OKLAHOMA GEOLOGY

Oklahoma Geological Survey Vol. 49, No. 2 April 1989

On the cover—

Granite Platforms of the Western Wichita Mountains, Oklahoma

Hills composed of Middle to Late Cambrian granite of the Wichita Granite Group rise as much as 900 ft above the surrounding Permian red-bed plains in the Lake Altus area of the western Wichita Mountains, Oklahoma. The crests of the four highest hills are distinctly beveled at elevations of 2,150 ft (the tightly clustered Flat Top, Soldier, and King Mountains—the latter shown in the cover photo) and 2,110 ft (Tepee Mountain, ~2 mi northeast of the other three). These platforms have been collectively referred to by Tanner (1954) as the Lake Altus surface. The platform on Flat Top Mountain is a discontinuous surface several thousand feet across. The platforms on the other three hills lie below central peaks, and have radial outward dips of 2–10° and widths of as much as a few hundred feet. They are widest and least steep on the west and southwest sides of the hills.

Tanner (1954) proposed the now widely accepted explanation for the origin of the granite platforms. He suggested that they are wave-cut benches of Middle Permian age that were exhumed by late Tertiary–Quaternary erosion of the overlying Permian marine sediments. This interpretation is no longer tenable. Recent work by the author has shown that the platforms are late Pliocene–early Pleistocene pediments cut to the level of the southeasterly sloping Southern High Plains surface (the Llano Estacado) which formerly existed in the Lake Altus area. This surface was created by the late Miocene–early Pliocene alluvial deposition of the Ogallala Formation. The eastern edge of the surface was eroded back to its present position in the Texas Panhandle (110 mi west of the Lake Altus area) by early Kansan time (Frye, 1973); thus, the platforms have been isolated and perched above the surrounding plains for the last 500,000 to 1,000,000 yr. Evidence for the new interpretation is as follows: (1) Studies of modern coasts show

(continued on p. 67)

OKLAHOMA GEOLOGICAL SURVEY

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THE PAGE IMPSONITE MINE, LE FLORE COUNTY, OKLAHOMA

Brian J. Cardott[1], *Neil H. Suneson*[1], *and Charles A. Ferguson*[1,2]

Introduction

The Oklahoma Geological Survey, in cooperation with the United States Geological Survey and the Arkansas Geological Commission, is currently mapping the geology of the frontal belt of the Oklahoma Ouachita Mountains as part of the COGEOMAP project. Other parts of the project include: a detailed study of potential hydrocarbon source rocks that are exposed at the surface, including determination of thermal maturity by vitrinite reflectance; organic petrology of solid hydrocarbons (asphaltite and asphaltic pyrobitumen) exposed at the surface; and organic geochemistry of solid and liquid hydrocarbons throughout the Ouachita Mountains. This brief paper is a progress report on the "rediscovery" of the Page impsonite mine and the implications of the petrology of the impsonite that was mined there. Impsonite is an asphaltic pyrobitumen ("natural substances composed of hydrocarbons . . ., the non-mineral constituents being infusible and largely insoluble in carbon disulfide," Abraham, 1960, p. 255,57) with high fixed-carbon content (50–85%) occurring as a fracture-filling vein deposit.

Location and Geology

The Page impsonite mine is located 1.5 mi east of the town of Page, in the Ouachita Mountains of southeast Oklahoma. The geology of the area, mapped by Seely (1963) (Fig. 1), consists of steeply S-dipping, imbricate thrust slices of four Carboniferous flysch units: Stanley Group, Jackfork Group, Johns Valley Shale, and Atoka Formation. The E–W-trending thrust slices are expressed as sharp ridges as high as 1,700 ft above intervening valley floors, held up by resistant, thick-bedded sandstones of the Jackfork Group. The underlying Stanley Group and overlying Johns Valley and Atoka Formations form valleys because of their relatively higher proportions of shale. The Page impsonite mine is within medium- to thick-bedded sandstones of the Wildhorse Mountain Formation of the Jackfork Group, ~3,000 ft above the top of the Stanley. This part of the Wildhorse Mountain Formation was described by Seely (1963, pl. II) as "sandstone, medium-dark-gray to white, moderately to well sorted, friable to hard, possessing pitted top surface and tracks of bottom organisms; interbedded gray shale."

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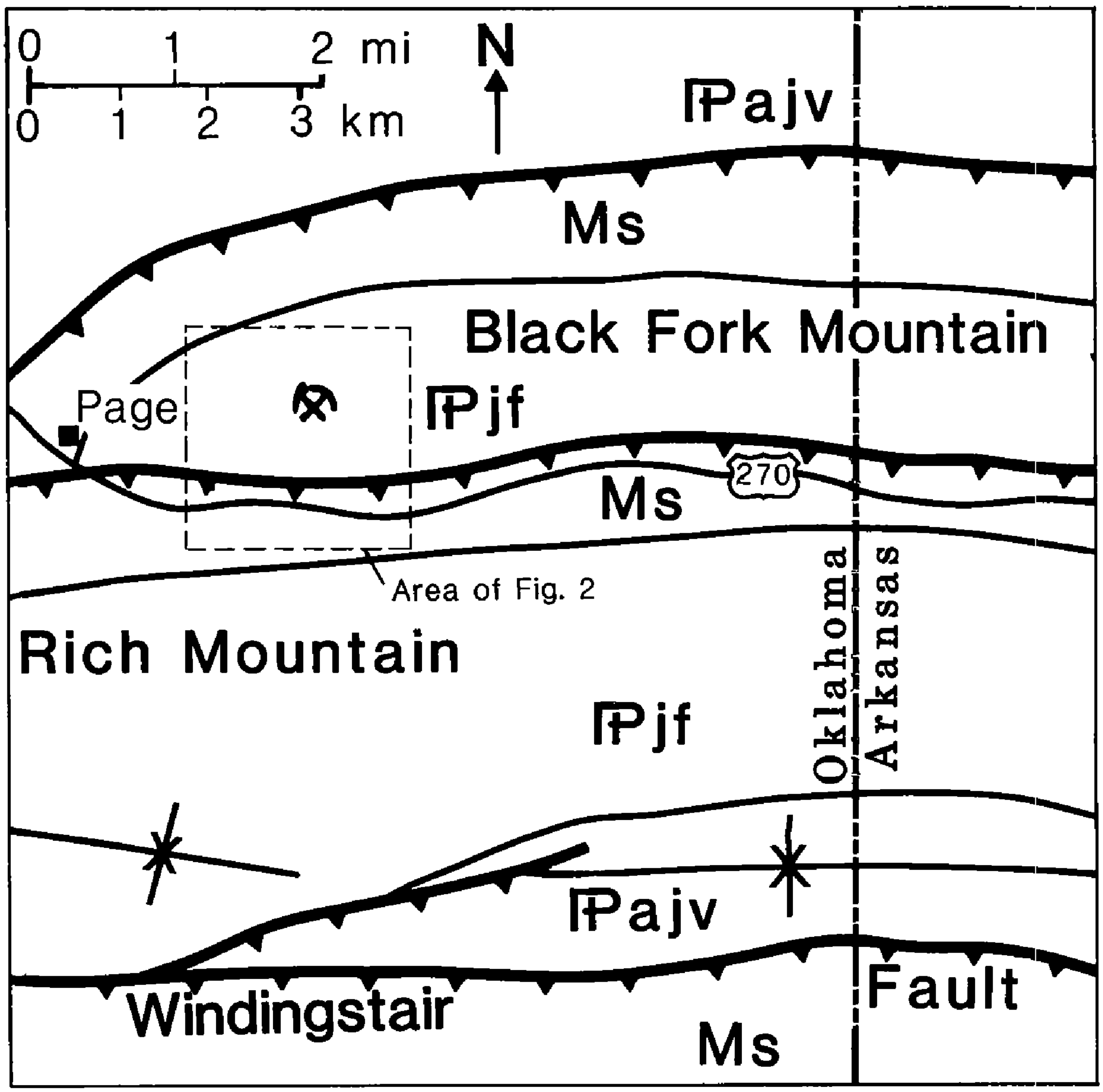
The exact location of the mine workings (CNE¼SE¼ sec. 24, T. 3 N., R. 26 E.) is shown in Figure 2. Two old roads are also shown in Figure 2; the western road was probably used to service the workings. Both roads are overgrown and deeply rutted, and cannot be negotiated with four-wheel-drive vehicles.



EXPLANATION

PENNSYLVANIAN
- IPajv — Atoka Formation and Johns Valley Shale
- IPjf — Jackford Group

MISSISSIPPIAN
- Ms — Stanley Group

Figure 1. Generalized geology of the Ouachita Mountains near Page, Oklahoma (modified from Seely, 1963). The Windingstair fault defines the southern edge of the frontal belt.

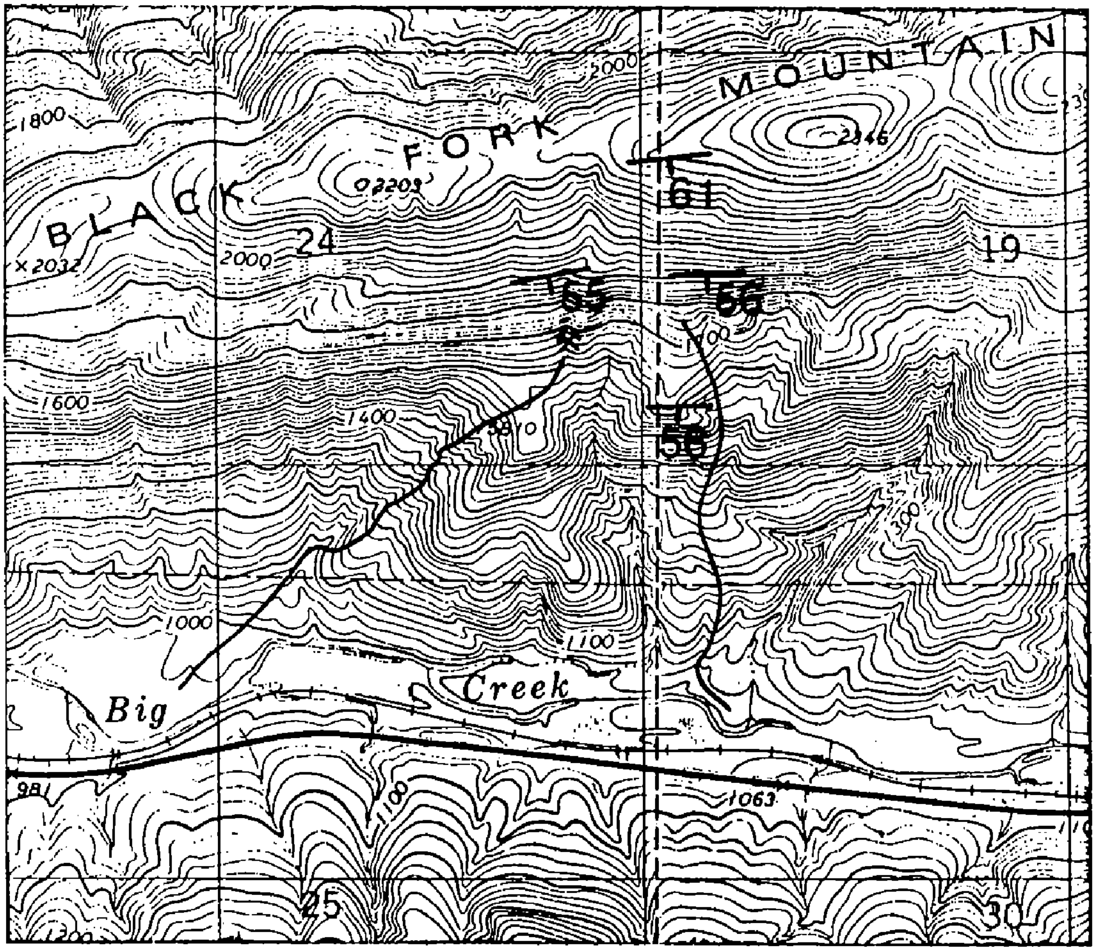


Figure 2. Part of the Page 7.5′ quadrangle, showing two old mine roads leading up to the Page impsonite workings, and the strike and dip of sandstone beds in the area. The major east–west highway is U.S. 270/59.

