OKLAHOMA GEOLOGY

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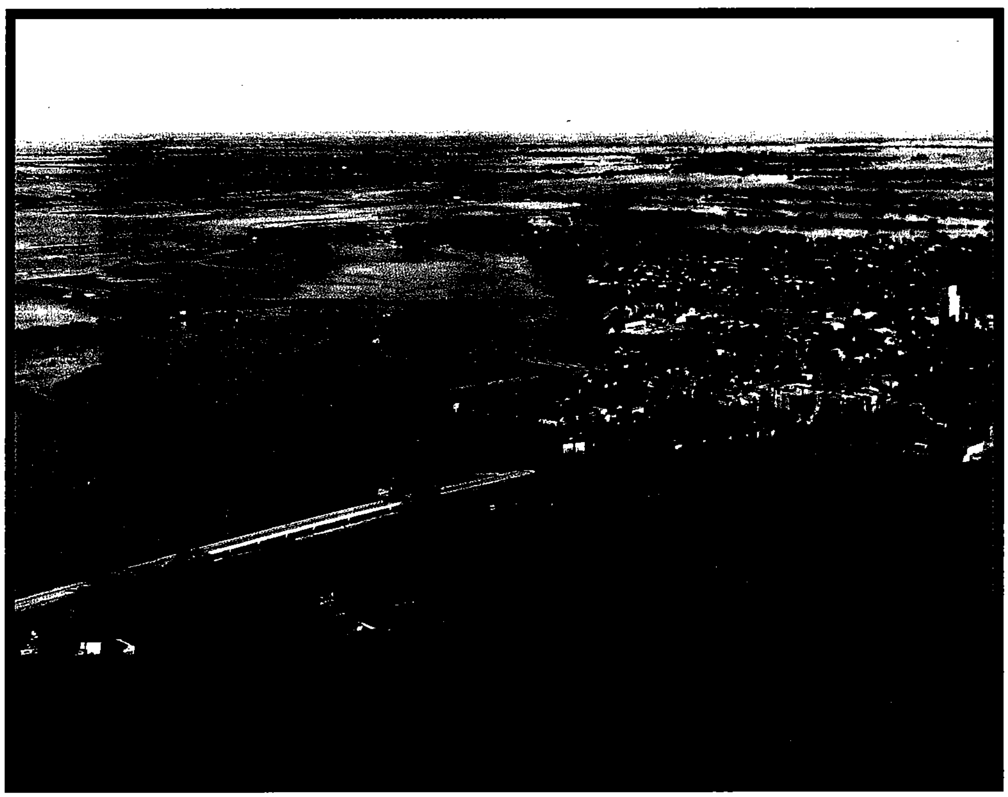

Featuring:
- *Geologic hazards in Oklahoma*
- *Oklahoma earthquakes, 2002*

on the cover

October 1973 Flood of Enid and Vicinity, North-Central Oklahoma

The cover photograph (by Kenneth Gill, U.S. Army Corps of Engineers) is a view of the Chikaskia River looking southwest at Blackwell, Oklahoma, near the intersection of U.S. Highway 177 (north-south highway) and State Highway 11 (east-west highway) in October 1973. Intense rainfall on October 10 and 11, 1973, produced record-breaking floods and extensive damage along many streams in north-central Oklahoma. (Information about the identification and mapping of flood-prone areas in Oklahoma is included in "Geologic Hazards in Oklahoma," p. 52 of this issue.) The rainfall was centered over Enid, Oklahoma, where flood damage was severe (Fig. 1). The National Weather Service's station in Enid recorded 15.68 in. of rainfall in a 13-hour period, and ~12 in. of that amount fell from 6:45 p.m. to 9:45 p.m., October 10. An area of ~500 mi^2 received >10 in. of rainfall; within that, an area of ~100 mi^2 received >15 in. (Bingham and others, 1974). The total rainfall for the 13-hour storm, 15.68 in., exceeded the State's previous 24-hour record of 12.3 in. for any October since the State began recording weather information in 1892.

The peak discharges for many streams within the storm area exceeded the calculated 100-year flood. All flood runoff from the storm drained into Keystone Lake at the confluence of the Arkansas and Cimarron Rivers ~90 mi east of Enid. Keystone Dam was designed by the Tulsa District, U.S. Army Corps of Engineers and was built under the supervision of the Corps. It was completed for flood-control operation in 1964. The lake stage and the amount of water stored at Keystone during the October 1973 flood were peak records for that time. Because the lake's capacity was adequate to store and regulate the entire storm runoff, flood damage below the dam was minimal.

In north-central Oklahoma, communities above the dam were not so fortunate. The Oklahoma State Civil Defense Agency estimated total flood damage at $78 million (U.S. Geological Survey, 1974). Nine lives were lost in the flood waters, seven within the city of Enid. At Blackwell, the Chikaskia River reached its highest recorded stage since 1923 and caused extensive flooding. The towns of Blackwell, Dover, Enid, Jefferson, and Tonkawa were badly damaged. There was also considerable damage to highways, county roads, bridges, city streets, and railroads. Thousands of acres of winter wheat and topsoil were lost through erosion.

In the United States, the average annual cost of flood damage is more than $2 billion (Moreland, 1993). In 1968, a nationwide assessment of flood hazards was initiated to support the National Flood Insurance Program (NFIP), administered first by the U.S. Department of Housing and Urban Development (HUD) and then (after 1979) by the Federal Emergency Management Agency (FEMA). Approximately 100,000 flood-hazard maps or map panels have been produced since the program began. Originally, these maps were produced to evaluate flood risk for the national flood-insurance program, but flood-plain managers, community planners, surveyors, engineers, and disaster- and emergency-response officials also use them for mitigation and risk assessment, as well as for disaster preparedness, response, and recovery activities.

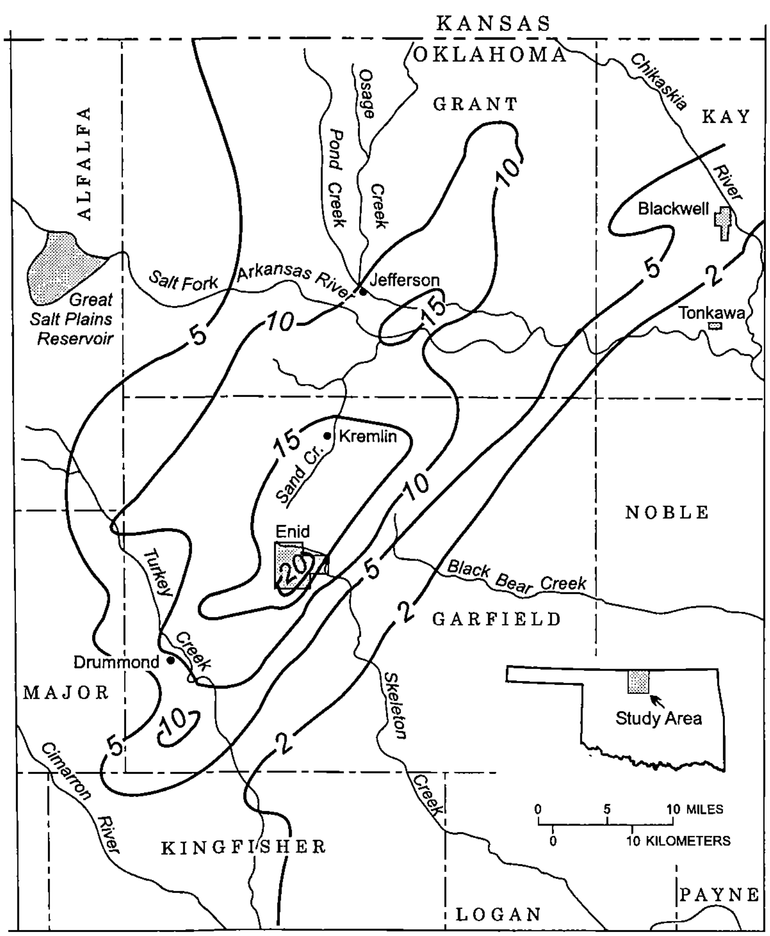

Figure 1. Rainfall map of 1973 storm, Enid and vicinity, north-central Oklahoma, showing rainfall in inches. Contour lines show areas of equal rainfall (modified from U.S. Geological Survey, 1974, fig. 1).

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OKLAHOMA GEOLOGY

Vol. 63, No. 2 Summer 2003

Geologic Hazards in Oklahoma

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ABSTRACT.—Natural geologic processes that have caused or might cause hazardous conditions in Oklahoma include earthquakes, landslides, expansive soils, floods, karst/salt dissolution, and radon.

At least four principal areas of seismic activity have been identified in the State: El Reno–Mustang, central Oklahoma; an area in south-central Oklahoma on the eastern margin of the Anadarko Basin; Love and Carter Counties, central southern Oklahoma; and an area north of the Ouachita Mountains in the Arkoma Basin of southeastern Oklahoma.

Most Oklahoma landslides occur in the eastern one-third of the State, owing to a wetter climate and steeper slopes associated with a more mountainous terrain. Many clay-rich shales, or soils derived from the weathering of shales, contain clay minerals, such as montmorillonite, that swell to as much as 1.5 to 2.0 times their original dry volume when they are wetted. More than 75% of Oklahoma contains bedrock units that have the ability to serve as sources of expansive soils.

Although floods can occur in any month in Oklahoma, major floods frequently occur in the spring and fall months. Flood-prone areas in Oklahoma have been identified and mapped by the U.S. Geological Survey, the U.S. Army Corps of Engineers, and private contractors. This mapping program is intended to delineate those areas that have, on average, about 1 chance in 100 of being inundated in any particular year.

Water-soluble rocks, such as limestone, dolomite, gypsum/anhydrite, and/or salt, are prone to the development of karst and dissolution features from the dissolving action of circulating ground waters. The sinkholes and caverns thus developed are potential hazards, owing to possible settlement or collapse of the land surface into the underground openings. Principal areas in Oklahoma where karst features are present in limestone and dolomite are the Ozark Mountains in northeastern Oklahoma, the Arbuckle Mountains in south-central Oklahoma, and the Limestone Hills (north of the Wichita Mountains) of southwestern Oklahoma. Gypsum and shallow salt deposits are present in many areas of western Oklahoma.

Approximately 80% of the State is underlain by formations with uranium contents that are equal to, or less than, the crustal average (2.5 ppm). The U.S. Environmental Protection Agency identified nine Oklahoma counties that have a moderate potential for elevated indoor radon levels.

Some activities of man that have created present, or might create future, geologic hazards in Oklahoma include disposal of industrial wastes, underground mining, and strip mining.

Solid and liquid industrial wastes have been disposed of in some areas of Oklahoma by surface burial in soil or rock units. Rock units in the State most favorable for surface disposal of wastes are impermeable sedimentary rocks, such as shale and clay, that can be excavated and that can prevent loss or migration of wastes from the disposal pit. Rock types in Oklahoma that are most desirable for surface disposal are porous and permeable sedimentary rocks, such as sandstone, limestone, and dolomite, that can store injected liquid wastes. These porous and permeable rock units should be surrounded by impermeable strata to assure containment.

Underground mines associated with the extraction of zinc/lead in Ottawa County in northeastern Oklahoma, and coal in the eastern Oklahoma coal field, along with a small number of underground gypsum, limestone, base-metal, and asphalt mines in other districts, are current and potential hazards because of the following possible problems: (1) collapse of roof rock, causing subsidence or collapse at the land surface; (2) the presence of acidic or toxic ground water; and (3) flooding of a new mine by accidentally breaking into a water-filled abandoned mine.

Lands disturbed through surface mining are potential problem areas because (1) spoil piles and fill material might not be fully compacted, and might still be subsiding or settling; (2) ponds and ground water in the mined areas might be acidic and/or toxic; and (3) highwalls and quarry faces might contain loose rocks or unstable slopes. Of all commodities mined by surface techniques, the extraction of coal has had the greatest impact on the environment in Oklahoma.

INTRODUCTION

Many geologic processes, such as mass wasting, water movements, and volcanic eruptions, become geologic hazards when human life and property are threatened. Furthermore, man's modification of the geologic environment through such activities as mining and waste disposal also can create hazards to life and property.

Data on potential hazards that result from natural geologic processes and from man-made geologic conditions generally are available from the Oklahoma Geological Survey (OGS) and several other State and Federal agencies. Data from geological and engineering reports, field investigations, aerial-photograph and topographic-map studies, industry and public records, and regional subsurface studies typically are compiled on large-scale base maps and aerial photographs. They then may be released as regional maps, generally at scales of 1:250,000 to 1:750,000. The maps and reports generated by these studies enable industry, government, and landowners to identify specific areas that require detailed site investigations and special engineering designs to avoid potential danger to life and property. Some of the data also are used to assist in the establishment of zoning ordinances, insurance rates, and construction codes.

The purpose of this report is to inform readers about geologic hazards, natural and man-made, in Oklahoma. This information should be useful to homeowners, planners, elected officials, contractors, and others for making decisions that will avoid and/or reduce losses from geologic hazards.

Two lists are given at the end of this report as an aid to the reader: a glossary of terms, and a set of acronyms and abbreviations.

NATURAL GEOLOGIC HAZARDS

Natural geologic processes that have caused, or might cause, hazardous conditions in Oklahoma include earthquakes, landslides, expansive soils, flood-prone areas, karst/salt dissolution, and radon.

Earthquakes

Oklahoma is within the stable interior of the United States. Although the State has had almost no significant tectonic activity since Pennsylvanian and Permian time (about 325–245 m.y. ago), an average of about 50 minor earthquakes occur in Oklahoma each year. The New Madrid, Missouri, earthquakes of 1811 and 1812 probably were the earliest historical earthquake tremors felt in what is now southeastern Oklahoma (then part of Arkansas Territory). Before Oklahoma became a state, the earliest documented earthquake epicenter within its current boundaries occurred on October 22, 1882, probably near Fort Gibson, Indian Territory, although it cannot be located precisely (Ross, 1882; Indian Pioneer Papers, date unknown). The *Cherokee Advocate* newspaper reported that at Fort Gibson "the trembling and vibrating were so severe as to cause doors and window shutters to open and shut, hogs in pens to fall and squeal, poultry to run and hide, the tops of weeds to dip, [and] cattle to [low]" (Ross, 1882). The first locatable earthquake in Oklahoma occurred near Jefferson, Grant County, on December 2, 1897 (Stover and others, 1981).

The largest known Oklahoma earthquake (with the possible exception of the Fort Gibson 1882 earthquake) occurred near El Reno, Canadian County, on April 9, 1952 (Table 1). This magnitude-5.5 (m_b) earthquake caused a 50-ft-long crack in the State Capitol Office Building in Oklahoma City. It was felt throughout Oklahoma and in parts of seven other states. The total felt area was ~140,000 mi^2 (Docekal, 1970; Kalb, 1964; von Hake, 1976). Des Moines, Iowa, and Austin, Texas, were at the northern and southern limits, respectively. This major earthquake produced intensity VIII effects near the epicenter on the Modified Mercalli (MM) intensity scale. The MM intensity scale assigns a Roman numeral to each of 12 levels described by effects on humans, man-made constructions, or natural features. For an intensity-level VIII earthquake, damage is slight in specially designed structures, considerable in ordinary substantial buildings, and great in poorly built structures.

A statewide network, consisting of a world-class geophysical observatory and eight satellite seismograph stations, records seismological data in Oklahoma (Fig. 1). The Oklahoma Geophysical Observatory (station TUL), operated by the OGS, began recording earthquake data on January 1, 1962. The statewide network, which became fully operational in 1977, has enabled detection and location of many low-magnitude earthquakes that would otherwise have gone undetected. From 1882 through 2001, 1,655 earthquakes have been located in Oklahoma (Fig. 1). Of these, 158 earthquakes were reported felt. Almost all Oklahoma earthquakes occur at shallow depths, less than 3 mi below ground level. These data were published on a regional-scale (1:750,000) map of the State (Lawson and Luza, 1995), and annual updates are published in *Oklahoma Geology Notes.* Oklahoma earthquake catalogs, earthquake maps, some seismograms, and related information can be accessed on the internet at **http://www.okgeosurvey1.gov**.

The earthquake database can be used to develop numerical estimates of earthquake risk, which give the theoretical frequency of earthquakes of any given size for different regions of Oklahoma. Numerical risk estimates are used in the design of large-scale structures, such as dams, high-rise buildings, and power plants, as well as providing information needed to establish insurance rates. Small-scale, relative-risk maps of the United States are used in various national and international building codes to establish engineering-design standards. For a number of years, the most common risk map used in the United States was based chiefly on historical earthquake activity, with some consideration given to nearby major geologic structures. A version of this type of map for the United States is depicted in Figure 2. This map example has four risk categories, which range from low to high, for damage that might be expected from an earthquake. North-central Oklahoma, east-central Kansas, and southeastern Nebraska are in seismic-risk zone 2, which means that moderate damage might be expected from an earthquake. The higher risk value is given to this region because several moderate-size earthquakes, magnitude 5 or greater, have occurred along (or west of) a major geologic

TABLE 1. — OKLAHOMA EARTHQUAKES WITH MAGNITUDES ≥4.0

Date	Origin time (UTC)[a]	County	Nearest town	Intensity MM[b]	Magnitudes[c] 3Hz	bLg	DUR	Lat. °N	Long. °W
1952 Apr 09	1629 15	Canadian	El Reno	7		5.0[d]		35.4	97.8
1939 Jun 01	0730	Hughes	Spalding	4		4.4		35.0	96.4
1997 Sep 06	2338 01.99	Coal	Stonewall	7		4.4	3.7	34.676	96.499
1926 Jun 20	1420	Sequoyah	W Marble City	5		4.3		35.6	94.9
1959 Jun 17	1027 07	Comanche	NE Faxon	–6		4.2		34.5	98.5
1995 Jan 18	1551 39.90	Garvin	Antioch	6	4.1	4.2		34.712	97.542
1998 Apr 28	1413 01.27	Comanche	NW Richards Spur	6		4.2		34.809	98.402
1956 Oct 30	1036 21	Rogers	Catoosa	7		4.1		36.2	95.8
1961 Apr 27	0730	Latimer	Wilburton	5		4.1		34.9	95.3
1929 Dec 28	0030	Canadian	El Reno	6		4.0		35.5	98.0
1959 Jun 15	1245	Pontotoc	Ada	5		4.0		34.8	96.7
1990 Nov 15	1144 41.63	Garvin	Lindsay	6	4.0	3.9	3.0	34.761	97.550

[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 Mercali (MM) earthquake-intensity scale.

[c]Magnitude is a measure of earthquake size, determined by taking the common logarithm (base 10) of the largest ground motion recorded during the arrival of a seismic-wave type and applying a standard correction for distance to the epicenter. Three magnitude types—mbLg (similar to Richter magnitude), m3Hz, and mDUR—are used by the OGS to determine the size of Oklahoma earthquakes (Lawson and Luza, 1995).

[d]The El Reno earthquake had a Gutenberg-Richter magnitude (mb) of 5.5.

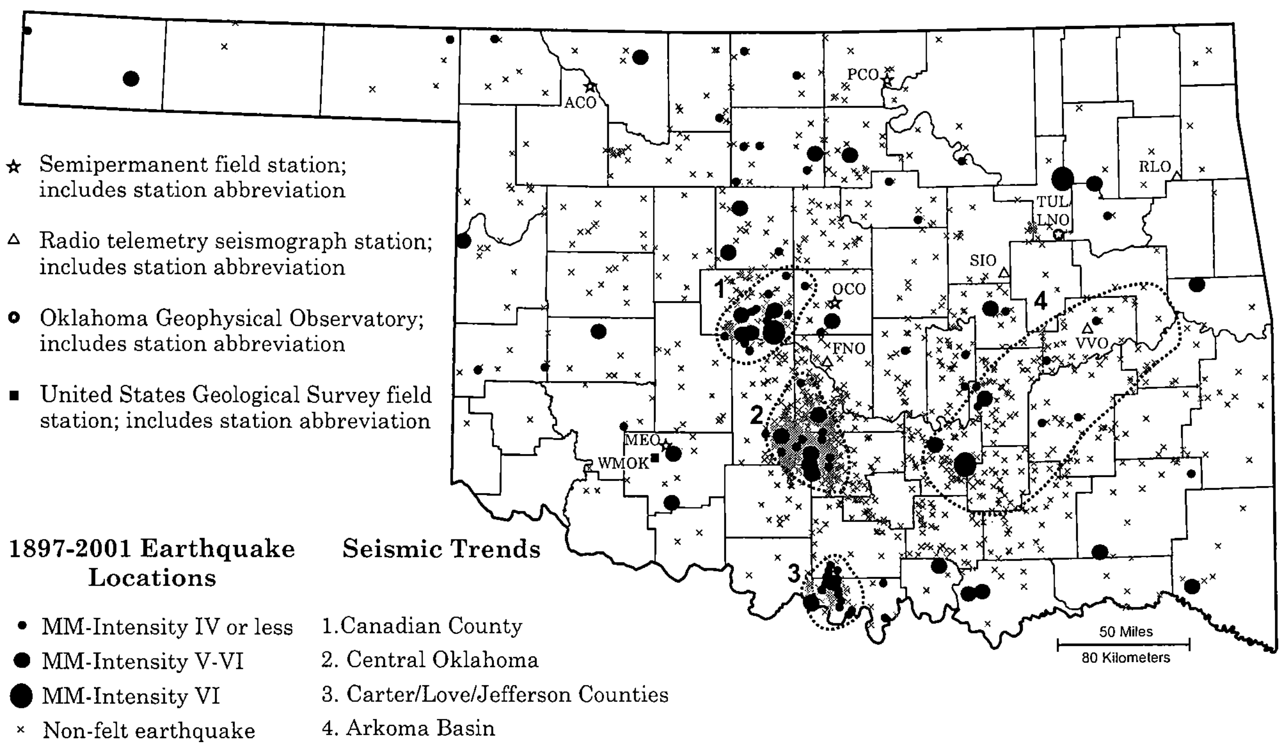


Figure 1. Map of Oklahoma showing felt-earthquake locations, seismic trends, and major tectonic features.

structure, the Nemaha Uplift, common to these three states. The remaining parts of Oklahoma, Kansas, and Nebraska are in seismic-risk zone 1, which means that minor damage might be expected from an earthquake. A second type of risk map, the probabilistic-risk map, is now used for most building-code applications, insurance rates, and disaster-mitigation planning (Fig. 3). This type of map is based on the probability that a certain level of ground motion will occur during an earthquake over a specific time interval. These maps are continually updated and revised as new geological data become available.

An analysis of Oklahoma earthquake data indicates at least four principal seismic areas on the basis of a consistent pattern of earthquake recurrence (Fig. 1). One area, in north-central Oklahoma, is 25 by 90 mi and extends northeastward from El Reno to Perry. The El Reno–Mustang area, near the south end of the zone, has had numerous earthquakes since 1908. The correlation of historical earthquake activity in this trend to known tectonic features remains unclear, inasmuch as the El Reno–Perry trend cuts diagonally across a major structural feature, the Nemaha Uplift.

The second principal area of seismic activity is on the eastern margin of the Anadarko Basin. A majority of these earthquakes are concentrated in a 25-mi-wide and 37-mi-long area that closely parallels the Central Oklahoma fault zone (sometimes referred to as the McClain County fault zone, McClain and Garvin Counties). More than 90% of the earthquakes within this zone have occurred since 1977. The increase in seismic activity is, in part, related to improved earthquake-detection capabilities.

A third principal area of seismic activity is in central southern Oklahoma, Love and Carter Counties. The first reported earthquake for this area occurred in 1974. Since 1974, a number of small, "felt" earthquakes have occurred within this region.

Another general area of earthquake activity is in the southeastern part of the State. Most of these earthquakes have occurred north of the Ouachita Mountains in the Arkoma Basin. Approximately 90% of all earthquakes in the Arkoma Basin were not felt but were instrumentally located. Typical earthquake-magnitude values range from 1.8 to 2.5, and focal depths are generally shallow (<3 mi).

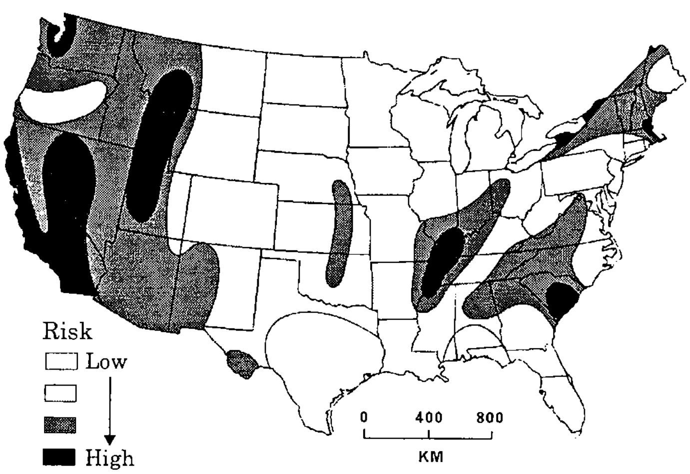


Figure 2. Earthquake-risk map of the United States, which shows relative risk of damage based mostly on known-earthquake history (from Algermissen, 1969).

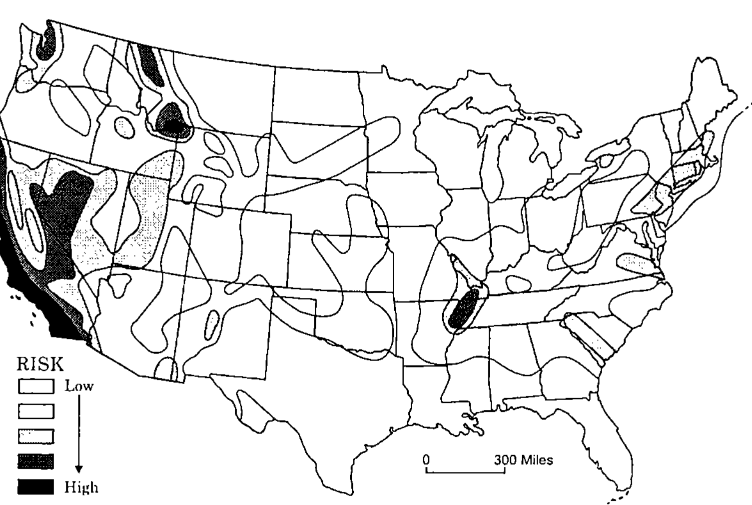


Figure 3. Earthquake-risk map, based on the probability that a certain level of ground motion will occur during an earthquake over a 50-year period (modified from Algermissen and others, 1982, pl. 2).

Landslides

Landslides and smaller slumps are a common highway-construction problem in parts of Oklahoma. Most of the landslides occur in the eastern one-third of the State (Hayes, 1971), owing to a wetter climate (39–59 in. of precipitation per year) and the steeper slopes associated with a more mountainous terrain (Fig. 4). In eastern Oklahoma, thick shale formations (such as the Johns Valley Shale, Savanna Formation, and shale beds within the Jackfork Group, all of Pennsylvanian age) weather quickly and produce large quantities of clayey colluvium. This material usually occurs as a veneer, one to several meters thick, that masks the underlying bedrock on a slope. Generally, the threat of landslides is high where natural slopes exceed a gradient of 2:1.

Rotational slump is the most common type of landslide that occurs in Oklahoma (Figs. 5, 6). Other, less common types include debris slides, block glides, and boulder flows. Rotational slumps can occur on either excavated slopes or embankments. Several construction practices are used to minimize the possibility of landslides. In Oklahoma, highway engineers use a process called *benching*. A bulldozer is used to make several benches or platforms parallel to the roadway alignment. The bases of the benches are cut through any potential unstable material. The embankment is then built upon the benches. Other techniques used to support unstable material include buttress walls and retaining walls.

Moisture from storm runoff and/or seepage is a major contributor to the destabilization of embankments. Perforated underdrain pipe is placed beneath the ditch on the uphill side to intercept water coming down the slope and to convey water away from the embankment. In some cases, underdrains are placed within and/or below the embankment material to reduce and/or eliminate water-related problems.

The Oklahoma Department of Transportation (ODOT) has conducted a landslide-recognition and landslide-stabilization program as it relates to highway construction (Hayes, 1971). Nationwide, small-scale maps (scale 1:7,500,000) have been prepared for Oklahoma and other states, and these maps are updated as new data become available (Radbruch-Hall and others, 1982).

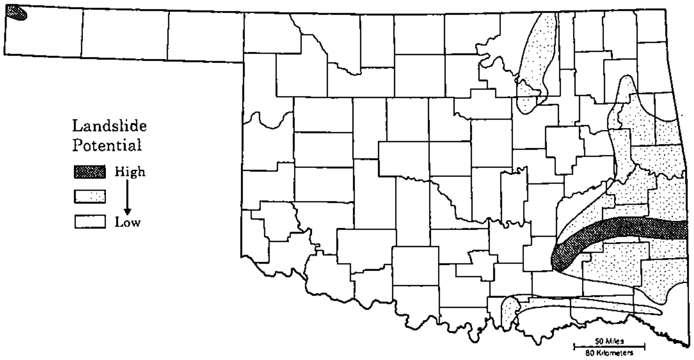


Figure 4. Map of Oklahoma showing landslide susceptibility (modified from Radbruch-Hall and others, 1982).

