvanian stratigraphy.

MINERAL INDUSTRY OF OKLAHOMA, 1985

The value of nonfuel mineral production in Oklahoma in 1985 was estimated at $237 million, declining about 3 percent from the $246 million reached in 1984, according to the Bureau of Mines, U.S. Department of the Interior (table 1). Declines were noted in clay, portland and masonry cement, iodine, crushed and dimension stone, and tripoli.

Although construction materials continued to represent most of the mineral value, building permits declined in the first half of 1985, the lowest 6-month period of activity since 1980. The dollar value of single-family residential construction permits was off more than 4.5 percent, compared with the first 8 months of 1984; multifamily permits declined 68 percent; commercial more than 34 percent; industrial, 20 percent; streets and highways, 25 percent; and other nonbuilding, 48 percent; thus accounting, in part, for the drop in production of industrial minerals in the State.

Iron and steel developments included a $4 million expansion of Allegheny Ludlum Steel Corp.'s Oklahoma Tubular Steel Division plant at Claremore. The plant size was increased from 48,000 to 120,000 sq ft; a tenth tubing mill was opened, allowing the production of more than 100 million ft of tubing per month. With the addition of 70–80 new jobs, the plant's staff was brought to 150. The steel tubing is used for the petroleum, heat-exchanger, and paper-production industries, and specialty alloys such as titanium tubing are made for aerospace.

The U.S. Office of Surface Mining (OSM) authorized the Oklahoma Department of Mines to resume enforcement of strip-mine regulations in the State beginning January 1, 1986; OSM had assumed responsibility for enforcing the State's reclamation and inspection laws on April 30, 1984. The Department of Mines authority to review and issue mining permits continued uninterrupted. The Oklahoma legislature nearly doubled the Department of Mines' budget and number of employees in fiscal year 1985; the agency's budget was $2.2 million and the number of workers was 49. Under an agreement between OSM and the State, Oklahoma immediately will monitor all of the State's 225 inactive mines and will resume responsibility for monitoring the approximately 25 active mines in the State on a mine-by-mine basis as permits and bonds are revised to correct deficiencies.

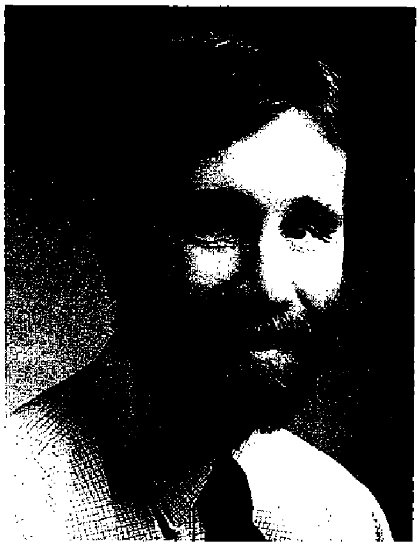
On October 18, Oklahoma Governor George Nigh declared an emergency for the coal-mining industry when a New York insurance company was declared insolvent and left 11 coal and noncoal mining companies without the bonds required to ensure reclamation of strip-mined lands. By November 26, alternate bonding arrangements were made for five active mines; six inactive mines also must find new insurance carriers, but did not have a deadline.

This report was prepared in the Denver Regional Office of State Activities in cooperation with the Oklahoma Geological Survey.

TABLE 1. — NONFUEL MINERAL PRODUCTION IN OKLAHOMA[1]

Mineral	1984 Quantity	1984 Value (thousands)	1985[P] Quantity	1985[P] Value (thousands)
Cement:				
Masonry . . . thousand short tons	49	$ 3,506	45	$ 3,300
Portland . . . do	1,732	84,701	1,700	85,200
Clays . . . do	979	2,498	783	1,999
Gemstones	NA	2	NA	2
Gypsum . . . thousand short tons	1,549	13,485	1,554	12,898
Sand and gravel:				
Construction . . . do	10,984	26,582	12,600	32,300
Stone:				
Crushed . . . do	25,500[e]	86,000[e]	25,000	71,000
Dimension . . . do	12[e]	771[e]	11	1,002
Combined value of feldspar, iodine, lime, pumice, salt, sand and gravel (industrial), and tripoli	XX	28,187	XX	29,778
Total	XX	245,732	XX	237,479

[e] Estimated. [P] Preliminary. NA Not available. XX Not applicable.
[1] Production as measured by mine shipments, sales, or marketable production (including consumption by producers).



Neil H. Suneson

NEIL SUNESON JOINS OGS STAFF

Last spring the Oklahoma Geological Survey was named co-recipient with the Arkansas Geological Commission of a $250,000 matching-funds grant from the U.S. Geological Survey to map the Ouachita Mountains area (see *Oklahoma Geology Notes*, v. 45, p. 74–75). The project is part of the Federal Survey's Cooperative Geologic Mapping Program (COGEOMAP), which was formulated to accelerate geologic mapping nationwide, with emphasis on certain localities, like the Ouachita area, which were deemed in need of detailed coverage.

Neil H. Suneson, most recently a geologist with Chevron U.S.A. in California, has become a member of the geologic staff of OGS to assist in this important program. His work will entail geologic mapping and coordinating field activities in the Ouachitas.

Suneson, a native of New Jersey, received a B.A. from Amherst College in Amherst, Massachusetts, an M.S. from Arizona State University, Tempe, and a Ph.D. from the University of California at Santa Barbara, all in geology. He wrote his Ph.D. dissertation on "The Origin of Bimodal Volcanism, West-Central Arizona."

