OKLAHOMA GEOLOGICAL SURVEY
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INVENTORY, DETECTION, AND CATALOG OF OKLAHOMA EARTHQUAKES

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(Text to accompany MAP GM-19)

The University of Oklahoma
Norman
1979

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This publication, printed by The University of Oklahoma Printing Services, Norman, Oklahoma (booklet), and Southwestern Stationery and Bank Supply, Inc., Oklahoma City, Oklahoma (map), is issued by the Oklahoma Geological Survey as authorized by Title 70, Oklahoma Statutes 1971, Section 3310, and Title 74, Oklahoma Statutes 1971, Sections 231-238. 1,100 copies have been prepared for distribution at a cost to the taxpayers of the State of Oklahoma of $4,965.

INVENTORY, DETECTION, AND CATALOG OF OKLAHOMA EARTHQUAKES

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INTRODUCTION

Since 1900, at least 182 earthquakes have occurred in Oklahoma. Of these, 90 earthquakes were reported felt by people, and the locations of the remaining earthquakes were determined from data recorded at distant and (or) local seismograph stations. Prior to 1954, more than half of the known Oklahoma earthquakes occurred in the vicinity of El Reno. In fact, the most intense earthquake disturbance known in Oklahoma took place near El Reno on April 9, 1952. This earthquake was felt in Des Moines, Iowa, as well as in Austin, Texas, and covered a felt area of approximately 362,000 square kilometers (140,000 square miles). An earthquake near Cushing in December 1900 is the earliest documented earthquake in Oklahoma. This event was followed by two additional earthquakes in the same area in April 1901.

The accompanying earthquake map of Oklahoma and catalog display the location of earthquake epicenters and their corresponding intensity values arranged into four time-period intervals. The beginning of each new time period represents a major change in seismic instrumentation, which resulted in improved earthquake detection and location accuracy. The map is intended for use as a guide to earthquake intensity and epicentral locations. The epicentral locations are based on data that may vary greatly in accuracy, particularly regarding earthquakes that occurred prior to 1960.

GLOSSARY OF EARTHQUAKE NOMENCLATURE

aftershock: an earthquake that follows a larger earthquake and originates at or near the focus of the larger earthquake.

coda: the latter part of an earthquake recording on a seismogram following the early, identifiable surface waves.

earthquake: shaking and (or) vibrations of the Earth caused by the sudden displacement of rocks below the Earth's surface.

epicenter: point on the Earth's surface directly above the earthquake source (focus).

fault: a break within the Earth's crust along which rock surfaces have moved past each other.

focal depth: the distance from the Earth's surface to the earthquake origin.

great-circle distance: the shortest distance measured on a sphere, such as the Earth's surface, between any two points.

hertz (Hz): a unit of frequency equal to one cycle per second.

hypocenter: a point within the Earth where the center of an earthquake originates; also focus.

intensity (of an earthquake): numerical scale devised to relate observable effects to earthquake size; the Modified Mercalli intensity scale of 1931 is the most commonly used scale in the United States.

magnitude: measurement of energy released by an earthquake. Several magnitude scales have been devised to make energy determinations; one of the most common is Richter magnitude.

nanometer: one billionth of a meter.

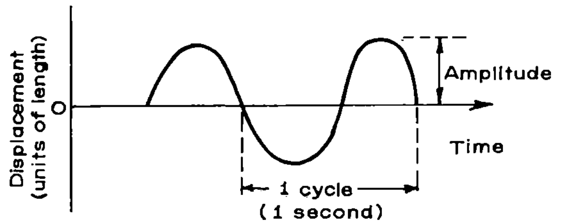
P wave: a longitudinal body wave or compressional wave produced by an earthquake (see Appendix A, page 11).

S wave: a transverse body wave or shear wave produced by an earthquake (see Appendix A, page 11).

seismogram: the record made by a seismograph.

seismograph: an instrument that records vibrations of the Earth, especially earthquakes.

wave-motion terminology:



This particular wave completes one cycle in 1 second; it has a period of 1 second and a frequency of one cycle per second or 1 hertz. Most earthquake phases resemble sine waves.

TECTONIC SETTING

Oklahoma is situated near the southern end of a geologic region referred to as the Stable Central Province (King, 1951; Hadley and Devine, 1974). This province, which covers more than 2.5 million square kilometers (1 million square miles), extends westward from the Appalachians to the eastern edge of the Rocky Mountains and from the Gulf Coastal Plain to south-central Canada.

The geologic and tectonic record in Oklahoma is mainly characterized by marine sedimentation which was terminated by episodes of uplift, gentle folding, and erosion, which, in turn, was followed by renewed sedimentation occurring on the unconformable surfaces (Ham and Wilson, 1967). The three principal mountain belts in Oklahoma are the Ouachita, Arbuckle, and Wichita Mountains (fig.1). These were the sites of folding, faulting, and uplift during the Pennsylvanian and Early Permian Periods. In addition to exposing a great variety of structures, these fold belts brought to the surface igneous rocks in the Arbuckle and Wichita Mountian areas and exposed thick sequences of folded and faulted Paleozoic sedimentary rocks in the Ouachita Mountains. Principal sites of sedimentation

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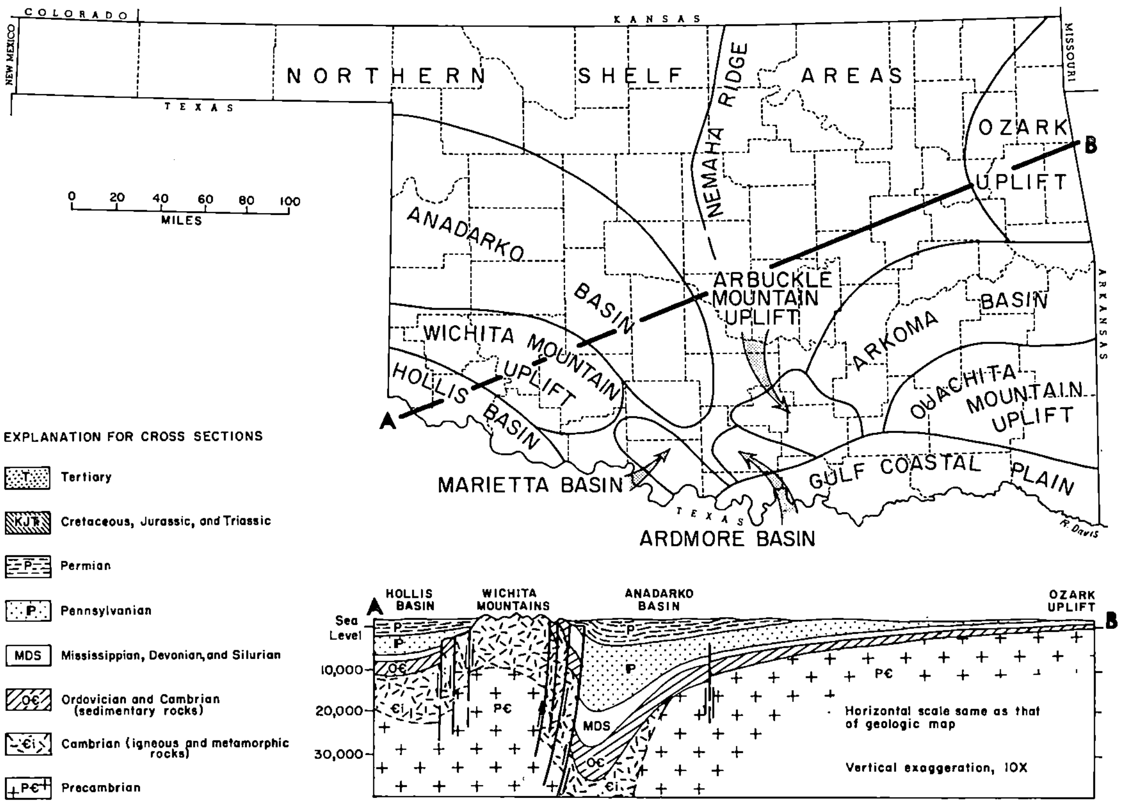

