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

OPEN-FILE REPORT 2008–1221

Prepared in cooperation with the
Ohio Department of Natural Resources,
Division of Geological Survey

Earthquakes in Ohio and Vicinity 1776–2007

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2008

This map summarizes more than 200 years of Ohio earthquake history. The history of Ohio earthquakes was derived from letters, journals, diaries, newspaper accounts, scholarly articles and, beginning in the early twentieth century, instrumental recordings (seismograms). All historical (pre-instrumental) earthquakes that were large enough to be felt have been located based on anecdotal accounts. Some of these events caused damage to buildings and their contents. The more recent widespread use of seismographs has allowed many small earthquakes, previously undetected, to be recorded and accurately located. The seismicity map (right) shows the historically located and instrumentally recorded earthquakes in and near Ohio.

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. Ohio is within the North American plate, far away from any plate boundaries. Usually it is not possible to determine exactly which fault causes an earthquake. Accordingly, the most direct indicators of earthquake hazards are the earthquakes themselves, not the faults on which they occur nor the motions of crustal plates.

Before earthquakes were instrumentally recorded, estimated locations were typically within a few tens of kilometers of the actual epicenters. Even with modern instrumentation, however, earthquake locations within the Earth are only approximations, usually within several kilometers of their actual locations. However, in areas where networks of closely spaced recording instruments exist earthquakes can be more accurately located. Despite location uncertainties earthquakes have occurred in most parts of Ohio during the last 200 years.

Magnitude (M) is the most common measure of an earthquake's size. An earthquake's magnitude reflects the total energy released as seismic waves. There are several methods to measure earthquake magnitude. The first and most frequently cited is the "Richter scale." The different methods used can give slightly different magnitude values for the same earthquake. As a result, differences of several tenths of a magnitude may be reported.

Although the size of an earthquake is characterized by its *magnitude*, a single number, the levels of ground shaking are characterized by a range of *intensity* values, which vary over the affected area. The Modified Mercalli Intensity (MMI) scale defines recognized intensity values from I (barely felt or not felt) to XII (total destruction; see table at far right). Modified Mercalli Intensity VI marks the onset of slight damage to poorly built structures, whereas MMI VII or higher generally results in considerable damage to buildings—even their collapse. An earthquake's intensity usually decreases away from its epicenter location. Earthquake isoseismal (intensity) maps show this pattern of decreasing seismic shaking away from the place where the earthquake occurred. Isoseismal maps also illustrate how different ground conditions affect intensity values resulting in intensity patterns that are more irregular than might be expected. Two isoseismal maps for Ohio earthquakes are shown (far right).

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 crustal properties, an earthquake that occurs in the eastern U. S. of the same magnitude as a west coast earthquake can affect a much larger area. A magnitude 4.0 eastern U.S. earthquake typically can be felt 100 km (60 mi) from where it occurred and will frequently cause damage near its source. A magnitude 5.5 eastern U.S. earthquake usually can be felt 500 km (300 mi) from where it occurred and can sometimes cause damage as far away as 40 km (25 mi).

EARTHQUAKES IN OHIO AND VICINITY

In terms of tectonic setting, Ohio is part of a much larger geographic area known as the Stable Continental Region (Wheeler, 2003). This region includes all of eastern North America. Exclusive of several selected areas, such as the New Madrid seismic zone, this region experiences infrequent earthquakes. Earthquakes, as previously stated, are generated as the result of movement on faults often thousands of feet below ground. Although there are many known faults within the Stable Continental Region, few of the earthquakes that occur here are associated with known faults.

Ohio has experienced more than 160 felt earthquakes since 1776. Most of these events caused no damage or injuries. However, 15 Ohio earthquakes resulted in property damage and some minor injuries. The largest historic earthquake in the State occurred in 1937. This event had an estimated magnitude of 5.4 and caused considerable damage in the town of Anna and in several other western Ohio communities. At least 40 earthquakes have been felt in this area since 1875. Northeastern Ohio, east of Cleveland, is another area of seismic interest. There a 5.0 magnitude event in 1986 caused moderate damage. In southern Ohio more than 30 earthquakes have been felt. Due to a lack of information and location uncertainty, two early felt events in 1776 and 1779 (Hansen, 2006) are not plotted on this map.