Those who are interested in visiting the Page impsonite mine should look for a turnout on the north side of U.S. Highway 270/59 1.7 mi east of the town of Page (mileage estimated from a major T intersection). The mine, 700 ft above the valley floor on the south side of Black Fork Mountain, is about an hour hiking time from the turnout. The old road leading to the mine is northwest of the easterly bend in the railroad tracks on the flood plain immediately north of Big Creek.

Description of Surface Workings

The surface workings of the Page impsonite mine consist of three and possibly four trenches and three mine dumps (Fig. 3); one of the trenches (no. 2) has an adit at its upslope end. The highest trench (no. 3) has a large depression at its upslope end, exposing several steeply dipping beds of sandstone. This depression may mark the location of a collapsed shaft. The road from Big Creek to the mine workings (Fig. 2) appears to end at the foot of dump no. 2. Two stone structures are also present—a small stone foundation about 10′ × 10′ just west of the top of dump no. 1, and a 20′ × 12′ stone structure divided into four or possibly five compartments, just west of trench no. 2.

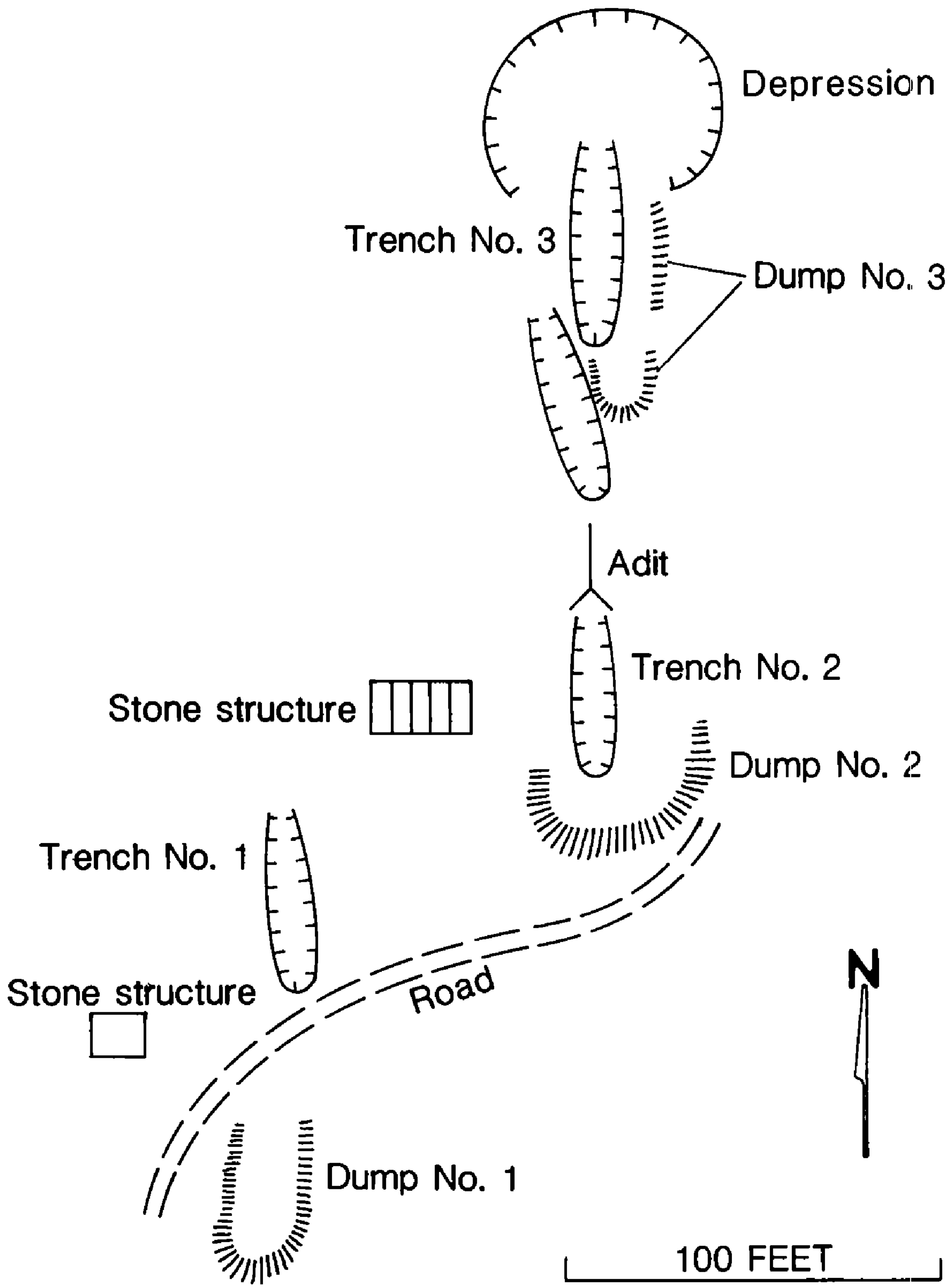


Figure 3. Sketch map of surface workings at the Page impsonite mine.

The lowest trench (no. 1) is oriented about N. 15° W., extends ~75 ft into the hillside, and is ~7 ft deep at its deepest part; it may be a collapsed adit. Dump no. 1, south of the trench, is elongate, being ~50 ft long, 20 ft wide, and averaging 10 ft high. The estimated volume of the dump is 200 yd^3. No impsonite was observed on the dump, which is covered with forest litter.

Trench no. 2, oriented about N–S, is ~35 ft long and 5 ft deep. The adit at the north end of trench no. 2 was nearly filled with water on 9 December 1987; it appeared to extend at least 20 ft into the hillside. Dump no. 2 is at the south end of the trench and is ~20 ft long, 25 ft wide, and 20 ft high at its highest point. The estimated volume of the dump is 150 yd^3. Impsonite is abundant on this dump. A small trench, unnumbered on Figure 3, is just north of trench no. 2; it is ~40 ft long and 5 ft deep.

Trench no. 3, the highest and northernmost of the trenches, is oriented about N–S and ends at a large, 40′ × 40′ × 12′ depression (collapsed shaft?) that exposes several sandstone beds. These beds have an average strike of N. 85° E., a dip of 52° S; they are south-facing. Some of the sandstones exposed in this large cut are poorly consolidated and appear to be impregnated with tar. Dump material is present along the east side of the trench and in a small 10′ × 10′ × 5′ dump (estimated volume, 10 yd^3) at the south end of the trench. Impsonite is abundant in the dump material.

Impsonite was not observed in place; the material collected for study came entirely from the mine dumps.

History and Description of the Deposit

The Page impsonite deposit was discovered in 1895 by a hunter who reported finding coal in Black Fork Mountain (Hutchison, 1911). Impsonite was mined from the deposit from about 1900 to 1924 (Ham, 1956). Ham (1956, p. 10) stated that "this deposit was worked for fuel on a small scale before 1911, but the main workings were developed apparently during World War I, when the impsonite was burned and the ashes shipped for their high content of vanadium." The main adit was open in 1945 (Fig. 4), and still open in 1954 when visited by Ham (Ham, 1956). The impsonite vein deposit is no longer exposed; therefore, any description of the vein must come from the literature. Taff (1909, p. 294) stated that "the grahamite vein fills a fault fissure that bears in an irregular southwest course, cuts across the strata, and pitches steeply toward the southeast." The vein deposit had a "variable and highly disturbed" (p. 295) orientation, with a known thickness as great as 3 m and dip of 50°. At the mine, "the rocks are fissured and sheared" (p. 294), with evidence of faulting subsequent to emplacement of bitumen in the fissure.

In a discussion on grahamite deposits of southeastern Oklahoma, Taff (1909, p. 295) tentatively classified the Page deposit as grahamite, while noting that its high fixed-carbon content probably placed it in a "class of bitumens or so-called asphaltites other than that of grahamite." Richardson (1910) classified the Page impsonite under the heading "metamorphosed grahamites." Hutchison (1911) referred to the Page impsonite as a deposit of grahamite. Abraham (1920) formally classified the Page deposit as impsonite.

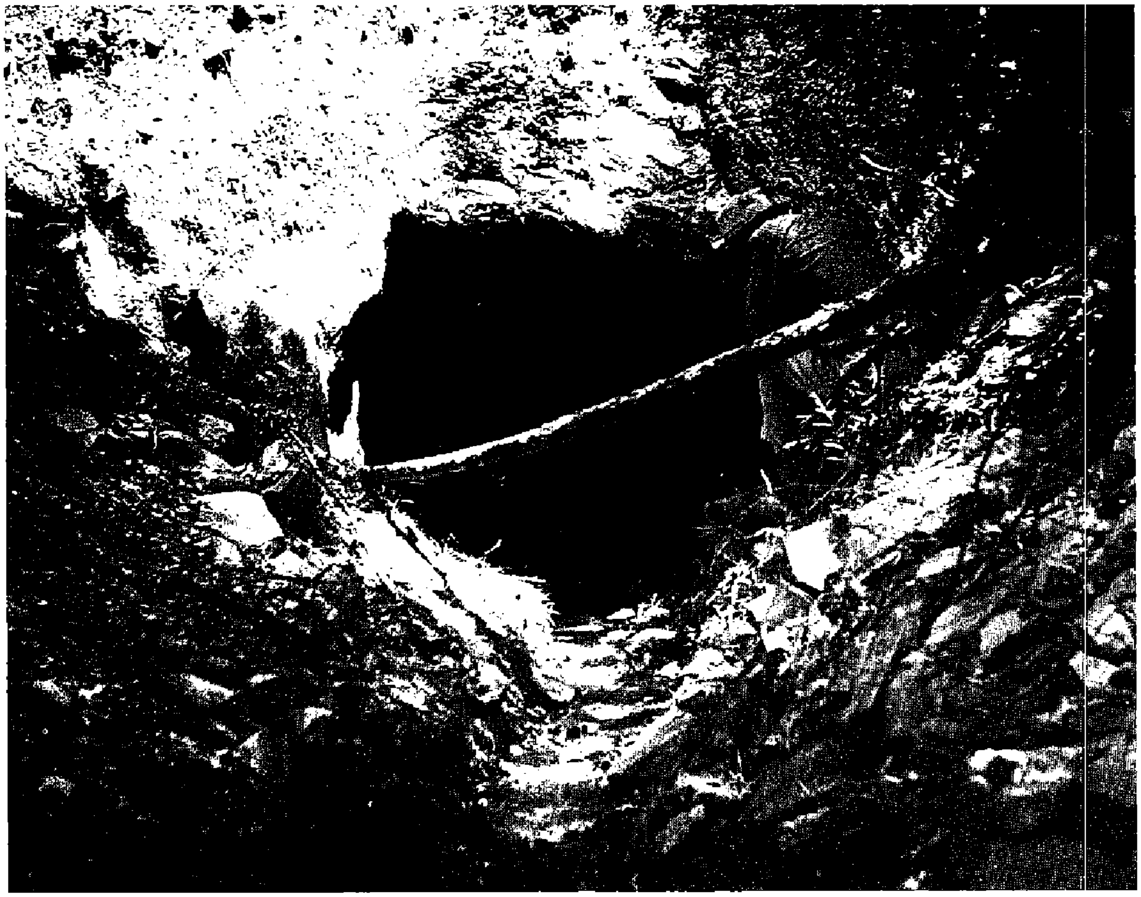


Figure 4. Photograph of an adit at the Page impsonite mine taken in 1945 by M. C. Oakes and J. O. Beach. Photo courtesy of Western History Collections, University of Oklahoma Library.

