Oklahoma Notes

OKLAHOMA GEOLOGICAL SURVEY VOL. 48, NO. 2 APRIL 1988

On the cover—

A Fossil Pennsylvanian Lycopod, Robbers Cave State Park

A fossilized compression of a Middle Pennsylvanian lycopod tree, identified by the writer as *Lepidodendron obovatum*, is exposed on the surface of the Bluejacket Sandstone Member of the Boggy Formation in the SW¼NE¼SE¼NW¼ sec. 13, T. 6 N., R. 18 E., Latimer County, Oklahoma, in Robbers Cave State Park. Lycopods comprise 10–20% of most compression floras of the Middle Pennsylvanian (Gillespie and others, 1978, p. 43).

The plant fossil shown in the photograph is one of many uncovered during the preparation of a gas-well site in the park. It was discovered while mapping the Wilburton 7.5′ Quadrangle for the Oklahoma Geological Survey's COGEOMAP project and will be visited during the AIPG field trip this fall. Other plant fossils exposed at the site include *Stigmaria ficoides*, the rootlike organs of *Lepidodendron*; *Calamites*, the ridged and jointed woody stems of relatives of modern scouring rushes that once grew up to 40 ft high; *Cordaites*, the strap-shaped, parallel-veined leaves of gymnospermous trees that grew as much as 125 ft high; as well as an abundance of seed-fern leaves. Small fossil twigs of *Lepidodendron*, the "scale tree,"are also exposed at the site. Because the diamond-shaped leaf cushions that occur in spirals around younger trunks and twigs have the appearance of scales, many finders believe they have discovered a fossil snake. It is, of course, impossible to "find the head" as proof (Gillespie and others, 1978, p. 43).The diamond-shaped leaf cushion actually represents the leaf base left behind after the leaf drops off (Fig. 1).

Some *Lepidodendron* trees grew to heights in excess of 100 ft and were at least 6 ft in diameter at the base. The massive, erect trunks of some species branched profusely to produce large crowns of leafy twigs. Some leaves were as much as 3 ft long (Taylor, 1981, p. 131). Figure 2 is a reconstruction of a *Lepidodendron* showing the rootlike organs (*Stigmaria*), as well as the trunk and branching crown.

(continued on p. 95)

OKLAHOMA GEOLOGICAL SURVEY
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OKLAHOMA GEOLOGICAL SURVEY VOL. 48, NO. 2 APRIL 1988

FUSULINID EVIDENCE FOR THE AGE AND CORRELATION OF THE "BROWNVILLE LIMESTONE" IN PAWNEE COUNTY, OKLAHOMA

George J. Verville[1] *and George A. Sanderson*[2]

Abstract

Schwagerina longissimoidea (Beede), *S. campa* Thompson, *Triticites ventricosus* (Meek and Hayden), and *T. inflatus* White have been identified from rocks in Pawnee County considered to be Late Pennsylvanian (Virgilian) in age and mapped as the "Brownville Limestone." These fusulinids are restricted stratigraphically to the lower Council Grove Group (Early Permian, Wolfcampian) in southern Kansas and to the early Wolfcampian Saddle Creek Limestone and Camp Creek Shale of north-central Texas. Fusulinids characteristic of the "Brownville Limestone" of Kansas are absent in the so-called "Brownville" in Pawnee County. The faunal evidence suggests a need for restudy of lithostratigraphy and biofacies of strata flanking the Pennsylvanian–Permian boundary in northern Oklahoma.

Introduction

The outcropping rocks in Pawnee County were described and mapped by P. B. Greig (1959), who noted the presence of fusulinids in many of the Late Pennsylvanian and Early Permian limestones but apparently made no attempt to utilize them for age determination or correlation. While our long-range objective is to document these fusulinid faunas and demonstrate their biostratigraphic significance, this note is concerned solely with the age and correlation of fusulinids collected from rocks assigned to the Late Pennsylvanian "Brownville Limestone" in Pawnee County.

Biostratigraphy

The fusulinid species *Schwagerina longissimoidea* (Beede), *S. campa* Thompson, *Triticites ventricosus* (Meek and Hayden), and *T. inflatus* White occur in outcrops mapped as the "Brownville Limestone" in Pawnee County by Greig (1959). These fusulinids, illustrated in Plates 1–3, are characteristic of Early Permian (Wolfcampian) strata throughout North America. All of the species identified occur in

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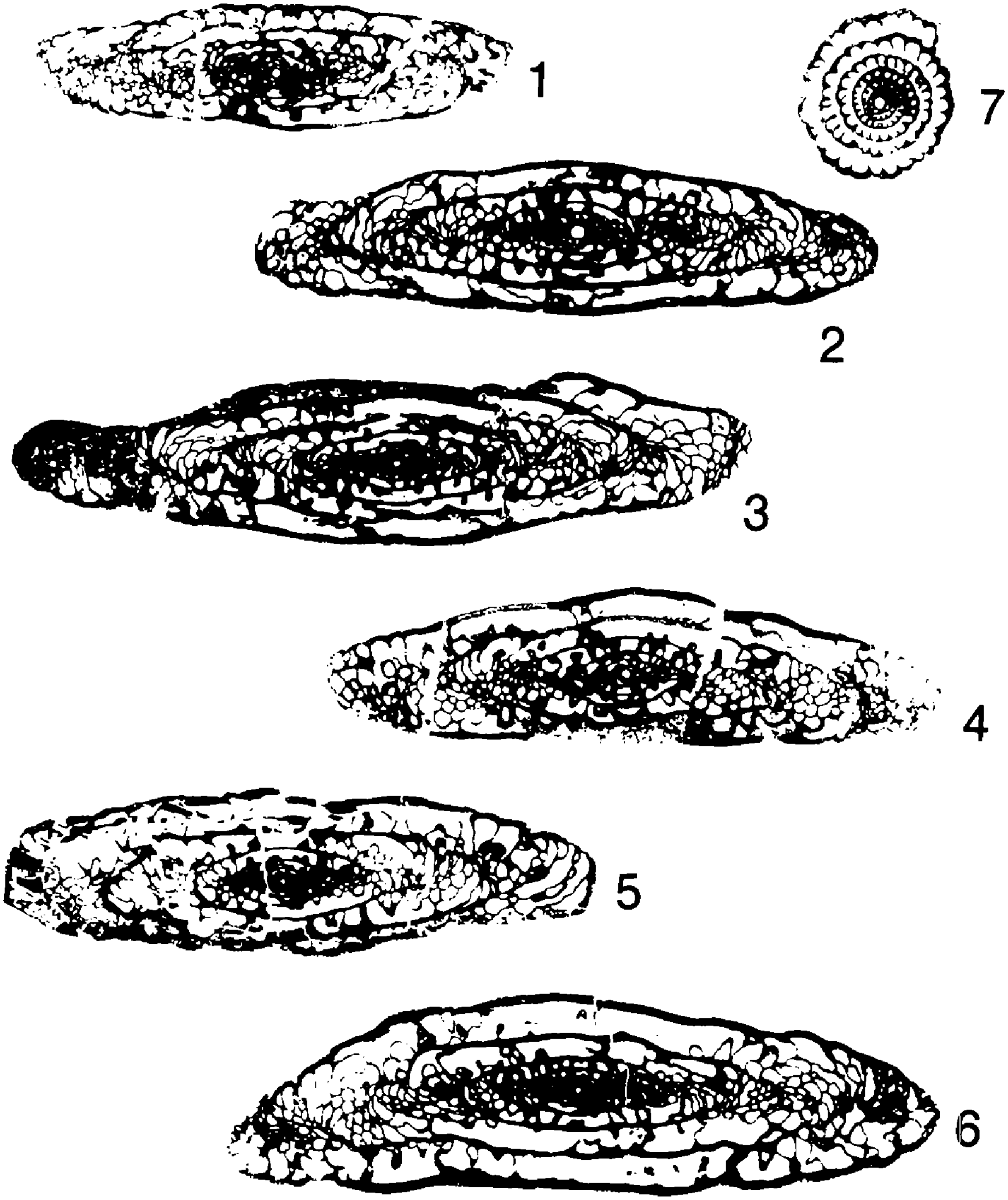

Plate 1. Figures 1–7, *Schwagerina longissimoidea* (Beede), × 10; 1–6, axial sections; 7, sagittal section. "Brownville Limestone" road cut, SE¼NE¼SE¼ sec. 17, T. 21 N., R. 6 E., Pawnee County, Oklahoma.

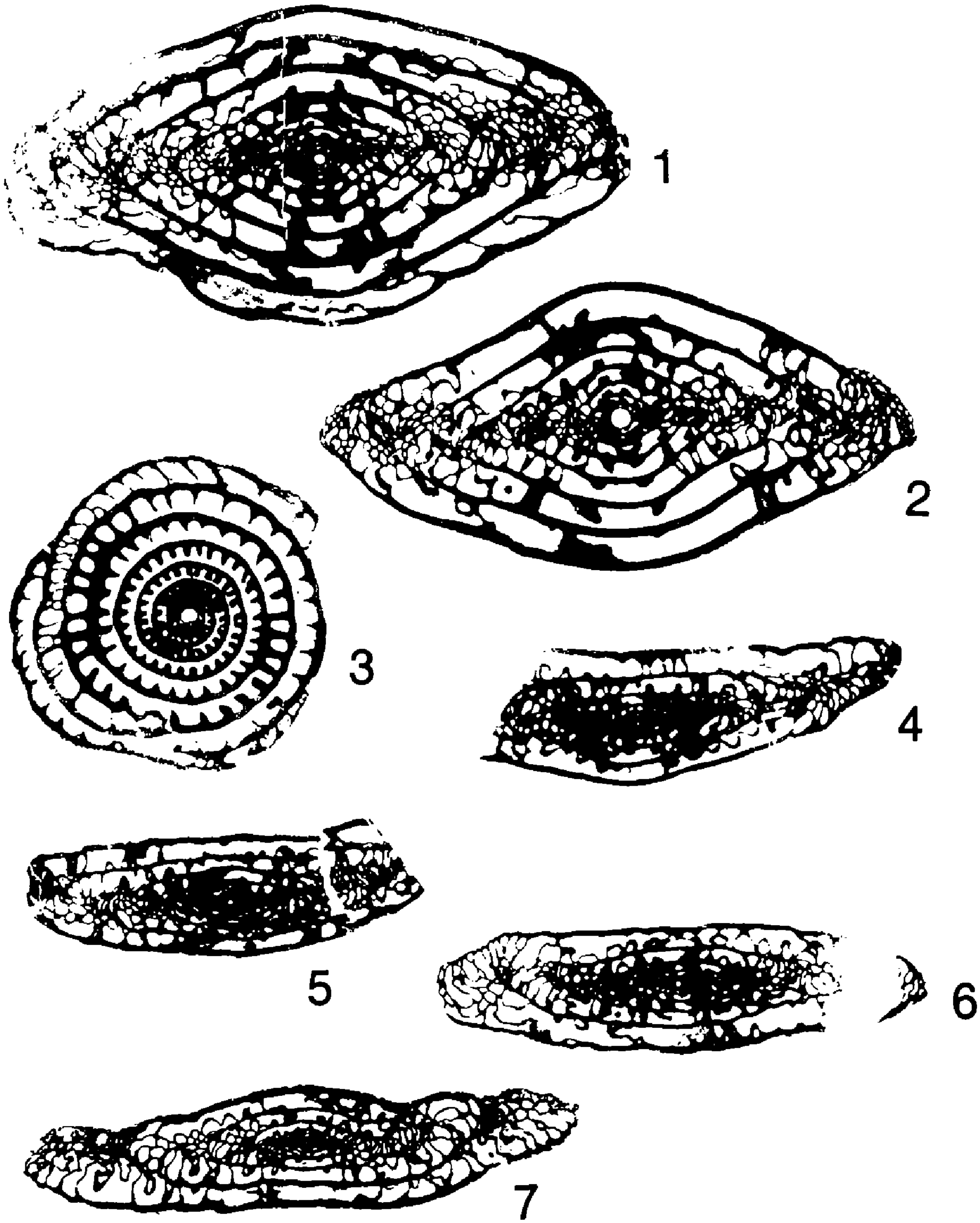

Plate 2. Figures 1–3, *Triticites ventricosus* (Meek and Hayden), × 10; 1,2, axial sections; 3, sagittal section. "Brownville Limestone" road cut, SE¼NE¼SE¼ sec. 17, T. 21 N., R. 6 E., Pawnee County, Oklahoma. Figures 4–7, *Schwagerina campa* Thompson, × 10; 4–7, axial sections. "Brownville Limestone" road cut, NW¼NW¼SW¼ sec. 20, T. 20 N., R. 6 E., Pawnee County, Oklahoma.

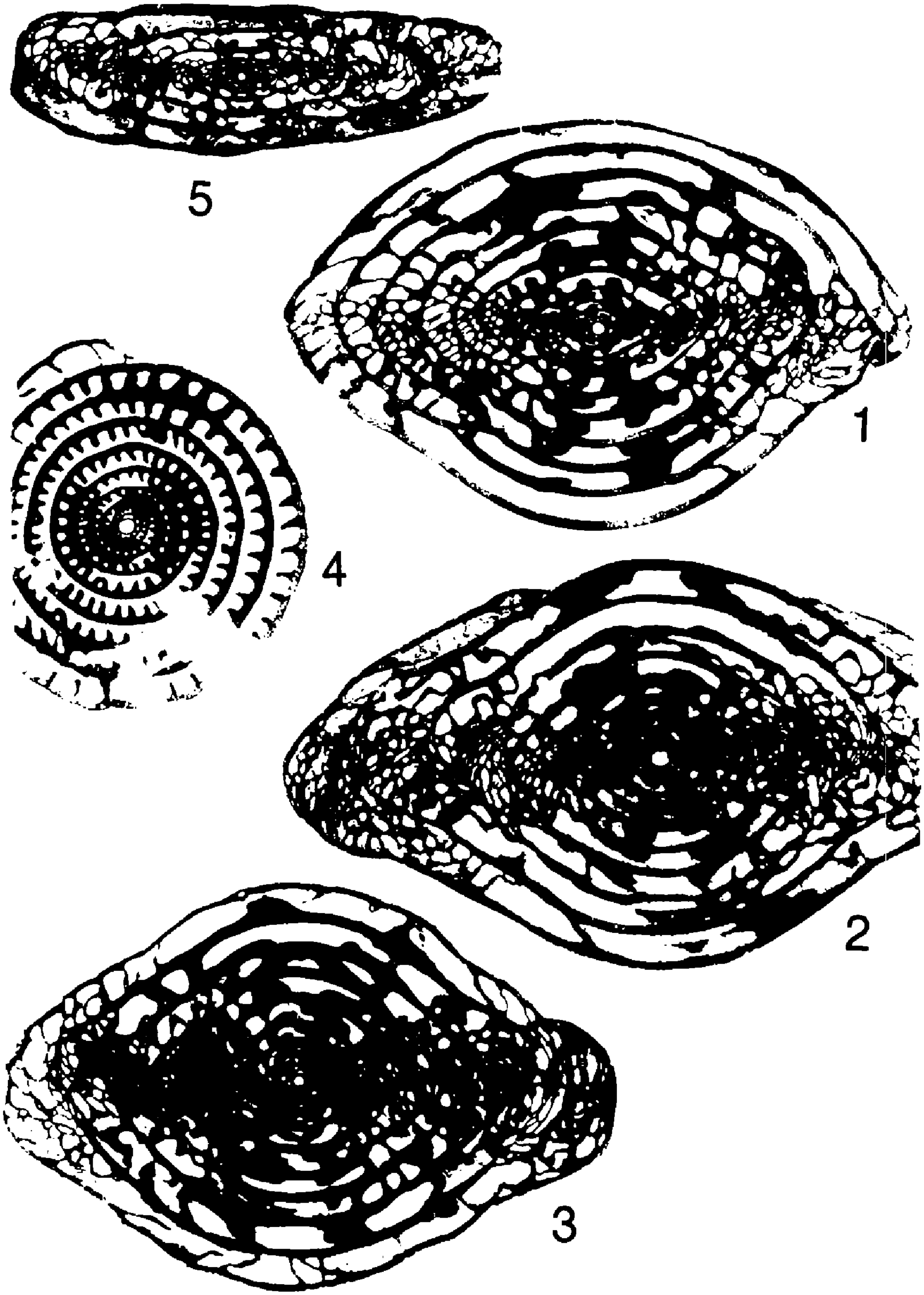

Plate 3. Figures 1–4, *Triticites inflatus* White, × 10; 1–3, axial sections; 4, sagittal section. "Brownville Limestone" road cut, NW¼NW¼SW¼ sec. 20, T. 20 N., R. 6 E., Pawnee County, Oklahoma. Figure 5, *Schwagerina longissimoidea* (Beede), × 10; 5, axial section. "Brownville Limestone" road cut, NW¼NW¼SW¼ sec. 20, T. 20 N., R. 6 E., Pawnee County, Oklahoma.

the lower part of the Council Grove Group (Foraker Limestone) of Kansas as well as in the Saddle Creek Limestone and Camp Creek Shale of north-central Texas. By contrast, the forms characteristic of the Brownville in Kansas are absent from the so-called "Brownville" in Pawnee County. Apparently the facies changes which occur southward from the more-marine section in Kansas to the northeastern Oklahoma shelf are more complex than previously recognized, indicating a need for reevaluation of the strata adjacent to the Pennsylvanian–Permian boundary.