The origins of Ohio earthquakes, as with earthquakes throughout the central and eastern U.S., are poorly understood. However, Ohio earthquakes appear to be associated with ancient zones of weakness within the North American continental crust. These zones of weakness are characterized by deeply buried and poorly documented faults. Some of these weak zones periodically release accumulated strain in the form of earthquakes.

Ohio is on the periphery of the New Madrid seismic zone, site of the 1811–1812 earthquake sequence, the largest earthquake sequence to occur in historical times in the continental U.S. Some of the events in this sequence had magnitudes in the range of 8.0 and were felt throughout all of the eastern U.S. The intensity of ground shaking generated by these large earthquakes toppled chimneys as far away from the epicenter as Cincinnati.

The table below lists notable earthquakes, magnitude 3.5 and greater, located in Ohio and vicinity. On the earthquake location map at right, these events, with one exception, are labeled with their dates of occurrence. The single exception is the earliest recorded earthquake in the State, a magnitude 4.0 event, that occurred in the summer of 1776 near the Muskingum River in south-central Ohio. The location for this event is an approximation and is not considered accurate. It is not listed in the table.

NOTABLE OHIO AND VICINITY EARTHQUAKES MAGNITUDE ≥ 3.5

YR	MO	DY	LAT(°N)	LON(°W)	MAG	SOURCE
1824	7	15	39.7	80.5	4.1	NCEER
1834	11	20	39.6	84.3	3.5	OSN
1834	11	20	38.65	83.8	3.5	OSN
1843	6	19	40.1	83.8	3.5	OSN
1848	4	6	39.65	82.53	3.7	NCEER
1854	1	11	39.4	83.7	3.5	CERI
1857	2	27	42.31	80.94	4.1	OSN
1873	1	4	40.2	83.0	3.8	NCEER
1875	6	18	40.2	84.0	4.7	NCEER
1884	9	19	40.7	84.1	4.8	PDE
1885	1	18	41.15	81.55	3.8	NCEER
1886	5	3	39.36	82.24	3.8	NCEER/OSN
1892	4	15	40.55	84.57	3.8	NCEER
1894	11	24	39.27	81.56	3.8	OSN
1901	5	17	38.73	82.99	4.3	NCEER
1926	11	5	39.1	82.1	3.6	NCEER
1929	3	8	40.4	84.2	3.7	NCEER
1930	9	30	40.3	84.3	4.2	NCEER
1931	9	20	40.43	84.27	4.7	NCEER
1937	3	2	40.49	84.27	4.9	NCEER
1937	3	9	40.47	84.28	5.4	NCEER/PDE
1943	3	9	41.63	81.31	4.4	NCEER
1944	11	13	40.4	84.4	4.1	NCEER
1947	8	10	41.93	85.0	4.5	NCEER
1952	6	20	39.64	82.02	3.9	NCEER
1953	6	12	41.7	83.6	3.5	NCEER
1956	1	27	40.5	84.0	3.7	NCEER
1956	1	27	40.4	84.2	3.7	NCEER
1961	2	22	41.2	83.3	3.7	NCEER
1967	4	8	39.65	82.53	3.7	NCEER
1974	10	20	39.06	81.61	3.8	NCEER
1979	11	9	38.49	82.81	3.8	NCEER/OSN
1983	8	17	38.47	82.77	3.5	NCEER/OSN
1986	1	31	41.65	81.16	5.0	PDE
1986	7	12	40.55	84.39	4.5	ASN
1987	7	13	41.896	80.767	3.8	PDE
1991	1	26	41.61	81.594	3.5	JCU
1993	10	16	41.698	81.012	3.6	PDE
1995	2	19	39.12	83.47	3.6	PDE
1998	9	25	41.495	80.388	5.2	PDE
2001	1	26	41.942	80.802	4.3	PDE
2003	6	30	41.8	81.2	3.6	PDE
2006	6	20	41.84	81.23	3.8	PDE

OHIO SEISMIC NETWORK

The Division of Geological Survey of the Ohio Department of Natural Resources coordinates a 25-station cooperative network of seismograph stations (OhioSeis) in order to continuously record earthquake activity in the state and the surrounding region as shown on the map. These stations are located across the state at colleges, universities, and other institutions, but are concentrated in the most seismically active areas or in areas that provide optimal conditions for detecting and locating small earthquakes. Small earthquakes are important because they occur more frequently than larger earthquakes and help to identify faults that may periodically produce larger, potentially damaging earthquakes.

