U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

Prepared in cooperation with
the Arkansas Geological Survey

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Earthquakes in Arkansas and Vicinity 1699–2010

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This map summarizes approximately 300 years of Arkansas earthquake history. It is one in a series of similar State earthquake-history maps. Work on the Arkansas map was done in collaboration with the Arkansas Geological Survey. The three previously released maps for Virginia (Tarr and Wheeler, 2006), Ohio (Dart and Hansen, 2008), and South Carolina (Dart and others, 2010) are accessible at *http://pubs.usgs.gov/of/2006/1017/*, *http://pubs.usgs.gov/of/2008/1221/*, and *http://pubs.usgs.gov/of/2010/1059/*.

As with the three previous maps, the history of Arkansas earthquakes was derived from letters, journals, diaries, newspaper accounts, academic journal articles, and beginning in the early 20th century, instrumental recordings (seismograms). All historical (pre-instrumental) earthquakes that were large enough to be felt have been located based on felt reports. Some of these events caused damage to buildings and their contents. The more recent widespread use of seismograph recordings has allowed many smaller magnitude earthquakes, previously undetected, to be located. The earthquake location map (center right) shows historically located and instrumentally recorded earthquakes in and near Arkansas. Most of these are instrumentally recorded events.

EARTHQUAKES

Earthquakes occur as a result of slip on faults, typically many kilometers underground, and most earthquakes occur along the boundaries of moving crustal plates. Arkansas is within the North American plate. The nearest plate boundary is approximately 1,700 kilometers south of Arkansas near the coast of Honduras, where the North American and Caribbean plates join, and is not related to the earthquakes in this region. Usually, it is not possible to determine exactly which faults cause earthquakes. Accordingly, the most direct indicators of earthquake hazards are the earthquakes themselves, not the faults on which they occur or the motions of crustal plates. No known seismogenic faults have been mapped at the ground surface within Arkansas.

Before earthquakes were instrumentally recorded, their locations at the ground surface (epicenters) were estimated, typically within a few tens of kilometers of their actual locations. Even with modern instrumentation, earthquake locations within the earth (hypocenters) are only approximations, usually within several kilometers of their actual subsurface locations. However, in areas where seismic networks of closely spaced recording instruments exist, earthquakes are more accurately located. The earthquake location symbols used on the map (center right) represent the best estimates of location and magnitude for both pre-instrumental and instrumental earthquakes. These data came from several earthquake sources (see list, below).

Intensity and Magnitude

An earthquake's *magnitude* (M) and *intensity* are measurements of its size and the severity of ground shaking, respectively. Although earthquake magnitude is characterized by a single number, intensity is expressed as a range of values based on varying levels of ground shaking over the affected (felt) area.

Typically, ground shaking will decrease from a maximum near the earthquake's epicenter to its lowest levels near the edge of the felt area. Intensity values are determined from the Modified Mercalli Intensity Scale (MMI, lower right), based on written accounts (letters, journals, and diaries), and published records (newspapers and official reports) of the ground shaking effects that people, buildings, and landscape have undergone within the affected region. The Modified Mercalli Intensity Scale consists of a range of values from Roman numeral I, barely felt or not felt, to XII, near total destruction. Isoseismal maps show the estimated level of ground shaking in terms of the distribution of intensities and the general pattern of decreasing shaking away from an earthquake's epicenter. Isoseismal maps also illustrate how different ground conditions can affect ground shaking, resulting in intensity patterns that may be more irregular than expected.

An earthquake's size reflects the total energy released and is measured in logarithmic units of magnitude. This means that the amount of energy released during an earthquake will be 30 times greater for a magnitude 5 earthquake than for a magnitude 4 earthquake (Bolt, 1978). There are several methods of calculating magnitude, all are based on seismic wave variables as recorded on earthquake seismograms. The different measuring methods can give slightly different magnitude values for the same earthquake. As a result, differences of several tenths of a magnitude may be reported. A more complete discussion of magnitude and the U.S. Geological Survey policy on reporting magnitude can be found at *http://earthquake.usgs.gov/aboutus/docs/020204mag_policy.php*. For pre-instrumental earthquakes, magnitudes are estimated from intensity values that were recorded at the time of the earthquake or shortly after.

EASTERN U.S. EARTHQUAKES

Earthquakes are less common east of the Rocky Mountains than in Pacific coast states, such as California. However, because of differences in geologic properties, an earthquake in the central United States (U.S.) of the same magnitude as a West Coast earthquake can affect a much larger area, by about ten times. A magnitude 4 central U.S. earthquake typically can be felt 100 km (60 mi) from where it occurred. By comparison, a magnitude 5.5 central U.S. earthquake usually can be felt at a distance of 500 km (300 mi) (Tarr and Wheeler, 2006).

EARTHQUAKES IN ARKANSAS AND VICINITY

In terms of tectonic setting, Arkansas is part of a much larger province known as the Stable Continental Region (Wheeler, 2003), which includes all of eastern North America. Exclusive of several selected areas, like the New Madrid Seismic Zone, the Stable Continental Region undergoes infrequent earthquakes. When earthquakes do occur, they can happen almost anywhere and at irregular intervals. Although there are many known faults within the Stable Continental Region of North America, few of the earthquakes that occur here are associated with known faults.