Fusulinids

Schwagerina longissimoidea was described by Beede (1916) from the lower part of the Elmdale Formation (now the Foraker Limestone) near Foraker, Oklahoma. *S. longissimoidea* also has been identified in the Hughes Creek Shale and Neva Limestone of Kansas; the Waldrip No. 3 Limestone and Camp Creek Shale of north-central Texas; the Ferguson Mountain Formation of east-central Nevada; and the Wildcat Peak Limestone of west-central Nevada. The species is illustrated on Plate 1, Figures 1–7, and Plate 3, Figure 5.

Schwagerina campa, named by M. L. Thompson (1954) from the Glenrock Limestone Member of the Red Eagle Formation, is illustrated on Plate 2, Figures 4–7. A smaller but closely similar form, *Pseudofusulina delicata*, was reported by R. C. Douglass (1962) from the Five Point Limestone Member of the Janesville Shale in southeastern Kansas.

Triticites ventricosus (Meek and Hayden, 1858) was described from "Juniata on Blue River and Manhattan on the Kansas," from rocks now assigned to the Hughes Creek Shale Member of the Foraker Limestone. For many years the morphologic variability of *T. ventricosus* was given considerable latitude, and many large forms of Late Pennsylvanian and Early Permian *Triticites* were assigned to the species. In 1954 Thompson designated one of the originally illustrated specimens as the holotype, thus restricting the concept of the species. Thompson regarded *T. ventricosus sensu stricto* as having a narrow stratigraphic range and occurring only in the Hughes Creek Shale. *T. ventricosus* (Meek and Hayden) *sensu lato* has been reported from Early Permian rocks throughout North America. Our specimens from the "Brownville" in Oklahoma are illustrated on Plate 2, Figures 1–3.

Triticites inflatus White is from the Saddle Creek Limestone of north-central Texas. This exceptionally large species was considered by Galloway and Ryniker (*in* White, 1932) to be a variety of *T. ventricosus*. Kauffman and Roth (1966) considered *T. ventricosus* var. *inflatus* to be sufficiently different from *T. ventricosus sensu stricto* to warrant raising it to specific status. The species, which is also known from the Camp Creek Shale of Texas, is illustrated by our specimens on Plate 3, Figures 1–4.

The fusulinid fauna of the "Brownville Limestone" member of the Wood Siding Formation in Kansas, which was described and illustrated by R. C. Douglass (1962), consists of *Leptotriticites brownvillensis* (Douglass), *Leptotriticites eoextentus* (Thompson), and *Millerella inflata* (Thompson). None of the species recovered from the "Brownville Limestone" in Pawnee County, Oklahoma, has ever been found in the Pennsylvanian Brownville Limestone of Kansas, but they are well known in the younger rocks of the Council Grove Group in Kansas and could conceivably occur also in more-marine portions of the Admire Group.

Thus, it appears that the so-called "Brownville Limestone" in Oklahoma has been miscorrelated and is of Wolfcampian rather than Virgilian age. Although there are differing opinions regarding placement of the systemic boundary, the fact remains that the Pawnee County "Brownville" does not appear to be the temporal equivalent of its Kansas namesake. This change in stratigraphic interpretation calls into question the age assignments of other Wolfcampian and Virgilian strata in northeastern Oklahoma. The latter are now under investigation.

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OKLAHOMA EARTHQUAKES, 1987

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

Instrumentation

A statewide network of 11 seismograph stations was used to locate 69 earthquakes in Oklahoma for 1987 (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 modified Sprengnether MEQ-800-B unit, including amplifier, filters, hot-stylus heat-sensitive-paper recording unit, and a clock; and a Kinemetrics time-signal-radio receiver for high-frequency WWV time signals. Each radio-telemetry system consists of one Geotech S-13 seismometer and one radio-telemetry unit. The telemetry unit amplifies the seismometer output and uses this output to frequency-modulate an audiotone. The signals are transmitted to Leonard in the 216- to 220-MHz band with 500-mW transmitters and 11-element beam antennas, giving an effective radiated forward power of 12.9 W. Transmission paths lengths vary from 50 to 75 km. Seismograms from the radio-telemetry stations are recorded at the Oklahoma Geophysical Observatory.

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

On October 15, the station at Bethel, BHO, was closed. A new station near Pickens, PKO, which opened on October 15 and located 16 km west of Bethel, was closed on December 12 because the operator moved. We are looking for a new site. On October 21, the seismometer at MEO was moved to a solid basalt ledge at 2 m depth in a turn-of-the-century gold-mine prospect shaft. The move

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[2]Oklahoma Geological Survey.

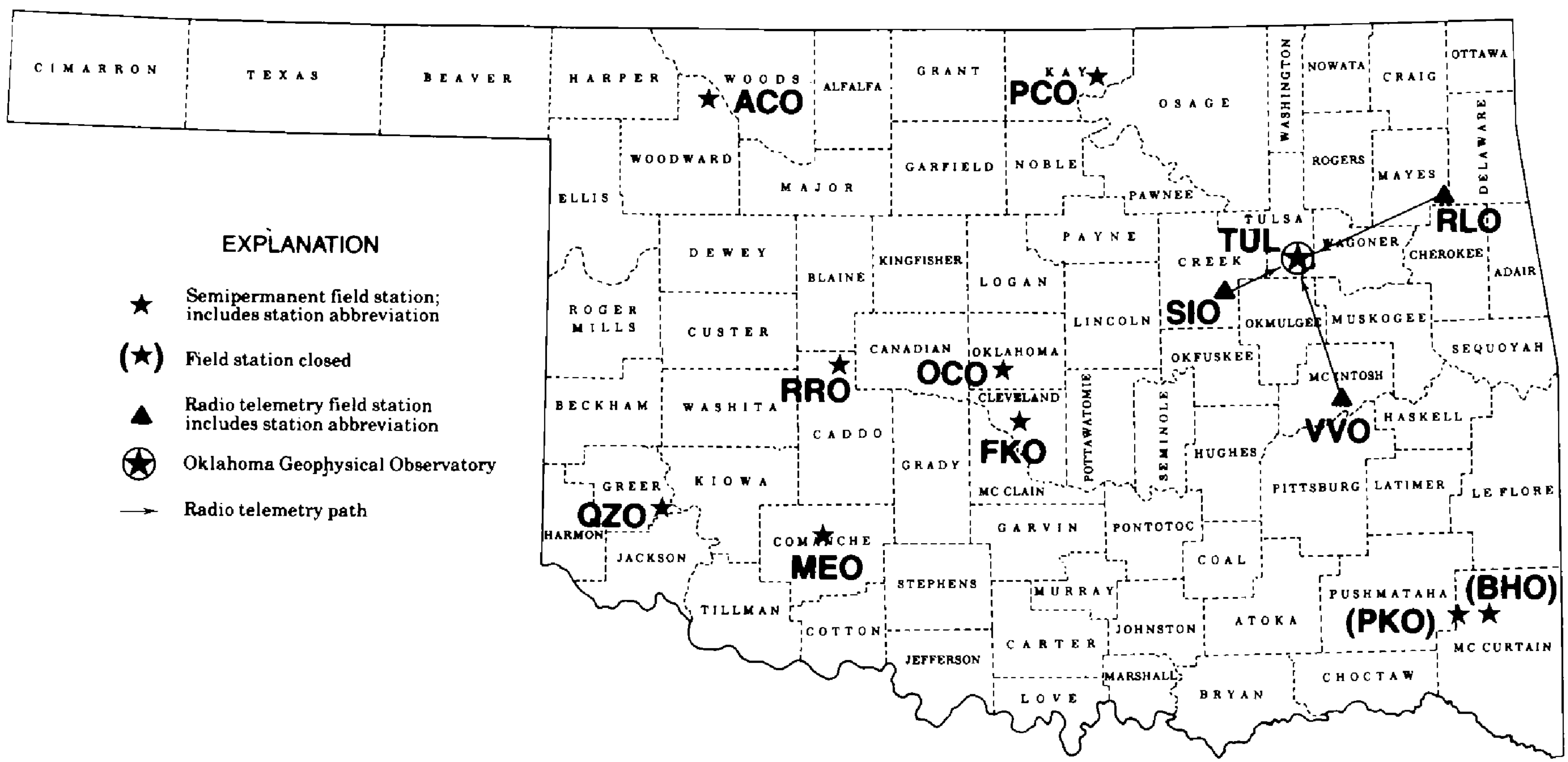

Figure 1. Active seismographs in Oklahoma.

decreased ground noise caused by wind and traffic, doubling the sensitivity for detection of local and distant earthquakes. A new station (FKO) began operation in northeast Norman on November 9. The station is operated by Dr. Judd Ahern, University of Oklahoma geophysics professor, and has equipment identical to that of the seven volunteer-operated stations. The records are archived at the Oklahoma Geophysical Observatory.

Data Reduction and Archiving

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

From statio 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 seven 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 1987, 69 Oklahoma earthquakes were located (Fig. 2; Table 1). Two 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).

On January 24, a magnitude 3.1 (mbLg) earthquake occurred ~15 km west of Kingfisher, north-central Oklahoma. This earthquake had a felt area of ~900 km^2 and no damage was reported (Fig. 3). The earthquake produced effects of intensity MM V in the Hennessey, Kingfisher, and Okarche areas (Fig. 3).

On December 8 at 7:42 p.m. CST, north-central Oklahoma experienced a moderate earthquake. The magnitude 3.7 (mbLg) earthquake was centered 14 km southwest of Hennessey. Some minor damage, such as broken windows, cracked plaster, and broken knickknacks, was reported. The earthquake, which had a felt area of 11,200 km^2, produced effects of intensity MM VI in the Hennessey, Kingfisher, and Piedmont areas (Fig. 3). A small, nonfelt aftershock, magnitude 2.5 (m3Hz), followed about 3 minutes later.

Earthquake-magnitude values range from a low of 1.2 (MDUR) in Rogers County to a high of 3.7 (mbLg) in Kingfisher County. Garvin and McClain Counties continue to be one of the most active areas in the State since 1979. Canadian County, which has had no reported earthquakes since 1983, contained two

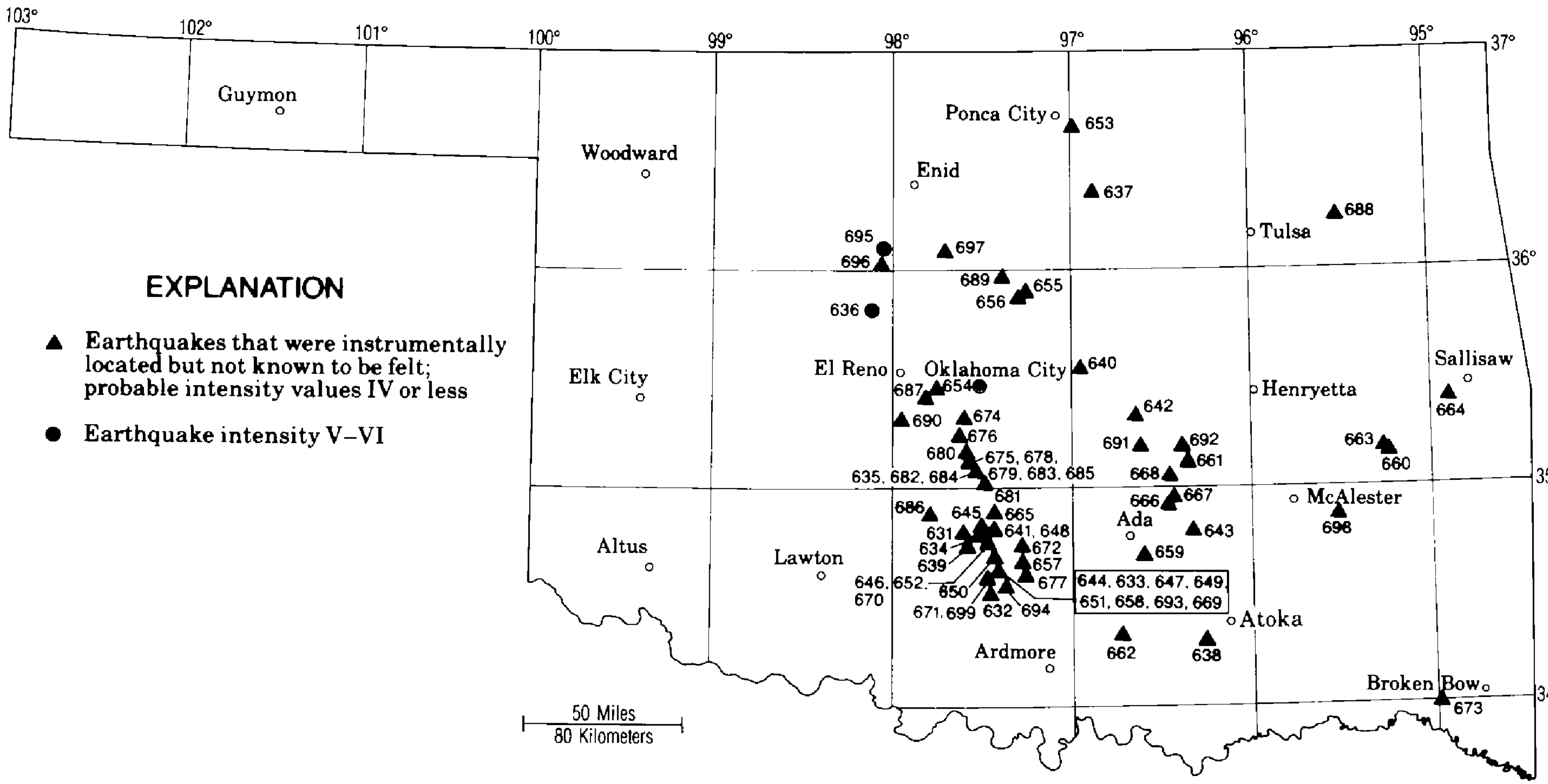

Figure 2. Distribution of Oklahoma earthquakes for 1987. Numbers correspond to event numbers in Table 1.