In and around his academic graduate work, he was employed as a field assistant in base-metals exploration (for Humble Oil and U.S. Steel) and uranium exploration (Chevron), as a laboratory teaching assistant (at Tempe and at Santa Barbara), and as a geologic field assistant for the USGS (in California and Arizona). Upon completing his doctorate, he went to work for Chevron in geothermal exploration in Oregon and Nevada, doing detailed geologic mapping, interpreting geochemical data, and integrating geophysical data with geologic observations. He later transferred to the production department of Chevron in Concord, California, doing subsurface mapping, log evaluation, and fracture analysis in the Lost Hills oil field, Kern County, California. He has several publications to his credit and is a member of GSA and AAPG.

Since beginning his work with OGS, Neil has been familiarizing himself with the area to be mapped, both through field visits and through an intensive study of previous work done in the Ouachitas. He is currently identifying areas with reliable geologic mapping and those that should be remapped for better understanding of stratigraphy and structure. He has compiled his own preliminary index maps of the southeastern part of the State, on which he has shown published and unpublished measured sections and cross sections. During the coming field season he will be mapping at a scale of 1:24,000 regionally, and at a larger scale where necessary.

OGS PUBLISHES MAP INDEXES

The Oklahoma Geological Survey has released a set of index maps delineating subsurface areas mapped in Oklahoma from 1940 to 1966. The maps, which come folded in a large manila envelope, have been issued as OGS Map GM-29.

This publication, designated a second edition, represents a reissue of OGS subsurface map indexes that have gone out of print due to popular demand. It contains six plates, each at a scale of 1:1,000,000, that offer 391 references to published and unpublished maps in the years 1940–50, 1951–56, 1957–58, 1959–60, 1961–63, and 1964–66. The six plates have been extracted from the "Index to Geologic Mapping in Oklahoma," including "Supplement 1" and "Supplement 2," published in 1961, 1964, and 1967.

Compiled by former OGS petroleum geologists Louise Jordan and John F. Roberts, these maps are still the most comprehensive source of information on subsurface geologic mapping in Oklahoma for the years they cover. They include references to maps showing thickness, gravity, magnetism, lithology, porosity, lithofacies, paleogeography, and structure.

A separate index for subsurface mapping done in 1967–76 is available as OGS Map GM-22; an index for 1977–79 is still in print as OGS Map GM-26.

OGS Map GM-29, *Index to Subsurface Geologic Mapping in Oklahoma, 1940–1966*, can be obtained from the Oklahoma Geological Survey at the address given inside the front cover of this issue. The price is $5.

Larry N. Stout

STOUT NEW GEOLOGIST/EDITOR FOR SURVEY

Larry N. Stout, a graduate of the University of Missouri–Columbia, has been named geologist/editor at the Oklahoma Geological Survey. Stout was previously geologist/editor for the Washington Division of Geology and Earth Resources, Olympia. At the Survey, Stout is head of the editorial section and will be responsible for editing geological manuscripts and scheduling of Survey publications.

His experience in the field of earth sciences includes more than 15 years as an editor and author in American geology and more than 10 years as a translator of Russian geological literature. He also has translated German and French geological literature.

Stout served as geologist/resident editor at the Egyptian Geological Survey and Mining Authority in Cairo. He earlier worked as science editor for the Deep Sea Drilling Project at Scripps Institution of Oceanography, La Jolla, California, and as geologist and technical editor for the Missouri Geological Survey.

His field experience includes work as a geologist for the J. R. Simplot Co. open-pit phosphate mine at Conda, Idaho, and geologic mapping in Missouri. He has done research on fresh-water ostracodes and Permian conodonts.

Stout is a member of the Geological Society of America, the American Quaternary Association, and the Association of Earth Science Editors.

GEOLOGY, SURGERY ENDOWMENTS FUNDED

An anonymous donor provided a major gift to the University of Oklahoma to establish two endowments as memorials to two OU alumni—geologist Willard L. Miller and surgeon H. Dale Collins.

The endowments will fund a professorship in the School of Geology and Geophysics and research fellowships for residents in surgery at the Health Sciences Center.

"These generous gifts to the University of Oklahoma are greatly appreciated and will enrich two of the University's outstanding academic programs," said OU President Frank E. Horton.

The geology professorship will be named for Miller, who received his geology degree in 1920. Miller worked his way through OU as an assistant registrar and an assistant in the president's office. A charter member of the Oklahoma City Geological Society in 1921, Miller was employed as a geologist for the Ramsey Petroleum Corporation for 25 years and was among the first geologists to approve the mapping of the Oklahoma City structure.

When Ramsey Petroleum was sold in 1946, Miller worked in partnership with Charles E. Stewart in oil and gas investments until 1971 but continued to manage two oil companies he had founded. He died in 1973 at age 77.

The endowment for surgery research fellowships honors Collins, a 1926 graduate of the OU College of Medicine. The Oklahoma City physician taught surgery at the Health Sciences Center and was a lieutenant colonel in the Army Medical Corps. He died in 1942 at age 41.

NOTES ON NEW PUBLICATIONS

Hydrology of the Arbuckle Mountain Area, South-Central Oklahoma

R. W. Fairchild, R. L. Hanson, and R. E. Davis wrote this 189-page USGS open-file report, available for reference at the U.S. Geological Survey, Water Resources Division, Room 621, Old Post Office Bldg., 215 Dean A. McGee Ave., Oklahoma City, OK 73102; phone (405) 231-4256.

Order OF 82-0775 from: U.S. Geological Survey, Western Distribution Branch, Open-File Services Section, Box 25425, Federal Center, Denver, CO 80225. The price is $4 for microfiche and $28.25 for a paper copy, postpaid; add 25% to the price for shipment outside North America.

