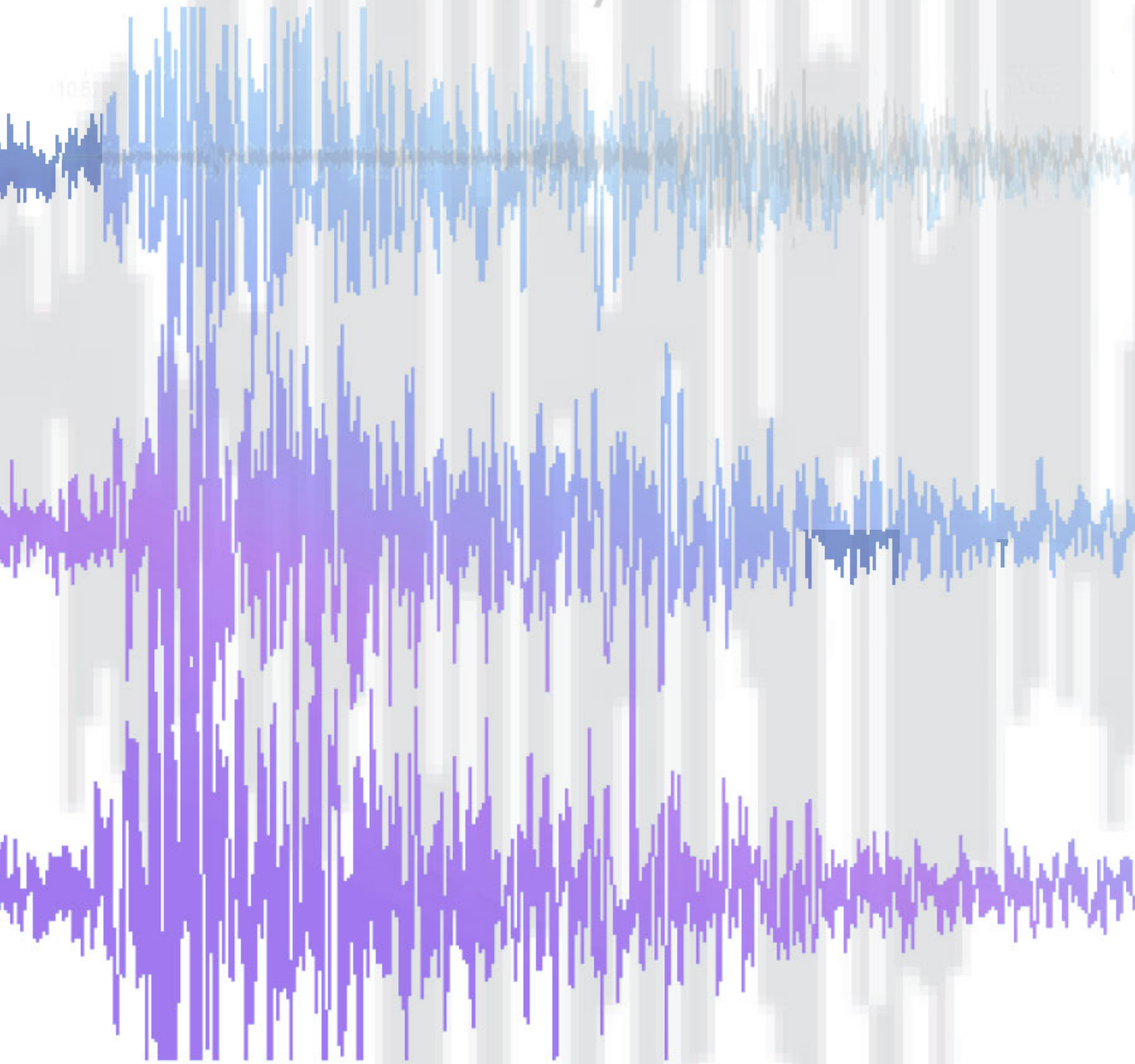
Educational Series 10

Earthquake Hazard in Pennsylvania



COMMONWEALTH OF PENNSYLVANIA
DEPARTMENT OF
CONSERVATION AND NATURAL RESOURCES
BUREAU OF TOPOGRAPHIC AND GEOLOGIC SURVEY

COMMONWEALTH OF PENNSYLVANIA
Edward G. Rendell, Governor
DEPARTMENT OF CONSERVATION AND NATURAL RESOURCES
Michael DiBerardinis, Secretary
OFFICE OF CONSERVATION AND ENGINEERING SERVICES
Larry G. Williamson, Deputy Secretary
BUREAU OF TOPOGRAPHIC AND GEOLOGIC SURVEY
Jay B. Parrish, Director

Pennsylvania web site: www.state.pa.us
Department of Conservation and Natural Resources
web site: www.dcnr.state.pa.us
Bureau of Topographic and Geologic Survey web site:
www.dcnr.state.pa.us/topogeo

First Edition, June 1989
Second Edition, May 2003
Third Printing, Slightly Revised, June 2006
Fourth Printing, June 2007

ON THE COVER: A seismograph recording (in purple-blue) of a Richter magnitude 5.3 earthquake that had an epicenter near Au Sable Forks, N. Y. It includes all three components of ground motion: vertical (top), north-south (middle) and east-west (bottom). Recorded at Millersville University, Millersville, Pa., on April 20, 2002.