TABLE 1.—OKLAHOMA EARTHQUAKE CATALOG FOR 1987

Event Number	Date and Origin Time (UTC)[a]		County	Intensity MM[b]	Magnitudes 3 Hz	bLg	DUR	Latitude deg N	Longitude deg W	Depth (km)[c]
631	JAN 6	080049.33	GARVIN				1.9	34.815	97.576	5.0R
632	JAN 10	032149.95	GARVIN		2.7	2.3	2.3	34.552	97.425	5.0R
633	JAN 12	060902.22	GARVIN		2.4	2.1	2.0	34.652	97.390	5.0R
634	JAN 16	031625.33	GARVIN				1.7	34.812	97.526	5.0R
635	JAN 17	041353.77	McCLAIN		2.3	2.3	2.2	35.051	97.517	5.0R
636	JAN 24	160817.01	KINGFISHER	5	3.4	3.1	2.8	35.828	98.097	5.0R
637	JAN 27	063623.00	PAWNEE				1.5	36.339	96.885	5.0R
638	JAN 29	000053.22	ATOKA		2.5	2.6	2.3	34.318	96.234	5.0R
639	FEB 4	134523.93	GARVIN				1.7	34.757	97.558	5.0R
640	FEB 16	005356.45	LINCOLN				1.3	35.574	96.960	5.0R
641	FEB 19	055011.47	GARVIN		2.0	2.1	2.1	34.836	97.488	5.0R
642	FEB 26	020407.15	SEMINOLE		2.0	1.9	2.1	35.308	96.620	5.0R
643	MAR 14	044303.54	HUGHES			2.8	2.7	34.790	96.331	5.0R
644	APR 22	012937.34	GARVIN				1.5	34.603	97.384	5.0R
645	APR 22	014000.61	GARVIN		1.7		2.0	34.845	97.515	5.0R
646	APR 22	031634.91	GARVIN		1.9	1.5	1.9	34.764	97.503	5.0R
647	APR 22	062747.84	GARVIN		2.4	2.0	2.4	34.591	97.394	5.0R
648	APR 22	085505.60	GARVIN				1.9	34.817	97.421	5.0R
649	APR 22	093526.00	GARVIN				1.4	34.591	97.394	5.0R
650	APR 22	094651.31	GARVIN		2.1	1.4	2.1	34.692	97.437	5.0R
651	APR 22	112309.45	GARVIN				1.5	34.591	97.394	5.0R
652	APR 22	130137.89	GARVIN		2.3	2.2	2.3	34.798	97.460	5.0R
653	MAY 7	073345.89	OSAGE		1.8		1.9	36.636	96.986	4.9
654	MAY 15	082907.53	CANADIAN		2.2		2.1	35.455	97.749	5.0R
655	MAY 17	054104.87	LOGAN		2.0	1.7	2.0	35.890	97.236	5.0R
656	MAY 17	150119.86	LOGAN		1.6		1.5	35.878	97.264	5.0R
657	MAY 28	191802.68	GARVIN		1.8		1.6	34.683	97.276	5.0R
658	JUN 1	174433.18	GARVIN		2.8	2.9	2.6	34.615	97.380	5.0R
659	JUN 2	202536.96	PONTOTOC		2.2		1.9	34.707	96.555	5.0R
660	JUN 7	073524.33	HASKELL				1.5	35.165	95.280	5.0R
661	JUN 18	022156.74	HUGHES		1.7	1.9	2.1	35.118	96.347	5.0R
662	JUN 29	072620.96	JOHNSTON		2.0	1.5	1.7	34.335	96.726	5.0R
663	JUL 5	222300.58	HASKELL		2.2		2.1	35.188	95.289	5.0R
664	JUL 8	033928.79	SEQUOYAH				1.5	35.393	94.892	5.0R
665	JUL 12	114450.94	McCLAIN				1.7	34.886	97.421	5.0R
666	JUL 18	151144.75	HUGHES		2.2		1.7	34.927	96.437	5.0R
667	AUG 23	170646.49	HUGHES		1.8		2.0	34.945	96.421	5.0R
668	AUG 29	093624.62	HUGHES				1.6	35.079	96.464	5.0R
669	SEP 3	221012.42	GARVIN		2.3	2.1	1.9	34.623	97.401	5.0R
670	SEP 5	034248.46	GARVIN		1.4		1.6	34.779	97.475	5.0R
671	SEP 6	101422.26	GARVIN		2.0	2.4	2.0	34.600	97.435	5.0R
672	SEP 7	071324.87	GARVIN				1.6	34.759	97.273	5.0R
673	SEP 17	123839.34	McCURTAIN		1.3		1.6	34.014	94.945	5.0R
674	SEP 21	133152.93	CLEVELAND		1.6	1.7	1.7	35.310	97.608	5.0R
675	SEP 21	135324.77	McCLAIN		2.2	2.2	2.1	35.119	97.536	5.0R
676	SEP 21	135959.47	McCLAIN		1.4		1.9	35.249	97.626	5.0R
677	SEP 21	141009.97	GARVIN		1.2		1.6	34.623	97.259	5.0R
678	SEP 21	142507.07	McCLAIN		2.0	1.9	2.0	35.129	97.570	5.0R
679	SEP 21	145245.57	McCLAIN		1.7		1.9	35.119	97.557	5.0R
680	SEP 21	150808.37	McCLAIN		1.8	2.0	2.0	35.178	97.575	5.0R
681	SEP 21	160032.05	McCLAIN		1.3		1.7	35.025	97.493	5.0R
682	SEP 21	160958.21	McCLAIN		1.7		1.9	35.057	97.524	5.0R
683	SEP 22	050836.11	McCLAIN		0.7			35.155	97.552	5.0R
684	SEP 22	052713.27	McCLAIN		1.4		1.8	35.046	97.518	5.0R
685	SEP 22	060735.83	McCLAIN		2.0	2.0	2.3	35.145	97.552	5.0R
686	SEP 22	071537.50	GRADY		1.8	1.9	2.1	34.900	97.786	5.0R
687	SEP 24	021847.39	CANADIAN		1.4		1.8	35.406	97.815	5.0R
688	OCT 2	052220.74	ROGERS				1.2	36.240	95.534	5.0R
689	OCT 5	035847.36	LOGAN		2.0		1.7	35.961	97.359	5.0R
690	OCT 23	140149.23	GRADY		2.9	2.5	2.4	35.328	97.904	5.0R
691	OCT 29	075333.65	SEMINOLE		2.6	1.9	2.5	35.215	96.589	5.0R
692	NOV 13	030456.30	HUGHES				1.1	35.204	96.370	5.0R
693	DEC 6	174348.18	GARVIN		3.0	2.6	2.6	34.664	97.394	5.0R
694	DEC 7	004400.95	GARVIN				2.0	34.581	97.348	5.0R
695	DEC 8	014240.28	KINGFISHER	6		3.7	3.6	36.055	98.024	5.0R
696	DEC 8	014547.47	KINGFISHER		2.5			36.056	98.030	5.0R

TABLE 1.—*Continued*

Event Number	Date and Origin Time (UTC)[a]		County	Intensity MM[b]	Magnitudes 3 Hz	bLg	DUR	Latitude deg N	Longitude deg W	Depth (km)[c]
697	DEC 12	030424.67	KINGFISHER		1.6		1.9	36.049	97.678	5.0R
698	DEC 16	070458.60	PITTSBURG		2.3		2.1	34.877	95.512	5.0R
699	DEC 29	043919.16	GARVIN		2.5		2.1	34.619	97.462	5.0R

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

TABLE 2.—EARTHQUAKES THAT WERE REPORTED FELT IN OKLAHOMA, 1987

Event No.	Date and Origin Time (UTC)[a]		Nearest City	County	Intensity MM[b]
636	JAN 24	160817.01	Kingfisher	Kingfisher	V
695	DEC 8	014240.28	Hennessey	Kingfisher	VI

[a]UTC refers to Coordinated Universal Time, formerly Greenwich Mean Time. The first two digits refer to the hour on a 24-hour clock. The next two digits refer to the minute, and the remaining digits are the second. To convert to local Central Standard Time, subtract 6 hours.
[b]Modified Mercalli (MM) earthquake-intensity scale (see Table 3).

locatable earthquakes. The Arkoma basin, which includes all or parts of Pontotoc, Coal, Hughes, McIntosh, Pittsburg, Latimer, and Le Flore Counties, experienced several low-magnitude earthquakes.

Catalog

A desk-top computer system, including linked HP-9825T and HP-9835A computers, hard and flexible disks, printers, and plotters, is used to calculate, catalog, and map local earthquake epicenters. Any earthquake within Oklahoma or within about 100–200 km of Oklahoma's borders is considered a local earthquake. A catalog containing date, origin time, county, intensity, magnitude, location, focal depth, and references is printed in page-sized format. Table 1 contains 1987 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, 1980–87).

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

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 person 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.

clock. The next two digits refer to the minute, and the remaining digits are the seconds. To convert to local Central Standard Time, subtract 6 hours.

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

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

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

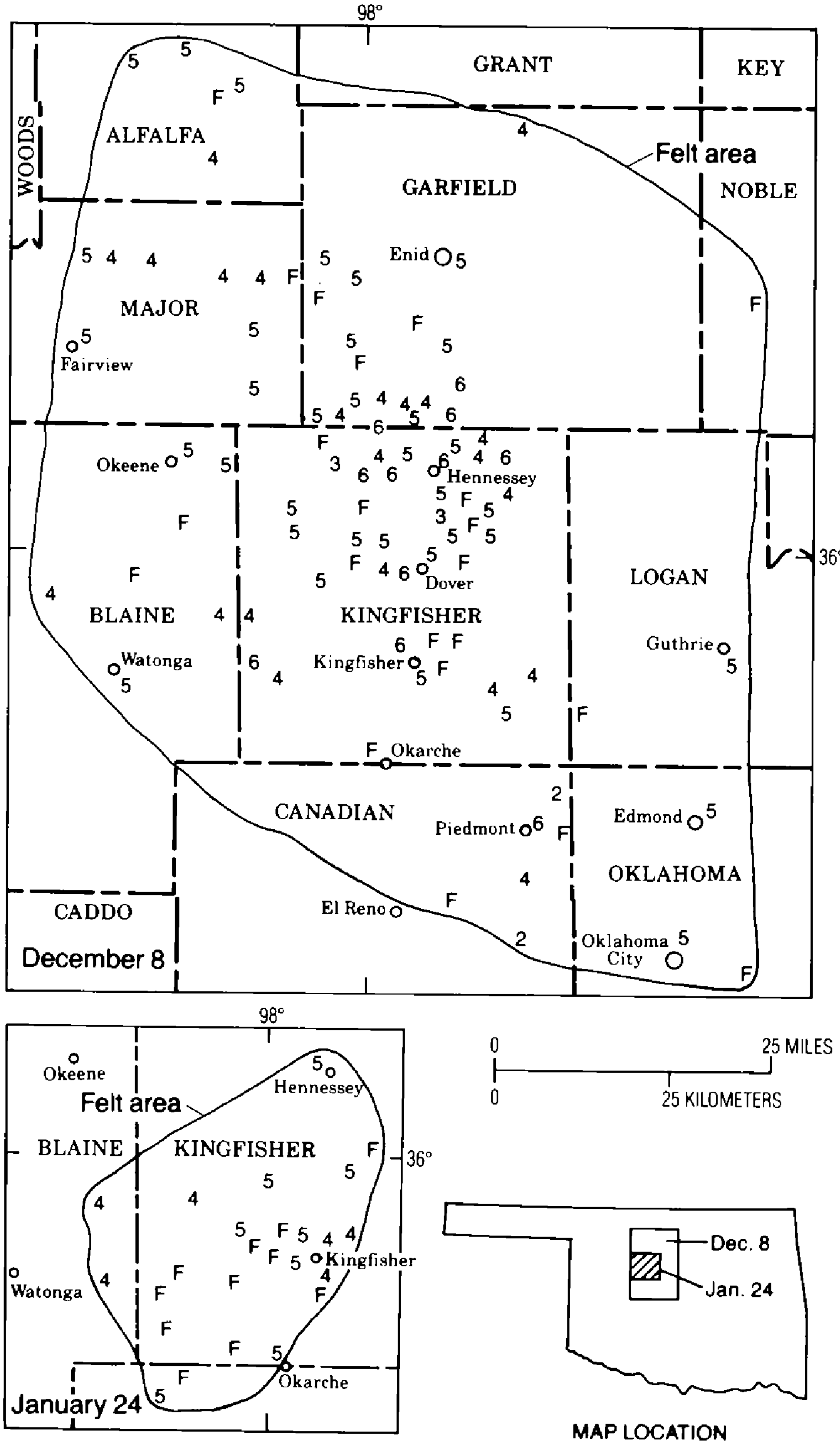

Figure 3. Modified Mercalli intensity values for the January 24 and December 8 earthquakes (see Table 3). For the January 24 earthquake, each value represents an individual felt report, and the felt area was ~900 km^2. For the December 8 earthquake, each value represents an individual felt report, or in towns and cities the value represents the highest MM-intensity effects reported, and the felt area was ~11,200 km^2.

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 range for measurement of m3Hz out to 400 km, but also had the disadvantage of increasing m3Hz by ~0.12 units compared to the previous formula. Their formulas were given in terms of log(A) but were restricted to wave periods of 0.2–0.5 sec. In order to use log(A/T), we assumed a period of 0.35 sec in converting the formulas for our use. The resulting equations are:

(epicenter 10–100 km from a seismograph)

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

(epicenter 100–200 km from a seismograph)

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

(epicenter 200–400 km from a seismograph)

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

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:

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

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

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

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

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

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

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

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

A crowd of about 400 gathered at the Skirvin Plaza Hotel in Oklahoma City December 1 and 2 to participate in the Governor's 1987 Energy Conference. Through a series of sessions and speakers that included OGS Director Charles J. Mankin, several panel discussion groups, and a number of exhibits, the group examined the natural gas industry from the differing perspectives of producers, pipeline operators, marketers, and end users.

Throughout the meeting speakers returned to the topics of reserves, new markets for natural gas, and transportation issues such as the controversial Order 500.

The meeting was sponsored by Oklahomans for Energy and Jobs, Inc., and the Natural Resources Education Foundation.

In addition to Dr. Mankin's participation, the Oklahoma Geological Survey had an exhibit booth in the Marketers Forum area of the meeting. On display were a computer-based exhibit showing several natural-resource-based data files, and maps and illustrations relating to current OGS projects. Attending the meeting and staffing the booth for the Survey were: Dr. Mankin; Kenneth S. Johnson, OGS associate director; Jock A. Campbell and L. Joy Hampton, petroleum geologists; Tom Bingham, geologist; Michelle J. Summers, geological data coordinator; and Connie Smith, associate editor/information officer.

In his address to the group, Mankin said that although there is no shortage of natural gas for Oklahoma in the near future (Fig. 1 and 2), consumers must be convinced that the supply is adequate. Natural gas is the dominant component of the mineral and energy industry in Oklahoma, he said, having gone from 20% of the total mineral and energy value in 1968 to 60% in 1986 (Fig. 3 and 4). Mineral and energy production is the most important segment of the Oklahoma economy, and recent downturns in prices have had a tremendous negative effect throughout the state.

"The issue at hand is not future supply," Mankin said, "but rather finding and promoting new markets."

Mankin and Nicholas Bush, president of the Natural Gas Supply Association, a gas-producer group based in Washington, D. C., both said that the natural-gas industry probably will be faced with oversupplies of its product for the next several years. Bush also said that the industry must gain the trust of large-volume customers to convince them that natural gas can be supplied at a price they will want to pay.

Bush cited statistics showing that proved reserves of natural gas in the U.S. declined last year, new discoveries were at the lowest since 1976, and production was at its lowest level since 1974. Such statistics may give customers the false impression that natural gas is in short supply, he said.

Bush thinks that natural gas could be the dominant domestic fuel in the future because of the abundant supplies and its potential for use with coal in power generation.

Even though natural gas is competitively priced and is in good supply, Mankin said that from 1980 to 1985 the consumption of natural gas in Oklahoma declined rather dramatically (Fig. 5).

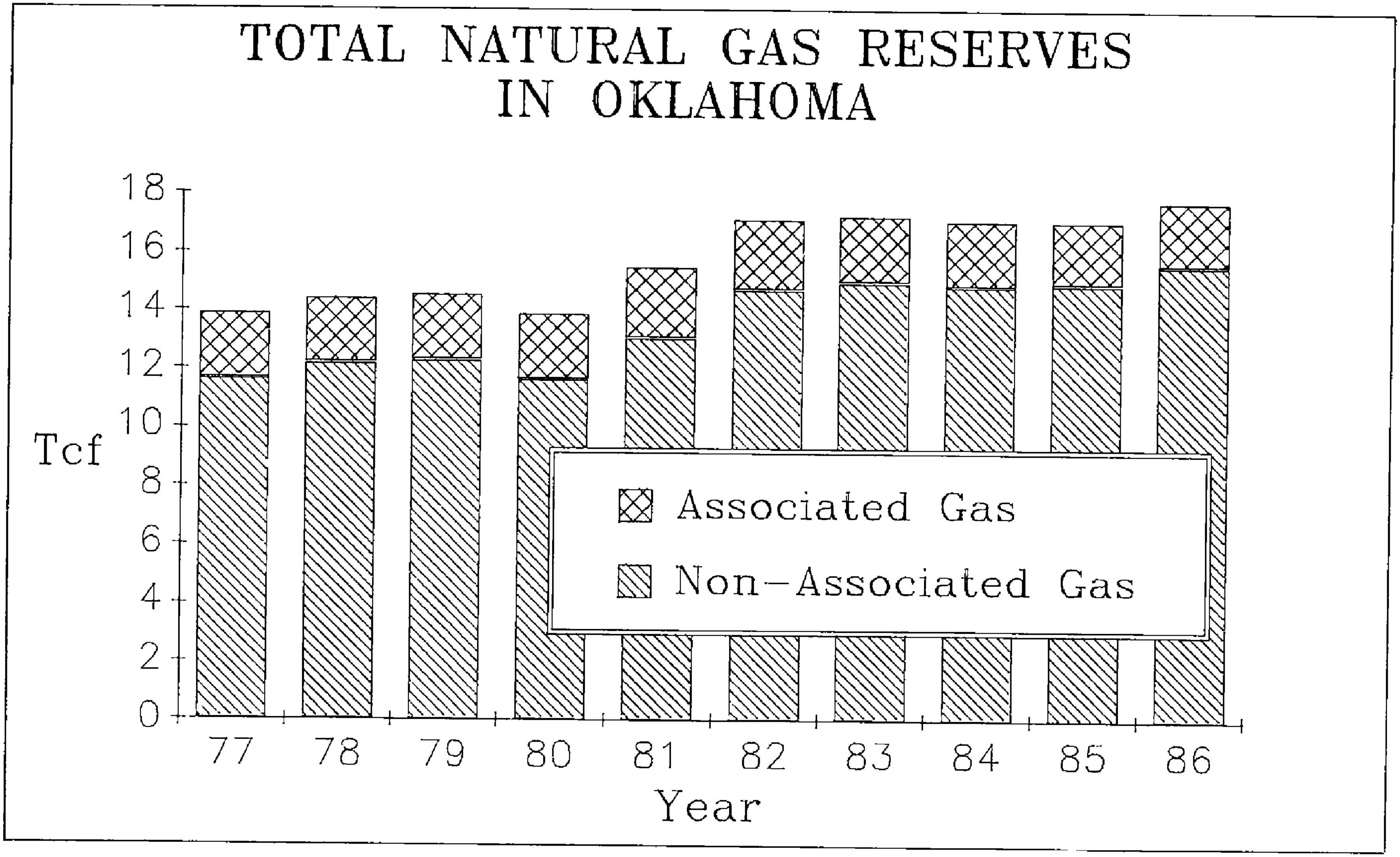

TOTAL NATURAL GAS RESERVES
IN OKLAHOMA
Tcf
0
2
4
6
8
10
12
14
16
18
77
78
79
80
81
82
83
84
85
86
Year
Associated Gas
Non-Associated Gas