Figure 1. Major geologic and tectonic provinces of Oklahoma.

were in elongated basins that subsided more rapidly than adjacent areas and received sediments 3,000 to 12,000 meters (10,000 to 40,000 feet) thick. The major sedimentary basins were confined to the southern half of the State and include the Anadarko, Arkoma, Ardmore, Marietta, and Hollis Basins and also the Ouachita Basin at the site of the present Ouachita Mountains. The Nemaha Ridge, a prominent feature in central Oklahoma, is a long north-south structure that extends northward from central Oklahoma through Kansas and into Nebraska. The Oklahoma portion of the ridge is 16 to 32 kilometers (10 to 20 miles) wide and nearly 240 kilometers (150 miles) long. The Nemaha Ridge, which developed mainly during the Pennsylvanian, consists of small crustal blocks that were raised sharply along the axis of the uplift. Uplifted crustal blocks that make up the Nemaha Ridge are typically 5 to 8 kilometers (3 to 5 miles) wide and 8 to 32 kilometers (5 to 20 miles) long and are bounded by faults on the east and (or) west sides of the Nemaha structures.

The Stable Central Province has displayed little tectonic activity since Late Pennsylvanian time. The historical record of seismicity in the region has been limited, with a notable exception being the area of New Madrid, Missouri, and adjacent regions in Kentucky, Tennessee, and Illinois.

The New Madrid earthquakes of 1811 and 1812 are probably the earliest historical earthquake tremors felt in Oklahoma (then Arkansas Territory) by early residents in southeastern Oklahoma settlements. The earliest documented earthquake in Oklahoma occurred near Cushing 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 occurred near El Reno on April 9, 1952. This magnitude-5.5 (Gutenberg and Richter, mb) earthquake was felt in Austin, Texas, as well as Des Moines, Iowa, and covered a felt area of approximately 362,000 square kilometers (140,000 square miles) (Docekal, 1970; Kalb, 1964; von Hake, 1976). The April 9 earthquake was followed by numerous aftershock events that lasted until August 14, 1952. While the El Reno area was the site of Oklahoma's most famous earthquake, several earthquakes have occurred in this area since 1908. In Oklahoma at least 182 earthquakes have occurred (Earthquake Map).

EARTHQUAKE INVENTORY

Knowledge of an earthquake, at least in historic times, depended entirely on the perception and sensitivity of people. An earthquake produces seismic waves with vibrations that can be felt and (or) heard by humans, and a large earthquake may also cause damage to buildings or other man-made objects as well as altering river courses and felling trees. The waves can also be recorded by seismographs, instruments designed and operated to record earthquake waves.

Prior to about 1950, the few seismographs that operated in states adjacent to Oklahoma were not sensitive enough to detect most earthquakes occurring in the State. Only written records of humans having felt earthquakes were available. These records were usually in local newspapers only. Some of the larger earthquakes felt had been listed in the "Seismological Notes" column of the bimonthly bulletin of the Seismological Society of America. A more complete listing appeared, beginning about 1929, in the annual publication *United States Earthquakes.*

Seismographs were first operated in Oklahoma in 1961 at the Jersey Production Research Company's (now Exxon) Leonard Earth Sciences Observatory in southern Tulsa County and at the U.S. Air Force Advanced Research Projects Agency's Wichita Mountains Seismological Observatory in Comanche County. The Leonard Earth Sciences Observatory has been designated by the abbreviation TUL from 1961 up to and including its current operation as the Oklahoma Geological Survey's Oklahoma Geophysical Observatory. The Air Force installation in Comanche County, designated by the abbreviation WMO, has, for several reasons, played little part in studying local earthquakes. It was designed and operated primarily to detect and distinguish between distant earthquakes and distant underground nuclear tests. WMO closed in 1971 after several years of sharply curtailed activity. Both WMO and TUL seismographs made excellent recordings of P waves from distant earthquakes, but they partially filtered out high-frequency waves characteristic of nearby earthquakes.

Eysteinn Tryggvason, formerly an earthquake seismologist at the University of Tulsa, acted as consultant to Jersey Production Research in interpreting TUL seismograms. In 1964 he compiled historical information on Oklahoma earthquakes, primarily from *United States Earthquakes* and Kalb (1964). This study led to the development of a formula used to assign a local Richter magnitude (ML) to some of the historical earthquakes based on the size of the area in which they were felt. Tryggvason also searched the TUL short-period seismic records of January 1962 through September 1962 through September 1963 and found 10 Oklahoma earthquakes and nine events which he classified as "natural or artificial (construction and quarry blasts) earthquakes." The seismograms from WMO and seismograph stations in other states were used to make location determinations of the 19 events. TUL-seismogram trace amplitudes were also used to determine approximate local Richter magnitudes (ML).

Jerry Docekal (1970), for his Ph.D. dissertation at the University of Nebraska, made an extensive study of earthquakes of the Midcontinent which included local newspaper accounts of Oklahoma earthquakes. Docekal located more details of the felt effects of many Oklahoma shocks. A program was established in 1970 to reduce information on Oklahoma earthquakes to a standard 80-column computer format with the intention of keypunching the information about each earthquake onto one 80-column computer card. The TUL short-period (SP) seismograms were searched for regional events (Oklahoma and vicinity). Of the few that were found, some were located with the aid of arrival times at other stations such as FAV (Fayetteville, Arkansas), LUB (Lubbock, Texas), GOL (Golden, Colorado), and ALQ (Albuquerque, New Mexico). Others were located using the TUL records alone, with the distance to the epicenter being determined by the interval between S and P phases and the direction of movement by the ratio of north-south and east-west motion of the S waves. This method was only applicable where the initial P-motion direction was clear on short-period, vertical (SPZ), north-south and east-west seismograms. At least half of the regional events seen did not produce arrivals at other stations or clear first motions at TUL and hence went unlocated.

A new vertical-motion short-period seismograph sensitive to high frequencies was added at TUL in April 1972. This improvement enabled the detection of many more regional earthquakes. However, most of these additional events could not be located other than specifying their distance from TUL. Jim Zollweg, St. Louis University, scanned several thousand short-period seismograms in the TUL archives and added some events to the Oklahoma list. Unfortunately, with the notable exception of an aftershock sequence near Durant, Oklahoma, few of these events were locatable.

In the early 1970's, TUL became the established source of information to the seismological community for Oklahoma earthquakes and some nearby earthquakes. The Observatory became one of about 50 agencies throughout the world that report epicenters directly to the International Seismological Centre in Newbury, England, for publication in its monthly bulletin and semiannual catalog. In 1975 the Observatory began officially to furnish the National Oceanic and Atmospheric Administration (NOAA) with data on earthquakes felt in Oklahoma for the annual publication of *United States Earthquakes.*

From 1974 to 1976 several earthquakes were felt in Oklahoma. Field surveys of these earthquakes suggested that earthquakes as small as magnitude 2 could be felt. Detailed intensity maps, which semi-quantify felt and observed effects, were made by taking house-to-house surveys of the affected areas (Lawson and DuBois, 1976). On June 24, 1976, a magnitude-1.4 (Nuttli, m3Hz) earthquake near Wilson, Oklahoma, was reported felt. With the possible exception of some Glenalmond, Scotland, earthquakes, this is the smallest known earthquake to have been felt anywhere in the world.

