Oklahoma
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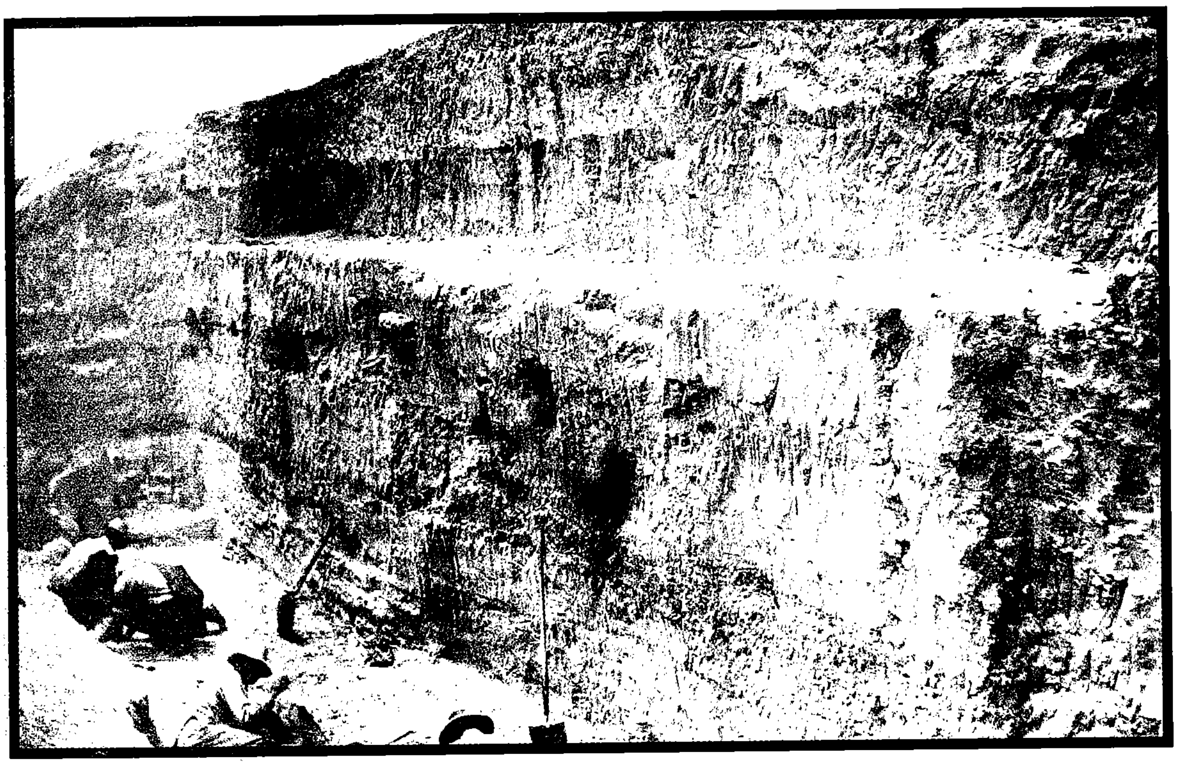
# OKLAHOMA GEOLOGY notes

Vol. 60, No. 2 Summer 2000



**Featuring:**
- *Miocene fossil marmot*
- *Sooner State earthquakes, 1999*
- *Earth science news*

## on the cover

# WPA fossil excavation near Optima, Texas County, Oklahoma

In the cover photograph, Works Progress Administration (WPA) workers are shown digging for fossil vertebrates in a pit near Optima, Texas County, Oklahoma. During the late 1930s, Dr. J. Willis Stovall of the University of Oklahoma supervised a WPA project at Optima to excavate late Miocene fossils in the Ogallala Formation. The Optima site was one of a number of fossil sites excavated throughout Oklahoma from 1935 to 1942 under the WPA (Czaplewski and others, 1994).

The huge hand-dug pit seen here, which was probably 20 to 30 ft deep when finished, was the largest of seven pits in the area that were excavated over a 20-month period in 1937 and 1938, under the direction of Nolan McWhirter. Much of the digging was through hard caliche, which made the work extremely difficult. In modern excavations the work would be a little easier—backhoes or front-end loaders would probably be used to dig down to the bone layer, then workers would use hand tools.

The pit shown on the cover produced hundreds of teeth and fragments of several kinds of extinct horses, camels, rhinoceroses, mastodons, carnivores, rodents, and other mammals, as well as an occasional bone of a tortoise, alligator, or bird. (See related article on a fossil marmot not previously reported from the Optima site, page 28.) The specimens collected are preserved in the Oklahoma Museum of Natural History in Norman at the University of Oklahoma. No Optima specimens are exhibited at the museum, but other late Miocene fossils of animals that lived in Oklahoma are on display.

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# OKLAHOMA GEOLOGY notes

**Vol. 60, No. 2** **Summer 2000**

# A Fossil Marmot from the Late Miocene of Western Oklahoma


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**ABSTRACT.**—Marmots (genus *Marmota*) are extremely rare in the Tertiary fossil record of North America; there are only three previous records from the Miocene and Pliocene of the entire continent. Each of the records consists of a single specimen that serves as the type for a new species. One of these is from the Clarendonian land mammal age, one is of Hemphillian age, and one is of Blancan age. Herein, we report specimens referred to *Marmota* sp. indet. as a new member of the Optima local fauna, Texas County, Oklahoma, of Hemphillian age. The Optima *Marmota* exhibits characters not shared by other Miocene marmots and may represent a new species; however, these Optima specimens are not sufficient to diagnose the species.


## INTRODUCTION

The Ogallala Formation of late Tertiary age is widespread across the central Great Plains of the United States. For the last century, it has been an important source of vertebrate fossils from sites ranging from Nebraska to Texas. One such fossiliferous locality is near Optima, Texas County, Oklahoma, where the Optima local fauna of late Miocene age has been recovered.

Beginning in 1928 and continuing during the 1930s, extensive collections of vertebrate fossils from Optima were amassed by the University of California Museum of Paleontology (Berkeley), by the University of Oklahoma (specimens now housed in the Oklahoma Museum of Natural History [Norman]), and by the American Museum of Natural History (New York). Hesse (1936) described 16 taxa of mammals in the first publication on the fauna. Savage (1939, 1941) added several more species to the Optima fauna, including two new species of carnivores, which he described. During subsequent years, specimens from Optima have been included in many published studies on selected taxa (mostly mammals). Gustavson (1990) provided the most recent complete list of the Optima fauna, which includes 2 reptiles (giant tortoise and alligator) and 26 mammals (1 xenarthran, 10 carnivores, 1 proboscidean, 5 perissodactyls, 6 artiodactyls, 2 rodents, and 1 lagomorph).

The Optima fauna is correlated with the late Hemphillian land mammal age (LMA), ca. 5.5 Ma (Tedford and others, 1987; Gustavson, 1990; Hh3 of Woodburne and Swisher, 1995). It is most nearly equivalent to the Coffee Ranch Local Fauna, Hemphill County, Texas, which is the stratotype in the Texas Panhandle for the Hemphillian LMA (Woodburne and Swisher, 1995).

Most of the known members of the Optima local fauna are medium- to large-sized vertebrates that have been found by quarrying. (The Optima locality has not been screenwashed systematically to recover microvertebrates.) Herein, we report on a moderate-sized rodent of the genus *Marmota*, one of the smallest known members of the fauna (in addition to the rodents *Mylagaulus* and *Dipoides* and the rabbit *Hypolagus*).

The genus *Marmota* consists of a group of relatively large sciurids commonly known as marmots and woodchucks. In the modern fauna, these rodents are widespread throughout temperate parts of North America, Asia, and Europe (Barash, 1989). The pre-Pleistocene fossil record of marmots is extremely poor. Only three Tertiary species have been identified in North America, each represented solely by its type specimen. Each also occurs in a different North American LMA. The currently recognized North American Tertiary species are *Marmota vetus* (Marsh, 1871), from the Clarendonian LMA of Nebraska; *Marmota minor* (Kellogg, 1910) of the Hemphillian LMA of Nevada; and *Marmota arizonae* Hay, 1921 from the Blancan LMA of Arizona (Korth, 1994). *M. vetus* is known only by a left dentary bearing all the teeth. *M. minor* is represented by maxillary and mandible fragments, upper and lower incisors, and skeletal fragments, all apparently from a single individual. *M. arizonae* is known from the anterior two-thirds of a cranium that includes the incisors and three molars. The earliest record of a marmot in Asia is *Marmota robusta* in the Haiyan Formation of the Yushe Basin in northern China (Flynn, 1997). The Chinese record is of late Pliocene or early Pleistocene age (possibly correlative with the Nihewan biochron) and is younger than 3 Ma (Flynn and others, 1997).

Phylogenetic evidence suggests that the tribe Marmotini, to which the marmots belong, was one of the last major lineages of sciurids to have evolved (Hafner, 1984; Korth, 1994). Paleontological, morphological, and molecular phylogenetic evidence indicates that *Marmota* arose first in North America (Black, 1963; Korth, 1994; Kruckenhauser and others, 1999) and probably migrated to Asia in the late Pliocene. Some of the extant species of marmots probably differentiated in Beringia and adjacent regions during, or following, the glacial periods of the late Pliocene and Pleistocene (Hoffmann and others, 1979).

The teeth of Sciuridae are notoriously difficult to measure consistently (H. T. Goodwin, personal communication, 1999). To establish consistent measurements for comparisons in this study, we remeasured casts of the teeth of other Tertiary *Marmota* species rather than using published measurements. Measurements on lower molars were made parallel (anteroposterior length) or at right angles (transverse width) to the labial edge of the tooth (see Fig. 1B).

## SYSTEMATICS

Order Rodentia
Family Sciuridae
Subfamily Sciurinae
Tribe Marmotini
*Marmota* Frisch, 1755
*Marmota* sp. indet.

### Referred Specimens

Oklahoma Museum of Natural History (OMNH) 11835, right I1 (upper first incisor) (Fig. 1A); OMNH 11834, left dentary fragment with i1 (lower first incisor) and m1 (lower first molar) (Fig. 1B,C,D).

### Locality and Horizon

OMNH locality V52, Optima, Texas County, Oklahoma; Ogallala Formation; Optima local fauna (also known as Guymon local fauna); late Miocene, late Hemphillian LMA.

### Description and Comparisons

The left dentary fragment (OMNH 11834) consists mainly of the horizontal ramus; the ascending ramus is completely broken away (Fig. 1C,D). A small part of the ventral base of the angular process is preserved. The diastema is 11 mm long. The mental foramen occurs on the lateral side about 2 mm below the middle of the diastema. The masseteric ridge has a smooth ventral edge but is broadly rounded dorsally. There is a small depression just above the anteroventral edge of the masseteric ridge. Two large, deep alveoli (posterolabial and anterior) and one small alveolus (lingual) indicate the former position of the p4 (lower fourth premolar). The bone surrounding the alveoli for the m2 (lower second molar) and m3 (lower third molar) has mostly been broken away, but it is possible to determine that m1 (which is preserved) and m2 each had four roots. The open root of the i1 is exposed by breakage beneath the level of the m3.