Educational Series 10

Earthquake Hazard in Pennsylvania

by Charles K. Scharnberger
Millersville University

PENNSYLVANIA GEOLOGICAL SURVEY
FOURTH SERIES
HARRISBURG

2003

Contents

Earthquake Hazard in Pennsylvania

by
Charles K. Scharnberger

Introduction

Compared to other states, especially California and Alaska, Pennsylvania is relatively free of earthquake activity. Even considering only the eastern half of North America, Pennsylvania has experienced fewer and milder earthquakes than most other states or Canadian provinces. Nevertheless, earthquakes do occur in our commonwealth, and Pennsylvania may be subject to the effects of earthquakes that have epicenters located outside our borders. Therefore, it is worth considering how much hazard earthquakes present to Pennsylvanians.

What Is an Earthquake?

Earthquakes occur when there is a sudden release of stored energy from a portion of a fault plane within the earth. Faults are fractures in the lithosphere—the rather brittle outer layer of the solid earth. Energy in the form of ***strain,*** small elastic distortion of the lithosphere, accumulates over a period of time due to ***stress*** acting on the rock of the lithosphere. The origin of this stress is believed by most geophysicists to be slow convective motion, driven by heat energy, which occurs below the lithosphere in the mantle. One consequence of this convection is the fragmentation of the lithosphere into tectonic plates, and the slow movement of these plates relative to each other. Much of our understanding of earthquakes, as well as other geologic phenomena such as volcanic eruptions and mountain building, is based on this theory of ***plate tectonics.***

The rock of the lithosphere can accommodate only so much strain energy. Eventually, the rock must fracture. When this happens, strain is relieved, the stress level drops, some energy is converted into heat, some movement (slip) occurs along the plane of fracture (the fault plane), and some energy is radiated away from the area of fracture in the form of elastic waves—called ***seismic waves***—which travel through the earth or along the surface of the earth. The arrival of these seismic waves at a point on the surface causes rapid and complex motions of the ground. This is what we feel as an earthquake. Once a fault has formed as the result of an initial fracture, earthquakes are likely to recur along the same fault, because this plane is now a zone of weakness in the lithosphere.

Figure 1 shows the relationship of a fault plane to the origin point of the seismic waves (called the ***hypocenter*** or ***focus*** of the earthquake) and the ***epicenter,*** the point on the surface of the earth directly above the hypocenter. Note that, unless the attitude of the fault plane is vertical, the epicenter will be located some distance from the trace of the fault along the surface of the earth.

Earthquake Magnitude

Seismic waves are detected and measured by seismographs. The energies of earthquakes are compared on the basis of their magnitudes, a concept first defined in the 1930s by Charles Richter of the California Institute of Technology. Richter wished to have a single number to describe an earthquake, independent of the distance from the epicenter at which the earthquake waves were recorded. The system he devised is commonly called the ***Richter Scale,*** a term that

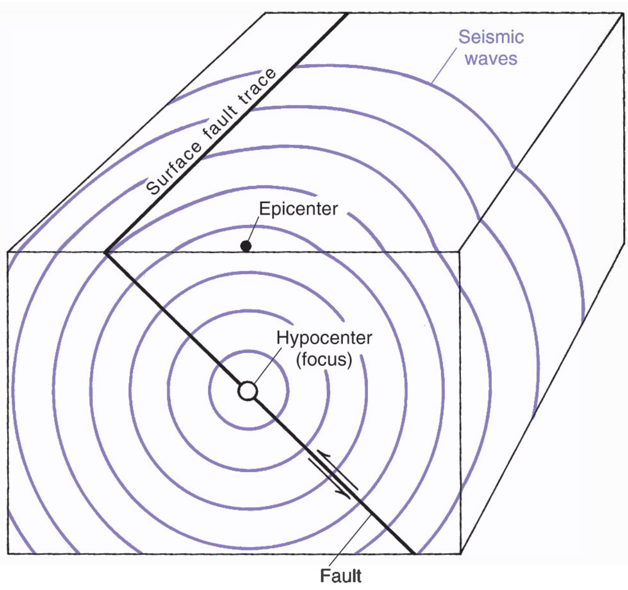


Figure 1. Relationships among the fault plane, the fault trace on the surface of the earth, the earthquake hypocenter (focus), the epicenter, fault slip (arrows), and seismic waves. (Based on Plummer, C. C., and McGeary, David, Physical geology, 4th ed., Wm. C. Brown Publishers, Figure 16.2, p. 345. Copyright © 1988. Reproduced with permission of The McGraw-Hill Companies.)

frequently leads to the mistaken impression that there is a kind of physical instrument—a scale similar to those used to measure weights—to which the term applies. In fact, the Richter Scale—Richter himself preferred to call it the ***magnitude scale***—is a scale of numbers that expresses the relative sizes of earthquakes. The numbers of the magnitude scale are logarithms, that is, numbers that express powers of 10. As originally defined by Richter on the basis of California earthquakes recorded locally on a particular type of seismograph, the magnitude represented the maximum amount of ground movement at a distance of 100 kilometers (62 miles) from the epicenter of an earthquake. Each whole number on the scale represented a tenfold difference in this amplitude of ground motion.