Physical Characteristics of the Impsonite

Grab samples of impsonite, 3–14 cm long, were collected from mine dumps surrounding the inactive mine workings. Megascopically, the impsonite is black, homogeneous, and structureless, with granular texture, hackly fracture, and semi-dull to semi-bright luster, sometimes vitreous (Fig. 5). Small, smooth surfaces exposed along fracture planes have irregular or circular shape. The samples are friable and have a black streak. Thin laminations give the impsonite the appearance of banded bituminous coal.

The chemical characteristics of the Page impsonite have been reported by Eldridge (1901), Abraham (1920,1960), Ham (1956), King and others (1963), Jacob and Wehner (1981), and Curiale (1983,1986), and summarized by Cardott (in prep.), but are beyond the scope of this report.

Optical Characteristics of the Impsonite

Under reflected white light in oil immersion at 500× magnification, the solid bitumen at Page is characterized by non-uniform, fine-granular microtexture (black

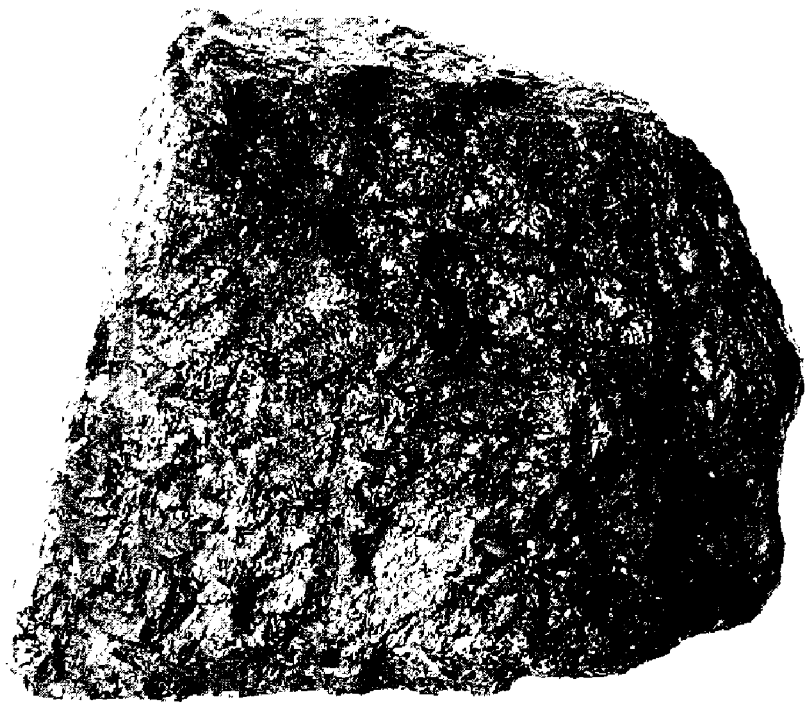


Figure 5. Hand specimen of impsonite from Page mine dump, showing characteristic megascopic features: black color, structureless, granular texture, hackly fracture, and semi-dull to semi-bright luster. Specimen is 6 cm long.

and white granules <1 μm in size, granules more pronounced during unit extinction); homogeneous composition; high reflectance; non-fluorescence under reflected blue-light excitation; random fractures; and sharp, irregular, straight, curved, or serrated grain edges.

Maximum bitumen reflectance was measured in plane-polarized, monochromatic (546 nm) white light in oil immersion ($n_e = 1.5180$). Mean maximum bitumen reflectance on whole-particle pellets from four samples and crushed-particle pellets from three samples is 1.41–1.96% R_o. Maximum reflectance is 1.30–2.21% R_o. Chemical and optical characteristics confirm that the Page deposit is impsonite. More specifically, the Page deposit classifies as epi-impsonite.

Origin of the Impsonite

Asphaltite (gilsonite, glance pitch, grahamite) and asphaltic pyrobitumen (wurtzilite, albertite, impsonite) have long been considered alteration products of crude oil (Eldridge, 1901; Richardson, 1910; Abraham, 1920,1960); Ham (1956), Howell and Lyons (1959), and Chenoweth (1985) recognized that the presence of asphaltites and asphaltic pyrobitumens in the Ouachita Mountains is evidence of oil generation and expulsion. Curiale (1983) suggested that the grahamites and impsonite of the Ouachita Mountains of Oklahoma are derived from near-surface, low-temperature alteration of crude oil by limited biodegradation, water-washing, and "devolatilization" (evaporation), and that local Ordovician–Silurian rocks sourced the oil. This oil is thought to have migrated into fractures created in the brittle sandstone country rock by folding and thrust faulting during the Middle to Late Pennsylvanian Ouachita orogeny.

Grahamite is the only other type of asphaltite or asphaltic pyrobitumen deposit known in the area. Thermal-maturity data by Curiale (1983) and Houseknecht and Matthews (1985) indicate that the thermal maturity of rock outcrops in the region is within the oil window. The presence of grahamite deposits in the area and the level of thermal maturity of the region suggest indirectly that the Page impsonite originated as a thermally altered grahamite formed from an asphaltene-rich asphalt.

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OKLAHOMA EARTHQUAKES, 1988

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

Instrumentation

A statewide network of 11 seismograph stations was used to locate 48 earthquakes in Oklahoma for 1988 (Fig. 1). The Oklahoma Geophysical Observatory (OGO) station, TUL, located near Leonard, Oklahoma, in southern Tulsa County, operates seven seismometers, three long-period and four short-period. The seismic responses at TUL are recorded on 14 paper-drum recorders and one digital recorder. Accurate timing is assured by a microprocessor clock that is continuously locked to the National Bureau of Standards cesium-beam clocks by low-frequency radio transmissions broadcast by WWVB (Lawson, 1980). Seven semipermanent volunteer-operated seismograph stations and three radio-telemetry seismograph stations complete the Oklahoma Geological Survey's seismic network. The operation and maintenance of 10 of the stations is partially supported by the U.S. Nuclear Regulatory Commission (Luza, 1978).

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

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

In 1988, Lawrence Livermore National Laboratory, with U.S. Department of Energy support, initiated a joint project with the Oklahoma Geological Survey to install a borehole seismometer on Observatory property. A cased, 770-m-deep borehole drilled in 1961 was evaluated for the project. Drilling mud was reverse-circulated out of the borehole. A corrosion inhibitor was added to the water left

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

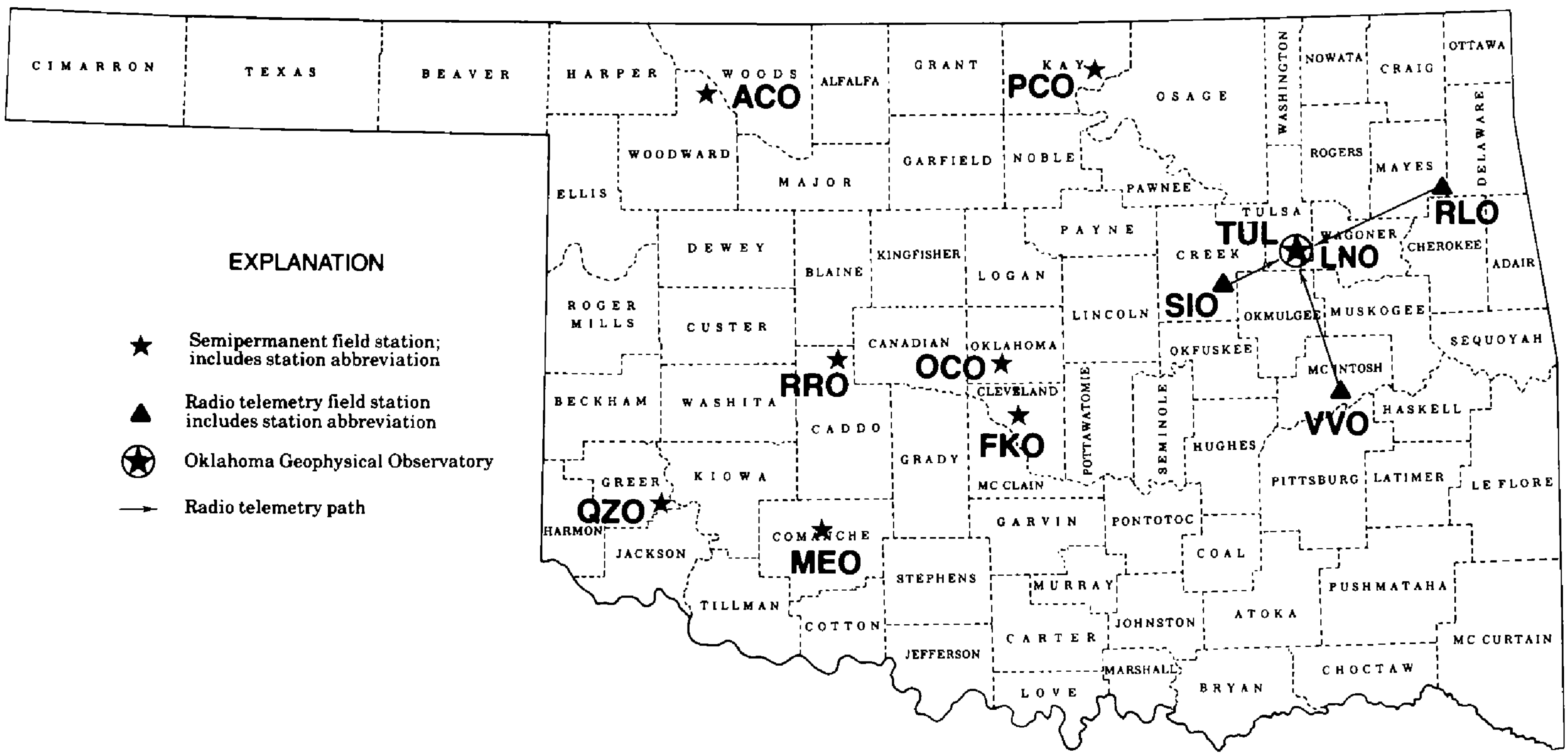

Figure 1. Active seismographs in Oklahoma.

in the borehole. Caliper, casing-inspection, cement-bond, hole-deviation, and gamma-ray logs were run. The deviation log indicated a 1.75° maximum departure from vertical. The cement-bond, caliper, and casing-inspection logs revealed the hole to be in excellent condition and, thus, a very favorable site for a borehole-seismometer installation.

Two Geotech 23900 seismometers were placed near the bottom of the well bore, and a third was placed in an adjacent, 5-m-deep, recently drilled borehole. The 23900 seismometer is the electrical and mechanical equivalent of a Geotech S-13, redesigned to fit a 100-mm-diameter pressure-resistant case.

The responses from the three borehole seismometers are digitally recorded at 200 samples/sec near the well bore. Also, the responses are continuously recorded on analog seismograms at the Observatory. The deepest seismometer (35.913° N., 95.789° W.; elevation 506 m below sea level) was designated station LNO. This station has recorded Pg phases not seen on seismograms from the vault seismometers. LNO will significantly enhance Oklahoma earthquake detection and location.