The Ohio Division of Geological Survey coordinates the seismic network and operates from the Ohio Earthquake Information Center at the Division's Laboratory at Alum Creek State Park, north of Columbus. This seismograph system allows earthquakes anywhere in the state to be rapidly located and their magnitudes to be quickly calculated.

The OhioSeis network was established with the purposes of accurately locating and evaluating Ohio earthquakes, providing information to the public, and defining areas of seismic risk. The network is a joint State and Federal project, part of the National Earthquake Hazards Reduction Program (NEHRP, http://www.nehrp.gov/).

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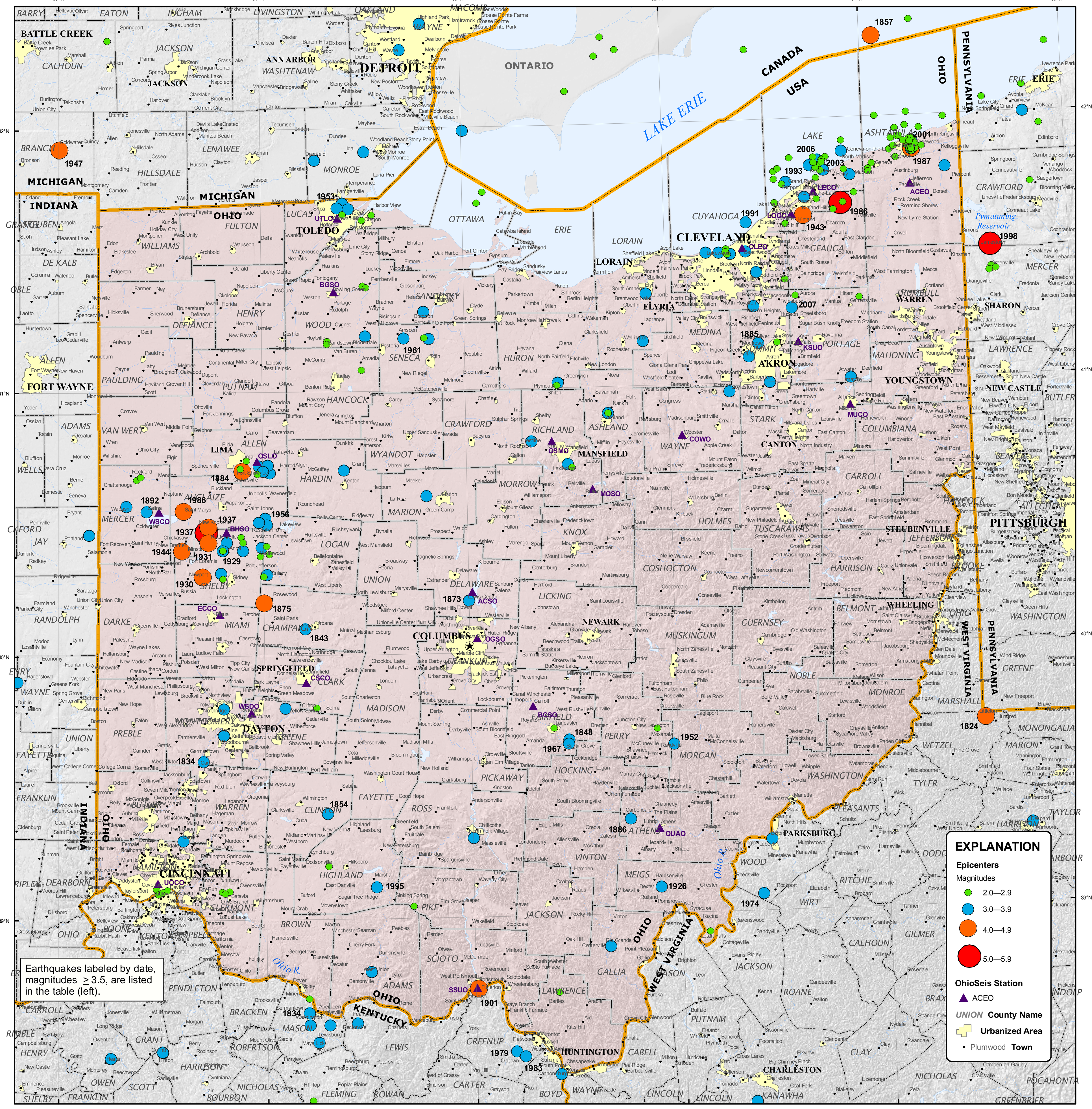
Earthquake Locations