Figure 5. Landslide in the Pennsylvanian Jackfork Group (mostly shale at this location) along State Highway 1, Talimena Drive, Le Flore County. Photograph by Oklahoma Department of Transportation.

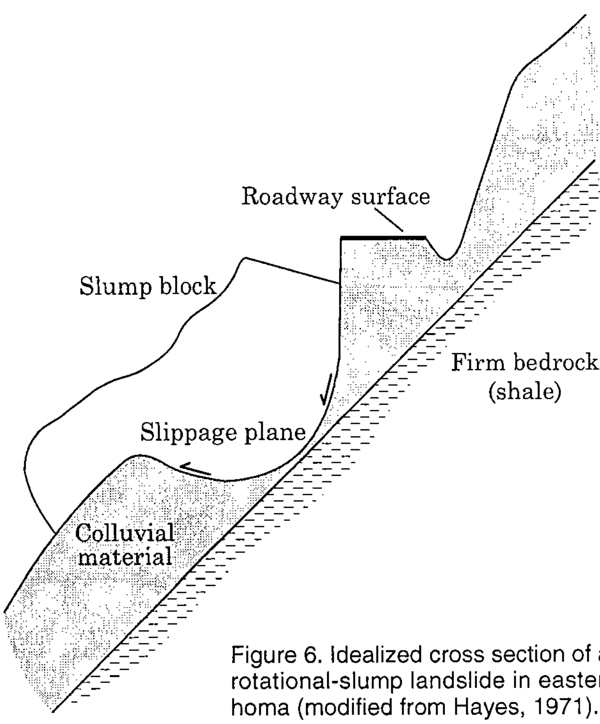


Figure 6. Idealized cross section of a typical rotational-slump landslide in eastern Oklahoma (modified from Hayes, 1971).

Expansive Soils

Clay-rich shales, or soils derived from the weathering of shales, may contain smectite-rich clay minerals, such as montmorillonite, that swell to as much as 1.5 to 2.0 times their original dry volume when they are wetted. More than 75% of Oklahoma contains bedrock units that can serve as sources for expansive soils (Fig. 7). The saturation of soil from rainfall, lawn watering, or sewer leakage can cause major damage through the expansion of soils beneath sidewalks, highways, utility lines, and foundations. If construction takes place on wet materials that have a high clay content, and these materials subsequently dry out, the resulting shrinkage could cause severe cracking in structures (Fig. 8). Creath (1996) reported that uninsured losses to property owners throughout the nation might be as high as $6 billion per year. Repairs to damaged foundations are very expensive—usually several thousands of dollars. In some years, the damage from expansive soils and subsequent repair costs exceed the damage from all other geologic hazards combined in Oklahoma.

Considerable information on soil and/or rock properties is available for building a foundation designed to withstand the effects of the existing soil and/or rock conditions. ODOT and the U.S. Department of Agriculture, National Resources Conservation Service (NRCS), formerly the Soil Conservation Service, have evaluated the expansive properties of soils and shale formations in Oklahoma. ODOT has released a series of district reports containing information on engineering characteristics, such as Atterberg limits and particle-size distribution, for each major geologic unit in Oklahoma (Hartronft and others, 1965, 1966, 1967, 1968, 1969, 1969a, 1969b, 1970). Atterberg limits and indices are empirical tests used to determine some physical properties of materials (Table 2). Each boundary or limit (shrinkage, plastic, and liquid) is defined by the water content for which the material is in a certain stage or state. The limits described are all expressed by their percentages of water content, and normally are shown as a unitless number. The plasticity index, PI, is the difference between the liquid and plastic limits, and represents the range in water content through which a material is in a plastic state. The plasticity index is inversely proportional to the ease with which water passes through a material. Therefore, a material

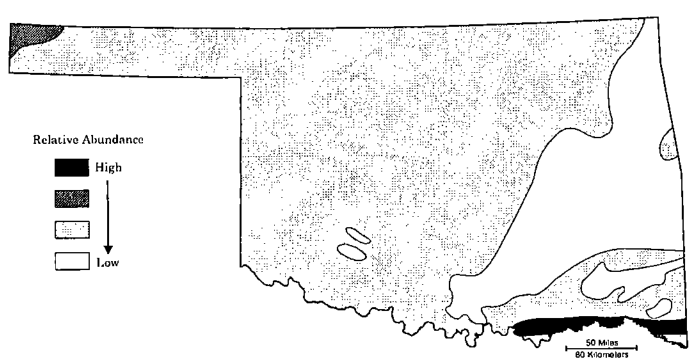


Figure 7. Map showing relative abundance of expansive soils in Oklahoma (modified from Schuster, 1981).

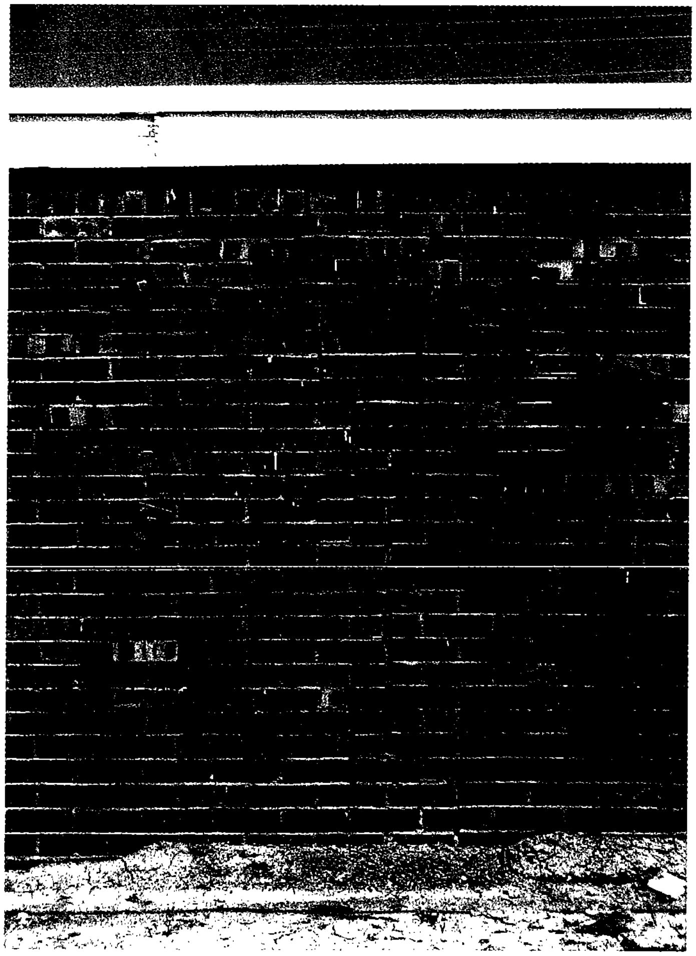


Figure 8. Crack in the wall of a building in Lawton, Oklahoma, caused by expansive soils. Photograph by Oklahoma Department of Transportation.

with a high plasticity index will generally have a low permeability. The plasticity index also can be used to assess clay content. Generally, materials that have high plasticity indices also have high clay-mineral contents (Table 3).

The plasticity index and shrinkage limit can be used to give some indication of the potential volume change that can be expected in a material (Table 4). In general, a high plasticity index and low shrinkage limit indicate a high shrink–swell potential. This is usually the case when clays of the montmorillonite family are present in significant enough quantities to cause large volume changes between swelling and shrinking.

There is considerable variation in properties from location to location. Therefore, descriptive terms, such as *high, moderate,* and *low,* are used to incorporate a range of values that describe some of the physical characteristics of rock and/or soil units.

The ODOT publications, although an excellent source of physical-properties information for the geologic formations in the State, have a limited distribution. However, some of the ODOT physical-property information and engineering data for various shale formations was summarized in various tables by Johnson and others (1980).

TABLE 2. — ATTERBERG LIMITS AND INDICES

Liquid state		
	Liquid limit (LL)	Plasticity index (PI) (PI = LL – PL)
Plastic state		
	Plastic limit (PL)	
Semi-solid state		
	Shrinkage limit (SL)	
Solid state		

Modified from Sowers and Sowers (1961).

TABLE 3. — PLASTICITY TERMINOLOGY IN RELATION TO PLASTICITY INDEX

Term	Plasticity index
Nonplastic	0–3
Slightly plastic	4–8
Medium plastic	9–30
Highly plastic	>30

Modified from Sowers and Sowers (1961).

TABLE 4. — SHRINK–SWELL POTENTIAL

Volume change	Shrinkage limit	Plasticity index
Probably high	0–10	>30
Probably moderate	10–12	15–30
Probably low	>12	0–15

Modified from Sowers and Sowers (1961).

The principal geologic units in the State that have high shrink–swell potential are the Cretaceous shales that crop out in southern Oklahoma. Dominant clay minerals in these shales are montmorillonite, illite, and kaolinite. Other shales that locally have a moderately high shrink–swell potential are several of the Pennsylvanian units in eastern Oklahoma and several of the Permian units in central Oklahoma.

Charts and tables containing data on shrink–swell potential for each major soil type are published by the NRCS in its soil surveys of nearly all the 77 counties in Oklahoma. These surveys can be examined at local NRCS offices, which are usually in the county seats. Office-location information and other related data can be found on the NRCS Oklahoma web site: **http://www.ok.nrcs.usda.gov/**.

The following example from the Cleveland County Soil Survey (Bourlier and others, 1987) is intended to show engineers, developers, builders, and/or home buyers how to use the county soil surveys to do preliminary site evaluation. Each modern soil survey contains a map index to the map sheets that cover the county. For Cleveland County there are 48 map sheets. Each sheet is at a scale of 1:20,000, or 1 in. equals ~1,670 ft. Our example (Fig. 9), which covers mainly secs. 25 and 26, T. 9 N., R. 3 W., is found on their no. 21 map sheet. The area of interest is east of Merkle Creek, north of Main Street, west of Berry Road, and south of Robinson Street. The predominant map-unit symbols are nos. 49 and 59. The index for soil map units lists the name of each map unit and the page where the map unit is described. Map symbol 49 is the Doolin–Urban land–Pawhuska complex, found on 0–3% slopes. A detailed description of this map unit is found on their page 50. Map symbol 59 corresponds to the Bethany–Urban land complex map unit, found on 0–3% slopes. A detailed description of this map unit is given on their page 59. Data on building-site development (their table 14), engineering index properties (their table 18), and physical and chemical properties of soils (their table 19), are useful for a preliminary site evaluation for expansive soils. This information is summarized in Tables 5–7 of this report. The data presented in the tables indicate that both map units have the potential of having moderate to severe shrink–swell problems. These data represent averages and/or ranges of test data taken at several locations and are useful as a general guide. Therefore, detailed on-site testing of a site is needed to confirm the regional test data as well as to provide data for a proper foundation design.

Unfortunately, most of us have purchased an existing house and/or business that did not have a soil analysis done prior to construction. However, some inexpensive ways help to minimize most problems associated with expansive soils. A uniform and constant moisture near the foundation will help minimize shrinkage that can occur in expansive soils during periods of drought. Proper drainage and grading techniques near the foundation will help minimize swelling during periods of high rainfall.

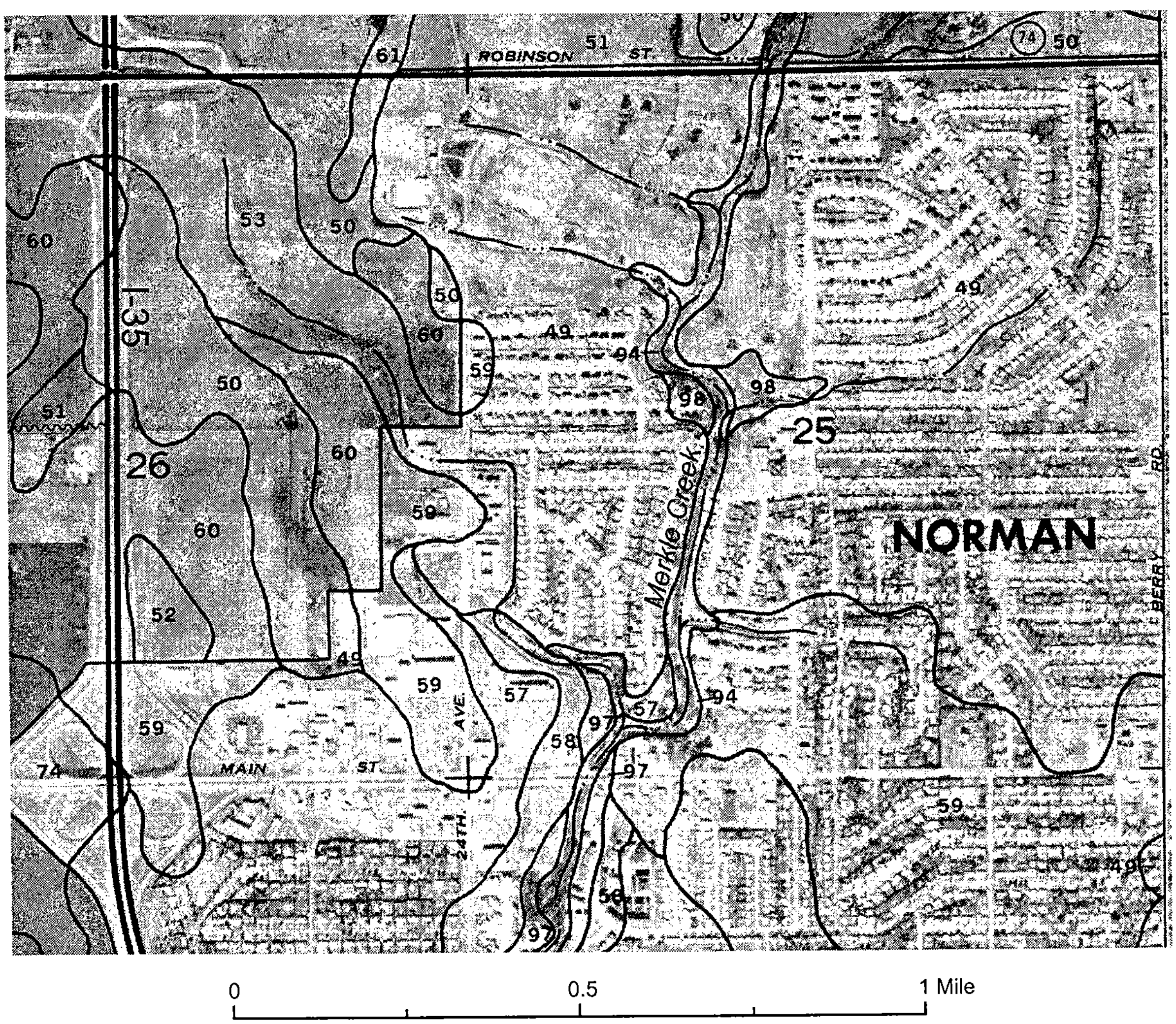


Figure 9. Soil-survey map of parts of secs. 23–26, T. 9 N., R. 3 W., Cleveland County, Oklahoma. The smaller numbers, map-unit symbols, correspond to soil map units in the Cleveland County soil-survey index (modified from Bourlier and others, 1987).

TABLE 5. — Data on Building-Site Development in Cleveland County

Map symbol & soil name	Shallow excavations	Dwellings without basements	Dwellings with basements	Small commercial buildings	Local roads and streets
49:					
Doolin	Moderate: too clayey	Severe: shrink–swell	Moderate: shrink–swell	Severe: shrink–swell	Severe: low strength, shrink–swell
Urban land					
Pawhuska	Moderate: too clayey	Severe: shrink–swell	Severe: shrink–swell	Severe: shrink–swell	Severe: low strength, shrink–swell
Urban land					
59:					
Bethany	Moderate: too clayey	Severe: shrink–swell	Severe: shrink–swell	Severe: shrink–swell	Severe: low strength, shrink–swell

Modified from Bourlier and others (1987, table 14, p. 246–247).

TABLE 6. — Data on Engineering Index Properties

Map symbol & soil name	Depth (inches)	USDA texture	Fragments >3 inches (Pct)	Liquid limit (Pct)	Plasticity index
49:					
Doolin	0–12	Silt loam	0	24–37	5–14
	12–80	Silty clay loam, clay loam, silty clay	0	37–60	15–34
Urban land					
Pawhuska	0–6	Silt loam	0	22–30	2–7
	6–72	Silty clay loam, silty clay, clay	0	41–70	20–40
Urban land					
59:					
Bethany	0–13	Silt loam	0	21–37	2–13
	13–22	Silty clay loam, clay loam	0	33–50	15–26
	22–84	Silty clay, clay, silty clay loam	0	37–60	15–33

Modified from Bourlier and others (1987, table 18, p. 281, 283).

TABLE 7. — Data on Physical and Chemical Properties of Soils

Map symbol & soil name	Depth (inches)	Clay (Pct)	Moist bulk density (g/cm^3)	Permeability (inches per hour)	Soil reaction (pH)	Shrink–swell potential
49:						
Doolin	0–12	10–27	1.30–1.55	0.6–2.0	5.1–7.8	Low
	12–80	35–55	1.35–1.65	<0.06	6.1–8.4	High
Urban land						
Pawhuska	0–6	18–27	1.30–1.50	0.6–2.0	5.6–8.4	Low
	6–72	35–50	1.35–1.65	<0.06	6.1–8.4	High
Urban land						
59:						
Bethany	0–13	15–26	1.30–1.50	0.6–2.0	5.6–7.3	Low
	13–22	27–35	1.45–1.70	0.2–0.6	6.1–7.3	Moderate
	22–84	35–50	1.40–1.70	0.06–0.2	6.1–8.4	High

Modified from Bourlier and others (1987, table 19, p. 294–295).

Flood-Prone Areas

Flood plains are those areas adjacent to rivers and streams that occasionally are flooded but are normally dry, sometimes for many years. During these dry periods, buildings or other structures sometimes are constructed on flood plains. When storms produce more runoff than a stream or river can carry within its normal channel, the water rises and floods the adjacent low-lying lands (Figs. 10, 11). Although floods can occur in any month in Oklahoma, major floods frequently occur in the spring and fall months (Tortorelli and others, 1991).

In the United States, the average annual cost of flood damage is more than $2 billion (Moreland, 1993). In 1968, a nationwide assessment of flood hazards was initiated to support the National Flood Insurance Program (NFIP), administered by the U.S. Department of Housing and Urban Development (HUD) and, after 1979, by the Federal Emergency Management Agency (FEMA). Approximately 100,000 flood-hazard maps or map panels have been produced since the program began. Although these maps originally were produced to evaluate flood risk for the national flood-insurance program, they also are used by flood-plain managers, community planners, surveyors, engineers, and disaster- and emergency-response officials for mitigation, risk assessment, and disaster preparedness, response, and recovery activities.

Flood-prone areas in Oklahoma are identified and mapped by the U.S. Geological Survey (Water Resources Division), the U.S. Army Corps of Engineers, and private contractors. The program is intended to delineate those areas that have, on the average, about 1 chance in 100 of being inundated in any particular year (a 100-year-flood frequency). This delineation is done through the use of readily available information on past floods and, sometimes, through detailed field surveys and inspections. Many of the early flood-prone maps, especially in areas where significant urban development has occurred, are being revised.

The Oklahoma Flood-Plain Management Act, effective May 1980, enabled Oklahoma to participate in the NFIP, as authorized in 1968. In order to participate in the flood-insurance program, communities and/or counties must meet minimum FEMA and Oklahoma flood-plain-management requirements. Eligibility is established by adopting codes which include (1) regulations for platting land for all types of building construction, and for the construction of any barrier in the flood plain that may divert, retard, or obstruct flood water; (2) regulations that establish minimum flood-protection elevations and flood-prevention requirements for structures in the flood plain; and (3) regulations that require coordination with the State Flood-Plain Board, other political subdivisions, and State agencies. The Oklahoma Water Resources Board (OWRB) administers the NFIP in cooperation with FEMA and acts as the State Flood-Plain Board. A list and status of participating communities and/or counties, arranged in alphabetical order, can be found on FEMA's web site at **http://www.fema.gov/fema/csb.htm**. As of June 2002, FEMA identified more than 350 Oklahoma communities and/or counties participating in the national flood-insurance program. A map-panel index is available for every participating community. Some indexes, especially the more recently revised indexes, have a map-repository list. Although repository locations are highly variable, some local places to look for flood-insurance rate maps are as follows: county clerk, city hall, county courthouse, city engineer, and/or city planning department.

Norman, Oklahoma, is covered by 12 maps. An area (the same as the expansive-soils example) is shown on panel 15 (of 85) of FEMA's Flood Insurance Rate Map south of Max Westheimer Airport (Fig. 12). The original map scale is 1 in. = 1,000 ft. Map scales are variable, however. Some of the more common map scales are 1 in. = 500, or 1,000, or 2,000 ft. In this example, two flood boundaries, a 100-year (zone A, in

Figure 10. Aerial view of the Chikaskia River looking north toward Blackwell, Oklahoma, during the Enid and vicinity flood of October 1973. The Chikaskia River flows from top to bottom, and the active channel is between the trees that grow on its banks. Photograph by Kenneth Gill, U.S. Army Corps of Engineers.

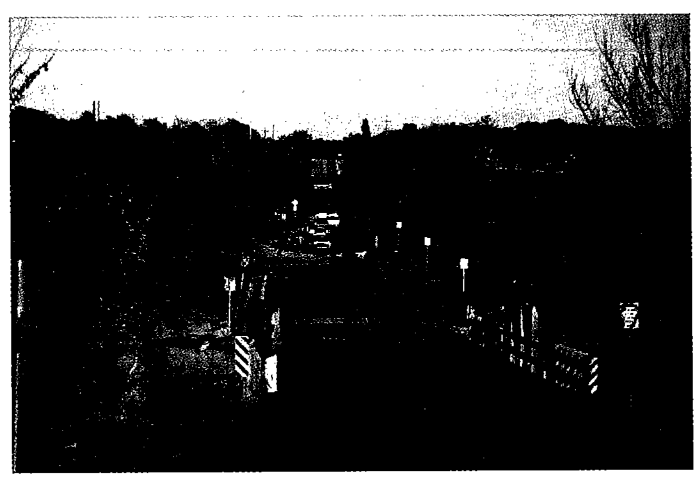
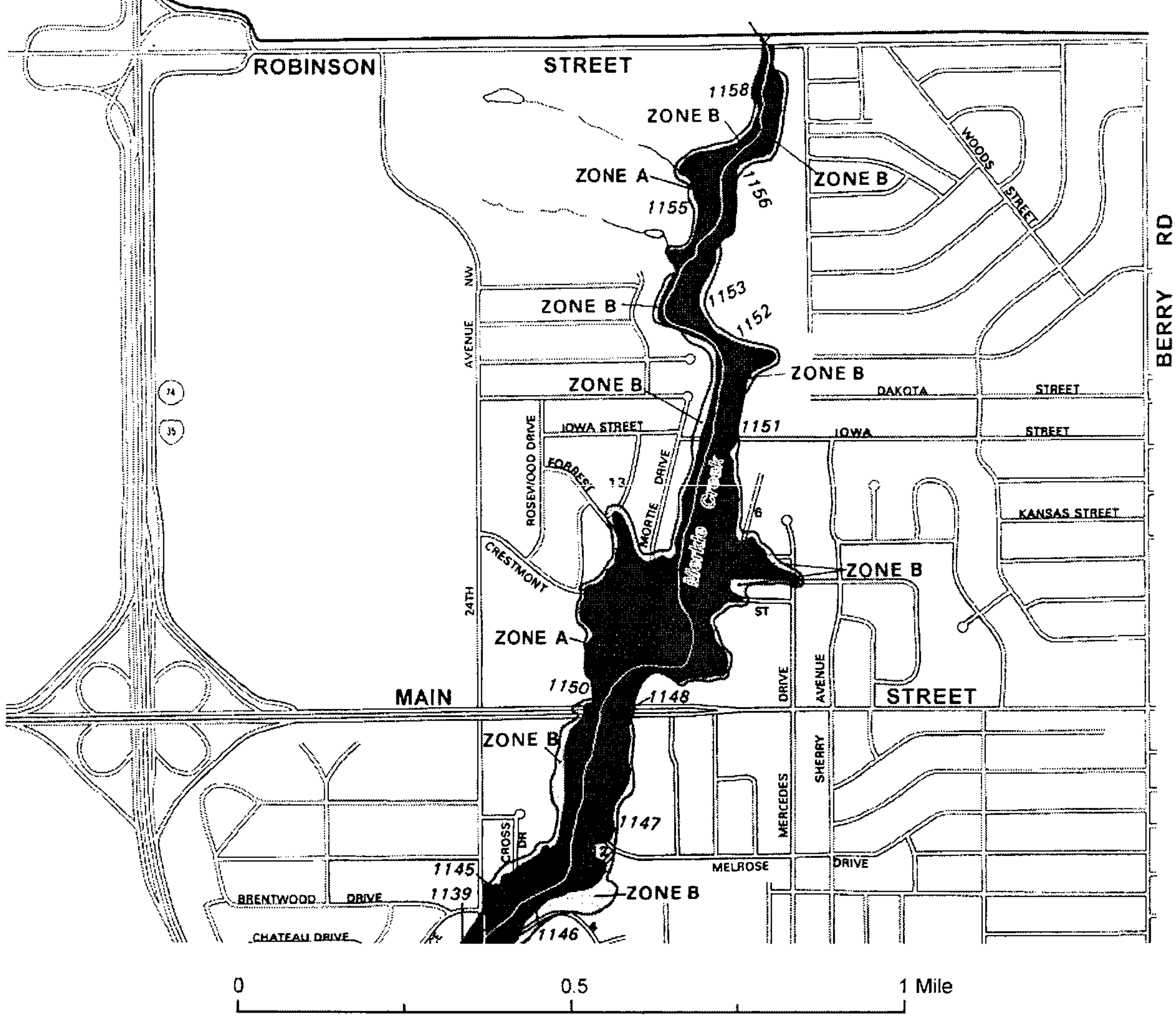


Figure 11. Twin bridges over the Little River at Lake Thunderbird, Cleveland County, were flooded as the result of storms of October 17–23, 1983, from remnants of hurricane Tico. Flooding and damages exceeded $12 million from these storms in an 11-county area in central Oklahoma (Hauth, 1985).

Figure 12. A part of panel 15 (of 85) of FEMA's Flood Insurance Rate Map for the City of Norman, Oklahoma. Merkle Creek is depicted also on the soil-survey map in Figure 9.



black) and a 500-year (zone B, in gray), are shown for Merkle Creek. Base flood-elevation lines, in feet, are shown for the 100-year flood (not all streets are represented on the map).

Areas of Karst and Salt Dissolution

Where water-soluble rocks, such as limestone, dolomite, gypsum/anhydrite, and salt, are at or near the land surface, they are prone to the development of karst and dissolution features from the dissolving action of circulating ground waters (Fig. 13). The sinkholes and caverns thus developed are potential hazards, owing to the possible settlement or collapse of the land surface into the underground openings. Principal areas in Oklahoma where karst features are present in limestone and dolomite are in the Ozark Mountains in northeastern Oklahoma, the Arbuckle Mountains in south-central Oklahoma, and the Limestone Hills (north of the Wichita Mountains) in southwestern Oklahoma (Fig. 14). Gypsum and shallow salt deposits are present in many areas of western Oklahoma.

Caves, cavities, sinkholes, and other karst features can be a hazard when an underground opening becomes large

Figure 13. Cavern developed in the Permian Cloud Chief Formation, Washita County, resulting from the dissolving action of circulating ground water through gypsum beds. Photograph by Rick Andrews.

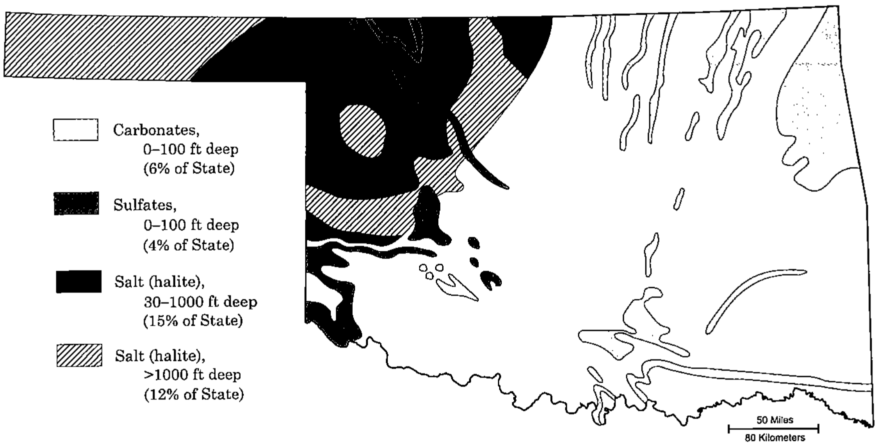


Figure 14. Map showing general distribution of karst terrains in Oklahoma (modified from Johnson and Quinlan, 1995).

