INTRODUCTION

People have become increasingly aware of the devastation that can be wrought by earthquakes in populated areas. Dramatic portrayals of the destructive potential of earthquakes are revealed in images of catastrophic destruction, such as Sumatra in 2004, where nearly 230,000 people died from a magnitude 9.1 earthquake and subsequent tsunami; Sichuan, China, in 2008, where more than 87,000 people were killed from a magnitude 7.9 earthquake; Haiti in 2010, where possibly as many as 316,000 people were killed from a magnitude 7.0 earthquake; and Japan, where nearly 21,000 lives were lost in 2011 from a magnitude 9.0 earthquake and subsequent tsunami.

In Ohio, and indeed in the eastern United States, there is a perception that destructive earthquakes happen elsewhere but not here, although the damaging magnitude 5.8 earthquake in central Virginia in 2011 awakened many people to the fact that strong earthquakes can occur in the eastern United States.

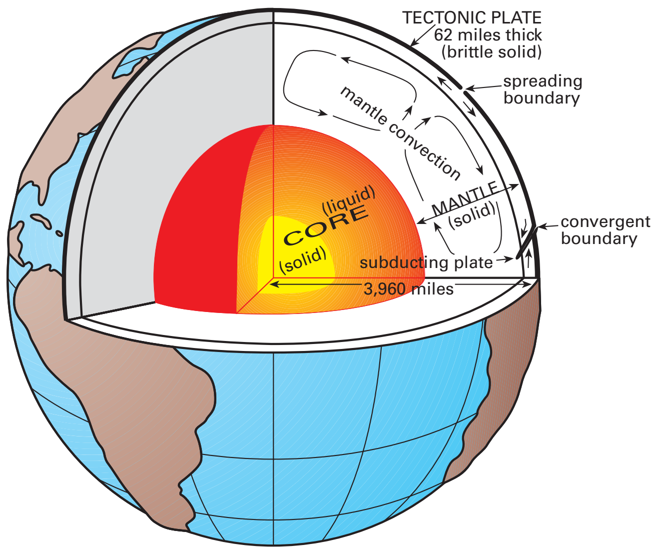
Seismologist Robin K. McGuire has stated that “major earthquakes are a low-probability, high-consequence event.” Because of the potential high consequences, geologists, emergency planners, and other government officials have taken a greater interest in understanding the potential for earthquakes in the eastern United States and in educating the population as to the risk in their areas. Although there have been great strides in increased earthquake awareness in the east, the low probability of such events makes it difficult to convince people that they should be prepared.

EARTHQUAKES AND SEISMIC WAVES

Earthquakes are a natural and inevitable consequence of the slow movement of Earth’s crustal plates. At the sites where these plates collide, earthquakes are a regular phenomenon. More than 100,000 earthquakes with magnitudes of 3 or greater occur worldwide each year, and 98 percent of these happen at plate boundaries. California is the site of numerous earthquakes because it sits on the boundary between the Pacific and North American plates.

Earthquakes occur along faults, which are zones of weakness in the upper crust, when sufficient strain builds up to overcome the frictional resistance of the blocks of rock on either side of the fault. When the blocks of rock snap, or quickly move past one another, an earthquake happens, releasing energy in the form of seismic waves.

Seismic waves are of two primary types: body waves and surface waves. Body waves are divided into primary (P) waves and secondary (S) waves. P-waves are the fastest (about 3.8 miles per second) of the body waves and move with a compressional



Interior zones of Earth. Earth's crust consists of great plates that slowly move across the surface of Earth in response to convection cells in the mantle. Most earthquakes occur where plates meet, such as at spreading or convergent boundaries. Modified from Washington Division of Geology and Earth Resources, Information Circular No. 85, 1988.

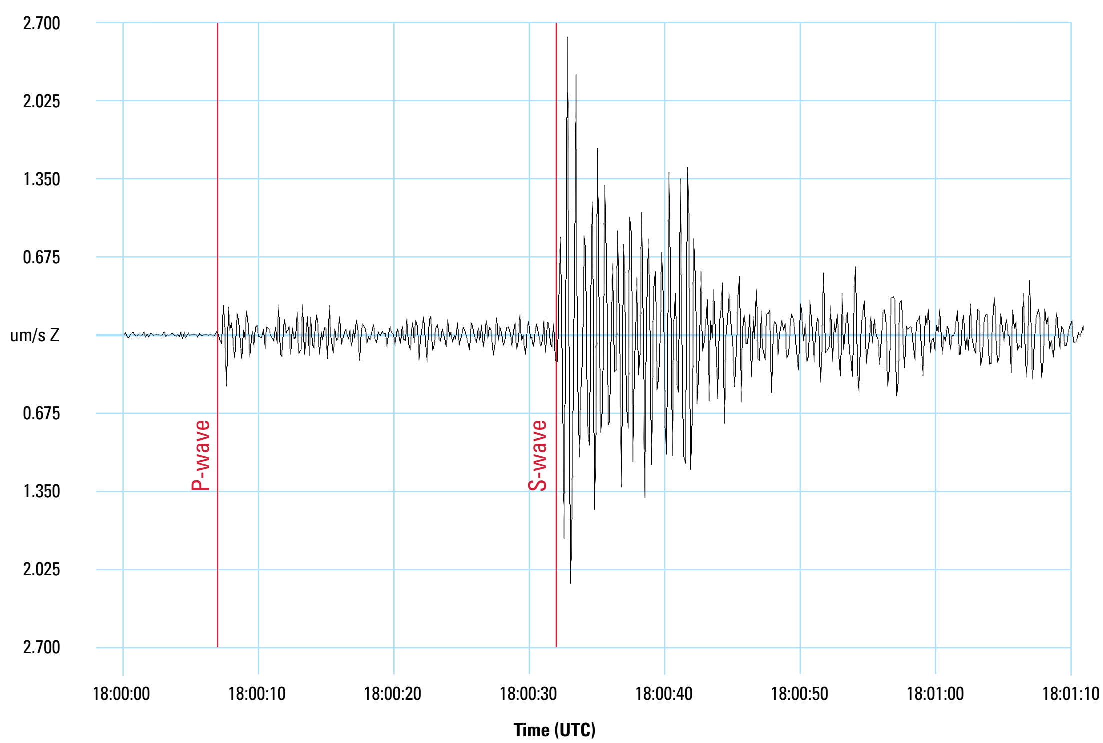
or push-pull motion. S-waves, also called *shear waves*, move more slowly (about 2.2 miles per second) and displace materials perpendicular to their direction of travel. Surface waves travel more slowly than either P-waves or S-waves and are responsible for some of the destructive effects of large earthquakes. The velocity of a wave depends on the density and elastic properties of the materials through which the wave passes.