Figure 1

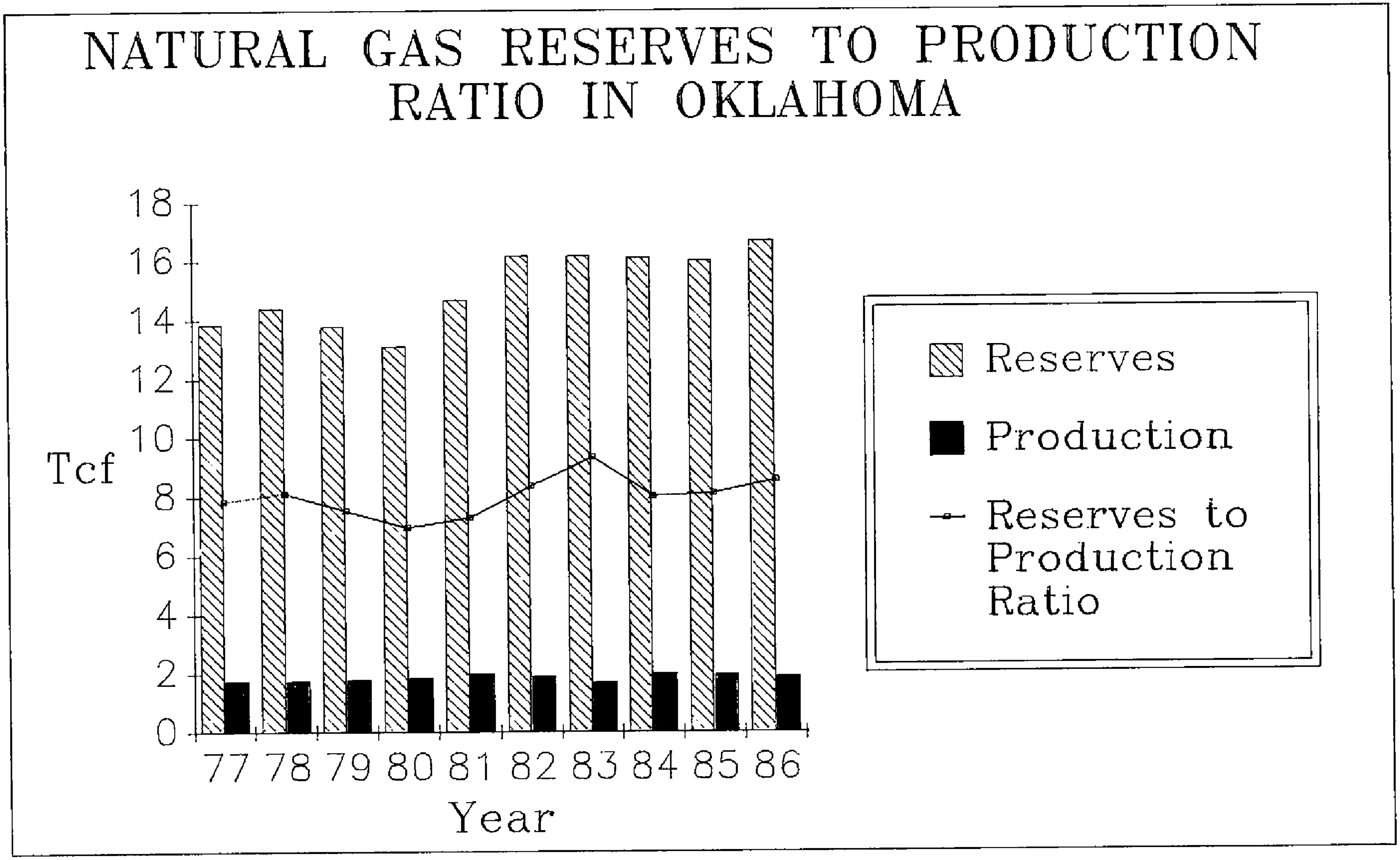

NATURAL GAS RESERVES TO PRODUCTION RATIO IN OKLAHOMA
Tcf
18
16
14
12
10
8
6
4
2
0
77 78 79 80 81 82 83 84 85 86
Year
Reserves
Production
Reserves to Production Ratio

Figure 2

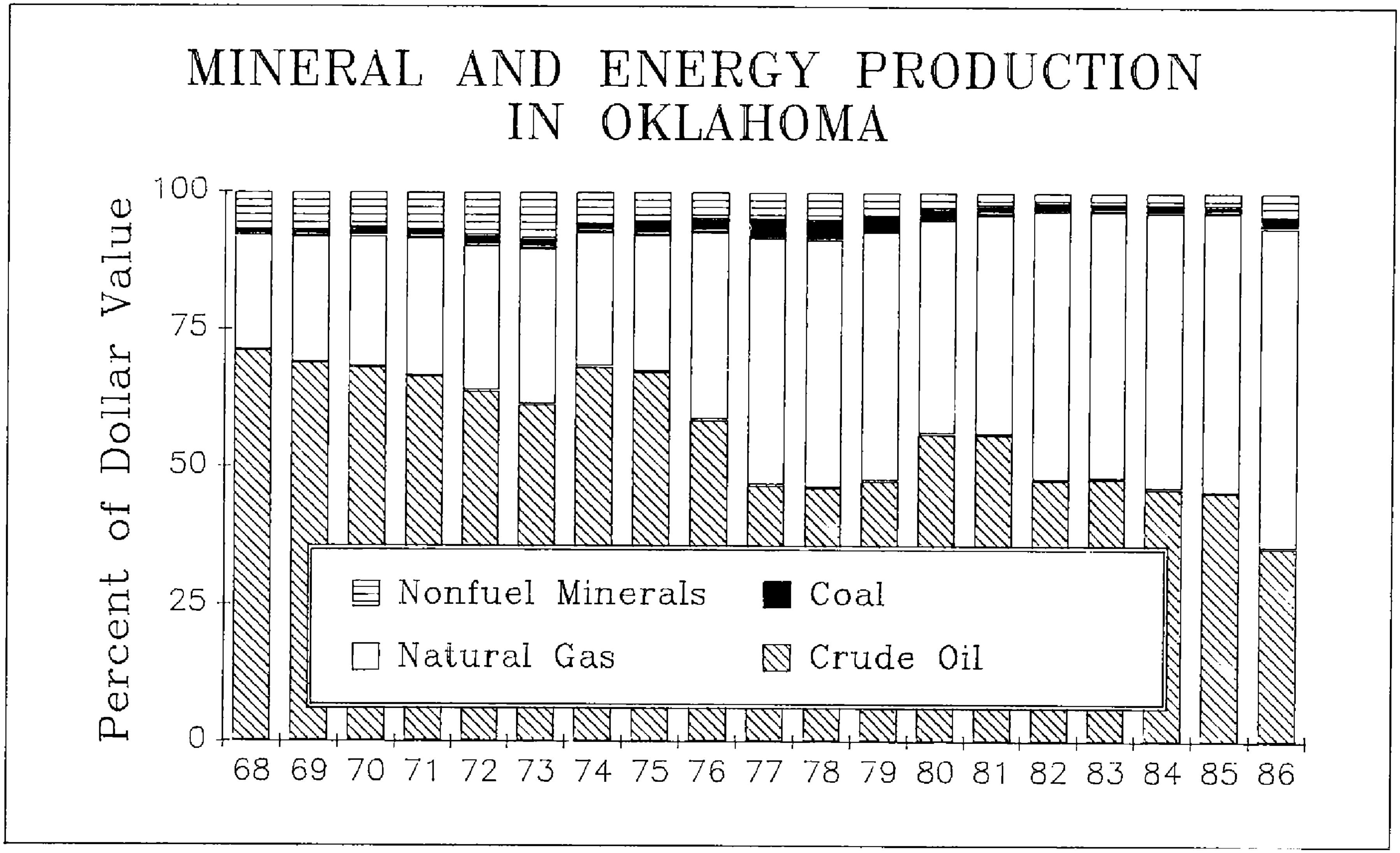

MINERAL AND ENERGY PRODUCTION
IN OKLAHOMA
Percent of Dollar Value
100
75
50
25
0
68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86
Nonfuel Minerals
Coal
Natural Gas
Crude Oil

Figure 3

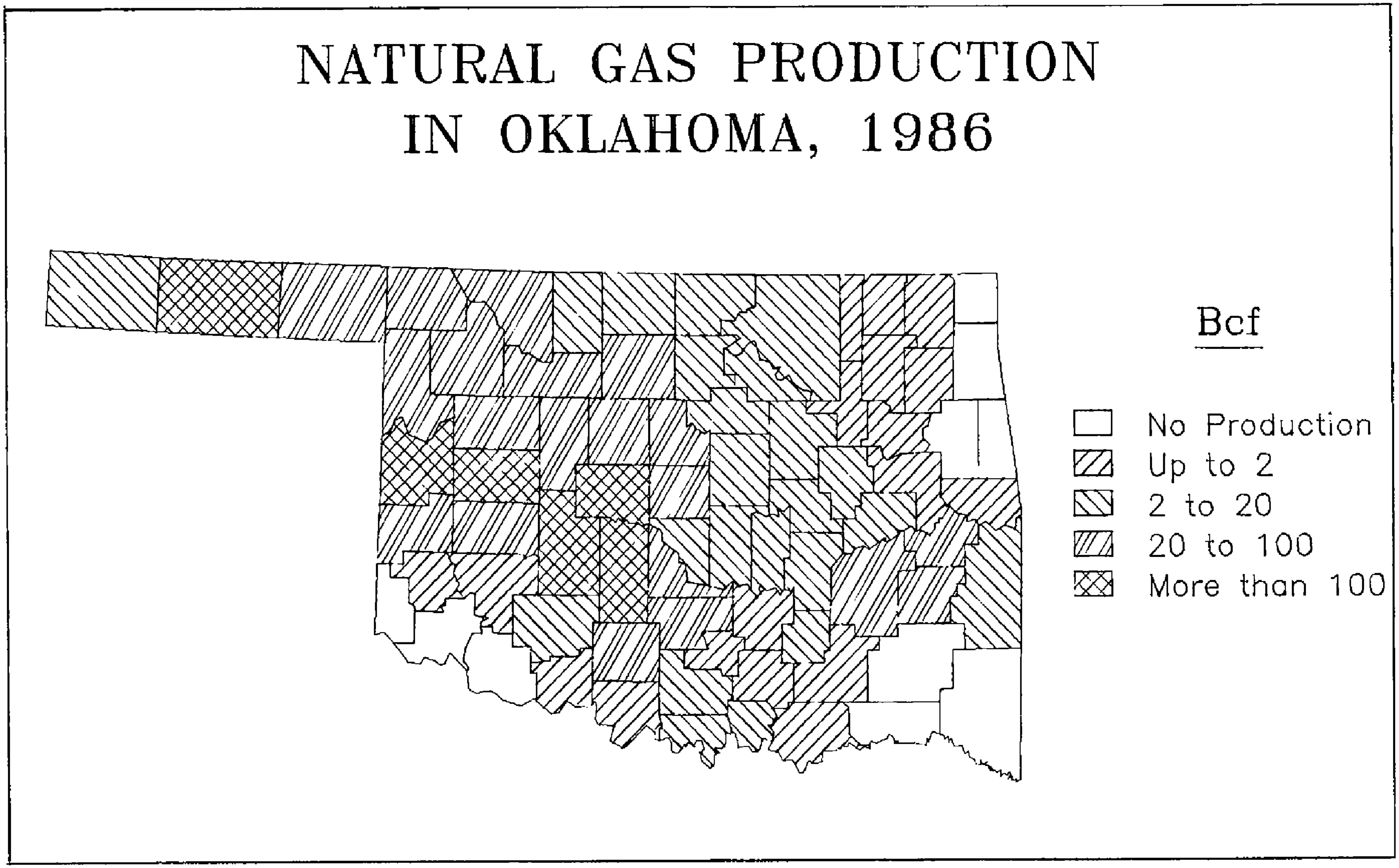

NATURAL GAS PRODUCTION
IN OKLAHOMA, 1986
Bcf
No Production
Up to 2
2 to 20
20 to 100
More than 100

Figure 4

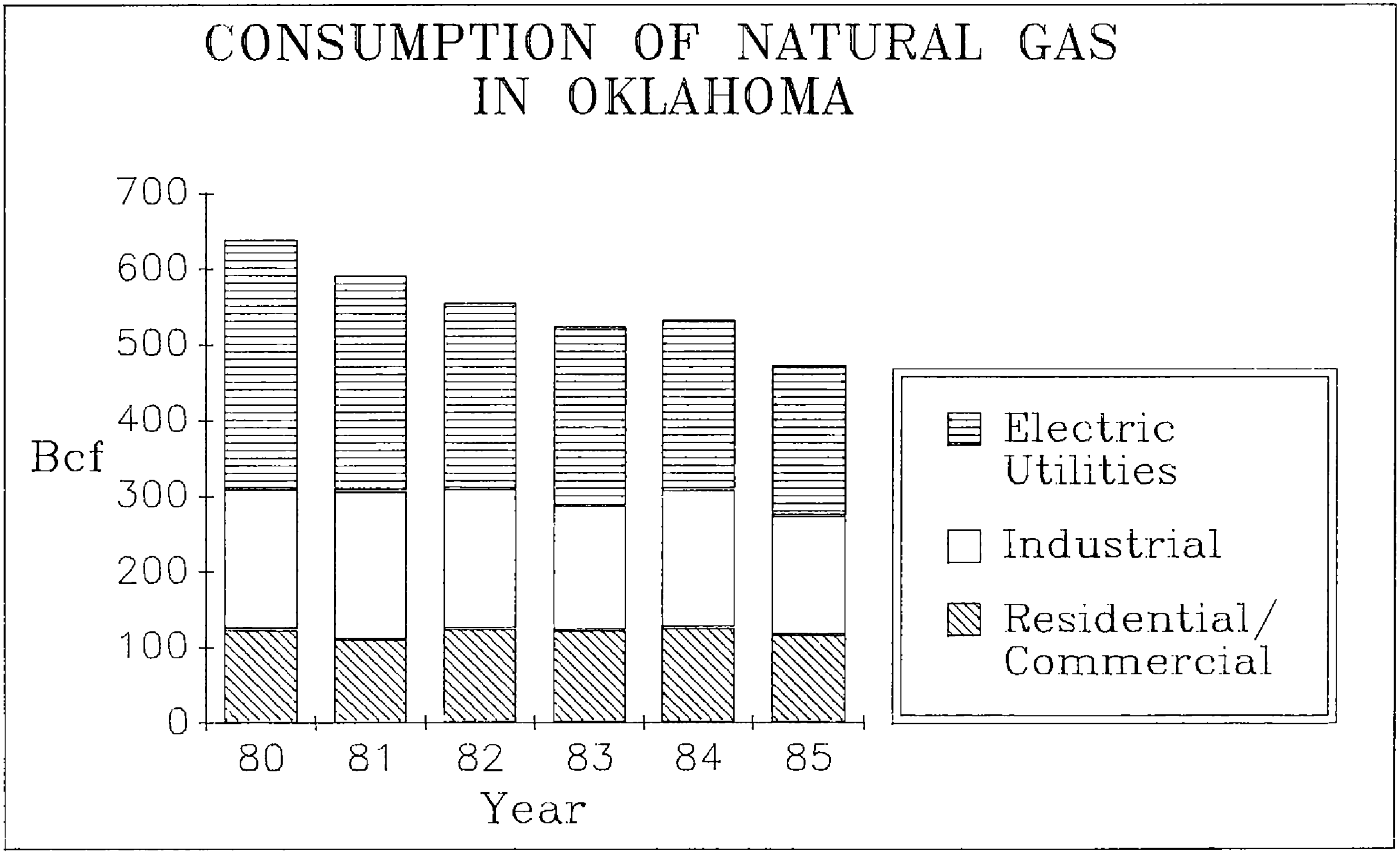

CONSUMPTION OF NATURAL GAS
IN OKLAHOMA
Bcf
700
600
500
400
300
200
100
0
80
81
82
83
84
85
Year
Electric Utilities
Industrial
Residential/ Commercial

Figure 5

Governor Henry Bellmon was another speaker who said that finding new markets is critical to the gas industry. In his welcoming address to the group he said that he is encouraging the use of natural gas as an auto fuel because it is cleaner and safer than gasoline, and is very efficient. The Governor's car already has been converted, and about 100 other vehicles in the State fleet will be switched to natural gas in the near future.