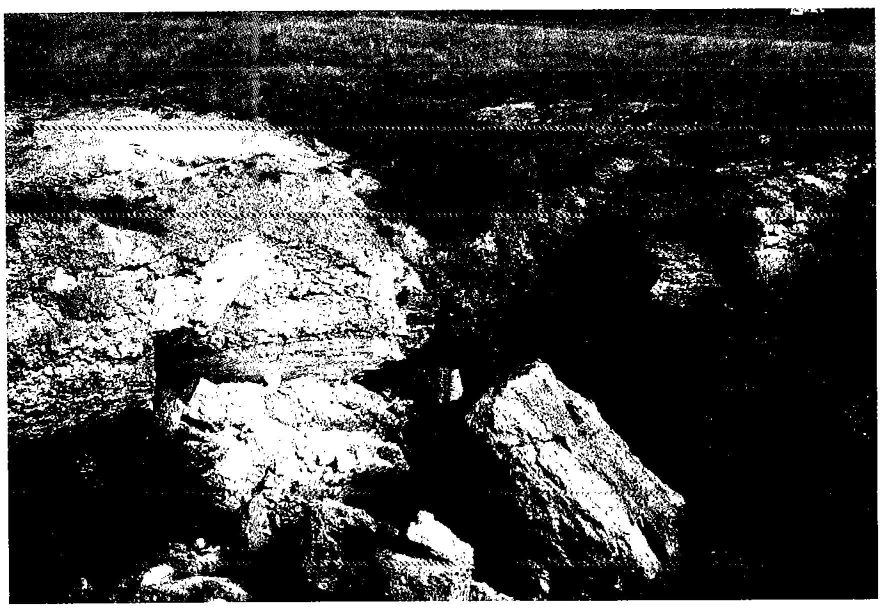


Figure 15. A 40-ft-deep sinkhole developed in the Permian Blaine Formation, western Greer County, where large blocks of gypsum, up to 10 ft wide by 20 ft long, collapsed into an underground cavern.

enough to allow the roof (and overlying ground and man-made structures) to collapse into the void (Fig. 15). Man-made structures most likely to be damaged or destroyed include houses, office buildings, dams, pipelines, roads, railroads, and other utilities or infrastructure; and, of course, there is the possibility of human injury or loss of life. By knowing the distribution, depth, and character of karst features before construction, engineers can either relocate the structure or design the construction to prevent or accommodate possible subsidence or collapse. Site-specific studies of the geology and geohydrology are needed when planning to build structures in a karst area.

Limestones, dolomites, and gypsums/anhydrites that crop out, and/or are within 20 ft of the land surface, normally represent the greatest potential for karst development and associated environmental and engineering problems (Fig. 16). Where the top of these karstic rocks is 20–100 ft deep, a somewhat lesser (yet real) potential exists for karst development and associated problems (Fig. 16). Karst also develops in Oklahoma limestones, dolomites, and gypsums/anhydrites at depths greater than 100 ft (perhaps as much as 200–300 ft, locally), but it is much more sporadic, is not well developed, and its potential to cause environmental or engineering problems is probably quite low.

Salt (halite) is a highly soluble rock that is as shallow as 30 ft below the land surface in parts of Oklahoma. Karst features in salt can be a problem locally in drilling for oil and gas and other minerals, and in building dams and/or other structures over cavities in the salt deposits. The dissolution of salt and its consequent collapse, associated

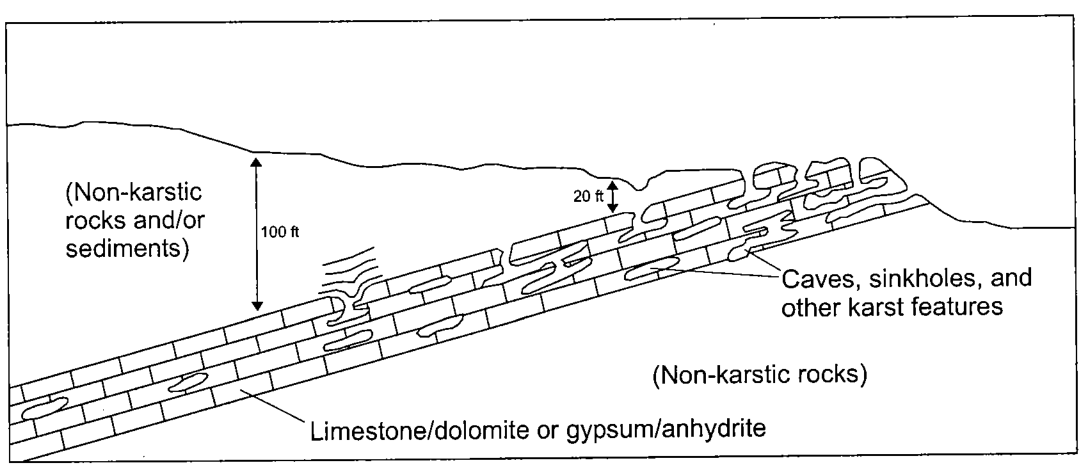


Figure 16. Schematic diagram showing the depth of karstic carbonates (limestone/dolomite) and sulfates (gypsum/anhydrite) in Oklahoma (modified from Johnson and Quinlan, 1995).

with boreholes (owing to salt-cavity development and to petroleum activity), has occurred at several places in the United States where salt beds are as deep as 1,000 ft (Johnson and Quinlan, 1995). In Oklahoma, there are no known natural occurrences of salt dissolution at depths greater than 1,000 ft.

Within Oklahoma's area of nearly 70,000 mi^2, limestone and dolomite crop out, or are no more than 100 ft deep, in about 4,130 mi^2 (6% of the State); gypsum/anhydrite crop out, or are no more than 100 ft deep, in about 2,740 mi^2 (4%); and salt is within 1,000 ft of the land surface in about 10,150 mi^2 (14.5%).

Radon

Radon is a naturally occurring radioactive gas formed by the spontaneous decay of uranium to lead. In the natural, near-surface environment, radon generated from uranium in rocks or soils either decays to a solid while it is still in the ground or escapes to the air, where it is diluted to insignificant levels. In buildings, and particularly in basements, however, radon can accumulate to high concentrations. When radon is inhaled and decays in human lungs, its solid daughter isotopes, which are also radioactive, can lodge in lung tissue. Lung-tissue damage, possibly resulting in cancer, occurs as these isotopes continue to decay and release alpha or beta particles and/or gamma radiation. Health hazards resulting from exposure and inhalation of above-normal levels of indoor radon gas, as well as radon detection, recommended safety levels, and remedial methods, are summarized in publications issued by the U.S. Environmental Protection Agency (1992, 1994, 2000, 2001).

Four fundamental factors determine how much radon in the ground enters a building: (1) radium (the immediate precursor of radon) must be present in the soil and/or bedrock beneath the foundation; higher concentrations of radium result in higher concentrations of radon, where other geological and pedological variables are equal; (2) 90% of radon decays to its solid progeny (polonium) in 13 days; therefore, radon must be able to rapidly enter pore spaces in the rock and/or soil, and subsequently the building; (3) for radon to enter a building, the structure must have openings (such as pore spaces or cracks) in the building materials that are below ground level; (4) a low internal air pressure within a building and a high external pressure within the ground creates a pressure differential across the ground/building interface; this produces a "pumping" effect on the soil/rock gases, including radon, from the ground into the building (Tanner, 1986).

Oklahoma has no known economic uranium deposits. However, the generation of indoor-radon concentrations in excess of the U.S. Environmental Protection Agency (EPA) standard (>4 pCi/L of air) does not require ore-grade uranium (>500 ppm). Under favorable conditions, rocks and residual soils containing much lower uranium contents are capable of generating above-normal radon levels. In Oklahoma, uranium is associated with many different rock types and geologic environments. Uranium occurrences in the State are divided into seven types, based on the mode of uranium enrichment and the size, distribution, and geologic continuity of the occurrence: (1) granitic rocks and their late-stage intrusives (dikes and sills); (2) arkosic sediments (weathered granite detritus); (3) dark, organic-rich shales; (4) phosphatic black shales; (5) lignite and bituminous-coal beds; (6) local point sources; and (7) stratiform bodies (confined to certain Permian stratigraphic units in western and southwestern Oklahoma).

The OGS, in cooperation with the Oklahoma State Department of Health (OSDH), evaluated near-surface geological conditions in Oklahoma for radon potential (Flood and others, 1990). Twenty-six areas in the State were assigned a radon-potential category. The boundary lines are approximate; the map scale is too small to portray individual beds accurately within a formation or show site-specific information. Areas underlain by formations with uranium contents that are equal to, or less than, the crustal average (2.5 ppm) are rated as having *generally very low* or *generally low* radon potential. Approximately 80% of the State is included in these two categories. About 7% of the State's land area has a *locally moderate* or *locally moderate* to *high* radon-potential rating. The rest of the State, 13%, is included in the *locally low* to *moderate* radon-potential category (Fig. 17).

This study was a reconnaissance-level investigation based on existing geological literature. The report and map are intended to serve as a guide for detailed future investigations. The map scale, limited analytical data, time constraints, and lateral lithologic variations in rock units precluded a site-by-site analysis. The study considered only uranium contents in rocks capable of generating above-normal radon levels. The report does not address other significant variables, such as soil characteristics, ground-water hydrology, precipitation and other atmospheric conditions, and types and conditions of building structures. The consideration of these variables is critical for determining site-specific radon potentials.

The OSDH, in cooperation with the EPA, conducted indoor radon surveys throughout Oklahoma. More than 3,150 sites were tested, and the results are available as a link on Oklahoma's Department of Environmental Quality's (DEQ) web site: **http://www.deq.state.ok.us**. Click on "Land Protection Division" and look for "radioactive materials" in small print near the top of the page. The data are accessible by county, city, and/or zip code. This study was part of a nationwide study to identify areas in the United States that have the potential for elevated indoor radon levels.

Indoor radon measurements, geology, aerial radiometric surveys, soil permeability, and building-foundation type were used by the EPA to develop a U.S. Radon Potential Map (**http://www.epa.gov/iaq/radon/zonemap.html**). EPA assigns each of the 3,141 counties in the United States to one of the following three zones: (1) zone 1 counties have a predicted average indoor-radon screening level greater than 4 pCi/L, (2) zone 2 counties have a predicted average indoor-radon screening level between 2 and 4 pCi/L, and (3) zone 3 counties have a predicted average indoor-radon screening level less than 2 pCi/L.

Oklahoma has no zone 1 counties, those with the highest potential, and nine counties were identified in zone 2, the moderate-potential category (Fig. 18).

Although the map does not predict indoor-radon levels, indoor radon can easily be measured by homeowners using a passive detection device and/or kit purchased at a nearby

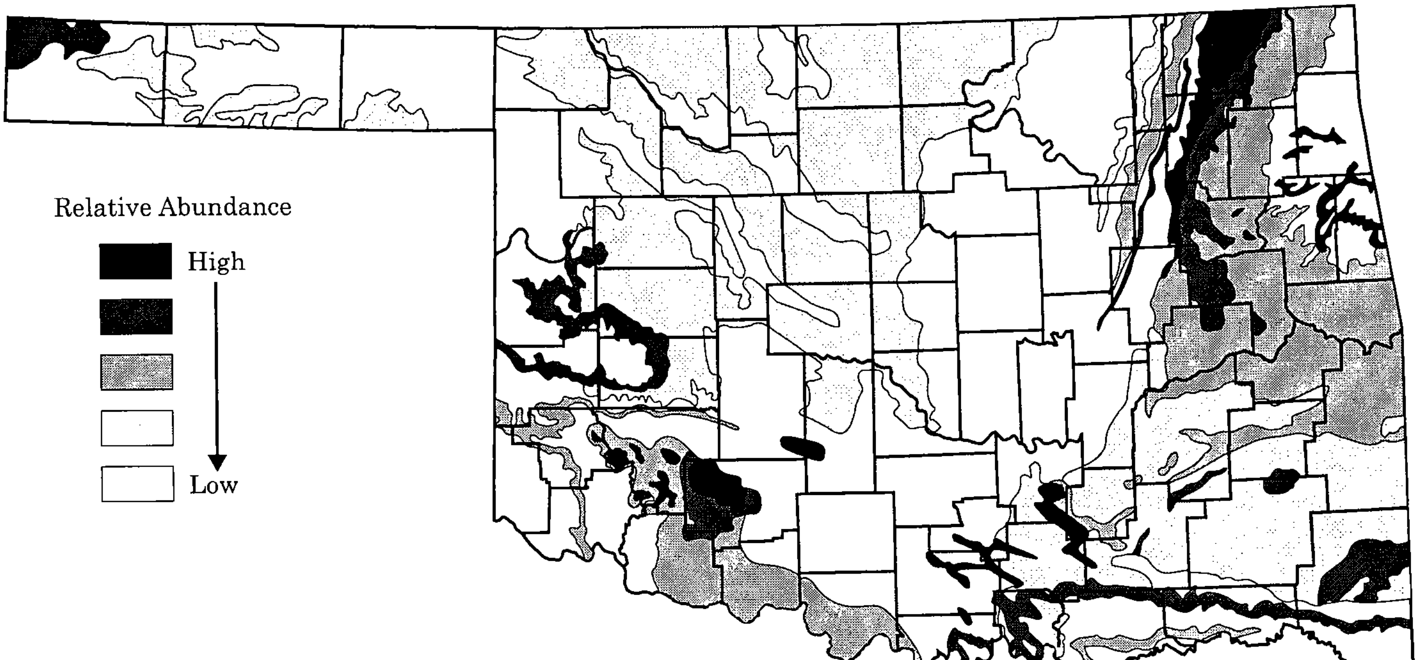


Figure 17. Radon-potential map for Oklahoma (modified from Flood and others, 1990).

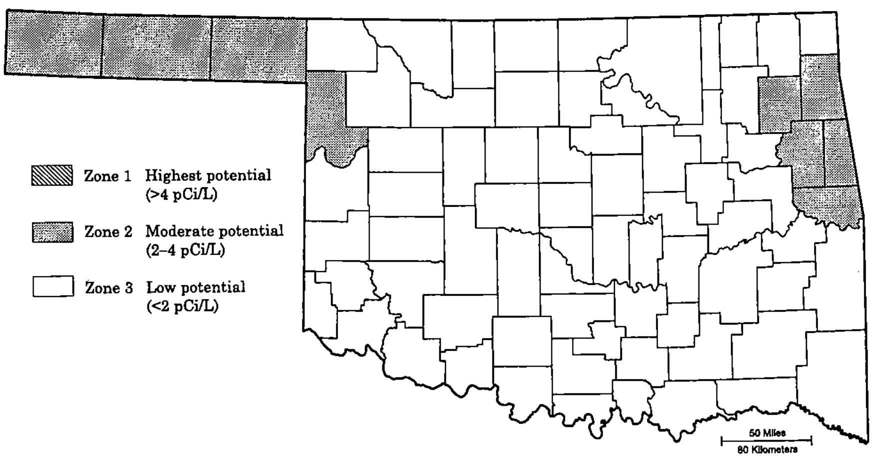


Figure 18. EPA's radon-potential map for Oklahoma. There are no counties in Oklahoma in zone 1.

store. The DEQ has a 48-hour test kit available for about $18. The price includes the kit, postage, and radon analysis.

MAN-MADE GEOLOGIC HAZARDS

Some activities of man that may have created present or future geologic hazards in Oklahoma include disposal of industrial wastes, underground mining, and strip mining.

Industrial-Waste Disposal in Geologic Formations

In the past, many hazardous wastes, such as acids, caustic solutions, flammable liquids, explosives, and liquids containing heavy metals, were disposed of either on the ground and/or in the ground, in streams and rivers, or stored in containers that were subsequently abandoned. These methods of disposal created thousands of uncontrolled or abandoned hazardous-waste sites throughout the United States. To properly regulate industrial-waste disposal, Oklahoma passed the Oklahoma Controlled Industrial Waste Disposal Act in June 1976; it was modified in 1978, and the OSDH established rules and regulations for the storage and disposal of industrial wastes. The rules and regulations subsequently were modified, and the program currently is administered by the DEQ.

In October 1976, Congress passed the Resource Conservation and Recovery Act (RCRA) for the regulation of hazardous and nonhazardous wastes. In December 1980, the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), commonly known as Superfund, was enacted by Congress and reauthorized by the Superfund Amendments and Reauthorization Act (SARA) in 1986. The law created a tax on chemical and petroleum industries and provided broad Federal authority to respond directly to releases or threatened releases of hazardous substances that might endanger public health or the environment. The Superfund program, which is administered by the EPA in cooperation with the states and tribal governments, locates, investigates, and cleans up hazardous-waste sites throughout the country. Kellogg (1990) provides an excellent historical summary of the various state and Federal hazardous-waste laws through 1989.

CERCLA established the following: (1) prohibitions and requirements concerning closed and abandoned hazardous-waste sites, (2) responsibility for releases of hazardous waste at these sites, and (3) a trust fund to provide for cleanup where no responsible party could be established. The law authorizes short-term removals and long-term remedial actions. The long-term remedial actions can be conducted only at sites listed on the EPA's National Priorities List (NPL).

More than 160 hazardous-waste sites have been identified in Oklahoma. Of these, 14 sites are on the NPL. The NPL includes former oil-refinery sites, landfills, a lead/zinc smelter, an Air Force base, and underground zinc/lead mines near Picher, Oklahoma (Tar Creek site). More information on the Oklahoma's CERCLA sites and Superfund sites is found on DEQ's web site: **http://www.deq.state.ok.us/**.

Solid and liquid industrial wastes have been disposed of in some areas of Oklahoma by surface burial in soil or rock units. At present, Oklahoma has only one operating industrial-waste surface-disposal site, in northwestern Major County. Of primary concern in selecting a suitable site for waste disposal is the need for assurance that the waste will be isolated from freshwater zones for as long as the waste is hazardous to man and his environment. Rock units in the State most favorable for surface disposal of wastes are impermeable sedimentary rocks, such as shale and clay, that can be excavated and that can prevent loss or migration of wastes from the disposal pit (Johnson and others, 1980). Most shales and clays consist chiefly of clay minerals, such as illite, montmorillonite, chlorite, and kaolinite, that have the ability to adsorb metal ions as well as to retard the lateral and vertical migration of fluids such as ground water and/or leachate. Areas likely to contain bedrock units suitable for surface disposal of industrial waste are shown in Figure 19.

Many other rock types in Oklahoma generally are not well suited for surface disposal of waste. Rocks such as limestone, dolomite, and gypsum/anhydrite are readily susceptible to dissolution and commonly are cavernous, which makes long-term containment in them unlikely. Granite and metamorphic rocks generally are intensely fractured, which might permit the downward and lateral migration of fluids. Many sandstone units are porous and permeable, which might also permit the infiltration and migration of fluids.

To help protect ground water from waste-disposal activities, maps showing the principal ground-water resources and recharge areas in Oklahoma were prepared by Johnson (1983). These maps, at a scale of 1:500,000 (⅛ in. = 1 mi), show the distribution, character, and recharge areas of bedrock aquifers, alluvium, and terrace deposits throughout the State. The OSDH, and subsequently the DEQ, have adopted these maps as one of the principal preliminary screening criteria for the suitability of a proposed site for waste disposal. However, a final decision concerning suitability should be based on site-specific studies.

The subsurface disposal of liquid industrial wastes has been carried out for many years in Oklahoma. Hazardous-waste products, such as spent acids, caustic solutions, solvents, and other chemicals, were injected into underground reservoirs (porous and permeable rock units that can hold fluids) deep below the land surface and are isolated from freshwater aquifers and the biosphere (Johnson and others, 1980). In 1988, 10 wells were used for disposal of liquid hazardous waste at eight different localities in Oklahoma (Walling, 1990). Nine of the wells are in northeastern Oklahoma, and one well is in central Oklahoma. Permitting and monitoring the operation of these disposal wells was carried out by the OSDH under the authority of the Oklahoma Controlled Industrial Waste Disposal Act of 1976, and later by the DEQ.

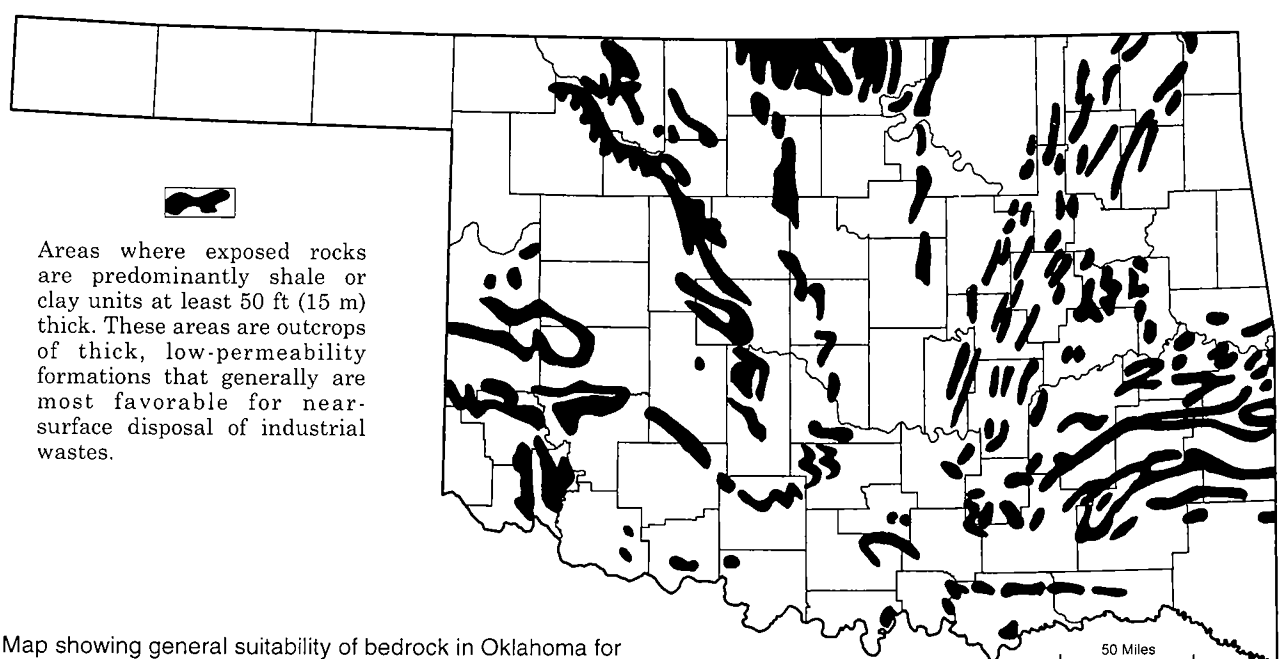


Figure 19. Map showing general suitability of bedrock in Oklahoma for surface disposal of industrial wastes (modified from Johnson, 1990).

In 1983, a Federal underground-injection-control program was established under the provisions of the Safe Drinking Water Act of 1974 to increase ground-water protection. Since then, state and Federal regulatory agencies have modified existing programs and/or developed new strategies to protect ground water by establishing even more effective regulations to control permitting, construction, operation, and closure of injection wells.

The underground-injection-control program divides injection wells into five classes. They are as follows:

Class I: wells used to inject liquid hazardous and nonhazardous wastes beneath the lowermost underground sources of drinking water;

Class II: wells used to dispose of fluids associated with the production of oil and natural gas, enhanced oil recovery, and storage of liquid hydrocarbons;

Class III: wells used to inject fluids for the extraction of minerals;

Class IV: wells used to dispose of hazardous or radioactive wastes into or above underground sources of drinking water (such wells and actions are banned);

Class V: wells not included in the other classes; generally wells used to inject nonhazardous fluids into or above an underground source of drinking water.

The Oklahoma Corporation Commission regulates the following: (1) class II wells; (2) class III wells used for the recovery and injection and/or disposal of mineral brines, such as iodine; and (3) class V wells utilized in the remediation of ground water associated with leaky underground and/or above-ground petroleum-products storage tanks. More than 3,800 class II wells are used to dispose of oil-field brines within the State. There are 11 brine-injection class III wells associated with the production of iodine in northwestern Oklahoma. The remaining well classes are regulated by the DEQ. As of January 2002, no wells were permitted for disposal of hazardous waste, and 12 wells were permitted for the disposal of nonhazardous wastes.

Rock types in Oklahoma that are most desirable for subsurface waste disposal are porous and permeable sedimentary rocks, such as sandstone, limestone, and dolomite, that can store injected liquid wastes (Johnson and others, 1980). Ideally, these porous and permeable rock units should be surrounded by impermeable strata to assure containment.

Johnson and others (1980) identified several geologic factors that need to be studied for a full evaluation of any potential disposal site. Some of these factors include lithology, porosity, permeability, thickness, lateral extent, and depth, as well as structure, geologic framework, confining rocks, hydrology, freshwater aquifers, compatibility of waste with the reservoir, mineral resources, and the presence of boreholes or other excavations. Principal nongeologic factors that need to be assessed include population density, transportation facilities, possible atmospheric degradation (odors, fumes, etc.), and the assured safety of freshwater streams and lakes.

Underground Mines

Underground mining has been conducted intermittently in Oklahoma since the early 1800s, but the major periods of such activity were from 1872 through the present in the eastern Oklahoma coal field, and from 1904 through 1970 in the Picher field, which is part of the world-famous Tri-State lead/zinc mining district that embraces part of northeastern Oklahoma and adjacent areas in Kansas and Missouri (Fig. 20). Underground mines in these two regions, along with a small number of underground gypsum, limestone, base-metal, and asphalt mines in other districts, are potential haz-

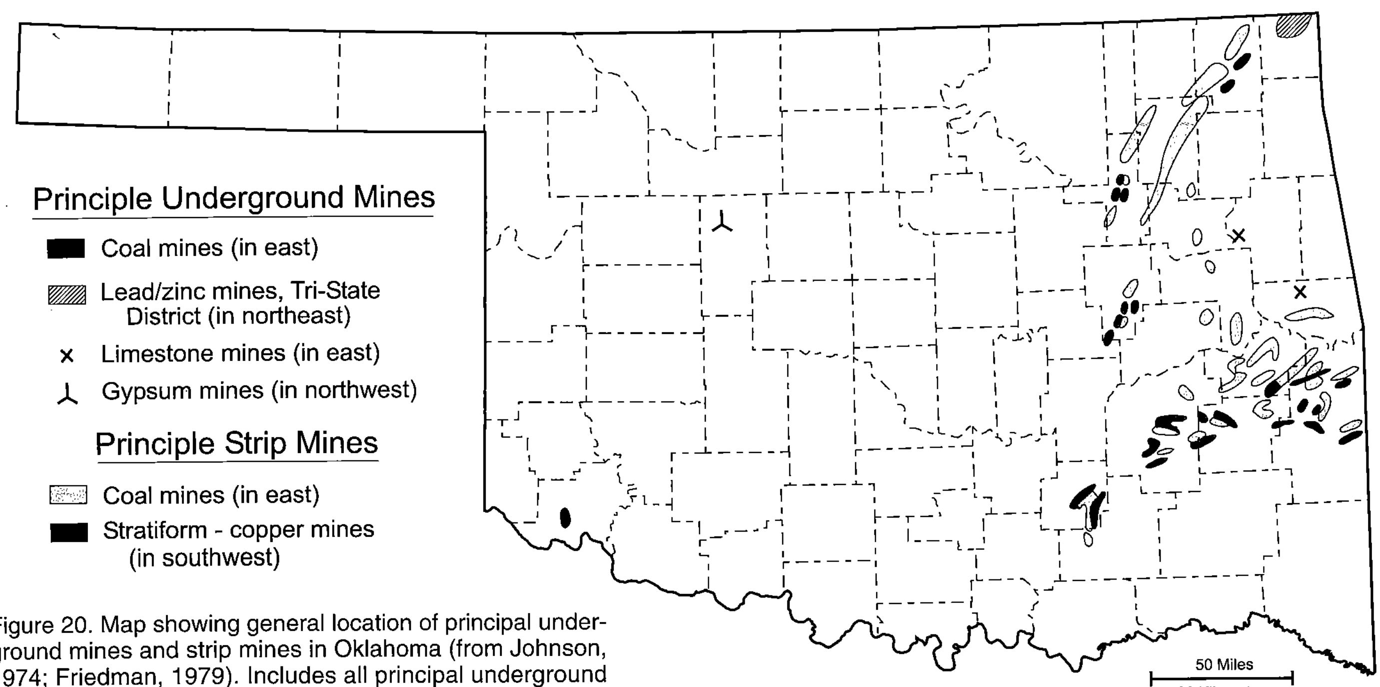


Figure 20. Map showing general location of principal underground mines and strip mines in Oklahoma (from Johnson, 1974; Friedman, 1979). Includes all principal underground mines, but only coal and copper strip mines are shown.

ards because of the following possible problems: (1) collapse of roof rock, causing subsidence or collapse at the land surface; (2) the presence of acidic or toxic ground water; and (3) flooding of a new mine by accidentally breaking into a water-filled abandoned mine.