The University of Oklahoma Earth Sciences Observatory, the Oklahoma Geological Survey, and the U.S. Nuclear Regulatory Commission started a cooperative program in 1976 to study seismicity of the Nemaha Uplift and other areas of Oklahoma. The Observatory staff began a program to computerize the accumulated earthquake catalog, which included a compilation of earthquake information from published and unpublished reports, with the data held on magnetic tape for complete or selected printing whenever needed.

The accumulated earthquake data were grouped according to earthquake intensity as well as four time-period intervals (Earthquake Map). The time categories were chosen to reflect those changes, such as seismograph improvements, that enhanced the detection and location of Oklahoma earthquakes. The first time period, 1900–60 (yellow symbols), represents the time interval in which all earthquakes in Oklahoma were located either from historical accounts or from seismograph stations outside the State. The next category, 1961–72 (green symbols), coincides with the installation of the first two seismograph stations (WMO and TUL) in Oklahoma. The seismographs at these stations provided excellent records of distant earthquakes. Although the location and detection of small local earthquakes were greatly improved by the presence of these two stations, most local earthquakes went unrecorded because of the poor high-frequency-response characteristics of the WMO and TUL seismographs. The Oklahoma Geophysical Observatory (TUL) began to record high-frequency seismograms in 1973. This greatly increased the capability to detect small earthquakes and to discriminate earthquakes from quarry blasts (blue symbols, 1973-76). However, the location of earthquakes depending either on finding felt reports and (or) having clear first-motion directions and horizontal-amplitude measurements made from the seismic records at the Observatory. The last group of symbols (red) displays earthquake intensity data for 1977 and 1978. This time period coincides with the establishment and operation of a statewide network of seismograph stations. By the middle of 1977, the Oklahoma Geophysical Observatory was operating a five-station network, and by 1978 nine stations were operating. These additional seismograph stations have tremendously improved earthquake detection and location accuracy in Oklahoma as well as in the adjacent areas. This is reflected by the large increase in locatable Oklahoma earthquakes. The Oklahoma seismograph network is recording and locating about 25 Oklahoma earthquakes per year as compared to previous years, such as 1974, when only four earthquakes were recorded.

SEISMOGRAPH NETWORK

The data required for location of local earthquakes consist of the arrival times of P and S phases at several (at least three) separate locations (see Appendix A for phase nomenclature). These arrival times are obtained from seismograms that record a wiggly line representing vertical ground motion over a frequency range of 1 hertz to about 20 hertz. The seismograms are also used to determine amplitude of ground motion, which is used to calculate earthquake magnitude.

Seismograms are recorded by seismographs. A modern seismograph consists of four basic sections: seismometer, signal conditioner, recorder, and timing system. The seismometer converts ground motion into a varying electric potential. The signal conditioner includes a solid-state amplifier or amplifiers to increase the varying potential produced by the seismometer and, usually, electronic filters to attenuate some frequencies and pass other frequencies. The recorder is usually a drum with a line (recorded in ink) representing earth motion. The line follows a spiral path around the drum. When the seismogram is removed, it appears as a sheet with a number of parallel wiggly lines, each one representing a successive 10- or 15-minute period, depending on the rate of rotation of the drum. The timing systems are crystal-controlled oscillator clocks that produce an offset in the seismogram trace at the beginning of each minute to allow precise measurement of seismic phase-arrival times. The timing system is usually compared daily to radio time signals broadcast by the National Bureau of Standards.

In Oklahoma ground motion at 10 widely separated locations is recorded (fig. 2; table 1). One of these sites is the Oklahoma Geophysical Observatory (abbreviation TUL) near Leonard, formerly The University of Oklahoma Earth Sciences Observatory. It was operated by Jersey Production Research Co. (now Exxon) from December 1961 to 1965 and by The University of Oklahoma from 1965 to 1978. In July 1978, the Observatory was transferred to the Oklahoma Geological Survey and renamed the Oklahoma Geophysical Observatory. However, before 1972 the seismographs, designed

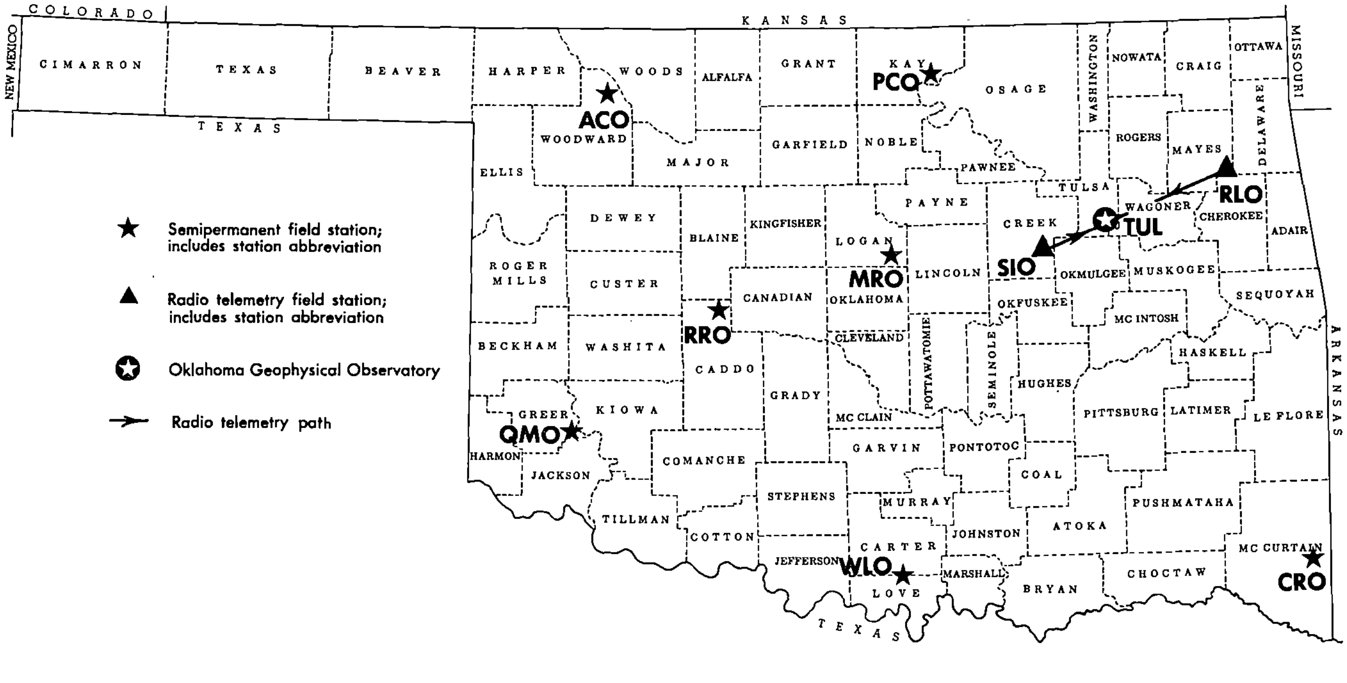

Figure 2. Active seismograph stations in Oklahoma.