MEASUREMENT OF EARTHQUAKES

Seismographs are instruments that record seismic waves generated by earthquakes. A seismometer is the component that transforms seismic-wave energy (ground motion) into electrical voltage that can be analyzed in digital form by computer or into analog form that is displayed on a paper or film tracing. The squiggly up-and-down series of lines that correspond to seismic-wave energy on these records are called *seismograms*.

One of the first seismograph stations in the country was established at John Carroll University in Cleveland in 1900, and another station was installed at Xavier University in Cincinnati in 1927. Both stations are now inactive. From 1977 to 1992, between 9 and 14 seismograph stations were operating in Ohio. In 1999, the Ohio Seismic Network (or OhioSeis) was established (see further details near the end of this brochure).

Earthquakes are measured in a number of ways, but two types of scales are most common and portray useful information: Magnitude scale and Modified Mercalli Intensity scale.



Seismogram from the November 20, 2013, 3.5-magnitude earthquake in northern Athens County, recorded at OhioSeis station WSDO at Wright State University, Dayton. This station is approximately 100 miles from the epicenter. A slightly larger earthquake occurred near this location on May 3, 1886. The arrivals of the P- and S-wave phases are noted.

Magnitude Scale

Magnitude is an instrumental scale that depicts the total energy released during an earthquake. It is expressed in Arabic numerals and is calculated by measuring the amplitude of seismic waves on a seismogram. The magnitude of a particular earthquake is approximately the same at any location because it is a function of amplitude of the seismic waves versus distance from the epicenter. An increase of one whole number on the magnitude scale corresponds to a 10-fold increase in ground motion or amplitude of seismic waves. The scale is logarithmic; therefore, an increase of two whole numbers on the scale is a 100-fold increase of seismic-wave amplitude. The amount of energy released during an earthquake is about 31 times greater for each whole-number increase on the magnitude scale. For example, a magnitude 6 earthquake is about 31 times larger than a magnitude 5; however, a magnitude 7 earthquake is about 961 times larger than a magnitude 5.

The magnitude scale is open ended, that is, it has no upper or lower limits. The largest earthquakes ever recorded are in the 9 magnitude range, and the smallest are negative magnitudes in the –1 or –2 range. Earthquakes with magnitudes between 2 and 3 commonly are felt by people in favorable locations in the epicentral area. Minor damage is generated by earthquakes in the magnitude 4 range, moderate damage in the magnitude 5 range, and major damage in the magnitude 6.5 range. Local variations in geology and construction practices can lead to wide differences in the amount of property destruction and loss of human life for earthquakes of similar magnitude.

The differing velocities of P-waves and S-waves are used to determine the distance of an earthquake from the seismograph. Epicenters are computed using the arrival times of P-waves and S-waves at three or more seismograph stations. Modern software permits comparatively rapid computation of earthquake epicenters.

Generally, the more seismographs available and the closer these instruments are to the epicenter, the more precisely an earthquake can be located. In areas of comparatively frequent seismic activity, a network of seismic instruments is deployed to maximize data collection. Such networks can detect very small earthquakes—many of them well below the threshold of human detection—and locate them accurately. This information, when collected for a long interval, may define the locations and characteristics of faults and give many clues to the potential size and frequency of future earthquakes.

Modified Mercalli Intensity		Magnitude
I	Detected only by sensitive instruments.	1.5
II	Felt by few persons at rest, especially on upper floors; delicately suspended objects may swing.	2
III	Felt noticeably indoors, but not always recognized as earthquake; standing autos rock slightly, vibrations feel like passing truck.	2.5
IV	Felt indoors by many, outdoors by few, at night some awaken; dishes, windows, doors disturbed; standing autos rock noticeably.	3
V	Felt by most people; some breakage of dishes, windows, and plaster; disturbance of tall objects.	3.5, 4
VI	Felt by all, many frightened and run outdoors; falling plaster and chimneys, damage minor.	4.5
VII	Everybody runs outdoors; damage to buildings varies depending on quality of construction; noticed by drivers of autos.	5
VIII	Panel walls thrown out of frames; walls, monuments, and chimneys fall; sand and mud ejected; drivers of autos disturbed.	5.5
IX	Buildings shifted off foundations, cracked, or thrown out of plumb; ground cracked; underground pipes broken.	6, 6.5
X	Most masonry and frame structures destroyed; ground cracked; rails bent; landslides.	7
XI	Few structures remain standing; bridges destroyed; fissures in ground, pipes broken; landslides; rails bent.	7.5
XII	Damage total; waves seen on ground surface, lines of sight and level distorted; objects thrown up into air.	8

Scale showing general relationship between epicentral Modified Mercalli Intensities and magnitude. Intensities can be highly variable, depending on local geologic conditions. Modified from D. W. Steeples, 1978, Earthquakes*: Kansas Geological Survey pamphlet.*

Seismologists use earthquake-wave records on seismographs to calculate the location, orientation, and sense of movement of the earthquake-generating fault. This procedure, known as a *fault-plane solution* or *focal mechanism*, provides valuable information on the geologic structure that produced an earthquake.

Modified Mercalli Intensity Scale

Another earthquake-measuring scale is called the Modified Mercalli Intensity (MMI) scale, which portrays the amount of ground shaking at a particular location on the basis of the effects felt by people and the observed damage to buildings and terrain. The MMI scale is defined by Roman numerals from I to XII—I being not felt and XII representing total destruction. Intensity is commonly greatest at the epicenter and decreases with distance away from this point; however, differences in local geology may result in pockets of comparatively high intensity and consequent damage at some distance from the epicenter.