Hydrologic Data for the Arbuckle Mountain Area, South-Central Oklahoma

This 74-page USGS open-file report, written by R. W. Fairchild and R. E. Davis, is available for reference at the U.S. Geological Survey, Water

Resources Division, Room 621, Old Post Office Bldg., 215 Dean A. McGee Ave., Oklahoma City, OK 73102; phone (405) 231-4256.

Order OF 83-0028 from: U.S. Geological Survey, Western Distribution Branch, Open-File Services Section, Box 25425, Federal Center, Denver, CO 80225. The price is $4 for microfiche and $11.75 for a paper copy, postpaid; add 25% to the price for foreign shipment.

Geology and Geochronology of Precambrian Rocks in the Central Interior Region of the United States

Written by Rodger E. Denison, E. G. Lidiak, M. E. Bickford, and Eva B. Kisvarsanyi, this 20-page USGS professional paper is part of the series *Correlation of Precambrian Rocks of the United States and Mexico*. The series describes the lithology, distribution, correlation, and isotopic ages of Precambrian terranes for five subareas between the Appalachians and the Rocky Mountains.

Order P 1241-C from: U.S. Geological Survey, Eastern Distribution Branch, Text Products Section, 604 South Pickett St., Alexandria, VA 22304. The price is $2, postpaid; add 25% to the price for foreign shipment.

Floods in Central, Southwest Oklahoma, October 17–23, 1983

In this 21-page USGS open-file report, Leland D. Hauth provides peak-stage and discharge information collected in Oklahoma during the floods caused by Hurricane Tico, October 17–23, 1983. The report can be examined at the U.S. Geological Survey, Water Resources Division, Room 621, Old Post Office Bldg., 215 Dean A. McGee Ave., Oklahoma City, OK 73102; phone (405) 231-4256.

Order OF 85-0494 from: U.S. Geological Survey, Western Distribution Branch, Open-File Services Section, Box 25425, Federal Center, Denver, CO 80225. The price is $4 for microfiche and $3.25 for a paper copy, postpaid; add 25% to the price for shipment outside North America.

Land Use and Land Cover and Associated Maps for Wichita Falls, Texas; Oklahoma

Four maps keyed to USGS Wichita Falls topographic map at a scale of 1:250,000 (1 in. = about 4 mi) comprise this data set. These maps are coded for statistical development. The maps are (1) land use and land cover, (2) political unit, (3) hydrological units, and (4) census county subdivision. Also included is one positive of the cultural base for Wichita Falls.

Order OF 84-0543 from: U.S. Geological Survey, Mid-Continent Mapping Center, 1400 Independence Rd., Rolla, MO 65401.

Water Quality in the Blue Creek Arm of Lake Eufaula and Blue Creek, Oklahoma, March–October 1978

Water-quality data of the Blue Creek arm of Lake Eufaula and Blue Creek are evaluated in terms of drinking-water standards and water-quality criteria in this USGS water-resources investigations report by Joanne K. Kurklin. The 91-page report is available for reference at the U.S. Geological Survey, Water Resources Division, Room 621, Old Post Office Bldg., 215 Dean A. McGee Ave., Oklahoma City, OK 73102; phone (405) 231-4256.

Order WRI 85-4039 from: U.S. Geological Survey, Western Distribution Branch, Open-File Services Section, Box 25425, Federal Center, Denver, CO 80225. The price is $4 for microfiche and $14.50 for a paper copy, postpaid; add 25% to the price for foreign shipment.

Ground-Water Quality Data for Oklahoma, 1982–84

Dale M. Ferree is the author of this USGS open-file report, which contains 412 ground-water-quality analyses since 1982 from 341 sites in 25 counties in Oklahoma. The 39-page report is available for reference at the U.S. Geological Survey, Water Resources Division, Room 621, Old Post Office Bldg., 215 Dean A. McGee Ave., Oklahoma City, OK 73102; phone (405) 231-4256.

Order OF 85-0417 from: U.S. Geological Survey, Western Distribution Branch, Open-File Services Section, Box 25425, Federal Center, Denver, CO 80225. The price is $4 for microfiche and $6.50 for a paper copy, postpaid; add 25% to the price for shipment outside the U.S. (except Canada and Mexico).

Reported Withdrawals and Estimated Use of Water in Oklahoma During 1982

Information provided in this USGS water-resources investigations report shows the relation between ground- and surface-water withdrawals, the relation between reported withdrawal and estimated use, and the relative importance of various water uses on a statewide and a county basis. Jerry D. Stoner wrote this 96-page report, which can be examined at the U.S. Geological Survey, Water Resources Division, Room 621, Old Post Office Bldg., 215 Dean A. McGee Ave., Oklahoma City, OK 73102; phone (405) 231-4256.

Order WRI 85-4084 from: U.S. Geological Survey, Western Distribution Branch, Open-File Services Section, Box 25425, Federal Center, Denver, CO 80225. The price is $4 for microfiche and $15.50 for a paper copy, postpaid; add 25% to the price for shipment outside North America.

Chemically Enhanced Drilling: An Annotated Tabulation of Published Results

Pamela J. Watson and William H. Engelmann wrote this 53-page report, which presents a Bureau of Mines literature survey that provides a data base useful for current and future studies in the area of chemically enhanced drilling and cutting. Publications describing laboratory testing and field studies of drilling and cutting with chemical additives are reviewed. Significant results are summarized and tabulated by rock or material type and also by chemical additive, with references. Selected studies related to fluid-enhanced processing or material testing are summarized in the appendixes.

Order GPO Stock No. 024-004-02150-1 from: Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402. The price is $2.25, postpaid; add 25% to the price for shipment outside the United States or its possessions.