Table 1. Oklahoma Station Locations and Operators

Abbr.	Geographic name and county	Latitude (° N.)	Longitude (° W.)	Elevation (meters)	Volunteer operator and operating date(s) (year/month/day)
TUL	Okla. Geophys. Observatory, Tulsa Co.	35.900000	95.792500	256	Observatory Staff P/J/K/S 61/12/08
WLO	SE of Wilson, Love Co.	34.064778	97.369722	284	James L. Steel 77/04/25
CRO	Carnasaw Mountain Lookout Tower, McCurtain Co.	34.149917	94.555611	302	Wanda Webb 77/05/17
ACO	Alabaster Cavern State Park, Woodward Co.	36.698556	99.146083	521	L. H. Shepherd 77/06/22
PCO	Ponca City, Kay Co.	36.691222	96.978222	325	H. Walther 77/07/05
RLO	Rose Lookout Tower, Mayes Co.	36.167000	95.025194	363	77/07/22
QMO	Quartz Mountain State Park, Greer Co.	34.892917	99.307056	479	J. Briley 77/07/29
MRO	Meridian, Logan Co.,	35.835556	97.226528	294	Roy F. Starks 78/03/16
SIO	Slick, Creek Co.	35.746333	96.307056	323	78/07/12
RRO	Red Rock Canyon State Park, Caddo Co.	35.456917	98.358444	482	Bud Turner 78/08/09
MZO	Mazie Landing, (CLOSED) Mayes Co.	36.131639	95.300139	182	Randy Blackwell 76/09/16–78/06/16
OLO	Oologah, (CLOSED) Rogers Co.	36.457250	95.710778	196	T/T/C Estes 76/11/28–77/08/07

to record phases from distant earthquakes, were not optimum for recording the higher frequencies characteristic of local earthquakes. Beginning in 1972, the recording of local earthquakes was greatly improved by the development and operation of additional seismographs.

At TUL there are four high-frequency seismometers (two to detect vertical motion, one to detect north-south horizontal motion, one to detect east-west horizontal motion) on a concrete pier in an underground vault. The floor of the vault is 4 meters below the ground, and the pier is founded on a sandstone bed 1.3 meters below the vault floor. Three low-frequency seismometers and a gravimeter are also on the pier. The sub-microvolt signals from the seismometers are carried by shielded cables along a 7-meter-long horizontal tunnel to a stairway leading up to the main recording building. The signals from the seismometers are conditioned and split to produce 11 drum-recorded and 16 film-recorded seismograms. Of these 27 seismograms, four drum-recorded vertical-ground-motion seismograms covering different frequency bands and two drum-recorded horizontal-ground-motion seismograms (one north-south, one east-west) are used in detecting, identifying, and locating local earthquakes. The other seismograms are used in studying distant earthquakes and other geophysical phenomena; they do not record, or barely record, high-frequency phases from local earthquakes. A master crystal-controlled timing system (clock) places minute marks on all of the seismograms.

Vertical ground motion from two other points is also recorded at the Oklahoma Geophysical Observatory. The other points are RLO (Rose Lookout) and SIO (Slick) (fig. 2). At each of these locations a vertical-ground-motion high-frequency seismometer is placed in a shallow (about 1 meter) cylindrical vault. The signal from the seismometer is transmitted by low-power VHF radio beam to Leonard, where the signals are conditioned and recorded on drum recorders.

The seven other seismograph sites are too distant from Leonard to use radiotelemetry without relay stations. These seven stations, called semipermanent, volunteer-operated stations, are at sites provided by individuals or state agencies and are operated by volunteers who change and label seismograms daily and check the timing system with National Bureau of Standards radio time signals. The volunteers mail seismograms weekly to the Oklahoma Geophysical Observatory.

Each volunteer station has a vertical-motion-sensing seismometer, Geotech S-13, in a shallow cylindrical tank, exactly the same as the seismometer installation at the radiotelemetry stations (fig. 3). A shallow buried (2 to 10 centimeters) shielded cable carries the seismometer signal over distances varying from 60 to 200 meters to the volunteer's house or building. A Sprengnether MEQ-800B seismic recorder, which combines in one unit the signal conditioners (amplifiers, filters), a crystal-controlled timing system (clock), and a drum recorder, is placed in a room chosen for the volunteer's

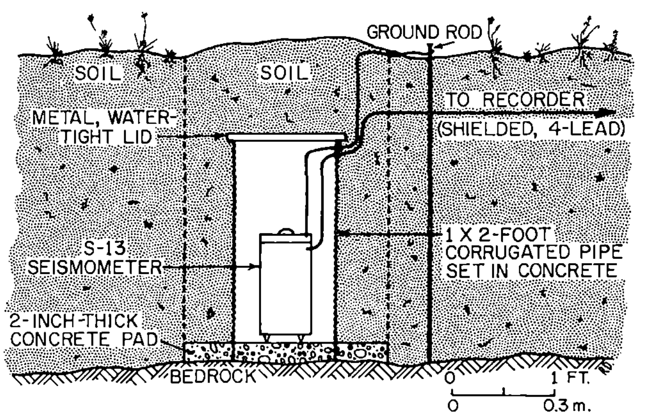

Figure 3. Diagrammatic representation of an S-13 seismometer installation.

convenience. A shortwave radio receiver to receive National Bureau of Standards time signals is placed beside the drum recorder. To check for time accuracy, the timing system is switched to make marks each second instead of every minute, and the timing-system marks and the radio second marks are recorded simultaneously on the seismogram. By advancing or retarding the clock until the marks coincide, the volunteer can keep the clock within 16 milliseconds of National Bureau of Standards time.

Table 1 lists the latitude, longitude, elevation in meters, and geographical name of the Oklahoma Geophysical Observatory (TUL), the radiotelemetry stations (RLO, SIO), active volunteer stations (WLO, CRO, ACO, PCO, QMO, MRO, RRO), and two volunteer stations (MZO, OLO) that were closed so that the equipment could be used to distribute stations evenly over most of Oklahoma. The table also gives names of the volunteer primarily responsible for the station. At some stations several volunteers have operated the station by turn.

One additional closed station on the map, WMO, was operated by the U.S. Air Force from November 1961 to June 1971 to detect distant underground nuclear tests and distinguish them from earthquakes. The frequency passbands of the WMO seismographs greatly attenuated high-frequency waves from near earthquakes, which made the detection and location of Oklahoma earthquakes quite difficult.

EARTHQUAKE CATALOG

An inventory of all known, locatable Oklahoma earthquakes is kept in a permanent file and stored on magnetic tape for use with a Hewlett Packard HP-9825A desk-top computer system for easy storage and retrieval. Major catalog categories include the event number, date, origin time, county, intensity, magnitude, location, focal depth, and source information. The information can be printed in a page-size format, and Appendix B contains a modified version of a 1900–1978 Oklahoma earthquake catalog.

The event number is the first entry in the catalog. The earthquakes are chronologically numbered, with number 1 being the first earthquake known to have occurred in Oklahoma. Each earthquake is numbered on the earthquake map, and this number corresponds to the equivalent event number in the catalog.

The earthquake date and time are given in UTC. (UTC refers to Coordinated Universal Time, formerly Greenwich mean time.) UTC provides a worldwide time standard for earthquake-origin times. 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.

Earthquakes are measured in terms of either actual effects (intensity) or magnitude, which is related to seismic energy. Felt and observed effects are generally given values according to an intensity scale developed in 1902 by Mercalli, an Italian seismologist. This intensity scale assigns a Roman numeral to each of 12 levels described by effects on humans, man-made construction, or natural features (table 2). The Mercalli scale was modified in 1931 by Wood and Neumann to take into account modern features such as tall buildings and automobiles. This modified Mercalli scale is frequently abbreviated as MM.

Table 2. Modified Mercalli (MM) Earthquake-Intensity Scale (abridged) (modified from Wood and Neumann, 1931)

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

Earthquake magnitude is a measurement of energy released at an earthquake source and is based on data derived from seismograph recordings. Several different magnitude scales were listed in the catalog, as follows: *ML* (Richter), *mb* (Gutenberg and Richter), *mbLg* (Nuttli), *mbeus* (Evernden), *m3Hz* (Nuttli), and *MDUR* (Lawson). Each magnitude scale was established to accommodate specific criteria, such as distance from the epicenter, availability of certain seismic data, frequency characteristics of the seismometer, and the regional geologic setting.