The I1 of the Optima marmot (OMNH 11835) consists of the slightly damaged tip and ~2 cm of the length of the crown, broken near the base (Fig. 1A). The I1 has a radius of curvature (Akersten, 1981) of 14 mm on the anterior (enameled) face. The anteroposterior diameter of the I1 is 4.9 mm, and the transverse diameter is 2.7 mm. The anteroposterior diameter of the i1 (OMNH 11834) is 4.0 mm, and the trans-

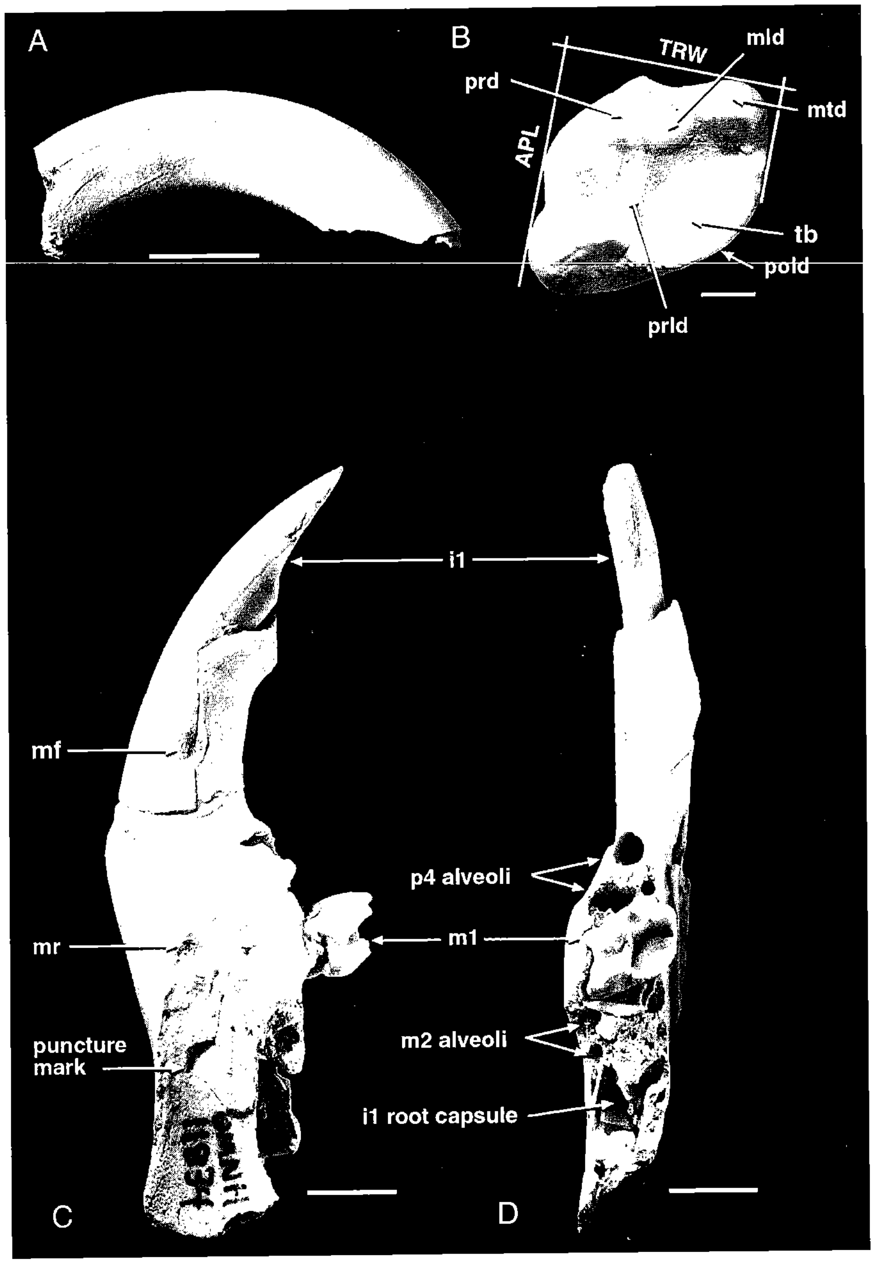


Figure 1. *Marmota* sp. indet. from the Optima local fauna, Oklahoma. (A) OMNH 11835, upper first incisor (I1) tip in lateral view. (Apex of incisor is to the right.) (B) OMNH 11834, left lower first molar (m1) in occlusal view. (C, D) OMNH 11834, left dentary fragment with lower first incisor (i1) and m1, in lateral and occlusal views, respectively. APL = anteroposterior length (measured parallel to the labial edge of the tooth); TRW = transverse width (measured perpendicular to the labial edge of the tooth); mf = mental foramen; mld = metalophid; mr = masseteric ridge; mtd = metaconid; pold = posterolophid; prd = protoconid; prld = protolophid; tb = talonid basin. Scale bars for A, C, D represent 5 mm. Scale bar for B represents 1 mm.

TABLE 1. — MEASUREMENTS (IN MILLIMETERS) OF LOWER FIRST MOLARS (M1) OF TERTIARY AND MODERN NORTH AMERICAN SPECIMENS OF *MARMOTA*

| Species/specimen | No. of specimens measured | Anteroposterior length[a,b] | | Transverse width[a,c] | |
|---|---|---|---|---|---|
| | | Observed range | Mean ± standard deviation | Observed range | Mean ± standard deviation |
| MODERN | | | | | |
| *M. monax* | 5 | 5.40–6.00 | 5.72±0.24 | 4.50–4.90 | 4.72±0.15 |
| *M. flaviventris* | 4 | 4.90–5.60 | 5.18±0.31 | 4.10–4.40 | 4.25±0.13 |
| *M. caligata* | 18 | 5.00–6.00 | 5.61±0.29 | 4.40–5.30 | 4.89±0.19 |
| TERTIARY | | | | | |
| *M. vetus*[d] | 1 | 3.60 | — | 3.20 | — |
| *M. minor*[e] | 1 | 4.00 | — | 4.05 | — |
| OMNH[f] 11834 | 1 | 4.70 | — | 4.50 | — |

[a]See Figure 1B.
[b]Measured by the authors parallel to the labial edge of the tooth.
[c]Measured by the authors at right angles to the labial edge of the tooth.
[d]Specimen number 10323, Yale Peabody Museum, New Haven, Connecticut.
[e]Specimen number 12538, University of California Museum of Paleontology, Berkeley.
[f]Oklahoma Museum of Natural History, University of Oklahoma, Norman.

verse diameter is 2.6 mm (Fig. 1C,D). The radius of curvature (Akersten, 1981) of i1 is 22.5 mm on the anterior (enameled) face; the complete tooth subtends an arc (Akersten, 1981) of 115°. Incisor measurements (upper and lower) of other Tertiary marmots have not been published.

The enamel faces of the upper and lower incisors of the Optima specimen are smooth. *M. vetus* has a single, shallow median groove on the lower incisor (Black, 1963). In *M. minor*, the upper incisors are shallowly grooved; the lower incisors are ungrooved but finely striated (Black, 1963). In *M. arizonae*, the upper incisor is "nearly smooth" (Hay, 1921). Thus, the Optima specimens differ from other Tertiary marmots in having ungrooved, unstriated upper and lower incisors.

The jaw from Oklahoma (OMNH 11834) is much smaller than that of any species of *Paenemarmota* (*P. barbouri, P. sawrockensis, and ?P. nevadensis*) and much larger than those of any species of *Cynomys* and *Cynomyoides* (Repenning, 1962; Goodwin, 1993; Korth, 1996). In overall size, the Optima marmot is considerably larger than the small, early species *M. vetus* and slightly larger than *M. minor*. The Optima m1 is both wider and less anteroposteriorly compressed than the m1 of either *M. vetus* or *M. minor*. Although direct comparisons with *M. arizonae* are not possible because the species is known only from upper teeth in a fragmentary cranium, the Optima marmot probably was slightly smaller than *M. arizonae* based on the similarity of *M. arizonae* to *M. flaviventris obscura* (Hay, 1921). Comparisons to measurements made on the m1 of three modern species of North American marmots indicate that the Optima marmot is a more diminutive species (Table 1).

The morphology of the Optima specimen's only preserved cheek tooth, the m1 (Fig. 1B) is similar to that in other marmots, including extant species. However, there are also differences. The metalophid on the Optima m1 is relatively strong and high; it joins the lingual end of the protolophid to form a high ridge that extends to the metaconid. The posterolophid is low and weak and no mesostylid is developed. In comparison, the metalophid of the m1 in *M. vetus* appears to have been relatively high (similar to that of the Optima specimen), but the posterolophid is strongly developed and separated by a notch from a weak mesostylid. However, because the type and only specimen of *M. vetus* is much more worn than the Optima specimen, a definitive comparison cannot be made. In *M. minor*, the only known m1 is slightly damaged; nevertheless, it is possible to determine that the metalophid is short and weak, and that it descends from the protoconid to the floor of the talonid. The posterolophid is well developed and separated by a notch from a weak mesostylid. Thus, in several ways, the shape of the Optima m1 differs from that of specimens from other Tertiary marmots for which the m1 is known. (The lower teeth of *M. arizonae* are unknown.)

The relative crown height of the Optima m1 is much less than that in prairie dogs (*Cynomys*); it is comparable to that in modern *M. monax* and *M. flaviventris*, but higher than that in extinct *M. vetus* and *M. minor*. The cheek teeth are much smaller and the dentary relatively less robust than in the putative prairie dog *Cynomyoides* of the Barstovian and Clarendonian LMAs (Korth, 1996). The Optima m1 is cuspate, as in other species of *Marmota*, rather than lophate, as in *Cynomys* and *Cynomyoides*.

There is a small indentation on the lateral side of the Optima dentary below the level of the m2 alveolus and posterior to the masseteric ridge. There, a small area of bone of the lateral wall of the jaw is broken along a roughly semicircular edge from which the surface has been pushed inward (Fig. 1C). This feature is 2.4 mm in diameter. It may be a puncture mark that appears to have occurred when the bone was fresh. We speculate that the feature is the result of a puncture by the tip of a canine, reflecting the bite of a small carnivore. Several small predatory mammals are known in the Optima fauna, including the bobcat-sized *Felis proterolyncis*, the small fox *Vulpes stenognathus*, the small badger *Pliotaxidea* cf. *P. nevadensis*, and the procyonid "coati" *Arctonasua fricki* (Savage, 1941; Baskin, 1982).