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 30° 20′ 00″ and 35° 40′ 00″, central meridian -85° 00′ 00″, latitude of origin 0° 00′ 00″

SCALE 1:1,000,000

EARTHQUAKE CATALOGS

Various institutions and agencies compile catalogs of earthquake data. Each uses different criteria in determining the catalog's content. The earthquake locations shown on the map were taken from several catalogs. To some extent, these catalogs cover overlapping time periods. An attempt has been made to locate and remove duplicate events. In the case of event duplication the order of catalog preference, as listed, was generally applied:

- OSN, Ohio Seismic Network, 1999–2007
- ASN, Anna Seismic Network, 1977–1992
- JCU, John Carrol University Seismological Observatory, 1900–1992
- UTLO, University of Toledo seismic station
- UK, University of Kentucky
- LCSN, Lamont-Doherty Cooperative Seismic Network, 1990–2005
- DNAG, Decade of North American Geology, 1534–1985
- NCEER, National Center for Earthquake Engineering Research, 1627–1985
- SIGUS, *Significant Earthquakes in the U.S.* (Stover and Coffman, 1993), 1568–1989
- PDE, Preliminary Determination of Epicenters, 1973–2007
- CERI, Center for Earthquake Research and Information, 1974–2007

The catalogs used may contain mining-related and other types of non-earthquake events. Mining events are typically of small magnitude and may not be easily differentiated from small earthquakes (Street and others, 2002). An attempt was made to exclude non-earthquake events.

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SEISMIC HAZARD

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. Seismic hazard maps, like the one shown at right, illustrate this variation. The risk level 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.

Seismic hazard maps are tools for determining acceptable risk. As such, they are critical in helping to save lives and preserve property. They provide information essential to the creation and updating of seismic design provisions for local building codes. Because most buildings and other structures in the central United States were not built to withstand severe ground shaking, damage could be catastrophic in the event of a powerful earthquake. The work of seismic-hazard scientists and engineers provides the groundwork for future urban environments that will be safer if large magnitude earthquakes occur. Additional applications of the information derived from these maps include insurance-rates setting, estimating hillside stability and landslide potential, and estimating assistance funds needed for earthquake education and preparedness.

Seismic hazard maps are an estimation of how the ground in a particular area is likely to respond to local and regional earthquakes. They differ from isoseismal maps in that they are probability maps. They illustrate what shaking levels are likely, or example a 2 percent probability that it will be worse over a stated time period (for example, 50 years).

The seismic energy released during an earthquake radiates in all directions as waves. As the seismic waves move upward they are amplified or de-amplified as they travel through the sediment layers near the ground surface. Seismic wave amplification or de-amplification can significantly affect the way the ground shakes during an earthquake.

An additional factor in determining how the ground will respond during an earthquake is the rate of shaking. As a seismic wave passes a given map location, the ground will vibrate. If ground vibration (oscillation) is rapid (short-period motion), the seismic wave's energy will dissipate quickly. Conversely, if the ground vibration is slow (long-period motion), the wave's energy will dissipate less rapidly. Long-period waves propagate farther and retain their energy over longer distances than do short-period waves.

A final factor in determining ground response to earthquake shaking is the strength of shaking. If ground shaking is particularly violent, sediments may break apart, preventing seismic waves from continuing to be transmitted through them. This would have the beneficial effect of limiting shaking, but such extreme shaking could result in catastrophic ground failure.

The generalized seismic-hazard map (right) is a computer-generated contour map. It portrays seismic hazard calculated by the U.S. Geological Survey as bands of color (cooler blues and grays for less hazard, warmer greens and yellows for greater hazard). Shaking level is expressed as 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 Cincinnati is between 6%*g* and 8%*g*. That means a structure built on firm rock has 1 in 50 odds (2 percent probability) of undergoing ground shaking of 6% – 8%*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 to it by the passing seismic wave.