The Richter magnitude, *ML*, as used in the catalog, is derived from the following equation:

$$ML = \log A - \log A_0 + 0.95 - 0.73 \log(\Delta) - \log(V/2800),$$

where *A* is the maximum center-to-peak amplitude of Sg waves, in millimeters, measured on a seismogram recorded from a short-period, vertical (SPZ) seismograph with a frequency response that does not differ greatly from that of a Wood-Anderson seismograph; *V* is the displacement magnification of the vertical-motion seismograph at periods below 0.8 seconds; $-\log A_0$ is Richter's empirical distance correction function for southern California; and Δ is the great-circle distance from epicenter to seismograph measured in kilometers. This equation is Eysteinn Tryggvason's unpublished approximation to Charles Richter's local-magnitude scale for southern California when applied to Oklahoma (Richter, 1958).

The Gutenberg and Richter magnitude, *mb*, is defined as

$$mb = \log(A/T) + Q,$$

where *A* is the maximum center-to-peak vertical-ground amplitude of P waves measured in microns at distances between 5 and 105 great-circle degrees from the epicenter; *T* is the dominant P-wave period measured in seconds, and *Q* is the Gutenberg-Richter empirical distance and depth correction factor (Richter, 1958).

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

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

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

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

where *A* is the maximum center-to-peak vertical-ground amplitude sustained for 3 or more cycles of Sg waves, near 1 hertz in frequency, measured in nanometers; *T* is the period of Sg waves measured in seconds; and Δ is the great-circle distance from station to epicenter measured in kilometers (Nuttli, 1973).

Evernden magnitude scale, *mbeus*, is defined as

$$mbeus = \log(A/T) - 3.27 + 2.0 \log(\Delta),$$

where *A* is the center-to-peak vertical-ground amplitude of Pn waves recorded between 200 km and 2,100 km from the epicenter measured in nanometers; *T* is the period of Pn waves measured in seconds; and Δ is the great-circle distance from the epicenter measured in kilometers (Evernden, 1967). For earthquake epicenters located between 11 km and 222 km from a seismograph station, Nuttli developed the *m3Hz* magnitude scale. 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 amplitude sustained for 3 or more cycles of Sg waves, near 3 hertz in frequency, measured in nanometers; *T* is the period of the Sg waves measured in seconds; and Δ is the great-circle distance from epicenter to station measured in kilometers (Zollweg, 1974).

The *MDUR* magnitude scale was developed by Jim Lawson 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. If the Pn wave is the first arrival, the interval between the earthquake-origin time and the decrease of the coda to twice the background-noise amplitude is measured instead (Lawson, 1978).

The location of each earthquake is given in degrees latitude and longitude. Prior to 1961 most earthquakes were located from historical records, but the occasional larger earthquake was located with records from seismograph stations situated outside of the State. In late 1961 two seismograph stations began operating within the State, and, by late 1978, 10 seismograph stations were recording seismological data. The earthquake-location accuracy was greatly improved after the statewide seismograph-station network was installed. This improved accuracy is reflected in the number of significant figures after the decimal point reported for longitude and latitude; the greater the number of figures, the more precise is the earthquake epicentral location.

The next column, depth to the earthquake hypocenter, was omitted from this catalog. For most Oklahoma earthquakes the exact focal depth is unknown. In almost all Oklahoma events, the stations are several times farther from the epicenter than the likely depth of the event. This makes the earthquake focus location indeterminate with respect to depth. The hypocenter is fixed at an arbitrary depth of 5 kilometers for purposes of computing latitude, longitude, and origin time. No evidence indicates that Oklahoma hypocenters have been deeper than 15 to 20 kilometers (9 to 12 miles).

The last column indicates the source or sources of information used to document the earthquake data. Capital letters are used to denote each reference. Jerry Docekal (D) made a comprehensive study of the earthquakes in the central United States for his Ph.D. dissertation at the University of Nebraska in 1970. Eysteinn Tryggvason (T), seismologist, formerly at The University of Tulsa, did extensive studies on the occurrence and location of Oklahoma earthquakes. Unfortunately, much of this work was never published. *United States Earthquakes* (U), annual publications, were used as a principal reference, particularly for earthquakes prior to 1968. The earliest known Oklahoma earthquakes were reported by Laura Wells (W) in her book *Young Cushing in Oklahoma Territory* (1975). Other sources for earthquake data for the catalog include International Seismological Centre (I), Oklahoma Geophysical Observatory (O), and James Zollweg's unpublished report (Z).

ACKNOWLEDGMENTS

Appreciation is extended to Kristi Binney and Shirley Jackson, who assisted in record labeling, changing, and cataloging. The following volunteer operators made the network operation possible by contributing station sites plus their services in changing seismograms on a seven-day-per-week basis: Todd, Ted, and Carolyn Estes (OLO); Randy Blackwell (MZO); Mr. and Mrs. J. L. Steel (WLO); Wanda Webb (CRO); L. H. Shepherd, Josie Daer, Staci Bliss, Leonna Colwell, and Sue Mitchell (ACO); Mr. and Mrs. H. C. Walther, Eric and Carl Walther (PCO); Jeff Briley, Dean Skidgel, and Tom Archer (QMO); Mr. and Mrs. Roy F. Starks (MRO); and Bud Turner and Linda Whitlow (RRO). Special thanks are extended to Robert A. Pike, director of Oklahoma State Parks, who permitted and encouraged the installation of ACO, QMO, and RRO. Jim Pitts, northeastern area state forester, Waite Bell, and J. E. McQuistion assisted in the installation and maintenance of RLO. J. R. (Sonny) Davis permitted the installation of radiotelemetry station SIO on the Jackson Ranch.

Special thanks are given to geology students and part-time Oklahoma Geological Survey employees John Skinner, Bridget Houston, and Chris Gay, who assisted in the map-preparation process, and to Roy D. Davis, cartographer, for the preparation of the map and illustrations for publication. Appreciation is expressed to Judy A. Russell and William D. Rose for editorial assistance. Don Steeples, Kansas Geological Survey, kindly reviewed the manuscript and made suggestions for its improvement. The installation of the semipermanent field stations was supported by the U.S. Nuclear Regulatory Commission, contract no. NRC 04-76-0314.

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APPENDIX A.—EARTHQUAKE-PHASE NOMENCLATURE

For purposes of earthquake location and phase identification, the average crustal structure of Oklahoma is represented by a two-layer crust over the mantle (fig. 4). Each layer is 20 kilometers thick. The upper layer is probably composed of *sial,* rocks like granite that are rich in silicon and aluminum. Its contact with the lower layer is called the Conrad discontinuity. The lower layer probably is made of rocks like gabbro or basalt which are called *sima* because they are rich in silicon and magnesium. The contact between the lower layer and mantle is called the Mohorovičić discontinuity. The upper mantle is probably composed of ultrabasic rocks like peridotite or dunite. Such a simplified cross section of the average crust is called a model. The model also specifies P-wave (longitudinal waves in which the rock vibrates in the direction in which the wave is traveling) and S-wave (transverse waves in which the rock vibrates perpendicular to the direction in which the wave is traveling) velocities for the two layers and the upper mantle. This particular model was developed by Nuttli and others (1969) for eastern Missouri, northeastern Arkansas, southern Illinois, western Tennessee, and western Kentucky. However, it gives excellent results for Oklahoma also. This model ignores sedimentary layers that may be as thick as 15 kilometers in the Anadarko Basin and other basins in Oklahoma, but it does represent a good average structure for the entire State.