Damage to buildings occurs when MMI reaches the VII range. The felt area and MMI for a particular earthquake are commonly portrayed by an isoseismal map (see isoseismal map for New Madrid on page 6), which is constructed by plotting the MMI (determined from press reports and questionnaires) and drawing lines surrounding areas of equal intensity. The chart to the left gives the general relations between MMI and magnitude; however, these correlations are very approximate because many geologic factors influence local intensity.

In the eastern United States, earthquakes tend to be felt over a much wider area than in the western United States. In fact, the damage area from an eastern quake is commonly about 10 times larger than from a western event of similar magnitude. In the eastern United States, the relatively brittle and flat-lying rocks tend to transmit seismic-wave energy, whereas the structurally complex rocks in the western United States tend to attenuate seismic-wave energy.

CRUSTAL GEOLOGY AND FAULTING IN OHIO

Ohio earthquakes are shallow-focus events, that is, they occur in the upper portion of the crust at depths of about 3 to 6 miles in crystalline (igneous and metamorphic) rocks of Precambrian age. Precambrian rocks are nowhere exposed in the state and lie beneath Paleozoic sedimentary rocks at depths of about 2,500 feet in western Ohio to more than 12,000 feet in southeastern Ohio.

Until the mid-1980s, these rocks were poorly understood and known primarily from a few samples obtained from deep oil-and-gas wells. Statewide aeromagnetic and gravity maps produced by the U.S. Geological Survey in cooperation with the Ohio Department of Natural Resources (ODNR), Division of Geological Survey revealed an unanticipated complexity to these Precambrian rocks. At the invitation of the ODNR Division of Geological Survey, an east–west, deep-crustal seismic-reflection profile was run across the state in 1987 by the Consortium for Continental Reflection Profiling (COCORP). This investigation opened up a new understanding of the geologic history of the Precambrian rocks beneath the state and gave geologists clues to the origins of some historic earthquakes in Ohio.

These studies, along with a study by a cooperative research group known as the Cincinnati Arch Consortium (consisting of the Ohio, Indiana, and Kentucky Geological Surveys and funded by industry sponsors), indicate that from about 800 million to a billion years ago, Ohio was the site of a collision between the North American continent and a continent to the east. This collision produced a mountain range, known as the *Grenville Mountains*, which stretched from Canada southward through Ohio and areas to the south. The Grenville Mountains were eventually eroded to a rolling surface that was covered by sedimentary rocks during the Paleozoic Era. Eastern Ohio is underlain by intensely deformed Precambrian rocks that mark the collision zone between the two continents. West-central Ohio is underlain by a north–south zone known as the *Grenville Front*, which marks the western edge of thrusting during the collision. The western part of the state, west of the Grenville Front, is underlain by extensive down-dropped, fault-bounded basins known as *rifts*.

These rifts mark the site where the crust began to split apart prior to the formation of the Grenville Mountains, eventually to form a new ocean basin. For unknown reasons the rifting ceased, creating a failed rift that left a down-dropped area that accumulated a thick fill of sediment. At least one of these rifts, known as the *Anna* or *Fort Wayne rift*, appears to be the source of many earthquakes in Shelby and Auglaize Counties.

In general, Ohio earthquakes occur along faults in Precambrian crystalline rocks that were mostly created during the Grenville mountain-building event, rifting, and later tectonic activities. Geologists think that favorably oriented faults are periodically reactivated in the current stress regime, which is northeast–southwest compression.

Very few faults in Ohio are visible at the surface, and no surface faults in Ohio are known to be associated with historic earthquakes. Furthermore, none of these faults exhibit evidence of movement during recent (Holocene) time; most of them probably have not been active since the Paleozoic. In fact, fault scarps generated by historic earthquakes have not been clearly demonstrated in the eastern United States. Most faults known in the subsurface of Ohio appear to originate in Precambrian rocks and die out upward in the overlying Paleozoic rocks. Therefore, most of them do not reach the surface where they can be directly mapped and studied. In addition, the bedrock surface over about two-thirds of the state is masked by a thick cover of glacial sediments.