As the concept of magnitude came to be used worldwide and had to be calculated from many different types of seismographs, new ways of defining the magnitude were introduced, so that today several different magnitude numbers might be found for the same earthquake. Thus, magnitudes are useful mostly for comparing earthquakes (the purpose Richter had in mind), rather than for finding the actual energy of an earthquake with more than rough precision.

There is no upper or lower limit to the Richter Scale, but as a matter of historical fact, no magnitude greater than about 9.5 has ever been calculated for an earthquake. Earthquakes in eastern North America seldom have magnitudes greater than 5.

Earthquake Intensity

Before the development of the magnitude scale, earthquakes were compared on the basis of ***intensity.*** Today, intensity values are an important supplement to the magnitudes because intensity is a semiquantitative expression of the effects caused by an earthquake. These may be effects on people, on man-made structures, or on natural features of the landscape. Intensities are determined after the earthquake on the basis of field observations made by trained personnel, or from survey forms filled out by persons who experienced the earthquake. The U.S. Geological Survey (USGS) uses reports sent in by postmasters and compiles intensity data by postal ZIP code.

Obviously, intensity is not a single number for a particular earthquake, but varies from place to place. Usually, the intensity is greatest in the immediate vicinity of the epicenter and decreases with increasing distance from the epicenter. However, many factors affect intensity; among them are topography, type and thickness of soil, direction from the epicenter relative to regional rock structure, and type of bedrock. The greatest intensities are commonly caused by landslides or other modes of ground failure induced by the seismic waves rather than by the direct effects of seismic shaking.

In the United States, intensities are expressed in terms of the ***Modified Mercalli scale.*** This scale was first proposed in Italy by Giuseppi Mercalli in the early 1900s and was modified in 1931 by the American seismologists H. O. Wood and F. Neumann (for this reason, it is also called the Wood-Neumann scale). Table 1 is an abridged version of the Modified Mercalli scale; Roman numerals are usually used to avoid confusion with earthquake magnitude.

Earthquakes Beyond Pennsylvania

Historically, large earthquakes have occurred in three regions of eastern North America: (1) the Mississippi Valley, especially near the town of New Madrid, Mo.; (2) the St. Lawrence Valley; and (3) Charleston, S. C.

New Madrid, Missouri

Three great earthquakes struck the vicinity of New Madrid in December 1811, January 1812, and February 1812. Although there were no seismographs to record these events, each earthquake in the series is estimated to have had a magnitude in excess of 7. These earthquakes were felt in western Pennsylvania, but no damage is known to have occurred there (Abdypoor and Bischke, 1982; all other references to the effects of large historic earthquakes in Pennsylvania are from this source). It is unlikely that future New Madrid earthquakes would be any greater than those of 1811–12, so Pennsylvanians probably do not have to worry about a threat from that quarter.

The St. Lawrence Region

One of the largest earthquakes in eastern North America occurred on February 28, 1925, and had an epicenter in the La Malbaie-Charlevoix region of Quebec. This earthquake had a magnitude near 7. Earthquakes having magnitudes estimated to have exceeded 6.5 occurred in the same region in 1663 and 1870 (Johnston and others, 1994; most magnitudes given in this section are from this source). At least a dozen earthquakes strong enough to be felt in Pennsylvania have originated in the St. Lawrence Seismic Zone since the time of European settlement, the most recent on November 25, 1988. Earthquake activity in Ontario, western New York, northwestern Pennsyl-

Table 1. ***The Modified Mercalli Scale of 1931 (Abridged Version)***

I. Not felt except by a very few under especially favorable circumstances.

II. Felt only by a few persons at rest, especially on the upper floors of buildings. Delicately suspended objects may swing.

III. Felt quite noticeably indoors, especially on the upper floors of buildings, but many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibration is like the passing of a truck. Duration is estimated.

IV. During the day felt indoors by many, outdoors by few. At night some are awakened. Dishes, windows, and doors are disturbed; walls make a creaking sound. Sensation is like a heavy truck striking a building. Standing motor cars are rocked noticeably.

V. Felt by nearly everyone; many are awakened. Some dishes, windows, etc., are broken; a few instances of cracked plaster occur; unstable objects are overturned. Disturbance of trees, poles, and other tall objects is sometimes noticed. Pendulum clocks may stop.

VI. Felt by all; many are frightened and run outdoors. Some heavy furniture is moved; a few instances of fallen plaster or damaged chimneys occur. Damage is slight.

VII. Everybody runs outdoors. Damage is *negligible* in buildings of good design and construction; *slight* to *moderate* in well-built ordinary structures; *considerable* in poorly built or badly designed structures. Some chimneys are broken. Noticed by persons driving motor cars.

VIII. Damage is *slight* in specially designed structures; *considerable* in ordinary substantial buildings, with partial collapse; *great* in poorly built structures. Panel walls are thrown out of frame structures. Chimneys, factory stacks, columns, walls, and monuments fall; heavy furniture is overturned. Sand and mud are ejected from the ground in small amounts. Changes occur in well water. Persons driving motor cars are disturbed.