Microcomputer Applications in Geology

Computing concepts and microcomputer operations are introduced in this 274-page reference, followed by applications including ready-to-use computer programs. Authors T. Hanley and D. F. Merriam cover topics such as digitizing with mapping applications, data-base management, oil and gas exploration, seismic interpretation, expert systems, and microcomputer retrieval systems. Some applications include regional oil and gas exploration, normative calculations in petrology, mineral stability diagrams, image analysis, computer-assisted drafting, natural language processing, geophysics, and structural geology. Microcomputer use in the consulting area is also discussed, with an emphasis on uranium exploration and ground-water studies.

Order from: Pergamon Press, Inc., Maxwell House, Fairview Park, Elmsford, NY 10523. The price is $35.

Multilingual Thesaurus of Geology

A joint ICSTI Working Group has developed a computerized multilingual thesaurus of geology and related sciences. In contrast to conventional multilingual thesauri, which give only different language entries into one logical system, this work is designed to connect different existing data bases in various languages with individual logical structures. Edited by G. N. Rassam, the 500-page thesaurus contains approximately 5,000 key entries with an average of 24 single language and relationship entries per key, giving a total of 120,000 individual entries. Prepared for further introduction are the mineral names and standard geographic names which will generate some 50,000 entries. Languages covered include English, French, German, Russian, Spanish, and Italian.

Order from: Pergamon Press, Inc., Maxwell House, Fairview Park, Elmsford, NY 10523. The price is $50.

OKLAHOMA ABSTRACTS

GSA Annual Meeting
Orlando, Florida, October 28–31, 1985

The following abstracts are reprinted as published from *Abstracts with Programs, 1985* of the Geological Society of America, v. 17, no. 7. Page numbers are given in brackets below the abstracts. Permission of the authors and of GSA to reproduce the abstracts is gratefully acknowledged.

Flow Directions and Hydraulic Gradients in the Variable Density Flow System at the Proposed High-Level Nuclear Waste Repository Site in the Texas Panhandle

SCOTT E. BAIR and TIMOTHY P. O'DONNELL, Stone & Webster Engineering Corp., P.O. Box 5200, Cherry Hill, NJ 08034

Bedded salt, welded tuff, and basalt are the three rock types proposed as possible host rock for the nation's first high-level nuclear waste repository. Regional flow at the proposed bedded salt site in the Texas Panhandle is unique because it contains waters with highly variable fluid density. The site area is underlain by three regional hydrostratigraphic units: a shallow aquifer system developed in the Ogallala Formation and Dockum Group containing waters with less than 1500 mg/l TDS, a shale and evaporite aquitard associated with the target salt horizon commonly containing waters with 300,000 mg/l TDS, and a deep aquifer system developed in the Wolfcamp Series and Pennsylvanian System commonly containing waters with 50,000 to 200,000 mg/l TDS. The associated fluid density variations can lead to miscalculation of flow directions, hydraulic gradients, and travel times. Head difference maps and potentiometric profiles show that use of equivalent freshwater heads is an overly conservative approach for determining vertical flow directions and a nonconservative approach for determining vertical hydraulic gradients and travel times, whereas the converse is true for use of equivalent brine heads. Pressure-depth diagrams based on shut-in pressure and specific-gravity data from drill-stem tests indicate that regionally the potential for downward flow exists in the shale and evaporite aquitard and the potential for horizontal flow exists in the deep aquifer system. Determination of the direction and magnitude of the vertical hydraulic gradient across the target salt horizon based on a method that solely uses pressure data and which incorporates the effects of variable fluid density indicates a downward-oriented hydraulic gradient at the proposed Texas Panhandle site. These methods do not require calculation of hydraulic head and, therefore, are a more realistic way of determining flow characteristics in variable density flow systems. [517]

Oil and Brine Inclusions at the Jumbo and Prescott Mines, Linn County, Kansas

SHEILA R. BLASCH, VIRGINIA M. RAGAN, and RAYMOND M. COVENEY, JR., Department of Geosciences, University of Missouri–Kansas City, Kansas City, MO 64110–2499

Well north of the Tri-State district, small deposits containing Pb, Zn, and Ba associated with organic matter occur in M. Pennsylvanian beds. One of these, the Jumbo Pb mine lies 2.5 km SE of Pleasanton, KS, and takes the form of a mineralized pipe or circle deposit. Similar mineralization occurs at the Prescott Zn deposit located approximately 12 km SSE of the Jumbo in [an] abandoned coal mine. Several minerals at both mines contain amber petroleum inclusions, fluorescent in UV light.

Primary oil inclusions in sphalerite from the Jumbo and Prescott mines homogenize at 83–93°C. Homogenization temperatures of oil inclusions in calcite are as low as 61°C. Aqueous inclusions in sphalerite fill at 82–110°C, generally 10–20°C higher than adjacent petroleum inclusions. Similar differences in homogenization temperatures for inclusions in Illinois fluorite and elsewhere have been attributed to higher rates of thermal expansion and compressibility for oil than water (Freas, 1961; Roedder, 1963).

Freezing data for aqueous inclusions in sphalerite imply salinities of 21–23 wt% NaCl equivalent. Some primary inclusions in calcite contain translucent reddish crystals, which may be a daughter mineral, possibly ferroan dolomite.