P and S waves travel outward from the hypocenter in all directions, but in figure 4 we have drawn only those waves that travel to the particular seismograph shown. The P wave traveling in a direct line is called Pg. Another P wave, called P*, is for part of its path traveling in the top of the second layer. This occurs because the particular ray shown is critically refracted from the first into the second layer (critical refraction implies that the wave is bent to travel parallel to the contact). Waves are always refracted when they pass from one layer to another in which they travel at a different velocity. Another P wave, Pn, is refracted along the top of the upper mantle.

Because Pn and P* lose energy on each refraction, and because they travel farther than Pg, they are smaller than Pg and are not usually seen. They are obscured on the seismogram by the larger Pg. However, beyond 160 to 180 kilometers away from the earthquake, the extra distance traveled by P* and Pn is more than made up for by their higher velocity along the lower part of their path, and they arrive before Pg and may be clearly seen. There are also corresponding S waves, called Sg, S*, and Sn, traveling similar paths. Beyond about 1,000 kilometers from the hypocenter, the P and S waves have traveled a curved path deep in the mantle. There are no separate phases owing to layering. The phases recorded at these distances are simply called P and S.

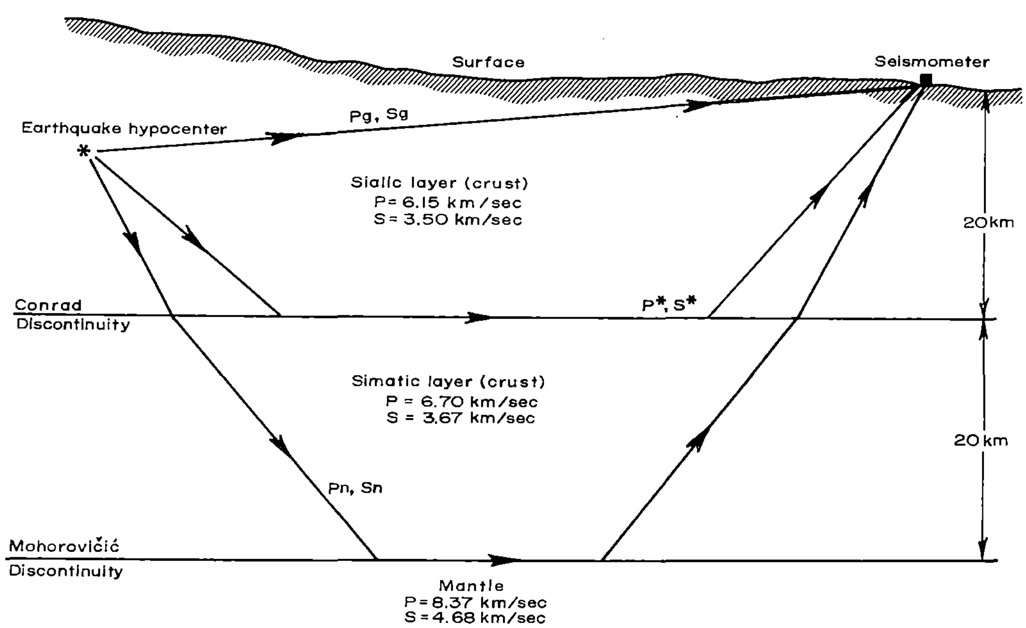

Figure 4. Crustal model used in locating Oklahoma earthquakes (modified from Nuttli and others, 1969).

APPENDIX B.—EARTHQUAKE CATALOG OF OKLAHOMA, 1900–1978

EVENT NUMBER	DATE AND ORIGIN TIME (UTC)				COUNTY	INTENSITY	MAGNITUDE	LATITUDE DEGREES N.	LONGITUDE DEGREES W.	SOURCES
1	1900	Dec			Payne	MM IV		36.0	96.8	W
2	1901	Apr	01		Payne	felt		36.0	96.8	W
3	1901	Apr	08	1330	Payne	felt		36.0	96.8	W
4	1908	Jul	19	Local A.M.	Canadian	MM III		35.7	97.7	D
5	1910				Canadian	felt		35.5	98.0	T,K
6	1915	Nov	08		Rogers	felt		36.2	95.8	T,K
7	1918	Sep	10	1630	Canadian	MM V		35.5	98.0	U
8	1918	Sep	11	0630	Canadian	MM VI		35.5	98.0	D
9	1918	Sep	11	0900	Canadian	MM VI		35.5	98.0	D
10	1918				Canadian	MM IV		35.5	97.7	D
11	1924	Jun	03		Pawnee	MM III		36.3	96.5	D,T,K
12	1926	Jun	20	1420	Sequoyah	MM V	3.6 ML	35.6	94.9	D,T
13	1929	Dec	28	0030	Canadian	MM VI	3.7 ML	35.5	98.0	U,T
14	1933	Aug	19	1930	Canadian	MM V		35.5	98.0	U,D,T
15	1934	Apr	11	1740	Choctaw	MM V	3.2 ML	33.9	95.5	U,T
16	1935	Nov	29		Payne	felt		36.2	97.0	T,K
17	1936	Mar	14	1720	McCurtain	MM V	2.4 ML	34.0	95.0	U,D,T
18	1936	Jul	12	0023	Cimarron	felt		36.9	103.0	U,D,T,K
19	1937	Jun	08	1426	Pottawatomie	MM IV		35.3	96.9	D,K
20	1939	Jun	01	0730	Hughes	MM IV	4.4 ML	35.0	96.4	U,D,T
21	1941	Oct	18	0748	Washita	MM V		35.4	99.0	U,D,T
22	1942	Jun	12	0550	Garfield	MM III	2.7 ML	36.4	97.9	U,D,T
23	1952	Apr	09	162915	Canadian	MM VII	5.5 mb	35.4	97.8	U,D,T,K
24	1952	Apr	09	1830	Canadian	felt		35.4	97.8	U,D,T,K
25	1952	Apr	11	2030	Canadian	MM IV		35.4	97.8	U,D,T,K
26	1952	Apr	16	0558	Canadian	felt		35.4	97.8	U,D,T
27	1952	Apr	16	0605	Canadian	MM V		35.4	97.8	U,D,T
28	1952	May	01	1140	Canadian	felt		35.4	97.8	T,K
29	1952	May	02	0155	Canadian	felt		35.4	97.8	T,K
30	1952	Jun	16		Canadian	felt		35.4	97.8	T,K
31	1952	Jun	16		Canadian	felt		35.4	97.8	T,K
32	1952	Jun	16		Canadian	felt		35.4	97.8	U,T,K
33	1952	Jun	16		Canadian	felt		35.4	97.8	T,K
34	1952	Jun	16		Canadian	felt		35.4	97.8	U,T,K
35	1952	Jun	16		Canadian	felt		35.4	97.8	U,T,K
36	1952	Jun	16	0030	Canadian	MM IV		35.4	97.8	U,D
37	1952	Jul	17	0200	Canadian	felt		35.4	97.8	U,D,T
38	1952	Aug	14	2140	Canadian	MM IV		35.4	97.8	U,D,T,K
39	1952	Oct	08	0415	Seminole	MM IV		35.1	96.5	U,D,T
40	1953	Mar	16	1250	Canadian	MM III		35.4	97.8	U,D,T
41	1953	Mar	17	1312	Canadian	MM V		35.4	98.0	U,D,T
42	1953	Mar	17	1425	Canadian	MM VI		35.4	98.0	U,D
43	1953	Jun	06	1740	Pontotoc	MM IV		34.8	96.7	U,D,T
44	1954	Apr			Hughes	MM IV		35.1	96.4	U
45	1954	Apr	11		Hughes	MM IV		35.1	96.4	U,D,T
46	1954	Apr	12	2305	Hughes	MM IV		35.1	96.4	U,D,T,K
47	1954	Apr	13	1848	Hughes	MM IV		35.1	96.4	U,D,T,K
48	1956	Feb	16	2330	Oklahoma	MM VI	3.8 ML	35.7	97.5	U,D,T
49	1956	Apr	02	160318	Pushmataha	MM V		34.2	95.6	U,D,T
50	1956	Oct	30	103621	Rogers	MM VII	4.2 ML	36.2	95.8	U,D,T
51	1959	Jun	15	1245	Pontotoc	MM V	2.7 ML	34.8	96.7	U,D,T,K
52	1959	Jun	17	102707	Comanche	MM VI	4.8 ML	34.5	98.5	U,D,T,K
53	1960	Mar	18	2130	Rogers	felt		36.2	95.8	T,K
54	1960	Mar	18	2330	Rogers	felt		36.2	95.8	T,K
55	1961	Jan	11	0140	Latimer	MM V		34.8	95.5	U,D,T,K
56	1961	Apr	26	0705	Pushmataha	MM III		34.6	95.0	D
57	1961	Apr	27	0300	Pushmataha	felt		34.6	95.0	U,D
58	1961	Apr	27	0500	Pushmataha	felt		34.6	95.0	U,D