IX. Damage is *considerable* in specially designed structures; well-designed frame structures are thrown out of plumb; damage is *great* in substantial buildings, with partial collapse. Buildings are shifted off their foundations. Ground is cracked conspicuously. Underground pipes are broken.

X. Some well-built wooden structures are destroyed; most masonry and frame structures are destroyed along with their foundations. Ground is badly cracked. Rails are bent. Considerable landslides occur on river banks and steep slopes. Sand and mud are shifted. Water is splashed (slopped) over banks.

XI. Few, if any, masonry structures remain standing. Bridges are destroyed. Broad fissures occur in the ground. Underground pipelines are completely out of service. Earth slumps and land slips occur in soft ground. Rails are bent greatly.

XII. Damage is total. Waves are seen on the ground surface. Lines of sight and level are distorted. Objects are thrown upward into the air.

vania, and eastern Ohio may represent a westward extension of this zone. An earthquake of unknown magnitude with an epicenter near Attica, N. Y., is reported to have cracked walls in Sayre (Bradford County), Pa., on August 12, 1929. On November 1, 1935, an earthquake with an epicenter near Timiskaming, Ontario (northwest of the St. Lawrence Seismic Zone proper), and an estimated magnitude of 6.4, was felt with intensity IV in northwestern Pennsylvania and, at lower intensities, throughout the commonwealth. The lower St. Lawrence region is too far away for even a large future earthquake to be likely to cause damage in Pennsylvania. If an earthquake having a magnitude of 6 or greater were to occur on the western extension of the St. Lawrence Seismic Zone, however, at least moderate damage might be expected in one or more of the counties of Pennsylvania's "northern tier."

Charleston, South Carolina

Charleston was the site of the largest historic earthquake to have struck the eastern seaboard of the United States, and one of the 10 largest earthquakes to occur anywhere in the world away from an active tectonic plate margin. The earthquake on August 31, 1886, had a magnitude estimated to have been around 7.5. Intensity reached X on the Modified Mercalli scale, and the city of Charleston was heavily damaged. Although this earthquake was felt in most of Pennsylvania, intensity here did not exceed IV, so a recurrence of the great Charleston earthquake would pose little hazard to Pennsylvanians.

Other East Coast Areas

Eastern Massachusetts experienced strong earthquake shocks in 1658, 1727, 1755, and 1925. The largest of these was the earthquake of November 18, 1755, which had an estimated magnitude of about 6.3. The epicenter is generally thought to have been offshore of Cape Ann, north of Boston, although the exact location is uncertain. This earthquake was felt with intensities of IV and V in eastern Pennsylvania. Intensity as high as VI might be expected from a magnitude 7 earthquake originating in the vicinity of Boston.

Southeastern New York and northern New Jersey have been the sites of moderate earthquakes. Two of these events, in 1737 and 1884, produced intensities as high as VII in New York City and were felt at intensity IV in eastern Pennsylvania. If an earthquake of magnitude 6 or greater were to occur in this area, it is likely that damage would result in the easternmost counties of Pennsylvania.

Earthquakes in Pennsylvania

Figure 2 shows the locations of historic epicenters in Pennsylvania; a list of Pennsylvania earthquakes by county is given in Table 2. Ambiguities always exist in lists of earthquakes, and no two lists for the same region are likely to agree in every detail. Some events identified as earthquakes in some lists may, in fact, have been something else—blasting in the course of mining operations, for example. Table 2 includes only those events that the author considers to be earthquakes with a high degree of certainty. Aftershocks—smaller earthquakes following a larger one in approximately the same location—are listed only if they occurred more than a year after the main shock; otherwise they are mentioned in the "Remarks" column. Earthquakes that can be considered foreshocks of larger events have been listed separately from their main shocks only if they occurred months to years earlier. It is likely that some earthquakes having magnitudes less than 3, other than aftershocks, have occurred in Pennsylvania but were not detected by seismographs or recognized as earthquakes and reported by persons who felt them. It is also possible that evidence for some earthquakes that occurred prior to the mid-twentieth century has not yet been discovered in historical documents. For example, the entire earthquake history of Lancaster County prior to 1885 was unknown to the scientific community until Armbruster and Seeber (1987) published the results of their search of newspapers and other archives.

Earthquakes having magnitudes greater than 5 can occur in Pennsylvania, as demonstrated by the earthquake of September 25, 1998 (Armbruster and others, 1998) (Table 2, Crawford County). Southeastern Pennsylvania, the state's most seismically active region, is not known to have experienced an earthquake with magnitude greater than 4.7, but the historical record goes back only about 200 years. No obvious reason exists to conclude that an earthquake of magnitude between 5 and 6 could not occur there also. An earthquake with magnitude greater than 6 is much less likely, but the fact that such large earthquakes have occurred elsewhere in the East means that this possibility cannot be ruled out entirely for Pennsylvania.

What is the Level of Earthquake Hazard in Pennsylvania?