All mining operations are permitted by the Oklahoma Department of Mines (ODM). As part of the permitting process, the mine operator must post an adequate bond to cover reclamation costs, should it be necessary for a third party to complete the reclamation process. Also, the mining operator's permit application must include the requirements to safeguard environmental resources and an operations and reclamation plan. Mining practices, reclamation, and health and safety procedures are monitored by ODM inspectors.

Large reserves of bituminous coal are distributed over an area of 10,000 mi^2 in eastern Oklahoma. These deposits have been mined continuously since 1872. Early production in Oklahoma was almost entirely from underground mines. Annual production from surface mines began to increase with the development of large earth-moving equipment. In 1943, about 50% of Oklahoma's annual coal production came from surface mines; this increased to 99% in 1964. In fiscal year 2000 (July 1, 1999–June 30, 2000), 244,577 tons of coal were mined from two underground mines, about 15% of the total annual production (Oklahoma Mining Commission and Department of Mines, 2002). About 40,000 acres have been impacted by underground coal mines (Kastl and others, 2001), including scattered gob piles (mine refuse), shaft openings, and subsidence features.

Underground mining for zinc and lead ores in the main part of the Picher field began in 1904, and the last recorded production occurred in 1970. In the main part of the field, an almost continuous underground network of mine workings extended from near Eagle-Picher Mining Company's central mill northward into Kansas. Detailed mine maps were made for each tract of land to ensure proper royalty payments and to provide a guide for future development. The U.S. Bureau of Mines donated their mine-map collection and drill-hole information to the Missouri Southern State College library in Joplin, Missouri. Also, the ODM maintains a collection of maps showing underground workings for coal mines and some lead/zinc mines in northeastern Oklahoma.

More than 2,500 acres are underlain by underground lead/zinc mines in the Oklahoma part of the Picher field. Luza (1986) studied stability problems associated with abandoned underground mines in the Picher field. In 1982, 481 shafts either were open or in some stage of collapse. Approximately 27 surface acres were disturbed as a result of shaft-related collapses. The largest collapse feature, >4 acres, is associated with three shafts at the Domado Mine in Ottawa County (Fig. 21). About 20 surface acres have been disturbed as a result of 55 non-shaft-related collapses. Most of these collapses are west of Commerce and west of Cardin. Apparently most of the non-shaft-related collapses are related to multiple mine levels and/or large stopes and/or incompetent-roof rock.

When the mines were abandoned, they filled with water. In 1979, mine water containing high concentrations of heavy metals began discharging into Tar Creek from natural springs, boreholes, and open mine shafts. In 1980, Oklahoma's Governor, George Nigh, established the Tar Creek Task Force to investigate the drainage of acid mine water into Tar Creek. The site was proposed to be added to the National Priorities List in 1981 and was listed in 1983. Since 1983, a number of studies and remedial actions have taken place, including (1) building dike and diversion structures to stop and/or reduce surface water from entering the abandoned mine workings, and (2) plugging deep, abandoned wells to prevent downward migration of acid mine water into the Roubidoux (Ordovician) aquifer.

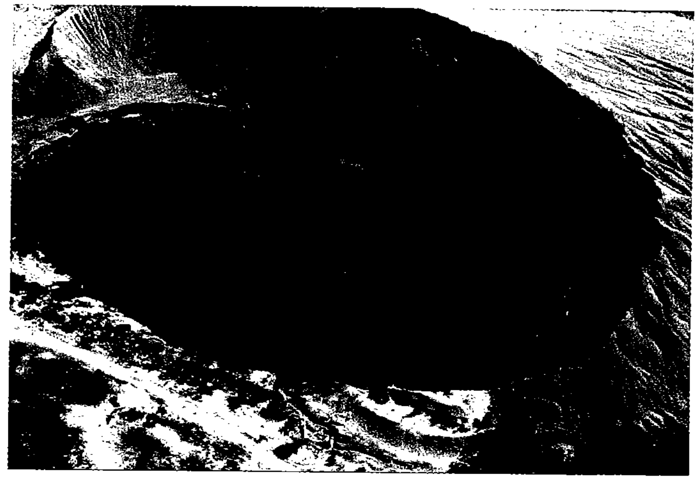


Figure 21. Aerial view of a 4-acre-collapse area associated with three mine shafts at the Domado Mine in Ottawa County, sec. 29, T. 29 N., R. 23 E. (from Luza, 1986).

Significant quantities of mill-waste material were generated by the milling of the lead/zinc ores. Luza (1986) reported that approximately 2,900 acres were overlain by mine and/or mill by-products. The discarded mill-waste material, chiefly composed of chert fragments 0.75 in. or less in diameter, was referred to as "chat" by the miners. The chat was transferred away from a mill by a series of conveyors and elevators and heaped into piles. Some piles attained heights greater than 200 ft. The chat has been used for railroad ballast; a base for roads, parking lots, and concrete slabs; and concrete and asphalt aggregate. Datin and Cates (2002) and the University of Oklahoma/Surbec–Art Environmental (2000) reported high concentrations of lead, zinc, and cadmium in the chat. They found most of the lead, zinc, and cadmium concentrated in the smaller particle sizes, <0.0077 in. The chat piles and unwashed chat used as a source of gravel in parking lots and driveways could be a potential source of soil, airborne, and waterborne contaminants. A 1993 study of blood-lead levels by the Indian Health Service found that 34% of Native American children in the area had blood-lead levels above the national standard. Since then, the EPA has provided funds to remove chat from lawns, yards, and recreation areas in the Picher area.

On January 26, 2000, Oklahoma's Governor, Frank Keating, formed the Tar Creek Superfund Task Force. The 10-member task force was charged with developing a comprehensive remediation plan for the Tar Creek Superfund site. Several recommendations were made by the Task Force, including the construction of a wetlands area within the boundaries of the Tar Creek Superfund Site to restore natural resources and reclaim the damaged environment. The final report of the Tar Creek Superfund Task Force is available as a link on the DEQ's web page, **http://www. deq.state.ok.us/.**

Strip Mines and Open-Pit Mines

Strip mining and other forms of open-pit mining have been going on in Oklahoma since pioneer days. The initiation of large-scale quarrying and opencast mining for stone, sand and gravel, asphalt, and other non-coal resources began in the late 1800s, with a great influx of people settling in what was Oklahoma Territory and Indian Territory. The beginning of significant strip-mining activity in the eastern Oklahoma coal field began about 1915. Lands disturbed through surface mining are potential problem areas because (1) spoil piles and fill material might not be fully compacted, and might still be subsiding or settling; (2) ponds and ground water in mined areas might be acidic and/or toxic; and (3) highwalls and quarry faces might contain loose rocks or unstable slopes.

Of all commodities mined by surface techniques, the extraction of coal has had the greatest impact on the environment in Oklahoma. An early study of disturbed coal-mine lands by Johnson (1974) was followed by a comprehensive study by Kastl and others (2001), who showed that the surface mining of coal has produced more than 32,000 acres of unreclaimed land in a 16-county area of eastern Oklahoma. Prior to 1968, surface coal mines typically left behind large areas with elongate ridges of spoil piles, water-filled pits, and steep highwalls (Fig. 22). Oklahoma's Mine Lands Reclamation Acts of 1968 and 1971 required some post-mining restoration of land affected by mining (Fig. 23). In 1977, the U.S. Congress passed Public Law 95-87, known as the Surface Mining Control and Reclamation Act. This established the Abandoned Mine Land (AML) trust fund (funded by taxes on active coal mining) to pay for the reclamation of abandoned coal-mine land that endangered public health and/or safety. The Office of Surface Mining Reclamation and Enforcement, U.S. Department of the Interior, is the Federal agency responsible for allocating the reclamation fees in the AML trust fund. The Oklahoma Conservation Commission is the State agency responsible for reclamation of abandoned coal-mine lands in Oklahoma.

Kastl and others (2001) reported that Oklahoma's AML Program had reclaimed 3,438 acres in 13 counties as of August 2001. The reclaimed acreage included the elimination of 170 hazardous water bodies, the closure of 286 mine openings, and the restoration of 132 subsidence sites. Furthermore, more than 212,000 linear feet of highwall was reclaimed.

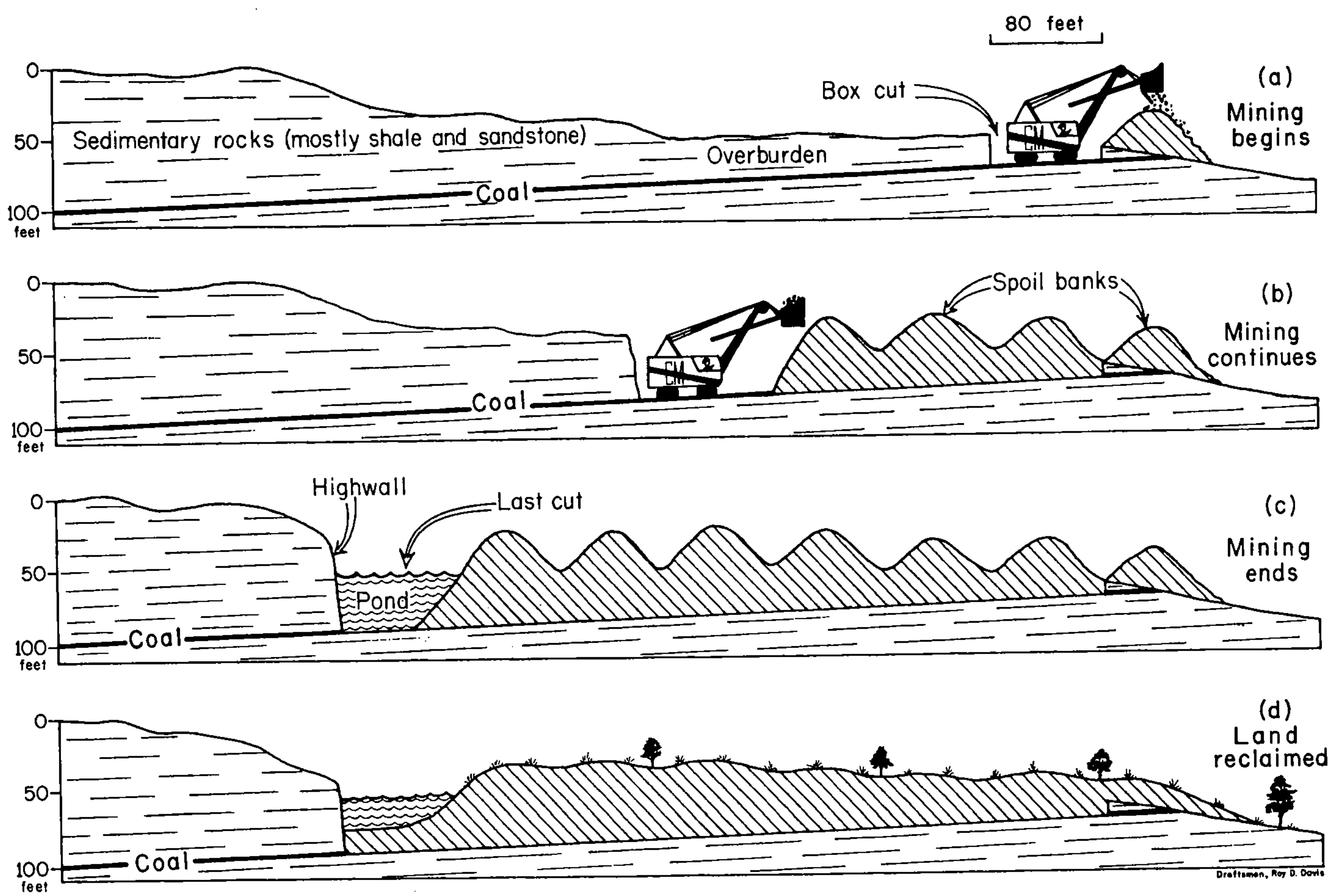


Figure 22. Schematic cross sections showing stages of surface mining for coal. Prior to 1968, most mined lands were left as shown in section c, but Oklahoma laws in 1968, 1971, and 1977 required leveling and land reclamation as in section d (from Johnson, 1974).

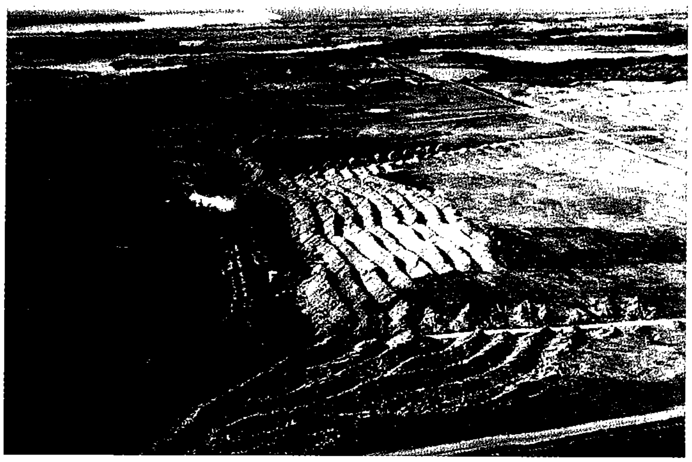


Figure 23. Aerial view of a coal-mining and reclamation operation in Rogers County. Spoil piles in central part of picture are being leveled as mining progresses. Photograph taken in May 1972, looking north across sec. 11, T. 23 N., R. 16 E., Rogers County, toward Oologah Reservoir in the background.

SUMMARY

This report provides a general overview of geologic hazards, both natural and man-made, in Oklahoma. Examples from a soil survey and a FEMA flood map are intended to illustrate how maps and reports can be used to evaluate a site for expansive soils and possible flood hazards, respectively. Other natural geologic processes that might cause hazardous conditions in Oklahoma include earthquakes, landslides, karst, salt dissolution, and radon.

Some activities of man that may have created present or future geologic hazards in Oklahoma include disposal of industrial wastes, underground mining, and strip mining. Some of the major Federal and State hazardous-waste laws that regulate the disposal of industrial and hazardous wastes are presented in the report, and State and Federal agencies that administer these laws are identified. Abandoned underground coal and lead/zinc mines in eastern Oklahoma are responsible for most of the possible problems associated with underground mining in Oklahoma. Of all commodities mined by surface techniques, the mining of coal, especially before 1971, has had the greatest impact on the environment in the State.

The Citizens' Guide to Geologic Hazards (Nuhfer and others, 1993), *Home Buyers' Guide to Geologic Hazards* (Creath, 1996), and *Facing Geologic and Hydrologic Hazards, Earth-Science Considerations* (Hays, 1981) are highly recommended for additional reading.

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Oklahoma Earthquakes, 2002

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INTRODUCTION

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

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

The New Madrid earthquakes of 1811 and 1812 were probably the earliest historical earthquake tremors felt in what is now southeastern Oklahoma (then part of Arkansas Territory). Before Oklahoma became a state, the earliest documented earthquake occurred on October 22, 1882, probably near Fort Gibson, Indian Territory, although it cannot be located precisely (Ross, 1882; Indian Pioneer Papers, date unknown). The *Cherokee Advocate* newspaper reported that at Fort Gibson "the trembling and vibrating were so severe as to cause doors and window shutters to open and shut, hogs in pens to fall and squeal, poultry to run and hide, the tops of weeds to dip, [and] cattle to lowe" (Ross, 1882, p. 1). These observations indicate Modified Mercalli (MM)-VIII intensity effects. (See the section, below, on Distribution of Oklahoma Earthquakes for information about the MM earthquake-intensity scale.) The next documented earthquake in Oklahoma occurred near Jefferson, Grant County, on December 2, 1897 (Stover and others, 1981). The next known Oklahoma earthquake happened near Cushing, Payne County, in December 1900. This event was followed in April 1901 by two additional earthquakes in the same area (Wells, 1975).

The largest known Oklahoma earthquake (with the possible exception of the 1882 earthquake) occurred near El Reno, Canadian County, on April 9, 1952. This magnitude-5.5 (mb, Gutenberg-Richter) earthquake caused a 50-ft-long crack in the State Capitol Office Building in Oklahoma City. It was felt throughout Oklahoma and in parts of seven other states. The total felt area was ~362,000 km^2 (Docekal, 1970; Kalb, 1964; von Hake, 1976); Des Moines, Iowa, and Austin, Texas, were at the northern and southern limits. From 1897 through 2002, 1,697 earthquakes have been located in Oklahoma.

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

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

INSTRUMENTATION

A statewide network of 10 seismograph stations was used to locate 42 earthquakes in Oklahoma for 2002 (Fig. 1). The statewide network consists of a central station (TUL/LNO), four radio-telemetry seismograph stations (FNO, RLO, SIO, VVO), and five field stations (ACO, CCOK, MEO, OCO, PCO). The U.S. Geological Survey (USGS) established a seismograph station, WMOK, 19 km southwest of the Oklahoma Geological Survey's (OGS) station at Meers (MEO). WMOK, the USGS station, does not record continuously. When triggered by moderately strong ground motion, it transmits a short segment of data to the National Earthquake Information Service in Golden, Colorado. WMOK is used mostly for distant earthquakes, although it sometimes records some of the larger Oklahoma earthquakes. Because WMOK is so near MEO, its arrival times do not improve the accuracy of location of Oklahoma earthquakes.

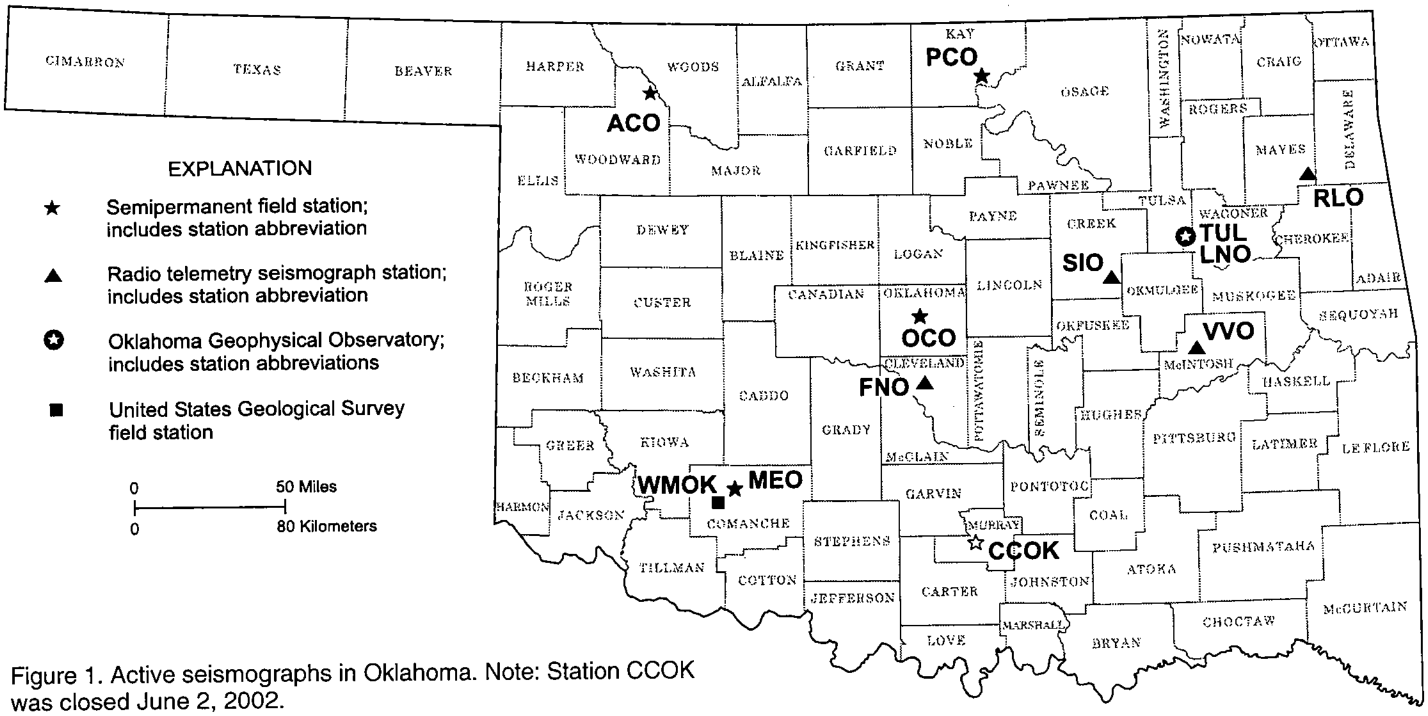

Figure 1. Active seismographs in Oklahoma. Note: Station CCOK was closed June 2, 2002.

Central Station

The OGS Observatory station, TUL/LNO, is located ~3.2 km south of Leonard, Oklahoma, in southeastern Tulsa County. At this site, digital and analog (paper) records from all stations are analyzed to detect, identify, and locate Oklahoma earthquakes. Seismometers at the central station are located on a pier in a 4-m-deep underground walk-in vault and in an 864-m-deep borehole. The vault is designated by the abbreviation, TUL, and the borehole has the international station abbreviation, LNO. In the vault, three Baby Benioff seismometers and a 3-component Guralp CMG3-TD seismometer record vertical, north-south, and east-west ground motion. Each Baby Benioff seismometer produces signals recorded on a drum recorder that uses a heat stylus and heat sensitive paper. (The original drum recorders used light beams to record on photopaper. The drum recorders were converted to ink recording in 1978 and later to more reliable recording on heat sensitive paper.)

The Guralp CMG3-TD ultra-broadband seismometer senses everything from the solid earth tides with their mHz frequencies to the high frequencies of Oklahoma earthquakes, which may approach 100 Hz. The CMG3-TD seismometer has a Global Positioning System (GPS) time receiver and digitizers in the case. The three digitizers each produce 200 samples per second. The CMG3-TD in the vault is a temporary replacement for the similar borehole seismometer, which currently is being rebuilt under warranty at the Guralp factory in the UK. When the borehole seismometer is operating again, it will provide the 200-sample-per-second signals from the central station that are used to detect and locate earthquakes in Oklahoma.

A Guralp eight-channel rack digitizer records the remote stations (RLO, VVO, and SIO) at 200 samples per second. Data are digitized and recorded by Guralp SCREAM software running on a PC. These samples are assembled into time-tagged data-compressed packets and transmitted at 38,400 bits per second to the Guralp SCREAM data acquisition software. Guralp SCREAM software, which runs on a PC, uncompresses the packets, organizes them into one-hour files on a disk, and will display one or more windows containing one or several moving traces. The windows may contain as little as one second or as much as 24 hours of ground motion. All digital data are archived on writable CD-ROMs. About two new CDs are added each week.

SCREAM sends slower packets (20 samples per second, and four samples per second) to another PC running SCREAM, and to the University of Indiana over the internet. From Indiana, the packets are sent continually or in once-per-day batches to a number of secondary schools in the United States. These slower packets lack the high frequencies characteristic of Oklahoma earthquakes but are very useful for studying teleseisms (distant earthquakes), which occur daily in the Earth's seismic belts. For distant earthquakes above magnitude 6, packages of the 20-sample-per-second, vertical, north-south, and east-west signals containing about one hour of recording are made up at the Observatory. These are sent by internet file transfer protocol to the PEPP (Princeton Earth Physics Project) data base, which is used primarily by American secondary schools.

Radio Telemetry Stations

Three radio-telemetry stations, (1) at Rose Lookout (RLO) in Mayes County, (2) at the Bald Hill Ranch near Vivian (VVO) in McIntosh County, and (3) at the Jackson Ranch near Slick (SIO) in Creek County, have Geotech S-13 seismometers in shallow tank vaults. The seismic signals are amplified and used to frequency modulate an audio tone that is transmitted to Leonard with 500-mW FM transmitters at various frequencies in the 216–220-MHz band.

Antennas on a 40-m-high tower near the OGS Observatory receive signals from the three radio-telemetry sites. These electrical signals are carried 350 m overland to the outside of the Observatory building. In a box on the outside wall, the electrical signals are converted to optical signals. The optical signals are sent through ~6 m of plastic fiber into the building, where they are converted back to electrical signals. This optical link is used to prevent wires from carrying lightning-induced surges into the building and damaging digitizers and computers.

The radio-telemetry signals are frequency-modulated audio tones. Discriminators convert the tones back into a voltage similar to the voltage produced at the field seismometer. These voltages are recorded on a 48-hour-paper-seismogram drum recorder, one recorder per station. The paper records are used mainly to backup the computer system.

The radio-telemetry signals are transmitted to three channels (one channel per station) on the Guralp rack digitizer. Each digitizer channel produces 200 samples per second. The digitizer includes a GPS (Global Positioning System) satellite receiver. The signals are assembled in memory into timed packets. The packets are transmitted to a PC running Guralp SCREAM data acquisition software.

A fourth radio-telemetry station, FNO, was installed in Norman in central Oklahoma on April 28, 1992. The seismometer, Geotech S-13, is on a concrete pad, ~7 km northeast of Sarkeys Energy Center (the building that houses the OGS main office). A discriminator converts the audio-signal frequency fluctuations to a voltage output. The voltage output is amplified and recorded by a Sprengnether MEQ-800 seismograph recorder (located in an OGS display case) at a trace speed of 60 mm/min.

Oklahoma earthquake catalogs, earthquake maps, some seismograms, and related information are on the Internet at http://www.okgeosurvey1.gov

Field Stations

Seismograms are recorded at four volunteer-operated seismographs (ACO, CCOK, MEO, and PCO). Each station consists of a Geotech S-13 short-period vertical-motion-sensing seismometer in a shallow tank vault, or in an abandoned mine shaft (station MEO). The seismometer signal runs through 60–600 m of cable in surface PVC conduit to the volunteer's house or other building. The volunteer has a Sprengnether MEQ-800B timing system amplifier-filter-drum recorder, which records 24 hours of seismic trace at 1 mm/min in a spiral path around the paper on the drum. A time-signal radio receiver tuned to the National Institute of Standards and Technology and high-frequency radio station WWV is used to set the time. The volunteers mail the seismograms to the Observatory weekly (or more often, if requested). When an earthquake is felt in Oklahoma, the volunteer operators fax seismogram copies to the Observatory so that the earthquake can be located rapidly. Station Cook was closed June 2, 2002.

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

DATA PROCESSING AND ANALYSIS

Data are processed on two networked Sun UNIX workstations—a SPARC20 and a SPARC 2+. All network digital and analog short-period (frequencies > ~1 Hz) and broadband seismograms are scanned for earthquakes in and near Oklahoma. The arrival times of P and S phases are recorded on a single-page form in a loose-leaf notebook. The arrivals then are entered into the SPARC20 or the SPARC 2+ using a user-friendly flexible program written in the Nawk language. The program uses the entries to write an input file with a unique file name.

From the input files, the hypocenters are located by Johannes Schweitzer's (1997) program HYPOSAT 3.2c. A Nawk program manages the input to HYPOSAT and puts the output in a single file and writes a line in an overall catalog file.

HYPOSAT must have a velocity model of the crust and top of the mantle to calculate travel times of P and S to each station from each successive hypocenter tried in the program. The nine-layer-plus-upper-mantle Chelsea model for Oklahoma, derived by Mitchell and Landisman (1971), is used exclusively for locating Oklahoma earthquakes. This model and three other Oklahoma models are outlined on the Observatory Web site at http://www.okgeosurvey1.gov/level2/geology/ok.crustal.models.html.

Each hypocenter is usually run in a preliminary form using the first four or so P and/or S arrivals from about four stations. Later, after all seismograms have been read, a final location is determined. The solutions are added manually to a catalog on the Observatory Web site at http://www.okgeosurvey1.gov/level2/okeqcat/okeqcat.2002.html.

DISTRIBUTION OF OKLAHOMA EARTHQUAKES, 2002

All Oklahoma earthquakes recorded on seismograms from three or more stations are located. In 2002, 42 Oklahoma earthquakes were located (Fig. 2; Table 2). Seventeen earthquakes were reported felt (Table 3), an unusually high number. The number of felt earthquakes in 2002 ties the number felt in 1952 for the most recorded in a single year. In 1952, 14 aftershocks associated with the El Reno earthquake accounted for most of the felt earthquakes recorded that year. The felt and observed effects of earthquakes generally are given values according to the Modified Mercalli Intensity scale, which assigns a Roman numeral to each of 12 levels described by effects on humans, man-made constructions, or natural features (Table 4).