EVENT NUMBER	DATE AND ORIGIN TIME (UTC)				COUNTY	INTENSITY	MAGNITUDE	LATITUDE DEGREES N.	LONGITUDE DEGREES W.	SOURCES
59	1961	Apr	27	0730	Latimer	MM V		34.9	95.3	U,D
60	1962	Apr	28	060911	Caddo		3.3 ML	35.3	98.6	T
61	1962	May	18	024029.3	Pittsburg		2.6 ML	35.1	95.4	T
62	1962	Aug	04	001807.3	Pittsburg		2.2 ML	35.2	95.6	T
63	1962	Sep	01	020956.1	Hughes		2.8 ML	35.2	96.0	T
64	1963	Jan	15	053337.0	Atoka		2.2 ML	34.6	95.9	T
65	1963	Mar	13	093334.0	Atoka		3.1 ML	34.6	95.9	T
66	1963	Jun	12	120831.0	Pontotoc		2.1 ML	34.7	96.8	T
67	1963	Jun	12	163852.0	Pontotoc		2.6 ML	34.7	96.8	T
68	1963	Jul	14	080823.2	Grady		2.0 ML	35.0	97.7	T
69	1963	Jul	14	081027.0	Grady		2.6 ML	35.0	97.7	T
70	1964	Feb	02	082244.1	Kiowa	MM V	2.8 mbeus	35.1	99.1	O,D,I
71	1966	Mar	26	051709	Creek		2.3 m3Hz	35.7	96.6	O,Z
72	1968	Jan	04	2230	Pittsburg	MM IV		34.85	95.55	O,U
73	1968	Oct	11	022255	Bryan	felt	2.3 m3Hz	34.0	96.4	O,U,Z
74	1968	Oct	11	024042	Bryan	felt	1.9 m3Hz	34.0	96.4	O,U,Z
75	1968	Oct	11	085542	Bryan	felt	2.8 m3Hz	34.0	96.4	O,U,Z
76	1968	Oct	11	093337	Bryan	felt	2.4 m3Hz	34.0	96.4	O,U,Z
77	1968	Oct	11	214457	Bryan		2.0 mbLg	34.0	96.4	O,Z
78	1968	Oct	12	035028	Bryan		1.8 mbLg	34.0	96.4	O,Z
79	1968	Oct	12	111906	Bryan		1.1 m3Hz	34.0	96.4	O,Z
80	1968	Oct	12	214644	Bryan		2.6 mbLg	34.0	96.4	O,Z
81	1968	Oct	14	034520	Bryan		2.0 m3Hz	34.0	96.4	O,Z
82	1968	Oct	14	142754	Bryan		1.5 MDUR	34.0	96.4	O,Z
83	1968	Oct	14	144254	Bryan	MM VI	3.5 m3Hz	34.0	96.4	O,U,Z
84	1968	Oct	17	071924	Bryan		1.7 mbLg	34.0	96.4	O,Z
85	1968	Oct	17	215457	Bryan		2.0 mbLg	34.0	96.4	O,Z
86	1968	Oct	18	211410	Bryan		2.8 mbLg	34.0	96.4	O,Z
87	1968	Nov	15	104125	Marshall		2.6 m3Hz	34.0	96.8	O,Z
88	1969	May	02	113322.5	Okfuskee	felt	3.6 mbeus	35.5	96.2	O,I
89	1969	May	02	115416	Okfuskee		0.8 MDUR	35.5	96.2	O,Z
90	1971	Mar	01	192732.1	Le Flore		2.5 mbeus	35.1	94.9	O
91	1971	Mar	13	192215.3	McIntosh		2.7 mbLg	35.2	95.8	O
92	1973	Jan	10	163815.3	Garfield	MM I	2.7 mbLg	36.4	98.0	O
93	1973	Sep	28	220303.1	Ottawa		2.0 m3Hz	36.8	94.9	O
94	1973	Oct	27	100845.4	Muskogee		1.9 m3Hz	35.8	95.2	O
95	1973	Nov	13	234339.3	Kay		1.9 m3Hz	36.8	97.0	O
96	1973	Nov	18	100352.7	Le Flore		3.1 mbLg	35.0	94.7	O
97	1973	Dec	25	041132.0	Le Flore		2.8 mbLg	35.1	94.5	O
98	1974	Jan	03	221205.8	Kay		2.2 mbLg	36.8	97.0	O
99	1974	May	10	011517.8	Carter		2.6 mbLg	34.2	97.3	O
100	1974	Nov	10	061918.6	Pontotoc		2.7 m3Hz	34.8	96.7	O
101	1974	Dec	16	023018.8	Oklahoma	MM III	2.6 m3Hz	35.4	97.5	O
102	1975	Mar	31	095206.0	Muskogee		2.9 m3Hz	35.6	95.3	O
103	1975	May	25	165846.2	Hughes		2.0 m3Hz	35.0	96.4	O
104	1975	Jun	16	015928.2	Johnston		2.9 m3Hz	34.2	96.5	O
105	1975	Sep	13	012502.1	Carter	MM V	3.4 mbLg	34.1	97.4	O
106	1975	Oct	12	025811.5	Canadian		3.2 mbLg	35.5	97.7	O
107	1975	Oct	30	003714.1	Pottawatomie		2.7 m3Hz	35.3	96.8	O
108	1975	Nov	29	142941.2	Garvin	MM V	3.6 mbLg	34.65	97.53	O
109	1975	Dec	19	052925.0	Carter	MM II	2.5 mbLg	34.1	97.4	O
110	1976	Jan	20	000525.4	McIntosh		2.1 m3Hz	35.54	95.42	O
111	1976	Feb	16	055949.1	Okfuskee		2.3 m3Hz	35.59	96.52	O
112	1976	Mar	16	073945.3	McIntosh	MM IV	2.7 m3Hz	35.43	95.60	O
113	1976	Mar	30	065316	Cimarron	MM V	2.1 mbLg	36.68	102.25	O
114	1976	Mar	30	092702.0	Cimarron	MM V	2.7 mbLg	36.68	102.25	O
115	1976	Apr	16	185946.1	Roger Mills	MM IV	3.4 mbLg	35.87	99.97	O
116	1976	Apr	17	024805.7	Carter	MM II	2.4 mbLg	34.1	97.4	O
117	1976	Apr	19	044243.9	Roger Mills	MM V	3.5 mbLg	35.87	99.97	O