Bellmon pointed out that Oklahoma has the cheapest natural gas at the wellhead in this country. He cited figures of $3 per mcf in Ohio, and $1.50 per mcf in Oklahoma—a fact that is being reiterated to Japanese businesses considering U.S. locations.

At the conference luncheon on Wednesday, C. M. "Mike" Naeve, a member of the Federal Energy Regulatory Commission, spoke to the group about FERC Order 500, which he called "seriously flawed." Order 500 is aimed at the "take-or-pay" clause that requires pipeline companies to buy or pay for certain minimum contracted amounts of gas, regardless of whether or not they actually take delivery of the gas.

Order 500, which was effective January 1 of this year, says that interstate pipelines can deny gas transportation services to producers who refuse to reduce the pipeline's take-or-pay liability by the amount of gas carried by the pipeline in the future for that producer. Naeve said that he expected some minor changes in late January or February, but did not feel that these would be of a drastic nature. He said that he did not vote for the order.

Bush, again speaking for producers, said that there is a possibility of severe price pressure next spring and summer because of Order 500.

Attorney Bland Williamson, speaking for the Oklahoma Independent Petroleum Association, condemned Order 500, saying that producers who try to enforce take-or-pay clauses might be denied their only means of getting their product to the markets.

Williamson said that producers, who used to be concerned primarily with finding reserves, must now understand marketing, transportation issues, orders, and regulations—knowledge that is too expensive for many small producers to acquire.

Although some economic forecasts say that the natural gas industry has hit bottom, Williamson and others at the conference said that recovery probably will be a slow process.

Bush echoed other speakers at the conference who said that the energy demands of the U.S. will grow and that natural gas can play an important role, although he expects usage to be essentially flat for the rest of this decade.

He added that the industry must work to overcome what he termed "50 years of counterproductive legislation and regulatory policies."

Connie Smith

OGS RELEASES ORDOVICIAN–DEVONIAN CORRELATION CHART AND BRACHIOPOD RANGE CHARTS

Late Ordovician Through Early Devonian Annotated Correlation Chart and Brachiopod Range Charts for the Southern Midcontinent Region, U.S.A., with a Discussion of Silurian and Devonian Conodont Faunas, by Thomas W. Amsden and James E. Barrick, has recently been issued by the Oklahoma Geological Survey as Bulletin 143.

This report comprises two papers on the stratigraphic sequence and faunas (conodonts and brachiopods) from middle Paleozoic strata in the region extending from the Texas Panhandle across Oklahoma to the Mississippi River.

The first paper (by Amsden) presents a stratigraphic correlation chart covering strata from the Middle–Late Ordovician Viola Group to the late Early Devonian (Sawkillian) Sallisaw Formation. The chart is annotated to provide information on the various stratigraphic units recognized. Generic and specific articulate brachiopod range charts show the known stratigraphic distribution of the various taxa recognized. The accompanying text discusses the paleoenvironmental factors believed to affect brachiopod distribution, and concludes with an analysis of Silurian–Devonian brachiopod phylogeny.

The second paper (by Barrick) discusses the stratigraphic distribution of conodont faunas in the Silurian–Devonian portion of the Hunton Group of Oklahoma, based in part on heretofore unpublished information. These conodonts are compared with those from other areas, including species from the Silurian–Devonian stratotype sequence in Czechoslovakia.

Amsden's abstract:

This report presents a stratigraphic correlation chart and three articulate-brachiopod range charts for the Upper Ordovician (Viola Group, Cincinnatian Series) through the Lower Devonian (Texas Panhandle, Oklahoma, Arkansas, eastern Missouri, and southwestern Illinois). The correlation chart is annotated to provide supplementary data on the lithostratigraphic-biostratigraphic succession, including references to major publications on various aspects of these strata. The distribution of articulate brachiopods is shown in three charts—one for species arranged stratigraphically, a second for genera arranged stratigraphically, and a third for genera arranged taxonomically. Deposition in the region under study took place mainly in tropical to subtropical, shallow-water carbonate seas occupied by a diverse benthic fauna. The paleoenvironment was affected by the introduction of fine terrigenous detritus, which in areas of greatest concentration sharply reduced the shelly biomass and faunal diversity. Deposition was interrupted by periods of uplift and subaerial erosion, and these episodes are preserved in the stratigraphic record by unconformable seams. The articulate brachiopods exhibit substantial phylogenetic change during Late Ordovician through Early Devonian time; however, much of the fossil-stratigraphic record is lost in the unconformities. It is herein suggested that the observed distribution of brachiopod taxa in this succession is best explained by an episodic evolution, with periods of stasis alternating with periods of accelerated phylogeny.

Four new genera and two new species are described in Appendix 1. The new genera are *Linterella*, *Luterella*, and *Undulorhyncha* from Late Silurian strata in

Oklahoma and Tennessee, and *Tonsella* from Late Ordovician (Hirnantian) strata in Arkansas, Oklahoma, and Missouri.

Barrick's abstract:

A nearly continuous chronologic sequence of conodont faunas extending from the late Llandoverian (C_5) to the early Lochkovian is present in the Hunton Group. Significant local faunal changes correspond to faunal turnovers recognized elsewhere, and occur within Hunton lithostratigraphic units. In contrast, distinct local faunal breaks occur at the contacts between succeeding Lower to Middle(?) Devonian units.

Bulletin 143 is available over the counter or postpaid from the Oklahoma Geological Survey at the address given inside the front cover of this issue. The price is $10 for paperbound copies, $14 for clothbound.

REVIEW: TEXAS–OKLAHOMA TECTONIC REGION COSUNA CHART

Neil H. Suneson[1]

Any review of a mammoth undertaking such as AAPG's recently published Texas–Oklahoma Tectonic Region COSUNA Chart (1986) must necessarily be limited by the reviewer's background in stratigraphy and his/her particular experience and prejudice in any one area covered by the chart. Despite this reviewer's unfamiliarity with much of the region covered by the TOT COSUNA Chart, several comments seem appropriate. I have attempted this review from the perspective of three hypothetical users: the visiting foreign geologist, the geology professor or graduate student, and the industry petroleum geologist.

The foreign geologist visiting Oklahoma or Texas for the first time might come armed with Elsevier's Geological Time Table (fourth edition, 1987; B. U. Haq and F. W. B. van Eysinga, compilers). Comparison of Elsevier's chart and the COSUNA Chart would highlight a few minor differences that may be the result of poor editing. For example, the Mississippian is divided into lower and upper and Pennsylvanian into lower, middle, and upper on Elsevier, but are undivided on COSUNA. Similarly, the Canadian Series (Lower Ordovician), Cayugan Series (Upper Silurian), and Cretaceous and Cenozoic are subdivided into stages and series, respectively, on Elsevier, but are undivided on COSUNA, despite the presence of enough printing space on the chart. (The absence of detail despite sufficient space is a serious failing in the lithostratigraphic columns on the

[1]Oklahoma Geological Survey.

COSUNA Chart.) There are also small differences in absolute ages of some geologic systems, series, and stages on the two charts; for example, the end of the Ordovician is 440 m.y. ago on Elsevier and 425 m.y. ago on COSUNA.

Ignoring the chronostratigraphic and format differences in the two charts, our foreign geologist would probably find the lithostratigraphic part of the COSUNA chart helpful. In fact, he might consider the correlations shown to be the magnificent result of a seemingly impossible task.

The geology professor looking for a thesis topic for his graduate student would probably find the COSUNA Chart to be of only limited usefulness. Again, detailed subdivisions of groups or formations, clearly possible in the format published, should have been included. For example, the Marmaton, Skiatook, Ochelata, Douglas, Shawnee, Wabaunsee, Admire, Council Grove, and Chase Groups in Column 1 (Northern Part, Chautauqua Platform) could have easily been subdivided into formations, as was done on the Mid-Continent COSUNA Chart. Similarly, the Bromide Formation (Column 6) could have been divided into the Mountain Lake and Pooleville Limestone Members, as was done for the Clarita Formation above, without changing the published format. Information on the stratigraphy of CSD Regions #240 and #250—which are included on the column location map—is not represented by columns. Except for Columns 17, 18, and 19, queried, dashed, or slanted contacts between units are virtually absent, suggesting that the nature and age of most of the contacts are known. The recurring problem of editorial inconsistency leaves the user to question how much of the chart was reviewed not only for consistency, but also for accuracy.

The appearance of informal names on the COSUNA Chart may be a larger problem than is indicated on the chart in the explanation of stratigraphic rank. For example, this reviewer is somewhat familiar with Oklahoma Ouachita Mountains stratigraphy (Column 14). The Lynn Mountain Formation is an informal name; Atoka Formation should have been used. Other units clearly within the Ouachita tectonic belt (south of the Choctaw fault) include the Woodford, Caney, Springer, and Wapanucka Formations, none of which appear in Column 14. These formations are shown in Column 3 (Lehigh basin), but only a geologist familiar with the area would know that they are also present in the Ouachita Mountains.

Academic researchers would probably point out several problems with the Texas–Oklahoma Tectonic Region COSUNA Chart: More-detailed subdivisions of major units should have been included; two regions supposedly covered by the chart are not covered; formation contact problems are ignored; informal names are used; and certain units are completely ignored.

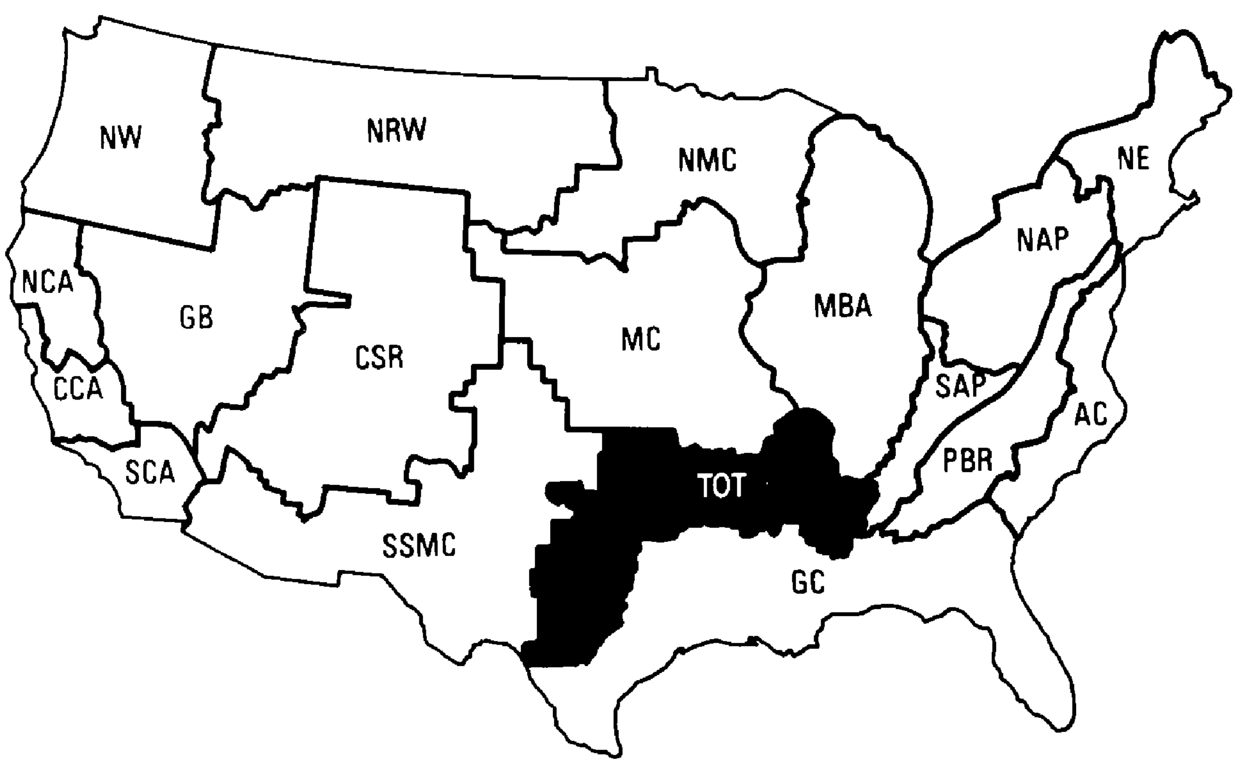
If the chart is of limited usefulness to geology professors and academic researchers, it is of less use to industry petroleum geologists. This is particularly surprising, considering that the COSUNA Chart is published by AAPG. Detailed subdivision of major producing units is critical to the petroleum geologist. For example, in the Oklahoma Arkoma basin, a large gas-producing area, Column 3 of the COSUNA Chart shows Atoka Formation without subdividing it into its principal gas-producing sandstones, namely, the Spiro, Panola, Red Oak, and Fanshawe, among others. A related problem with the COSUNA Chart for petroleum geologists is the absence of subsurface names. Local or poorly defined subsurface terminology could have been avoided while publishing widespread and commonly used reservoir units.

In Summary, the Texas–Oklahoma Tectonic Region correlation chart is a brave attempt to correlate the stratigraphy of a large and very complex area of North America. It probably will be of great value as an introduction to the stratigraphy of the area, despite some unanswered questions. For the academic or industry geologist, the COSUNA Chart will probably serve only as a very limited research tool unusable for hydrocarbon exploration. My principal criticisms are: (1) lack of detail, particularly where the format allowed for detail; (2) lack of references (at least some of the computerized data available from the University of Oklahoma should have been published with the chart); (3) large areas are excluded from coverage; (4) questionable contacts and formation names are not properly flagged; (5) certain formations are omitted from their proper place on the chart. Solutions to some of these problems would have been best solved in the early planning of the COSUNA series. The space alotted to the Carboniferous and Permian of the Texas–Oklahoma region should be larger than it is. Inserts showing more detail in other places would have been helpful. Stricter editing should have occurred. (Many of the "Contributors and Reviewers" cited at the top of the COSUNA Chart, when I contacted them, claimed to have little knowledge of the stratigraphy covered by the chart.)

As a regional correlation tool, AAPG's COSUNA Chart is a first step. Even within its published format, it should have been more detailed. The most valuable piece of information on the chart for usable data may be the address to which one can send for the references used to compile the chart.

This review benefited greatly from the comments of Frank Adler, Virgil Barnes, Alan Bennison, Jim Chaplin, and Tim Denison.

COSUNA CHART INDEX MAP



Robert H. Dott
(1896–1988)

In Memoriam

ROBERT H. DOTT

Former Director of the Oklahoma Geological Survey

Robert Henry Dott, director of the Oklahoma Geological Survey from 1935 until June 30, 1952, was born January 8, 1896, in Sioux City, Iowa. He died February 2 at his home in Tulsa.

Ninety-two years. That is a long time, and surely his death was not untimely, but I had the feeling that this fine man would go on forever. Certainly he will in the hearts of those who loved and admired him and in the science he served.

Dott's professional career before coming to the Survey was varied, but always focused on petroleum geology. He completed his undergraduate and graduate studies at the University of Michigan, receiving a B.S. in 1917 and an A.M. in 1920. His academic pursuits were interrupted by World War I while he served in the U.S. Air Force from 1918 to 1919. Following receipt of his master's degree, he worked as a geologist for Empire Gas and Fuel Co., Standard Oil of New Jersey, Carter Oil Co., and Mid-Continent Petroleum Corp. He was chief geologist for Sunray Oil Co. from 1929 to 1931, then worked as a consulting geologist until becoming director of the Survey in 1935.

What Dott accomplished as director and what the Oklahoma Geological Survey accomplished under his directorship is history (see *A History of the Oklahoma*

Geological Survey, 1908–1983, OGS Special Publication 83-2). He built on a foundation already laid, but he built a strong structure. A lot of basic research was published during his administration—mapping, stratigraphy, structural geology, paleontology, results of chemical analyses, etc.—and some work was done on petroleum and coal. There was quite a lot put out on water resources, partly because of the close association with USGS hydrologists, who at that time were in residence with the OGS, partly because of the State Mineral Survey (see below), mostly because there was a need for it.

But more significant than any of these during that period was the work done on mineral resources—industrial minerals like limestone, dolomite, glass sand, salt, clays, gypsum, volcanic ash, and tripoli; even lowly materials like plain sand and gravel and aggregates. Work was done on lead, zinc, titanium, cadmium, manganese, and phosphates. There was some work done on copper, a little on iron ores. Dott initiated the OGS Mineral Reports series to disseminate the acquired information, although much of the information on deposits was also passed along person-to-person in response to inquiries from producers or would-be producers—as it still is. Thirty-six of these reports were issued before the series was terminated in 1959; 22 were published while Dott was director.