Various institutions and agencies compile earthquake data. The earthquake data plotted on the map (right) are from several sources. Below are these sources and the time periods of their data listings.

- AGS (Arkansas Geological Survey), 1699–2010
- MDEQ (M.B.E. Bograd, Mississippi Department of Environmental Quality, personal commun., 2010), 1853–2002
- NMSN/CERI (New Madrid Seismic Network/Center for Earthquake Research and Information), 1974–2010
- NCEER (National Center for Earthquake Engineering Research), 1627–1985
- PDE (Preliminary Determination of Epicenters), 1973–2010

The earthquake location symbols shown on the map are sized and colored according to magnitude (see map explanation, right). The map is intended as a general information tool only, and not for hazard assessment or engineering design purposes.

New Madrid Seismic Zone

Northeastern Arkansas is located within the New Madrid seismic zone, the most seismically active area in central and eastern North America. In the winter of 1811–1812, at least three major earthquakes occurred in the New Madrid seismic zone. They were among the largest historical earthquakes to occur in North America. The modern seismicity in the New Madrid seismic zone is associated with the Reelfoot rift (Ervin and McGinnis, 1975), a northeasterly-trending, 70-km-wide, deeply buried graben (Hildenbrand and others, 1982; Hildenbrand, 1985). The seismicity and current deformation in the region are controlled by a regional stress field in which the maximum compressive stress is oriented approximately east-northeast-west-southwest. Within this stress field, ancient faults, most of which originally formed as extensional features during rifting, have been reactivated mainly as strike-slip faults. The modern seismicity is concentrated into three major trends that form a northeasterly-trending, zigzag pattern.

Enola Earthquake Swarm

The Enola swarm began with a magnitude 1.2 earthquake on January 12, 1982, near the town of Enola in Faulkner County, Arkansas. More than 40,000 seismic events have been recorded since this date. Most of these earthquakes were small-magnitude events that were not felt. However, as many as 93 of the swarm's recorded events were felt. The largest of these was a magnitude 4.5 earthquake that occurred on January 21, 1982. No structural damage was reported (Ausbrooks and Doerr, 2007). The Enola swarm involved several episodes of activity and does not appear to be associated with a single fault (Rabak and others, 2010). The swarm is not considered to be associated with the New Madrid seismic zone (McFarland, 2001). The swarm's seismic activity is ongoing, with periods of increased activity in 2001 and in October 2010. Magnitude 4.0 and 3.8 swarm earthquakes on October 11 and 15, 2010, were felt widely across Arkansas.