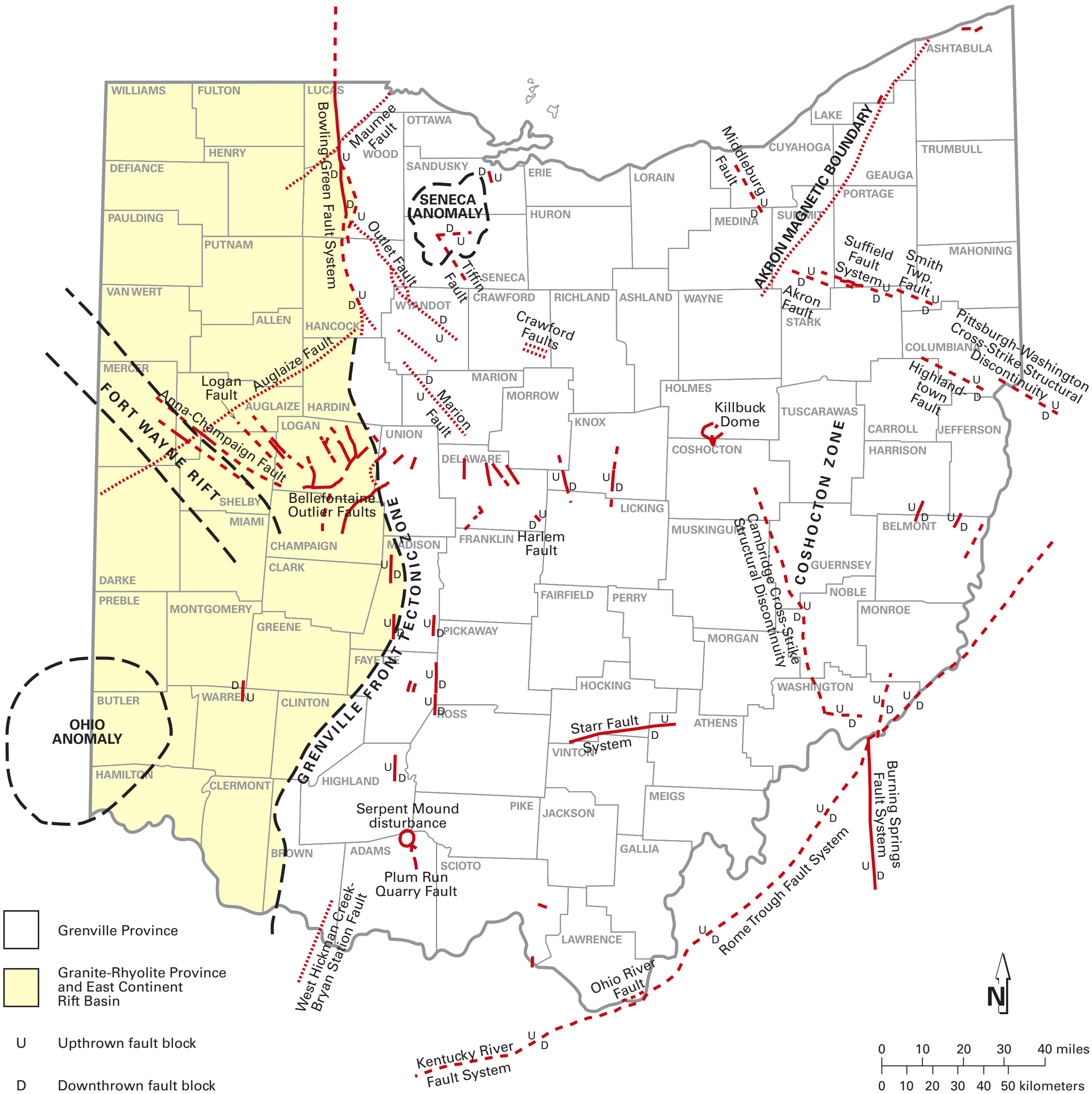
Most subsurface faults in the state have been discovered through mapping of rock units using oil-and-gas well data or by geophysical means, such as aeromagnetic, gravity, or seismic-reflection profiling. Precise, detailed recording of earthquakes by seismograph networks is also a great aid in identifying faults and other geologic structures in the subsurface of Ohio. The fact that there are many unmapped faults in the subsurface of the state is dramatized by the large number of small earthquakes that occur in locations at which no faults are mapped.

HISTORIC EARTHQUAKE ACTIVITY IN OHIO

More than 200 earthquakes of magnitude 2.0 or greater with epicenters in Ohio have occurred since 1776, and 15 of these events are known to have caused minor to moderate damage. Fortunately, there have been no deaths and only a few minor injuries recorded for these events.

Most earthquakes that occurred in Ohio before the 1960s have been located and assigned intensities and approximate magnitudes based on newspaper accounts. Epicentral locations for many of these events probably have a considerable margin of error. Noninstrumental data should be used cautiously.

Seismic activity is concentrated in, but not confined to, three areas of the state. One of the most historically active seismic areas is known as the *western Ohio seismic zone* (also referred to as the *Anna Seismogenic Zone*) and comprises Shelby and



Basement structures in Ohio (modified from Baronoski, 2013). This map portrays a number of deep faults and other structures that have been identified by a variety of geologic studies. Some faults are well known, whereas others are speculative. Very few of them are visible at the surface. The Fort Wayne (Anna) rift in western Ohio is the site of numerous historic earthquakes.

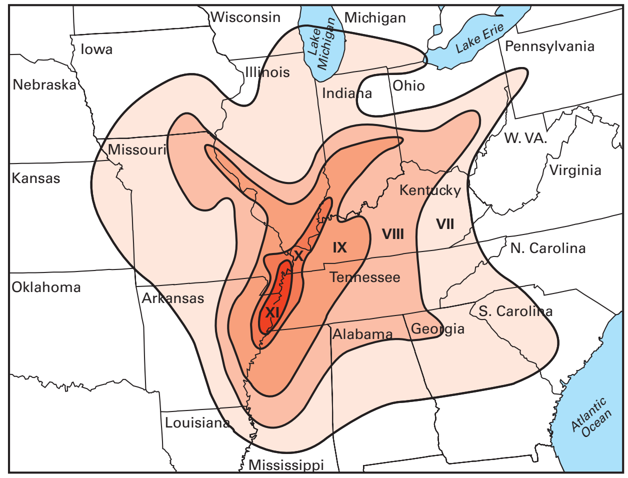
Auglaize Counties and portions of some adjacent counties in western Ohio. More than 40 felt earthquakes have occurred there since 1875. Although most of these events have caused little or no damage, earthquakes in 1875, 1930, 1931, 1937, 1977, and 1986 caused minor to moderate damage. Earthquake damage has been most severe in the Shelby County community of Anna. This town is centered over a 400-feet-deep buried valley that was formed in preglacial time by the Teays River, which follows the trend of the Fort Wayne (Anna) rift. Scientists think that Anna has experienced comparatively severe ground motion because of amplification of seismic waves by the thick valley fill.

Northeastern Ohio has experienced more than 80 felt earthquakes since 1836; most have been small and caused little or no damage. Magnitude 4.5 events occurred in 1943 and 2001 and a magnitude 5.0 event occurred in 1986; the latter event caused minor to moderate damage and several injuries. Some geologists have suggested that some of these earthquakes occurred on an extensive north–south linear feature in Precambrian basement rocks known as the *Akron magnetic boundary*. At least 40 small earthquakes have occurred since 1987 in association with a deep, now abandoned, Class I injection well in Ashtabula.

Southeastern Ohio has been the epicentral location for at least 25 earthquakes above magnitude 2.0 since 1776. Events in 1776 and 1779 (locations uncertain), in 1901 near Portsmouth (Scioto Co.), in 1926 near Pomeroy (Meigs Co.), and in 1952 near Crooksville (Perry Co.) caused minor to moderate damage. The geologic sources for these events are poorly understood.

Small earthquakes have been scattered throughout other portions of the state, particularly in southwestern Ohio in the vicinity of Cincinnati and in northwestern Ohio, including the Toledo area.