It is not clear whether organics have played an active chemical role in either transporting or precipitating the sulfides of the Jumbo and Prescott mines. Nevertheless, data from both mines are consistent with the basinal brine theory of origin postulated for Mississippi Valley-type deposits and suggest the possibility that these small deposits formed at or near a local oil-water interface or that local formational waters were exceptionally rich in oil droplets. [525]

Structural Analysis of Ouachita Mountains in Arkansas

ANN E. BLYTHE, ARNON SUGAR, and STEPHEN PAUL PHIPPS, Geology Department, University of Pennsylvania, Philadelphia, PA 19104

Existing mapping, reconnaissance field work, and the construction of three deep, balanced (frontal zone) and semi-balanced (interior zones) cross-sections through the Arkansas Ouachitas demonstrate that (1) Ouachita folds extend well north of the Arkansas River, and probably form above bedding-plane decollements, some of them blind; (2) angular anticlines with steep forelimbs and long, gentle back limbs dominate the Ouachita foreland; these folds have structural relief of 1 to 3 km; many of them are cut by crestal faults with displacements much smaller than the height of the folds; (3) moderate north dip of cleavage and bedding dominates the Stanley Formation outcrop belt north of the Benton uplift; (4) steep south dips and multiple imbricate thrust faults dominate the Athens Plateau.

The cross-sections suggest that asymmetric frontal folds may be fault-propagation folds, or may form over backthrusts (triangle zones), or over basement-cutting flexural normal faults. Fault propagation may also have formed many map-scale folds in the Benton uplift, Cossatot and Trap Mountains, as well as geometrically similar folds in the Broken Bow uplift and at Black Knob Ridge in Oklahoma. Common north-side-up faults on the north side of the Benton uplift, as well as the possible occurrence of triangle zones beneath the frontal folds, suggest that back-thrusting may be quite important in the Ouachitas. Much of the complexity of the Jackfork Sandstone-dominated Aly belt ("Maumelle Chaotic Zone" of Viele) may be caused by intimate admixtures of fore- and back-thrusting. The Benton Anticlinorium is probably cored by North American basement; it is probably allochthonous and rides on a thrust that we identify largely with the surface Y City fault. Although some Ouachita sedimentary rocks may have been deposited on transitional or oceanic crust, it is unlikely that a suture is exposed in the Ouachitas. Ouachita *structures* (not lithologies) are similar to Appalachian ones.

[526]

The Effect of Crude Oil Migration on the Redistribution of Hydrocarbons: Possible Implications for Petroleum Exploration

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Recent investigations of shale-sandstone sequences isolated from cores indicate that considerable hydrocarbon redistribution may occur during migration. In the present study, the effects of laboratory simulated oil migration on the stable carbon isotopic composition and the chromatographic distribution of hydrocarbon constituents of crude oils (Model I) and organic-rich shales (Model II) are examined. Model I consists of a preparative HPLC system in which crude oils are passed through water-wet mineral phases, e.g., silica, of varying particle size. After each run, aliquots of the column eluent and extracts of the stationary mineral phase are separated into saturate, aromatic and NSO fractions by column chromatography and further analyzed by gas chromatography, stable isotope mass spectrometry and X-ray fluorescence. In Model II, organic-rich shales and adjacent, clean sands of varying particle size were loaded into high pressure vessels and heated in the presence of water. After heating, portions of the shales and sands were analyzed for their respective hydrocarbon compositions as in Model I. Preliminary results for both models indicate that a redistribution of the C_{15+} aliphatic hydrocarbon fractions in favor of the lower molecular weight components

occurs with increased distance of migration. Stable carbon isotope results suggest that, with increased migration, $\delta^{13}C$ values for the aromatic fraction of oils remain unchanged, while the saturate and NSO fractions become slightly depleted in ^{13}C. Trace element analyses (XRF) indicate that the concentrations of Ni, V and S decrease with increased distance of migration. These phenomena may, in some cases, become accentuated with increasing distance of migration and should be considered when attempting oil/oil or oil/source rock correlations. [528]

Left-Lateral Intraplate Deformation Along the Amarillo–Wichita Uplift, Texas Panhandle and Oklahoma[1]

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The west-northwest trending Amarillo–Wichita Uplift in the Texas Panhandle and southwestern Oklahoma was produced as a result of recurrent large-scale intraplate deformation during the Late Paleozoic Ancestral Rocky Mountain orogeny. The area was broadly folded in the Late Devonian to Early Mississippian. Cambrian through Devonian units were downwarped into the Anadarko Basin, truncated by erosion, and unconformably overlain by Upper Devonian to Mississippian strata. To the south, Mississippian units overlie Ordovician strata and Precambrian basement along the axis of the Texas Arch.

Strike-slip faulting along the axis of the Southern Oklahoma Aulacogen formed the Amarillo–Wichita Uplift during the Pennsylvanian. In the Texas Panhandle, the uplift has been internally deformed into a series of pull-apart grabens which are filled with up to 1500 m of Pennsylvanian arkosic debris. The Whittenburg Trough, a large (15 x 65 km) pull-apart basin along the southwest flank of the uplift, contains about 2300 m of syntectonic deposits. Erosional edges of older units beneath the Mississippian are presently offset 120 km in a left-lateral sense along the uplift. Pre-Mississipian units located in the Hardeman Basin of southwestern Oklahoma originally aligned with those in the western Anadarko Basin of the Texas Panhandle. Restoration to the pre-faulting configuration also realigns offset Proterozoic basement terranes. The orientation of strike-slip and reverse faults and related folds indicate northeast-southwest directed compression during the Pennsylvanian. [533–534]

[1]Study funded by the U.S. Department of Energy under contract no. DE–AC97–83WM46651.

Southward Verging Structures and Coaxial Refolding in the Benton Uplift, Ouachita Mts., Arkansas: A Result of Southerly Directed Thrusting

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The Lower Paleozoic rocks in the Benton Uplift form a series of southward facing, inclined horizontal folds with wavelengths of the order of one kilometer, which have undergone coaxial refolding.