Beyond that, experiments were conducted on these materials to make them more valuable to the economy of Oklahoma. Dott established the Industrial Research Laboratory as part of the Oklahoma Geological Survey. He hired an experienced chemical engineer, Albert L. Burwell, to supervise, and some remarkable developments resulted: there was a process of making rock wool (an excellent insulating substance) from dolomite, which led to the opening of a rock-wool plant; there were experiments to find good coals for coking (a good source was found by mixing an Oklahoma coal with an Arkansas coal); there were experiments to see if brines would provide a source for magnesia—and so forth.

And again beyond all this, Dott was a first-class promoter of manufacturing in Oklahoma. Oklahoma needed manufacturing. So he involved the the Survey in out-of-state "Made in Oklahoma" tours and in-state Industrial Minerals Conferences. He sent staffed exhibits to Oklahoma State Fairs. The OGS was much in evidence with potentials for developers. He made the State's resources known.

Dott led the Survey through two disruptive periods—a massive depression and a second world war—and it came through. There was a county-by-county State Mineral Survey, a kind of a make-work program of the Works Progress Administration (WPA), that contributed masses of data during the Depression. There were investigations of strategic minerals during the war that added knowledge of resources. He supervised and encouraged all this. Another thing—he started our Core and Sample Library to preserve some of the material the drillers were bringing up from the depths; it is one of the best such repositories that there is. He also began publication of the periodical *The Hopper*, which in 1956 became *Oklahoma Geology Notes*. He authored or co-authored 16 publications for the Oklahoma Geological Survey, plus articles for field-trip guides, AAPG *Bulletin*, *Oil Weekly*, the *Chronicles of Oklahoma*—

He was a member of the American Association of Petroleum Geologists, the Association of American State Geologists, the Tulsa Geological Society, and Sigma Xi, and a fellow of the Geological Society of America. He was named an honorary member of AAPG and AASG. He was three times a member of the International

Geological Congress—in 1933, 1956, and 1960. He was twice a visiting Distinguished Lecturer for AAPG, speaking widely on "The Stratigraphy of Oklahoma" in 1951 and on "The AAPG and How it Functions" in 1957.

Robert H. Dott did and was all these things.

But that isn't the person. I can't say too much about that, because there is too much to say. Robert and Esther Dott were two of the absolutely best people I have ever known, and they were so much a part of our lives for so many years. I think of the time they took our family into their home when our house was sold from over our heads, and there was no place to live because there were 30,000 sailors in Norman. I think of too many things.

Bobby (Dr. Robert H. Dott, Jr., a professor in the Department of Geology and Geophysics at the University of Wisconsin at Madison and one of the top geologists of his time) and Bobette (creator of beautiful paintings and wife of Fred Bird, of Portland, Oregon) have a fine heritage, as do the Dott's seven grandchildren and six great-grandchildren.

We shall all miss Bob Dott.

Elizabeth A. Ham

A memorial service was held at All Souls Unitarian Church in Tulsa on March 14. Contributions may be sent to the Garden of All Souls Memorial Society, 2952 South Peoria, Tulsa, Oklahoma 74114, or to the American Association of Petroleum Geologists Memorial Fund, In Memory of Robert H. Dott, P.O. Box 979, Tulsa, Oklahoma 74101.

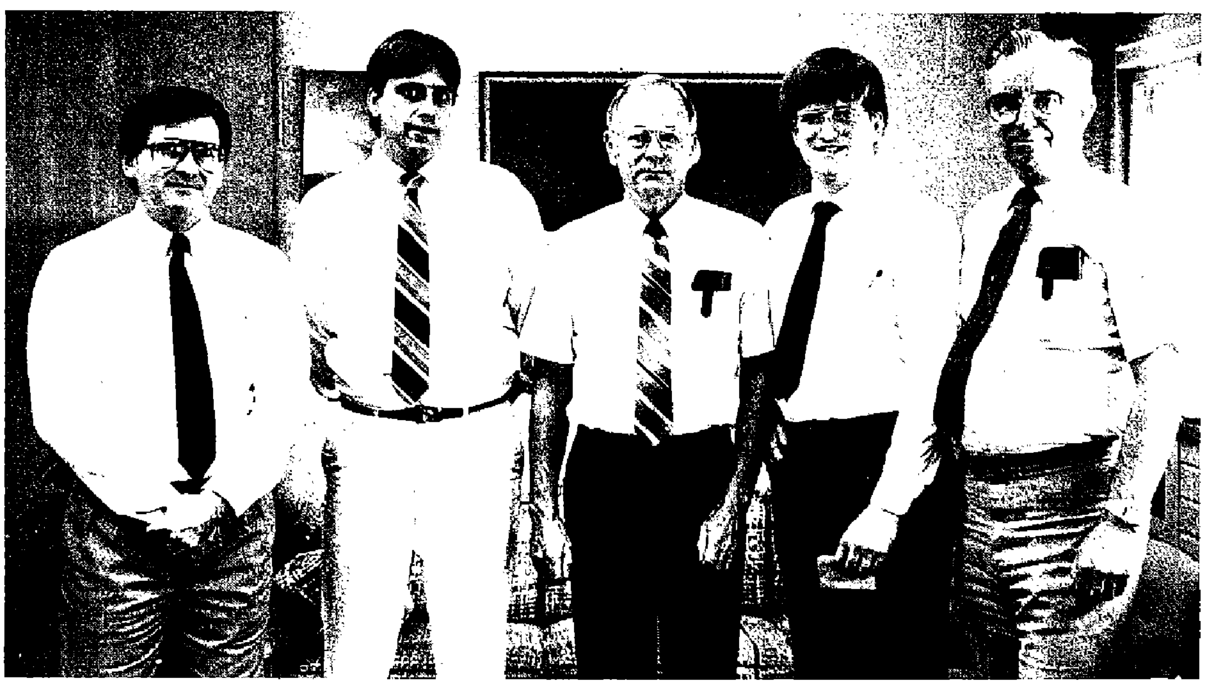
OGS RECEIVES GIFTS FOR CORE AND SAMPLE LIBRARY

The Oklahoma Geological Survey received gifts from Tenneco Oil Exploration and Production and Mobil Oil Companies to help automate the cataloging of material housed at the Survey's Core and Sample Library. Tenneco's gift of $1,000 was used to purchase a microcomputer, while Mobil donated the staff time to enter information on the cores contained in the library.

The money was presented to the Survey by Patrick O. Williams, project geological engineer, and Stephen H. Brown, exploration geologist, both with Tenneco. R. Alan Langen, staff geologist, presented the commitment from Mobil for the data entry of the core information. The three company representatives met last summer with OGS director Charles J. Mankin and Core and Sample Library manager Eldon Cox to finalize plans for the project.

"These donations will provide the capability to the staff of the Core and Sample Library to locate information much faster than the methods currently in use, and will allow more information to be compiled and searched on each of the cores in the library," said Mankin. "These cores and samples are important sources of information for both research, and exploration and development projects. The ability to search the core catalog by computer for specific information will be extremely beneficial because of the extensive use of these materials by industry and academia."

"Future plans call for including the sample catalog on the computer as well," he added.



Representatives of Tenneco Oil Exploration, Mobil Oil Co., and the Oklahoma Geological Survey pose for a photo last summer after meeting to discuss plans to computerize the catalog for the OGS Core and Sample Library. From left to right are: Patrick O. Williams, Tenneco; R. Alan Langen, Mobil; Eldon Cox, manager of the Core and Sample Library; Stephen H. Brown, Tenneco; and Charles J. Mankin, director of the OGS.

UPCOMING MEETINGS

Geology of Industrial Minerals, 24th Annual Meeting, May 2–5, 1988, Greenville, South Carolina. Information: Alan-Jon Zupan, South Carolina Geological Survey, Harbison Forest Road, Columbia, SC 29210; (803) 737-9440.

Practical Approaches to Ground-Water Hydrology and Contamination Short Course, June 6–10 or July 18–22, 1988, Roman Nose Resort, Watonga, Oklahoma. Information: Shari Dunn, School of Geology, Oklahoma State University, 151 Physical Sciences Bldg., Stillwater, OK 74078; (405) 624-6358.

Society of Economic Paleontologist and Mineralogist, Fifth Annual Midyear Meeting, August 21–24, 1988, Columbus, Ohio. Information: Jeanne Couch, Meetings Coordinator, SEPM, P.O. Box 4756, Tulsa, OK 74159-0756; (918) 743-9765.

Geological Society of America, 1988 Centennial Celebration, October 31–November 3, 1988, Denver, Colorado. Abstracts due June 10; preregistration due October 7. Information: GSA, Meetings Dept., P.O. Box 9140, Boulder, CO 80301; (303) 447-2020.

If you have not received the Second Circular for the 28th International Geologic Congress to be held in the U.S. in July 1989, write to:

28th IGC
P.O. Box 727
Tulsa, OK 74101 USA

OKLAHOMA ABSTRACTS

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

Basin Lithofacies of Siliciclastics of Springer–Morrow Formations (Mississippian–Pennsylvanian), Panhandle and Anadarko Basin, Oklahoma

C. W. KEIGHIN and R. M. FLORES, U.S. Geological Survey, Denver, CO

Investigations of 6,500 ft of core and 100 thin sections from 30 drill holes from the Oklahoma Panhandle to the southwestern portion of the Anadarko basin, Oklahoma, have led to the recognition of three lithofacies of the Springer–Morrow Formations of Mississippian–Pennsylvanian age. Lithofacies include (1) fluvial-influenced coastal (FIC); (2) tidal-influenced shallow marine (TISM); and (3) mixed, which includes features of both FIC and TISM. FIC facies is restricted to downhole depths of 4,400 to 8,000 ft; TISM facies occurs between 4,000-ft and 18,000-ft downhole depths.

Thin-section study of sandstones indicates that quartzarenites are the most common rocks in both the FIC and the TISM facies. Subarkose sandstones are present in the FIC facies, and sublitharenites are present in the TISM facies. Calcite skeletal fragments of mainly brachiopods and crinoids were more abundant in the FIC facies than in the TISM facies. The mixed facies includes quartzarenites, subarkose sandstones, and sublitharenites. Iron-bearing carbonate cements are observed in rocks of all facies types. Porosity is typically less than 10% and has generally been reduced by iron-bearing carbonate cements; silica and/or clay cements are less common. Fracture porosity was identified in core samples but was rare in thin sections. No obvious relation exists between downhole depths and amount of porosity. Dissolution porosity appears to be less common than primary porosity.

Reprinted as published in the American Association of Petroleum Geologists *Bulletin*, v. 71, p. 575.

Geochemical Study of Oils, Source Rocks, and Tar Sands in Pauls Valley Area, Anadarko Basin, Oklahoma

P. J. JONES, C. A. LEWIS, R. P. PHILP, L. H. LIN, and G. E. MICHAEL, University of Oklahoma, Norman, OK

An organic geochemical study of numerous oils and source rocks from the Anadarko basin has been undertaken in an attempt to determine the number of genetically related families of oils in the Pauls Valley area of the Anadarko basin, in addition to determining the potential source rocks for these oils. In the study area it was found that, of the oils examined, there were basically two families of oils. The majority of oils examined from the Oil Creek, Bromide, Hunton, and

other sands appeared to have a similar source which appeared to be the Woodford Shale. A smaller and distinct group of oils appeared to be source and reservoired in the Viola Limestone. The correlations were made by determination of the various classes of biomarkers in the oils and source rock extract. The compounds examined included n-alkanes, isoprenoids, steranes, hopanes, and monoaromatic steroid hydrocarbons. The distributions of these compounds will be discussed in addition to the way in which the data are used to make the above-mentioned correlations.

In the course of this study, a number of tar-sand samples in Upper Mississippian tar sands from Carter County, Oklahoma, were also examined in some detail. These samples were of particular interest since they presented an opportunity to study samples that had been biodegraded to differing degrees. Hence several classes of biomarkers, namely alkanes, steranes, hopanes, mono and tri-aromatic steranes, and porphyrins, were analyzed from these different tar sands. The aims of the study were twofold, with the first being to study the in-situ effects of progressive biodegradation on a series of samples derived from the same source. The second was to determine the origin of the oil responsible for the tar sands. Results will be presented to show progressive changes in the biomarker distributions resulting from biodegradation, such as selective removal of certain stereoisomers and ring cleavage within the steranes. In addition, the attempted correlation of the tar-sand oils with the Oil Creek oil will be discussed and data presented to demonstrate that in all probability this oil is indeed responsible for these particular tar sands.

Reprinted as published in the American Association of Petroleum Geologists *Bulletin*, v. 71, p. 574.

Seismic Expression of Upper Morrow Channel Sands, Western Anadarko Basin, Oklahoma and Texas

JENS R. HALVERSON, Diamond Shamrock Exploration Co., Amarillo, TX

In the western Anadarko basin (western Oklahoma and Texas panhandle), the Lower Pennsylvanian upper Morrow channel sands are both a prolific and elusive exploration target. Initial production from some of these sands can reach well over 1,000 BOPD, and yet an offset well only 1,000 ft away from a good producer can miss the channel sand entirely. This paper explores the use of high-resolution seismic data and color seismic inversion techniques in detecting the sands before the drill bit.

One-dimensional merged log modeling, two-dimensional log interpolation modeling, color seismic inversion processing, and seismic facies mapping techniques have been applied to two upper Morrow channel-sand fields in the Texas panhandle: the Lear and Darden fields. The channel sands reach an isopach thickness of 40–50 ft at a depth below surface of 8,000–10,000 ft, putting the channel sands within the "thin bed regime." This location is also below the "tuning point" where there is a correlation between the amplitude of the reflection and the thickness of the channel sand. The sands reach an interval velocity of 13,500 ft/sec and are encased within hundreds of feet of shale with an interval velocity of 10,500 ft/sec, providing a good acoustic impedance contrast and making the sands detectable on good signal-to-noise ratio seismic data. Comparison of geologic isopach and geophysical seismic facies maps shows a good correlation in the delineation of the upper Morrow channel sands.

The use of these seismic-stratigraphy methods should substantially increase exploration and development success when high-resolution seismic data and advanced interpretation techniques are employed.

Reprinted as published in the American Association of Petroleum Geologists *Bulletin*, v. 71, p. 993.

Facies Analysis, Paleoenvironmental Interpretation, and Diagenetic History of Britt Sandstone (Upper Mississippian), Southeastern Anadarko Basin, Oklahoma

JOHN P. HAIDUK, Henry Gungoll Operating, Inc., Enid, OK

The Britt sandstones record a regressive-transgressive couplet in response to deltaic progradation, abandonment, and subsidence in the southeastern Anadarko basin, during the Late Mississippian. Four principal facies compose the sequence: (1) deltaic bar-finger sands, (2) shelf sand ridges, (3) delta-destructional sand bars, and (4) storm deposits.

Platform sands were reworked into shelf sand ridges in mid-shelf, with elongated delta-destructional bars forming along the subsiding delta front. Storm surges mixed coarse-grained coquinoid sands with muds and silts typical of lower energy environments. Scouring of storm deposits into underlying sediments was common.

Petrologically mature, with the exception of storm deposits, each facies is quartzitic, with trace amounts of potassic and plagioclase feldspar, rock fragments, and heavy minerals. Glauconite is restricted to delta-destructional bars. Storm deposits are dominated by fragmented fossils and sparse oolitic units.

Numerous episodes of diagenetic activity have altered extensively the reservoir quality of these sands. Volumetrically, silica and carbonate cementation were the most important diagenetic processes. Chlorite is the dominant authigenic clay mineral. Porosity is predominantly secondary, and the dissolution of quartz and quartz overgrowths provided much of the reservoir in these highly productive strata.

Reprinted as published in the American Association of Petroleum Geologists *Bulletin*, v. 71, p. 993.

Chlorite Grain Coats and Preservation of Primary Porosity in Deeply Buried Springer Formation and Lower Morrowan Sandstones, Southeastern Anadarko Basin, Oklahoma

MELISSA H. McBRIDE, Ecology and Environment, Overland Park, KS; PAUL C. FRANKS, University of Tulsa, Tulsa, OK; and RICHARD E. LARESE, Amoco Production Co., Tulsa, OK

Petrographic studies of Upper Mississippian Springer and Lower Pennsylvanian (Morrowan) sandstones in six cores from the southeastern Anadarko basin, Caddo and Grady Counties, Oklahoma, reveal a complex diagenetic history that led to the destruction of much primary intergranular porosity. The Springer and lower Morrowan sandstones form prolific oil and gas reservoirs, despite the fine-grained

nature of the rocks, the growth of authigenic clays, extensive cementation by quartz overgrowths and carbonate minerals, and burial depths of 11,500–14,800 ft. More than any other factors, the diagenetic creation and preservation of porosity are the major geologic controls on hydrocarbon production from these sandstones.