Geologic History and Faults

The great majority of earthquakes occur along boundaries between tectonic plates. The reason for this is not completely clear, but it appears

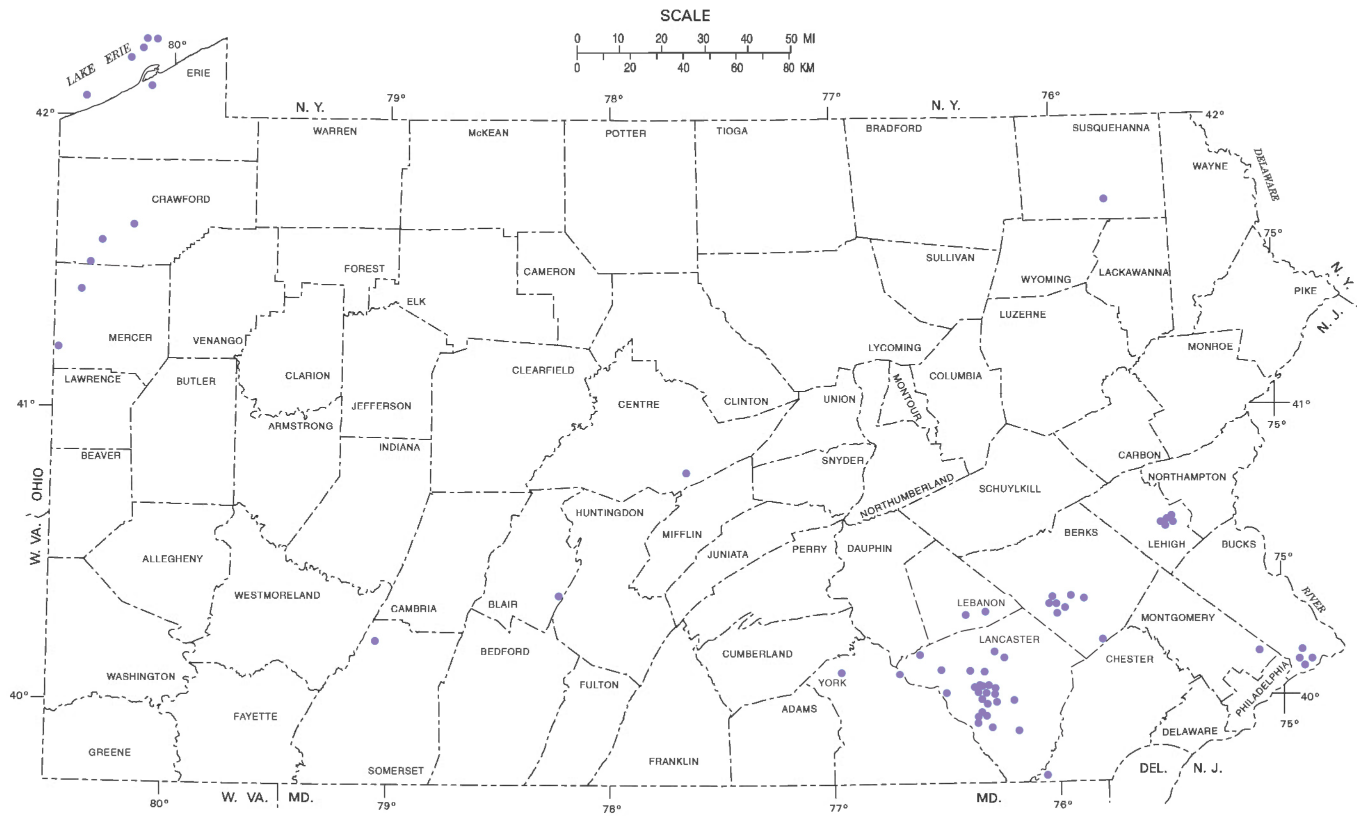


Figure 2. Locations of historic earthquake epicenters in Pennsylvania. Many locations are approximate. Pre-twentieth-century earthquakes felt in Philadelphia are not shown because their epicenter locations are unknown.

