Ohio Geology
A Quarterly Publication of the Division of Geological Survey
Winter 1998

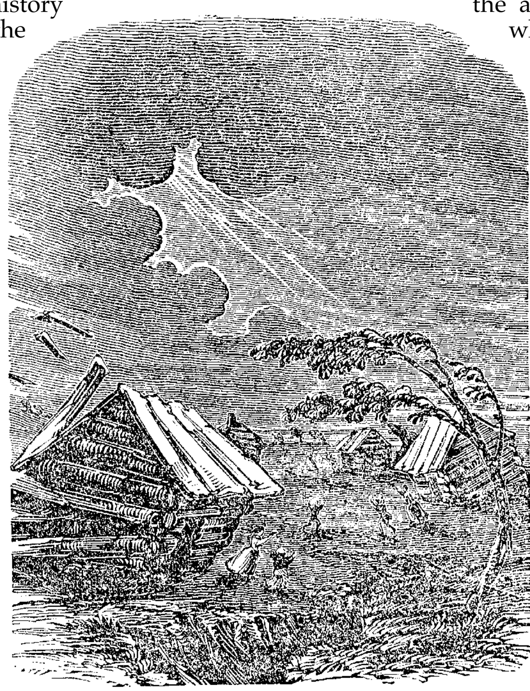
"THE AWFUL VISITOR"—THE GREAT NEW MADRID EARTHQUAKES IN OHIO

by Michael C. Hansen

Late in 1811, Ohio was just beginning to emerge from the wilderness. Statehood had been granted only eight years before, and settlers of European descent were establishing small communities across the landscape. The population of the state was a little more than 230,000. Cincinnati, Ohio's largest metropolis, had just over 2,500 residents, and Dayton had only 383. This was land with a written history that spanned only a couple of decades. Moderate earthquakes having uncertain epicentral locations had been felt in the Ohio Valley in 1776 and in 1791 or 1792, but no segment of the population, indigenous or immigrant, could anticipate from oral or written history the extent and power of the great earthquake sequence that began on December 16, 1811.

In the early hours of December 16, most Ohio residents were deep in sleep, unaware that the primary or P wave from a tremendous earthquake was speeding toward them at nearly 14,000 miles per hour. The initial shaking in Cincinnati began only a minute and 18 seconds after the vibrations left their point of origin along an ancient crustal rift deep beneath the Mississippi River valley in the bootheel region of southern Missouri, where that state joins with Arkansas, Kentucky, and Tennessee. A minute later, the slower surface (S) waves arrived in Ohio and began the dangerous shaking that some observers said lasted for several minutes. The first shock began to shake the Queen City at 2:24 a.m., according to the journal kept by 26-year-old Cincinnati physician and scientific observer Daniel Drake. This was the first of four major shocks, and hundreds of smaller ones, that would fan out like ripples in a pond, some of them reaching to the Atlantic coast and many of them reaching Ohio, for the next two months.

The epicentral region of the great quakes underwent a shaking that has not been experienced before or since in historic times in the eastern U.S. The 800 residents of New Madrid, Missouri, and 200 residents of Little Prairie (now Caruthersville), about 30 miles south of New Madrid, saw their communities undergo total destruction as the great quakes shook the ground so violently that no one could stand. Waves were visible on the ground surface, trees split or were snapped off, the ground was rent with fissures up to 10 feet wide, and sand, water, and debris were violently spouted as high as the treetops. Whole sections of ground subsided and were soon flooded. Banks along the Mississippi River caved in, taking with them large trees, and creating giant waves on the river. Fissuring in the river bed caused water spouts to shoot into the air and waterfalls to form where portions of the river bed were uplifted. Islands in the river disappeared and new ones rose up from the muddy bottom. All of this chaos was accompanied by an ear-splitting cacophony resembling thunder and artillery fire. Hardly a dwelling was left standing in New Madrid, and Little Prairie was totally destroyed. Surprisingly, there were very few confirmed fatalities—perhaps fewer than a dozen. There may have been only a modest number of fatalities in part because the log cabins occupied by most settlers were very resistant to immediate collapse from earthquake waves. Although most of these structures were rendered uninhabitable, their destruction was not instantaneous, thus allowing residents time to evacuate the dwelling.