Numerous earthquakes with epicenters in other states have been felt in Ohio and at least three of them have caused damage. The 1811–1812 series of earthquakes at New Madrid, Missouri—the largest earthquakes in historic times in the continental United States—were felt strongly throughout Ohio and were reported to have knocked down chimneys in Cincinnati. Estimated Modified Mercalli Intensities of VII to VIII were achieved in southwestern Ohio during these events. In 1980, an earthquake with a magnitude of 5.3 centered at Sharpsburg, Kentucky, was strongly felt throughout Ohio and caused minor to moderate damage in some communities near the Ohio River in southwestern Ohio. On September 25, 1998, a magnitude 5.2 earthquake occurred just east of the Ohio-Pennsylvania state line in Crawford County, Pennsylvania, near Pymatuning Reservoir. This earthquake caused minor damage in the epicentral area, including portions of Ohio near the state line.



Isoseismal map showing potential Modified Mercalli Intensities for an 8.0 Richter magnitude earthquake at New Madrid, Missouri. Potentially damaging Modified Mercalli Intensities of VII and VIII are projected across most of the southern half of Ohio. During an actual event of this magnitude, it is probable that intensities would be much more variable, depending on local geology. Source: U.S. Geology Survey.

Significant Ohio Earthquakes

Summer 1776: The earliest Ohio earthquake to be noted occurred at 8 A.M. sometime during the summer of 1776 and was chronicled by John Heckewelder, a Moravian missionary, who reported that "the southwest side of the house was raised with such violence that the furniture of the room was nearly overturned." Heckewelder spent the summer of 1776 at the Moravian mission of Lichtenau, which was in present-day Coshocton County. Because his report is the only account of this event, it is impossible to determine an epicentral location with any certainty. Indeed, the epicenter of this earthquake may not have been in Ohio.

1811–1812: On December 16, 1811, and January 23 and February 7, 1812, the largest earthquakes ever to strike the central and eastern United States occurred at New Madrid, Missouri, and were felt throughout an area of about two million square miles, including all of Ohio. In Ohio, some chimneys were toppled in the Cincinnati area, which experienced the strongest shaking from these events. Should earthquakes of this intensity be repeated at New Madrid, they would probably cause considerable damage in southwestern Ohio.

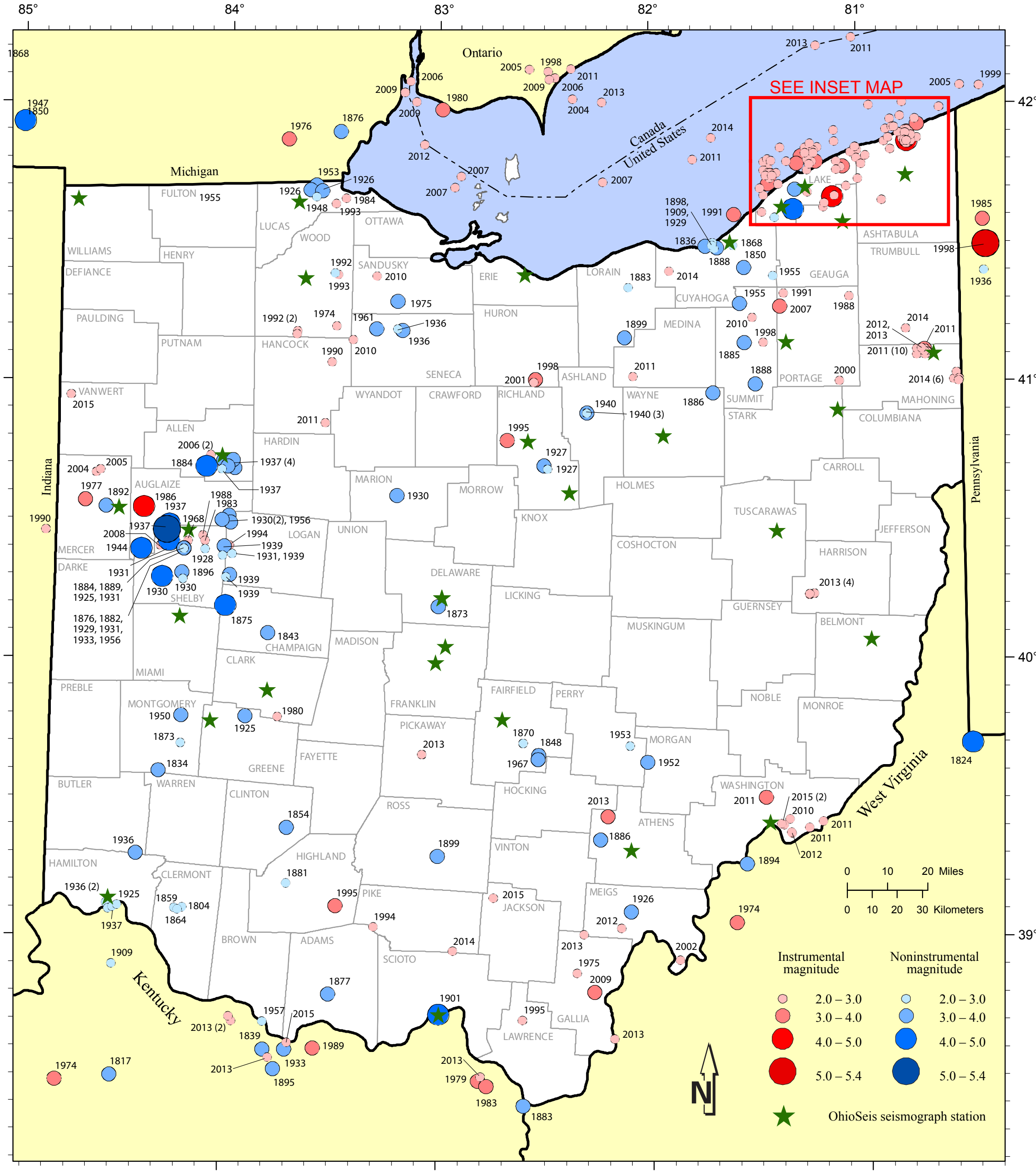
June 18, 1875: This earthquake was felt throughout an area of at least 40,000 square miles and was most intense at Sidney (Shelby Co.) and Urbana (Champaign Co.), where masonry walls were cracked and chimneys toppled. Based on damage and felt reports, seismologists interpreted this event to have had a MMI of VII.