## DISCUSSION

Many late Tertiary species of sciurids have been placed in, or referred to, the genus *Marmota* (Bryant, 1945; Black, 1963; Hibbard, 1964; Gustafson, 1978). However, many of them actually pertain to other genera. In particular, several named species originally ascribed to *Marmota* are now referred to the giant ground squirrel *Paenemarmota* (Repenning, 1962; Korth, 1994). As noted above, species of *Paenemarmota* are much larger than species of *Marmota*. Korth (1994) limited the Tertiary species of *Marmota* to *M. vetus* (Marsh, 1871), *M. minor* (Kellogg, 1910), and *M. arizonae* Hay, 1921. *Marmota* species, including the Optima specimens, differ morphologically from *Paenemarmota* in the absence of prominent grooves on the upper incisors (*M. minor* has a shallow groove on I1 [Black, 1963]) and in the absence of a deep groove within the talonid basin of the molars at the base of the ectolophid and metalophid (the "basin trench" of Repenning [1962]). *Marmota* species also differ from *Paenemarmota, Cynomys*, and *Cynomyoides* in the absence of accessory cuspules within the talonid basin. Instead, the floor of the talonid basin in *Marmota* is relatively smooth and featureless, as in OMNH 11834 (Fig. 1B). The Oklahoma specimens are referred to the genus *Marmota*.

As noted above, the Optima marmot specimens differ in size and in details of dental morphology from other named species of *Marmota*. The specimens probably represent a new species, but they are not sufficient to diagnose the species. The undescribed species is most similar to the approximately contemporaneous *M. minor* from the Thousand Creek fauna, Nevada. Yet, the Optima jaw differs from the type and only known specimen of *M. minor* in having a slightly larger, less anteroposteriorly compressed m1 and a much less prominent masseteric ridge of the dentary. It is difficult to judge the systematic significance of these differences without more and better specimens of *M. minor* from the type locality in Nevada and/or from Optima.

Tertiary records of marmots are extremely rare. The Optima record represents the first known occurrence of a marmot in the Hemphillian LMA of the Great Plains and only the fourth known locality in North America in which pre-Pleistocene *Marmota* fossils have been recovered.

## ACKNOWLEDGMENTS

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# Oklahoma Earthquakes, 1999

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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 are usually not felt by humans (Table 1). Only 20 earthquakes, on average, exceed a magnitude 7.0 each year. An earthquake that exceeds a magnitude 7.0 is considered to be a major earthquake and serious damage could result.

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 east Pacific Oceans. Earthquakes also occur where plates collide and/or slide pas t each other. Although most earthquakes originate at plate boundaries, a small percentage occur within plates. The New Madrid earthquakes of 1811–12 are examples of large and destructive intraplate earthquakes in the United States.

The New Madrid earthquakes of 1811 and 1812 are probably the earliest historical earthquake tremors felt in Oklahoma (Arkansas Territory) by residents in southeastern Oklahoma settlements. Before Oklahoma became a state, the earliest documented earthquake occurred 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 MM-VIII intensity effects. 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 by two additional earthquakes in the same area in April 1901 (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), with Des Moines, Iowa, and Austin, Texas, at the northern and southern limits. From 1897 through 1999, 1,596 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 39 earthquakes in Oklahoma for 1999 (Fig. 1). The Oklahoma Geological Survey (OGS) Observatory station, TUL, located near Leonard, Oklahoma, in southern Tulsa County, records 15 continuous seismic signals from sensors located at four stations. The data are recorded, analyzed, and archived on a GSE digital seismic system provided by the Defense Advanced Research Projects Agency/Nuclear Monitoring Research Office.

Signals are digitized by one Geotech RDAS (Remote Data Acquisition System) unit at either 3,600 or 1,200 24-bit samples per second. The RDAS then applies digital anti-alias filtering to eliminate frequencies too high for the final sampling rate. After one to three digital filter and resampling

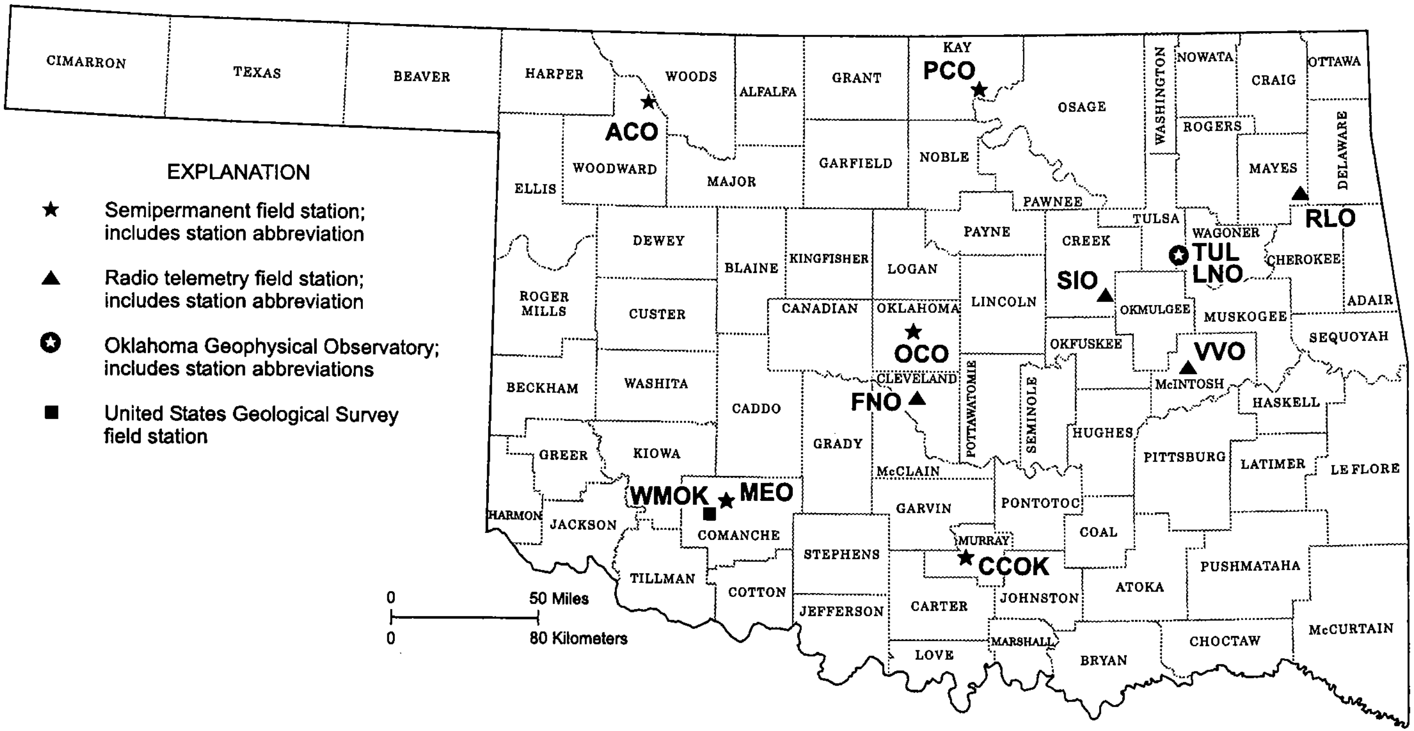


Figure 1. Active seismographs in Oklahoma.

stages, the RDAS produces 60, 40, 20, or 10 24-bit samples per second. The samples are time-tagged by RDAS clocks locked to low-frequency time signals from National Institute of Standards and Technology station WWVB. The signals are passed by RS422 serial links to an AST 386/25 RTDS (Real Time Data Server) computer, which has a Lynx™ real-time Unix-like operating system. The partially processed signals are passed by ethernet to a Sun SPARC 2+ Unix workstation with 64 megabytes of memory, two 660-megabyte disks, two 2.1-gigabyte disks, and two 2.5 gigabyte Exabyte™ tape drives. All of the data from the most recent two weeks are retained on disk. Each day, data from the preceding day (167 million bytes) are automatically archived onto Exabyte tape. All Oklahoma earthquakes, and other selected events, are placed in named de-archive directories on disk. An Oracle™ data base on the Sun SPARC 2+ keeps track of every second of data on the permanent archive tapes, the last 14 days' data on disk, and data in the de-archive directories. Data analysis is done by Teledyne-Geotech and Science Applications International Corp. software on the SPARC 2+ workstation.

The digital system signals are from three sensors in the Observatory vault (international station abbreviation TUL); from a three-component broadband sensor in a 120-m borehole; and from single sensors located at Rose Lookout (RLO) in Mayes County, at the Bald Hill Ranch near Vivian (VVO) in McIntosh County, and at the Jackson Ranch near Slick (SIO) in Creek County.

TUL has three (vertical, north–south, east–west) Geotech GS-13 seismometers that produce 40-sample-per-second short-period signals. A three-component broadband Geotech KS54000-0103 seismometer in a 120-m-deep borehole produces seven digital data channels. Three are broadband signals from seismic signals in vertical, north–south, and east–west directions. From the broadband signals the SPARC 2+ workstation derives three long-period signals. A seventh signal, the vertical earth tides, is recorded from the vertical mass displacement signal from the KS54000-0103. The broadband signals are archived at 10 samples per second, and the long-period and vertical-earth-tide signals are recorded at 1 sample per second. On November 10, 1994, the broadband sample rate was increased from 10 samples per second to 20 samples per second. This increase was for two purposes. One was to allow the broadband borehole seismometer to record higher frequencies characteristic of Oklahoma earthquakes. The other was to make the signals compatible for the GSETT-3 (Group of Scientific Experts Technical Test-3), which began in 1995. GSETT-3 is a prototype international seismic-monitoring system to detect underground nuclear tests. Data segments will be copied automatically and sent to the International Data Center by Internet without affecting the recording and analysis of Oklahoma earthquakes.

Through Department of Defense funding (DEPSCoR) the OGS added a second digital system at Leonard in 1997. It consists of a Guralp CMG-1TD three-component (vertical, north–south, and east–west earth motion) broadband (10 microhertz to 90 hertz) seismometer at a depth of 864 m in a borehole. The output of each component is sampled 2,000 times per second by computer elements inside the seismometer case. The 2,000-sample-per-second streams are digitally filtered and decimated to produce three output streams at 200, 20, and 4 samples per second. These streams are sent to the surface and overland to the Observatory by optical fiber. Optical fiber also sends GPS (Global Positioning System satellite) time signals downhole to the computer in the seismometer.

The optical signals are decompressed and archived by an IBM-compatible computer with Guralp Scream software. The four-hour-long data files are transferred to a Sun SPARC20 computer, where they are analyzed by two seismic software packages: SAC2000, developed by Lawrence Livermore National Lab, and GeoTool, developed by Defense Advanced Research Projects Agency.