Thin-section petrography and scanning electron microscopy show that porous intervals were formed mainly by extensive dissolution and leaching of detrital grains and authigenic cements. Locally, however, appreciable primary porosity was preserved in Cunningham (Springer Formation) and Primrose (Morrowan) sandstones (as much as 20% in one sample of Primrose sandstone) by the formation of chlorite grain coats on detrital quartz during the early stages of burial and diagenesis. The chlorite grain coats inhibited the occlusion of pore space by preventing pervasive cementation of the rocks by quartz overgrowths. Cross-plots of porosity versus the abundance of authigenic quartz and grain-coating chlorite document the relationship in two of the cores.

Reprinted as published in the American Association of Petroleum Geologists *Bulletin*, v. 71, p. 994.

Depositional Architecture of Springer "Old Woman" Sandstone, Central Anadarko Basin, Oklahoma

MICHAEL R. O'DONNELL, Ward Petroleum Corp., Enid, OK; and JOHN P. HAIDUK, Henry H. Gungoll and Associates, Enid, OK

The fluvial meander belt containing the "Old Woman" sandstone served as a conduit for clastics transported into the Anadarko basin. Mappable for a distance of more than 30 mi (48 km), sand bodies characterizing this system average 0.5 mi (0.8 km) in width and attain maximum thicknesses of 50–70 ft (15–20 m). Channel and point-bar sandstone facies display a fining-upward sequence and sharp basal contact, as inferred from gamma-ray and resistivity logs.

Sandstones of the "Old Woman" fluvial complex overlie the laminated shales and silts of the penecontemporaneous flood-plain environment. These flood-plain deposits are underlain by crinoidal wackestones and packstones deposited in the subtidal regime. Encroachment of the fluvial complex into a marine setting is interpreted from this sequence. Thin flood-plain deposits and lack of shallow marine clastic sediments suggest rapid advancement.

Quartzitic and petrologically mature, the "Old Woman" sandstone is fine grained, with small-scale troughs and laminations, and a few mudstone rip-up clasts. Diagenesis has altered the mineralogic composition mainly by siliceous and carbonate cementation. Porosity is secondary, resulting from dissolution of various metastable constituents.

The "Old Woman" sandstone was established as a hydrocarbon reservoir in the early 1960s, and sporadic development continued for years. The present-day petroleum market has prompted a resurgence in drilling activity owing to the economic viability of this reservoir. Successful wells are concentrated in newly discovered meander-belt bends; however, the elusiveness of this fluvial system challenges today's exploration geologists as it has for the past quarter century.

Reprinted as published in the American Association of Petroleum Geologists *Bulletin*, v. 71, p. 995.

Hydrocarbons in an Overmature Basin: I. Thermal Maturity of Atoka and Hartshorne Formations, Arkoma Basin, Oklahoma and Arkansas

LORI A. HATHON and DAVID W. HOUSEKNECHT, University of Missouri, Columbia, MO

With exploration expanding into deeper portions of the Arkoma basin, it has become important to determine whether the basin's thermal maturity is a factor that must be integrated into exploitation strategies.

Lateral thermal maturity patterns can be detailed by analysis of the Hartshorne coal bed. From west to east, the Hartshorne increases systematically from 0.7 to over 2.0% vitrinite reflectance (R_0). In the west, R_0 contours cross the basin nearly perpendicular to structural strike. To the east, R_0 contours are concave eastward, indicating higher thermal maturities in the center of the basin than along its northern and southern margins.

Vertical thermal maturity patterns can be locally detailed by analyzing dispersed organic matter concentrated from Atoka cores and cuttings. Depth versus R_0 profiles display a constant slope through the basin, and absolute values of thermal maturity display a lateral variation similar to the Hartshorne coal bed. Mean R_0 values in productive Atoka beds range from about 2 to nearly 5%, depending on depth and location within the basin.

The observed thermal maturity of the basin probably resulted from the combined effects of overpressured conditions, gravity-driven fluid flow related to the Arbuckle uplift, and facies-dependent dewatering pathways. Surprisingly, observed levels of thermal maturity indicate that much of the Atoka Formation is overmature, and would be considered nonprospective according to most published thermal maturity-hydrocarbon window relationships. Nevertheless, significant gas reserves exist in patterns that do not appear to be influenced by either lateral or vertical trends in thermal maturity.

Reprinted as published in the American Association of Petroleum Geologists *Bulletin*, v. 71, p. 993–994.

Hydrocarbons in an Overmature Basin: II. Is There a Thermal Maturity Limit to Methane Production in Arkoma Basin, Oklahoma and Arkansas?

DAVID W. HOUSEKNECHT and LORI A. HATHON, University of Missouri, Columbia, MO

Since the pioneering work of David White in the Appalachians, it has been "known" that there are thermal maturity limits on the occurrence of oil and gas. Most recent literature indicates that no commercial gas accumulations exist above a vitrinite reflectance (R_0) of about 3%, not because methane is thermally degraded, but because reservoir quality is believed to be destroyed by high temperatures. However, in the Arkoma basin, methane is produced from rocks that range from less than 1 to about 5% R_0, with no apparent relationship between thermal maturity and gas production patterns.

Petrography of several Atoka reservoir sandstones indicates that diagenetic processes that occurred during shallow burial preserved porosity in some

sandstones and destroyed porosity in others. During deeper burial, accumulation of hydrocarbons (including oil in some reservoirs) in porous sandstones located in favorable structural positions effectively terminated inorganic diagenesis and prevented further deterioration of reservoir quality. However, inorganic diagenesis proceeded below hydrocarbon-water contacts, resulting in nearly total destruction of porosity. This post-accumulation diagenesis occurred during or following organic metagenesis (overmaturation), as evidenced by quartz cement that fills bubbles and cracks in pyrobitumen.

Good reservoir quality was thus preserved in Atokan sandstones from which water had been displaced by hydrocarbon accumulation, whereas reservoir quality was totally destroyed by high temperature diagenesis in "wet" sandstones. This indicates that methane exploration is viable in strata characterized by R_0 values of up to 5%, if it can be demonstrated that trap formation and hydrocarbon accumulation predated thermal overmaturation.

Reprinted as published in the American Association of Petroleum Geologists *Bulletin*, v. 71, p. 994.

Petrographic Constraints on Provenance and Sediment Dispersal Patterns, Atokan Sandstones of Arkoma Basin, Oklahoma and Arkansas

LOUIS M. ROSS, JR. and DAVID W. HOUSEKNECHT, University of Missouri, Columbia, MO

Atokan strata of the Arkoma basin record the transition from sedimentation on a passive rifted margin to sedimentation in a foreland basin that developed as a result of convergent tectonic activity along the Ouachita orogenic belt. Sandstone compositions reveal how provenance and sediment dispersal patterns changed during Atokan sedimentation.

The basal Atokan Spiro sandstone is composed almost exclusively of quartz grains derived from older platform strata north of the basin. In contrast, younger Atokan sandstones (Red Oak, etc.) contain 70–90% quartz, 5–25% metamorphic lithic fragments (mostly slate) and 2–10% feldspar (more plagioclase than K-feldspar). Moreover, in many middle Atokan sandstones, the percentages of lithic fragments and feldspar have been significantly reduced during diagenesis by grain dissolution.

In addition to the abundant framework grain species mentioned, Atokan sandstones locally contain small percentages of volcanic glass and ultramafic lithic fragments. Microprobe analyses of the ultramafic fragments indicate that they are composed of clinopyroxene crystals whose compositions suggest derivation from orogenic, tholeiitic basalt (e.g., an island arc).

Integration of these compositional characteristics with facies and paleocurrent data suggests that the Spiro was deposited on a tectonically stable, south-facing shelf with predominantly southward sediment dispersal. The overlying Atokan sandstones were deposited in a tectonically active, rapidly evolving foreland basin. Most of the sediment deposited in this foreland basin was derived from the rising Ouachita orogenic belt to the east and south, and was dispersed longitudinally westward within the basin. The grain compositions suggest that the orogenic belt contained rocks of oceanic affinities, thereby supporting hypotheses of its accretionary origin.

Reprinted as published in the American Association of Petroleum Geologists *Bulletin*, v. 71, p. 996.

Correlation and Facies Analysis in Exploration for Subtle Traps Within Hunton Group, Oklahoma

RICHARD D. FRITZ, Masera Corp., Tulsa, OK

The bulk of Hunton production to date is associated with rather well-defined structural and/or truncation-style traps. Yet the trapping mechanism in these settings, to a large extent, depends on the development of particular depositional facies within the Hunton Group.

Accurate correlation and subdivision of the Hunton require an understanding of the overall depositional environment and history. The depositional model for the Silurian Chimneyhill and Henryhouse formations and the Devonian Haragan and Bois d'Arc formations is a carbonate ramp. Both aggradational and progradational sequences formed, as did several unconformities during periods of erosion and nondeposition. The Frisco, however, was deposited on submerged paleohighs, probably as a mud-mound deposit.

Using the foregoing depositional models as a guide, subdivisions of the Hunton, based on regional markers related to changes in sea level between progradational episodes, can be recognized and correlated throughout the Anadarko–Arkoma region. Comparing core data and log signatures, along with applying depositional cycles, permits more detailed correlations as their component facies are recognized by log character. Reservoir-prone facies within the carbonate cycles can then be identified, correlated, and mapped.

The Cheyenne Valley field in Major County, Oklahoma, represents an excellent example of the relationship between facies and reservoir development that can be delineated by correlation from an environmental perspective. This field is an exploration model for subtle traps in the carbonates of the Hunton Group.

Reprinted as published in the American Association of Petroleum Geologists *Bulletin*, v. 71, p. 992–993.

Depositional Model and Diagenetic History of Frisco Formation (Lower Devonian) in Central Oklahoma

PATRICK L. MEDLOCK, Masera Corp., Tulsa, OK

The Lower Devonian Frisco Limestone is a prolific reservoir within the Hunton Group. The giant Fitts and West Edmond fields produce from the Frisco, as do other small fields in the eastern Anadarko basin, central Oklahoma, and western Arkoma basin. A crinoidal-mud-mound complex is the inferred depositional model, based on geometry and lithotypes. Mound growth was probably initiated on paleostructural highs. Facies in the mud-mound complex include mound-core, flank/intermound, and mound-crest. The mound-core facies, consisting of poorly sorted wackestones and mudstones, formed as thickets of crinoid-baffled lime mud. The flank/intermound facies, which is moderately sorted packstones, formed in areas of low crinoid population, allowing current activity to winnow much of the lime mud to form carbonate sand. The mound-crest facies, which is predominantly grainstones with some packstones, was deposited as a sand sheet as the mound reached active wave base.

Unlike the dolomitized reservoirs of other Hunton formations, the Frisco is a limestone reservoir that underwent an intricate, multiphase, diagenetic history. Although secondary porosity developed during subaerial exposure, depositional facies exhibited considerable control on porosity distribution. Solution-enhanced primary porosity and secondary vuggy porosity are the most significant types.

Reprinted as published in the American Association of Petroleum Geologists *Bulletin*, v. 71. p. 994.

Depositional Setting and Thin-Section Petrology of Misener Formation (Devonian) in Northeast Nash and Nearby Fields, North-Central Oklahoma

BILLY M. FRANCIS and CHARLES F. MANSFIELD, University of Tulsa, Tulsa, OK

The Devonian-age Misener formation is a mixed quartzose-carbonate sequence that is widely but discontinuously distributed in northern Oklahoma. Eleven conventional cores representing five different Misener oil fields in Grant and Garfield Counties were examined to determine the depositional setting and petrology of the formation. The Misener ranges in thickness to approximately 60 ft and is everywhere overlain by the Woodford Shale. The Misener–Woodford sequence unconformably overlies the Hunton Group (Silurian–Devonian), Sylvan Shale (Ordovician), Viola Limestone (Ordovician), and Simpson Group (Ordovician). Core descriptions show the Misener to be a clean sand containing scattered disrupted clay laminae, shale clasts, and pyrite nodules. The contacts between the overlying Woodford Shale and the underlying Hunton and pre-Hunton strata are sharp and slightly undulose. Thin-section petrology indicates the Misener contains fine- to medium-grained, rounded to subangular, quartz-rich sandstone with little or no dolomite and, in places, grades into a dolomite-rich sandstone with floating quartz grains. Quartz overgrowths are abundant and calcite cement is less common. Other components comprising the Misener strata include phosphatic shale clasts, phosphatic fossil fragments, glauconite, and chert. Porosity ranges from 0 to 14% and much of it appears to have been diagenetically induced.

Reprinted as published in the American Association of Petroleum Geologists *Bulletin*, v. 71, p. 992.

Idiosyncrasies of Cherokee Genetic Sequence of Strata, North-Central Oklahoma

JAMES E. O'BRIEN, Consultant, Mannford, OK

In plan view, the individual genetic increments of strata that comprise the Cherokee genetic sequence of strata are, for the most part, a complex maze of anastomosing fluvial channels generally trending north–south. This picture is further complicated by many isolated pods, splays, and partially preserved minor channels between and outside of the main channels.

When viewed in cross section, a few of the individual thick sandstone deposits (50–100 ft) are the result of a single depositional event. Most of these deposits are the result of the stacking of two or three individual channels. An additional complication occurs when downcutting into an underlying interval results in younger sandstones being stacked on older sandstones or occupying an interval that would appear to correlate with the older unit.

The rigid use of stereotype principles, such as type electric log signatures (e.g., bell shaped indicating a channel, inverted bell a bar, etc.), unimaginative isopach contouring, computer generated data and/or maps, and scout card or other published information will yield erroneous interpretations. Electric logs need to be intelligently examined and interpreted. Numerous cross sections need to be constructed to show proper stratigraphic relationships. Well cuttings need to be examined microscopically. Isopach maps must be constructed with interpretive imagination, not by rote, in order to yield valid oil-finding interpretations.

Reprinted as published in the American Association of Petroleum Geologists *Bulletin*, v. 71, p. 995.

Stratigraphic Sequence of a Transgressive Barrier-Bar System, Red Fork Sandstone, Wakita Trend, Grant County, Oklahoma

KATHLEEN L. O'REILLY, Environmental Protection Agency, Dallas, TX

The stratigraphic sequence of the Red Fork sandstone (Boggy Formation, Krebs Group) along the Wakita trend, north-central Oklahoma, is interpreted as a transgressive barrier-bar system. The Red Fork sands were deposited along the northern shelf of the Anadarko basin in an elongate belt about 1–7 km wide. Within the belt, the sandstone forms podlike bodies ranging from 1 to 16 km long.

The Red Fork is positioned in a generally onlapping sequence of strata, from the Inola Limestone Member at the base to the Tiawah ("Pink") Limestone Member at the top. Shales that are interpreted as lagoonal deposits underlie and have a sharp contact with the Red Fork. To the north, the underlying shale is variegated green and red, and contains abundant rootlets and woody detritus; shale to the south is dark-gray and contains abundant brachiopod fragments. Glauconitic siltstone and shale overlie and have a gradational contact with the Red Fork sandstone.

Sedimentation of the Red Fork sand was apparently localized on an east–west-striking hinge formed by increasing dip on the surface of the Inola. Shale overlying the Inola thickens to the south, forming a relatively flat surface upon which Red Fork deposition occurred. No evidence exists of valleys or channels cutting into shale underlying the Red Fork sandstone.

Sedimentary structures in the Red Fork sandstone support interpretation of the stratigraphic sequence as a barrier-bar complex. Sandstone geometry and the nature of the encasing rocks are distinctly characteristic of transgressive barrier-bar systems.

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Seismic Expression of Red Fork Channels in Major and Kay Counties, Oklahoma

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This paper investigates the application of regional seismic to exploration and development of Red Fork sands of the Cherokee Group, in Major and Kay Counties, Oklahoma. A computer-aided exploration system (CAEX) was used to justify the subtle seismic expressions with the geological interpretation. Modeling shows that the low-velocity shales are the anomalous rock in the Cherokee package, which is most represented by siltstone and thin sands. Because the Red Fork channel sands were incised into or deposited with laterally time-equivalent siltstones, no strong reflection coefficient is associated with the top of the sands. The objective sands become a seismic anomaly only when they cut into and replace a low-velocity shale. This knowledge allows mapping the channel thickness by interpreting the shale thickness from seismic data. A group shoot line in Major County, Oklahoma, has been tied to the geologic control, and the channel thicknesses have been interpreted assuming a detectable vertical resolution of 10 ft.

A personal computer-based geophysical work station is used to construct velocity logs representative of the geology to produce forward-modeled synthetic seismic sections, and to display, in color, the seismic trace attributes. These synthetic sections are used as tools to compare with and interpret the seismic line and to evaluate the interpretive value of lower cost, lesser quality data versus reprocessing or new data acquisition.