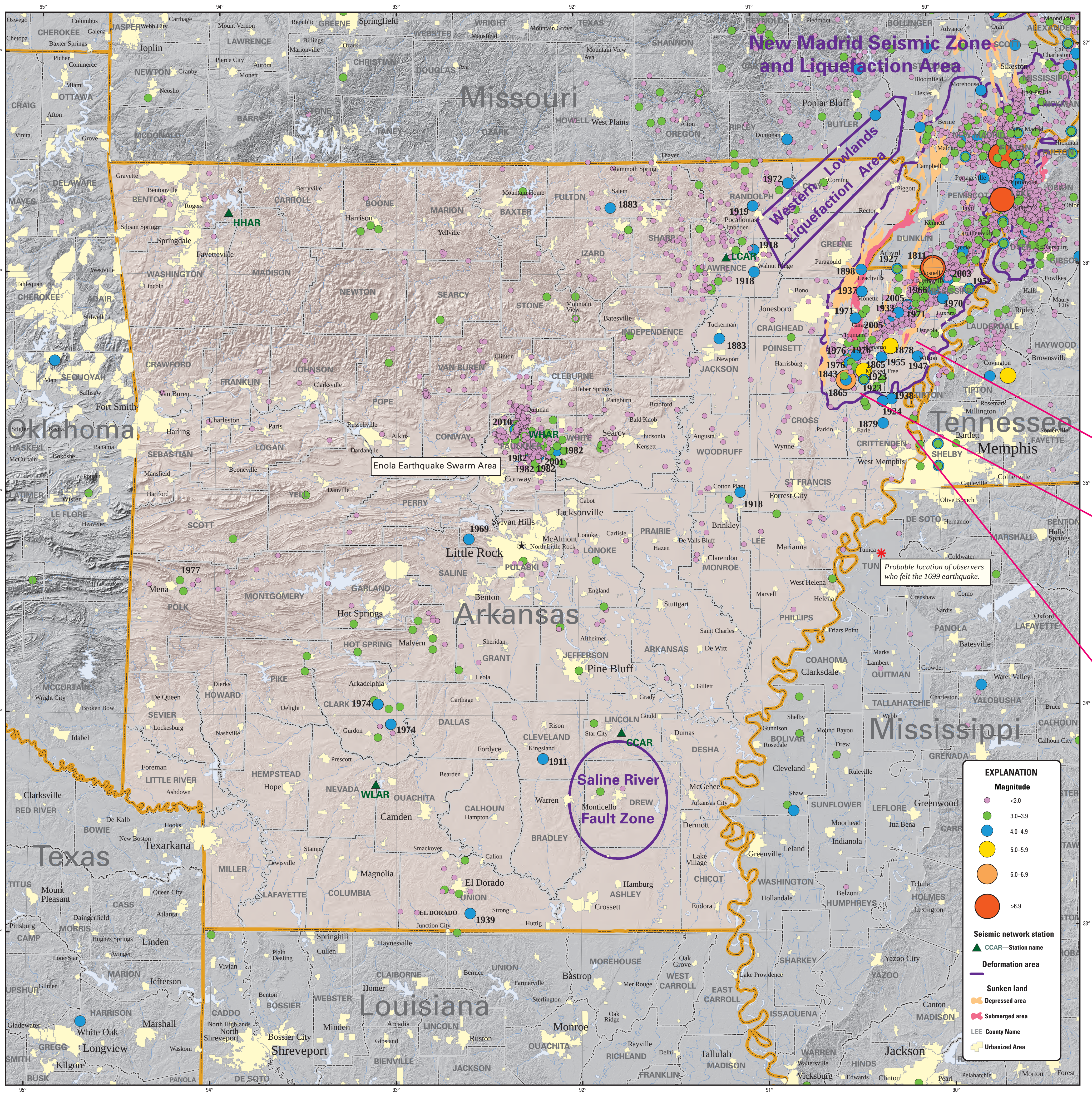
Notable Arkansas Earthquakes

Arkansas has had a long earthquake history. Information about the earthquake history of Arkansas is available at *http://earthquake.usgs.gov/earthquakes/states/arkansas/history.php* and *http://earthquake.usgs.gov/earthquakes/states/historical_state.php*. Arkansas's earliest seismic event was documented by Jesuit missionaries in 1699 traveling down the Mississippi River near present day Helena, Arkansas, in Phillips County (Wheeler and others, 2003). Other notable earthquakes are felt events within the past 200 years of magnitude 4.0 and greater. Several of these earthquakes caused property damage within the State. Arkansas' magnitude 4.0 and greater earthquakes are identified by date and location on the map (center right).

ARKANSAS SEISMIC NETWORK

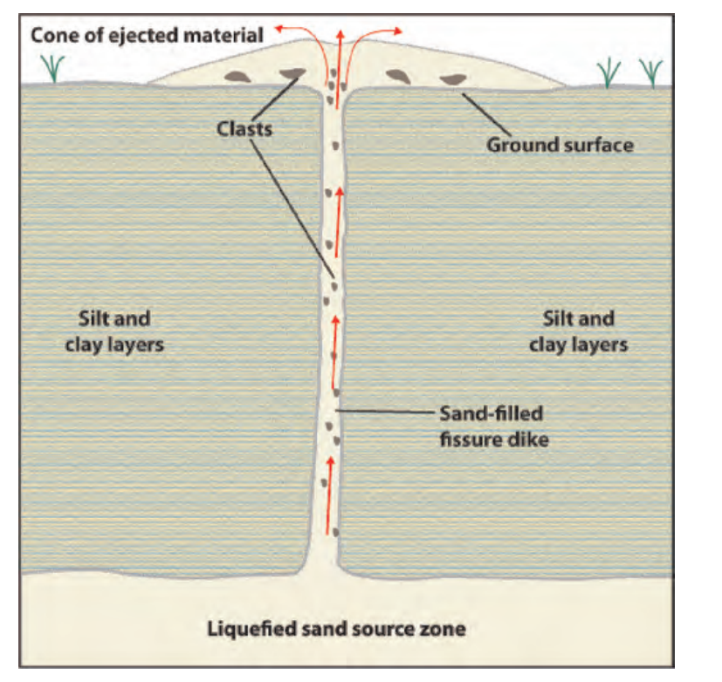
The Arkansas Seismic Network (ASN) consists of six state-of-the-art permanent broadband seismic stations strategically placed within selected State Parks across Arkansas. The ASN was funded through the Arkansas Governor's General Improvement Fund in response to the Magnet Cove earthquake swarm in 2008. The goal of the ASN is to establish better and more uniform earthquake detection outside of the New Madrid seismic zone (NMSZ). The network was installed in spring of 2010 and is seamlessly integrated with the regional and national seismic networks. The ASN is operated and maintained in cooperation with the Arkansas Geological Survey (AGS), Center for Earthquake Research and Information (CERI) at the University of Memphis and Arkansas State Parks (ASP). For additional information visit: *http://www.geology.ar.gov/geohazards/ark_seismic_network.htm*.

Earthquake Locations



Base from U.S. Geological Survey National Elevation Dataset (*http://nationalmap.gov/viewers.html*).
National Hydrologic Database, and Digital Chart of the World (ESRI, 1993)
Albers equal-area conic projection, standard parallels 30°30′00″ and 35°00′00′′, central meridian 81°00′00′′, latitude of origin 00°00′00″

SCALE 1:1 150 000
Albers Conic Equal-Area Projection



Interpretative diagram of a sand blow and the liquefaction process (after Obermeier and others, 1987).