The 200-sample-per-second streams from the Guralp seismometer have allowed us to see signals from Oklahoma earthquakes up to 90 hertz. With the older system (40 samples per second), 16 hertz was the upper limit. An example of 90 hertz energy, from the magnitude 4.2 earthquake of April 28, 1998, may be seen on the spectrogram at the Internet address http://www.okgeosurvey1.gov/level2/ok. grams/K980428hzlzne.html.

RLO, VVO, and SIO 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. The signals are received by antennas on a 40-m-high tower at Leonard; the tones are discriminated to produce a voltage that is proportional to the remote seismometer voltage; and the voltages are digitized at 40 samples per second by the vault RDAS.

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

A fourth radio-telemetry station, FNO, was installed in central Oklahoma on April 28, 1992, in Norman. 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 60 mm/min trace speed.

In the Leonard vault, seven additional seismometers produce analog (wiggly-line) recordings on paper-drum recorders. Eleven such recordings are produced, five of which are the proper frequencies to record some aspect of nearby earthquakes. One paper recording is produced from each of RLO, VVO, and SIO. The paper records are used as a digital system backup, and to scan for earthquakes faster than is possible on computer screens.

In addition to the digital and analog seismograms recorded at the OGS Observatory and main office, seismograms are recorded by five volunteer-operated seismographs. Each 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 200–1,800 ft 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. The times are set by a time signal radio receiver tuned to the National Institute of Standards and Technology and high-frequency radio station WWV. 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 OCO, which contains equipment similar to the volunteer-operated stations, is at the Omniplex museum in Oklahoma City. Omniplex staff members change the seismic records daily as well as maintain the equipment. OGS Observatory staff help interpret the seismic data and archive the seismograms with all other Oklahoma network seismograms.

The U.S. Geological Survey established a seismograph station 19 km from the OGS station at MEO at Meers. 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.

## DATA REDUCTION AND ARCHIVING

Prior to 1997, data processing was done by a series of manual steps, with earthquake locations calculated on a Hewlett-Packard 9825T desktop programmable calculator. This procedure has been in transition to processing on networked Sun Unix workstations.

All network digital and analog short-period (frequencies above about 1 hertz) 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; for example, "hyposat-in.2000004111040" would be the name for input data for an earthquake occurring on April 11, 2000, within a minute of 1110 GMT/UTC.

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 (e.g., hyposat-out.199804011555.C) 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

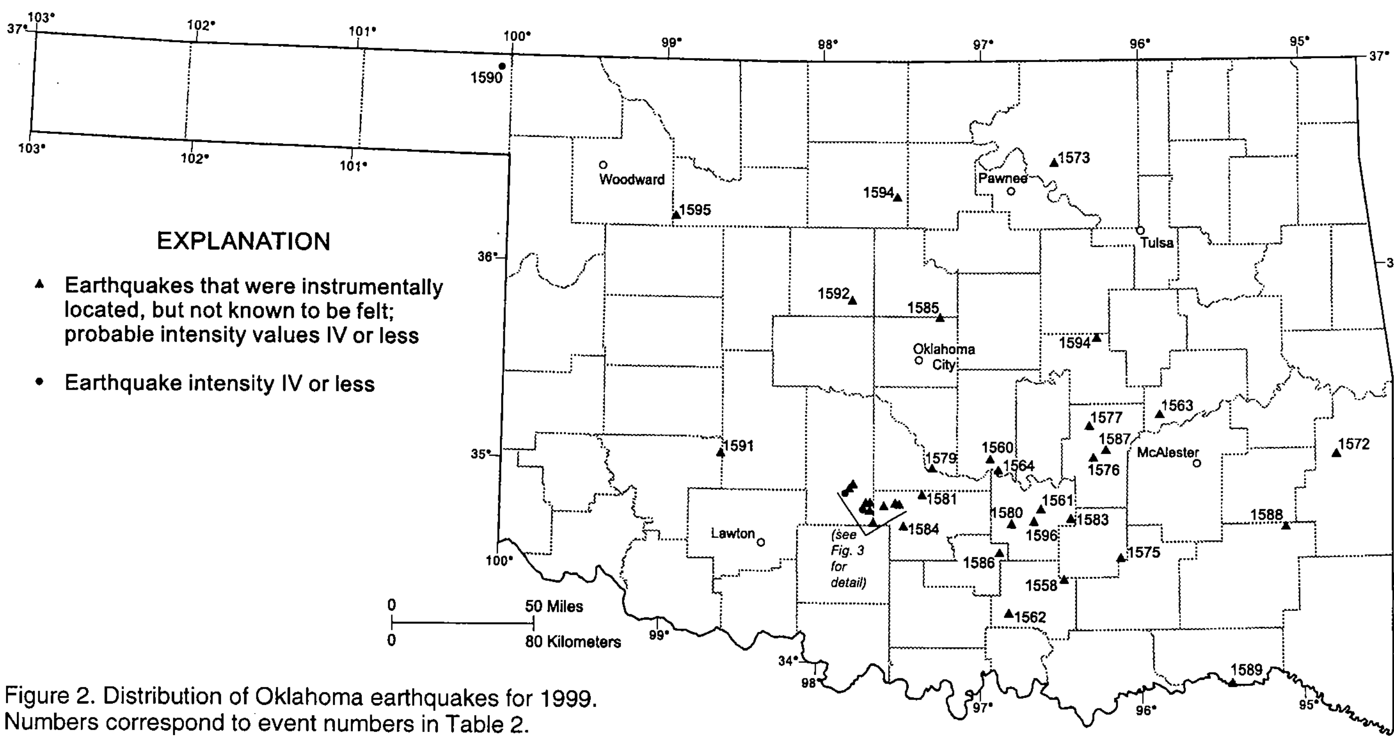


Figure 2. Distribution of Oklahoma earthquakes for 1999. Numbers correspond to event numbers in Table 2.

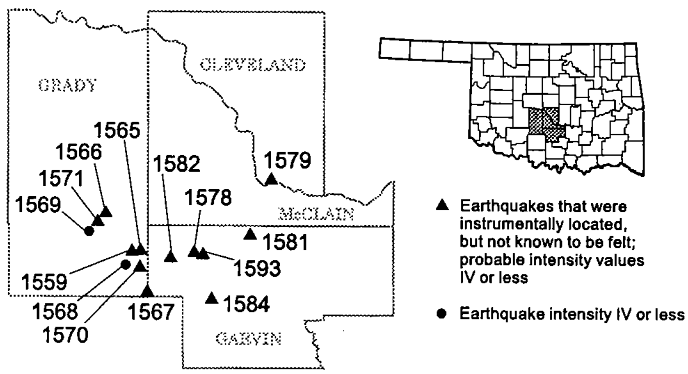


Figure 3. Distribution of 1999 earthquakes, Grady and Garvin Counties, Oklahoma. Numbers correspond to event numbers in Table 2.

location is determined. The solutions are added manually to a catalog on the Observatory Web site at http://www.okgeosurvey1.gov/level2/okeqcat/okeqcat.2000.html.

## EARTHQUAKE DISTRIBUTION

All Oklahoma earthquakes recorded on seismograms from three or more stations are located. In 1999, 39 Oklahoma earthquakes were located (Figs. 2, 3; Table 2). Three earthquakes were reported felt (Table 3). 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).

Three small earthquakes were reported felt, two in Grady County on April 16, and the other in Beaver County on October 25. The felt areas for these earthquakes are probably restricted to a few tens of square kilometers from the epicentral locations. No damage was reported from these events.

Earthquake-magnitude values ranged from a low of 1.0 (MDUR) in Pottawatomie County to a high of 3.0 (mbLg) in Beaver County. Eight of the 1999 locatable earthquakes occurred in Grady County. Garvin County experienced five earthquakes; Pontotoc County had four; Hughes County had three; and Johnston and Pottawatomie each had two.

## CATALOG

For both preliminary and final locations, the catalog of Oklahoma earthquakes is in HTML (World Wide Web) format; one HTML page contains all 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 Sun SPARC20 at the Observatory in Leonard, and a second copy is on a ONENet server. ONENet is the network of the Oklahoma Regents for Higher Education. The server copy, at the World Wide Web address http://www.okgeosurvey1.gov, is used for both public distribution and in-house reference; the Observatory copy is a backup copy.

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 (1980–90, 1993–99), Lawson and others (1991, 1992), and for the *Earthquake Map of Oklahoma* (Lawson and Luza, 1995b). The Oklahoma earthquakes article published annually in *Oklahoma Geology Notes* uses an additional sequential number not found on the World Wide Web catalog.