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Stratigraphy and Depositional Environments of Cherokee Group (Desmoinesian, Middle Pennsylvanian), Central Cherokee Basin, Southeast Kansas

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Rocks of the Cherokee Group of the Cherokee basin in southeastern Kansas are divided into the Krebs and overlying Cabaniss Formations. These units consist of medium- to light-gray shale interbedded with dark-gray shale, rippled sandstone and siltstone, coal, underclay, and argillaceous limestone. Laterally extensive radioactive dark-gray shales serve as a basis for detailed stratigraphic correlation of the Cherokee Group.

Cross sections of the Cherokee Group indicate that the Cherokee basin in Kansas subsided during deposition of the Krebs and lower Cabaniss Formations. Sediment progressively onlapped the Nemaha uplift during deposition of the Cherokee Group and eventually covered the uplift before deposition of upper Cabaniss strata.

The distribution of lithofacies of the Cherokee Group reflects numerous environmental changes in the study area due to deltaic progradation or eustatic sea-level changes. During deposition of the lower Cherokee strata between the top of the Mississippian limestone and the Bluejacket B shale (located near the base of the Cabaniss Formation), the Cherokee basin in Kansas is characterized as having a prodeltaic environment during stillstands at high sea level. Stacked channel

sandstone bodies of fluvial origin represent lowstands of sea level when deltaic deposition prevailed to the south in Oklahoma.

The strata from the top of the Bluejacket B shale to the top of the V shale in the upper part of the Cabaniss Formation include five major lithologic cycles that can be recognized throughout the study area. Each lithologic cycle consists, from base to top, of marine to non-marine shale, siltstone, sandstone, underclay, coal, and marine shale. These strata represent an upward transition from marine to non-marine deposition. The sandstone and siltstone represent non-marine deposition by crevasse splays and distributary channels that prograded across the basin from the north and east.

Between the top of the V shale and the top of the Cherokee Group, specific marine shale and limestone units laterally extend from the Cherokee basin into the Sedgwick basin, indicating that a connection of depositional environments occurred during periods of high sea level. Limestone content increases along the western and southern borders of the study area. Sandstone isolith maps for this interval do not indicate a major source of sediment.

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Relationship Between Structural Development, Carbonate Reservoir Development, and Basement Faulting in Southern Scott and Northwestern Finney Counties, Kansas

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Hydrocarbon production from carbonate reservoirs in the Hugoton embayment, southwest Kansas, is mainly from structurally positive features with well-developed porosity and permeability. In the study area, these reservoirs tend to be associated with oolite development on shallow shelflike areas and accumulations of oolites along relatively rapid changes in paleorelief. However, not all positive structures of similar depositional environments displayed productive reservoir characteristics. In an attempt to understand reservoir development and the timing of the apparent tectonic events in this area, structural and magnetic lineation data (defined by airborne magnetic data) were correlated.

The magnetic data were processed to maximize magnetic resolution in a way that available information was not smoothed nor additional noise added. These data were used primarily to delineate faults and basement-rock-type changes. Correlation of these features with known reservoirs was used to define important trends for hydrocarbon production, and aided in dating these fault movements.

The Damme, Shallow Water, and Hugoton North fields are associated with block-faulted structures along linear trends. These major trends are defined by both structural and magnetic data represented by strong northwest–southeast slope changes that coincide with the edges of the Damme and Hugoton North fields. An intersecting tectonic zone is associated with the Shallow Water field, as evidenced by northeast–southwest-trending magnetic and structural highs. Several of these faults have been verified by seismic data. Porosity and permeability development appears to be dependent on fracturing associated with these faults that appear to have been active during Early Pennsylvanian. The Nunn field is an exception to the general model, in that this field has developed over a known basement high, yet is reflected in the magnetic data as a low, suggesting basement-rock-type changes or reversals along the fault systems that delineate this field.

Based on the observations made in this study, new prospects in areas of poor well control can be developed.

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Seismic Stratigraphy of Early Pennsylvanian Morrowan Sandstones, Minneola Complex, Ford and Clark Counties, Kansas

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The oil fields of the Minneola complex in southwest Kansas produce from northwest–southeast-trending marine sandstones of Morrowan age. Reservoir quality stratigraphic traps developed at the intersection of sandstone trends and topographic lows or channels on the underlying eroded Mississippian surface.

The discovery well, Ladd 1-8 Norton, was drilled in Sec. 8, T30S, R25W, Clark County, Kansas, on a seismic anomaly recognized on 12-fold Vibroseis data. Eleven feet (3m) of productive Morrowan sandstone at 5,280 ft (1,609 m) was completed for 157 BOPD. Electric logs in the discovery well revealed that an expanded (up to 100 ft or 30 m) Morrow section consisting of sandstone and shale had been deposited in lows on the underlying eroded Mississippian surface. Modeling indicated that the addition of this low-velocity clastic material within these channels caused a variety of seismic anomalies, the distribution of which guided subsequent exploration and development drilling. These seismic anomalies are associated with topographic lows on the Mississippian unconformity surface rather than the productive sandstones. The anomalies vary in character and consist of (1) diffractions, (2) high amplitude bright spots, (3) breaks in seismic continuity of the Mississippian reflector (polarity reversals), (4) sagging of the Marmaton reflector, and (5) possible faulting of Viola–Arbuckle reflectors. These anomalies vary according to the thickness of sediment deposited within the erosionally low areas, the varying geometry and lithologies of these deposits, variations in overlying sediments, and the angle at which the seismic line is shot across the lows. Subsurface control and seismic data can be used to trace the paleodrainage pattern and to interpret the distribution of the overlying productive Morrowan sandstones.

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Computer Stereograms of Oklahoma Subsurface Geology

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Three-dimensional stereoscopic illustrations have not been a standard part of the subsurface geologist's tool kit. Now, the immense complexity of stereograms can be resolved by inexpensive software on a personal computer, with which the subsurface geologist can gain an entirely new viewpoint. These new illustrations yield new patterns, new relationships, and prospective anomalies. The illustrations are particularly helpful in areas of complex structural geology. This study presents a regional sampling of this new mode of geologic illustration; Oklahoma was chosen because of its wide variety of structural styles, the prolific reserves associated with those structures, and the abundance of geologic data.

A statewide data base of 2,806 structural elevations on the base of the Pennsylvanian System was digitized from scout-ticket tops. In addition, three detailed data bases of local structures were digitized, using all the available structural control plus interpreted points to aid the programming. Contour maps and block diagrams were constructed with readily available, inexpensive software, using kriging algorithms. Stereo pairs were created by rotating the blocks 4° within the computer program. The pairs were positioned 2.5 in. apart to match an average viewer's interpupillary distance. The three-dimensional blocks may be viewed with a stereoscope or with naked eyes focused on a distant point.

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Oil and Gas Developments in Oklahoma and Panhandle of Texas in 1986

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In 1986, a 46% drop in the price of oil and a 10% drop in the price of gas, coupled with a decrease in demand, forced a 40.4% decrease in drilling, a 67% drop in gas production, and an 11% drop in oil production in Oklahoma and the Panhandle of Texas (Texas Railroad Commission District 10).

Exploration focused on development and extension of existing fields, with development wells outnumbering exploratory wells 18 to 1.

Operators completed 58.6% fewer exploratory wells and 59.2% fewer development wells in 1986 than in 1985. The 1986 success rate for exploratory wells dropped 0.8%, and the success rate for development wells increased 0.9%. The Cherokee shelf was the most active trend, with 53 exploratory wells completed in 1986.

The dominant plays were the Morrow–Springer and granite wash in the Anadarko basin, Misener on the Sedgwick shelf, Viola and Hunton in the Golden Trend along the Pauls Valley uplift, and Wapanucka, Cromwell, and Atoka in the Arkoma basin.

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Depositional Environments of Upper Morrow Sandstone in Southeast Tracy and Southeast Eva Fields, Texas County, Oklahoma

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Southeast Tracy Field, Texas County, Oklahoma, produces gas from an upper Morrow sandstone. The field has produced over 33 bcf of gas and a negligible amount of oil from 12 wells, since its discovery in November 1958. Development drilling on the southern end of the Southeast Tracy field has extended its boundary to within 1.4 mi of the Southeast Eva field, which produces from stratigraphically equivalent upper Morrow sandstones. The Southeast Eva field has produced over 188,000 bbl of oil and 1 bcf of gas from 7 wells since its discovery in February 1978.

The upper Morrow sandstone in the Southeast Tracy field has a shoestring geometry, characterized by a north–south trend 8 mi long and 1.5 mi wide. The sandstone has a broad, U-shaped base and is more than 70 ft thick. The shale interval between the base of the sandstone and underlying marker beds progressively thins from north to south. The sandstone in the Southeast Tracy field has a blocky to bell-shaped, electric-log profile, and is interpreted as a channel-fill. The channel trend extends southward from the Postle field, a thick upper Morrow fluvial and deltaic complex to the north.

Well-log profiles and a study of drill cuttings suggest the presence of a clean, well-sorted coarsening-upward sandstone in the southern part of Southeast Tracy field. In Southeast Eva field, the upper Morrow interval, equivalent to the channel sandstone in Southeast Tracy field, is characterized by four sandstones and intervening shales. These sandstones are each less than 30 ft thick, have limited areal extent, and have no distinct directional trend. These characteristics suggest change in depositional environment. Sandstones at Southeast Eva are interpreted, at this stage of development drilling, as shoreline-reworked, channel-mouth sands.

Drill cuttings from most wells in the Southeast Eva field contain calcite, dolomite, pyrite, and scattered glauconite grains. The occurrence of these materials may account for calculated water saturations as high as 60% in some producing wells.

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Sedimentology, Petrology, and Reservoir Characteristics of Lower Strawn Sandstone, Bent Tree Field, Hardeman County, Texas

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Reservoir sandstones of the lower Strawn Formation (early Middle Pennsylvanian) in the Bent Tree field of Hardeman County, Texas, are coarse- to fine-grained, texturally submature arkoses. Cores show the sandstones to have been deposited in 1.5–4.5-m-thick fining-upward successions of aggraded or prograded bar units. Each bar unit has a sharp erosional base overlain by cross-bedded, coarse-grained, conglomeratic sandstone, which, in turn, is overlain by medium- to fine-grained, horizontally bedded or ripple-bedded sandstone. The coarse conglomeratic sandstones are interpreted to represent deposition in main channels of a braided fluvial system that were progressively filled by aggrading and prograding bars. The interbedded, finer grained, more immature sandstones appear to have been deposited in auxiliary channels or swales, or in proximal overbank settings.

The detrital framework grain suite of the reservoir sandstones averages 47% quartz, 30% feldspars, 19% igneous rock fragments, and 4% sedimentary rock fragments. The source of these sands was a plutonic/cratonic igneous massif with minor exposures of older sedimentary strata, and was probably the ancestral Wichita Mountains. Diagenesis has significantly affected the petrographic and reservoir properties of the lower Strawn sandstones, primarily through the in-situ alteration of detrital feldspathic grains and by the precipitation of authigenic quartz overgrowths, chlorite clay, and carbonate cements.

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Possible Late Middle Ordovician Organic Carbon Isotope Excursion: Evidence from Ordovician Oils and Hydrocarbon Source Rocks, Mid-Continent and East-Central United States

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Oils generated by Middle Ordovician rocks are found throughout the Mid-Continent and east-central regions of the United States. Gas chromatographic characteristics of these oils include a relatively high abundance of n-alkanes with carbon numbers less than 20, a strong predominance of odd-numbered n-alkanes between C_{10} and C_{20}, and relatively small amounts of branched and cyclic alkanes. Saturated and aromatic hydrocarbon fractions of 43 Ordovician oils from the Anadarko, Ardmore, Forest City, Illinois, Michigan, Salina–Sedgwick, and Williston basins and the Iowa shelf demonstrate a wide range in carbon isotope composition

$$(\delta^{13}C_{sat} = -24.9‰ \text{ to } -33.9‰,\ \delta^{13}C_{arom} = -24.3‰ \text{ to } -33.7‰).$$

Saturated and aromatic hydrocarbons extracted from late Middle Ordovician shales (17 core samples) show ranges in $\delta^{13}C$ similar to that of the oils.

The wide ranges in $\delta^{13}C$ for oils and rock extracts reflect a major, positive excursion(s) (6–9 per ‰) in organic matter $\delta^{13}C$ in late Middle Ordovician rocks. This excursion has at least a regional significance in that it can be documented in sections 480 mi (770 km) apart in south-central Kansas and eastern Iowa. The distance may be as much as 930 mi (1,500 km) if the carbon isotope variations observed in Michigan basin Ordovician oils and in organic matter from late Middle Ordovician rocks in southwestern Ontario are related to the same carbon isotope excursion. Organic-matter $\delta^{13}C$ in core samples from south-central Kansas and eastern Iowa is not directly related to variations in quantity or quality of organic matter, or maceral composition. The positive excursion in organic matter $\delta^{13}C$ is a possible result of increased organic matter productivity and/or preservation.

The parallel shifts in organic and carbonate $\delta^{13}C$ in core samples from 1 E. M. Greene well, Washington County, Iowa, imply changes in the isotope composition of the ocean-atmosphere carbon reservoir. Differences in the magnitude of the carbon isotope shifts between organic matter (8.8‰) and carbonate (4.2‰) in this core suggest a decrease, either locally or regionally, in available dissolved CO_2, possibly a result of high organic-matter productivity and/or limited circulation in the late Middle Ordovician seas.

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(continued from p. 46)

Most plant fossils are preserved in sedimentary rocks of fresh- or brackish-water origin. Finer-textured sediments such as shales, siltstones, and fine-grained sandstones contain the best-preserved plant fossils (Arnold, 1947, p. 20–21). Evidence found in the rocks exposed at the gas-well site indicates that they were deposited as fresh- or brackish-water sediments, probably just above sea level in a coastal-swamp environment. That the fossil plants found at this site once grew in a swamp is confirmed by the presence of an overlying clayey shale containing abundant plant material, grading upward into underclay. A thin (1-in.-thick) bed of coal (Secor) occurs at the top of the underclay. This sequence of beds is typical of Middle Pennsylvanian swamp environments, which have provided a wealth of well-preserved fossil plant material, not only in Oklahoma, but throughout the coal-bearing regions of the world.

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LeRoy A. Hemish

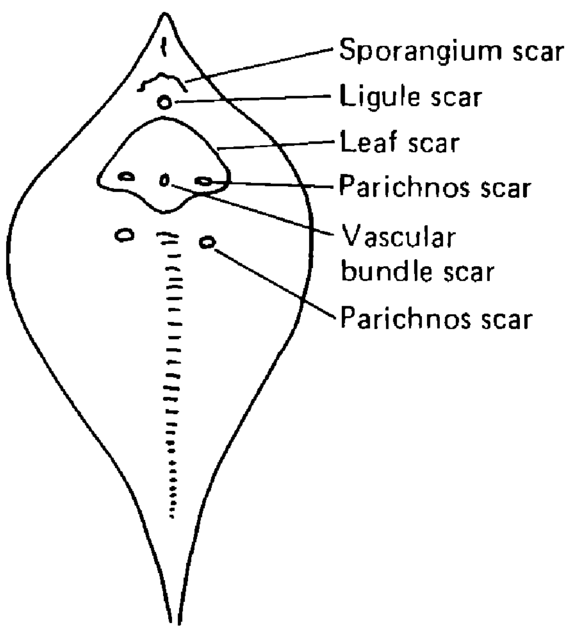

Figure 1. Features of an idealized *L. obovatum* leaf cushion (from Taylor, 1981, fig. 8.8, B.).

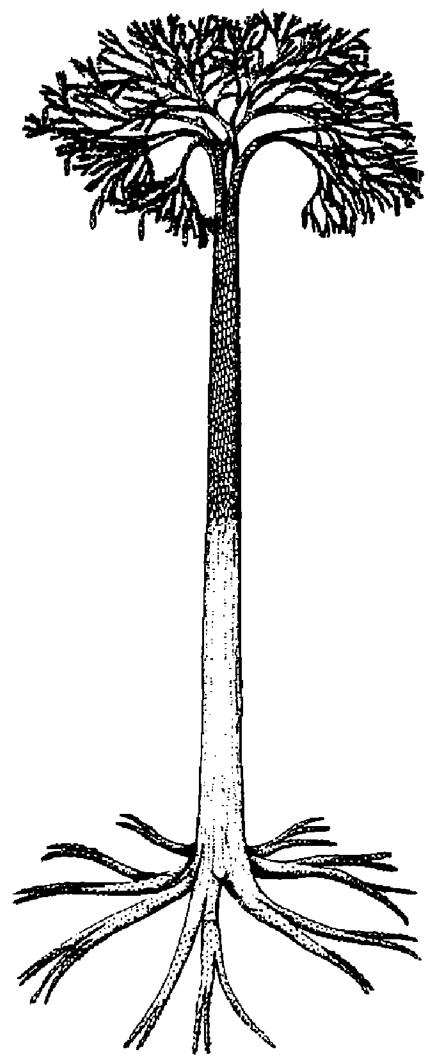

Figure 2 (right). Reconstruction of *Lepidodendron* sp. (from Stewart, 1983, fig. 11.3, A).