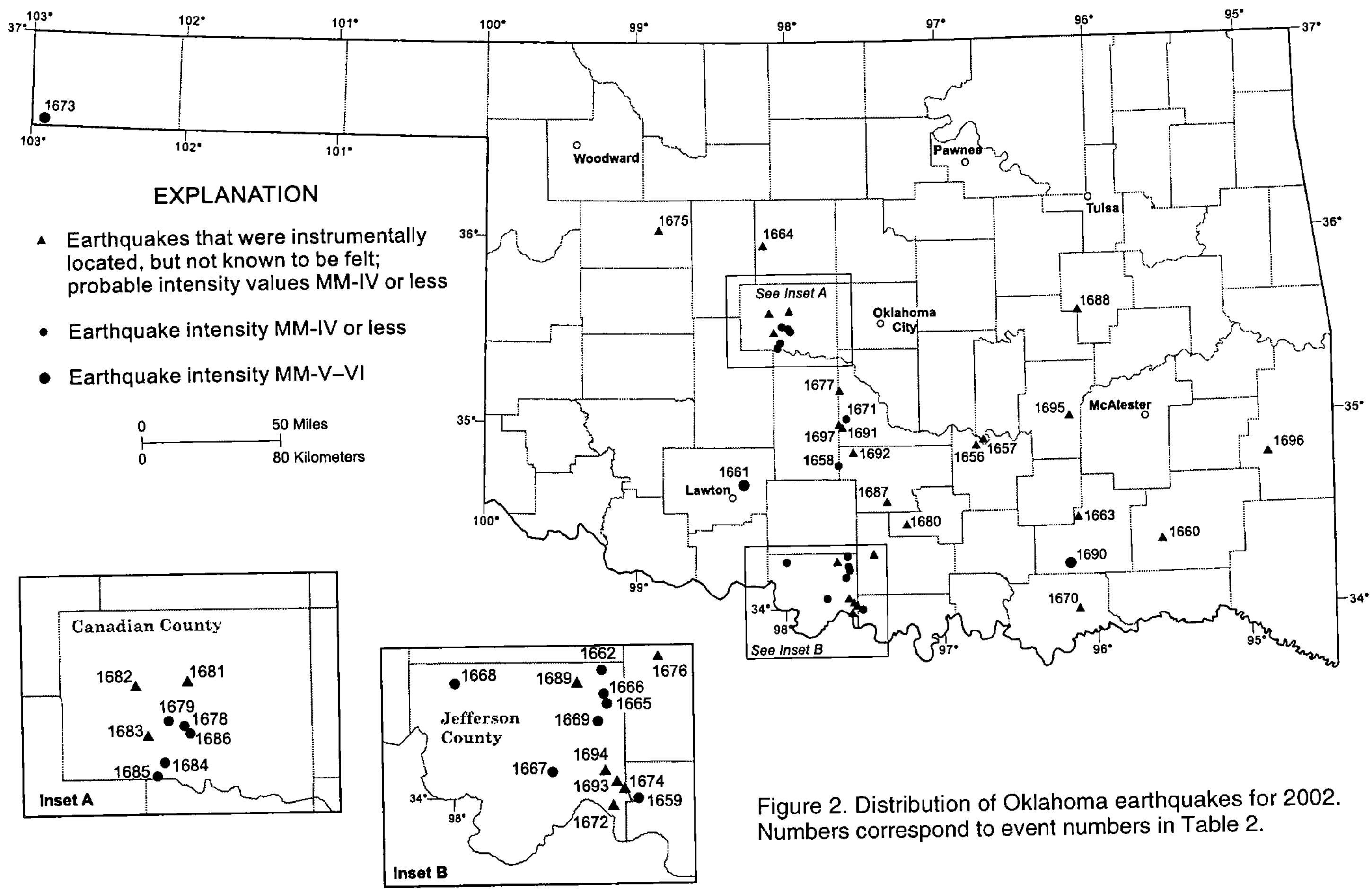

Figure 2. Distribution of Oklahoma earthquakes for 2002. Numbers correspond to event numbers in Table 2.

On February 8, a magnitude 3.8 (mbLg) earthquake (event no. 1661) occurred in east-central Comanche County ~10 km northeast of Lawton (Tables 2, 3). The earthquake, which produced MM IV–VI effects over 900 km², was felt in Apache, Cooperton, Indiahoma, Cache, Meers, Medicine Park, Elgin, Porter Hill, Lakeside Village, Fort Sill, and Lawton (Fig. 3). Felt reports (161) ranged from "windows and other things rattled, the house shook throughout" in Apache to "heard a loud noise like thunder, windows rattled, building swayed back and forth" at Fort Sill. Prior to this earthquake, eight earthquakes were known to have occurred in Comanche County.

A magnitude 3.6 (mbLg) earthquake (event no. 1673) shook residents in Cimarron County and nearby states on June 19 (Tables 2, 3). The earthquake, which produced MM V–VI effects over 3,000 km², was felt in Keyes, Boise City, Felt, and Kenton Oklahoma; in Dalhart and Texline, Texas; and in Clayton and Seneca, New Mexico (Fig. 4). Felt reports (23) ranged from "heard things rattle in the house, ground shook, almost lost my balance" near Clayton, New Mexico, to "I was lying in bed and it felt like someone bounced on the bed; there was a sudden jolt followed by gentle shaking" in Boise City, Oklahoma. This earthquake was the third known to have occurred in Cimarron County.

On October 20 (October 19 local time), a magnitude 3.3 (mbLg) earthquake (event no. 1690) occurred near Caney, Oklahoma (Tables 2, 3). The earthquake, which produced MM V–VI effects over 850 km², was felt throughout Bryan, southeastern Atoka, and eastern Johnston Counties in Oklahoma and near Denison, Texas (Fig. 5). Felt reports (56) ranged from "we heard a loud boom and then for a few seconds the house and everything in it moved; we could hear dishes and other things rattle" near Caney, Oklahoma to "heard a rumbling sound followed by windows rattling" in Durant, Oklahoma. Although numerous earthquakes (32) have been located in Atoka County, the October 19 (local time) earthquake is the first felt earthquake with epicenter in the county.

Other felt earthquakes include a magnitude 2.6 (mbLg) earthquake (event no. 1659) centered 7 km northwest of Courtney, Love County, on January 25 (Tables 2, 3). The earthquake was felt by residents in three households located 5.5 km south of Wilson. They reported being awakened by the earthquake. The felt area for the Courtney earthquake was probably less than 850 km². On May 31, a magnitude 3.0 (mbLg) earthquake (event no. 1671) occurred near Dibble, McClain County (Tables 2, 3). This earthquake was felt by at least one individual; it produced MM III effects. Four felt reports were received for a January 3 earthquake (event no. 1658) that occurred 7 km northeast of Cox City in southeastern Grady County. This magnitude 2.3 (mbLg) earthquake shook residents living ~6 km north of Lindsay, Oklahoma. One individual reported, "I heard a low rumble like thunder; then the oven rattled and shook. The floor shook and I made a comment to my family that we had just had an earthquake. They were sitting in the opposite room and laughed at me

TABLE 2. — OKLAHOMA EARTHQUAKE CATALOG FOR 2002

Event no.	Date and origin time (UTC)[a]		County	Intensity MM[b]	Magnitudes m3Hz	mbLg	MDUR	Latitude deg N[c]	Longitude deg W[c]	Depth (km)[c]
1656	Jan 02	06 30 06.42	Pontotoc		1.7		1.9	34.850	96.780	7.01 C
1657	Jan 02	06 33 47.42	Seminole		1.3		1.4	34.874	96.731	5.00R C
1658	Jan 03	01 50 15.78	Grady	F	2.1	2.3	2.0	34.753	97.679	5.00R C
1659	Jan 25	10 31 27.55	Love	III	2.3	2.6	2.3	33.988	97.530	5.00R C
1660	Jan 27	06 00 12.99	Pushmataha		1.6		1.8	34.330	95.579	5.00R C
1661	Feb 08	16 07 13.84	Comanche	VI	3.5	3.8		34.651	98.302	5.00R C
1662	Mar 12	10 52 04.6	Jefferson	II		2.2		34.270	97.630	5.00R C
1663	Mar 13	08 40 51.18	Atoka		1.9		1.7	34.460	96.124	5.00R C
1664	Mar 13	10 39 57.42	Kingfisher		1.9	1.9	2.1	35.922	98.157	5.00R C
1665	Mar 14	01 06 29.8	Jefferson	II	2.1	2.4	2.3	34.195	97.613	5.00R C
1666	Apr 12	09 17 41.3	Jefferson	II	1.8		1.7	34.215	97.618	5.00R C
1667	Apr 19	03 49 39.92	Jefferson	II	1.9	2.0	2.0	34.049	97.763	5.00R C
1668	Apr 19	03 54 03.76	Jefferson	I	1.8		1.8	34.244	98.021	5.00R C
1669	Apr 30	02 31 04.00	Jefferson	II	1.9		1.9	34.155	97.641	5.00R C
1670	May 24	11 41 46.87	Bryan		1.8		1.8	33.971	96.126	5.00R C
1671	May 31	09 57 09.87	McClain	III	2.7	3.0	2.8	35.000	97.623	5.00R C
1672	May 31	10 09 24.50	Jefferson		2.0		1.8	33.974	97.596	5.00R C
1673	Jun 19	12 14 18.04	Cimarron	VI		3.6		36.542	102.918	5.00R C
1674	Jul 09	18 03 69.07	Jefferson		2.3	2.5	2.2	34.004	97.563	5.00R C
1675	Jul 28	01 38 34.55	Dewey				2.0	36.006	98.852	5.00R C
1676	Aug 13	11 20 23.78	Carter				2.2	34.276	97.462	5.00R C
1677	Sep 15	12 31 11.56	McClain				2.1	35.150	97.667	5.00R C
1678	Sep 21	16 58 01.38	Canadian	III	1.9		1.9	35.484	97.999	5.00R C
1679	Sep 21	22 54 31.65	Canadian	II	2.1		2.0	35.497	98.040	5.00R C
1680	Sep 22	00 39 24.95	Murray				2.0	34.435	97.239	5.00R C
1681	Sep 22	01 27 11.32	Canadian				1.9	35.578	97.990	5.00R C
1682	Sep 22	03 30 45.42	Canadian				1.9	35.567	98.121	5.00R C
1683	Sep 22	04 42 10.19	Canadian				1.9	35.461	98.092	5.00R C
1684	Sep 22	05 32 55.25	Canadian	II			2.1	35.412	98.048	5.00R C
1685	Sep 22	11 50 56.44	Canadian	II			1.9	35.385	98.068	5.00R C
1686	Sep 22	20 44 36.37	Canadian	III	2.5	2.7	2.6	35.472	97.987	5.00R C
1687	Sep 24	21 55 11.93	Garvin				1.7	34.555	97.363	5.00R C
1688	Oct 01	08 32 40.80	Okmulgee		1.6		1.9	35.562	96.091	5.00R C
1689	Oct 19	14 56 20.30	Jefferson		1.9		1.8	34.244	97.696	5.00R C
1690	Oct 20	02 18 14.06	Atoka	VI	3.6	3.3	3.0	34.214	96.181	5.00R C
1691	Oct 29	01 19 18.29	McClain		1.6	1.6		34.950	97.652	5.00R C
1692	Oct 31	19 29 28.42	Garvin		2.2	2.2	2.1	34.822	97.583	5.00R C
1693	Nov 06	23 29 18.76	Jefferson		2.5	2.5	2.2	34.021	97.584	5.00R C
1694	Nov 07	03 01 34.05	Jefferson		1.9		1.9	34.050	97.624	5.00R C
1695	Nov 16	23 43 37.85	Hughes		1.6		1.9	34.994	96.159	5.00R C
1696	Dec 05	05 41 31.58	LeFlore		2.4		2.2	34.768	94.878	5.00R C
1697	Dec 27	08 24 46.61	McClain		1.5		1.9	34.965	97.669	5.00R C

[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 six hours.

[b]Modified Mercalli (MM) earthquake-intensity scale (see Table 4). "F" indicates earthquake was reported felt, intensity unknown, generally ≤IV.

[c]If R is preceded by a number in the latitude and/or longitude column(s), the location was restrained. 5.00R indicates that the depth was restrained to 5.00 km from the beginning of the calculation. If R is preceded by a number other than 5.00, the depth was restrained at that depth part way through the location calculations. When R does not appear, the number was an unrestrained depth, re-adjusted at every iteration during the location. C refers to the Chelsea velocity model (Mitchell and Landisman, 1971).

and said they hadn't felt anything." The felt area for the Cox City earthquake was ~200 km^2.

On September 21–22, 16 earthquakes occurred in central Canadian County. (Such a series of minor earthquakes is sometimes referred to as an earthquake swarm.) Only eight of these earthquakes could be located by using records from three or more seismograph stations (Table 2). Five of the eight earthquakes were reported felt (Table 3). Magnitude values

TABLE 3. — EARTHQUAKES REPORTED FELT IN OKLAHOMA, 2002

Event no.	Date and origin time (UTC)[a]				Nearest city	County	Intensity MM[b]
1658	Jan 03	01	50	15.78	7 km NE of Cox City	Grady	F
1659	Jan 25	10	31	27.55	7 km NW of Courtney	Love	III
1661	Feb 08	16	07	13.84	10 km NE of Lawton	Comanche	VI
1662	Mar 12	10	52	04.6	11 km north of Ringling	Jefferson	II
1665	Mar 14	01	06	29.8	near Cornish	Jefferson	II
1666	Apr 12	09	17	41.3	near Ringling	Jefferson	II
1667	Apr 19	03	49	39.92	10 km west of Grady	Jefferson	II
1668	Apr 19	03	54	03.76	near Addington	Jefferson	I
1669	Apr 30	02	31	04.00	near Cornish	Jefferson	II
1671	May 31	09	57	09.87	near Dibble	McClain	III
1673	Jun 19	12	14	18.04	20 km south of Wheeles	Cimarron	VI
1678	Sep 21	16	58	01.38	7 km SW of El Reno	Canadian	III
1679	Sep 21	22	54	31.65	7 km SW of El Reno	Canadian	II
1684	Sep 22	05	32	55.25	10 km west of Union City	Canadian	II
1685	Sep 22	11	50	56.44	12 km west of Union City	Canadian	II
1686	Sep 22	20	44	36.37	8 km SW of El Reno	Canadian	III
1690	Oct 20	02	18	14.06	near Caney	Atoka	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 six hours.

[b]Modified Mercalli (MM) earthquake-intensity scale (see Table 4). "F" indicates earthquake was reported felt, intensity unknown, generally ≤IV.

ranged from 1.9 (MDUR) to 2.7 (mbLg). The largest earthquake (event no. 1686) produced MM III effects and was felt in Union City and El Reno. The felt areas for all the Canadian County earthquakes were restricted to a few 100 square kilometers.

In 2002, earthquake-magnitude values ranged from a low 1.3 (m3Hz) in Seminole County (event no. 1657) to a high of 3.8 (mbLg) in Comanche County (event no. 1661) (Table 2). Eleven earthquakes were located in Jefferson County. Canadian County experienced 16 earthquakes, but, as already noted, only eight of them were located. Other counties that experienced multiple earthquakes include Atoka (two), Garvin (two), and McClain (four).

CATALOG

For both preliminary and final locations, the catalog of Oklahoma earthquakes is in HTML (World Wide Web) format; one HTML page contains all of the earthquakes that occurred in one year (a single page lists earthquakes for multiple years prior to 1977). In order to assure absolute uniformity, the catalog is stored only in HTML format. One copy is on a ONENet server. (ONENet is the network of the Oklahoma Regents for Higher Education.) This server copy, at the World Wide Web address http://www.okgeosurvey1.gov, is used both for public distribution and for in-house reference. A second (backup) copy is on a Sun SPARC20 workstation at the Observatory in Leonard.

Each event in the catalog is sequentially numbered and arranged according to date and origin time. The numbering system is compatible with the system used by Lawson and Luza (1980–1990, 1993–2002), Lawson and others (1991, 1992), and for the *Earthquake Map of Oklahoma* (Lawson

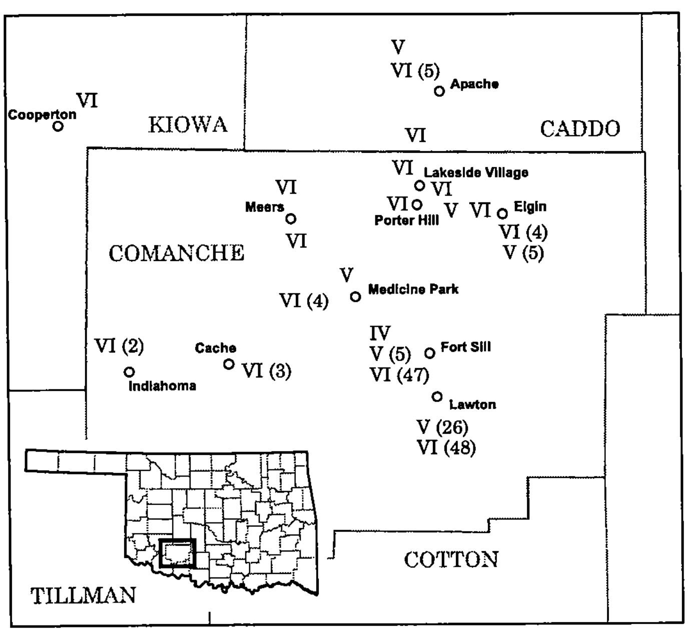

Figure 3. Modified Mercalli (MM) intensity values (Roman numerals) for the February 8 earthquake (event no. 1661) in Comanche County (Tables 2, 3). Numbers in parentheses indicate the number of felt reports for each location. Intensity values by themselves indicate single reports.

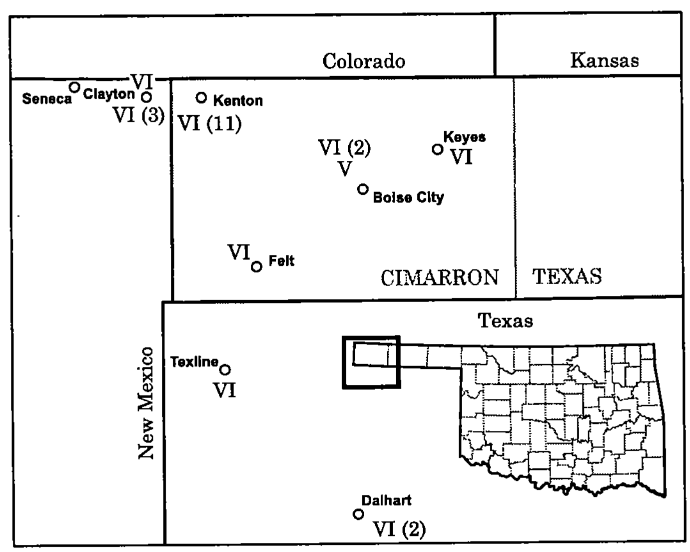

Figure 4. Modified Mercalli (MM) intensity values (Roman numerals) for the June 19 earthquake (event no. 1673) in Cimarron County (Tables 2, 3). Numbers in parentheses indicate the number of felt reports for each location. Intensity values by themselves indicate single reports.

TABLE 4. — MODIFIED MERCALLI (MM) EARTHQUAKE-INTENSITY SCALE (Abridged) (Modified from Wood and Neumann, 1931)

I	Not felt except by a very few under especially favorable circumstances.
II	Felt only by a few persons at rest, especially on upper floors of buildings. Suspended objects may swing.
III	Felt quite noticeably indoors, especially on upper floors of buildings. Automobiles may rock slightly.
IV	During the day felt indoors by many, outdoors by few. At night some awakened. Dishes, doors, windows disturbed. Automobiles rocked noticeably.
V	Felt by nearly everyone, many awakened. Some dishes, windows, etc., broken; unstable objects overturned. Pendulum clocks may stop.
VI	Felt by all; many frightened and run outdoors.
VII	Everybody runs outdoors. Damage negligible in buildings of good design and construction. Shock noticed by persons driving automobiles.
VIII	Damage slight in specially designed structures; considerable in ordinary substantial buildings; great in poorly built structures. Fall of chimneys, stacks, columns. Persons driving automobiles disturbed.
IX	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.

and Luza, 1995b). The sequential event number is not found on the World Wide Web catalog.

The dates and times for the cataloged earthquakes 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 six hours.

Earthquake magnitude is a measurement of energy and is based on data from seismograph records. The magnitude of a local earthquake is determined by taking the logarithm (base 10) of the largest ground motion recorded during the arrival of a seismic-wave type and applying a standard correction for distance to the epicenter. An increase of one unit in the magnitude value corresponds to a tenfold increase in the amplitude of the earthquake waves. There are several different scales used to report magnitude. Table 2 has three magnitude scales, which are mbLg (Nuttli), m3Hz (Nuttli), and MDUR (Lawson). Each magnitude scale was established to accommodate specific criteria, such as the distance from the epicenter, as well as the availability of certain seismic data.

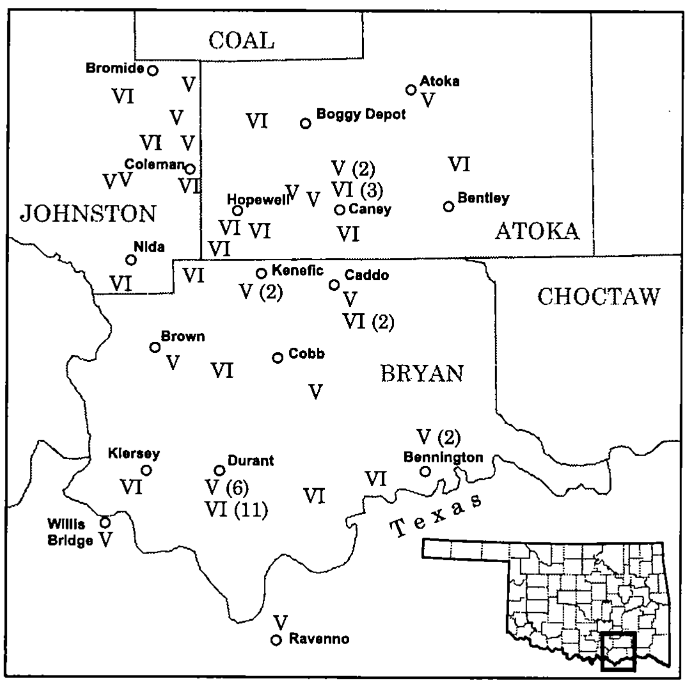

Figure 5. Modified Mercalli (MM) intensity values (Roman numerals) for the October 20 earthquake (event no. 1690) in Atoka County (Tables 2, 3). Numbers in parentheses indicate the number of felt reports for each location. Intensity values by themselves indicate single reports.

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:

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

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

In 1979, St. Louis University (Stauder and others, 1979, p. 28) modified the formulas for m3Hz. The OGS Observatory has used this modification since January 1, 1982. The modified formulas have the advantage of extending the distance range for measurement of m3Hz out to 400 km, but they also have the disadvantage of increasing m3Hz by about 0.12 units compared to the previous formula. Their formulas were given in terms of log(A) but were restricted to wave periods of 0.2–0.5 sec. In order to use log(A/T), we assumed a period of 0.35 sec in converting the formulas for our use. The resulting equations are:

(epicenter 10–100 km from a seismograph)

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

(epicenter 100–200 km from a seismograph)

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

(epicenter 200–400 km from a seismograph)

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

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

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

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

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

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

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

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

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. Since January 1, 1982, the interval from the beginning of any P wave (such as Pg, P*, and/or Pn) to the decrease of the coda to twice the background-noise amplitude has been used.

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 that give the approximate frequency of 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 information necessary to evaluate insurance rates.

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James King and Amie Friend maintain the OGS Observatory at Leonard. Volunteer seismograph-station operators and landowners at various locations in Oklahoma make possible the operation of a statewide seismic network.

This work was funded directly by the Oklahoma Geological Survey. The GSE digital seismic system, provided by the Defense Advanced Research Projects Agency/Nuclear Monitoring Research Office, considerably enhanced the OGS's ability to analyze Oklahoma earthquakes. A borehole seismic system, a joint project with the Lawrence Livermore National Laboratories, was useful in recording Oklahoma earthquakes. The three-component broadband Guralp seismometer in the 864-m borehole and the Guralp data acquisition system were funded by a DARPA-DEPSCoR grant. The Observatory exists because of building and land-purchase gifts from Jersey Production Research Co. (now merged into Exxon) and the Sarkeys Foundation.

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geonews roundup

A first for Norman: its own temblors

By Lauren E. Elkins

NORMAN—Phone calls from concerned residents flooded the Norman Police Department and the Oklahoma Geological Survey on Monday [Dec. 8, 2003] after two earthquakes shook the area.

The first earthquake—measured at 1.7 on the Richter scale—was recorded at 9:50 a.m. at the Oklahoma Geological Survey, geologist Kenneth Luza said.

A more powerful earthquake, measuring 2.0, followed at 1:18 p.m.

Luza said the two earthquakes were the first recorded earthquakes ever to be felt in Norman. The epicenter appeared to be three miles northeast of Cole in McClain County, about seven miles southwest of Norman, Luza said.

Lynette Lobban, who was working at the Fred Jones Jr. Museum of Art on the University of Oklahoma campus, said she felt "a big, sudden jolt" but thought it was related to ongoing construction on the museum's expansion project.

Norman police dispatchers said they received 20 to 30 calls from residents between 1:20 p.m. and 2 p.m.

"They wanted to know what was going on. They felt something, but they didn't know what it was," Lt. Tom Easley said.

Most of the callers were in neighborhoods north of Main Street and west of Interstate 35, Easley said.

"They described what they felt as an explosion," he said.

Easley said no one at the police department felt the earthquakes, but next door at City Hall, employee Tarena Furr said she heard a loud boom and her desk shook.

Oklahoma Natural Gas spokesman Don Sherry said there were no reports of any damage to the company's underground lines.

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5th quake hits Norman

By Lauren E. Elkins

NORMAN—The fifth earthquake in three days shook the area Wednesday afternoon [Dec. 10, 2003] as part of what geologists call an "earthquake swarm."

The earthquake occurred at 1:15 p.m., and measured 2.0 on the Richter scale, said geologist Kenneth Luza of the Oklahoma Geological Survey.

"It just happens this way," Luza said. "It's part of an earthquake swarm, with many small earthquakes over a period of days."

Earthquake activity

Mon., Dec. 8, 9:50 a.m., 1.7 Richter scale
Mon., Dec. 8, 1:18 p.m., 2.0
Wed., Dec. 10, 12:09 a.m., 2.2
Wed., Dec. 10, 12:32 a.m., 2.1
Wed., Dec. 10, 1:15 p.m., 2.0

The first two earthquakes took place Monday, followed by two more early Wednesday.

"I didn't think we'd have as many as we've been having, but they do happen in this state," Luza said. "This is not rare; they do occur."

Luza said a similar swarm occurred in Canadian County last year, with several earthquakes at various intervals over a two- to three-day period.

The epicenter appears to be somewhere near the McClain-Cleveland County line, and Luza said these and any small earthquakes in the near future should not be cause for concern.

"There doesn't seem to be any indication that it will lead to a larger event," he said. "It's just a little readjustment going on in the deep subsurface."

Norman police did not report any calls related to Wednesday's quakes.

Contributing: Staff Writer Jane Glenn Cannon

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For more information about earthquakes in Oklahoma, visit the Oklahoma Geological Survey website at **http://www.ogs.ou.edu/**; click on "Earthquakes," then click on "OGS Earthquake Observatory."

Soil Change

Energy board oversees 5,000th cleanup

By Adam Wilmoth

J. C. Mercer has spent thousands of dollars and countless hours improving his 183-acre property north of Noble, but he has never been fully satisfied.

Despite his effort, Mercer, 84, had to look the other way as he walked past abandoned oil-field equipment that lay dormant since he was in grade school.

"There was so much concrete scattered around, and I couldn't afford to clean it up myself," Mercer said.

Three abandoned oil well sites and damage to the surrounding soil had scarred Mercer's property for about 80 years, but the Oklahoma Energy Resources Board last month cleaned up the eyesore and restored the property to its natural state at no cost to Mercer.

"I was delighted to see it happen," Mercer said. "I couldn't put a price on that."

Funded by voluntary contributions from the state's energy producers, the board cleans up surface damage caused by operators who have gone out of business or cannot be identified. The group celebrated its 10th anniversary last month and will commemorate its 5,000th cleanup today with a ceremony at 1:30 p.m. in the Blue Room of the state Capitol.

"The 5,000th site to me is just one of those meaningful milestones of our industry going pretty far down the road of cleaning up messes created decades ago when there was no regulation about surface damage," Chairman Bob Sullivan said. "As Oklahomans, the producers and royalty owners feel the responsibility to clean up these messes. We've got many more to go, but it's more than a good start."

Improved techniques and the fact that most of the difficult sites have already been restored has allowed the board to

Soil change *(continued)*

increase its pace to about 1,000 restored sites a year, Environmental Committee Chairman Pete Brown said. The average cleanup now takes about two months and costs more than $3,000.

More than 1,000 more sites have already been identified, and the board usually learns of several additional sites every day, Brown said.

Besides cleaning up unsightly abandoned well sites, the board also works to clean up the industry's sometimes-tarnished image.

"What we're doing helps restore public confidence and opens people's minds about the industry," Brown said. "If you're a good neighbor, people will like you and listen to you. If you're perceived as a bad neighbor, they'll turn a deaf ear to you."

The public relations campaign extends far beyond actual site cleanups. While about half of the group's revenue goes to restoration projects, the other half is reserved for education.

The Fossils to Fuel program teaches students in grades three through six basic concepts of how oil and natural gas is formed and used. Petro Active teaches middle school students about the formation and recovery of oil and natural gas and includes experiments that can be performed in the classroom.

Both programs are endorsed by the Oklahoma Education Department, and free training is available for teachers.

"One thing we found when we started looking at science books all over the United States is that the amount of science dedicated to energy is very small even though we can't survive without energy today," Brown said. "We took that void and worked with teachers and industry professionals and developed a curricula where kids can learn and enjoy themselves at the same time."