## TABLE 2. — OKLAHOMA EARTHQUAKE CATALOG FOR 1999

| Event no. | Date and origin time (UTC)[a] | | County | Intensity MM[b] | Magnitudes 3Hz | bLg | DUR | Latitude deg N | Longitude deg W | Depth (km)[c] | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1558 | Jan 17 | 08 01 08.38 | Johnston | | | | 1.7 | 34.4107 | 96.4869 | 3.56 | C |
| 1559 | Feb 13 | 06 20 56.37 | Grady | | | | 2.2 | 34.7904 | 97.7191 | 15.46 | C |
| 1560 | Mar 14 | 16 17 10.57 | Pottawatomie | | | | 1.2 | 35.0134 | 96.9375 | 7.76 | C |
| 1561 | Mar 20 | 04 40 13.12 | Pontotoc | | | | 1.2 | 34.7634 | 96.6290 | 2.46 | C |
| 1562 | Apr 07 | 20 43 10.60 | Johnston | | | | 1.5 | 34.2390 | 96.8316 | 5.00R | C |
| 1563 | Apr 10 | 13 51 21.79 | McIntosh | | | | 1.1 | 35.2357 | 95.8920 | 5.00R | C |
| 1564 | Apr 16 | 11 50 51.22 | Pottawatomie | | | | 1.0 | 34.9565 | 96.9002 | 17.41 | C |
| 1565 | Apr 16 | 15 43 47.31 | Grady | | | | 1.9 | 34.7964 | 97.6964 | 6.14 | C |
| 1566 | Apr 16 | 16 04 34.75 | Grady | | | | 1.4 | 34.8812 | 97.8153 | 0.10 | C |
| 1567 | Apr 16 | 16 32 37.27 | Grady | | | | 1.5 | 34.6946 | 97.6775 | 14.49 | C |
| 1568 | Apr 16 | 17 32 44.77 | Grady | F | | | 2.1 | 34.7629 | 97.7401 | 14.35 | C |
| 1569 | Apr 16 | 18 27 30.43 | Grady | F | | | 1.4 | 34.8448 | 97.8488 | 7.38 | C |
| 1570 | Apr 16 | 20 23 46.89 | Grady | | | | 1.7 | 34.7567 | 97.6985 | 5.00R | C |
| 1571 | Apr 16 | 22 21 50.21 | Grady | | | | 1.3 | 34.8663 | 97.8210 | 6.79 | C |
| 1572 | Apr 24 | 00 06 21.78 | LeFlore | | | | 1.3 | 35.0282 | 94.8031 | 5.00R | C |
| 1573 | May 06 | 06 43 12.88 | Osage | | | | 2.1 | 36.4908 | 96.5409 | 5.00R | C |
| 1574 | May 14 | 07 43 29.48 | Garfield | | | | 1.9 | 36.3207 | 97.5349 | 13.41 | C |
| 1575 | May 17 | 18 20 01.32 | Coal | | | | 2.3 | 34.5128 | 96.1392 | 5.00R | C |
| 1576 | May 20 | 10 50 43.49 | Hughes | | | | 1.2 | 35.0172 | 96.3078 | 11.64 | C |
| 1577 | Jun 27 | 11 16 29.89 | Hughes | | 1.6 | 1.7 | 1.7 | 35.1794 | 96.3230 | 8.54 | C |
| 1578 | Jun 29 | 14 32 18.25 | Garvin | | | 1.8 | 1.6 | 34.7892 | 97.5272 | 3.63 | C |
| 1579 | Jul 14 | 08 55 22.80 | Cleveland | | 1.6 | 1.5 | 1.6 | 34.9674 | 97.3087 | 6.31 | C |
| 1580 | Aug 05 | 18 51 12.50 | Pontotoc | | | | 1.7 | 34.6941 | 96.8081 | 5.00R | C |
| 1581 | Aug 09 | 14 30 08.27 | Garvin | | 1.9 | | | 34.8363 | 97.3683 | 5.00R | C |
| 1582 | Aug 09 | 14 56 23.01 | Garvin | | 1.9 | | 1.8 | 34.7812 | 97.6084 | 5.00R | C |
| 1583 | Aug 22 | 18 41 16.29 | Pontotoc | | 1.3 | 1.3 | 1.2 | 34.7153 | 96.4412 | 5.00R | C |
| 1584 | Aug 24 | 13 58 23.65 | Garvin | | 2.3 | 2.1 | 1.9 | 34.6737 | 97.4849 | 3.59 | C |
| 1585 | Sep 09 | 15 07 24.02 | Oklahoma | | 1.8 | | 1.6 | 35.7242 | 97.2612 | 5.00R | C |
| 1586 | Sep 15 | 19 30 18.81 | Murray | | 1.9 | 2.0 | 1.6 | 34.5464 | 96.8854 | 0.10 | C |
| 1587 | Sep 17 | 03 16 52.78 | Hughes | | | | 1.9 | 35.0539 | 96.2237 | 17.78 | C |
| 1588 | Oct 08 | 22 32 09.91 | Pushmataha | | 1.7 | | 1.3 | 34.6713 | 95.1268 | 5.00R | C |
| 1589 | Oct 09 | 22 36 00.89 | Choctaw | | 2.2 | 2.1 | 1.9 | 33.8836 | 95.4735 | 5.09 | C |
| 1590 | Oct 25 | 23 19 51.68 | Beaver | F | 2.8 | 3.0 | 2.5 | 36.9462 | 100.0700 | 5.00R | C |
| 1591 | Oct 28 | 10 51 29.72 | Kiowa | | 1.9 | | 2.3 | 35.0385 | 98.6361 | 0.10 | C |
| 1592 | Oct 31 | 14 09 39.97 | Kingfisher | | | | 2.1 | 35.8046 | 97.8191 | 9.37 | C |
| 1593 | Nov 01 | 04 27 20.32 | Garvin | | 2.1 | 2.2 | 2.0 | 34.7852 | 97.5213 | 15.30 | C |
| 1594 | Nov 20 | 09 08 04.70 | Okfuskee | | 1.2 | 1.2 | 1.4 | 35.6212 | 96.2782 | 10.56 | C |
| 1595 | Nov 22 | 06 13 22.85 | Major | | | | 2.4 | 36.2196 | 98.9457 | 5.00R | C |
| 1596 | Dec 07 | 10 35 02.40 | Pontotoc | | 2.0 | | 1.8 | 34.6994 | 96.6742 | 5.67 | 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 6 hours.

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

[c]5.0R indicates that the depth was restrained to 5.0 km from the beginning of the calculation. If R is preceded by a number other than 5.0, 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.

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 6 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. When the magnitude value is in-

**TABLE 3. — EARTHQUAKES REPORTED FELT IN OKLAHOMA, 1999**

| Event no. | Date and origin time (UTC)[a] | | Nearest city | County | Intensity MM[b] |
|---|---|---|---|---|---|
| 1568 | Apr 16 | 17 32 44.77 | 20 km E Rush Springs | Grady | F |
| 1569 | Apr 16 | 18 27 30.43 | 12 km NE Rush Springs | Grady | F |
| 1590 | Oct 25 | 23 19 51.68 | 10 km N of Gate | Beaver | F |

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

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

**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. |

creased one unit, the amplitude of the earthquake waves increases 10 times. 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.

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:

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

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

In 1979, St. Louis University (Stauder and others, 1979) modified the formulas for m3Hz. This modification was used by the OGS Observatory beginning January 1, 1982. The modified formulas had the advantage of extending the distance range for measurement of m3Hz out to 400 km, but also had the disadvantage of increasing m3Hz by about 0.12 units compared to the previous formula. Their formulas were given in terms of log($A$) but were restricted to wave periods of 0.2–0.5 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)

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

(epicenter 100–200 km from a seismograph)

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

(epicenter 200–400 km from a seismograph)

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

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

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

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

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

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 $\Delta$ 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:

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

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

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

## ACKNOWLEDGMENTS

Todd McCormick, James King, and Amie Friend maintained 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 830-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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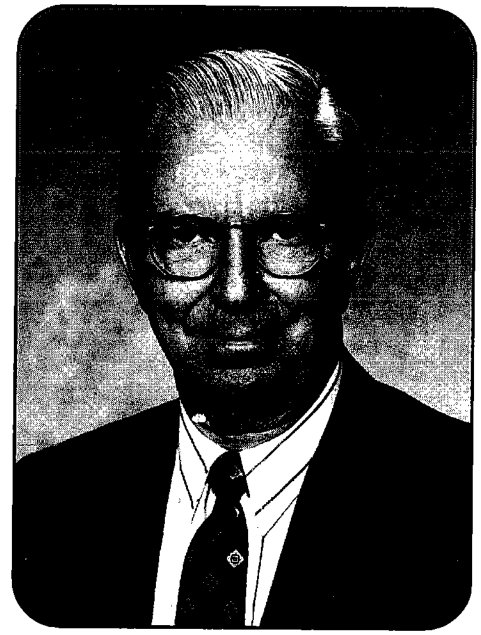


Charles J. Mankin

# OGS director named AAPG Honorary Member

Oklahoma Geological Survey Director Charles J. Mankin received one of the American Association of Petroleum Geologists' highest awards at the opening of the organization's 2000 annual convention in New Orleans last April.

The AAPG Honorary Membership Award is presented to AAPG members who have distinguished themselves by their accomplishments and through service to the profession of petroleum geology and AAPG.

Mankin has directed the OGS since 1967 and has served as a faculty member and director of the University of Oklahoma School of Geology and Geophysics. He belongs to numerous professional societies and has served as energy advisor to Oklahoma governors throughout his tenure as OGS director. He also has appeared many times by invitation before Congressional and Oklahoma Legislature committees.

In AAPG, Mankin served on seven different committees, and chaired the Geological Highway Map Committee two times.

"Mankin was the driving force on one of the most critical pieces of geologic legislation in the past 25 years—the National Geologic Mapping Act. The fruits of that legislation will be a part of his fine legacy," wrote William E. Fisher, who nominated Mankin for the award.

"The State of Oklahoma has been very good to me," Mankin said in his response to the award. "My 40-plus years at the University of Oklahoma have given me opportunities beyond my wildest dreams. I have had the privilege of serving as a faculty member, as director of the School of Geology and Geophysics, as executive director of the Energy Resources Institute, and for the past 33-plus years as director and State geologist of the Oklahoma Geological Survey.

"Through the years I have had the opportunity to get to know, to work with, and to learn from literally hundreds of very bright and considerate people. For better or for worse, I am the product of this process."

Mankin had previously received the Public Service Award from AAPG.

# new OGS publications

**BULLETIN 147**

**• *by* Kent S. Smith and Richard L. Cifelli**
**• 36 pages**
**• Paperbound, laminated cover**
**• $3**

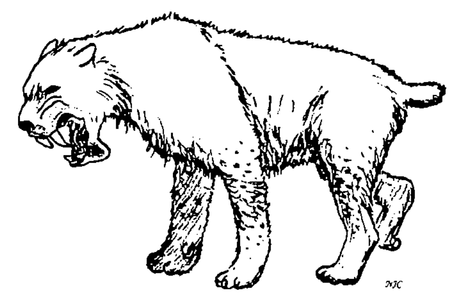
## A Synopsis of the Pleistocene Vertebrates of Oklahoma

Bones of Pleistocene mammals are the most commonly found fossil vertebrate remains in Oklahoma. The discovery and scientific study of the State's Pleistocene vertebrates began well before statehood, and a large volume of scientific literature has been devoted, in part or exclusively, to describing this rich fauna. No publication has provided a comprehensive overview of this literature, however, and thus the significance of these finds might be missed.

This volume, which is intended as a useful resource for both professionals and amateurs, attempts to fill this gap by reviewing existing reports on Pleistocene vertebrates of Oklahoma. Sections cover described local faunas, faunules of precisely known ages, notable faunules of imprecisely known ages, and three archeological sites that include diverse vertebrate assemblages. The publication also contains a provisional listing of known sites producing remains of proboscideans.

Most Pleistocene vertebrates discovered in Oklahoma are from the western part of the State. The vast majority—81%—are from the Late Pleistocene (Rancholabrean land-mammal age). At present, 130 vertebrate taxa, including 14 fish, 6 amphibians, 30 reptiles, 4 birds, and 76 mammals have been reported from the Pleistocene of Oklahoma.

Kent Smith is a member of the Zoology faculty at the University of Oklahoma (OU) and a research associate at the Oklahoma Museum of Natural History (OMNH). Richard Cifelli is curator of vertebrate paleontology at the OMNH and a professor in the Department of Zoology and in the School of Geology and Geophysics.



The cover of Bulletin 147 features a drawing of a scimitar cat found in western Oklahoma and decribed as a new taxon. *Illustration by Nicholas J. Czaplewski.*

**SPECIAL PUBLICATION 2000-1**

**• *by* Robert O. Fay**
**• Paperbound**
**• 14 pages**
**• $1**

## Bibliography of Copper Occurrences in Pennsylvanian and Permian Red Beds and Associated Rocks in Oklahoma, Texas, and Kansas (1805 to 1996)

Widespread occurrences of copper mineralization in Pennsylvanian and Permian red-bed deposits in the Midcontinent have long been known. Some of these accumulations have been sufficiently large to support mining activities. While much data have been collected from these occurrences, a generally accepted explanation for their origin has yet to emerge.