OHIO SEISMIC ZONES

Anna Seismic Zone
This small seismic zone in western Ohio (right) has had moderately frequent earthquakes at least since the first one was reported in 1875. The two largest earthquakes (March 2 and 9, 1937) located in the zone caused damage. Moderately damaging earthquakes occur in the Anna seismic zone every two or three decades, and smaller earthquakes are felt here two or three times per decade. Historically, seismicity has been episodic with periods of frequent activity and periods of low activity.

Some of the Anna seismic zone earthquakes appear to coincide with the known faults, while others do not. At earthquake depths the positions of even known faults are uncertain, and many small or deeply buried faults may remain undetected. Accordingly, few earthquakes in the seismic zone can be linked to known faults and it is difficult to determine if a specific known fault is active and capable of generating an earthquake.

The Anna seismic zone lacks paleoseismological evidence for faulting younger than Paleozoic. However, north-, north-northeast-, and northwest-striking faults in lower Paleozoic and Precambrian crystalline rocks have been mapped and are part of the Precambrian-age East Continental Rift Zone. No evidence has been found that the zone has had an earthquake larger than magnitude 7 in the past several thousand years.

Northeast Ohio Seismic Zone
The Northeast Ohio seismic zone (map at upper right) has had moderately frequent earthquakes at least since the first one was reported in 1836. The largest earthquake in this zone (magnitude 5.0) occurred in 1986. This event produced Modified Mercalli intensities of VI in the epicentral region. A damaging earthquake (magnitude 5.2) occurred in 1998 near Pymatuning in northwestern Pennsylvania, just east of the Ohio border. An earthquake in the Ashtabula, Ohio, area (magnitude 4.3) in 2001 caused minor damage. Historically this zone has recorded only a few earthquakes per decade, but felt earthquakes have been reported more frequently in recent decades. This is probably a result of increased population, greater public awareness, improved communications, and perhaps episodic seismicity.

NEARBY SEISMIC ZONES

Eastern Tennessee Seismic Zone
The Eastern Tennessee seismic zone (map at upper right) is one of the most active earthquake areas in the southeastern United States. A few earthquakes located within this zone have caused property damage. The largest recorded earthquake in this zone (magnitude 4.6) occurred in 2003, near Fort Payne, Alabama. Felt earthquakes occur about once a year in this seismic zone, and seismographs have recorded hundreds of smaller, unfelt earthquakes in recent decades.