Public opinion polls paid for by the board show that the group's efforts have been successful, Sullivan said. The polls show that Oklahomans no longer view the industry as polluters, but rather as responsible developers of the state's oil and gas resources, he said.

The effort has apparently worked with Mercer, who is finally pleased with all of his property.

"The oil industry owes the land to clean up behind themselves," he said. "They've made a fortune on it, but they left the land a mess. They made the mess, and they are being responsible to clean it up. I appreciate that."

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For more information on the Oklahoma Energy Resources Board, visit their website at **http://www.oerb.com/**.

INHOFE OUTLINES TAR CREEK PLAN

By Chris Casteel

WASHINGTON—Sen. Jim Inhofe on Thursday [Nov. 20, 2003] released details of a $45 million plan to clean up water, collapsing mines and other hazards in a portion of the Tar Creek Superfund site in northeast Oklahoma.

The plan addresses the perimeter of an environmental mess that stretches for 40 miles in Oklahoma, and promises action in the core area when more legal obstacles are removed.

The document fleshes out a plan announced by Inhofe in the spring to pay the University of Oklahoma and Oklahoma Department of Environmental Quality $45 million over three years to work on the site.

Congress already has approved $2.5 million for the first year, and at least $12.5 million more is expected to be included in spending bills in the next few days.

Though the effects of lead and zinc mining have posed environmental hazards for decades in the northeastern strip known as Tar Creek, a concerted effort by the state's congressional delegation did not materialize until this year.

Former Gov. Frank Keating made it a priority and appointed a task force that made recommendations. Gov. Brad Henry also has been pushing for action and trying to forge the consensus that has been lacking. He was in Washington last week to meet with Oklahoma lawmakers and the head of the Environmental Protection Agency.

Inhofe and Rep. Brad Carson, D-Claremore, have been working all year on the issue, though they are deeply divided over the question of whether people in Picher and Cardin—ground zero of the Tar Creek site—should get federal money to move out voluntarily. Carson has proposed a federal buyout; Inhofe opposes it.

Permission courtesy *The Daily Oklahoman*, as published November 21, 2003.

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For more information on Tar Creek, visit the Oklahoma Department of Environmental Quality's website at **http://www.deq.state.ok.us/**; click on "Tar Creek Information."

Cleanup plan

Tar Creek includes portions of five communities: Picher, Cardin, Quapaw, North Miami, and Commerce. Much of the land is owned by Quapaw Tribe.

Among the goals for the perimeter are:

- Close mine hazards and fill sinkholes;
- Produce detailed maps of undermined areas to help in land use planning;
- Remove chat and use it as fill to close mine shafts and subsidences, covering it with organic matter and revegitating the area;
- Determine the safest and most effective mix of chat in asphalt as a paving material, and pave roads in the site using chat asphalt, focusing first on the Picher and Cardin areas;
- Remove chat from stream channels to improve drainage and water quality and enhance the success of other proposed water quality projects and;
- Build a passive treatment system for the polluted water that seeps from the mines.

Rural water availability explained

Cleveland County proposal draws supply questions from residents

By Ellie Sutter

NORMAN—Residents of unincorporated eastern rural Cleveland County who want to learn more about the establishment of a rural water district are invited to an organizational public meeting at 7 p.m. Thursday [Nov. 20, 2003] at 12 Corners Baptist Church at 156th and Etowah Road in Noble.

Many people in the 140-square-mile area that the district will comprise are concerned that their wells will run dry and that they need to hook on to the district.

However John Harrington, Garber-Wellington Aquifer expert at the Association of Central Oklahoma Governments, said people living in about 90 square miles of the proposed district have no need for water that such a district would supply.

Cleveland County Commissioners Leroy Krohmer, George Skinner and Bill Graves recently approved the creation of the rural water district.

The purpose of Thursday's organizational meeting is to elect a board of directors for the water district and establish by-laws.

Residents of record, who petitioned the commissioners to establish the district, are: Ernest Martin, 17101 Box Road; Richard Hill, 20101 144th; Robert Hendley, 11370 Bryant Road; and Daryl and Brandi Covey, 15151 180th.

Harrington said most residents in the 140-square-mile district have an excellent supply of good well water because it comes from the Garber-Wellington Aquifer.

"But south of about State Highway 39, the nature of the ground water system changes," he said.

Harrington said, "Hill and the Coveys may actually have a problem with groundwater in their area—very little success rate, poor yields. However, Martin and Hendley have plenty of neighbors with wells having yields 10 to 20 gallons per minute."

He said that people in Slaughterville are well into the Garber-Wellington and have a supply of good water available.

Hill and the Coveys, who are not on the aquifer, may have problems with the person drilling their wells, Harrington said.

"When they hire a driller, they need to tell him not to drill into the red," Harrington said, explaining that red water contains minerals.

The driller needs to stop before he hits the red clay, which turns the water red with minerals, or plug off the bottom of the well, Harrington said.

He said a study of the aquifer, which began in 1980, shows no change in the overall level of water in the aquifer, even though this has been a time of growth of the area.

He likened the size of the aquifer to "1,500 Lake Thunderbirds" and added that it is unlikely the availability of water will be a problem in the foreseeable future.

He said if residents in southern Cleveland County are near the river, they can get water from the alluvial sands.

He also noted that it is the responsibility of people who buy property to make it a priority to learn where the aquifer is and what water is available.

Nathan Ellis, assistant division chief of the financial assistance division of the Oklahoma Water Resources Board, said money to build such a rural water district comes from a variety of sources, including state and federal grants, the Indian Health Service, and from fees charged residents who join the district.

Permission courtesy *The Daily Oklahoman*, as published November 15, 2003.

For further information about rural water in Oklahoma, visit the Oklahoma Rural Water Association's website at **http://www.okruralwater.org/**.

For more information on the work that the Association of Central Oklahoma Government is doing on the Garber-Wellington aquifer, visit ACOG's website at **http://acogok.org/**; click on "Programs and Services," then click on "Water Resources Division," then scroll down to "Garber-Wellington Aquifer."

DANGEROUS GROUND — Coal mining's rocky past leaves scars on state

By David Zizzo

STIGLER—Chicken farmer Allen Brewer is no chicken, but he is worried.

Up the hill on his Haskell County land, somewhere in a tangle of vines he leaves as a natural barrier for the unsuspecting, lies the legacy of a reckless past—holes in the ground.

"If anybody falls in there, they're gone," he said.

Brewer's land is part of a swath of eastern Oklahoma pockmarked with entrances—portals, they're called—and air shafts. They're remnants of a once-widespread scramble for what Indians called "the rock that burns." Coal.

They were left by miners who turned the ground beneath an estimated 40,000 acres in 16 counties, including the city of Tulsa, into a Swiss cheese of caverns up to 200 feet across.

"Down underneath, it looks like a town... laid out in streets and blocks," said Jim Dycus, 76, who spent a lifetime surveying mines. "It's amazing how they did this by hand."

Most who sought the soft energy-rich rock left long ago, but their mines—from "doggie holes" carved by a single family to complexes covering several square miles—remain. Flooded and subject to shifting earth and crumbling support columns of coal or timber, those mines, some more than a century old, are giving way.

"We don't have any way to predict where or when these are going to occur," said Mike Sharp, assistant director of the abandoned mine land program for the Oklahoma Conservation Commission.

Collapses in shallower reaches of a mine, up to about 200 feet below the surface, can lead to subsidences on the surface—from slight depressions to sinkholes. Some can crumple houses or turn an above-ground pool into a below-

Dangerous ground *(continued)*

ground pool, both of which happened in the Wilburton area recently.

That's in addition to the danger of portals and air shafts, vertical vents up to 7 feet in diameter with hardly a way to climb out, even if you were to survive a fall to the water or rock at the bottom.

Danger above and below

Mining below ground isn't the only source of problems from Oklahoma's search for coal, or even the source of the most serious problems, experts say. Strip mines have scarred another 30,000 acres on the surface.

"They present the most readily apparent dangers," Sharp said.

Strip mining is the carpet bombing of mineral recovery. Rather than precision tunneling down to and along a vein of coal, strip mining consists of heavy equipment tearing dirt and rock from the land until the target resource is laid bare.

When the coal vein, averaging a few feet thick, is removed, often what's left in a pit is a pile of rock "spoils" on one side and a "high wall" on the other. Approach a high wall from the wrong direction in this rolling terrain, and the sheer drop of 70 feet or more can be a fatal surprise, officials say.

Many old high walls have become partially submerged in ponds that formed in old pits, like the one Henry Roye pointed out north of Stigler, ground zero for defunct mines. This wall, mostly underwater, could swallow any vehicle, he said, such as a school bus that might stray from the gravel road that passes within a few feet.

"It's not as peaceful as it looks," said Roye, emergency coordinator for the Conservation Commission.

Few of these mining relics are, they say.

Vehicles actually have been known to disappear in pit ponds, Roye said, such as a pickup driven one party night decades ago by a drunken school buddy. Roye told of following skid marks across a T-intersection to a pit, where he found his stunned friend floating in 50 feet of water, clinging to a wooden tailgate.

"The pickup was gone, but somehow he got out," said Roye, who's enough of a dead ringer for cowboy actor Glenn Ford that people tail him for autographs when he visits Branson, Mo.

Over the years, numerous people have drowned swimming in the pits, he said. Roye also considers open shafts deadly traps in the underbrush.

"I've walked as close as 30 feet to one and couldn't see it," he said.

In Okmulgee County, a cow didn't see one. The missing animal was found at the bottom of a 90-foot vertical air shaft the landowner, until then, didn't know was there.

Widely known among wary locals, some eastern Oklahoma shafts and pits become the stuff of urban legend, the rural kind. Roye heard so many tales of victims falling into one abyss that he had himself lowered there for a look.

"The neighbors just swore there's a body," Henry said. All he turned up, though, were "rumors stacked on top of rumors."

They "walked away"

An abandoned mine in Poteau claimed a 14-year-old victim. The boy was exploring a shaft when he suffered what old miners call "black damps," suffocation caused by a chemical reaction in which coal strips oxygen from the deadened air.

That tragedy a decade ago led to a Conservation Commission program to identify shafts and high-wall hazards.

All these problems are at least a quarter-century old because on Aug. 3, 1977, things in the mining industry changed.

That's when Congress enacted the Surface Mining Control and Reclamation Act. No longer would mine operators be able to do what they were used to.

"They just pulled their equipment out and walked away," Roye said.

Since 1977, operators have been held responsible for the surface effects of their mining. These days, strip mining companies post thousands of dollars in bond per acre to ensure they replace dirt and plant vegetation.

However, critics say, a bond can't guarantee reclamation if a company goes bankrupt.

"It's kind of like putting a Band-Aid on a cut artery," surveyor Dycus said.

For the coal industry, the law means "underground is cheaper," said Tek Tsegay, technical services manager for the state Department of Mines. In underground mines closed after 1977, only shafts and portals have to be reclaimed, he said.

Officials say the 1977 law and environmental regulations that made low-sulfur Wyoming coal more attractive contributed to one collapse—the coal industry in Oklahoma. At its peak about 1980, Oklahoma had 77 coal operators and 250 coal removal sites. Today, four companies operate one underground mine and eight strip mines.

Since 1977, operators that remain also have been charged for the sins of their forefathers. Thirty-five cents per ton for strip-mined coal and 15 cents a ton for underground-mined coal goes into a fund that's supposed to be used to repair damage from the past.

That has raised at least $1.5 billion more than has been spent by the states that qualify for such aid, Sharp said. But so far, that money has been used to balance the federal budget rather than reclaim abandoned coal mines, he said.

The portion dribbled out to Oklahoma has paid for 120 reclamation projects covering 1,000 acres. Conservation contractors stuff boulders into shafts and portals, sometimes leaving access for bats and snakes that live there. They excavate and refill sinkholes and spread mountains of mining spoils flat enough to build an airport on it, such as in Stigler.

But much more is needed, up to $12 million a year for at least a decade, Sharp said.

These days, the commission lists $90 million in "high priority" places such as chicken farmer Brewer's land—sites in need of immediate reclamation to protect the public. It lists $40 million more in projects presenting less imminent threats.

"We've only scratched the surface," Sharp said.

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OKLAHOMA COAL

- Oklahoma has 8 billion tons of coal in 19 eastern counties, covering 8,000 square miles. Only 1.6 billion tons is economically recoverable.
- Ranked 19th of 32 coal-bearing states in reserves, Oklahoma has the largest deposits west of the Mississippi and east of the Rocky Mountains.
- From 1873 to 2002, Oklahoma produced 282 million tons of coal from underground and surface mines.

. . . .

For more information on the Oklahoma Conservation Commission's Abandoned Mine Land Program, visit the OCC's website at **http://www.okcc.state.ok.us**; click on "Divisions," then click on "Mine Reclamation."

"Boy, that was beautiful stuff"

75 years since oil was hit: Lives were cheap, crude was gold

By Susan Parrott

H. V. Foster was no geologist, but he had a hunch. The oilman thought a smart chance for oil existed if you found jack oak growing near red outcrops of rock.

But three decades of drilling around Oklahoma City returned nothing but disappointment. While boomtowns sprouted across the state in the early 20th century, Oklahoma City was known as dry hole country.

Still, Foster had a hunch. Believing other companies hadn't drilled deep enough, he leased thousands of acres in an area near what is now SE 59 and Bryant. In July 1928, Foster Petroleum Co. partnered with Indian Territory Illuminating Co., boring 6,000 feet into the red earth.

The impossible happened at 3:15 p.m. on Dec. 4, 1928. A geyser of oil filled the sky.

"It seemed that all hell broke loose. Here came the big gas with a roar, and it was accompanied by oil. Boy, that was beautiful stuff," oilfield worker O. A. Huffman said after the blast.

Crude covered roughnecks, automobiles and reporters awaiting the gusher.

"Oil was filling the holes and ran down the short road on the lease like rainwater after a gully washer," Huffman said.

During its first 27 days of open flow, the well produced 110,496 barrels of oil, which sold for $1.56 a barrel. Adjusted for inflation, the oil would bring $1.86 million today.

Foster's hunch brought in the giant Oklahoma City field and the largest drilling war in Oklahoma.

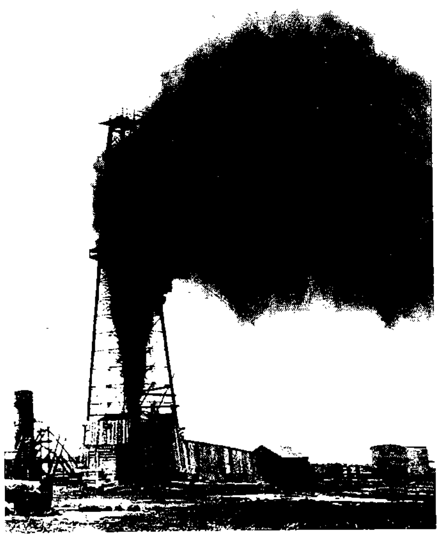

Photo provided by the Oklahoma Historical Society.

The Discovery Well No. 1 of the Oklahoma City oil field blows on Dec. 4, 1928, in southeast Oklahoma City. The Indian Territory Illuminating Oil Co. and Foster Petrolelum Co. drilled the well.

Boomtown

The oil industry started piling into Oklahoma City, grabbing up leases in a stampede for riches.

"Tent cities grew like pigweed in a wet summer," wrote historian William Donahue Ellis in his book "On the Oil Lands."

Lease by lease, drillers advanced northward into populated areas, erecting a forest of derricks, largely unregulated. The oil field was the first in a major Oklahoma city.

"If someone owned a piece of property and had a successful well, the other owners would drill every 50 feet or so along the property line. It allowed them to produce it but in a very wasteful man-

The reward

Average price for a barrel of crude and barrels produced annually in Oklahoma:

- 1900: 75¢, 6,472 barrels
- 1915: 58¢, 97.9 million barrels
- 1928: $1.39, 249.9 million barrels
- 1931: 66¢, 180.6 million barrels
- 1935: $1.02, 185.3 million barrels
- 2002: $24.44, 64.8 million barrels

Who's who

- **Wildcatter:** One who drills wells in the hope of finding gas or oil in territory not known to be a gas or oil field.
- **Roughneck:** A driller's helper and general all-around worker on a drilling rig.
- **Roustabout:** A laborer who assists the foreman in the general work about producing oil wells and around the property of the oil company. The roustabout is a semi-skilled laborer in that he requires considerable training to fit him for his work.

Sources: "Early Oklahoma Oil: A Photographic History," Mid-Continent Oil and Gas Association of Oklahoma and American Gas Association.

Blowout raged 11 days

By Susan Parrott

Wild wells, floods of crude and unbridled bursts of natural gas marked the giant Oklahoma City oil field, begat 75 years ago when the ITIO-Foster No. 1 blew into town.

But the most famous of the gushers came sveral years later. The "Wild Mary Sudnik" raged untamed for 11 days in March 1930, spreading a layer of crude from Oklahoma City to Norman and drawing worldwide media attention.

Historian Bob Blackburn said the pressure blew tools and mud from the hold as if shot from a cannon.

Then came a stream of oil, gas and sand, blowing the traveling block and cable about like toys.

The oil fell in sheets like a cloudburst, coating everything in sight. A hundred men finally capped the well using a special 3,000-pound "bonnet."

No one died in the blast, but the blowout punctuated the perils of drilling in the high-pressure field.

"It was very dangerous and people were being killed all the time," Blackburn said.

Other perils followed the oil play into Oklahoma City. Gamblers, con men and prostitutes brought a lawlessness to parts of the city.

Roughnecks—often robbed of their weekly pay—started carrying guns.

"It was a physical, violent culture that followed the oil patch around," Blackburn said.

But for the wildcatters and lease holders, the potential windfall was worth the risk. "If you were a sharecropper's son, it gave you a chance to get off the farm, "Blackburn said.

"We had this atmosphere of a boomtown here. Money was flowing."

Reprinted with permission as published in *The Daily Oklahoman* November 30, 2003.

ner," said James Caster, a retired University of Central Oklahoma professor.

Soon, the city was covered with derricks, even marching up the Capitol lawns. In East Texas, another bonanza hit, and suddenly the nation found itself with too much oil. The price collapsed, and production dwindled.

Lasting impact

While the oil boom didn't insulate Oklahoma from the Great Depression, it cushioned the blow, said Bob Blackburn, director of the Oklahoma Historical Society.

"In the 1930s, the majority of tax income into the state was gross production," Blackburn said. "Oil built the infrastructure."

Glenn Pool, the Healdton field, the Osage field and the Seminole field had all pushed Oklahoma to the top of the oil-producing states. But the 13,000-acre Oklahoma City field was one of the most productive in the world, yielding 476 million barrels by 1940 and infusing billions into the state economy.

Indeed, some of downtown's most magnificent buildings—the Skirvin Hotel and First National Center—were constructed while other states reeled economically, Blackburn said.

And oil remained visibly evident long after the derricks came down, said Paul Lambert, executive director of the Oklahoma Heritage Association. The oily remnants of bygone gushers clung to the red soil that drew Foster.

"For years, the ground just glistened," Lambert said.

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For more information about the history of oil and gas development in Oklahoma, see "An Enduring Partnership—Oklahoma and the Petroleum Industry," a 21-page booklet available from the Oklahoma Geological Survey (cost is $1.00 plus postage).

Contact OGS Publication Sales Office at (405) 360-2886; fax 405-366-2882; email: ogssales@ou.edu

Limestone plan rocks emotions of community

By Tom Lindley

FITZHUGH—When dark clouds swirling with trouble blew into town in the spring, people scrambled to the new tornado shelter and took comfort behind reinforced concrete.

The peace and tranquillity of this close-knit community again faces an outside threat, but this time there may be no place to hide from the irresistible winds of progress.

More than 100 residents—almost a third of the town—filed into the Baptist church last week, hoping to convince a representative from the Oklahoma Department of Mines that a proposed 200-acre limestone quarry would dig a hole so big in the community's heart that it would stop beating.

For more than six hours, neighbor after neighbor stepped to the microphone to protest the mine. Reason and passion grappled with anger and defiance as people sitting in the pews looked for something to hold on to as they rode the rails of an emotional roller-coaster.

"Anybody can see this is no place for a mine site," said Larry Little, who lives near where the limestone would be mined. "We are rich in the quality of life here, but we can't afford a lawyer to defend us."

A lawyer might be their last hope. John Pugh, the bureau hearing officer who conducted the informal hearing, indicated that the by-the-book permitting process in Oklahoma leaves no room for emotion. It's a process that seldom denies a qualified mine applicant a chance to make a living.

Pugh said that statutorily his agency is not responsible for determining if residents are correct in their predictions that hundreds of heavy-laden trucks would pose a serious threat to school buses and ranchers hauling horse trailers.

Neither would he address predictions that the narrow, blacktop road would quickly be destroyed, forcing taxpayers to ante up to rebuild it.

That would have to be taken up with the State Department of Transportation and Pontotoc County Commissioners, he said.

What if the limestone dust and the blasting noise makes some of the 27 families who live within a mile of the mine sick? Pugh was asked.

That, Pugh said, would have to be addressed by the Department of Environmental Quality, which has jurisdiction over off-site air quality issues.

What about other concerns adjacent property owners have about the safety of their children, homes, livestock and water wells?

That would have to be taken up somewhere else as well, probably in court or with the state Legislature, he said.

The likelihood of being shuffled from one state agency to another, where the full weight of all the concerns will never get measured, frustrated residents, who took it out on Pugh and mining company owner Larry Stewart of Stillwater.

Pugh, who also grew testy as the day wore on, said it may be another 30 days before he can determine if Stewart, who Pugh said has had a good compliance record with the state, has met the criteria to mine limestone within the Fitzhugh city limits.

Stewart said he is only doing what his family has done for nearly 40 years—find rock, crush it and sell it, to enable Oklahoma to grow and prosper.

"I understand what you are feeling, but growth is coming and that will require rock," Stewart said. "Every home will require a foundation and a driveway. I believe it's better to affect 10 families today than 50 families 10 years from now."

The two faults in the earth that met long ago beneath the property leased by Stewart could produce quality limestone for roads and concrete for decades to come. But they also have produced controversy because a mixture of new homes and picturesque ranches, stocked with horses, cattle and strong family values, sit on top of the limestone.

Stewart, trying to alleviate concerns, promised to be a good neighbor and said he didn't intend to bring harm when his exploratory dart landed on tiny Fitzhugh.

Even so, people who live a secluded, quiet country life here suddenly feel like they have been ratted out by a satellite map and a geologist's report, and run over by the stampede for the almighty buck.

"This land, my heritage, is in danger of being destroyed to a point that it will make it unusable and unlivable," said Sharon Phillips, who lives within a mile of the mine site. "But I cannot leave

Limestone plan *(continued)*

the land that I love. The land that was worked by my papa and his mule team. The land that my papa said would be mine one day to make my living and raise my family."

John and Chloe Elliot were born and educated in Fitzhugh and went away to carve out a highly successful living before building a retirement home here 11 years ago.

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"You are messing with our heartstrings," Brenda Cope said.

Darkness was approaching as the church emptied Tuesday. Wearing somber expressions, people clustered in the parking lot to talk about what to do next before going home to feed their cattle and make dinner.

Ominous clouds gathered to the west, and lightning rolled across the sky.

It might be a sign of things to come. Then again, Fitzhugh knows how to ride out a storm.

Reprinted with permission as published in *The Daily Oklahoman* November 9, 2003.

For more information on the Oklahoma Department of Mines, visit their website at **http://www.mines.state.ok.us/**.

Going, going, gone: Legendary property sold

Fabled land changes hands

Most of the auctioned land was purchased by a Vermont company.

By David Zizzo

WAPANUCKA—Tales of outlaws, treasures and local legend were thicker than the scrub oak that tangles these hills.

"I think they've seen Elvis here," one guy in camouflage coveralls said as locals gathered in a clearing last week with people from New Mexico to Vermont.

They were here to buy a piece of the 590 acres being auctioned by Tulsa sisters Ceci and JoAnne Gillespie. Some wanted a spot to fish and hunt deer. Another man said he "just loved land."

When it ended, title to most of this Johnston County property rich with limestone and lore went to an East Coast company. Vermont Stone Co. bid $1,000 an acre for 511 of the 590 acres. Dale Wood, a former Oklahoma City radio personality living in Dallas, paid $725 an acre for the rest of the land that he said he plans to use for investment and "recreational purposes."

The sale means the land changed hands. But interest over its history and its purported history will go on.

The ruins of the Wapanucka Academy, a 19th century American Indian school, are still there. So is the grave site of missionary Mary Greenleaf, on a plot reserved for the Oklahoma Historical Society.

So, too, are the symbols etched on boulders, on cliffs and in caves, and the tales that swirl about them.

Legend has it that outlaw Jesse James and his gang hid in the hills and buried gold, leaving cryptic clues to their location.

Before Pete Truett's grandfather lost his title to an adjacent valley on a bet, the outlaws visited a boarding house run by his grandmother, Truett said while waiting for the auction. "She said they come there and stayed all night and they fed them."

Land's history

- Site of the Wapanucka Academy, a Chickasaw school for girls that operated from 1852 to 1901.
- It was used as a Confederate hospital and jail during the Civil War. It is the site of a memorial for Mary Greenleaf, a missionary from Massachusetts who worked one year at the academy before dying of dysentery.

Legend of the land

- Some claim outlaws Jesse and Frank James hid out here and left buried treasure.
- It's said to be part of millions of dollars in gold gathered by supporters of the Knights of the Golden Circle, a secret group dedicated to reviving the Confederacy.

Tony Nichols, 77, said he remembers digging for loot as a child, finding only a rusted wagon wheel. "There's been more people lost jewelry up there than people have found."

JoAnne Gillespie said she and her sister have had "some really fun times" trying to quarry the land's obvious treasure—limestone—and trying to find its legendary one. But, she said, she's "kind of ready to move on."

Vermont Stone officials said they'd let the sisters oversee treasure hunting on the land, Ceci Gillespie said.

So the search might continue, guided by those who claim they can crack the code they believe outlaws left behind with their loot.

"We'll just follow them around and find it," Ceci Gillespie said.

Reprinted with permission as published in *The Daily Oklahoman* November 3, 2003.

Limestone plan *(continued)*

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new OGS publications

CIRCULAR 108

- Dan T. Boyd, *editor*
- 245 pages
- Paperbound, laminated cover
- $13

Finding and Producing Cherokee Reservoirs in the Southern Midcontinent, 2002 Symposium

This volume contains the proceedings of a two-day workshop held by the OGS in May 2002 in Oklahoma City, cosponsored by the Oklahoma Geological Survey and the National Petroleum Technology Office of the U.S. Department of Energy, to help operators identify practical techniques and appropriate technology used to find new oil and gas fields and increase production from older ones.

Cherokee-age sandstones, granite washes, and coals are some of the most prolific petroleum reservoirs in this area, and they contain reserves that are an important target for exploration. Cherokee reservoirs account for approximately 15% of the gas and more than 50% of the oil produced thus far in Oklahoma. The 15 papers and 9 abstracts in this book address almost every aspect of finding and producing Cherokee reservoirs, from the exploration phase through development drilling, secondary recovery, and enhanced recovery. Information is included on stratigraphic correlation, environment of deposition, log interpretation, well-completion-stimulation, and seismic stratigraphy, with an equal split between material that is field specific and information with a wider regional perspective.

SPECIAL PUBLICATION 2003-1

- Robert O. Fay
- 38 pages
- Paperbound, laminated cover
- $9

Copper, Lead, and Zinc in the Ouachita Mountains in Oklahoma and Adjacent Parts of Arkansas

Copper, lead, and zinc minerals have been mined in the Ouachita Mountains since the early 1800s. The mines and prospects are in and around the Choctaw anticline in the southern Ouachita Mountains, where the rocks are tightly folded and overturned and the faults dip steeply northward. In the course of this investigation, Fay examined about 25 mines and prospects, some of which are in Polk and Sevier Counties, Arkansas, about 4–6 miles east of the Oklahoma border. Many of the prospects are small pits, but some mines were large, with the largest being the Davis Mine in Sevier County, where the vein is 40 feet wide, 208 feet deep, and half a mile long. Most of the mines were closed about 1920 because of bad economics, excessive water, or depleted ore, although some of the mines may still have rich ore in them. The book includes the history of mining, the geology of the area, and ore deposits, specifically focusing on the Carson, Buffalo, and Bellah Districts.

SPECIAL PUBLICATION 2003-2

- Richard D. Andrews
- 87 pages
- Paperbound, laminated cover
- $16

Cromwell Play in Southeastern Oklahoma

The Cromwell play has long been a prolific producer of oil in Oklahoma, and now also is an important source of natural gas. The play extends from the Arkoma Basin of southeastern Oklahoma westward into structural provinces east of the Arbuckle Uplift. This book contains material presented at a recent workshop held in October 2003 in Norman, sponsored by the Oklahoma Geological Survey in cooperation with the Petroleum Technology Transfer Council.