September 19, 1884: An earthquake in the vicinity of Lima (Allen Co.) had an epicentral MMI of VI. Reports of fallen ceiling plaster came from as far away as Zanesville (Muskingum Co.) and Parkersburg, West Virginia. On the basis of a felt area of more than 140,000 square miles, this earthquake had a magnitude of approximately 4.8. Workmen on top of the Washington Monument in Washington, D.C., reported feeling this earthquake.

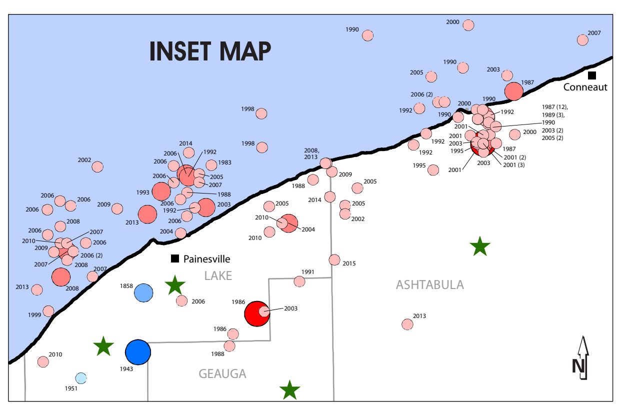
May 17, 1901: During this earthquake, bricks were dislodged from chimneys and some windows were cracked in Portsmouth (Scioto Co.), and chimneys were damaged in Sciotoville. Modified Mercalli Intensities of VI were generated in the epicentral area. Based on felt area, this earthquake is assigned a magnitude of 4.3.

November 5, 1926: This earthquake was centered near Pomeroy and Keno, in Meigs County, where chimneys were toppled. A stove was overturned at Chester. Modified Mercalli Intensities of VII were generated in the epicentral area, but the earthquake apparently was felt only in portions of Meigs County and adjacent parts of West Virginia. On the basis of this small felt area, this event has been assigned a magnitude of 3.6. Explosive earth sounds were reported to have accompanied this earthquake.

EARTHQUAKES IN OHIO



Locations of felt earthquakes or those with magnitudes of 2.0 or greater in Ohio and its border areas. Locations and magnitudes of historic earthquakes are represented by symbols corresponding to felt area or maximum epicentral MMI. Noninstrumental locations may be in error by a considerable distance, especially for early events.



September 30, 1930: This earthquake cracked plaster and toppled a chimney in Anna (Shelby Co.). An epicentral MMI of VII and a magnitude of 4.2 have been assigned to this event.

September 20, 1931: In this event, homes in Anna and Sidney (Shelby Co.) experienced toppled chimneys and cracked plaster. Store merchandise and crockery were knocked off shelves, and stones were jarred loose from the foundation of the Lutheran church in Anna. A ceiling collapsed in a school at Botkins, north of Anna. A MMI of VII and a magnitude of 4.7 have been assigned to this earthquake.

March 2 and 9, 1937: These two earthquakes are the most damaging to have struck Ohio. Maximum intensities were experienced at Anna (Shelby Co.), where a MMI of VII was associated with the March 2 event and a MMI of VIII with the March 9 event. In Anna, chimneys were toppled, organ pipes were twisted in the Lutheran church, the masonry school building was so badly cracked that it was razed, water wells were disturbed, and cemetery monuments were rotated. Both earthquakes were felt throughout a multistate area—plaster was cracked as far away as Fort Wayne, Indiana. The March 9 event was felt throughout an area of about 150,000 square miles. Based on analysis of seismograms from these earthquakes, the U.S. Geological Survey (Stover and Coffman, 1993) assigned magnitudes of 4.7 and 4.9, respectively, to these events. On the basis of felt area, these earthquakes have been assigned magnitudes of 4.9 and 5.4, respectively.

Toppled chimneys were common in Anna, Ohio, from the March 2 and March 9, 1937, earthquakes. In this home, the chimney crashed through the ceiling, scattering bricks in a bedroom. Fortunately, no serious injuries resulted from these earthquakes.

January 31, 1986: This earthquake, which had a magnitude of 5.0 and a MMI in the high VI range, occurred in Lake County, east of Cleveland, in the general vicinity of a magnitude 4.5 event in 1943. The 1986 earthquake cracked plaster and masonry, broke windows, and caused changes in water wells. The epicenter was only a few miles from the Perry nuclear power plant; it is the most intensively studied earthquake in Ohio and was the subject of several scientific reports (for example, Nicholson and others, 1988).

July 12, 1986: Minor damage, consisting primarily of cracked windows and plaster and fallen bricks from chimneys, was reported from this MMI VI earthquake centered northwest of Anna, near St. Marys, in Auglaize County. It had a magnitude of 4.5.

January 25, 2001: The city of Ashtabula was struck by a magnitude 4.5 earthquake that caused minor damage to about 50 homes and businesses. This earthquake was the largest in a series of shallow earthquakes that began in 1987 and were attributed to fluids from a Class I deep-injection well. Nearly 40 earthquakes above magnitude 2.0 were recorded at Ashtabula through 2001. Prior to 1987, no earthquakes had been noted in the area.