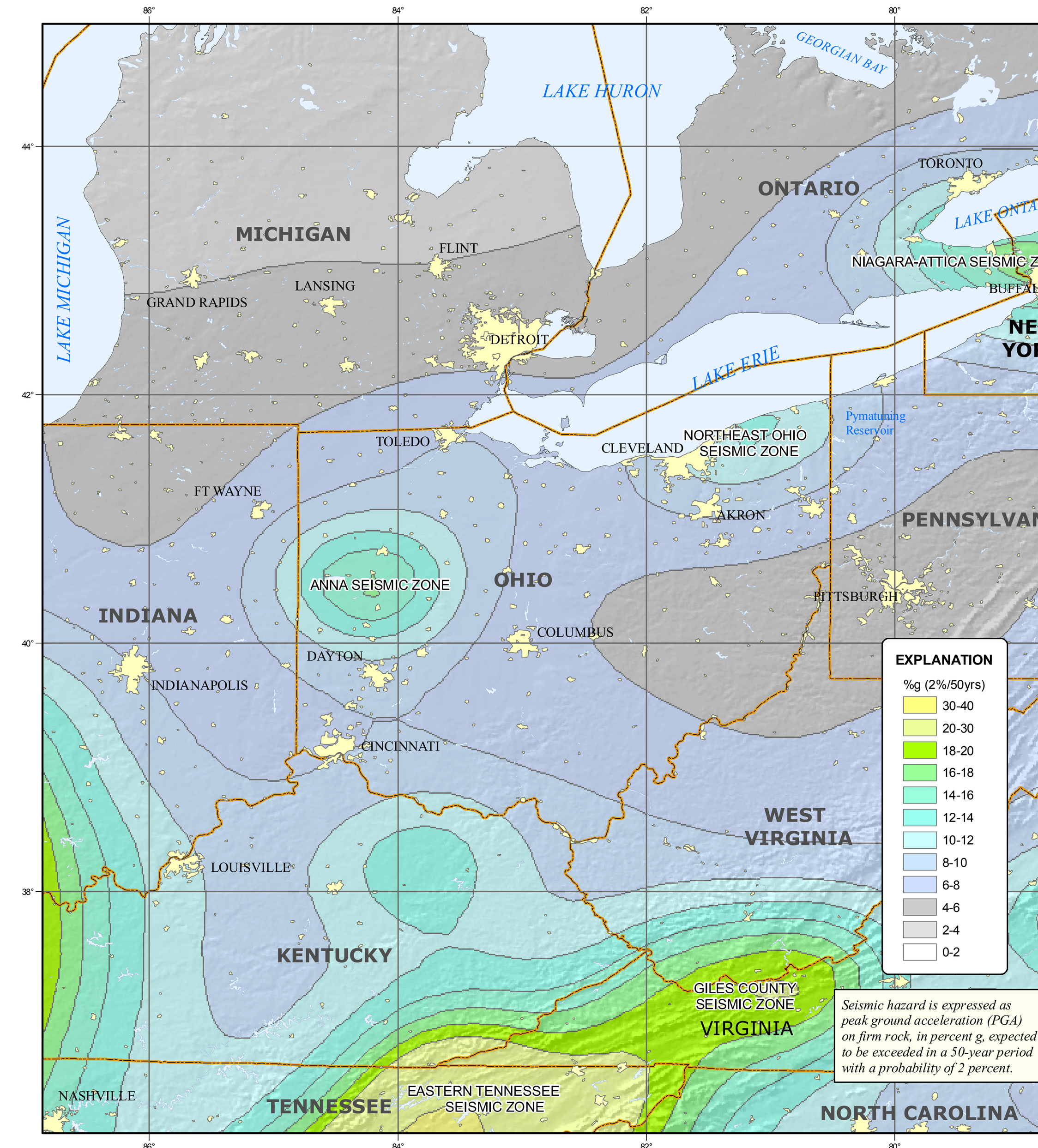
The Eastern Tennessee seismic zone contains many known faults. However, the locations of these faults are poorly known at earthquake depths. Few, if any, earthquakes in the Eastern Tennessee seismic zone can be linked to known faults, and it is difficult to determine if any known faults are seismically active.

Giles County Seismic Zone
Since at least 1828, earthquakes have been reported in the Giles County seismic zone. The largest known damaging earthquake (M5.6) in the zone occurred in 1897. Smaller earthquakes are felt or cause light damage once or twice a decade (Tarr and Wheeler, 2006).

Niagara-Attica Seismic Zone, New York-Ontario
The Niagara-Attica seismic zone in southern Ontario and western New York State (map at upper right) has had moderately frequent earthquakes at least since the first one was reported in 1840. The largest event (magnitude 4.9) in the zone caused moderate damage in 1929 near Attica, New York. Earthquakes too small to cause damage are felt roughly three or four times per decade.

In this zone many faults are known, but few have been traced to earthquake depths; and only a few earthquakes in the zone can be associated with named faults. It is, therefore, difficult to determine if any known faults are seismically active. Numerous smaller or deeply buried faults may remain undetected.

Regional Seismic Hazard



Base from U.S. Geological Survey National Elevation Dataset, National Hydrologic Database, and Digital Chart of the World (ESRI, 1993)

Geographic projection, Datum: D North American 1983

SCALE 1:2,500,000

ABBREVIATED MODIFIED MERCALLI INTENSITY SCALE

Expressed as Roman numerals, earthquake intensities are not instrumentally derived values. They are instead assigned based on descriptive reports from intensity.

- I. Not felt except by a very few under especially favorable conditions.
- II. Felt only by a few persons at rest, especially on upper floors of buildings.
- III. Felt quite noticeably by persons indoors, especially on upper floors of buildings. Many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibrations similar to the passing of a truck. Duration estimated.
- IV. Felt indoors by many, outdoors by few during the day. At night, some awakened. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building. Standing motor cars rocked noticeably.
- V. Felt by nearly everyone; many awakened. Some dishes, windows broken. Unstable objects overturned. Pendulum clocks may stop.
- VI. Felt by all, many frightened. Some heavy furniture moved; a few instances of fallen plaster. Damage slight.
- VII. Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable damage in poorly built or badly designed structures; some chimneys broken.
- VIII. Damage slight in specially designed structures; considerable damage in ordinary substantial buildings with partial collapse. Damage great in poorly built structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned.
- IX. Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb. Damage great in substantial buildings with partial collapse. Buildings shifted off foundations.
- X. Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations. Rails bent.
- XI. Few, if any (masonry) structures remain standing. Bridges destroyed. Rails bent greatly.
- XII. Damage total. Lines of sight and level are distorted. Objects thrown into the air.