This pattern can be explained by the initiation of folding prior to southerly directed thrusting. The initial folding produced relatively simple upright folds, steep cleavage and sympathetic minor folds. The development of southerly directed thrusting led to these being [overridden] and created the presently observed asymmetry. The incremental strain induced during this second episode can be likened to a simple shear couple between which the pre-existing folds were rotated. Limbs which dipped toward the direction of transport rotated toward the upright position, were shortened and produced symmetrical, second generation folds with axial surfaces normal to the bedding which refolded tight folds of the first episode. Limbs which dipped away from the direction of transport rotated toward the horizontal. They were stretched and experienced a reversal of sense of simple shear which distorted pre-existing minor folds and produced new ones facing in the opposite direction. The early formed cleavage was rotated by the same reversal of simple shear giving the appearance of exaggerated refraction. The cleavage which developed during the second phase is approximately horizontal and transects both limbs of the early folds. The intersection of the two cleavages is parallel to both the first and second fold hinges giving rise to a weak pencil structure parallel to the hinges.

Previous explanations for this southward vergence involved major inversions of the succession and its associated structures in connection with ramping on northward directed thrusts. The explanation tended here suggests such inversions are not necessary but invokes the need for major southward directed thrusting in the Lower Paleozoic rocks involved in the Ouachita Orogenic Belt. [538]

The Youngest Carpoid: Occurrence, Affinities, and Life Mode of a Pennsylvanian Mitrate From Oklahoma

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Abundant, well preserved mitrates occur in the Pennsylvanian (Morrowan) Gene Autry Shale Member, Golf Course Formation, southern Oklahoma, postdating the youngest previously known carpoids (Lower

Devonian) by about 70 million years. The new carpoid has a small (to 4 mm) barrel-shaped theca, with two adaulacophorals covering the superior face and three marginals (two lateral, one central-anterior) forming the inferior face. A stout spine articulates with the anterior marginal. The stylocone and distal aulacophore ossicles each have a prominent spine on the inferior side. These features recall the Middle Ordovician Kirkocystidae.

We hypothesize that most mitrates, including this one, were adapted to an infaunal life mode. The streamlined, generally symmetrical body shape is an adaptation to moving on or through the substrate. Spines and blades on the lower surface of the stylocone and proximal aulacophore are inferred to be adaptations for gripping the substrate as the animal pulled itself backwards (aulacophore first). The single main thecal orifice opposite the aulacophore was the site of both mouth and anus.

The new mitrate is part of a diverse invertebrate fauna dominated by molluscs (cephalopods, scaphopods, polyplacophorans, gastropods, bivalves, and rostroconchs) and echinoderms (crinoids, blastoids, ophiuroids, asteroids, and echinoids). Discovery of a Pennsylvanian mitrate creates a major cryptogene in the Carpoidea and suggests that the record of the "rare" echinoderm classes is far from complete. [586]

Stratigraphy and Tectonic Development of the Southern Ouachita Thrust Belt—Implications of New Subsurface Data, Arkansas

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Recent drilling in southwest Arkansas has provided new constraints on the age, facies and tectonics of the buried Southern Ouachita thrust belt. Results are consistent with Pennsylvanian collision of the North American craton with an island arc/continental fragment via a south-dipping subduction zone. Reprocessing of the Ouachita COCORP seismic line further supports this geometry.

Ouachita facies rocks south of the Benton Uplift consist of deformed Mississippian and Lower Morrowan clastics deposited in a forearc basin setting. Early to middle Ordovician flora found in core and cuttings suggest reworking and sourcing from an older terrane. Unconformably overlying the thrust belt is a post-orogenic sequence of Upper Morrowan, Atokan, and Desmoinesian age rocks. This is a transgressive sequence up to 4,500′ thick that ranges from marginal marine (marsh? through deltaic) clastics to open marine carbonates. This sequence is significantly different from time-equivalent rocks of the Frontal Ouachitas where the Atoka consists of 15-20,000′ of turbidites that have been involved in thrusting. This indicates that the Ouachita orogeny terminated much earlier to the south than to the north.

Palynological analysis from this post-orogenic section identified marine acritarchs and scolecodonts with South American affinities. Their presence suggests deposition south of the North American craton on an exotic basement complex with both a northern and southern provenance. A remnant of this exotic southern terrane apparently remained attached to the North American craton following Triassic rifting and the opening of the Gulf of Mexico. [624]

The Composition of Permian Seawater

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We demonstrated earlier that fluid inclusions in Miocene halite can be used to define the composition of contemporary Miocene seawater. During the past year we have extracted inclusion fluids from halite in the Lower Permian Wellington Formation near Lyons, Kansas and from the Upper Permian Salado Formation near Carlsbad, New Mexico to define the composition of Permian seawater. The extracted inclusion fluids were analyzed by ion chromatography. The concentration of Na^+, Cl^-, and Mg^{+2} in these fluids falls along the evaporation path of present-day seawater. Compared to evaporated modern seawater the solutions are slightly enriched with respect to Br^- and K^+. The excess of these ions is probably due to their transfer from enclosing halite to the inclusion fluids during recrystallization.

The concentration of $SO_4{}^{-2}$ in the inclusion fluids is lower than in evaporated modern seawater. The $SO_4{}^{-2}$ deficit in the fluids from halite in the Wellington Formation is almost certainly due to dolomitization followed by gypsum and/or anhydrite precipitation. No difference between the $SO_4{}^{-2}$ concentration of lower Permian and present-day seawater is required to explain the $SO_4{}^{-2}$ deficit in these fluids. This explanation does not account for the $SO_4{}^{-2}$ deficit in the inclusion fluids from the Salado Formation.