Typical small dike in vertical section. Image source: Obermeier, S.F., 1998, Seismic Liquefaction Features: Examples from Paleoseismic Investigations in the Continental United States, USGS Open-File Report 98–488, slide 19, *http://pubs.usgs.gov/of/1998/of98–488/*.

ARKANSAS AREAS OF DEFORMATION, LIQUEFACTION, AND FAULTING

The U.S. Geological Survey Quaternary Faults Database (*http://earthquake.usgs.gov/qfaults*) documents several areas of known and inferred recent deformation and faulting within the map area. The word recent refers to events that are of Quaternary age (younger than 1.6 million years). These areas in Arkansas are shown on the Earthquake Location Map (above) and described below.

As a result of strong ground shaking, liquefaction features often develop in the epicentral areas of large earthquakes. Liquefaction features are ground-surface features that form when buried saturated sand, under pressure due to the shaking, liquefies and vents upward, often in the form of sand and water geysers, known as sand blows. The resulting sand deposits are typically circular in shape and several meters in diameter. Over time, these sand deposits can themselves become buried forming buried sand lenses. In regions having long seismic histories, paleoseismologists are sometimes able to excavate these buried liquefaction features and date the sequential histories of past large earthquakes, thereby determining approximate recurrence intervals of large events (see figures, left).

New Madrid Liquefaction Area

The New Madrid earthquake sequence of 1811–1812 produced subsidence and widespread liquefaction (sand blows and sand-filled fissures) throughout the New Madrid seismic zone and surface deformation at several locations (Crone and Schweig, 1994). The liquefaction features, including depressed and submerged land (Jibson and Keefer, 1988), are concentrated in a 40–60-km-wide belt from near Charleston, Miss., to Marked Tree, Ark. (Obermeier, 1988), and are the most widespread expression of recent strong earthquakes in the New Madrid region. Most of these features formed at the time of the major 1811–1812 earthquakes. The resulting depressed and submerged areas, referred to as sunken lands, are associated with surface deformation and the impoundment of the Little and St. Francis rivers (Guccione and VanArsdale, 1995; and Guccione and others, 2000), see map explanation above.

Evidence of Quaternary faulting in the New Madrid region is based on the occurrence of large magnitude earthquakes in the 1811–1812 sequence, the abundant ongoing seismic activity, and surface deformation associated with the Reelfoot fault scarp. Other than the faulting associated with the Reelfoot scarp, individual seismogenic faults in the New Madrid seismic zone are not expressed at the ground surface. The general subsurface locations of these seismogenic faults are inferred to be associated with areas of abundant recorded microseismicity.

Saline River Fault Zone Area

Quaternary deformation in the Saline River fault zone area is inferred and is thought to be associated with a trend of earthquake epicenters following the Saline River in southeastern Arkansas (Cox and VanArsdale, 1997). Cox and VanArsdale describe several small faults of various orientations exposed in road cuts and in an exploratory trench. In addition, from shallow-seismic reflection data, Cox and VanArsdale interpret the existence of sub-surface faults. However, the relationship of the exposed features to the deeper structures and to the regional pattern of seismicity is not well understood. Because there is no significant geomorphic expression of known or suspected faulting, active deformation is questionable. This discussion of the Saline River fault zone area was derived, in part, from a compilation by Crone, 1998.

ABBREVIATED MODIFIED MERCALLI INTENSITY SCALE

Expressed as Roman numerals, earthquake intensities are not instrumentally derived; they are assigned values based on descriptive reports of felt shaking and damage. The different intensity levels are defined as folllows:

I. Not felt.
II. Felt by a few persons at rest, especially on upper floors, or in favorable locations.
III. Felt indoors, especially on upper floors. Hanging objects swing. Many may not recognize it as an earthquake. Standing automobiles may rock slightly. Vibrations felt. Duration estimated.
IV. Felt outdoors by many. Some sleepers awaken. Dishes, glasses, windows, doors clink and rattle. Walls make creaking sounds. Heavy vibrations and jolting sensations felt. Standing automobiles rock noticeably.
V. Felt outdoors. Felt by nearly everyone; many sleepers awaken. Unstable objects are displaced. Liquids are disturbed. Pendulum clocks may stop. Doors swing. Pictures move.
VI. Felt by all, many frightened, some panic. Walking unsteady. Windows break, pictures fall. Objects fall off shelves. Furniture moves and is overturned. Some plaster cracking and falling. Damage to buildings is slight. Trees and bushes shake.
VII. Difficulty standing. Noticeable to drivers. Hanging objects move. Furniture breaks. Some damage to buildings. Some wall cracking and plaster falling. Some chimneys break. Small landslides form. Waves and water turbidity noticed.
VIII. Damage to structures variable (slight to considerable) depending on Construction style. Chimneys, factory stacks, columns, monuments, and towers may twist and fall. Heavy furniture is overturned. Masonry and stucco is damaged. Tree limbs break. Flow and temperature changes occur in wells and springs. Some ground cracking. Steering impaired.
IX. General panic. Damage great in substantial buildings with partial collapse. Buildings shifted off foundations. Serious damage to reservoirs and underground pipelines. Ground cracks and liquefaction features form in alluvial areas.
X. Some well-built wooden structures are destroyed; most masonry and frame structures are destroyed. Rails are bent. Heavy damage to dams and embankments occurs. Large landslides form.
XI. Few, if any (masonry) structures remain standing. Bridges are destroyed. Rails are bent greatly. Underground pipelines are disabled.
XII. Damage nearly total. Large rock masses are displaced. Lines of sight and level are distorted. Objects are thrown into the air.