This bibliography, compiled over a number of years by OGS geologist Robert O. Fay, serves to provide data that can be used as a starting point for an investigation of these unusual deposits. It contains more than 400 listings from a broad range of sources, including USGS and state survey publications, historical journals, theses and dissertations, and government reports.

**OGS Bulletin 147** and **SP 2000-1** 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, 1218-B W. Rock Creek Road, Norman; phone (405) 360-2886, fax 405-366-2882, e-mail ogssales@ou.edu. Request the 2000–2001 OGS *List of Available Publications* for current listings and prices.

## OGS Web site offers rock club calendar and news

The Oklahoma Geological Survey Web site (http://www.ou.edu/special/ogs-pttc/) now has a rock club calendar page that lists events for people of all ages interested in rockhounding and collecting rocks, minerals, and fossils in Oklahoma. It also contains news items of interest to Oklahoma rockhounds.

To add an item to the calendar or to contribute a news item to the Web site, contact Neil Suneson at the OGS, (405) 325-3031; e-mail nsuneson@ou.edu.

For more information about rockhounding, refer to the list below for the Oklahoma rock club in your area.

**Ada Gem, Mineral & Fossil Club**
P.O. Box 117
Clarita, OK 74535
Meets 2nd Thursday, 7 p.m. (most mos.)
Ada Public Library
124 S. Rennie, Ada
Contact: Bill Lyon, (580) 332-8666, jblyon@chickasaw.com

**Enid Gem and Mineral Society**
2614 W. Oklahoma
Enid, OK 73703
Meets 1st Thursday, 7:30 p.m. (except Sept. & Dec.)
Hoover Building
Garfield County Fairgrounds, Enid
Contact: Frances Johnson, (580) 233-1852

**McCurtain County Gem and Mineral Club**
Route 4, Box 60
Broken Bow, OK 74728
Meets 3rd Tuesday, 7:30 p.m.
Museum of the Red River
812 Lincoln Road, Idabel
Contact: Cephis Hall, (580) 494-6612

**Oklahoma Mineral and Gem Society**
P.O. Box 25632
Oklahoma City, OK 73125
Meets 3rd Thursday, 7:30 p.m. (except June & Dec.)
Will Rogers Garden Exhibition Bldg.
3400 N.W. 36th St., Oklahoma City
Contact: Max or Arlene Burkhalter, (405) 732-0808, maburk1@msn.com

**Osage Hills Gem and Mineral Society**
P.O. Box 612
Bartlesville, OK 74005
Meets 3rd Thursday, 7 p.m. (except Aug. & Dec.)
East Christian Church
3221 Tuxedo Blvd, Bartlesville
Contact: Mel Albright, (918) 336-8036, mela@galstar.com

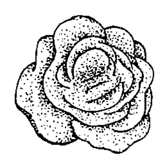
**Rough & Tumbled Rock & Gem Club**
129 Viola Ave.
Ponca City, OK 74601
Meets 4th Tuesday, 7 p.m.
Albright United Methodist Church
128 S. Palm, Ponca City
Contact: Don Hopkins, (580) 762-5287, donalma@poncacity.net

**Shawnee Gem & Mineral Club**
111 W. Hickory
Shawnee, OK 74804
Meets 1st Tuesday, 7:30 p.m.
Northridge Church of Christ
1001 E. MacArthur St., Shawnee
Contact: Tom Morris, (405) 386-2314, dethwrdn@flash.net

**Stillwater Mineral and Gem Society**
1116 S. Gray
Stillwater, OK 74074
Meets 4th Thurs. (3rd Thurs. Nov. & Dec.), 7:30 p.m.
First United Methodist Church
400 W. 7th Ave., Stillwater
Contact: Dan and Ruby Lingelbach, (405) 372-8635

**Tahlequah Rock and Mineral Society**
P.O. Box 932
Tahlequah, OK 74465
Meets 3rd Tuesday, 7 p.m.
Tahlequah Public Library
120 S. College Ave., Tahlequah
Contact: Maxene Woods, (918) 456-8198

**Tulsa Rock and Mineral Society**
P.O. Box 2292
Tulsa, OK 74101
Meets 2nd Monday, 7 p.m.
Tulsa City-County Library
400 Civic Center
Contact: Bob Shaha, (918) 342-5661



*State Rock of Oklahoma, the barite rose.*

## MINERAL NAMED FOR OKLAHOMA PROFESSOR

A newly discovered mineral has been named for David London, professor at the University of Oklahoma's School of Geology and Geophysics.

Londonite, a cesium beryllium aluminoborate, is a gem-quality mineral that occurs in granitic pegmatites of Madagascar.

The name for the mineral was proposed to the International Mineralogical Association's Commission on New Minerals and Mineral Names by its discoverers, William B. Simmons, Karen L. Weber, and Al U. Falster at the University of New Orleans, and Federico Pezzotta of the Museum of Natural History of Milan.

London has been a leading researcher in the geology and origins of granitic pegmatites and the occurrence of gem materials in these rocks. Pegmatites are the dominant sources of the emerald, aquamarine, topaz, tourmaline (the official gemstone of the United States), orange garnet, and other rarer gemstones.

# Oklahoma legislature names new State Fossil

A 16-foot-tall terror from the Jurassic Period has lumbered into position alongside the mountain boomer, scissor-tailed flycatcher, buffalo, and white bass as an official emblem of the State of Oklahoma.

*Saurophaganax maximus,* a fearsome dinosaur that lived 150 million years ago, was chosen this spring by the Oklahoma State Legislature to be the "Official State Fossil."

Oklahoma can boast the only known specimens of this dinosaur, which is an allosaur similar in size and appearance to *Tyrannosaurus rex.* The specimens were found in a quarry in Cimarron County, near Black Mesa, in the late 1930s by WPA crews working under the direction of OU paleontologist J. Willis Stovall (see "On the Cover," p. 26).

*Saurophaganax,* whose name means "greatest king of the reptile eaters," predated *T. rex* by about 80 million years. Unlike *T. rex,* which had tiny, almost useless arms and small claws, *Saurophaganax* was equipped with long arms and three-clawed hands that allowed it to grasp its prey. These deadly claws were the largest of any meat-eating dinosaur.

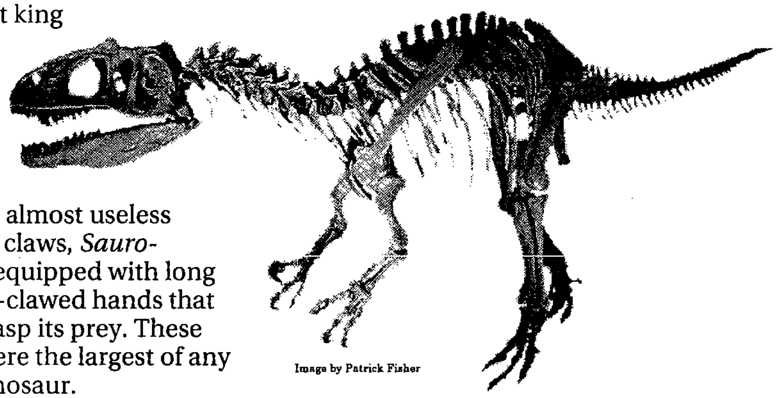


Image by Patrick Fisher

## *Saurophaganax* showcased in newly opened museum

Skeletons of *Saurophaganax* and an *Apatosaurus* (the large-bodied, long-necked herbivore commonly called *"Brontosaurus"*)—appear to struggle in mortal combat in the University of Oklahoma's newly opened Sam Noble Oklahoma Museum of Natural History. A mural backdrop portrays the living dinosaurs and other animals that lived in Oklahoma during the Jurassic Period.

The museum building, in its new location at 2401 Chautauqua in Norman, offers 11 times more space for exhibits than the old Oklahoma Museum of Natural History building. The *Saurophaganax* and *Apatosaurus* exhibit is the centerpiece of the museum's Hall of Ancient Life, which depicts life in Oklahoma through time.

Admission fees at the museum are $4 for adults, $3 for seniors and OU faculty and staff (with ID), and $2 for children ages 6–7. Children 5 and under and OU students with valid OU ID are admitted free. For more information call (405) 325-4712; or check the museum's Web site, http://www.snomnh.ou.edu/.

**Send Geonews Roundup contributions to: *Notes* Editor, Oklahoma Geological Survey, 100 E. Boyd, Room N-131, Norman, OK 73019, fax: 405-325-7069, e-mail: tpeeters@ou.edu. Thank you!**

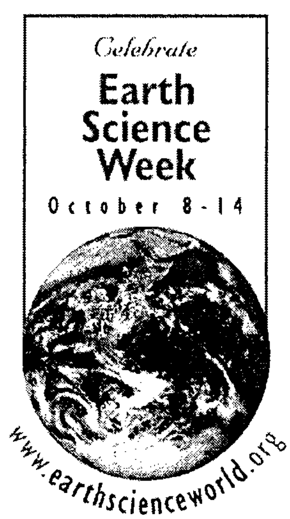
## SIPES installs new officers

The following individuals were installed as officers at the March 25, 2000, meeting of the Society of Independent Professional Earth Scientists (SIPES):

President: A. T. (Toby) Carleton, Midland, Texas
Vice President: Scott A. Wainwright, New Orleans, Louisiana
Vice President of Natural Resources: Roger L. Martin, Wichita, Kansas
Secretary: James L. Claughton, Corpus Christi, Texas

Newly elected to the board of directors are Robert W. Buehler, San Antonio; Robert C. Leibrock, Midland; Marion E. Spitler, Dallas; Lawrence H. Davis, Oklahoma City; and Wiliam T. Goff III, Denver.

## Information available for Earth Science Week 2000




Across the nation, the week of October 8–14 will be celebrated as Earth Science Week 2000.

In recognition of Earth Science Week in Oklahoma, the Oklahoma Geological Survey is preparing a publication that will provide answers to some of the questions most commonly asked of our geologists. For information, contact Neil Suneson, (405) 325-3031, e-mail nsuneson@ou.edu. OGS publications prepared for past Earth Science Week celebrations are still available.

The American Geological Institute, the sponsor organization for Earth Science Week, offers free kits (one per individual) and information to help teachers, field-trip leaders, and others prepare for Earth Science Week. Write to Earth Science Week, American Geological Institute, 4220 King St., Alexandria, VA 22302; phone (703) 379-2480, fax (703) 379-7563, Web www.earthscienceworld.org.