The concentration of Li^+ in the inclusion fluids is higher by a factor of ca. 4 than the concentration to be expected from the evaporation of modern seawater. With this exception, the composition of Permian seawater appears to have been remarkably similar to that of modern seawater. [640]

Carbonate Cements in Desmoinesian and Missourian Limestones and Sandstones of Southeastern Kansas

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Desmoinesian Cherokee Group sandstones and overlying Late Desmoinesian through Late Missourian limestones of southeastern Kansas contain five types of ferroan carbonate cements: (1) early siderite in sandstones, (2) rare, early Fe-calcite in sandstones; (3) post-compactional Fe-calcite in limestones, (4) late-stage Fe-Ca-dolomite in limestones, and (5) late-stage Ca-ankerite in sandstones and in septarian nodules in associated shales. Microprobe analyses indicate that Fe-calcites in both sandstones and limestones have essentially the same composition, while compositions of Ca-Fe-dolomite and Ca-ankerite differ chiefly in Mg/Fe, about 2.5 in Ca-Fe-dolomite and 0.8 in Ca-ankerite. Compositions of Ca-ankerites are constant within and among sand bodies over a large area and are the same as those found in septarian nodules, which also contain sphalerite. Ca-Fe-dolomite cements in overlying limestones show similar compositional consistency despite changing depth, depositional setting, and geographic location.

The differences between the composition of late stage carbonates in sandstones and limestones may be a result of differences of host lithology, not different mode or conditions of formation. The Late Pennsylvanian–Early Permian Ouachita orogeny is the probable source of a regional influence necessary to account for observed compositional consistency. Heated brines derived from sediments of the Ouachita–Arkoma basin system may have caused an anomalously high geothermal gradient in the mid-continent. These fluids may have carried the necessary Mg and Fe or may have caused enough increase in temperature to initiate the conversion of smectite to illite in argillaceous rocks of southeastern Kansas, releasing Mg and Fe. [659]

Organic Geochemistry of Mid-Continent Ordovician Oils

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Early Paleozoic oils (e.g., Ordovician) retain the biochemical imprint of oceanic life (e.g., bacteria, cyanobacteria, green algae, early invertebrates) prior to evolution of land plants and vertebrates. Thus, these oils have geochemical features which make them unique with respect to younger oils, but also share some common properties with the latter. Characteristic mid-continent Ordovician oil features include predominance of n-C_{14} to n-C_{19} over n-C_{20+} (with n-$C_{15, 17,}$ and $_{19}$ dominant) alkanes in the C_{+15} saturate hydrocarbon fraction, low amounts of isoprenoids (i.e., Pr/n-$C_{17} \approx$ 0.06 to 0.2) and abundant C_{27} and C_{29} diasteranes relative to normal steranes.

Properties common to both Ordovician and younger oils are: nearly equal amounts of C_{15+} n-alkanes, cycloalkanes, and aromatics and pristane/phytane ratios of 0.7 to 1.6. Collectively, these Ordovician oils have a relatively negative stable carbon isotopic composition (i.e., $\delta^{13}C_{sat}$ and $\delta^{13}C_{aro} \approx -28$ to $-31‰$) but are not unique with respect to other marine oils. Although terpane distributions are generally similar to geologically younger oils, the Ordovician oils contain significant amounts of C_{19}, C_{20}, and C_{21} tricyclic diterpanes relative to the C_{23} homolog as well as large contributions by C_{31+} pentacyclic triterpanes.

Presence of long-chained n-alkanes (n-C_{25+}), C_{29} steranes, and C_{24} tetracyclic terpanes, which are generally accepted as input from land plants in, e.g., Tertiary deposits, are also present in Ordovician oils. The characteristics listed above describe oils from the Williston and Michigan basins as well as Ordovician oils from Kansas and Oklahoma. [684]

Midcontinent Strategic and Critical Minerals Project

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The Midcontinent SCM Project is a cooperative effort between the USGS and the state geological surveys of SD, MN, WI, NE, IA, IL, KS, MO, OK, AR, KY, and TN. Objectives are to define the principal sedimentary and basement terranes of an area bounded by 36°–46° N. Lat. and 88°–100° W. Long., to develop mineral-occurrence models for these terranes, and to assess the resource potential of the region for strategic and critical minerals.

Maps completed to date, all at 1:1,000,000 scale, show locations and sample availability for more than 3,000 selected deep drill holes; basement geology of more than 50 units composing 8 Precambrian lithologic terranes; isotopic ages of basement rocks; Bouguer gravity anomalies; isopachs of Phanerozoic deposits; and isopachs and clastic/carbonate facies of the Sauk sequence (Cambrian and Lower Ordovician). Other products include 13 N-S and E-W cross sections showing Phanerozoic sequences and principal lithologies; and maps of mineral occurrences, alkaline and related igneous rocks, and potentiometric surface and salinity of water in Cambrian–Ordovician and Mississippian rocks. Topical projects include fluid-inclusion, petrographic, and geochemical studies of Mississippi Valley-type Pb-Zn mineralization; and studies of S isotopes in mineralized and unmineralized rocks, the relation of metal anomalies in basal sandstones to basement lithologies, and the paleo-hydrodynamics of metal-bearing fluids.

New regional and topical studies now underway include a regional tectonic map; an isopach/lithofacies map and detailed E-W cross-sections of Mississippian carbonates; sedimentary Mn potential of the Zuni strandline; southern extension of the Early Proterozoic Wisconsin magmatic zone and Archean gneiss; and lithology and geophysics of the Keweenawan rift system. [692–693]

Responses to Cycles Within and Among Pennsylvanian Basins: Migration, Ecotypy or Evolution?

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First appearances of distinct morphologies in a region can be due to migration from another region, or a plastic response in an incumbent taxon to new habitat conditions, or speciation within the region (perhaps following migration and isolation). The cyclic strata in North America's Pennsylvanian basins provide a laboratory in which the migration hypothesis and ecophenotypic responses can be tested. Species-level status should only be conferred after these alternatives have been eliminated.