INTENSITY	I	II	III	IV	V	VI	VII	VIII	IX	X+
SHAKING	None	Weak	Weak	Light	Moderate	Strong	Very Strong	Severe	Violent	Extreem
DAMAGE	None	None	None	None	Very Light	Light	Moderate	Moderate Heavy	Heavy	Very Heavy
MAGNITUDE	1.5	2	2.5	3 3.5	4	4.5	5	5.5 6	6.5	7+

Image source: Arkansas Geological Survey.

SEISMIC HAZARD

Seismic hazard maps, like the one shown at right, are tools for determining possible risk. As such, they are critical in helping to save lives and preserve property by providing information essential to the creation and updating of the seismic design provisions of local building codes. Additional applications of the information derived from seismic hazard maps include setting insurance rates, determining related ground-failure hazards, engaging in disaster response planning, and promoting earthquake education.

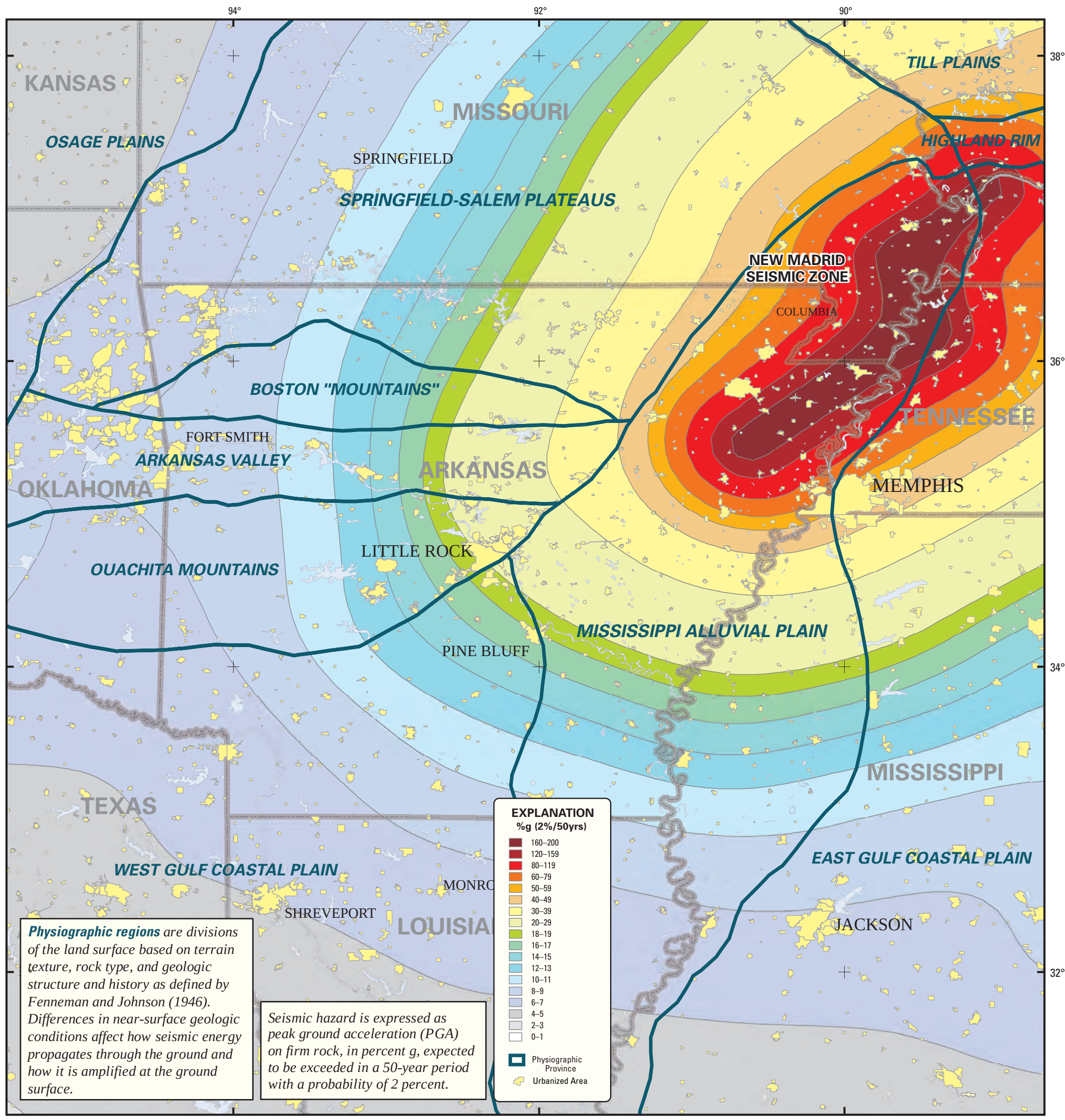
Some level of seismic hazard from earthquake ground shaking exists in every part of the United States. The severity of the ground shaking, however, can vary greatly from place to place. Regional seismic hazard maps illustrate this variation. The hazard shown on seismic hazard maps is based on a variety of factors, such as earthquake rate of occurrence, magnitude, extent of affected area, strength and pattern of ground shaking, and geologic setting.