Chapters include material on Cromwell (Morrow)–Springer boundary and clay mineralogy of shale, stratigraphy (including the Arkoma Basin, Ada High, Frank's Graben, and Lawrence Horst Provinces, and the Morrowan in the Ozark Uplift), and a discussion of Cromwell Sandstone in the Arkoma Basin, including petrology. Three cross sections clarify regional correlations, identify unconformities, and document facies changes.

The book also includes in-depth studies of the Scipio NW field and Raiford SE field. The Scipio NW field is about equal distance between McAlester and Henryetta in the southwest corner of McIntosh County. The study area is located near the center of the Cromwell play and Arkoma Basin, and includes four closely spaced but separate gas pools along upthrown fault blocks. The Raiford SE field, also located in south-central McIntosh County, includes a study area with three closely spaced but separate gas pools that produce mainly from the upper Jefferson sandstone, Cromwell Sandstone, and Hunton limestone. The two field are used to illustrate different aspects of Cromwell reservoirs and production.

Circular 108 and Special Publications 2003-1 and 2003-2 can be purchased by mail from the Survey at 100 E. Boyd, Room N-131, Norman, OK 73019; fax 405-325-7069. To mail order, add 20% to the cost for postage, with a minimum of $2 per order.

All OGS publications can be purchased over the counter at the OGS Publication Sales Office, 2020 Industrial Blvd., Norman; phone (405) 360-2886, fax 405-366-2882, e-mail ogssales@ou.edu.

upcoming meetings

APRIL

SPE/DOE 14th Symposium on Improved Oil Recovery, April 17–21, 2004, Tulsa, Oklahoma. Information: Web: http://www.ior2004.org.

4th Annual AAPG/SEG Spring Student Expo, April 22–24, 2004, Norman, Oklahoma. Information: Sue Crites, School of Geology, University of Oklahoma, Norman, OK; (405) 325-8971; e-mail: scrites@ou.edu. Web: http://www.aapg.org/member/student/outlook/2004/01jan/springexpo.cfm.

Second Hydrogen Expo, USA, and the National Hydrogen Association's 15th Annual Conference, April 26–29, 2004, Los Angeles, California. Information: Web: http://www.hydrogenexpo.com and www.hydrogenconference.org.

SEPTEMBER

Geological Society of America, Penrose Conference "Mass Redistribution in Continental Magmatic-Hydrothermal Systems," September 6–11, 2004, Yellowstone National Park and Butte (Fairmont Hot Springs), Montana. Information: Web: http://www.geosociety.org/penrose/.

Houston APPEX, American Association of Petroleum Geologists, Prospect & Property Expo, September 14–16, 2004, Houston, Texas. Information: Michelle Mayfield Gentzen, AAPG, P.O. Box 979, Tulsa, OK 74101; (918) 560-2679; fax 918-560-2684; e-mail: mmayfiel@aapg.org. Web: http://www.aapg.org/meetings/.

Society of Petroleum Engineers, Annual Technical Conference and Convention, September 26–29, 2004, Houston, Texas. Information: SPE, P.O. Box 833836, Richardson, TX 75083; (972)952-9393; fax 972-952-9435; e-mail: spedal@spe.org. Web: http://www.spe.org/.

OCTOBER

OGS Field Symposium: "Stratigraphic and Structural Evolution of the Ouachita Mountains and Arkoma Basin: Applications to Petroleum Exploration," October 26–28, 2004, Poteau, Oklahoma. Information: Neil Suneson, Oklahoma Geological Survey, 100 E. Boyd, Room N-131, Norman, OK 73019; (405) 325-3031 *or* (800) 330-3996; fax 405-325-7069; e-mail: nsuneson@ou.edu. Web: http://www.ogs.ou.edu/.

OGS Workshop

UNCONVENTIONAL ENERGY RESOURCES IN THE SOUTHERN MIDCONTINENT

March 9–10, 2004 ⁂ Oklahoma City

Unconventional energy resources will contribute significantly to the energy supply of the United States in the future. A two-day program co-sponsored by the Oklahoma Geological Survey and the National Energy Technology Laboratory of the U.S. Department of Energy will focus on reservoir characterization, exploration models, successful practices, development, and potential gas yields from unconventional energy resources in the southern Midcontinent. Topics discussed will include coalbed methane, gas shales, and tight gas. Coalbed methane papers will cover Arkansas, Kansas, and Oklahoma. Several papers will discuss the Barnett Shale gas play in the Fort Worth Basin. In addition to the 20 oral papers listed below, there will be three poster presentations and eight exhibits.

- **Targeted Reservoir Characterization of Unconventional Gas: Tight Sand, Coalbed Methane, Deep Gas, and Fracture Gas Shale,** by Carrie L. Decker, *Gas Technology Institute, Houston, Texas*
- **Overview of Unconventional Energy Resources of Oklahoma,** by Brian J. Cardott, *Oklahoma Geological Survey, Norman, Oklahoma*
- **Reversing the Trend: The Impact of Unconventional Energy Development on Drilling Activity and Production in Oklahoma,** by James O. Puckette, *Oklahoma State University, Stillwater, Oklahoma*
- **Interaction of Gas, Organic Solids, and Water in Paleozoic Basins: Implication for Accumulation of CBM, Shale Gas, and Tight Gas,** by Alton A. Brown, *Consultant, Richardson, Texas*
- **Characteristics of Coalbed Methane and Shale Gas: Similarities, Differences, and Overlooked Resources,** by Andrew R. Scott, *Altuda Geological Consulting, San Antonio, Texas*
- **Reservoir Characterization of Coals and Carbonaceous Shales in the Western Region of the Pennsylvanian-Age Interior Coal Province,** by Steven A. Tedesco, *Atoka Geochemical Services Corporation, Englewood, Colorado*
- **The Barnett Shale: An Unconventional Gas Play in the Fort Worth Basin—Now the Largest Gas Field in the State of Texas,** by Jeffrey D. Hall, *Devon Energy Corporation, Oklahoma City, Oklahoma*
- **The Barnett Shale Play, Fort Worth Basin,** by Kent A. Bowker, *Star of Texas Energy Services, Inc., The Woodlands, Texas*
- **Assessment of the Gas Potential and Yields from Fractured Shales: The Barnett Shale Model,** by Daniel M. Jarvie, *Humble Instruments & Services, Inc., Humble, Texas*
- **Facies Distribution and Petroleum Potential of Woodford Shale in the Southern Midcontinent, USA,** by John B. Comer, *Indiana Geological Survey, Bloomington, Indiana*
- **New Technologies for the Exploitation of Tight Gas in Pennsylvanian and Mississippian Reservoirs in the Northwestern Shelf of the Anadarko Basin,** by E. L. Ames III, *Ames Energy Consultants, San Antonio, Texas*
- **Coalbed-Methane Development in Kansas,** by Timothy R. Carr, K. David Newell, Troy A. Johnson, W. Matthew Brown, and Jonathan P. Lange, *Kansas Geological Survey, Lawrence, Kansas*
- **Natural Gas Potential of Arkansas Coals,** by William L. Prior, *Arkansas Geological Commission, Little Rock, Arkansas*
- **Coalbed-Methane Activity in Oklahoma, 2004 Update,** by Brian J. Cardott, *Oklahoma Geological Survey, Norman, Oklahoma*
- **Comparison of Reservoir Properties from Cooperative Research Core Holes in the Western Interior Basin,** by Timothy Pratt and Chris Hoffman, *TICORA Geosciences, Inc., Arvada, Colorado*
- **Coalbed-Methane Potential in Osage County, Oklahoma,** by John F. Sinclair, *Amvest Oil & Gas, Charlottesville, Virginia*
- **Vertical CBM Wells in the Arkoma Basin: Methods and Economics,** by John H. Wendell, Jr., *Wendell Consulting LLC, Fort Worth, Texas*
- **Using Traditional Completion Practices to Optimize Horizontal CBM Wells in the Hartshorne Coal, Arkoma Basin, Oklahoma,** by Brian D.Weatherl, *Source Rock Energy Partners, LLC, Tulsa, Oklahoma*
- **Horizontal Drilling the Lower Hartshorne Coal, Arkoma Basin, Oklahoma: Techniques and Results,** by Curtis B. Matthews, *El Paso Production Company, Houston, Texas*

REGISTRATION INFORMATION

The fee for advance registration (*by March 1*) is $65 and includes lunches and a copy of the proceedings; late and on-site registration is $75. Students rates are available.

For more information, contact Brian Cardott (email: bcardott@ou.edu), Oklahoma Geological Survey, 100 E. Boyd, Room N-131, Norman, OK 73019; phone (405) 325-3031 or (800) 330-3996. For registration forms, contact Tammie Creel (tcreel@ou.edu) at the same address and phone numbers.

AAPG Annual Convention

Dallas, Texas

April 18–21, 2004

Welome to Dallas! This year's theme, "Embrace the Future—Celebrate the Past" represents changes our industry has experienced. In the past, Dallas was the birthplace of many major oil companies and located in proximity to numerous world-class oil and gas field discoveries. More recently, the industry landscape has changed—most of the major companies have either merged with others or moved to other locations. Our city has redefined itself as the land of independents, with the vision to become the new center of industry leaders.

The Technical Committee has organized the following themes for your continuing educational benefit: Petroleum Risk and Strategy; Exploration and Exploitation; Environmental Issues; Advances and Applications in Technology; Revitalizing Reservoirs; Structure and Tectonics; Sedimentary Geology; Petroleum Systems, Geochemistry and Basin Modeling; and Education. New to this year's group of themes is that of Education, an element which received much attention from the entire Technical Committee. Our industry has had difficulties as of late encouraging the younger generation to consider a career in the petroleum industry. It is the hope of the Committee that the addition of the Education theme will highlight this issue and focus on a framework for positive change.

Dallas has undergone many exciting changes since we last hosted the annual meeting seven years ago—a new light rail system has been constructed to provide fast and efficient public transport, the arts district boasts the addition of the "Nasher Sculpture Center," and our city has become even more cosmopolitan with the addition of numerous shops and restaurants that offer many international cuisines.

So don't be shy—plan to attend the 2004 AAPG Annual Convention, another great opportunity to stimulate the mind, embrace the future and convene with friends from your past.

Terence G. O'Hare
General Chair

Convention Agenda

Technical Program

Monday, April 19

Forum: Delivering on Our Promises: Managing E&P in the 21st Century
Evolution of Deep Water Deposits: Refining the Lowstand Model
North American Provinces: USA, Mexico, Canada—Onshore
Hydrothermally Altered Carbonate Reservoirs: Models and Case Studies
Sea Level Change, Past Climates, and the Restructuring of Shallow Marine Communities
Gas Hydrate Exploitation, Sediment Strength, and Slope Instability Along Continental Margins
Forum: Technical, Business, and Ethical Challenges for Independents and Consultants
Forum: Petroleum Asset Risk Management
Incorporating Structural and Stratigraphic Heterogeneity into Static and Dynamic Reservoir Models
From Source to Sink: Sediment Production, Transport, and Deposition
Unconventional Gas
Basin Modeling: Framework to Fluids
Forum: Teaching Earth Sciences K–12 and Public Outreach
Contraction and Inversion: Processes and Provinces

Tuesday, April 20

Forum: Recent Discovery and Development Case Histories
Forum: Business Strategies for Exploration Evaluation: Onshore North America
Clastic Facies Models Revisited
Geochemical Exploration for Oil and Gas
E&P Environmental Issues and Best Management Practices: Impacts on Water, Soil, and Ecosystems
Characterization and Modeling of Fractured Reservoirs
Structural Styles Influenced by Shale and Salt
Use of Outcrop Analogs in Reservoir Characterization and Modeling
Forum: The Future of Global Energy: Technical, Environmental, Economic, and Policy Issues
CO_2 Sequestration
Ground Water Issues: Resource, Exploration, Exploitation, and Remediation
New Developments in Stratigraphy: Sequence, Cyclo-, Allo-, and Beyond
Geological Uncertainty in Reservoir Modeling and Prediction

Wednesday, April 21

Forum: Climate Change: Sense and Non-Sense in Our Great Geophysical Experiment
The Role of Climate in a Sequence Stratigraphic Framework
Dynamic Trapping: Fractures, Faults, and Fluid Flow
Exploration Above, Below, and Adjacent to Salt
Advancements in Pore Pressure Prediction Techniques and Applications
Deltas Revisited
Carbonate Diagenesis: Old Foundations and New Paradigms
Deep- and Ultra-Deepwater Provinces
Sequence Stratigraphy and Facies Architecture of Shoreline and Shelf Systems
Re-Examining Structural Models: Geometric, Kinematic, and Mechanical
Stress Characterization and Applications from Bore-Hole to Basin-Scale

Exploration in Mobile Shale Basins
Rock Properties and Their Seismic Expression from the Pore Scale to the Seismic Scale
Asia, Siberia, and South Pacific
Africa, Middle East, Europe, Caspian and Black Sea Region

Short Courses

Pre-Convention

Geochemical Exploration for Oil and Gas—Strategies for Desktop Mapping: More Bang for the Buck from Your Well Data, *April 17*
Rocks to Models: An Introduction to 3-D Reservoir Characterization and Modeling, *April 17–18*
3-D Laser Scanning and Virtual Photorealistic Outcrops: Acquisition, Visualization, and Analysis, *April 17–18*
Reservoir Engineering for Petroleum Geologists, *April 17–18*
Untangle the Web! Federal Environmental Regulations: Oil and Gas Operations from Surface to Subsurface, *April 17*
Spatial Analysis: Uncertainty and Risk, *April 17*
Preparing for National Geology Exams, *April 17*
Advances in Coalbed Methane Exploration and Development: A Review of Coalbed Methane Potential and Opportunities in North America, *April 18*
Siltstones, Mudstones, and Shales: Depositional Processes and Reservoir Characteristics, *April 17*
Recognizing Continental Trace Fossils in Outcrops and Core, *April 17–18*
Sequence Stratigraphy for Graduate Students, *April 17–18*

Post-Convention

E&P Methods and Technologies: Selection and Applications, *April 22– 24*
Understanding the Nature of Seismic Data for Geologists Who Have Inherited a 3-D Survey, *April 22–23*

Field Trips

Pre-Convention

Carbonate Deformation: Outcrop Analogs for Fractured Reservoirs, *April 16–18*
Modern Clastic Depositional Environments, Barrier-Island Systems, Mustang Island, Port Aransas, Texas, *April 16–18*
Dinosaur Tracks in the Cretaceous Glen Rose Formation of Central Texas, *April 18*
Pennsylvanian Adventures in Palo Pinto County: Sedimentology and Structure of Terrestrial to Shallow Marine Outcrop Reservoir Analogs, Pennsylvanian Mingus Formation, Mineral Wells, Texas, *April 17*
Structure and Stratigraphy of the Arbuckle Mountains, Ardmore Basin, and Criner Hills, Southern Oklahoma, *April 17*

Post-Convention

Petroleum Systems: Ardmore Basin and Arbuckle Mountains, *April 22–23*
Overview of Coal and Coalbed Methane in the Arkoma Basin, Eastern Oklahoma, *April 21–22*
Fluvial-Deltaic-Submarine Fan Systems: Architecture and Reservoir Characteristics, Arkansas, *April 21–24*
Imaging and Visualization of Reservoir Analog Outcrops Field Trip and Workshop, *April 21–25*
Applied Sequence Stratigraphy: Lessons Learned from the Triassic Dockum Group, Palo Duro Canyon Area, *April 22–23*

For more information, contact:
AAPG Convention Department, P.O. Box 979, Tulsa, OK 74101; phone (800) 364-2274 *or* (918) 560-2679; fax 800-281-2283 *or* 918-560-2684; e-mail: convene@aapg.org
World Wide Web: www.aapg.org/meetings/dallas04
Preregistration deadline: March 17, 2004

Dodrill Museum Opens in Cushing

THE DODRILL MUSEUM OF MINERALS AND FOSSILS opened on March 1, 2001, in Cushing, Oklahoma.

Founded by Richard and Melba Dodrill, the museum houses over 10,000 specimens collected over a period of 50 years. A wide variety of geological materials are displayed, including meteorites, fluorescent minerals, gemstones, petrified wood, and a large number of fossils. Trilobites, crinoids, and mammoth bones are just some of the fossils on exhibit. The museum has a large collection of Native American artifacts and early-day Oklahoma memorabilia.

The museum is open for walk-in visitors; however, 45-minute tours can be scheduled in advance. Tours are available for school, church, civic, and senior-citizen groups. In addition, the Dodrills also are available for public presentations and demonstrations. The museum has a library with books and videos on dinosaurs, fossils, rocks, minerals, jewelry-making, faceting, and related topics.

There is no charge to visit the museum, but donations are welcome.

The Dodrill Museum

Open 10 a.m. to 4:00 p.m.
Monday through Saturday

123 S. Cleveland
Cushing, Oklahoma
(918) 225-0662

Mailing address:
P.O. Box 1308
Cushing, OK 74023

notes on new publications

These publications can be obtained from the U.S. Geological Survey, Water Resources Division, 202 N.W. 66th St., Bldg. 7, Oklahoma City, OK 73116; phone (405) 843-7570; fax 405-843-7712. A limited number of copies are available free of charge. Most are also available on-line at http://ok.water.usgs.gov/; click on "On-Line Bibliography."

Assessment and Comparison of 1976–77 and 2002 Water Quality in Mineshafts in the Picher Mining District, Northeastern Oklahoma and Southeastern Kansas

USGS Water-Resources Investigations Report 03-4248

The Picher mining district was the site of lead and zinc mining from about 1900 to the mid-1970s. This 64-page USGS report, written by Kelli L. DeHay and prepared in cooperation with the Oklahoma Department of Environment Quality, assesses water quality in abandoned mineshafts in 2002 and compares water quality in 2002 to water quality in 1976–77 to determine how the water quality has changed with time. Seven abandoned mineshafts at selected depths were sampled for analysis of water properties and dissolved metals to compare to past water-quality data.

Order WRI 03-4248 or access online at http://water.usgs.gov/pubs/wri/wri034248/.

Aquifer Characteristics, Water Availability, and Water Quality of the Quaternary Aquifer, Osage County, Northeastern Oklahoma, 2001–2002

USGS Water-Resources Investigations Report 03-4235

Additional sources of water are needed on the Osage Reservation for future growth and development. The Quaternary aquifer along the Arkansas River may represent a substantial water resource, but limited amounts of hydrogeologic data were available for the aquifer. Prepared in cooperation with the Osage Tribal Council and Bureau of Indian Affairs, this 40-page USGS report presents the measured sediment thickness, saturated thickness, sediment grain-size, net sand, and calculated hydraulic conductivity and transmissivity, as well as potential water availability for the Quaternary aquifer in Osage County, based on data collected in 2001–2002. Summary statistics for aquifer characteristics and water-quality data are included. Shana L. Mashburn, Caleb C. Cope, and Marvin M. Abbott are the authors.

Order WRI 03-4235 or access online at http://water.usgs.gov/pubs/wri/wri034235/.

The Norman Landfill Environmental Research Site: What Happens to the Waste in Landfills?

USGS Fact Sheet FS-040-03

Research at the Norman Landfill Environmental Research Site has shown that chemicals leaching from old unlined landfills are contaminating ground water, but that some of the contaminant concentrations are being reduced by natural attenuation. Modern landfills are designed to minimize contamination of ground water, but they eventually may leak contaminants into the environment. This 4-page USGS fact sheet by Scott C. Christenson and Isabelle M. Cozzarelli explains how research results from the Norman Landfill will be useful to scientists and regulators trying to determine the effects of landfill leachate on the environment.

Order FS-040-03 or access online at http://water.usgs.gov/pubs/fs/fs-040-03/.

Digital Atlas of Lake Texoma

USGS Open-File Report 02-428

The U.S. Environmental Protection Agency, U.S. Geological Survey, and U.S. Army Corps of Engineers worked together to create this digital atlas of Lake Texoma. The CD contains 29 digital map sets covering Cooke and Gryason Counties in Texas, and Bryan, Carter, Johnston, Love, Marshall, Murray, and Pontotoc Counties in Oklahoma. Data sets in this report were compiled by Jason R. Masoner, David S. Burden, and Guy W. Sewell for use in a specific project, but the data may be of value to other interested parties. The CD includes ArcExplorer Version 2, which can be used to display and query GIS data sets. ArcExplorer runs under the Microsoft Windows 95, 98, NT, 2000, operating systems.

Order OFR 02-428.

Surface-Water Quality Assessment of the North Fork Red River Basin Upstream from Lake Altus, Oklahoma, 2002

USGS Open-File Report 03-362

Elevated salinity in the North Fork Red River is a major concern of the Bureau of Reclamation W. C. Austin Project at Lake Altus. Agricultural practices, petroleum production, and natural dissolution of salt-bearing bedrock have the potential to influence the quality of nearby surface water. The USGS, in cooperation with the U.S. Bureau of Reclamation, sampled stream discharge and water chemistry at 19 stations on the North Fork Red River and tributaries during July 8–11, 2002. The concentration of dissolved solids, especially sulfate and chloride, generally increases downstream as the river passes over salt-bearing rocks of Permian age. This 23-page report by S. Jerrod Smith, Martin L. Schneider, Jason R. Masoner, and Robert L. Blazs presents data from a surface-water quality assessment that will be used to determine the ground-water and surface-water interaction in the North Fork Red River upstream from Lake Altus.

Order OFR 03-362 or access online at http://water.usgs.gov/pubs/of/2003/ofr03362/.

Changes in Streamflow and Summary of Major-Ion Chemistry and Loads in the North Fork Red River Basin Upstream from Lake Altus, Northwestern Texas and Western Oklahoma, 1945–1999

USGS Water-Resources Investigations Report 03-4086

The quality and quantity of surface water are major concerns at Lake Altus, and water-resource managers and consumers need historical information to make informed decisions about future development. This 36-page USGS report by S. Jerrod Smith and Kenneth L. Wahl, prepared in cooperation with the Bureau of Reclamation, summarizes a study of historic streamflow conditions and surface-water quality in the North Fork Red River basin upstream from Lake Altus.

Order WRI 03-4086 or access online at http://water.usgs.gov/pubs/wri/wri034086/.

Phosphorus Concentrations, Loads, and Yields in the Illinois River Basin, Arkansas and Oklahoma, 1997–2001

USGS Water-Resources Investigations Report 03-4168

The Illinois River and tributaries—Flint Creek and the Baron Fork—are designated scenic rivers in Oklahoma. Recent phosphorus increases in streams in the basin have resulted in the growth of excess algae, which have limited the aesthetic benefits of water bodies in the basin, especially the Illinois River and Lake Tenkiller. Data from water-quality samples from 1997 to 2001 were used to summarize phosphorus concentrations and estimate phosphorus load, yields, and flow-weighted concentrations in the Illinois River basin and tributaries. Phosphorus concentrations are compared among stations in the Illinois River basin to those measued at relatively undeveloped basins of the United States, and to those measured at all USGS National Water-Quality Assessment program stations. Prepared in cooperation with the Oklahoma Scenic Rivers Commission and the Oklahoma Water Resources Board, this 39-page report was written by Barbara E. Pickup, William J. Andrews, Brian E. Haggard, and W. Reed Green.

Order WRI 03-4168 or access online at http://water.usgs.gov/pubs/wri/wri034168/.

Comparison of Irrigation Water Use Estimates Calculated from Remotely Sensed Irrigated Acres and State Reported Irrigated Acres in the Lake Altus Drainage Basin, Oklahoma and Texas, 2000 Growing Season

USGS Water-Resources Investigations Report 03-4155

Increased demand for water in the Lake Altus drainage basin requires more accurate estimates of water use for irrigation. Agriculture is the primary land use in the drainage basin. Written by Jason R. Masoner, Carol S. Mladinich, Alexandria M. Konduris, and S. Jerrod Smith, this 38-page USGS report, prepared in cooperation with the U.S. Bureau of Reclamation, presents the techniques and results of an effort to map irrigated crop acres in the Lake Altus drainage basin using satellite imagery and remote-sensing techniques, and compare irrigation water-use estimates calculated from the remotely sensed irrigated acres with those calculated from State-reported irrigated crop acres for the 2000 growing season.

Order WRI 03-4155 or access online at http://water.usgs.gov/pubs/wri/wri034155/.

Oklahoma abstracts

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

U.S. DOE–Sponsored Development Case Study of a Karsted Carbonate "Island" Hydrocarbon Reservoir: West Carney Hunton Field, Lincoln and Logan Counties, Oklahoma

JAMES R. DERBY, Consulting Geologist, Tulsa, OK; *JASON C. ANDREWS* and *JOE PODPECHAN*, Independent Geologists, Tulsa, OK; and *SANDEEP RAMAKRISHNA*, University of Tulsa, Tulsa, OK

The West Carney Hunton Field (WCHF) produces oil and gas from the Silurian Hunton Group, a carbonate unit lying between the Ordovician Sylvan Shale below and the Upper Devonian Woodford Shale above. The field is unique in its manner of production; a typical well initially appears uneconomical in that it produces very large quantities of water, with some hydrocarbons. Reservoir rock in the field can best be described as a heterogeneous system composed of an erratic distribution of "high" and "low" permeability carbonates with varying amounts of porosity. The field is made commercial only by significantly dropping reservoir pressure, which allows hydrocarbons stored in the "low" permeability component of the reservoir to flow into the "high" permeability component where it can be efficiently produced. This is accomplished by pumping very large quantities of water; hundreds to in some cases thousands of barrels a day. Within days to weeks the quantity of hydrocarbons produced increases while the quantity of water produced decreases, ultimately resulting in a profitable well. Field development and production history is complicated by an unusual distribution of reservoir quality dolomite and limestone across the field. The recent trend of operators in the field is to drill horizontally, increasing the quantity of "good" reservoir rock intersected by the borehole. Distribution of porosity types, lithologies, and production is best understood by a model for two distinctly different reservoirs in the same stratigraphic horizon and of slightly different geological ages.

Reprinted as published in the American Association of Petroleum Geologists *2003 Annual Convention Official Program*, v. 12, p. A41.

The Central Oklahoma Carney District: A Unique Hunton Oil and Gas Play

ZUHAIR AL-SHAIEB and *KENNETH J. RECHLIN*, Oklahoma State University, Stillwater, OK; and *DAVID CHERNICKY*, New Dominion LLC, Tulsa, OK

The Ordovician–Devonian Hunton Group was deposited in a shallow epicontinental sea during a period of relatively slow subsidence. Hydrocarbon reservoirs in the Carney District represent a lagoonal facies and are rimmed by an inter-supratidal facies which were deposited in a ramp environment. This particular setting has not been identified in other Hunton Group reservoirs of the Anadarko Basin. Reservoir characterization methods were specifically designed for the various reservoir zones identified.

The subtidal/lagoonal facies comprises one of the two facies present in the immediate Carney area and is stratigraphically equivalent to the Silurian Cochrane Formation and possibly the lowermost Henryhouse Formation. This low-energy facies is mainly composed of wackestone to packstone with the major biota including brachiopods and tabulate corals. The brachiopod beds are primarily biostrome type deposits, whereas the tabulate corals are likely fragments of a patch reef associated with the brachiopod biostrome. The reservoir interval commonly contains shelter porosity associated with brachiopod beds and intragranular porosity associated with the tabulate corals. Vugular porosity also developed with these reservoirs as a result of fluid migration during karstification.

The dolomitized lithofacies occurs in an intertidal to supratidal environment and is characterized by vertical burrowing, chicken-wire structures, and algal laminations. This zone is most often present in the Silurian Clarita Formation of the Hunton Group. Reservoirs of this type exhibit relatively high porosity and permeability. Porosity is mainly intercrystalline (sucrosic) and vugular in the dolomitic facies. The stratigraphic framework was established utilizing electro-facies derived from wire-line logs and conodont biostratigraphy.

Reprinted as published in the American Association of Petroleum Geologists *2003 Annual Convention Official Program*, v. 12, p. A4.

Proportional Integrated Evaluation: A Technique for Evaluating Multiple, Deltaic, Red Fork Sands in Competitive Reservoirs

ROBERT F. EHINGER, Consulting Geologist, Oklahoma City, OK

Increased development drilling in multiple-zone Red Fork reservoirs has led to 12+ gas wells per section in some Custer and Roger Mills fields. Geologic and reserve evaluations become more difficult and time intensive as the newer wells complicate two of the parameters that are used in volumetric calculations. These are the current reservoir pressure and the realistic drainage area. Statistically, a Red Fork reservoir that contains a total of six individual sands with an average of three sands per well, would require 20 maps to define all the possible sand unit combinations. To improve the overall evaluation of these complex reservoirs, one must incorporate other parameters into the study. These would include the character of the HC shows, the magnitude of the drilling breaks, detailed S.P., and G.R. log responses plus an estimation of the pressure and reserve depletion from the older, offsetting wells.

The "Proportional Integrated Evaluation" approach incorporates some relatively simple graphic techniques to faciliate a better understanding of the overall reservoir. This semi-quanti-

tative technique does not replace conventional isopach mapping, but is a correlary to the more conventional methods.

Reprinted as published in the American Association of Petroleum Geologists *2003 Mid-Continent Section Meeting Official Program Book*, p. 30.