## Water Quality of the Quaternary and Ada-Vamoosa Aquifers on the Osage Reservation, Osage County, Oklahoma, 1997

*USGS Water-Resources Investigations Report 99-4231*

In response to concerns about the effects that oil production might have on water quality and to obtain information needed to plan and manage the increasing demands for water on the Osage Reservation, the U.S. Geological Survey, in cooperation with the Osage Tribe, conducted a study of the water quality in the Quaternary and Ada-Vamoosa aquifers in the Osage Reservation, northeastern Oklahoma. This 76-page report by Marvin M. Abbott contains the findings of this study.

The project included documenting information for rural-domestic-water wells, collecting 120 water-quality samples from those wells, and comparing the water quality to proximity to oil wells. The water wells were located and sampled from September to December 1997.

About 38,500 oil wells have been drilled in the reservation since drilling began in 1896, and about 1,480 square miles or 64 percent of the reservation is within a quarter mile of an oil well.

Order WRI 99-4231 from: 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.

## Depth-Duration Frequency of Precipitation for Oklahoma

*USGS Water-Resources Investigations Report 99-4232*

Precipitation depths for various durations and frequencies, or depth-duration frequency of precipitation, have many uses. Depth-duration frequency of precipitation is commonly used for the design of drainage structures that control and route localized runoff—such as parking lots, storm drains, and culverts. It also is used to compile rainfall-runoff models, which incorporate precipitation characteristics. Accurate depth-duration frequency of precipitation estimates are important for economical and safe structural designs at stream crossings and for developing reliable flood prediction models.

This 113-page report, by Robert L. Tortorelli, Alan Rea, and William H. Asquith, updates depth-duration frequency of precipitation from previous studies for Oklahoma. The USGS, in cooperation with the Oklahoma Department of Transportation, conducted the study to define updated precipitation characteristics for Oklahoma.

The precipitation durations investigated were: 15, 30, and 60 minutes: 1, 2, 3,6, 12, and 24 hours; and 1, 3, and 7 days. The seven selected frequencies investigated, expressed as recurrence intervals, were: 2, 5, 10, 25, 50, 100, and 500 years. The precipitation station data, contours, and surfaces are published separately in digital form in the Open-File Report listed below.

Order WRI 99-4232 from: 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.

## Digital Data Sets of Depth-Duration Frequency of Precipitation for Oklahoma

*USGS Open-File Report 99-463*

Prepared by Alan Rea and Robert Tortorelli as a companion report to WRI 99-4232 (above), these geospatial data sets were produced as part of a regional precipitation frequency analysis for Oklahoma.

The data sets consist of surface grids of precipitation depths for seven frequencies (expressed as recurrence intervals of 2, 5, 10, 25, 50, 100, and 500 years) and 12 durations (15, 30, and 60 minutes; 1, 2, 3, 6, 12, and 24 hours; and 1, 3, and 7 days). Eighty-four depth-duration-frequency surfaces were produced from precipitation-station data. Precipitation-station data from which the surfaces were interpolated and contour lines derived from each surface also are included. Contour intervals vary from 0.05 to 0.5 inch.

OFR 99-463 is a CD-ROM and can be ordered from: 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. The data sets also are available at the USGS Website at http://water.usgs.gov/lookup/get?ofr99-463.

# upcoming meetings

**SEPTEMBER 2000**

**The Society for Organic Petrology, Annual Meeting,** September 16–18, Bloomington, Indiana. Information: Charles Barker, USGS, Box 25046, MS 939, Denver, CO 80225; (303) 236-5797, fax 303-236-0459; e-mail: barker @usgs.gov; Web: http://www.tsop.org.

**Hartshorne Play Workshop** *(repeat of 1998 OGS workshop),* September 20, Oklahoma City, Oklahoma. Information: Carol Jones, Oklahoma City Geological Society, (405) 236-8086, ext. 11.

**Hartshorne Play Workshop** *(repeat of 1998 OGS workshop),* September 21, Tulsa, Oklahoma. Information: Tom Heinecke, Tulsa Geological Society, (918) 748-5407.

**OCTOBER 2000**

**Society of Petroleum Engineers, Annual Meeting,** October 1–4, Dallas, Texas. Information: SPE, (214) 952-9393; Web: http://www.spe.org.

**American Institute of Professional Geologists, Annual Meeting,** October 11–15, Milwaukee, Wisconsin. Information: AIPG, 8703 Yates Dr., Ste. 200, Westminster, CO 80030; (303) 412-6205; e-mail: aipg@netcom.com.

**American Association of Petroleum Geologists International Conference,** October 15–18, Bali, Indonesia. Information: AAPG Conventions Dept., Box 979, Tulsa, OK 74101; (918) 560-2639, fax 918-560-2626.

**Geospatial Information and Technology Association, Annual GIS for Oil and Gas Conference,** October 21–23, Houston, Texas. Information: GITA, 14456 East Evans Ave., Aurora, CO 80014; (303) 337-0513, fax 303-337-1001; e-mail: staff@gita.org; Web: http://www.gita. org.

**Gulf Coast Association of Geological Societies 50th Anniversary Meeting,** October 25–27, Houston, Texas. Information: Mr. T. S. Brown, CAEX Services, Inc., 5555 San Felipe, Ste. 500, Houston, TX 77056; (713) 850-8255; e-mail: tsbrown@caexserv.com.

**Society of Vertebrate Paleontology, Annual Meeting,** October 25–28, Mexico City, Mexico. Information: Sean Allen or Debbie Pederson, (847) 480-9095; e-mail: svp@ sherwood.com; Web: http://www.museum.stte.il.us/svp.

## OGS to present a workshop on Hunton reservoirs

The Oklahoma Geological Survey, in cooperation with the Petroleum Technology Transfer Council, will present a one-day workshop this fall on petroleum occurrence, exploration, and development in rocks of the Hunton Group (Ordovician, Silurian, and Devonian) in Oklahoma and the Texas Panhandle. This workshop on the Hunton play will be held at the Moore-Norman Technology Center, 4701 12th Ave., NW, in Norman. Participants will have a choice of attending October 17 or 18.

The workshop will examine lithostratigraphic relationships of the individual formations and members that make up the Hunton Group. Also studied will be Hunton relationships with the underlying Sylvan Shale (Ordovician) and the overlying Woodford Shale (Devonian–Mississippian).

The shallower parts of the Anadarko and Arkoma basins have been drilled intensively. Thus, valuable geological information is available for defining environments of deposition, stratigraphic relationships, and economic potential. Many of the concepts developed from these studies are applicable to the largely unexplored deeper parts of the Anadarko basin and to areas of the Cherokee platform that have not been developed because of high water cuts in the Hunton.

The workshop will provide a general overview of carbonate-reservoir basics, a history of Hunton oil and gas exploration and development, and aspects of Hunton stratigraphy such as facies, dolomitization, and karstification. Also to be discussed are submersible-pump applications in Hunton reservoirs with high water cuts.

Hunton reservoirs in three Oklahoma fields will be examined in detail: those in Leedey field in Dewey County, East Arnett field in Ellis County, and Prairie Gem field in Lincoln County.

Kurt Rottmann, an Oklahoma City consultant geologist, will lead the workshop. He has contributed to several previous OGS workshops on fluvial-dominated deltaic petroleum reservoirs, and most recently to those on waterflooding.

Also participating in presenting the workshop are several other Oklahoma geologists: Edward A. ("Ted") Beaumont, a Tulsa consultant; Robert A. Northcutt, an Oklahoma City independent; and Zuhair Al-Shaieb, Jim Puckette, and Paul Blubaugh at Oklahoma State University, Stillwater. Pat Brown, a production engineer with New Dominion Oil Company in Stillwater, is also on the program. T. L. Rowland, an Oklahoma City geological consultant, will provide a brief memorial for the late Thomas W. Amsden, whose research laid the groundwork for further exploration and development of the Hunton.

The price for the workshop will be set at a later date; it will include the cost of workbooks that contain the material presented at the meeting.

For information, contact Michelle Summers, Oklahoma Geological Survey, 100 E. Boyd, Room N-131, Norman, OK 73019; (800) 330-3996 or (405) 325-3031, fax (405) 325-7069.

# Oklahoma abstracts

The Oklahoma Geological Survey thanks the *Canadian Journal of Earth Sciences* and the Geological Society of America for permission to reprint the following abstracts of interest to Oklahoma geologists.

## First Record of *Seymouria* (Vertebrata: Seymouriamorpha) from Early Permian Fissure Fills at Richards Spur, Oklahoma

*CORWIN SULLIVAN* and *ROBERT R. REISZ*, Dept. of Zoology, Erindale Campus, University of Toronto, Mississauga, ON L5L 1C6, Canada

Isolated skeletal elements of the amphibian genus *Seymouria* were recently discovered at the Richards Spur locality near Fort Sill, Oklahoma, a prolific source of Early Permian tetrapod remains. Five of the seven described bones are of juvenile size and include three neural arches, a humerus, and a femur, whereas the other two are partial vertebrae, apparently adult. All seven are morphologically similar to equivalent skeletal elements in *Seymouria* specimens previously collected in Europe and North America, apart from features reflecting the early developmental stage of the juvenile bones. The femur and humerus are clearly distinct from those of other seymouriamorphs such as *Ariekanerpeton* and *Kotlassia*. The rarity of *Seymouria* at the Richards Spur locality implies that it was not a regular component of the fauna, and it is also associated with the less markedly terrestrial assemblage that consistently occurs at localities in the southwestern United States. However, its skeletal morphology and occurrence at terrestrial localities such as Richards Spur imply a primarily terrestrial, rather than an amphibious, mode of life. Conflicting biostratigraphic correlations imply that the exact age of the Richards Spur deposits is uncertain, and equivalence to the Arroyo Formation of Texas may be erroneous.

Reprinted as published in the *Canadian Journal of Earth Sciences*, v. 36, no. 8, p. 1257, August 1999.

## A New Permian Vertebrate Trackway in North-Central Oklahoma

*BROOKE A. SWANSON*, Dept. of Geology, Gustavus Adolphus College, 800 West College Ave., St. Peter, MN 56082

Trackways contribute to paleobiological interpretations by adding behavioral and ecological information unavailable from skeletal fossils. This study focuses on a recently discovered vertebrate trackway north of Perry, Oklahoma. In excess of 1,000 reptile and amphibian tracks have been documented at the site. These include 16 terrestrial vertebrate trackways representing a minimum of 8 ichnotaxa. In addition to the abundance and diversity of tracks, the track producing layer is easily traceable ½ mile to the north and south. The tracks are found on a single dolomite bedding plane in the Early Permian Wellington Formation. This is the first Permian trackway site reported from Oklahoma.

The paleoenvironment of this region during the Early Permian has been problematic. The gray, flat-lying shales and dolomites of this part of the Wellington Formation have cyclic depositional patterns and other sedimentologic features that have led some workers to the interpretation of a marginal marine paleoenvironment. Alternate interpretations of a lacustrine or estuarine environment are supported by the occasional occurrence of a nonmarine fauna of insects, vertebrates, and plants. The trackway data contribute to a reinterpretation of this part of the Wellington.