Because many buildings and other structures in the central United States are not built to withstand severe ground shaking, damage could be catastrophic in the event of a powerful earthquake. The generalized seismic hazard map (right) illustrates this hazard. It is a computer generated contour map (Petersen and others, 2008) portraying seismic hazard calculated by the USGS as color bands (cooler for lesser hazard, warmer for greater hazard). Shaking level is expressed as a percentage of the acceleration of gravity (% *g*), and seismic hazard values are computed for particular time intervals (here, 50 years) and probability of exceedance (here, 2 percent). For example, the hazard value in Little Rock, Ark., is between 18–30%*g* .That means structures built on firm rock have a 1 in 50 chance (2-percent probability) of undergoing ground shaking of 18–30 percent *g* or higher in the next 50 years. In terms of shaking, the acceleration a person or object experiences is proportional to the force applied by the passing seismic wave. The value 50 is a random amount and has no inherent significance.

Seismic hazard maps are estimates of how the ground in a particular area is likely to respond to local and regional earthquakes. They differ from isoseismal maps (below) in that they are probability maps, illustrating likely shaking levels. Sediment and soil properties near the ground surface are important in hazard map design. During an earthquake, seismic energy radiates in all directions as waves. As the seismic waves move upward they are amplified or de-amplified as they travel through sediment and soil layers, thus greatly affecting the level of ground shaking that might occur. The map at right is a regional depiction of ground response to earthquake shaking; it does not show the amplifying or de-amplifying effects of local near-surface soil conditions.

For additional information on seismic hazard mapping, consult these internet web links:
http://earthquake.usgs.gov/regional/ceus//urban_map/index.php
http://earthquake.usgs.gov/hazards/
http://earthquake.usgs.gov/hazards/products/

Regional Seismic Hazard



Physiographic regions are divisions of the land surface based on terrain texture, rock type, and geologic structure and history as defined by Fenneman and Johnson (1946). Differences in near-surface geologic conditions affect how seismic energy propagates through the ground and how it is amplified at the ground surface.

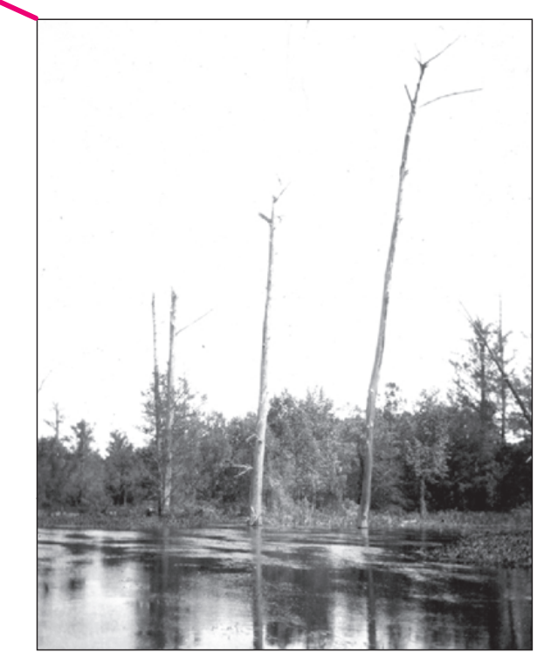
Seismic hazard is expressed as peak ground acceleration (PGA) on firm rock, in percent g, expected to be exceeded in a 50-year period with a probability of 2 percent.

Data from Petersen and others, 2008
Base from National Hydrologic Database, and Digital Chart of the World (ESRI, 1993)

SCALE 1:4 000 000
Geographic Projection NAD83

Big Lake, sunken land that formed during the New Madrid earthquakes of 1811–1812. Photograph by Pat Lendennie. Image source: The Encyclopedia of Arkansas History and Culture, *http://www.encyclopediaofarkansas.net/encyclopedia/entry-*

Aerial view of sandblow liquefaction features within the New Madrid 1811–1812 meizoseismal region. White spots are areas where sand vented onto the darker ground surface. The vented sand formed cones that are 15 to 50 cm in height and tens of meters in width. Image source: Obermeier, S.F., 1998, Seismic Liquefaction Features: Examples from Paleoseismic Investigations in the Continental United States, USGS Open-File Report 98–488, slide 14. *http://pubs.usgs.gov/of/1998/of98-488/*.