INTENSITY AND MAGNITUDE

Intensity is an estimation of earthquake shaking level based on effects on people, buildings, and the landscape expressed here by using the Modified Mercalli Intensity Scale (table at left). During an earthquake, intensity will vary over the affected region. Intensity values for different locations are derived from written accounts (letters, journals and diaries) and published records (newspapers and official reports). These values diminish from a maximum, usually observed near the earthquake's epicenter, to the lowest levels of the scale near the edge of the felt area.

Although an earthquake has a wide distribution of intensity values (isoseismal maps, below left), it has only one *magnitude*. An earthquake's magnitude represents the total energy released. The magnitudes of pre-instrumental earthquakes are estimates based on intensity values recorded at the time of the earthquake or shortly after. The earthquake symbols plotted on the large state map (far left) represent the best estimates of time, location, and magnitude tabulated using several earthquake catalogs.

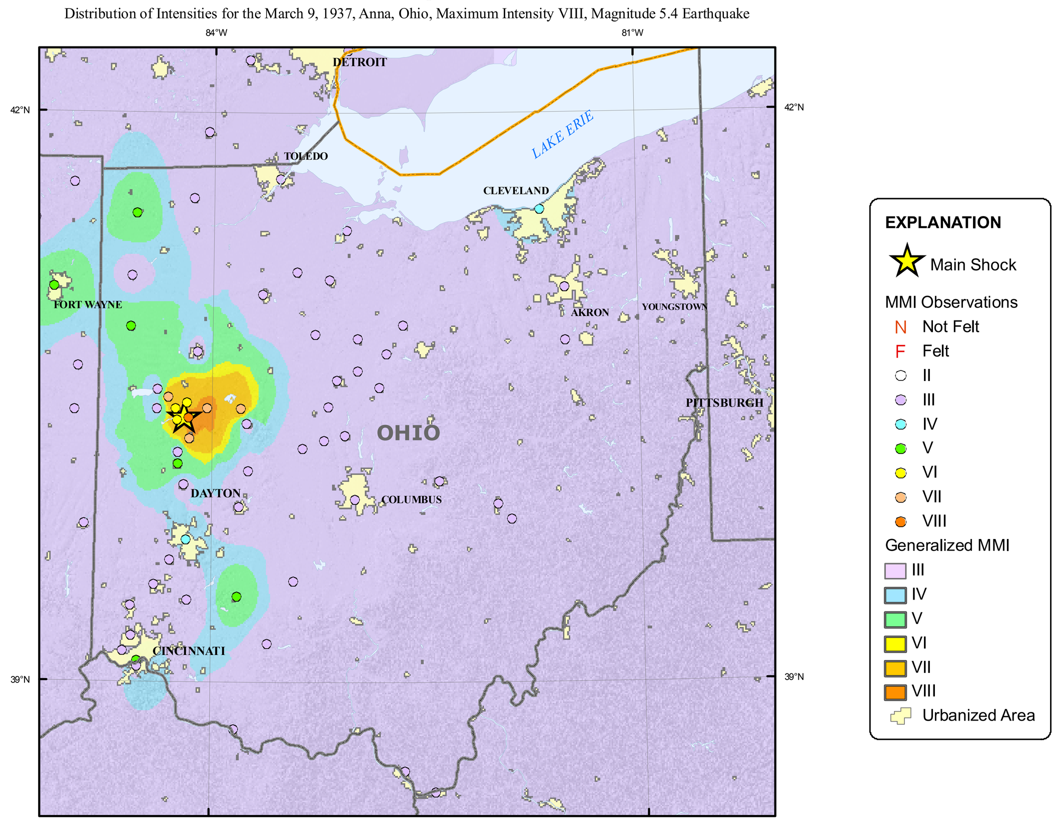
NOTES ON THE ISOSEISMAL MAPS

Isoseismal maps illustrate the level of ground shaking that occurred at various locations during a particular earthquake. The distributions of intensity values in Ohio and vicinity for two earthquakes are shown on the isoseismal maps (left). These events are the March 9, 1937, maximum intensity VII, magnitude 5.4, Anna earthquake and the January 31, 1986, maximum intensity VI, magnitude 5.0, northeast Ohio earthquake.