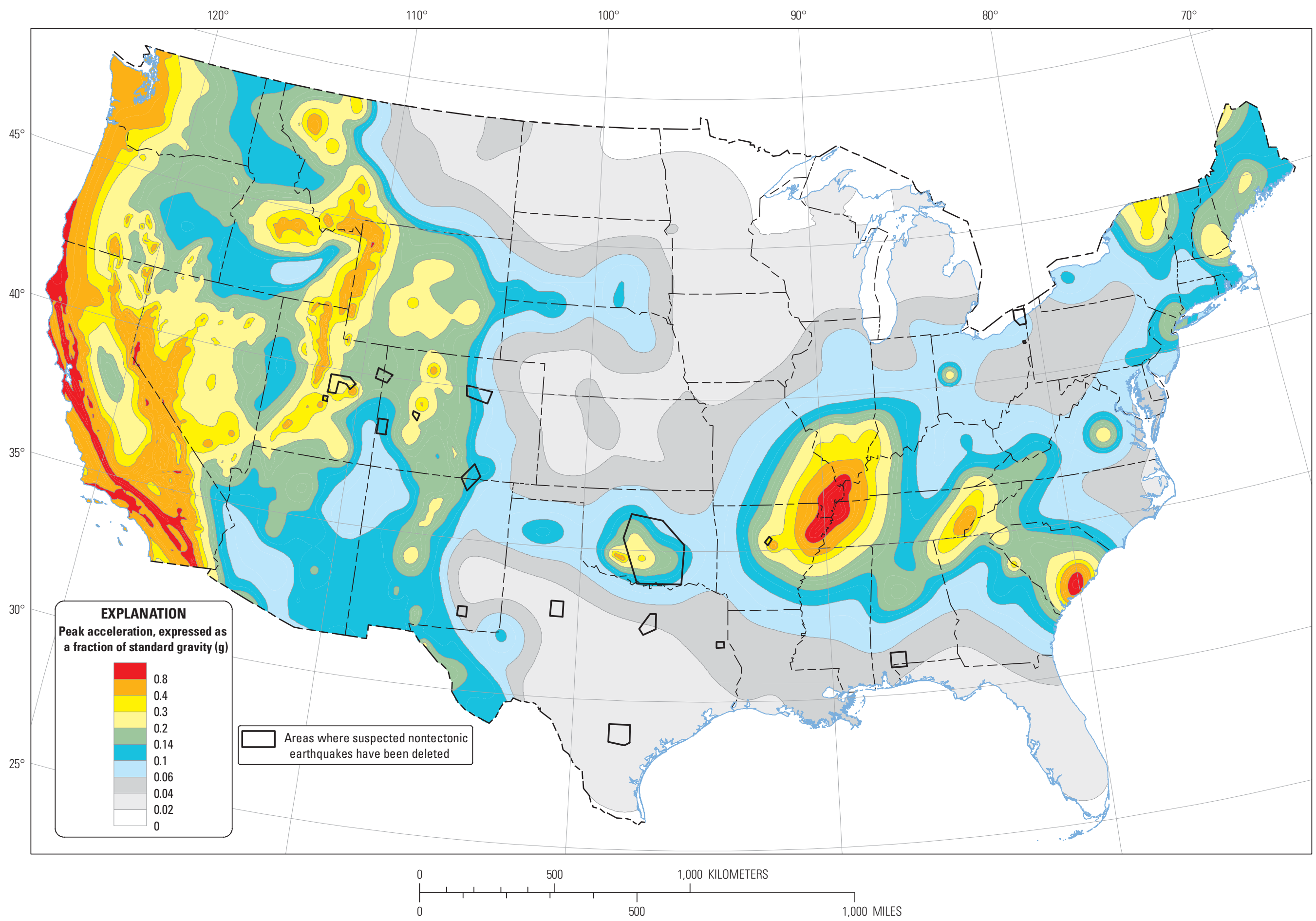
SEISMIC RISK AND SEISMIC HAZARD IN OHIO

Seismic hazard refers to the physical phenomena, such as ground shaking, associated with an earthquake. Seismic risk refers to the probability that damage from an earthquake will equal or exceed specified values within a specified period of time. In evaluating the seismic hazard of an area, consideration must be given to geologic factors such as susceptibility of unconsolidated sediments to increased ground motion, landslides, and the potential for liquefaction—a phenomenon in which normally solid sediments become liquefied and lose bearing strength during an earthquake.

Historic earthquake activity is an important part of the process of determining Ohio's seismic risk. It must be kept in mind that our 200-year history of earthquake activity in Ohio is just an instant geologically. Earthquakes in Ohio, and indeed the eastern United States, tend to have long recurrence intervals, that is, hundreds or even thousands of years between large, damaging earthquakes. For example, had the 1811–1812 earthquakes at New Madrid, Missouri, occurred a century or two earlier, it is unlikely that we would currently perceive this area as capable of generating such large earthquakes.

This brief historic record of earthquakes in Ohio would suggest that a magnitude 5 earthquake is about the maximum event for the state. However, there is some concern that an earthquake in the magnitude 6 range could occur. On the basis of available data, it is difficult to accurately predict the maximum-size earthquake that could occur in the state and certainly impossible to predict when such an event would occur. In part, the size of an earthquake is a function of the area of a fault available for rupture. However, because all known earthquake-generating faults in Ohio are concealed beneath several thousand feet of Paleozoic sedimentary rock, it is difficult to directly determine the size of these faults.

On the basis of historic seismic activity, it is likely that large earthquakes with epicenters in the state would occur in the western Ohio seismic zone or in northeastern Ohio; there is a lesser possibility of a large earthquake in southeastern Ohio. Some researchers have suggested that northeastern Ohio is capable of a maximum magnitude 6.5 earthquake, whereas western Ohio may be capable of producing an event in the 6 to 7 magnitude range (maximum MMI of IX). These suggestions are speculations at best, because there are inadequate data to accurately judge the extent of the area available for rupture on any earthquake-generating fault.



Peak acceleration (expressed as a percent of gravity) having a 2-percent probability of exceedance in 50 years. The acceleration of gravity is expressed as 1g. Modified from Petersen and others, 2015.

RANGES OF ACCELERATION AS A FUNCTION OF INTENSITY
(adapted from Bolt, 2006)

MM Intensity	Range of acceleration (g's)
IV	0.015 – 0.02
V	0.03 – 0.04
VI	0.06 – 0.07
VII	0.10 – 0.15
VIII	0.25 – 0.30
IX	0.50 – 0.55
X	> 0.60

Note: 1g = 980 cm/sec²

A comparatively new field of study, paleoseismology, is beginning to be used to evaluate the long-term seismic risk of many areas. Geologists examine stream banks and other exposures of sediment searching for sand blows, sand dikes, and other features that were formed by liquefaction during a large earthquake in prehistoric times. No such paleoseismic evidence of a large earthquake has yet been found in Ohio, but extensive searches have not been carried out.