Lake St. Francis, Ark., 1904. Cypress trees killed by submergence resulting from the New Madrid earthquakes of 1811–1812. Plate 4–B in U.S. Geological Survey Bulletin 494, 1912. Photo by M.L. Fuller. Image source: USGS Photographic Library, *http://libraryphoto.cr.usgs.gov/earth.htm*

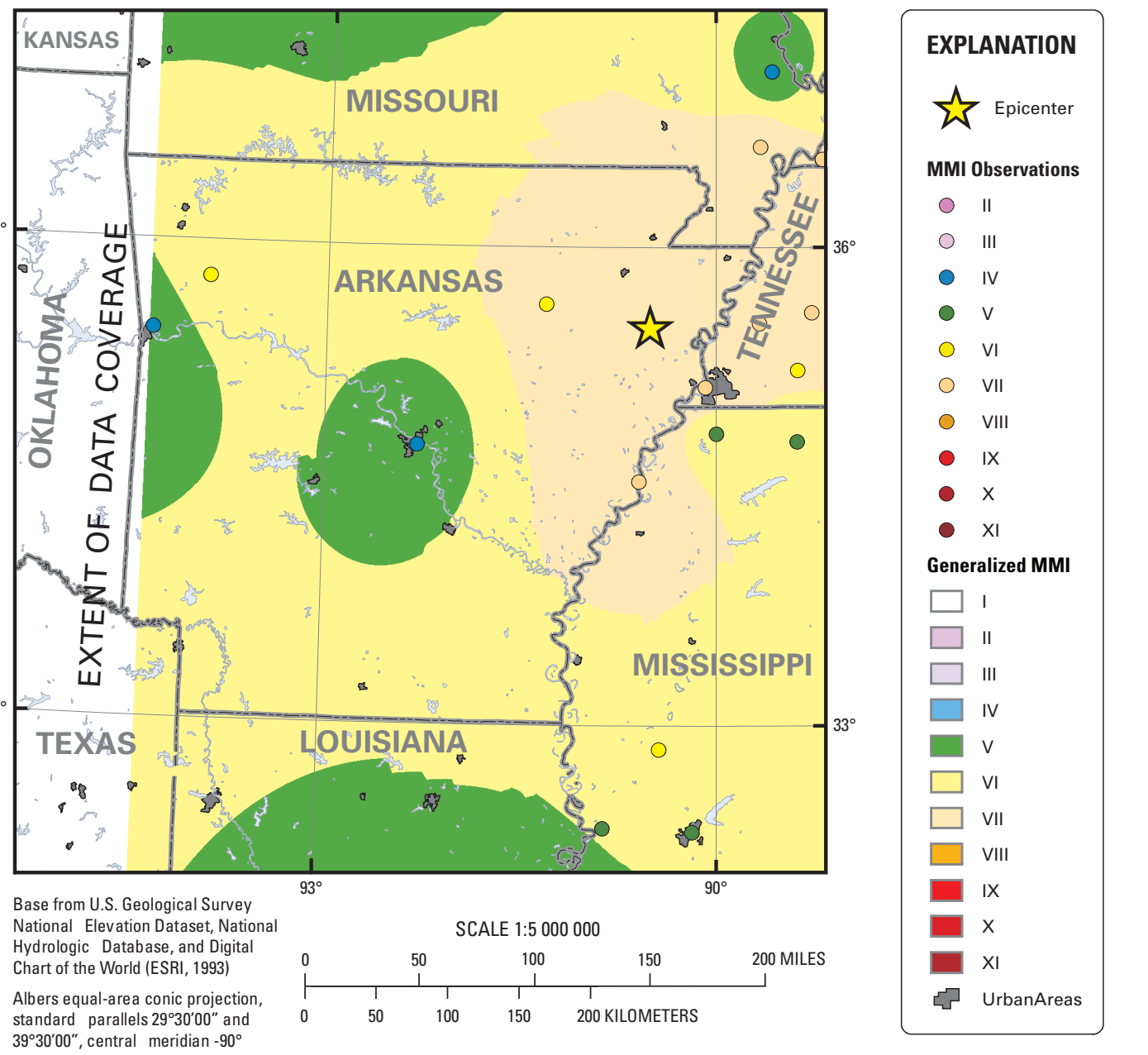
CONVERSION FACTORS

Multiply	By	To obtain
meters (m)	3.281	feet (ft)
kilometers (km)	0.6214	miles (mi)

ISOSEISMAL MAPS

The isoseismal maps (below) show interpolated and contoured intensity values for the January 5, 1843, intensity VII; and the December 16, 1811, intensity XI northeast Arkansas earthquakes. The locations of intensity observations and their assigned values are shown as solid colored circles. The December 16, 1811, earthquake at 2:15 a.m. local time (08:15 UTC), was the first event in the New Madrid sequence. Intensity data for this event came from Hough and others (2000), Hough and Martin (2002), Bakun and others (2002), Street (1982), and Nuttli (1973). Intensity data for the 1843 event came from Bakun and others (2002). The data were interpolated using an inverse distance weighted algorithm. The extent of interpolation was defined by the locations of the intensity observations.