Data Reduction and Archiving

Arrival times from all visible teleseisms (phases from distant earthquakes) at TUL, RLO, MEO, VVO, SIO, and OCO are sent to the U.S. National Earthquake Information Service and the International Seismological Centre in England. P-wave and surface-wave amplitudes from TUL, plus selected arrival times from ACO, 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 station TUL, at the OGO near Leonard, five short-period vertical seismograms (with differing frequency responses) anc one short-period vertical seismogram from the LNO borehole seismometer signal are searched exhaustively for local and regional earthquake phases. Also searched are two TUL short-period horizontal seismograms; two short-period vertical seismograms from each of RLO, SIO, and OCO; and one short-period vertical seismogram from each of the seven other stations.

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 1988, 48 Oklahoma earthquakes were located (Fig. 2; Table 1). No earthquakes were reported felt. The felt and observed effects of earthquakes are generally given values according to the Modified Mercalli intensity scale, which assigns a Roman numeral to each of 12 levels described by effects on humans, man-made constructions, or natural features (Table 2).

Earthquake-magnitude values range from a low of 1.0 (m3Hz) in McClain and Garvin Counties to a high of 2.7 (m3Hz) in Dewey and Garvin Counties. Garvin and McClain Counties continue to be one of the most active areas in the State

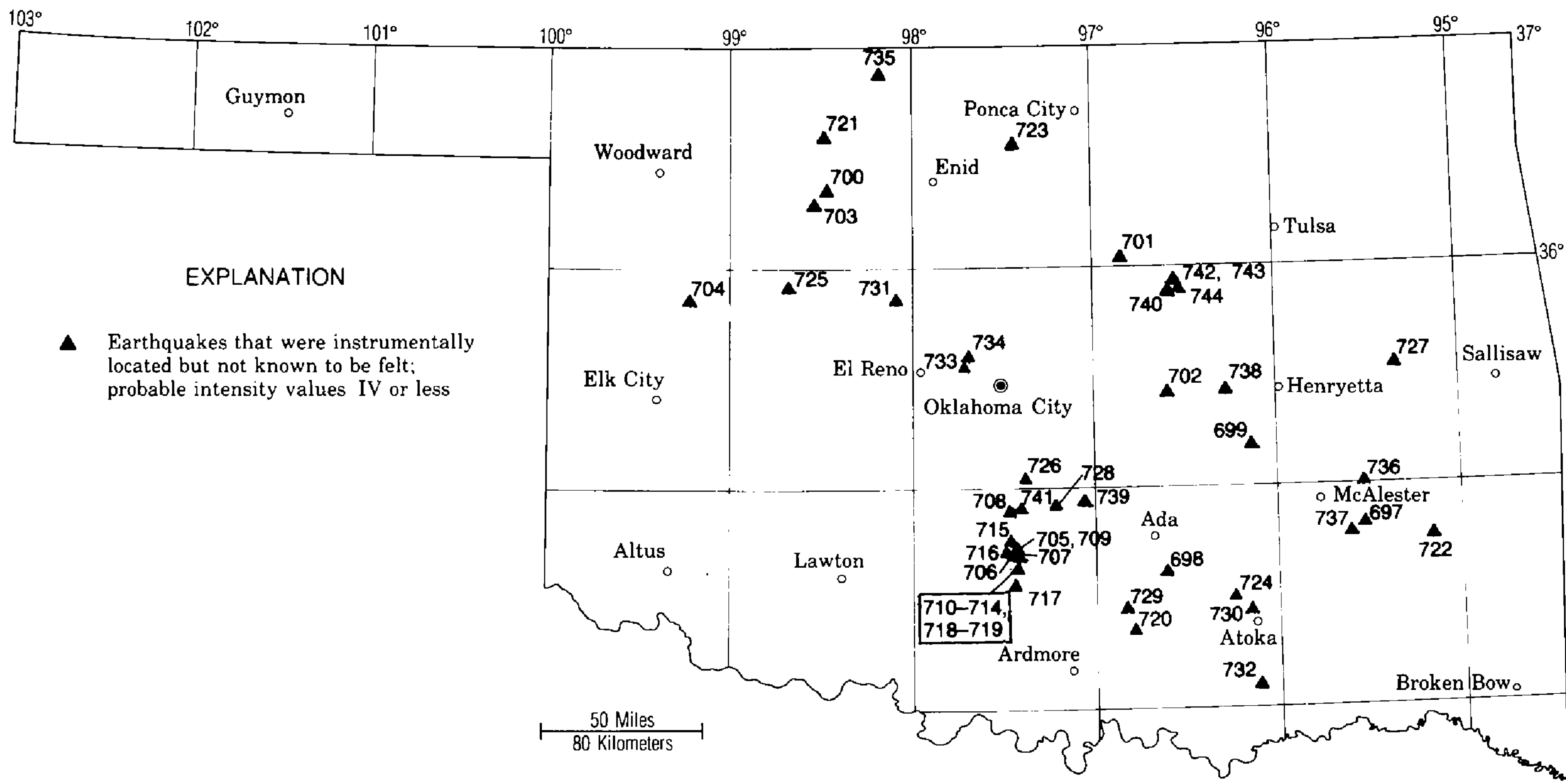

Figure 2. Distribution of Oklahoma earthquakes for 1988. Numbers correspond to event numbers in Table 1.

TABLE 1.—OKLAHOMA EARTHQUAKE CATALOG FOR 1988

Event Number	Date and Origin Time (UTC)[1]		County	Intensity MM[2]	Magnitudes 3Hz	bLg	DUR	Latitude deg N	Longitude deg W	Depth (km)[3]
697	JAN 2	094728.24	PITTSBURG				1.3	34.846	95.534	5.0R
698	JAN 6	130412.33	PONTOTOC		2.4	2.2	2.2	34.644	96.624	5.0R
699	JAN 11	043653.06	HUGHES		2.1		2.2	35.174	96.126	5.0R
700	JAN 30	225920.37	MAJOR		2.0	1.9	2.1	36.380	98.466	5.0R
701	MAR 19	092737.70	PAYNE				1.4	36.041	96.824	5.0R
702	MAR 24	022547.87	OKFUSKEE		2.4		2.3	35.414	96.573	5.0R
703	MAR 30	154655.29	MAJOR		2.2		2.3	36.310	98.543	5.0R
704	APR 21	105808.13	DEWEY		1.3		1.7	35.855	99.207	5.0R
705	APR 29	145956.63	GARVIN		1.5		1.8	34.741	97.469	5.0R
706	APR 29	152355.99	GARVIN		1.9		2.0	34.716	97.483	5.0R
707	APR 29	152727.67	GARVIN		1.3		1.7	34.714	97.473	5.0R
708	APR 29	153918.09	McCLAIN		1.0		1.6	34.884	97.496	5.0R
709	APR 29	154947.62	GARVIN		1.0		1.5	34.736	97.469	5.0R
710	APR 29	160728.87	GARVIN		2.3	2.0	2.3	34.695	97.478	5.0R
711	APR 29	171806.14	GARVIN		2.6	2.5	2.4	34.682	97.471	5.0R
712	APR 29	183940.86	GARVIN		2.2	1.9	2.1	34.688	97.473	5.0R
713	APR 29	184152.96	GARVIN		1.2			34.668	97.453	5.0R
714	APR 29	190753.15	GARVIN		1.3		1.7	34.674	97.473	5.0R
715	APR 29	190953.92	GARVIN		1.3		1.7	34.780	97.473	5.0R
716	APR 29	192857.96	GARVIN		1.5		1.9	34.717	97.492	5.0R
717	APR 29	202825.67	GARVIN		1.3		1.7	34.590	97.437	5.0R
718	APR 29	224608.53	GARVIN		1.1		1.7	34.656	97.448	5.0R
719	APR 29	230945.40	GARVIN		2.7	2.2	2.5	34.663	97.473	5.0R
720	MAY 1	204125.99	JOHNSTON				1.7	34.356	96.804	5.0R
721	MAY 26	183539.44	ALFALFA		2.1		2.2	36.599	98.478	5.0R
722	JUN 5	025655.47	LATIMER		2.3	1.6	2.1	34.743	95.190	5.0R
723	JUN 14	021450.04	NOBLE		2.0		1.8	36.533	97.455	5.0R
724	JUN 21	231245.62	COAL		2.2	1.4	2.1	34.507	96.263	5.0R
725	JUL 5	232241.59	DEWEY		2.7	2.3	2.5	35.910	98.710	5.0R
726	JUL 24	081354.75	McCLAIN		1.7		1.7	35.084	97.373	5.0R
727	AUG 29	005650.45	McINTOSH				0.9	35.532	95.355	5.0R
728	SEP 18	114430.14	McCLAIN		1.9		1.9	34.926	97.191	5.0R
729	SEP 28	184834.02	JOHNSTON		2.2	1.9	1.8	34.465	96.847	5.0R
730	OCT 3	220200.97	COAL		2.2	1.6	2.0	34.427	96.148	5.0R
731	OCT 12	101145.99	KINGFISHER		2.3	2.1	2.2	35.883	98.075	5.0R
732	OCT 13	144206.75	BRYAN		2.3	2.9	2.4	34.091	96.144	5.0R
733	OCT 19	071931.53	CANADIAN				1.4	35.549	97.709	5.0R
734	OCT 19	073440.27	CANADIAN				1.3	35.584	97.698	5.0R
735	OCT 21	103119.43	ALFALFA				1.7	36.907	98.214	5.0R
736	NOV 7	125337.76	PITTSBURG		1.8		1.9	35.013	95.515	5.0R
737	NOV 28	234843.54	PITTSBURG				1.4	34.801	95.623	5.0R
738	NOV 29	023633.68	OKFUSKEE				1.4	35.419	96.270	5.0R
739	DEC 1	110724.70	POTTAWATOMIE				1.7	34.926	97.031	5.0R
740	DEC 2	063027.62	CREEK		1.8		2.0	35.898	96.565	6.3R
741	DEC 3	192033.84	McCLAIN		1.9	1.9	2.0	34.898	97.435	5.0R
742	DEC 7	123842.49	CREEK		1.5		1.8	35.914	96.538	5.0R
743	DEC 8	021025.46	CREEK		1.2		1.3	35.914	96.542	5.0R
744	DEC 12	032639.23	CREEK				1.5	35.894	96.542	5.0R

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

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

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

since 1979. Creek and Pittsburg Counties experienced four and three earthquakes, respectively. Dewey, Major, Alfalfa, Canadian, Coal, and Johnston Counties each contained two locatable earthquakes.

Catalog

A desk-top computer system, including linked HP-9825T and HP-9835-A computers, hard and flexible disks, and printers, is used to calculate and catalog local earthquake epicenters. Any earthquake within Oklahoma or within about 100–200 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 1988 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, 1980–88).

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

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

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

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

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

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

(epicenter 10–100 km from a seismograph)

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

(epicenter 100–200 km from a seismograph)

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

(epicenter 200–400 km from a seismograph)

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

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

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

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

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

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

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

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

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

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

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

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28th INTERNATIONAL GEOLOGICAL CONGRESS
Washington, D.C., July 9–19, 1989

Geoscientists around the world are preparing for the 28th International Geological Congress, the first in more than 50 years to be held in the United States, and it promises to be the biggest ever. The Convention Center is in downtown Washington, close to government buildings, museums, monuments, and hotels and business facilities.

The International Geological Congress has been held about every four years since the 1800s, and the meetings have enabled geologists from all over the world to exchange new concepts and data. These gatherings of broad-based, international groups have promoted the science of geology and the cooperation and collaboration of geoscientists needed for solving the important problems of the earth sciences. This interdisciplinary approach is featured in the IGC science program.