A variety of earthquake hazard/risk maps have been issued by various organizations in the last three decades. The most useful and widely used are those produced by the U.S. Geological Survey in 2015 (see Petersen and others, 2015, under "Further Reading") to illustrate maximum probable ground motion within periods of time ranging from 50 to 250 years. These maps depict horizontal acceleration expressed as a percent of gravity (see U.S. map above) and are particularly useful to engineers, architects, and insurance actuaries.

Acceleration is the rate of change of motion as Earth's surface moves back and forth during an earthquake (ground shaking). The acceleration due to gravity is 32 feet per second squared (980 centimeters per second squared), which is commonly expressed as 1.0g. At an acceleration rate of 0.1g, some damage may occur in poorly constructed buildings. Between 0.1g and 0.2g, most people begin to have difficulty in keeping their footing and may experience nausea. Acceleration maps developed by the U.S. Geological Survey allow engineers and architects to design buildings to withstand maximum probable accelerations in a specified area.

Acceleration is a prime component in maps prepared by Building Official Code Administration (BOCA) International. In Ohio these maps are used in designing new commercial buildings and structures housing more than four families. Regulations for seismic considerations in new construction are uniformly applied statewide by the Ohio Department of Commerce, Board of Building Standards.

In a large object with a great mass, such as a building, the ground motion, particularly horizontal motion, can produce tremendous forces that can seriously damage a structure if the duration of the shaking lasts for a comparatively long period of time. During many earthquakes, the destructive shaking lasts only for about 10 seconds. Some very destructive earthquakes generate severe shaking for a minute or more. The 1986 northeastern Ohio earthquake generated accelerations as high as 0.23g; however, these were momentary peak accelerations of such short duration that they did not cause significant damage.

National seismic risk maps are greatly generalized and intended to depict these risks on a broad scale. Ideally, detailed seismic risk maps should be produced for areas of the state that have historic seismic activity. Such maps would include critical analysis of historic earthquakes; detailed mapping of bedrock, structural, and surficial geology; investigation of prehistoric earthquake (paleoseismic) activity; and analysis of sediments and their engineering characteristics.

OhioSeis
The Ohio Seismic Network

In early 1999, the first statewide cooperative seismic network, OhioSeis, became operational. This network uses broadband seismometers to digitally record earthquakes in Ohio and from throughout the world. The network was established with the primary purpose of detecting, locating, and determining magnitudes for earthquakes in the state. These data not only provide information to the public immediately after an earthquake but, after a long period of monitoring, will more clearly define zones of highest seismic risk in the state and help to identify deeply buried faults and other earthquake-generating structures. OhioSeis was funded in part by the Federal Emergency Management Agency (FEMA) through the Ohio Emergency Management Agency as part of the National Earthquake Hazards Reduction Program (NEHRP); it is coordinated by the ODNR Division of Geological Survey from the Ohio Earthquake Information Center at Alum Creek State Park in Delaware County. Station locations (noted on epicenter map on reverse) are: Ashtabula EMA (Ashtabula Co.), Belmont College (Belmont Co.), Bloom-Carroll Schools (Fairfield Co.), Botkins High School (Shelby Co.), Bowling Green State University (Wood Co.), Bowling Green State University–Firelands (Erie Co.), Clark State Community College (Clark Co.), Cleveland Museum of Natural History (Cuyahoga Co.), College of Wooster (Wayne Co.), Edison Community College (Miami Co.), Geauga Parks District (Geauga Co.), Kent State University (Portage Co.), Kent State University–Tuscarawas (Tuscarawas Co.), Lake Erie College (Lake Co.), Lakeland Community College (Lake Co.), Marietta College (Washington Co.), Mohican Outdoor School (Richland Co.), Mount Union University (Stark Co.), Nettle Lake (Williams Co.), ODNR Division of Geological Survey (Delaware Co.), Ohio State University (Franklin Co.), Ohio State University–Lima (Allen Co.), Ohio State University–Mansfield (Richland Co.), Ohio University (Athens Co.), Shawnee State University (Scioto Co.), University of Cincinnati (Hamilton Co.), Wright State University–Celina (Mercer Co.), Wright State University–Dayton (Montgomery Co.), and Youngstown State University (Mahoning Co.). The stations are operated independently by volunteers as part of a cooperative agreement. Each station is connected to the Internet for rapid access and transfer of data. The Ohio Earthquake Information Center hosts a U.S. Geological Survey Advanced National Seismic Network station, which relays data via satellite to the National Earthquake Information Center in Golden, Colorado. In addition, 14 high-quality, vault-based seismic stations from the EarthScope Transportable Array have been retained in Ohio in 2015 under various agreements.

FURTHER READING

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WEB SITES

State of Ohio:

geosurvey.ohiodnr.gov
ODNR Division of Geological Survey—Information on OhioSeis and earthquakes in Ohio as well as other geologic information about the state.

ema.ohio.gov
Ohio Emergency Management Agency.

geosurvey.ohiodnr.gov/earthquakes-ohioseis/ohioseis-home
Ohio Seismic Network (OhioSeis)—Extensive information on Ohio earthquakes, including an annotated catalog of Ohio and border-region events; postings on current, instrumentally recorded earthquakes in Ohio and border regions; and contact and earthquake-reporting information.

U.S. Geological Survey:

earthquake.usgs.gov/earthquakes/dyfi
Did You Feel It?—Earthquake reporting website.

earthquake.usgs.gov/hazards/products/conterminous
Geologic hazards—Earthquake hazard maps and other useful information on earthquake risk in the United States.

earthquake.usgs.gov/earthquakes/map
Recent earthquake bulletins and interactive map.

STATE OF OHIO
DEPARTMENT OF NATURAL RESOURCES
DIVISION OF GEOLOGICAL SURVEY
Thomas J. Serenko, Chief

2045 Morse Rd., Bldg. C-1
Columbus, Ohio 43229-6693
(614) 265-6576
geo.survey@dnr.state.oh.us

OhioGeology.com