Reprinted as published in the Geological Society of America *1999 Abstracts with Programs*, v. 31, no. 7, p. A-468–A469.

## A New Permian Vertebrate Locality in North-Central Oklahoma

*SUSAN JOY*, Dept. of Geology, Gustavus Adolphus College, 800 W. College Ave., St. Peter, MN 56082

This study describes a new Early Permian vertebrate locality north of Perry, Oklahoma. The excavated site is located within a channel deposit consisting of alternating sandstone and mudstone layers, and has yielded numerous plants as well as fish, amphibian, and reptile fossils.

The paleoenvironment of this part of the Wellington Formation has remained problematic. In contrast to the red fluvial deposits of most Early Permian sites, the sediments surrounding the new locality consist of relatively flat-lying dolomites and shales that have been interpreted as lacustrine or marginal marine in origin. The flora and fauna of the channel fill along with fossil insects as well as a new extensive vertebrate trackway site found nearby allow for a reinterpretation of the paleoenvironment of these deposits.

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## Provincialism in *Idiognathodus* and *Streptognathodus* During the Kasimovian (Late Carboniferous)

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Direct comparison of Late Carboniferous conodont faunas from the Moscow Basin, Russia, the Donets Basin, Ukraine, and the North American Midcontinent region reveals that two distinct species groups of *Idiognathodus* existed during the Kasimovian. Evolution occurred independently in lineages in Eur-

asia (Moscow and Donets basins) and the Midcontinent region, which were partially isolated from each other at this time.

Earliest Kasimovian *Idiognathodus* faunas of the Midcontinent region are characterized by the *I. delicatus/expansus* lineage and a lineage of troughed Pa elements that includes *I. nodocarinatus*. An early Kasimovian radiation produced a new group of nodose *Idiognathodus* species, out of which appeared the middle Kasimovian clade of species that comprise *Streptognathodus*. In the late Kasimovian, another species radiation occurred, originating with the regional cryptogene *S. firmus*, and displaced the middle Kasimovian fauna. In Eurasia, an early Kasimovian species of *Idiognathodus*, often called "*S. cancellosus*," produced a series of descendants with increasing carina length and reduced lobes that lead to "*S. oppletus*" by the middle Kasimovian, and "*S.*" *firmus* by the late Kasimovian. More typical *Idiognathodus* species such as *I. sagittalis* also occur, but differ from Midcontinent species.

During major eustatic highstands some *Idiognathodus* species migrated from one region into the other. These migrants permit correlations to be made between the conodont successions of the two regions. The migration of *Streptognathodus firmus* to North America may be responsible for the late Kasimovian fauna turnover in the Midcontinent.

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## Ammonitella Size as a Conservative Trait: Evidence from Two Carboniferous Ammonoid Lineages

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The glaphyritid genus *Syngastrioceras* is among the most abundant ammonoid taxa in the southern midcontinent. Representatives of the *S. globosum–S. oblatum* lineage were collected from eight different localities in the northern Arkansas Hale and Bloyd Formations (Morrowan). Mean ammonitella diameter in these populations ranges from 0.80 to 0.85 mm, but the differences are not statistically significant. Interestingly, *Eoasianites angulatus* from the Seminole Formation (Missourian) of Oklahoma, a probable descendant of *Syngastrioceras*, has a very similar mean ammonitella diameter (0.76 mm).

It has long been thought by biostratigraphers that the *Reticuloceratidae* may have given rise to the *Schistoceratidae* in the Morrowan, with the reticuloceratid species *Retites semiretia* as the likely ancestor of the earliest known schistoceratid, *Branneroceras branneri*. Evidence for this relationship was based mainly on the similarity of the sutures and shell ornamentation. Specimens of *R. semiretia* were collected from horizons in the Cane Hill and Prairie Grove Members of the Hale Formation, whereas specimens of *B. branneri* were collected from the overlying Brentwood Member of the Bloyd Formation. Mean ammonitella diameter in the *R. semiretia* populations ranges from 0.78 to 0.81 mm, while in the *B. branneri* population the mean was 0.82 mm; however, once again, the differences are not statistically significant.

These data suggest that ammonitella size is a conservative character. Thus, these results have important implications for future phylogenetic analysis of ammonoids.

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## Electrical Geophysical Study Over the Norman Landfill, Near Norman, Oklahoma

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In 1995 and 1996 the U.S. Geological Survey made 40 Schlumberger dc electrical resistivity soundings at the Norman Landfill, near Norman, Oklahoma. Interpretation of the resistivity data indicates that high resistivities (>300 ohm-m) are related to dry sand, intermediate resistivities (45–300 ohm-m) are related to freshwater saturated sand, and low resistivities (<45 ohm-m) are related to fine-grained materials or materials saturated with the conductive fluids. Interpreted resistivity maps show a low resistivity anomaly that extends from under the landfill to just past a nearby slough. This anomaly corresponds to known areas of ground water contamination. A resistivity cross section, constructed from interpreted Schlumberger soundings, shows that this low resistivity anomaly is about 5 m deep and up to 9 m thick.

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## Development of Exploration Reflection Seismology: A Linkage of Physics and Geology through the University of Oklahoma

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Reflection seismic profiling has been used to image the Earth's crust more extensively than any other geophysical technique. This method was developed by collaboration between a physicist, J. Clarence Karcher, and geologists associated with the University of Oklahoma. Karcher worked on, and thought about, seismic reflections from 1917 until the first definitive experiments were carried out in 1921 in Oklahoma City and in the Arbuckle Mountains.

This story is particularly interesting because (1) it is a classic example of cross-disciplinary research between physics and geology; (2) it illustrates the movement from more basic research to commercial application; and (3) it displays the roles of federal and industrial funding of research.

In this presentation we concentrate on the interaction between Karcher and the academic community centered around the University of Oklahoma from the period 1919–1921. W. P. Haseman of the Department of Physics, and D. W. Ohern of the Oklahoma Geological Survey, along with Irving Perrine, were the key connections. The field test which demonstrated the power and usefulness of seismic reflection was conducted in July 1921 at Vines Branch in the Arbuckles on a geological structure called the Vines Dome. The choice of this location was made by Ohern and Perrine based on well-known surficial geology and good map control. The resulting seismic image could clearly be matched with the profile constructed from structural geology.

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## Hazards and Resource Recognition in an Urban Environment

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In FY98, the Oklahoma Geological Survey began mapping the geology of the Oklahoma City metro area (OCMA) as part of the USGS-sponsored STATEMAP program. Eight 7.5′ geologic maps of the OCMA are available; 24 are planned. Because the area is being developed rapidly, a key purpose of the mapping is to provide landowners and city planners and engineers with enough geologic-map information that will allow them to make sound land-use decisions. The recognition of geologic hazards and resources is an immediate benefit of the mapping; three examples follow.

During the summer of 1998, many home foundations cracked and municipal water mains broke due to soil shrinkage caused by lack of rainfall. Most of the severe damage occurred in northwest OCMA in areas underlain by the Permian Hennessey Shale. Little damage occurred to the east in areas underlain by the subjacent Garber Sandstone. Geologic maps show where developers and city officials should "over-engineer" home slabs and water mains to prevent future problems during droughts.

The Garber Sandstone and underlying Wellington Formation are the major bedrock aquifers in the OCMA. Accurate delineation of their surface exposures is an important first step in their protection. This is especially critical if an interstate bypass is built east of Oklahoma City and subsequent development occurs.

Pleistocene terraces composed of silt, sand, and gravel border the North Canadian River, which flows through the OCMA. Several terraces were quarried in the past; two sand and gravel operators are currently active. In parts of the western OCMA, housing developments were built on the terraces, making them unavailable for quarrying. In other areas, old excavations were landscaped prior to development or are used for city parks. The new maps show where landowners and/or developers might consider exploiting their sand and gravel resources before building on them.

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## Evaluation of Vadose Zone Fate and Transport: High Plains Regional Ground Water (HPGW) Study, National Water-Quality Assessment (NAWQA) Program

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As part of the NAWQA program, the USGS is evaluating ground-water quality in the High Plains aquifer system. The High Plains aquifer system underlies 174,000 square miles in parts of eight states (CO, KS, NE, NM, OK, SD, TX, and WY). Beginning in 1999 and continuing for a period of 6 years, the High Plains Regional Ground Water Study intensively initiated studies into the quality of ground-water resources within the study area. Investigations began in the Central High Plains and will continue to move to the Southern High Plains and Northern High Plains as the project progresses. The goal of this assessment is to characterize, in a nationally consistent manner, the broad-scale geographic variations of ground-water quality related to major contaminant sources and background conditions. As part of the investigation, several vadose zone core sections will be taken throughout the Central High Plains region to examine their hydrogeologic parameter values and targeted constituent concentrations. Soil physical and chemical parameters are measured from sections of the vadose zone cores. This data will be used as input parameters for an unsaturated flow and transport model. The model is used to evaluate the fate and transport of pesticides, chloride, and tritium through the unsaturated zone. Calibration of the model using water quality data from the cores is attempted.

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## Water-Quality Assessment of the Ozark Plateaus

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The first high-intensity phase of the Ozark Plateaus study unit of the National Water-Quality Assessment (NAWQA) Program of the U.S. Geological Survey (USGS) was conducted between 1992 and 1995. Increases in confined-animal and human populations threaten to increasingly impair the quality of water in the highly sensitive karst environment of the Ozark Plateaus.

Nutrient (nitrate and phosphorus) and bacteria concentrations in streams are higher in basins with greater agricultural land use or that contain wastewater-treatment plants than in basins with greater forested land use. In ground water, nutrient concentrations were higher in areas with greater agricultural land use, higher in springs than wells, and higher in the Springfield Plateau aquifer than the Ozark aquifer.

Pesticides were detected in streams and ground water more often in agricultural areas than in forested areas. The most commonly detected pesticides in water were the herbicides atrazine, desethylatrazine, tebuthiuron, metolachlor, simazine, and prometon. Concentrations generally were low with maximum concentrations in streams and ground water of 0.29 and 1.0 micrograms per liter, respectively.

Dissolved trace elements (barium, copper, manganese, molybdenum, and zinc) in stream samples were detected more often and at higher concentrations in areas of historical or ongoing lead-zinc mining than at sites in other areas. Concentrations of lead and zinc in bed sediment and biological tissue are substantially higher at stream sites downstream from lead-zinc mines.

The Ozark Plateaus have a high number of fish species compared to the rest of the United States. Approximately 175 species are present in the Ozarks and at least 19 of these species exist nowhere else in the world. Algae-grazing stonerollers are the most abundant type of fish in streams located in agricultural basins and other minnows, darters, or sunfish are the most abundant fish in streams located in forested basins.

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