EVENT NUMBER	DATE AND ORIGIN TIME (UTC)				COUNTY	INTENSITY	MAGNITUDE	LATITUDE DEGREES N.	LONGITUDE DEGREES W.	SOURCES
118	1976	Jun	07	013049.6	Le Flore		1.9 mbLg	34.66	94.62	O
119	1976	Jun	23	082117.8	Carter	MM III	2.7 mbLg	34.1	97.4	O
120	1976	Jun	24	080239.5	Carter	MM II	1.4 m3Hz	34.1	97.4	O
121	1976	Sep	20	094016.2	Carter	MM III	2.1 mbLg	34.16	97.40	O
122	1976	Oct	03	163108.8	Hughes		2.3 m3Hz	34.93	96.22	O
123	1976	Oct	19	135136.9	Muskogee		1.6 m3Hz	35.56	95.68	O
124	1976	Oct	20	040539.8	Coal		2.5 mbLg	34.75	96.12	O
125	1976	Oct	22	171550.5	Pottawatomie		3.0 mbLg	35.38	97.06	O
126	1976	Nov	11	161221.9	Logan		2.2 mbLg	35.85	97.32	O
127	1976	Nov	19	055224.8	Hughes		2.3 m3Hz	35.23	96.38	O
128	1976	Dec	17		Love	felt		34.06	97.37	O
129	1976	Dec	19	082636.7	Pittsburg	MM I	2.9 mbLg	34.92	95.73	O
130	1977	Feb	04	205229.3	Love	MM II	1.9 mbLg	34.07	97.37	O
131	1977	Feb	10	012816.3	Love	MM II	2.0 mbLg	34.07	97.37	O
132	1977	Mar	03	140816.5	Noble		1.9 m3Hz	36.26	97.14	O
133	1977	Mar	09	162108.1	Coal		2.1 m3Hz	34.59	96.51	O
134	1977	Mar	12	210419.6	Seminole		2.3 mbLg	34.99	96.63	O
135	1977	Mar	26	213712.6	Love	MM III	2.4 mbLg	34.07	97.37	O
136	1977	Apr	28	023056.1	Payne		1.8 mbLg	36.01	97.20	O
137	1977	May	22	121504.7	Noble		1.4 mbLg	36.24	97.25	O
138	1977	Jun	16	020246.6	Love		2.0 mbLg	34.04	97.36	O
139	1977	Jun	16	222424.1	Love		1.8 MDUR	33.91	97.44	O
140	1977	Jun	30	230322.0	Carter		2.5 mbLg	34.19	96.96	O
141	1977	Jul	10	083909.3	Okfuskee		1.6 mbLg	35.48	96.30	O
142	1977	Aug	10	001118.2	Garvin		1.9 mbLg	34.68	97.55	O
143	1977	Sep	12	023630.1	Choctaw		2.5 m3Hz	33.95	95.24	O
144	1977	Sep	26	015510.6	Love		1.7 mbLg	33.99	97.35	O
145	1977	Sep	29	071901.1	Noble		2.1 m3Hz	36.39	97.07	O
146	1977	Oct	06	003608.4	Kingfisher		2.1 mbLg	35.82	97.77	O
147	1977	Dec	08	194740.2	Canadian		2.0 mbLg	35.45	97.93	O
148	1978	Jan	08	041633.6	Kay		1.5 m3Hz	36.97	97.46	O
149	1978	Jan	08	101917.7	Logan		2.1 m3Hz	35.82	97.64	O
150	1978	Feb	10	064202.4	Coal		2.1 m3Hz	34.71	96.16	O
151	1978	Feb	14	010938.6	Logan		1.7 m3Hz	35.78	97.59	O
152	1978	Feb	21	111248.1	Tillman		2.2 mbLg	34.54	99.00	O
153	1978	Mar	03	022437.3	Hughes		2.5 m3Hz	35.09	96.28	O
154	1978	Mar	05	144650.5	Le Flore		2.9 mbLg	34.70	95.03	O
155	1978	Mar	09	063050.8	Love	MM II	2.6 mbLg	34.01	97.38	O
156	1978	Apr	02	213248.1	Atoka		2.5 m3Hz	34.64	96.06	O
157	1978	Apr	11	085102.4	Pittsburg		1.7 m3Hz	34.69	95.68	O
158	1978	Apr	13	034350.8	Johnston		2.0 mbLg	34.35	96.82	O
159	1978	Apr	19	142054.1	Tulsa		1.5 m3Hz	36.09	96.14	O
160	1978	Apr	20	081304.0	Coal		1.7 m3Hz	34.59	96.29	O
161	1978	May	01	225913.4	McCurtain		2.2 mbLg	34.40	94.67	O
162	1978	May	04	043552.9	Okfuskee		1.3 m3Hz	35.59	96.35	O
163	1978	May	17	231115.7	Canadian	MM I	2.3 mbLg	35.53	97.91	O
164	1978	May	18	001922.4	Canadian	MM III	2.7 mbLg	35.50	97.95	O
165	1978	May	18	003217.6	Canadian	MM II	2.1 mbLg	35.60	97.83	O
166	1978	May	19	003937.5	McClain		2.0 mbLg	35.14	97.50	O
167	1978	May	19	062732.7	Logan		1.8 m3Hz	36.00	97.37	O
168	1978	May	28	091900.2	Hughes		2.1 m3Hz	35.21	96.14	O
169	1978	Jun	22	051015.5	Dewey		2.0 m3Hz	35.92	99.09	O
170	1978	Aug	03	003537.1	Beaver		2.1 mbLg	36.69	100.16	O
171	1978	Aug	06	042856.8	Ellis		2.6 MDUR	36.07	99.94	O
172	1978	Aug	08	120748.7	Carter		2.2 mbLg	34.13	97.46	O
173	1978	Aug	26	145752.0	Carter		1.4 MDUR	34.18	97.46	O
174	1978	Sep	08	051606.6	Mayes		1.4 MDUR	36.16	95.28	O
175	1978	Sep	26	211717.7	Canadian		2.2 mbLg	35.52	97.87	O
176	1978	Sep	27	015603.8	Canadian		2.1 mbLg	35.52	97.84	O

EVENT NUMBER	DATE AND ORIGIN TIME (UTC)				COUNTY	INTENSITY	MAGNITUDE	LATITUDE DEGREES N.	LONGITUDE DEGREES W.	SOURCES
177	1978	Sep	27	205603.8	Love		2.4 m3Hz	33.88	97.48	O
178	1978	Dec	08	111853.9	Atoka		1.8 mbLg	34.68	96.06	O
179	1978	Dec	19	020028.9	Haskell		1.7 mbLg	35.09	95.13	O
180	1978	Dec	27	220030.0	Love		2.0 m3Hz	34.00	97.51	O
181	1978	Dec	28	053032.4	Love		1.4 m3Hz	34.08	97.46	O
182	1978	Dec	28	135409.8	Love		1.9 m3Hz	33.99	97.46	O

Type faces: Text in 8- and 10-pt. English Times leaded 1 pt.
Heads in 9- and 12-pt. bold Helvetica
Captions in 8-pt. Helvetica, leaded 1 pt.
Table heads in 10-pt. bold English Times
Map in 8- and 10-pt. Century Schoolbook

Presswork: Map, Harris-LUP
Text, Miehle (2-color)

Binding: Saddlestitched with two wire staples

Paper: Text on 70-lb. Warren's Patina
Map on Substance 50 white Nekoosa Regular Finish Offset

Ink (map): Blue, PMS305; red, PMS185; yellow, PMS102; black, PMS Dense Black