The 1989 technical program includes two colloquia, more than 200 symposia dealing with many aspects of the geosciences, several dozen poster sessions, and, as an innovation, several dozen short courses (before and during the congress) and numerous workshops. An extensive selection of field trips is being offered to almost every geologic province in the United States, including Alaska and Hawaii, and to Canada, Mexico, the Bahamas, and the British Virgin Islands. Shorter trips, such as visits to historical sites, museums, government institutions, and laboratories, are scheduled; they include city tours and sight-seeing jaunts in and around Washington.

The 28th Session of the International Geological Congress will be held in collaboration with and under sponsorship of the International Union of Geological Sciences. It will be co-hosted by the U.S. Geological Survey and the National Academy of Sciences in cooperation with dozens of scientific societies and industry organizations.

—GSA

International Geological Congress Agenda

Colloquia

The Twentieth Anniversary of the Apollo 11 Lunar Landing: A Planetary Perspective
World Natural Resources

Symposia Categories

General (19 symposia)
The Sedimentary Crust in Space and Time (27)
Resources: Oil, Gas, Coal, and Mineral Deposits (29)
Surface and Near-Surface Processes (21)
Applied Geosciences: The Environment, Hazards, and Engineering Works (17)
The Crystalline Crust in Space and Time (23)
Tectonic Processes (15)
The Mantle and Core in Space and Time (4)
Mineralogy (9)
Geology and Social Issues (4)
History of Geology (4)
Paleontology (11)
Mathematical Geology (3)
Comparative Planetology (6)

Short Courses

Volcanic Hazards, *July 2–3*
Sedimentary Basin Analysis, *July 6–8*
Modeling Ground-Water Flow, *July 7–8*
Hydrothermal Systems, *July 7–8*
Paleoenvironmental Interpretation of Paleosols, *July 7–8*
Quaternary Dating Methods, *July 7–8*
Digital Geologic and Geographic Information Systems, *July 7–8*
Experimental Rock Deformation, *July 7–8*
Applications of Personal Computers to Geology, *July 7–8 or July 15–16*
Earth Science Exhibits: Concepts, Designs, and Procedures, *July 8 or July 15*
Coastal Land Loss, *July 15*
Generation and Accumulation of Petroleum, *July 15*
Seismic Stratigraphy, *July 15*
Seafloor Spreading Processes, *July 15*
Geomorphology from Space, *July 15*
Earthquake Hazards, *July 15–16*
Role of Ground-Water Geochemistry in Geologic Processes, *July 15–16*
Brines and Evaporites, *July 15–16*
Carbonate Sedimentology and Petrology, *July 15–16*
Methods of Mineral Resource Assessment, *July 15–16*
Geochronological Techniques, *July 15–16*
Climate, Past and Future, *July 15–16*
Metazoan Biomineralization: Patterns, Processes, and Evolutionary Trends, *July 15–16*

Paleotological Techniques, *July 15–16*
North American Geology—An Overview, *July 15–16*
Plate Tectonics and Continental Geology, *July 15–16*
Balanced Cross Sections, *July 15–16*
Metamorphic Pressure–Temperature–Time Paths, *July 15–16*
Advances in Geostatistics, *July 15–16*
Glacial–Marine Sedimentation, *July 15–16*
Quantitative Three-Dimensional Structural Techniques, *July 15–16*
Mineral Deposit Modeling, *July 15–16*
Fluid Inclusions, *July 15–16*
Planetary Geology, *July 16*

Workshops

Geohydrological Problems in Toxic Waste Management, *July 7–8*
Earth Science Education, *July 7–8*
Metamorphic Fluids, *July 15*
Quantitative Stratigraphy, *July 15*
Geological Problems in Radioactive Waste Isolation—A Worldwide Review, *July 15–16*
Landscape Evolution and Hazards, *July 15–16*
Deforestation, Desertification, and Erosion, *July 15–16*
Acid Deposition, *July 15–16*
Red Beds and Associated Mineral Deposits, *July 15–16*
Mineral Deposits: Their Evolution and Its Significance, *July 15–16*
Shelf Sands and Sandstone Reservoirs, *July 15–16*
Extinctions in the Geologic Record, *July 15–16*
Fossil Crinoids, *July 15–16*
Geology and Mineralogy of Diamonds, *July 15–16*
Three-Dimensional Geologic Maps, *July 15–16*
Paleostress Determinations Using Fault Slip Data, *July 15–16*
Arctic Plate Reconstruction, *July 15–16*

Field Trips

Alaska and Hawaii

Alaskan Geological and Geophysical Transect, *June 26–July 5*
Modern Clastic Depositional Systems of Alaska, *June 29–July 7*
Geology of Hawaii, *July 1–7 or July 21–27*
Quaternary Geology along the Richardson and Glenn Highways, Alaska, *July 2–7*
Glaciers and Glaciology of Alaska, *July 21–29*

Western United States

Grand Canyon River Trips, *June 26–July 5, June 27–July 6, July 20–29, or July 21–30*
Tectonic Evolution of Northern California, *June 28–July 7*
Quaternary Geology of the Great Basin, *June 28–July 7*
Sedimentation and Tectonics in Coastal Southern California, *June 29–July 7*
Tectonics of the Eastern Part of the Cordilleran Orogenic Belt, Chihuahua, New Mexico, and Arizona, *June 29–July 7*
Tertiary and Cretaceous Coals in the Rocky Mountains Region, June 29–July 8

Cretaceous Shelf Sandstones and Shelf Depositional Sequences, Western Interior Basin, Utah and New Mexico, *June 30–July 7*

Coal, Uranium, and Oil and Gas in Mesozoic Rocks of the San Juan Basin: Anatomy of a Giant Energy-Rich Basin, *June 30–July 7*

Geology of the Colorado Plateau, *June 30–July 7*

The Idaho–Wyoming Thrust Belt, *June 30–July 7*

Extensional Tectonics in the Basin and Range Province, *June 30–July 7*

Petroleum Geology and Structural Transect across Western Transverse Ranges and Southern Coast Ranges, California, *July 1–7*

Early Mesozoic Tectonic History of the Western Great Basin, Nevada, *July 1–7*

Shelf Carbonates of the Paradox Basin: San Juan River Raft Trip, *July 1–7*

Cambrian and Early Ordovician Stratigraphy and Paleontology, Basin and Range Province, *July 1–7*

Devils Tower–Black Hills Alkalic Igneous Rocks and General Geology, *July 1–7*

Cenozoic Volcanism in the Cascade Range and Columbia Plateau, *July 2–7*

Geology and Mineral Deposits of the Front Range, Colorado, *July 2–7*

Mesozoic and Cenozoic Siliceous Sediments of California, *July 3–7*

Petroleum Potential of the Basin and Range Province, *July 3–7*

Colorado Plateau to Basin and Range Overflight, *July 6–7 or July 20–21*

Oil in the California Monterey Formation, *July 20–24*

Paleosols and Paleoenvironments, Bighorn Basin, Wyoming, *July 20–24*

Evolution of Resource-Rich Foreland and Intermontane Basins in Eastern Utah and Western Colorado, *July 20–24*

Porphyry Copper Deposits of Southern Arizona, *July 20–24*

Cordilleran Volcanism, Plutonism, and Magma Generation at Various Crustal Levels, *July 20–25*

Mineralization in Silicic Calderas: Questa, New Mexico, and San Juan Mountains, Colorado, *July 20–25*

Precambrian Rocks and Mineralization, Central and Southern Wyoming, *July 20–25*

Arc Volcanism in the Southern Cascade Range, *July 20–26*

Classic Vertebrate Localities, Rocky Mountains, *July 20–27*

Geologic Evolution of the Northernmost Coast Ranges and Western Klamath Mountains, *July 20–28*

Quaternary Volcanism of Long Valley Caldera and Mono–Inyo Craters, Eastern California, *July 20–28*

Upper Permian Capitan Reef Complex, and Comparison to Pennsylvanian–Permian Shelf Reefs of the Southwestern United States, *July 20–28*

Late Proterozoic and Cambrian Tectonics, Sedimentation, and Record of Metazoan Radiation in the Western United States, *July 20–28*

Middle Proterozoic Belt Supergroup, Western Montana, *July 20–28*

Snake River Plain–Yellowstone Volcanic Province, *July 21–29*

Accreted Terranes of the North Cascades Range, Washington, *July 20–29*

The San Andreas Transform Belt, *July 20–29*

Structural Geology and Stratigraphy of Trans-Pecos Texas, *July 20–29*

Geology of Sedimentary-Rock-Hosted, Disseminated Gold Deposits in the Great Basin, Western United States, *July 20–29*

Geology and Geophysics of the Rio Grande Rift and Southern Rocky Mountains, *July 20–30*

Yellowstone and Grand Teton National Parks and the Middle Rocky Mountains, *July 20–30*

Cascade Range, *July 20–August 4*

Glacial Lake Missoula and the Channeled Scablands, *July 21–26*

Midcontinent

Precambrian and Paleozoic Geology and Ore Deposits in the Midcontinent Region, *June 29–July 7*
Carboniferous Geology of the Eastern United States, *June 29–July 8*
Early Proterozoic Rocks of the Great Lakes Region, *July 1–7*
Lake Superior Basin Segment of the Central North American Rift System, *July 20–25*
Montana High-Potassium Igneous Province, *July 20–27*
Mineral Deposits and Layering in the Stillwater Complex and the Duluth Complex, *July 20–29*
Precambrian Geology and Mineral Resources of the Lake Superior Region—An Overview, *July 20–August 2*

Coastal and Coastal Plain

Florida Phosphate Deposits, *June 30–July 7*
Upper Cretaceous and Cenozoic Geology of the Southeastern Atlantic Coastal Plain, *July 1–9*
Pleistocene and Holocene Carbonate Environments on San Salvador Island, Bahamas, *July 2–7*
Florida Keys and Dry Tortugas Reefs, *July 2–7*
Sedimentary Architecture of a Modern River and Delta System—Mississippi River, *July 3–7*
Outer Banks Depositional Systems, North Carolina, *July 4–8*
Geology of Gulf Coast Lignites, *July 5–8*
Giant Subtidal Stromatolites of the Exuma Islands, Bahamas, *July 20–22*
Sedimentology of the Barrier Island and Marshy Coast, West-Central Florida, *July 20–23*
Coastal Depositional Systems of the Northwestern Gulf of Mexico, *July 20–25*
Modern Clastic Depositional Environments, South Carolina, *July 20–25*
Carbonate Sedimentation, Stratigraphy, and Diagenesis on a Subarid Carbonate Platform, Turks and Caicos Islands, British West Indies, *July 20–26*
Carbonate Rock Sequences from the Cretaceous of Texas, *July 20–26*
Upper Cretaceous and Paleogene Biostratigraphy and Lithostratigraphy of the Eastern Gulf Coastal Plain, *July 20–30*

Appalachian Region

Boston to Buffalo, in the Footsteps of Amos Eaton and Edward Hitchcock, *June 28–July 8*
Southern Appalachian Windows: Comparison of Styles, Scales, Geometry, and Detachment Levels of Thrust Faults in the Foreland and Internides of a Thrust-Dominated Orogen, *June 29–July 8*
The Adirondack Mountains—A Section of Deep Proterozoic Crust, *June 30–July 8*
Cambrian–Ordovician Carbonate Banks and Siliciclastic Basins of the Appalachians, *June 30–July 8*
Sedimentology and Thermal–Mechanical History of Basins in the Central Appalachian Orogen, *July 1–8*
Sedimentary Sequences in a Foreland Basin: The New York System, *July 2–8*
Valley and Ridge and Blue Ridge Traverse, Central Virginia, *July 2–8*
Central and Southern Appalachian Geomorphology, *July 2–8*
Transect across New England Appalachians, *July 2–8*
Tectonics of the Virginia Blue Ridge and Piedmont, *July 19–24*
Characteristics of the Mid-Carboniferous Boundary and Associated Coal-Bearing Rocks of the Appalachian Basin, *July 19–27*