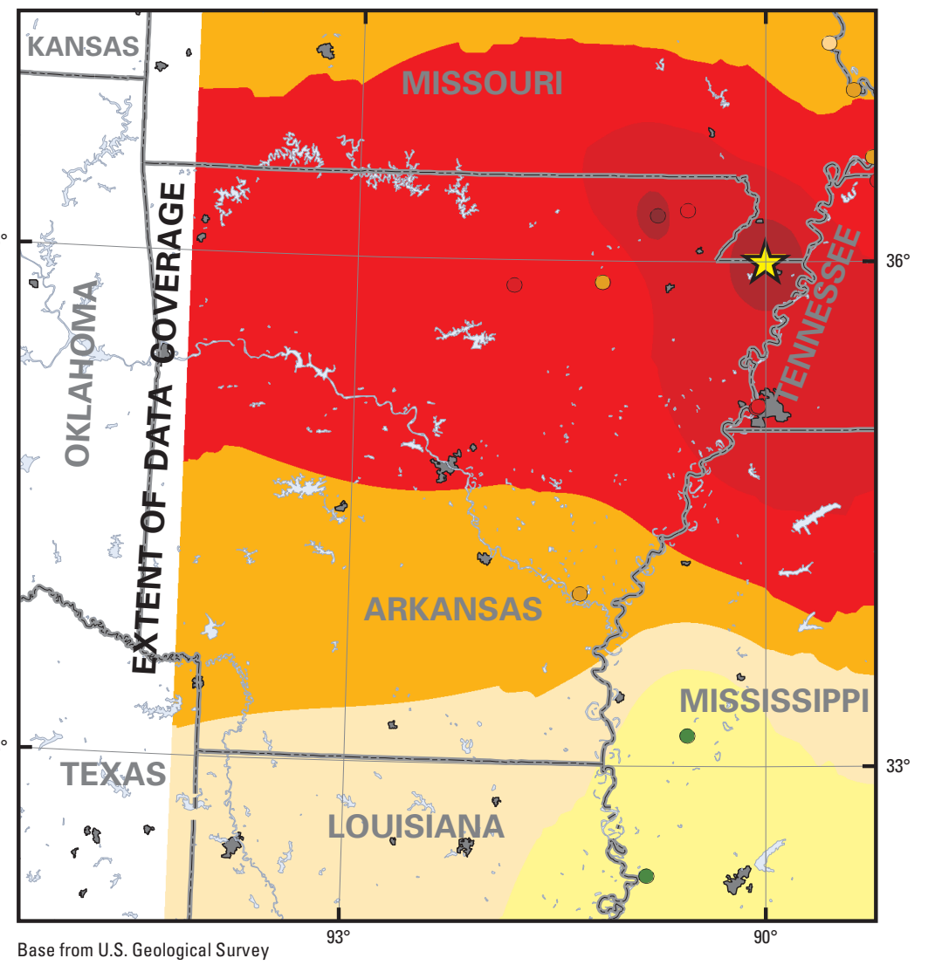
Distribution of intensity for the January 5, 1843, northeast Arkansas, maximum intensity VII, magnitude 6.0 earthquake



Base from U.S. Geological Survey National Elevation Dataset, National Hydrologic Database, and Digital Chart of the World (ESRI, 1993)
Albers equal-area conic projection, standard parallels 29°30′00″ and 39°30′00″, central meridian -90° 00′00″, latitude of origin 0°00′00″

SCALE 1:5 000 000

Distribution of Intensity for the December 16, 1811, northeast Arkansas, maximum intensity XI, magnitude 8.1 earthquake



Base from U.S. Geological Survey National Elevation Dataset, National Hydrologic Database, and Digital Chart of the World (ESRI, 1993)
Albers equal-area conic projection, standard parallels 29°30′00″ and 39°30′00″, central meridian -90° 00′00″, latitude of origin 0°00′00″

SCALE 1:5 000 000

INTERNET EARTHQUAKE INFORMATION RESOURCES

Advanced National Seismic System (ANSS): *http://www.ncedc.org/anss/catalog-search.html*. Last accessed on April 27, 2010. Information on U.S. earthquakes.

Arkansas Center for Earthquake Education and Technology Transfer (ACEETT): *http://quake.ualr.edu/*. Last accessed on June 7, 2010. Information on Arkansas earthquakes.

Center for Earthquake Research and Information (CERI): *http://www.ceri.memphis.edu/seismic/catalogs/cat_nm.html*. Last accessed on March 17, 2011. The New Madrid earthquake catalog and information on Central U.S. earthquakes.

Earthquake Engineering Research Institute (EERI): *http://www.eeri.org/site/*. Last accessed on March 11, 2010. Technical information on earthquakes.

National Center for Earthquake Engineering Research (NCEER): *http://folkworm.ceri.memphis.edu/catalogs/html/cat_nceer.html*. Last accessed on March 17, 2011. Information on Central U.S. earthquakes before 1986.

National Earthquake Hazards Reduction Program (NEHRP): *http://www.nehrp.gov/* and the National Seismic Hazards Maps Program (NSHM): *http://earthquake.usgs.gov/hazards/products/conterminous/2008/catalogs/*. Last accessed on Mary 15, 2010. Information on hazards risk reduction in the United States and information on U.S. probabilistic maps and data.

National Geophysical Data Center (NGDC/DNAG/NOAA): *http://www.ngdc.noaa.gov/hazard/earthqk.shtml*. Last accessed on March 11, 2010. Information on geophysical data products and services.

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