Sample populations of the archaeogastropod genus *Glabrocingulum* from north-central Texas, Oklahoma, the Appalachian Basin, Illinois, Colorado and New Mexico have been studied using the above guidelines. Ecophenotypic effects have been recognized within and among cycles in a basin. Migration appears responsible for many more first appearances than speciation, using two lines of morphological evidence (shell coiling and surface sculpture) to rule out covergence between species in different basins. Each species persists for several cycles within a basin, indicating the presence of refugia during regressions. Extinctions within a basin are followed by immigration of some, but not all available forms present in adjacent regions. This lack of wide distribution suggests long-term isolation among basins, with only brief, infrequent and filtered interchange. Despite repeated environmental stress and opportunities for geographic isolation, species of this genus display few splitting events. [709]

The Colonial Rugose Coral Genus *Petalaxis* in the Middle Carboniferous of North America and Its Stratigraphic Significance

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The colonial rugose coral genus *Petalaxis* has an extensive world wide distribution in the Middle Carboniferous System. This interval includes the Bashkirian and Moscovian in the USSR where these corals are common in the Urals, Moscow Basin, Donetz Basin and the Voronezh Anteclise. The genus also occurs commonly in both the Bashkirian and Moscovian of Spain and in the early Moscovian of Japan.

The approximate equivalent stratigraphic interval in North America includes the Morrowan, Atokan and Desmoinesian Series of the Pennsylvanian System. Colonial rugose corals are rare in this interval primarily as the result of adverse terrigenous facies in most areas. Recent studies, however, have produced as yet undescribed species of *Petalaxis* at the following four widely distributed localities in the southern Mid-continent: (1) Ozarks, NE Oklahoma, Sausbee Fm, Brewer Bend Mbr; (2) Ardmore Basin, So Oklahoma, Jolliff Ls; (3) Llano Uplift, central Texas, Marble Falls Ls; & (4) Bishop Cap-Organ Mts, So New Mexico, La Tuna Fm. All of these occurrences are from strata of Morrowan age and the first three occur with the conodont zone *Idiognathodus sinuosis*. In the Ozark area there is also the abundant occurrence of the goniatite *Branneroceras branneri*, which indicates a correlation with the western European goniatite zone G2. An age determination of the New Mexico locality is less precise but conodonts suggest a middle or late Morrowan age and the corals occur with the Morrowan brachiopod *Tesuquea formosa*. It is startling that all four of these only known middle Carboniferous occurrences in North America are in strata of very nearly the same age. They may represent a single migration of the genus into North America and they will provide a basis for comparison with other Bashkirian occurrences in the world. [730]

Total (Finite) Strain in the Interiors of Thrust Sheets, Benton Uplift, Ouachita Mountains

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[Carbonate] rocks in the Collier Formation (Lower Ordovician), the oldest exposed unit in the Arkansas Ouachitas, can be expected to provide the most complete strain information from the core of the mountain belt. Previous analysis of fibrous crystal growth in syntectonic fractures indicates that the rocks have experienced up to 4 increments of noncoaxial progressive strain. This study shows that total (finite) strain within thrust sheets averaged 75% and was relatively homogeneous over an outcrop area of about 250 km^2, increasing only near thrust fault traces.

The carbonate rocks contain deformed ooids, mud pellets, and fecal(?) pellets in a micrite matrix. Rf/Φ plots from most XY planes were markedly asymmetrical, probably due to the noncoaxial strain history. Where Rf/Φ data could be used, differences in strain of ooids and pellets in the same samples suggest 14% to 18% pretectonic volume loss due to compaction. 'Autocovariance' (Fry) analyses of pellets show that matrix strain exceeded pellet strain by 20% to 30%, indicating that crystal plasticity fails to account for total bulk strain. Evidence for synchronous pressure solution has been observed, and grain boundary sliding probably occurred due to high P_f during deformation. An acceptable total strain model suggests that the rocks experienced about 20% volume loss during pretectonic compaction followed by 2% negative dilation per 10% tectonic strain to the average 75% total plane strain. Monoclinic symmetry of most mesoscopic structural elements indicates that regional deformation approximated simple shear. [745]

Structural and Stratigraphic Fabric of the Ouachita Thrustbelt, Ok. and Ark.: A Paleozoic Accretionary Complex

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The Ouachita thrustbelt of Ok. and Ark. demonstrates many of the stratigraphic and structural relationships typical of heavily sedimented modern accretionary complexes. The Ouachita accretionary complex initially developed in Dev.–Miss. time above a south-dipping subduction zone exotic to the then southern margin of N. America. Emplacement onto the N. American margin took place, with associated development and deformation of the Arkoma foreland basin, in the Pennsylvanian.

The highly deformed L. Paleozoic units (through the Arkansas Novaculite) may be interpreted as accreted material, the overlying less deformed turbidites (Stanley and Jackfork groups and, in part, the Atoka) as trench and trench-slope (ponded basin) deposits. Regional structural fabric, sequential deformational history, surface and subsurface stratigraphic relationships, sedimentary provenance, and limited paleontological affinity data are all consistent with this tectonic setting as demonstrated in active equivalents.

A comparison is made with the Tertiary to recent accretionary complex of the Makran, where internal tectonostratigraphic fabric, as revealed by surface geology and offshore seismic data, is directly analogous to aspects of the internal fabric of the Ouachita thrustbelt. Application of this concept can provide a powerful means of refining our view of the tectonic history of the Ouachitas. For example, domains of true reverse (southward) structural vergence may not be accounted for by rotation alone but can be interpreted as resulting from the effects of a strong seaward-dipping anisotrophy typically developed in some modern complexes (e.g., Oregon–Washington). [746]

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