Marble, Granite, and Slate Industries of Vermont, *July 20–22*
Geomorphology and Plant Ecology of the Shenandoah Valley, *July 20–23*
Paleozoic Sea-Level Changes in the Appalachian Basin, *July 20–24*
Migmatites of Southern New England, Their Origins and Tectonometamorphic Settings, *July 20–24*
Geology and Hydrocarbon Potential of the Eastern Overthrust, *July 20–24*
Geology and Engineering Geology of the New York Metropolitan Area, *July 20–25*
Northern Appalachian Transect: Southeastern Quebec, Canada, through Western Maine, U.S.A., *July 20–26*
Paleozoic Stratigraphy, Structure, and Deformation, and Suspect Terranes of the Appalachians in New England, *July 20–26*
Geological Cross-Section through Part of the Southern Appalachian Orogen: Inner Piedmont to Valley and Ridge, *July 20–26*
Geometry and Deformation Fabrics in the Central and Southern Appalachian Valley and Ridge and Blue Ridge, *July 20–27*
Tectonic, Depositional, and Paleoecological History of Early Mesozoic Rift Basins, Eastern North America, *July 20–30*

Special Topics

Engineering Geology of Western U.S. Urban Centers, *June 28–July 7*
Remote Sensing in Exploration Geology, *June 30–July 8*
Hydrogeology of the Floridan Aquifer System, *July 1–8*
Geology of Nevada Test Site and Surrounding Area, *July 5–7*
Physical and Hydrologic-Flow Properties of Fractures, *July 20–24*
Karst Hydrogeology, Central Florida and Yucatan, Mexico, *July 20–26*
Geology of the Wine Country of New York State, *July 20–28*
Landslides in Central California, *July 20–29*
Engineering Geology of Major Dams on the Columbia River, *July 20–30*
Contrasts in Style of American Thrust Belts, *July 20–31*

Local and During-Congress Field Trips

Jurassic Igneous Rocks of the Culpeper Basin, Virginia, *July 12*
The Industrial Minerals and Rodingite Dikes of the Hunting Hill Serpentinite Mass, Montgomery County, Maryland, *July 12*
Cretaceous and Tertiary Stratigraphy of the Elk Neck Area, Northeastern Maryland, *July 12*
Metamorphic Rocks of Potomac Accreted Terrane in Potomac River Gorge, Virginia, *July 13 or July 18*
A Geologic Walk through Rock Creek Park (Southern Section), Washington, D.C., *July 13*
Relationship of Coastal Plain Sedimentation to Basement Tectonics, Maryland, *July 13*
Flyover Showing Geomorphology and Coastal Processes along the Atlantic Shoreline, from Cape Henlopen, Delaware, to Cape Charles, Virginia, *July 13, July 14, July 17, or July 18*
Early Paleozoic Continental Shelf to Basin Transition, Northern Virginia, *July 13*
A Different View of Stone Monuments, Memorials, and Buildings of Washington, D.C., *July 13*
Geomorphology, Vegetation, and Potomac Canal Construction Problems, Great Falls, Potomac River, Virginia, *July 13*
Metabasalts and Related Rocks of the Appalachian Blue Ridge Province—Traces of Proterozoic Rifting in Eastern North America, *July 14*
Fluvial and Lacustrine Facies of the Early Mesozoic Culpeper Basin, Virginia, *July 14*

Hydrology, Geology, and Environmental Problems of the Washington–Baltimore Urban Area, *July 14*
Geology and Engineering Problems of the Washington, D.C., Metropolitan Area, *July 14*
Geology of the Baltimore Gneiss Domes Region, Maryland, *July 15*
Geology and History of the Chesapeake and Ohio Canal, Maryland, *July 15*
Blue Ridge, Little North Mountain, and Allegheny Structural Fronts, Northern Virginia and Eastern West Virginia, *July 15*
Seismic and Geochemical Research in Chesapeake Bay, Maryland, *July 15 or July 18*
Stratigraphy and Structure Across the Blue Ridge Anticlinorium and Inner Piedmont in Central Virginia, *July 15–16*
Coastal Geomorphology of the Maryland and Delaware Barrier Islands, *July 15–16*
Coastal Plain and Appalachian Piedmont Geomorphology and Soils, *July 15–16*
Anthracite Coal Basins of Eastern Pennsylvania, *July 15–16*
Titanium-Mineral Deposits of the Roseland Anorthosite–Ferrodiorite Terrane, Blue Ridge Province of Central Virginia, *July 15–16*
Tertiary Stratigraphy and Paleontology, Chesapeake Bay Region, Virginia and Maryland, *July 15–17*
Shoreline Erosion in the Upper Chesapeake Bay Area, Maryland, *July 16*
A Geologic Walk through Rock Creek Park (Northern Section), Washington, D.C., *July 17*
Ultramafite-Associated Cu–Fe–Co–Ni–Zn Deposits of the Sykesville District, Maryland Piedmont, *July 17*

The Second Circular of the IGC is the most complete description of all congress events; to get a copy, write 28th IGC, Box 727, Tulsa, OK 74101-0727. All inquiries and general correspondence concerning the congress should be addressed to Bruce Hanshaw, Secretary General, 28th International Geological Congress, P.O. Box 1001, Herndon, VA 22070-1001; phone (703) 648-6053. The deadline for late preregistration is May 1. (On-site registration will be available at a higher rate.)

UPCOMING MEETINGS

American Association of Petroleum Geologists, Mid-Continent Section Meeting, September 24–26, 1989, Oklahoma City, Oklahoma. Information: AAPG, Convention Dept., P.O. Box 979, Tulsa, OK 74101; (918) 584-2555.

Association of Engineering Geologists, Annual Meeting, October 1–6, 1989, Vail, Colorado. *Abstracts due May 1.* Information: Michael W. West, Michael W. West & Associates, Inc., 290 Bank Western Bldg., 8906 West Bowles Ave., Littleton, CO 80123; (303) 972-1537.

American Institute of Professional Geologists, Annual Meeting, October 4–7, 1989, Arlington, Virginia. Information: Stan Johnson, Virginia Division of Mineral Resources, Box 3667, Charlottesville, VA 22903; (804) 293-5121.

Society of Economic Paleontologists and Mineralogists, Midcontinent Section, Annual Meeting and Field Trip, October 14–16, 1989, Rolla, Missouri. Information: Jay Gregg, Dept. of Geology and Geophysics, University of Missouri, Rolla, MO 65401; (314) 341-4664.

NEW OGS PUBLICATIONS

GEOLOGIC MAP GM-30. *A Stratigraphic and Structural Study of the Eram Coal and Associated Strata in Eastern Okmulgee County and Western Muskogee County, Oklahoma,* by LeRoy A. Hemish, assisted by Kenneth N. Beyma. 1 sheet, scale 1:31,680, with accompanying text. Price: $3.

Author's abstract:

A structural and stratigraphic study of the strata in eastern Okmulgee County and western Muskogee County, Oklahoma, undertaken to establish the stratigraphic position of the Eram coal, has shown that a major NE-trending fault zone extends across the study area. The author believes that this zone is a southwestern extension of the Seneca fault zone mapped in northeastern Oklahoma.

The Eram coal occurs within the fault zone. Because rocks are downthrown as much as 450 ft in the fault zone, a section of rocks cropping out east of Morris in Okmulgee County is repeated between the fault zone in the Eram area and the town of Boynton, ~5 mi east (perpendicular to strike), in Muskogee County. In accordance with its structural position within the fault zone, the Eram coal is shown to be stratigraphically equivalent to the Mineral coal (also known as the Morris coal).

HYDROLOGIC ATLAS 2. *Reconnaissance of the Water Resources of the Tulsa Quadrangle, Northeastern Oklahoma,* by Melvin V. Marcher and Roy H. Bingham. Set of 4 maps (including geologic map), scale 1:250,000. Price: $6 per set, folded in envelope.

Hydrologic Atlas 2, which has been out of print, is now available. The Tulsa Quadrangle includes ~5,600 mi^2 in northeastern Oklahoma. The four maps of HA-2 show the geology, availability of ground water, chemical quality of ground water, and surface-water information on the area.

First printed in 1971, this atlas was the second of nine hydrologic atlases designed to provide reconnaissance-level ground-water information on the State, exclusive of the Panhandle. Other atlases available in the series are the Fort Smith, Ardmore and Sherman, Oklahoma City, Clinton, Lawton, Enid, Woodward, and McAlester and Texarkana Quadrangles.

GM-30 and HA-2 can be purchased over the counter or postpaid from the Survey at 830 Van Vleet Oval, Room 163, Norman, OK 73019; phone (405) 325-3031.

NOTES ON NEW PUBLICATIONS

The State Geological Surveys—A History

This comprehensive, 500-page volume was published in November 1988 by the Association of American State Geologists. Edited by retired Pennsylvania State Geologist Arthur A. Socolow, the hard-cover book contains the history, organization, and functions of each of the 50 state geological surveys in individual chapters prepared by the respective surveys. More than 30 of the state surveys originated over 100 years ago, and the accounts of the development and activities of America's state geological surveys shed light on a major component of geologic mapping and research which has been achieved in the United States.

Order from: Geological Survey of Alabama, P.O. Box 0, Tuscaloosa, AL 35486. The price is $20 postpaid. Make check payable to Association of American State Geologists.

Land Use and Land Cover and Associated Maps for Tulsa, Oklahoma; Arkansas; Missouri; Kansas

This data set consists of one map keyed to USGS topographic map Tulsa at 1:250,000 (1 in. = about 4 mi). This map is coded for statistical data development. The map shows land use and land cover, political unit, hydrological units, and census county subdivision. Also included is one positive of the cultural base for Tulsa.

Order OF 86-0018 from: U.S. Geological Survey, Mid-Continent Mapping Center, 1400 Independence Road, MS–231, Rolla, MO 65401; phone (314) 341-0851. The price is $4 for a paper diazo reproduction; add 25% to the price for shipment outside North America. (A $1 postage and handling charge is applicable on orders of less than $10.)

Chemical Analyses of Stream Sediment in the Tar Creek Basin of the Picher Mining Area, Northeast Oklahoma

A study of the Picher mining area and Tar Creek was undertaken to determine the chemical evolution of mine water and the effects of mine-water discharge on the chemistry of surface water and surface-water sediments. This 13-page USGS open-file report, by David L. Parkhurst, Michael Doughten, and Paul P. Hearn, presents chemical analyses of 47 sediment samples taken downstream from mine-water discharge points of abandoned lead and zinc mines.

Order OF 88-469 from: U.S. Geological Survey, Water Resources Division, 215 Dean A. McGee Ave., Room 621, Oklahoma City, OK 73102; phone (405) 231-4256. A limited number of copies are available free of charge.

OKLAHOMA ABSTRACTS

The Oklahoma Geological Survey thanks the Geological Society of America, the Society of Economic Paleontologists and Mineralogists, and the authors for permission to reprint the following abstracts of interest to Oklahoma geologists.

Habitat of Petroleum in Permian Rocks of the Midcontinent Region

JOCK A. CAMPBELL, CHARLES J. MANKIN, Oklahoma Geological Survey, Norman, OK 73019; A. B. SCHWARZKOPF, Geological Information Systems, University of Oklahoma, Norman, OK 73019; and JOHN H. RAYMER, Oklahoma Geological Survey

Permian reservoirs offer one of the shallowest potential exploration plays in the midcontinent. It is our contention that most of the discoveries in Permian reservoirs to date are the result of wildcatting and the drilling of surface structures historically, and the drilling for structural traps in pre-Permian rocks in recent decades. We believe that Permian strata deserve exploration on their own merit, based on their reservoir potential and the widespread occurrence of hydrocarbons trapped in Permian rocks.