Contemporary accounts from newspapers of earthquake effects in cities and towns over a broad region were the sources of the intensity observations plotted on the isoseismal maps. The intensity observations are shown as color-coded circles. Each observation was assigned a Modified Mercalli Intensity (MMI) and the results were contoured. The mapped intensity values (integers) correspond to the Roman numeral values in the table (above left). An observation coded "F" is a location where shaking was felt but no MMI value was assigned and "N" if source document indicated that the event was not felt.

Contouring of the assigned intensity values, shown as circles on the maps (left), was computer generated using an inverse-distance weighted algorithm. The assigned values are from Neumann (1937) for the Anna earthquake and from Stover and Brewer (1994) for the northeast Ohio earthquake.

Isoseismal Map
Distribution of Intensities for the March 9, 1937, Anna, Ohio, Maximum Intensity VIII, Magnitude 5.4 Earthquake

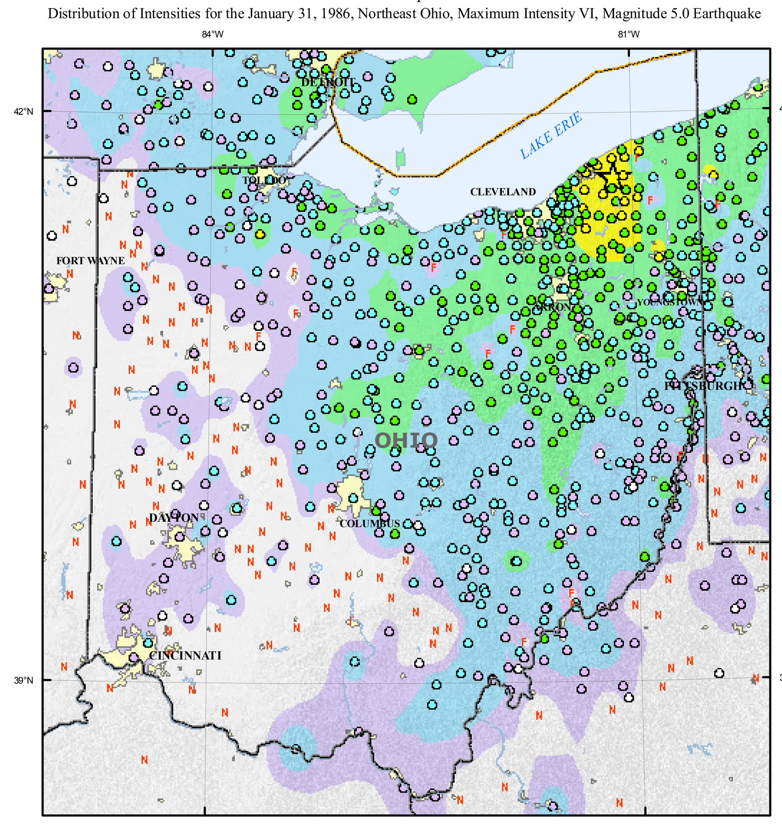


Base from U.S. Geological Survey National Elevation Dataset, National Hydrologic Database, and Digital Chart of the World (ESRI, 1993).

Albers equal-area conic projection, standard parallels 29° 30′ 00″ and 45° 30′ 00″, central meridian -83° 00′ 00″, latitude of origin 0° 00′ 00″

SCALE 1:2,500,000

Isoseismal Map
Distribution of Intensities for the January 31, 1986, Northeast Ohio, Maximum Intensity VI, Magnitude 5.0 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 45° 30′ 00″, central meridian -83° 00′ 00″, latitude of origin 0° 00′ 00″

SCALE 1:2,500,000

Author's Note

The information presented here was derived from existing sources and earlier publications. Specifically, general information on earthquake occurence and seismic hazard came from Tarr and Wheeler, 2006. This downloadable report is available at http://pubs.usgs.gov/of/2006/1017/. Several additional publications provided detailed information on Ohio earthquake history. They include Stover and Coffman, 1993; Crone and Wheeler, 2000; Wheeler, 2003; Hansen, 2006.

CITATION

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