Table 2. *Selected Earthquakes in Pennsylvania Through March 2006*

Date (local time)		Where strongly felt	Magnitude	Remarks
		ADAMS COUNTY		
May 26,	1994		2.8	
		BERKS COUNTY		
Nov. 21,	1777	Unknown	Unknown	
May 28,	1906	Geigertown	Unknown	
June 8,	1937	Reading	Unknown	
Jan. 7,	1954	Sinking Spring	3.2 (est.)	Aftershocks for 1 year
June 25,	1972	Wyomissing	Unknown	Start of series of small earthquakes lasting a few days
Aug. 12,	1973	Wyomissing	Unknown	
May 10,	1993	Spring Twp.	2.8	
Jan. 15,	1994	Spring Twp.	4.0, 4.6	Two events about 1 hour apart. Long aftershock sequence into the late 1990s
Oct. 28,	1996	Wyomissing	2.5	May be delayed aftershock of Jan. 15, 1994, earthquake
		BLAIR COUNTY		
July 15,	1938	Clover Creek	3.2 (est.)	
		BUCKS COUNTY		
Dec. 27,	1961	Bristol-Levittown	Unknown	Epicenter may have been in New Jersey
Nov. 14,	1981	Bristol-Levittown	Unknown	Epicenter may have been in New Jersey
Apr. 12,	1982	Bristol-Levittown	2.5	Epicenter may have been in New Jersey
May 12,	1982	Bristol-Levittown	2.5	Epicenter may have been in New Jersey
May 12,	1982		2.4	
May 10,	1984		2.2	
Feb. 2,	1989		Unknown	
		CENTRE COUNTY		
Mar. 25,	1937		Unknown	
Aug. 15,	1991	Centre Hall	3.0	
		CHESTER COUNTY		
Dec. 17,	1752		3.6	
Jan. 25,	1821	New London	3.1	
Oct. 17,	1996	Nottingham	2.3	Epicenter may have been in Maryland
		CRAWFORD COUNTY		
Sept. 15,	1852	Meadville	Unknown	
Apr. 14,	1985	Conneaut Lake	3.2	
Sept. 25,	1998	Jamestown (Mercer Co.)	5.2	Largest known Pennsylvania earthquake; many aftershocks
		ERIE COUNTY		
Nov. 1,	1870	Erie	3.5	
Sept. 26,	1921	Erie	2.9	
Feb. 16,	1930	Erie	2.9	
Oct. 29,	1934	Erie	3.2 (est.)	Strongest aftershock felt at Albion on Nov. 5
Dec. 17,	1990	Erie	2.5	
Aug. 30,	1998	Erie	2.1	
Oct. 30,	1999	Erie	2.5	
		FAYETTE COUNTY		
Dec. 8,	1896	Dunbar	3.8	
Oct. 8,	1965	Connellsville	3.3	
		FRANKLIN COUNTY		
Mar. 19,	1880	Chambersburg	3.5	Epicenter may have been in Maryland

Table 2. *Continued.*

Date (local time)		Where strongly felt	Magnitude	Remarks
		LACKAWANNA COUNTY		
Sept. 27,	1940	Unknown	Unknown	May be mining-related event
		LANCASTER COUNTY		
Dec. 17,	1752	Lancaster	3.6 (est.)	Epicenter may have been in Chester County
Jan. 11,	1798	Lancaster	Unknown	
Nov. 20,	1800	Lititz	3.9 (est.)	
Jan. 27,	1801	Lancaster	Unknown	
Mar. 19,	1818	Lancaster	Unknown	
Aug. 21,	1820	Mt. Joy	3.4 (est.)	
May 4,	1822	Lancaster	Unknown	
May 1,	1825	Millersville	3.1	Reported from "Millerstown," which was the name of present-day Millersville in 1825
Sept. 5,	1829	Lancaster	Unknown	
Feb. 5,	1834	Marticville	3.8 (est.)	
Jan. 20,	1861	Lancaster	3.5	
Sept. 17,	1865	Willow Street	Unknown	
Nov. 7,	1866	Lancaster	Unknown	
Mar. 8,	1885	Lancaster	Unknown	
Sept. 26,	1886	Elizabethtown	Unknown	
Mar. 8,	1889	Conestoga	4.1 (est.)	
May 6,	1892	Terre Hill	Unknown	
Dec. 7,	1972	Lititz	3.5 (est.)	
July 16,	1978	Conestoga	3.1	
Oct. 6,	1978	Manheim Twp.	3.0	
Apr. 22,	1984	Marticville	4.1	Magnitude 3 foreshock 4 days earlier; many aftershocks
Sept. 19,	1984	Lancaster	Unknown	
May 2,	1986	Conestoga	2.6	May be delayed aftershock of Apr. 22, 1984, earthquake
Mar. 11,	1995	East Petersburg	2.0, 2.4	Two events about 1 hour apart
Nov. 14,	1997	Lititz	3.0	
Oct. 5,	2000	Conestoga	2.3	May be delayed aftershock of Apr. 22, 1984, earthquake
		LEBANON COUNTY		
Jan. 15,	1885	Schaefferstown	2.7 (est.)	
May 12,	1964	Cornwall	3.2 (est.)	
		LEHIGH COUNTY		
May 31,	1884	Allentown	2.9 (est.)	
May 31,	1908	Allentown	3.1 (est.)	
June 22,	1928	Allentown	2.4 (est.)	
Nov. 23,	1951	Allentown	3.3 (est.)	
Sept. 14,	1961	Allentown	Unknown	
		LUZERNE COUNTY		
Feb. 24,	2000		2.3	
		MERCER COUNTY		
Aug. 17,	1873	Sharon	Unknown	Epicenter may have been in Ohio
Dec. 11,	1890	Greenville	2.9	
Aug. 26,	1936	Greenville	2.9	
		MONROE COUNTY		
Oct. 24,	1942	Stroudsburg	3.4	Epicenter may have been in New Jersey
		MONTGOMERY COUNTY		
Mar. 5,	1980	Abington	3.5	Strongest of a series of 6 earthquakes over 9 days felt in Montgomery and lower Bucks Counties