Petroleum production is widespread from both carbonate and siliciclastic strata of Early Permian age in the midcontinent region. The world class accumulation of the Panhandle–Guymon–Hugoton–Panoma field complex is well known to most petroleum geologists, but the regional attributes of the Permian as a focus for exploration potential have not been addressed except in combination with the underlying Pennsylvanian strata.

Production is from siliciclastic rocks of Wolfcampian age in the Wichita–Amarillo Mountain front area and, locally, along the Nemaha and Central Kansas Uplifts. Wolfcampian carbonates produce along the Cimarron Arch in the western Anadarko Basin, and on the Central Kansas and Nemaha Uplifts. Only carbonate rocks produce in southwestern Nebraska and adjacent Colorado.

Production from Leonardian strata is less widespread, but commonly occurs in the eastern part of the Wichita Mountain front area and, locally, in association with the Amarillo Mountain front, and to the north in association with the Cimarron Arch. At least seven fields produce from Leonardian strata in the western Denver Basin.

A review of producing fields and rocks in the region indicates that petroleum traps are primarily stratigraphic and diagenetic in most of the Anadarko Basin. However, petroleum pooled in Permian strata has been discovered primarily by virtue of the chance association of those reservoirs with the crests of anticlinal structures.

Reprinted as published in *Permian Rocks of the Midcontinent*, Midcontinent SEPM Special Publication No. 1, 1988, p. 13.

Nonpetroleum Mineral Resources of Permian Rocks in Oklahoma and the Texas Panhandle

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Permian strata of western Oklahoma and the Texas Panhandle comprise a thick sequence of evaporites and red beds deposited in and peripheral to shallow epicontinental seas north and northeast of the Matador Arch. Those strata are as much as 5,000–7,000 ft thick in major basins of the region (the Anadarko, Palo Duro, Hollis–Hardeman, and Dalhart Basins), and they crop out extensively on the flanks of those basins.

Principal nonpetroleum mineral resources in Permian strata of the region are salt, gypsum, anhydrite, dolomite, shale, brine, ground water, and copper. The distribution of evaporites in the stratigraphic column is a major control on the location of those resources. Each of those resources has been, or still is being produced commercially within the two-state region. Salt (halite) is produced by solar evaporation of natural brines emitted at the surface at two localities, and it is recovered in the form of salt-saturated brines produced from deep brine wells at three other localities. Gypsum, anhydrite, dolomite, and shale are mined at many quarries and pits within the region, principally for use in the construction industry. Fresh ground water is being produced for municipal, industrial, irrigation, and domestic use from a number of major Permian aquifers in the region. Copper has been produced from red-bed-type copper shales and copper-bearing sandstones at several localities in the region.

Of somewhat lesser importance are smaller deposits of limestone, indurated sandstone, and uranium; each of which has been produced on a limited scale in the past. Of least importance at the present time are the scattered small deposits of celestite, potash, and flint, none of which has been produced commercially in the region.

Reprinted as published in *Permian Rocks of the Midcontinent*, Midcontinent SEPM Special Publication No. 1, 1988, p. 37.

Lithostratigraphy of Lower Permian Rocks in Kay County, North-Central Oklahoma, and Their Stratigraphic Relationships to Lithic Correlatives in Kansas and Nebraska

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Recent detailed geologic mapping of surface rocks, core-hole data, and the examination of sample logs and electric logs in Kay County, Oklahoma, suggest that the usage of traditional lithostratigraphic subdivisions recognized in Kansas and Nebraska for the Council Grove and Chase Groups (Permian) needs reviewing and clarification. The lithostratigraphic relationships of those subdivisions are not clearly demonstrable due to one or more of the following problems: (1) failure to designate a specific type section, (2) poor and incomplete type sections, especially in demonstrating lower and upper boundary relationships, (3) poor, if any, geological descriptions of type sections, (4) some formal units were never duly proposed or duly described, (5) some formation type sections are located quite distant from the designated group type area, and (6) many of the originally designated type sections are now largely inaccessible.

Surface exposures of rocks in Kay County, Oklahoma, are assigned to the upper part of the Council Grove Group (repetitive sequences of algal, non-cherty limestones and shales with locally, lenticular sandstones), the Chase Group (thicker, chert-bearing limestones with less common but thicker shale and lenticular sandstone units), and to the lower part of the Sumner Group (mudstones and shales alternating with very thin dolomites, fissile shales, and anhydrite/gypsum beds). Rocks assigned to those groups are subdivided into a northern facies, where lithologies, thicknesses, and subdivisions of the formations are more comparable to those in Kansas and Nebraska, and into a southern facies, where units are highly variable in lithology and thickness, subdivisions of formations are more difficult to identify, and traceability of units from northern localities is more tenuous. With minor exceptions, limestones thin, pinch out, and become siliciclastic-rich to the south in Kay County; correspondingly, there is an abrupt increase in percentage of sandstone in the section.

Reprinted as published in *Permian Rocks of the Midcontinent*, Midcontinent SEPM Special Publication No. 1, 1988, p. 79.

Principal Aquifers in Permian Strata of Central and Western Oklahoma

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The Permian sequence of sandstones, shale, and evaporite deposits in central and western Oklahoma includes six major freshwater aquifers that provide water for public supply, industrial, irrigation, stock, and domestic use. The Elk City, Rush Springs–Marlow, Cedar Hills, Garber–Wellington, and Oscar aquifers consist of sandstone; the Blaine aquifer consists of gypsum and dolomite. Those six aquifers underlie much of central and western Oklahoma and constitute an important source of water for the region because surface-water supplies are limited. Many streams cease to flow for much of the year, and streams in some areas are too saline for most uses because of the natural discharge of brine from the ground-water system.

Permian aquifers commonly range in thickness from 100 to 400 ft, although the Garber–Wellington aquifer is locally as much as 1,000 ft thick. Wells completed in the sandstone aquifers typically yield 25–300 gpm (gallons per minute) of water that contains 200–1,000 mg/L (milligrams per liter) dissolved solids, whereas those wells completed in the gypsum–dolomite aquifer typically yield 100–2,500 gpm of slightly to moderately saline water that contains 1,500–6,000 mg/L dissolved solids. In contrast, wells completed in Permian rock units other than the principal aquifers typically yield only 2–5 gpm of slightly to moderately saline water that contains 1,000–5,000 mg/L dissolved solids. The principal use of water from the Rush Springs–Marlow and Blaine aquifers is irrigation, whereas the other four aquifers are used mainly for public water supply.

Reprinted as published in *Permian Rocks of the Midcontinent,* Midcontinent SEPM Special Publication No. 1, 1988, p. 45.

Permian System in Western Midcontinent

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The Wolfcampian, Leonardian, and Guadalupian series of the Permian System in the west Texas region are recognized in the Permian System of the western midcontinent. In the latter region, tectonic events during the Wolfcampian and Leonardian and subsequent changes in depositional patterns provide the basis for establishment of upper and lower stages in the Wolfcampian and Leonardian Series. The evolution from dominantly marine beds (Wolfcampian) to cyclic marginal-marine to continental red beds and evaporites (Leonardian and Guadalupian) reflects the regression and withdrawal of marine waters from the western midcontinent during Permian time.

Reprinted as published in *Permian Rocks of the Midcontinent,* Midcontinent SEPM Special Publication No. 1, 1988, p. 3.

Permian Fusulinids from the Conoco Inc. 33-1 Core, Kay County, Oklahoma

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The Conoco Inc. 33-1 well in Kay County, Oklahoma, was continuously cored through the Wolfcampian section, recovering 675 ft of 6 inch diameter core. The cored interval begins in the Gage Shale and goes completely through the Indian Cave Sandstone. In that interval, much of the Chase Group and all of the Council Grove and Admire Groups were penetrated. Fusulinids were recovered from 21 stratigraphic horizons, and they correlate well with similar faunas from the outcrops and subsurface of the region.

Reprinted as published in *Permian Rocks of the Midcontinent,* Midcontinent SEPM Special Publication No. 1, 1988, p. 213.

Late Mississippian and Pennsylvanian Depositional History in the Arkoma Basin Area, Oklahoma and Arkansas

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The Arkoma basin was depositionally part of a broad, stable shelf along a passive continental margin during much of its history. During the Chesterian, Morrowan, and early Atokan, the depositional patterns on the shelf varied greatly, depending on the inconsistent development of carbonate environments and the intermittent introduction of terrigenous clastics (quartz arenites) from the north.

Beginning with the middle Atokan, flexural downwarping of the south margin of the shelf was accompanied by down-to-the-south syndepositional normal faults developed sequentially to the north, as a result of continued collapse of the Ouachita trough. Lithic arenites were introduced into this developing trough from the east, apparently derived from a tectonic provenance southeast of the Ouachita trough, on the southwest margin of the Black Warrior basin. Further closure plus rapid deposition resulted in the closing and filling of this incipient foreland basin by the end of deposition of the middle Atoka.

With further compressional deformation, the axis of deposition shifted farther northward with the development of a fully formed and continually subsiding foreland basin (beginning in late Atokan). Lithic arenites were transported westward along the axis of the basin (documented in earliest Desmoinesian). In Arkansas some of the early Desmoinesian sediments apparently came from the uplifted Ouachita thrust belt immediately to the south.

During the rest of the early Desmoinesian (most of Krebs Group), with the continued subsidence of the foreland basin, extensive deltaic deposits (sublitharenites) were introduced from the north and provided the primary source of sediments to the foreland basin in Oklahoma. They apparently came from the continental interior to the west and north of the Ozark dome.

Although there is evidence of a limited source of sediments from the Ouachita fold belt in Arkansas during the deposition of the Hartshorne Sandstone (earliest Desmoinesian), the fold belt to the west in Oklahoma was apparently quiescent and presumably standing at or near sea level throughout the time of deposition of the upper Atoka and the whole of the early Desmoinesian Krebs Group (Hartshorne, McAlester, Savanna, and Boggy Formations).

Although added field confirmations are needed, it is concluded that renewed folding and uplift of the Ouachita fold belt following the deposition of the early Desmoinesian Krebs Group involved also the compression and folding of the Arkoma basin. This ended the progressive downwarping of this basin and shifted the depocenter still farther to the northwest. The core area of the Ouachita fold belt was extensively elevated for the first time resulting in the erosion and transportation of chert pebbles and other sediments to the northwest (Thurman Sandstone).

Beginning with the middle Desmoinesian, Cabaniss Group deposition was in a narrow successor foreland basin located to the northwest of the Arkoma basin and to the northeast of the Hunton arch. The Ouachita fold belt was the primary source for terrigenous sediments, periodically including chert-pebble conglomerates, to this area throughout the remainder of the Pennsylvanian.

Reprinted as published in the Geological Society of America *Bulletin*, v. 100, p. 1787.

Petrologic, Paleomagnetic, and Structural Evidence of a Paleozoic Rift System in Oklahoma, New Mexico, Colorado, and Utah: Discussion

[See discussion in the Geological Society of America *Bulletin*, v. 100, p. 1846–1847.]

Horizontal Grooves in Granite, Western Wichita Mountains, Oklahoma

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In the western Wichita Mountains of Oklahoma, hills eroded in granite of Cambrian age rise above the red bed plains cut in the Permian Hennessey Fm. Vertical flights of horizontal grooves are well developed at the bases of many of these hills and also on granitic bedrock knobs and boulders. Earlier workers have ascribed these features to wave erosion in Permian times. In these terms the grooves were buried by Permian marine sediments and then exhumed. This interpretation is no longer tenable. Evidence and argument are adduced to suggest that the grooves were developed by ground-water weathering at the contact between the granitic and sedimentary rocks, and that they are congeners of the flared slopes and other forms of basal steepening described from other parts of the world. The Wichita grooves, however, display a wider variety of forms and a fineness of detail not matched by any other known locality.