Cherokee Basin Filling History

RICHARD D. FRITZ, American Association of Petroleum Geologists, Tulsa, OK; *EDWARD A. BEAUMONT*, TriOks Exploration, LLC; and *LARRY D. GERKEN*, Newfield Exploration, Tulsa, OK

The Middle Pennsylvanian Red Fork Sandstone formed as a result of progradation across eastern Kansas and most of Oklahoma. It is one of several transgressive-regressive sequences (cyclothems) developed within the Desmoinesian "Cherokee" Group. Sea-level changes together with varying subsidence were dominant factors controlling the general stratigraphic (correlative) characteristics of the Red Fork interval. Progradation was episodic with sand deposition in the more active part of the basin during lower sea-level stands and valley-fill deposition in the more stable areas during sea-level rises.

The Red Fork was correlated, subdivided and mapped using data from more than 27,000 wells. Maps of Red Fork sand trends reveal a fluvial-deltaic complex covering most of Oklahoma. The Red Fork consists primarily of undifferentiated alluvial-valley and plain (fluvial) bodies in the northernmost part of Oklahoma, fluvial-deltaic bodies in most of the remaining parts of shelf area and off-shelf submarine-fan and slope-basinal floor complexes within the deeper part of the Anadarko Basin. The basinal facies can also be interpreted as low-stand deltaic deposits.

The Red Fork appears to represent one Vail-type third-order sequence. It can be divided into at least three parasequences which for the purpose of this study are called upper, middle and lower. Each parasequence represents a transgressive-regressive episode often separated by thin regional limestones or shale markers. Correlation of these parasequences is relatively easy from the lower shelf to the basin, and more difficult on the upper shelf.

The provenance for the Red Fork was most likely an extensive drainage system to the north and northeast of Oklahoma. This drainage system probably extended as far as the Canadian Shield or even Greenland and appears to be subparallel to the Midcontinent Rift. A secondary source for the Red Fork was the Wichita–Amarillo Mountains in the south.

Much of the oil and gas has been trapped in stratigraphic traps, and a significant amount of oil is in channel sandstones and trends at high angles to the structural grain. The Cherokita–Wakita Trend, South Thomas Field, East Clinton Field and Strong City Field represent excellent examples of facies and reservoir development controlled by facies distribution and related diagenesis.

Reprinted as published in the American Association of Petroleum Geologists *2003 Mid-Continent Section Meeting Official Program Book*, p. 31–32.

Skinner Sandstone: Depositional History, Reservoir Distribution and Sequence Stratigraphy

JIM PUCKETTE, Oklahoma State University, Stillwater, OK; and *LARRY GERKEN*, Newfield Exploration, Tulsa, OK

The Skinner Sandstone interval (Middle Pennsylvanian, Desmoinesian) contains two important oil and gas producing reservoirs that represent two major depositional cycles in the Cabaniss Subgroup of the "Cherokee Group." The lower cycle contains the Lower Skinner Sandstone, a major producing reservoir on the NE Oklahoma Platform. The upper cycle contains the Upper Skinner Sandstone, a significant producer on the platform and in the Anadarko basin. Both cycles represent progradational sequences whose primary E–W sand distribution trends are markedly different than N–S trends of the older "Cherokee" Red Fork and Bartlesville sands. The shift in the Skinner distribution pattern was likely a response to changing accommodation space as a result of Red Fork deposition and regional tectonics.

Westerly progradation of the Lower Skinner was limited by the Nemaha Uplift. Minor extension of the fluvial-deltaic complex beyond the uplift occurs where the system prograded beyond the southern end. By Upper Skinner time, the effect of the Nemaha Uplift was reduced and the Upper Skinner fluvial-deltaic system extended across the ridge in northern Oklahoma. However, major progradation occurred to the south where the system skirted the southern end of the Nemaha and extended westward into the Anadarko basin.

The skinner appears to represent a third-order sequence. The two major cycles consist of lowstand fluvial channels and incised valley fills, transgressive coal, limestones and dark shales and highstand deltas. Much of the oil and gas is trapped in deltaic and marginal-marine sandstones, but the highest per well reserves are from incised valley fill reservoirs.

Reprinted as published in the American Association of Petroleum Geologists *2003 Mid-Continent Section Meeting Official Program Book*, p. 40.

Stratigraphy, Timing and Rock Properties of Lower Skinner Valley Fill Sandstones

WILLIAM AARON SIEMERS and *JAMES PUCKETTE*, Oklahoma State University, Stillwater, OK

High-resolution stratigraphy based on core and wireline logs was used to establish the timing of deposition and boundaries of the Pennsylvanian Lower Skinner valley fill sandstone. This sandstone produces large volumes of oil and gas from traps that combine two key components: porous reservoir and anticlinal folding. Lower Skinner valleys formed in response to a drop in sea level that exposed much of the NE Oklahoma Platform to erosion by streams that incised underlying strata. The resulting valleys, which form narrow, linear trends, filled with sediment during this lowstand or the subsequent transgression.

Lower Skinner valleys that eroded through underlying "Skinner" highstand deltaic and marginal marine strata resulted in the juxtaposition of fluvial Lower Skinner sandstone on the partially eroded Pink Limestone marker. In some cases, incision removed the Pink Limestone, and Skinner valley fill sediments were deposited directly on Red Fork strata. When valley fill sandstone directly overlies the Red Fork Sandstone, identifying the contact with confidence is difficult. Core derived data, including sedimentary structures were used to determine the position of the Skinner–Red Fork contact, whereas detailed correlation between wells outside the valleys was used to determine the "Skinner" interval removed by erosion, the relative timing of incision, and its stratigraphic position.

Porosity in valley fill sandstones is mostly secondary. Three distinct pore sizes (micro, small and large) were identified. Microporosity is intragranular or associated with pore-filling authigenic clay. Small- and large-sized pores reflect partial to complete dissolution of detrital feldspar grains and metamorphic rock fragments.

Reprinted as published in the American Association of Petroleum Geologists *2003 Mid-Continent Section Meeting Official Program Book*, p. 43.

When Seismic is Not Enough: Improving Success by Integrating High-Resolution Surface Geochemical Data with Seismic Data

DANIEL HITZMAN, DIETMAR SCHUMACHER, and *BROOKS ROUNTREE*, Geo-Microbial Technologies, Inc., Ochelata, OK

Seismic data are unsurpassed for imaging trap and reservoir geometry, however, in many geological settings seismic data yield no information about whether a trap is charged with hydrocarbons. In other settings, the quality of seismic data is poor due to unfavorable geology or surface conditions. For this presentation we will review the results of integrated seismic and geochemical surveys (1) over pinnacle reefs East Texas, (2) in the Ft. Worth basin of North Texas, and (3) across Pennsylvanian channel sandstones in Oklahoma and Texas.

Geochemical data acquired over the pinnacle reefs clearly discriminates between hydrocarbon-charged reefs and dry or non-commercial reefs. In the Fort Worth basin, geochemical evaluation of a seismically defined Ordovician Ellenburger structural trap identified a minor seepage anomaly associated with it and an extensive microseepage anomaly over a nearby structural low. Subsequent drilling yielded a dry hole on the "high" and discovered a new Park Springs Conglomerate (Pennsylvanian) field in the area of the seismic "low." The channel sandstone examples demonstrate the use of gridded microbial surveys to discriminate between hydrocarbon-charged and uncharged Pennsylvanian channel sandstones.

Applications such as these require close sample spacing and are most effective when results are integrated with subsurface data. The need for such integration cannot be overemphasized. High-resolution microseepage surveys offer a flexible, low-risk and low-cost technology that naturally complements traditional geologic and seismic methods. Properly integrated with 2-D and 3-D seismic, their use has led to the discovery of new reserves and the drilling of fewer dry or marginal wells.

Reprinted as published in the American Association of Petroleum Geologists *2003 Mid-Continent Section Meeting Official Program Book*, p. 34–35.

A Deposition and Reservoir Model for the Prue Sandstone in the Southwest Oklahoma City Area and the Effect of Foam Fracturing on Unlocking Its Reserves

JOHN R. BROKER, Cimarex Energy Co., Tulsa, OK; *LES J. BROKER* and *THOMAS N. CAPUCILLE*, Consultants, Edmond, OK

The study area extends from Oklahoma City Field approximately 25 miles to the southwest and covers 10 townships. The study was originally a Masters thesis by John Broker. This original study and additional reservoir analysis lead to the drilling and completion of a significant discovery well in the Prue Sandstone in Section 22–T10N–R5W. This discovery has lead to the drilling of several development wells.

The study indicates that the Prue Sandstone was deposited around the western side of the Oklahoma City Field area as a highstand delta sequence. A significant drop in sea level then caused incision of a valley through the delta complex and deposition of a lowstand delta sequence west of the study area. The incision cut through the underlying Verdigris Limestone. Subsequent to incision, sea level rose, backfilling the valleys with sand and shales forming a major incised valley fill complex covering parts of the entire study area. The sandstone accumulated to a thickness of 80 feet.

Original completions in the Prue Sandstone date to initial development of the Oklahoma City Field in the early thirties. During the 1980's the Prue channel was developed west of the Oklahoma City Field with production extending 12 miles under the Oklahoma City Airport. Several wells west of this area encountered a lower porosity Prue IVF Sand which was tested and produced with minimal economic success. The aforementioned discovery in Section 22–T10N–R5W was drilled in this area of known Prue sand but was completed with modern techniques. The results using new completion procedures have lead to further expansion of the play.

The integration of core analysis, log analysis, regional depositional modeling, sequence stratigraphy, and completion technology used in the Prue Sandstone has lead to a workable exploration model for Cherokee sands in the southeastern Anadarko Basin.

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Tidal Deposits of the Labette Shale and Peru Sandstone, Southwestern Rogers County, Oklahoma

SCOTT SCHAD, JEANETTE KING, ROBERT COLEMAN, and *DENNIS KERR*, University of Tulsa, Tulsa, OK

A road cut north of Catoosa, Oklahoma affords a rare exposure of the otherwise heavily weathered upper Desmoinesian Labette Shale and Peru sandstone. About 20 m of interstratified rippled sandstone and mudstone, and lenses of sandstone are exposed. Calibrated digital photo mosaics were assembled. Photos were processed to produce an image similar to a seismic profile.

Evidence for tidal sedimentation includes: reversing ripple cross-laminated sets, mud drapes on ripple laminae and ripple forms, and stratal bundling of sand-rich and sand-poor strata. A plot of tidal set thickness vs. ordered set number reveals a quasi-regular pattern, but it does not display the pattern expected for neap-spring tidal bundles. The tidal bundles are readily observed by their resistance to weathering with the sand-rich part forming small ledges and sand-poor part forming small benches or recesses.

Original and image-processed photos were used to correlate stratal surfaces across the road cut. Two-meter-thick strata with horizontal to low-relief erosional contacts characterize the lower three-quarters of the exposure; tidal bundles dip at low angle in the lower part grading to horizontal in the upper part. Slumped and fluidized sandstone lenses with several meters of erosional relief characterize the upper one-quarter of the exposure. In addition, each upward successive lens is wider and thicker (reaching 6 m) than the underlying lens. These features strongly suggest that the Labette–Peru was deposited in tidal channels that became more proximal with time (i.e., shoaling upward).

Reprinted as published in the American Association of Petroleum Geologists *2003 Mid-Continent Section Meeting Official Program Book*, p. 42–43.

Midcontinent Backfilled Valleys: Reservoirs and Outcrop Analogs

RODERICK TILLMAN, Consulting Geologist, Tulsa, OK

Examples of backfilled valleys occur in parts of the Atoka in Northwest Arkansas, the Bartlesville Sandstone in eastern Oklahoma, and the Morrow Sandstone in the Oklahoma panhandle. Many valleyfill reservoirs in the midcontinent are backfilled, dominantly-tidal sandstones. This type of sand body differs from those formed entirely by fluvial (river) processes.

Valleys are commonly incised during sea level fall and filled during subsequent sea level rises. Valley filling tidal deposits commonly contain contain clay as drapes and thin beds, have variable grain size from bed to bed and form in cycles.

Differentiation of single stage (valley cut and filled in one stage) from multistage channels is important in both exploration and development. Individual channel fills commonly form separate compartments. Detailed gamma-ray logs of NW Arkansas outcropping tidal facies may allow recognition of similar facies in the nearby subsurface.

Tidal reservoir sand bodies to be examined include accretion point bars, tidal thalweg sandstones, and tidal-flat sandstones, all of which occur in Northwest Arkansas in outcrops to be visited during the Midcontinent SEPM/AAPG Field Trip to be held in October 10–11, 2003.

Development of criteria for recognition of tidal facies has lagged behind those for recognition of fluvial and shoreface deposits. Tidal point bars may be excellent reservoirs, but are commonly misidentified as "fluvial." Laterally-linked tidal point-bars often form discrete sand bodies as a result of both depositional and erosional processes.

Reprinted as published in the American Association of Petroleum Geologists *2003 Mid-Continent Section Meeting Official Program Book*, p. 44.

Correlation of Selected Lower Cherokee Units in Northeast Oklahoma

J. GLENN COLE and *R. VANCE HALL*, Hall Geological Services, LLC, Tulsa, OK

The Tulsa Geological Society Stratigraphic Committee is updating its northeast Oklahoma type logs. This project has revealed some problematic correlations in the lower part of the Cherokee section. In order to resolve these issues we have attempted to tie well logs to the outcrop, especially where measured sections are available.

Two specific problems are addressed. The correlation of the surface Bluejacket Sandstone with the subsurface Bartlesville sand is discussed. The correlation of coals and other units below the Bartlesville sand, especially the Rowe coal, are discussed. Stratigraphic cross sections illustrate the problems and conclusions.

Reprinted as published in the American Association of Petroleum Geologists *2003 Mid-Continent Section Meeting Official Program Book*, p. 28.

A Review of Coalbed Methane Operational Issues in the Cherokee Basin, Kansas and Oklahoma—A Case Study

JOHN COATES, Patrick Petroleum, Tulsa, OK

Commercial coalbed methane (CBM) projects require the successful integration of a number of disciplines, including but not limited to geology, engineering, land, gas marketing and the regulatory environment. This talk reviews Mid-Continent examples of how any one of the disciplines can make or break a CBM project. As CBM activity grows in the Mid-Continent, operators are experiencing new challenges not seen in other CBM basins around the country. A few examples to be discussed include: (1) thin bed completions of very high permeability coal; (2) oil, wax and paraffin production in conjunction with gas and water; (3) fracture stimulation programs in areas of many old unplugged wells; and (4) experienced and divided mineral ownership.

In addition to the challenges, the Mid-Continent offers tremendous potential for CBM operators. The examples to be discussed include: (1) high rank gassy coals with good permeability; (2) abundant service company infrastructure; (3) oil and gas knowledgeable regulatory environment; and (4) excellent gas markets and gas infrastructure. All of these factors combine to determine the economic success of a CBM project.

Reprinted as published in the American Association of Petroleum Geologists *2003 Mid-Continent Section Meeting Official Program Book*, p. 28.

Regional Trends in Coalbed Gas Composition and Thermal Maturation in Eastern Kansas: Implications for Predicting Quality and Location of Coalbed Gas

K. DAVID NEWELL and *L. MICHAEL MAGNUSON*, Kansas Geological Survey, Lawrence, KS

Compositional (i.e., hydrocarbon gas wetness) and isotopic analyses (δC^{13}, δD for methane) for gases desorbed from Pennsylvanian (Desmoinesian) Cherokee Group coals from Montgomery County, KS, and Cass County, MO, suggests that these gases are of mixed microbial and thermogenic origin. Analyses of conventionally-produced gases from Pennsylvanian and Mississippian reservoirs in eastern Kansas indicate that these gases also range from microbial to thermogenic in origin, but thermogenic gases are more common west of a line extending from Wyandotte County (near Kansas City) to Chautauqua County, KS (along the KS-OK state line). Thermogenic processes increase deeper into the Cherokee and Forest City basins and southward into Oklahoma, whereas biogenic processes affect gas compositions farther east along the shallow flanks of these basins. Initial data indicate Kansas coalbed gases have heating values comparable to gases produced from conventional reservoirs. Helium can be an important but variable constituent in gas from coals and organic-rich shales. Helium values approaching 1% have been reported. The mixed origin of the conventional and coalbed gases in eastern Kansas has implications for predicting the quantity and quality of coalbed-gas production trends. Different production fairways of separate biogenic and thermogenic origin are possible.

Reprinted as published in the American Association of Petroleum Geologists *2003 Mid-Continent Section Meeting Official Program Book*, p. 39.

The Nemaha and Nearby Fault Zones in the Context of Midcontinent Strike-Slip Structural Geology

WILLIAM McBEE, Consulting Geologist, Tulsa, OK

The Nemaha zone has been described as an integral part of the mid-Proterozoic-aged Midcontinent Rift System. Neither geophysical analyses, geological dating nor tectonic framework support this. Detailed mapping of subsurface data from hundreds of wells in Oklahoma and Kansas show that the Nemaha zone has a structural style and history entirely different from that of the Midcontinent Rift. There is abundant evidence to demonstrate that the Nemaha may be either a right-lateral, conjugate, Reidel R' shear fault, or a second order, right-lateral wrench-fault. Data indicate that initial movement was at least as old as mid-Ordovician (Taconic), but it probably originated much earlier.

Evidence presented here will show that the Nemaha zone is a true wrench fault, of limited horizontal displacement and rooted in the deep crust. The fault dip along its trace flips from high-angle normal to high-angle reverse, with pull-apart grabens and pop-up structures along its length.

East of the Nemaha zone in Oklahoma, there are a number of less prominent faults and associated structures parallel to it which trap oil and gas fields. They also provide evidence of strike-slip movement.

Reprinted as published in the American Association of Petroleum Geologists *2003 Mid-Continent Section Meeting Official Program Book*, p. 38.

Cyclo-Stratigraphic Architecture and the Controlling Processes of Upper Pennsylvanian Oread Cyclothem in the Transition Zone Between Shelf and Deltaic Depositional Systems, Southeast Kansas and Northeast Oklahoma

MICHAEL BRUEMMER, WAN YANG, and *MONICA TURNER-WILLIAMS,* Wichita State University, Wichita, KS

Close juxtaposition of deltaic and shelf depositional systems of the Oread cyclothem in SE Kansas and NE Oklahoma formed a unique stratigraphic architecture. We reconstructed the architecture using 50 outcrop sections and 150 logs in a 2000-km^2 area to understand the controlling processes. The ~ {!0 ~ }layer-cake ~ {!1 ~ } siliciclastics and limestones of the shelfal Oread cyclothem change to deltaic deposits southward. The persistent and thin Leavenworth Limestone signifies marine transgression. Maximum-transgressive anoxic and phosphatic Heebner Shale is ~~ 2 m on the shelf, but thickens to 23-m deltaic deposits in 5 km. Regressive Plattsmouth algal-mound facies changes to arenaceous packstone, and pinches out into deltaic sandstones in 3 km. Extensive Elgin deltaic deposition occurred during continued regression but was interrupted basinward by Kereford minor transgression. We speculate that an upwelling system developed in the study area, similar to that along NW African Shelf. The onshore and alongshore currents formed a hydrographic barrier to northward Heebner delta progradation. The offshore currents caused shelf anoxia. Westward retreat of upwelling system during early regression allowed shelf carbonate deposition. The alongshore currents, however, still prevented northward deltaic progradation, causing juxtaposition of carbonate and deltaic systems indicated by a 150-m-wide conglomerate-sandstone zone, similar to the Mahakam Delta in Java Sea. Syndepositional topography also affected the transition. Complete withdrawal of the upwelling system in late regression removed the barrier, thus, thick (10–50 m) Elgin deltas prograded 20 km shelfward, overwhelming several minor cycles. Interplay of eustasy, oceanic upwelling, sediment supply, and topography caused the unique Oread stratigraphic architecture.

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Facies Architecture of the Upper Pennsylvanian Oread Cyclothem, Subsurface Southeastern Kansas and Northeastern Oklahoma

WAN YANG and *MICHAEL BRUEMMER,* Wichita State University, Wichita, KS

The archetypal Oread Cyclothem consists of three minor cyclothems and change drastically in lithology, thickness and depositional environment at the southern margin of Kansas Shelf. Our subsurface study area extends from the outcrop belt, covering 1,900 km^2 in Chautauqua and Cowley counties, Kansas, and Osage and Kay counties, Oklahoma. Based on outcrop analogs, the three-dimensional facies architecture of the Oread Cyclothem is reconstructed by interpreting eight cross sections and eight isopach, log facies, and paleogeographic maps using 100 wireline logs, cuttings, and cores.

Limestones thin and change into calcareous sandstone and shale to the south. The thick, phylloidal algal mound-rich Plattsmouth Limestone thins abruptly into siliciclastics where it onlaps the Heebner Shale deltaic systems. Carbonate deposition was controlled by depositional topography and proximity to the southern siliciclastic source. Regressive siliciclastic deposits in the minor cyclothems consist of an upward succession of shelf and prodeltaic, delta-front, and fluvial facies. The thin shelf shale of the maximum-transgressive Heebner Shale juxtaposes southern deltaic systems with a steep (0.5°) prodeltaic slope. The delta lobs are oriented east–west, suggesting that northward progradation was diverted to the west. Incised valley systems in the regressive Jackson Park Sahle interval are well developed and, in places, cut through underlying Kereford Limestone. Valley-fill sandstones are blocky, stacked, and up to 40 m thick. Valley development occurred at the end of Oread cycle, coinciding with maximum sea-level fall. Depositional topography, sea-level fluctuations, and oceanic upwelling were the dominant controls on the facies architecture of Oread Cyclothem and its minor cyclothems.

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Hydrogeologic Insight in Identification and Characterization of Saltwater Contamination and Associated Environmental Impacts in Kansas and Oklahoma

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Geological and hydrological properties of saltwater contamination sites have proved to be valuable, along with geochemical methods, for source identification and historical characterization of contamination in Kansas and Oklahoma. The observations are based on over 100 different studies of varying extent during the last 25 years. The geochemical methods are based primarily on mixing curves of bromide/chloride and sulfate/chloride ratios versus chloride concentration. The ratios range widely for saltwaters from subsurface formations and evaporite dissolution, or generated by evapotranspiration and industrial or other anthropogenic processes. Permian strata contain soluble evaporite minerals and natural saltwater in many locations. Permian saltwater has naturally intruded into overlying lower Cretaceous rock and Cenozoic sediments. Changes in land and water use, including geomorphic alteration of the land surface, can generate saline water by evapo-

transpiration concentration of natural dissolved constituents. Heterogeneity in the permeability of aquifer sediments and rocks can lead to stratification of saltwater contamination, both from sources at an aquifer base and the land surface. Sloping surfaces of low-permeability bedrock can affect the movement of dense saltwater pollution at the base of permeable aquifer sediments. Higher hydraulic head in confined, saltwater-containing bedrock than in an overlying aquifer can lead to upward saltwater flow in unplugged boreholes. Lateral and vertical changes in aquifer hydraulic heads caused by human activities can shift the movement of saltwater contamination. Changes in cation ratios caused by exchange on aquifer clays can be used to evaluate whether a saltwater plume is advancing or has been substantially flushed.

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Environmental Impact of Produced Water and Hydrocarbon Releases at a Long-Term Research Site on Skiatook Lake, Osage County, Northeastern Oklahoma

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The USGS is investigating the impact of past oil production (1913–1973?) at a 1.5-hectare site adjacent to Skiatook Lake in northeastern Oklahoma. Produced water (PW) and hydrocarbon (HC) releases from surface pits, tanks, and broken pipelines have produced extensive soil and bedrock contamination whose dimensions are controlled by (1) the topographic position of two pits near a drainage divide; (2) the distribution, porosity, and permeability of surficial eolian sand, slope wash, and colluvium; and (3) the underlying gently dipping permeable sandstone and impermeable shale. A ground-water plume that intersects Skiatook Lake extends to depths of at least 8 meters and underlies a broad surface salt scar downslope north of the two pits. Total dissolved solids in the plume are as much as 35,000 ppm, with the presence of major dissolved Na and Cl confirming a PW source. Saline bedrock, as defined by electrical conductivity from ground geophysics and Cl-rich extracts of shallow core samples, extends several meters beyond the surface salt scar into the surrounding oak forest. Leaves of some oak trees near the salt scar show anomalously high Cl concentrations. Although the adjacent forested areas show colonization by blackjack and post oak during the mid-to-late 1900s, growth of these oaks was limited in the impact area where grasses, shrubs, and forbs dominate. Both degraded and undegraded oil from past HC production is present in pits and trenches. Oil-contaminated soil adjacent to pits and trenches contain microbial populations that are thermodynamically poised at the level of iron reduction.

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High Resolution Correlation of the Shawnee Group (Virgilian, Pennsylvanian) in Kansas and Oklahoma

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This study utilizes lithocorrelation, correlation of surface generated spectral gamma-ray scinillometer, and conodont biostratigraphy in order to correlate Shawnee Group Strata from Kansas into Oklahoma. The Shawnee Group (Pennsylvanian, Virgilian) extends from Iowa, Nebraska, Missouri, and Kansas into northern Oklahoma. The cyclothemic succession is remarkably consistent from Iowa to Kansas with an abrupt lithofacies change occurring at the Kansas–Oklahoma border. This change in lithofacies succession represents shelfal deltaic deposition in the Oklahoma region. This results in some members such as the Heebner Shale thickening from 2–3 meters to 20 meters with interbedded sandstosnes because of high stand-deltaic progradation. These deltaic wedges greatly complicate correlation of individual members and formations from Kansas into Oklahoma. It is largely for this reason that the stratigraphic terminology utilized in Oklahoma differs substantially from that utilized in Kansas and northward. Additionally, Osage County, that is the county adjacent to Kansas, has not had a completed geologic map created, further complicating correlation.

Marine condensed sections within the Shawnee Group including the Heebner Shale, Queen Hill Shale, and Larsh–Burroak Shale have been physically traced using field mapping, gamma-ray analysis and conodont biostratigraphy. These condensed sections can now be used for surface-to-subsurface correlations of individual cyclothemic sequences utilizing gamma-ray signatures and biostratigraphic ties. Limestone units that are extremely widespread and continuous north of Oklahoma are found to be lenticular and are only traceable locally for short distances in Oklahoma. A number of local names used for these limestones in Oklahoma can now be dropped and their Kansas equivalents can be adopted.

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The Role of Seafloor Hydrothermal Venting in the Generation of Elevated Metal Concentrations in Pennsylvanian Black Shales

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It has long been recognized that black shales are commonly enriched in transition metal concentrations, although the causal mechanisms are highly debated. Pennsylvanian black shales of midcontinent North America are no exception, with many beds enriched in transition metals by as much as two to three orders of magnitude relative to the Post-Archean Shale Standard (PAAS). High-resolution sampling of the Missourian Hushpuckney Shale Member of the Swope Limestone in several cores—focusing on the transitions between bioturbated, organic-lean, gray shales and laminated, phosphatic, organic-rich, black shales—was undertaken to evaluate the relative roles of different enrichment mechanisms. Concentrations of a

broad suite of transition metals (Fe, Zn, Pb, U, V, Cr, Ni, Mo) are highly enriched within the black shale facies compared to the over- and underlying gray shales, but the level of enrichment varies in cores from different locations (Iowa, Missouri, Oklahoma, Kansas). Fe/Al and Pb/Al ratios are highest in Oklahoma, where they are as much as six and thirty times higher, respectively, than those calculated for PAAS. In Iowa, Fe/Al ratios exhibit only minor enrichment relative to PAAS, but the concentrations of other metals, such as Zn, U, V and Mo, are several hundred times higher than PAAS. Petrographic observations and $\delta^{34}S$ values of sulfide imply that the enrichments are likely not caused by post-depositional (epigenetic) mineralization.

Previously, others have suggested that scavenging from normal ocean water was not the sole source of metals. We hypothesize that white-smoker hydrothermal vents, with fluids rich in metals but not sulfide, were present in the Pennsylvanian sea and raised bottom-water metal concentrations contemporaneous with shale deposition. The composition of the potential Pennsylvanian vent fluids is explored using isotope mass balance calculations and a comparison between modern vent fluid compositions and observed metal enrichments. While mechanisms of metal sequestration and concentrations in black versus gray shales were controlled by low-temperature paleoceanographic conditions, the presence of metal-rich hydrothermal fluids venting into Pennsylvanian seas might have been a critical factor in determining the absolute level and spatial variation of metal enrichment.

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Tertiary History of C_4 Biomass in the Great Plains, USA

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We use the carbon isotope composition of paleosols to reconstruct the history of C_4 biomass on the Great Plains from ca. 23 to 1 Ma. The proportion of C_4 biomass was uniform and moderate (12%–34%) throughout the Miocene, increased between 6.4 and 4.0 Ma, and reached modern levels by 2.5 Ma. Ecological changes in Great Plains ungulates preceded the increase in C_4 biomass. The contrasts in the paleosol and ungulate records may indicate initial development of C_3 grasslands after the middle Miocene or a greater role for ecological interactions within communities in structuring ungulate faunas. Contrasts in paleosol records from different continents point to regional rather than global controls on the evolution of C_4 grasslands.

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