Table 2. *Continued.*

Date (local time)		Where strongly felt	Magnitude	Remarks
		PHILADELPHIA AREA[1]		
Dec. 18,	1737			
Nov. 27,	1755			
Mar. 23,	1758			
Mar. 22,	1763			
Oct. 13,	1763			
Oct. 30,	1763			
Apr. 25,	1772			
Nov. 22–23,	1777			
Nov. 29,	1780			
Mar. 17,	1800			
Nov. 29,	1800			
Nov. 12,	1801			
Dec. 8–9,	1811			
Dec. 16,	1811			
Jan. 8,	1817			
Aug. 17,	1840			
Nov. 11 and 14,	1840			
June 17,	1871			
Mar. 25,	1879			
		SOMERSET COUNTY		
Feb. 3,	1982	Jennerstown	2.6	
		SULLIVAN COUNTY		
Oct. 28,	1946	Unknown	Unknown	May be mining-related event
		SUSQUEHANNA COUNTY		
Aug. 14,	1982	Hop Bottom	Unknown	
		TIOGA COUNTY		
Dec. 16,	1869	Tioga	3.1	
Dec. 14,	1990	Tioga	3.0	
		WARREN COUNTY		
July 8,	1995	Warren	2.4	
		YORK COUNTY		
June 16,	1997	Dillsburg	2.4	

[1]Earthquakes whose epicenters are unknown and that were felt in Philadelphia.

that stress levels are higher along plate boundaries, and that strain energy builds up more rapidly in those areas. Eastern North America, including Pennsylvania, today is far from the nearest plate boundary—the Mid-Atlantic Ridge, some 2,000 miles to the east. Nevertheless, the eastern states and eastern provinces of Canada do experience a moderate level of earthquake activity, including occasional earthquakes with magnitudes greater than 6 that are capable of producing significant damage. Seismicity in the East may be related to what happened here about 200 million years ago. At that time, the supercontinent called Pangaea broke up and the Atlantic Ocean began to form. This event, called ***rifting*** by geologists, produced many faults, and some of these faults may be experiencing reactivation by the present-day stress, which is squeezing eastern North America in a roughly east-west direction. Johnston and others (1994) found that nearly 70 percent of earthquakes with magnitudes of at least 6 in so-called stable continental regions occur in areas that experienced rifting sometime during the past 200 million years.

It might seem, then, that a straightforward approach to earthquake hazard evaluation in the East would be to locate all the faults, or at least those that are 200 million years old or younger. Unfortunately, this approach does not work very well because it is impossible to demonstrate that any particular fault is active, even when earthquake epicenters are located in the vicinity of the fault's surface trace. Actual displacement of the earth's surface along a fault line during an earthquake is extremely rare in the East. Complicating the problem is the fact that the vast majority of mapped faults in our region have no seismicity at all associated with them. Therefore, simply knowing where the faults are tells us little, if anything, about earthquake hazard.

Despite the difficulty of identifying specific faults that are responsible for earthquakes in the East, regions of perisistent earthquake activity have been delineated and named. An example in Pennsylvania is the Lancaster Seismic Zone (Armbruster and Seeber, 1987), which encompasses all seismicity in Lancaster, York, Lebanon, and Berks Counties. As indicated in Table 2, this is the most active seismic zone in Pennsylvania.

A Probabilistic Approach

It appears that the best guides to seismic hazard in Pennsylvania and elsewhere in the East are the earthquakes themselves. The earthquake history of a region can be the basis for conducting a probabilistic earthquake-hazard analysis.

As part of the National Earthquake Hazard Reduction Program, seismologists working for the USGS have used earthquake history to estimate the probabilities of earthquakes of various magnitudes occurring in various locations over a given period of time. They have produced a series of maps that show the results as ground-motion hazard maps. These maps have been designed to be useful for the determination of building codes. Usually, 50 years is the time frame considered because that is what architects and structural engineers take to be the useful lifetime of a new building. The expected decrease in intensity with distance from the epicenter is also taken into consideration to arrive at an estimate of the probability that certain levels of ground shaking will be experienced at any given location.

The expected level of ground shaking is expressed in terms of some measure of ground acceleration or velocity, such as the peak horizontal ground acceleration (the largest acceleration recorded during an earthquake). These terms are used because building codes are written to indicate how much horizontal force a building should be able to withstand during an earthquake. Table 3 gives the levels of peak acceleration and the *roughly* equivalent values of earthquake intensity on the Modified Mercalli scale. Figure 3 shows contours of peak horizontal ground acceleration having a 2 percent probability of being experienced in any 50-year period, as calculated by USGS seismologists. The contour values are percentages of the acceleration due to gravity (g), which is 9.8 meters/second/second, or 32 feet/second/second. The original map on which Figure 3 is based, as well as other seismic-hazard maps, may be viewed on the USGS web site at http://eqhazmaps.usgs.gov/.

Table 3. *Approximate Correlation of Peak Horizontal Ground Acceleration (PHGA) with Modified Mercalli Intensity (MMI)*

PHGA (percent of g, acceleration due to gravity)	MMI
<6	<VI
6–8	VI
8–16	VII
16–32	VIII
>32	IX+

The Pennsylvania Department of Environmental Protection requires that structures built in areas that can expect peak horizontal ground acceleration to exceed 10 percent g with a probability of 10 percent in 250 years (which is equivalent to 2 percent probability in 50 years) incorporate specific seismic safety design features.