Flared slopes at other localities are mostly exposed weathering fronts that developed in the scarpfoot zones of hills and boulders. The Wichita grooves differ, however, in that they formed in the vadose zone opposite high permeability sandstone beds. Subsurface waters accumulated and sat in these beds and through time deeply corroded the adjacent granite. Little or no corrosion occurred opposite the lower permeability siltstone and shale beds which are intercalated with the sandstones. Some etching at the level of the water table may also have occurred. The Quaternary geomorphologic history of the region establishes the age of the grooves as middle to late Pleistocene, or Holocene.

Reprinted as published in the Geological Society of America *Abstracts with Programs, 1988*, v. 20, no. 7, p. A284.

Aeromagnetic and Gravity Signature of the Wichita Frontal Fault System

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The Wichita frontal fault system, extending NW–SE more than 300 km across SW Oklahoma, is the transitional boundary between the Wichita Mountains to the south and the Anadarko Basin to the north. The Wichita Mountains contain a bimodal suite of igneous rocks emplaced during late Precambrian–Cambrian rifting; subsequent late Paleozoic compression and left-lateral wrenching occurred along the Wichita frontal fault system. Gravity and aeromagnetic expressions of the fault system are dominated by steep gradients due to large differences in density and magnetic susceptibility between the rocks of the uplift and the basin. Near the Slick Hills northwest of Lawton, Okla., the fault system widens and changes trend; the regional gravity data show a more gentle gradient and a change in trend from NW–SE in the east to almost N–S in the west.

The Meers fault is the southernmost fault in the widened part of the frontal fault system. Holocene movement on at least 26 km of the Meers fault shows that this and possibly other faults in the system may be seismogenic. Detailed gravity and magnetic data in the widened part of the fault system clarify the subsurface relationship of the Meers to other faults in the system. Preliminary magnetic models of data from a 1954 aeromagnetic survey (E–W flight lines at 500-ft elev. with ¼ mi spacing) indicate that the Meers fault is nearly vertical. The models also show that the Mountain View fault, the northernmost fault in the fault system, has a moderate southward dip consistent with the interpretation of COCORP reflection data in a 1982 study by J. A. Brewer. A wedge(s) of buried high-susceptibility material, possibly gabbro, lies between these two faults. The wedge both widens and tilts down to the NW. Detailed gravity data along the N–S COCORP line 6, ~20 km W of the NW end of the Holocene scarp on the Meers fault, indicate that the buried wedge is very dense. Aeromagnetic data suggest that the NW end of this scarp may be controlled by subsurface splaying of the fault a few kilometers to the NW. Analysis of gravity data from over 300 new stations will provide insight into the relation of the Meers fault to other faults in the Wichita frontal fault system.

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The Meers Fault, SW Oklahoma: Evidence of Multiple Episodes of Quaternary Surface Faulting

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The WNW-striking Meers fault in SW Oklahoma has a net Quaternary slip of left-lateral reverse with down-to-the-south movement. The last surface faulting is late Holocene. The 26- to 37-km-long scarp cuts two facies of Permian-age rocks,

the relatively resistant limestone-pebble Post Oak Conglomerate along the west half, and the easily eroded Hennessy Shale to the east. Detailed studies of Quaternary deposits in the shale show evidence of a single vertical displacement (with unknown lateral slip) but geologic relations in the conglomerate suggest possible multiple episodes of Quaternary surface faulting.

An excavation on the downthrown side of a 3.35-m-high scarp in the Post Oak suggest more than one Quaternary faulting event. At the bottom of the exposure, a 45-cm-thick pod of A-horizon material, interpreted as a soil pressure ridge, lies on Post Oak residuum. The pod is buried by a scarp-derived colluvial wedge that is capped by a weak A horizon adjacent to the fault. The A horizon is truncated at the fault by sheared conglomerate, indicating a second faulting event. Radiocarbon dating of organic material from the pressure ridge and the A horizon will constrain the ages of these events.

Scarp heights in the Post Oak vary depending on the local topography but, where topographic effects are minimal, the scarps commonly exceed 3 m. Prominent inflection points in some higher Post Oak scarps might be bevels that indicate erosion and reactivation of the fault. In comparison, nearby scarps in latest Quaternary stream alluvium are commonly 1–2 m high and probably result from only the last faulting event.

Surface faulting has ponded alluvium upslope from the scarp in the Post Oak at several sites. Pairs of trenches subparallel to the scarp at two ponded-alluvium sites show 1–2 m of reverse slip and 1.5 to 5 m of left-lateral offset. In the ponded alluvium, an abrupt upward change from a basal cobbly gravel to organic-rich sandy silt marks the time of scarp formation. Radiocarbon dating of the silt should constrain that time.

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Geologic History of the Ouachita Orogenic Belt

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Lying mostly in the subsurface, the late Paleozoic Ouachita orogenic belt flanks the southern margin of the North American craton. It closely mimics the trace of a deeply buried, early Paleozoic continent-ocean boundary, which is defined by gravity and seismic reflection-refraction surveys. Outcrops in the Ouachita Mountains and the Marathon region record Late Cambrian–Ordovician deposition of shale, sandstone, and micrite on the North American continental slope and rise. As the ocean widened and deepened, there followed deposition of middle Paleozoic siliceous shale, chert, and novaculite, probably on oceanic crust. The pre-orogenic Ouachita rocks were deposited adjacent to but not on the North American continent.

South to southeasterly subduction of the North American plate closed the ocean, generally from east to west. As much as 16 km of Carboniferous flysch in the Ouachitas and 4.5 km in the Marathons engulfed the closing ocean and in part spread onto North American continental crust. Subduction and thrust faulting formed an off-shore accretionary wedge composed of pre-orogenic rocks and Carboniferous strata that entered the subduction zone. Some Carboniferous strata were underplated. The accretionary wedge was obducted onto North American crust, which broke down by high-angle faulting. Right lateral faulting accompanied obduction of the Marathons. Unconformable Permian strata mark the end of the orogeny.

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Site Selection Process for Oklahoma's Superconducting Super Collider

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Preliminary exclusionary criteria for a statewide assessment of possible SSC sites included rock characteristics, ground-water conditions, and geologic structure. Areas containing complex geologic terrain, bedrock and alluvial aquifers and their known recharge areas, major alluvial deposits, and those too small to accommodate the SSC oval and associated facilities were excluded from further consideration. This process identified 30 candidate sites. These sites were reexamined using three additional geotechnical criteria: potential for rock dissolution, proximity to active faults and fuel and non-fuel resource development.

Twelve sites remained for detailed analysis. Three site-selection matrices compared topography, lithology, structure, hydrology, resources, seismicity, and site flexibility for each site. The top two sites became the preferred sites, the next two were less preferred, and the other eight were eliminated.

The geotechnically rated top four sites were ranked using natural, environmental, and cultural factors such as regional setting, oil- and gas-well density, urban congestion, regional conditions, utilities, regional and cultural resources and amenities, environmental obstacles and flood-prone areas. The top geotechnical site also ranked highest using these criteria. Therefore, this site became the best qualified site and was presented to the Oklahoma SSC Commission for their approval. This site became Oklahoma's proposed site to DOE for the SSC.

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(continued from p. 30)

that waves are incapable of cutting shore platforms in granite; (2) the platforms closely resemble modern granite pediments; (3) the platforms are best developed on the west hillsides, facing the Llano Estacado; (4) an east–west topographic profile shows that the platforms lie at precisely the elevation predicted by an eastward linear projection of the Llano Estacado; (5) the slightly lower elevation of the platform on Tepee Mountain is consistent with the easterly 10 ft/mi slope of the projected surface; and (6) earlier studies (Gustavson and others, 1981) have presented strong arguments for the Southern High Plains surface extending well into and probably to the east of the Wichita Mountains.

The granite platforms of the Lake Altus area are pediment outliers of the Southern High Plains, and thus are congeners of and correlative with the late Tertiary "subsummit pediplains" of the Rocky Mountains.

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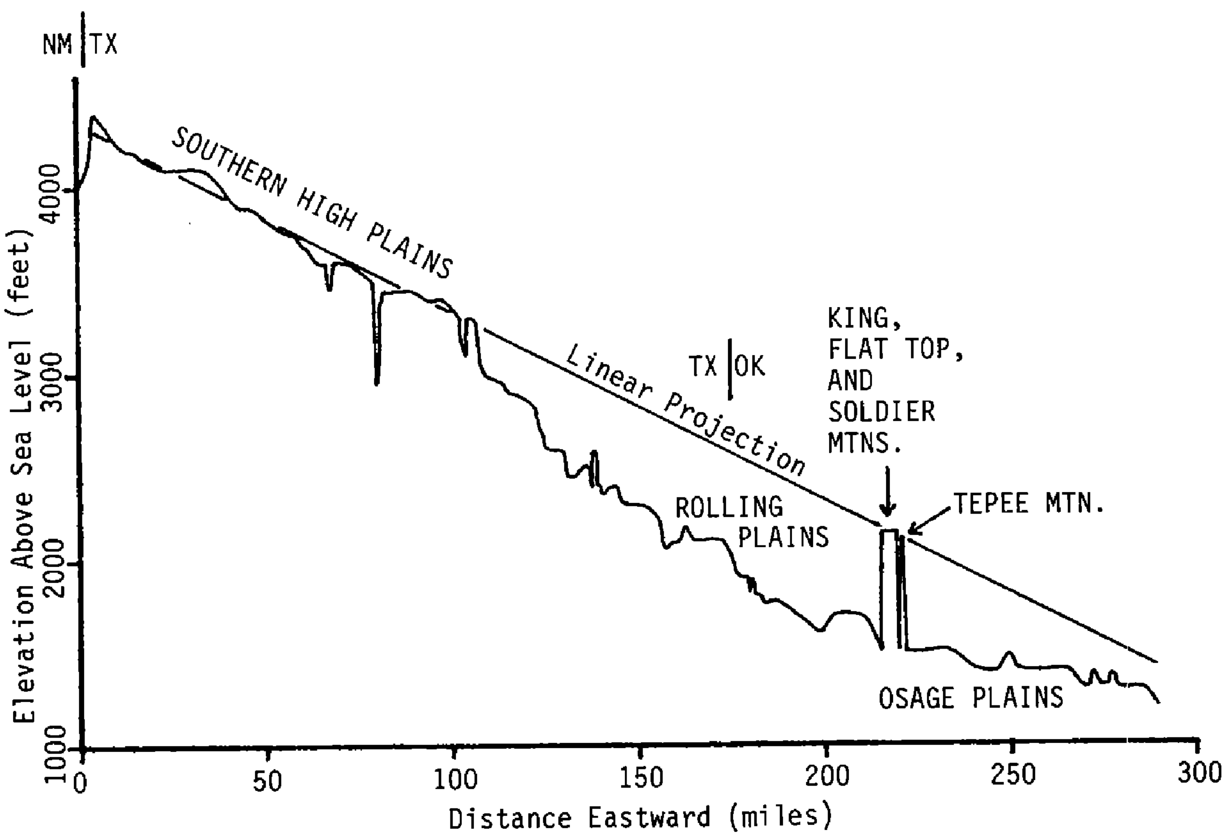
James A. Harrell
University of Toledo



East–west topographic profile along the 35th parallel in parts of New Mexico, Texas, and Oklahoma. (Note: Only the levels of the granite platforms are shown in the western Wichita Mountains.)