Conclusion

Two of the areas that have generated the largest historical earthquakes in eastern North America—New Madrid, Mo., and Charleston, S. C.—are too far away for earthquakes having epicenters there to cause damage in Pennsylvania, although earthquakes occurring in those areas that have magnitudes near 7 would be felt in Pennsylvania. Eastern Massachusetts is closer, and a magnitude 7 earthquake there could produce intensity VI effects in northeastern Pennsylvania.

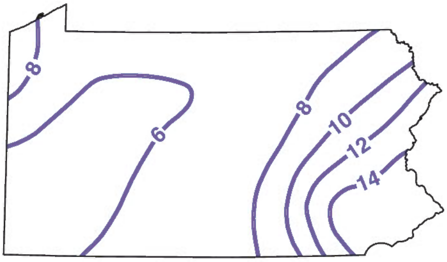


Figure 3. An earthquake-hazard map for Pennsylvania. The contours represent earthquake ground motions that have a 2 percent probability of being experienced in 50 years. The numbers are percentages of g, the acceleration due to gravity. See Table 3 for approximate corresponding values of Modified Mercalli intensity. From Frankel and others (2002).

Similar intensities might be expected in north-central and northwestern Pennsylvania from earthquakes that have epicenters in the western part of the St. Lawrence zone. The possibility that a magnitude 7 earthquake could occur having an epicenter near New York City cannot be completely discounted, and such an earthquake could produce significant damage (intensity VIII) in eastern Pennsylvania.

Pennsylvanians probably will continue to feel small earthquakes generated on local faults, although the exact identity of those faults is likely to remain elusive. A large local earthquake, one with magnitude greater than 6, though unlikely, is not impossible. A probabilistic analysis that takes into consideration the threat from earthquakes both outside and inside Pennsylvania's borders indicates a relatively low level of earthquake hazard in our commonwealth. Nevertheless, some precautions might be in order. These include contingency planning by emergency management agencies and emergency response services; incorporation of at least moderate earthquake resistance into the design of new buildings and other engineered structures, such as bridges and pipelines; and individual preparedness that would include having on hand a flashlight, battery-powered radio, water and food supply, and first-aid kit—as one might prepare for the possibility of a disaster of any sort. Further information about how to prepare for earthquakes and other emergencies may be obtained from the Southeastern Pennsylvania Chapter of the American Red Cross, 23rd and Chestnut Streets, Philadelphia, PA 19103, or from their web site at http://www.redcross-philly.org.

References

Abdypoor, Gladees, and Bischke, R. E., 1982, Earthquakes felt in the state of Pennsylvania; with emphasis on earthquakes felt in Philadelphia, Pa. and surrounding areas: Philadelphia, Temple University Department of Geology, 354 p.

Armbruster, J. G., and Seeber, Leonardo, 1987, The 23 April 1984 Martic earthquake and the Lancaster Seismic Zone in eastern Pennsylvania: Bulletin of the Seismological Society of America, v. 77, no. 3, p. 877–890.

Armbruster, John, Barton, Henry, Bodin, Paul, and others, 1998, Preliminary results from the investigation of the Pymatuning earthquake of September 25, 1998: Pennsylvania Geology, v. 29, no. 4, p. 2–14.

Faill, R. T., compiler, 2004, Earthquake catalog and epicenter map of Pennsylvania: Pennsylvania Geological Survey, 4th ser., Map 69, CD-ROM.

Frankel, A. D., Petersen, M. D., Mueller, C. S., and others, 2002, Documentation for the 2002 update of the national seismic hazard maps: U.S. Geological Survey Open-File Report 02-420.

Johnston, A. C., Coppersmith, K. J., Kanter, L. R., and Cornell, C. A., 1994, Assessment of large earthquake potential, Volume 1, *in* The earthquakes of stable continental regions: Palo Alto, Calif., Electric Power Research Institute Report TR-102261-VI, 5 v.

Munsey, Jeffrey, 2006, Identification of "new" historic earthquakes in the central and eastern United States through online keyword searches: Internal Report, Tennessee Valley Authority.

PENNSYLVANIA GEOLOGICAL SURVEY EDUCATIONAL SERIES

ES 1 *Rocks and Minerals of Pennsylvania*
ES 2 *Common Fossils of Pennsylvania*
ES 3 *The Geology of Pennsylvania's Groundwater*
ES 4 *The Geological Story of Pennsylvania*
ES 5 *Geology and the Gettysburg Campaign*
ES 6 *Pennsylvania and the Ice Age*
ES 7 *Coal in Pennsylvania*
ES 8 *Oil and Gas in Pennsylvania*
ES 9 *Landslides in Pennsylvania*
ES 10 *Earthquake Hazard in Pennsylvania*
ES 11 *Sinkholes in Pennsylvania*
ES 12 *The Nonfuel Mineral Resources of Pennsylvania*
ES 13 *Reading and Using Maps*

ADDITIONAL COPIES OF THIS PUBLICATION
MAY BE OBTAINED FROM
PENNSYLVANIA GEOLOGICAL SURVEY
3240 SCHOOLHOUSE ROAD
MIDDLETOWN, PA 17057-3534
717-702-2017

2200–BK–DCNR3115