Impression of the destruction of New Madrid by the earthquakes of 1811-1812 (from Howe, Henry, 1851, The great west: Cincinnati).

At daylight on December 16, New Madrid residents began to collect themselves from the earthquake just hours before and to survey the terrible destruction that lay all about them. Just about 8:00 a.m., another violent shock, nearly as strong as the first, completed the annihilation of the community. Little did they realize that two more great earthquakes, on January 23, 1812, at 9:00 a.m., and the largest of all, on February 7, 1812, at 3:45 a.m., would plague their community. The Missouri bootheel region would shake continuously from December 1811 until more than a year later. Periodic aftershocks plagued the area

We were again alarmed by the awful visitor. It was by far the most awful, both in its severity and the length of its duration of any that has been felt in this town and has left impressions upon the mind which time will scarcely erase.

—Remarks in the Dayton Ohio Centinel *of February 13, 1812, concerning the New Madrid earthquake of February 7*

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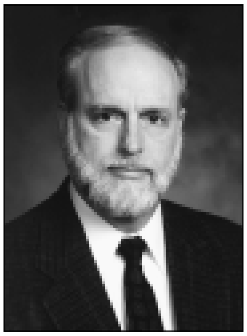

Thomas M. Berg, Division Chief and State Geologist

From The State Geologist...

Thomas M. Berg

THE CENTRAL GREAT LAKES GEOLOGIC MAPPING COALITION

The lead article by Mike Hansen in this issue of *Ohio Geology* on the sequence of central U.S. earthquakes in 1811 and 1812 should certainly give most of our readers something to reflect on. That another series of massive earthquakes will strike the central part of our country and have severe effects on Ohio is a certainty. The big uncertainty is when it will happen. It may not happen for another 100 to 500 years. Tomorrow? Probably not, but no one really knows. Does this mean that the Ohio Geological Survey will simply throw up its collective hands and ignore the issue? Not at all!

There are other heavy-duty geological concerns here in our state that also call for our attention. Examples include dwindling water supplies in the face of enormous urban expansion. We have concerns about important environmental issues such as nonpoint-source pollution. There are important matters surrounding land use in Ohio that are increasingly gaining the attention of our legislators. Protecting farmlands is a crucial concern today. At the same time, we need to know where important industrial-mineral deposits are located so that we can maintain our transportation infrastructure.

The Geological Survey recognizes that responding to geologic hazards such as earthquakes and to environmental, water-resource, and mineral-resource concerns in Ohio requires solid and reliable geologic information. And the fundamental, most important information component is the geologic map. In Ohio and in the close-by states of Illinois, Indiana, and Michigan, one of the principal kinds of geologic map needed to deal with hazards and resource issues is the three-dimensional, surficial-materials map. These central Great Lakes states were overridden by continental ice sheets four or more times, and the glaciers left enormous quantities of unconsolidated sediments after melting. The glacial and periglacial deposits are the materials that citizens interact with on a daily basis. For example, during an earthquake, some glacial deposits are susceptible to liquefaction, and structures built on those materials can collapse. The glacial sediments in the four-state region include extensive sand and gravel deposits that are needed for construction and infrastructure maintenance. The glacial deposits also include some of the most productive buried-valley aquifers of the Midwest. Unfortunately, only a very small percentage of the surficial materials in the four-state region have been mapped in three dimensions.

Recognizing the urgent need for this kind of geologic mapping, the geological surveys of Illinois, Indiana, Michigan, and Ohio and the United States Geological Survey (USGS) have formed a partnership called the Central Great Lakes Geologic Mapping Coalition in order to conduct an aggressive program of three-dimensional, surficial-materials mapping. The pooling of expertise, training, talent, experience, and equipment among the four state surveys and the USGS will promote very efficient and uniform detailed geologic mapping of this type. The Coalition expects to conduct this mapping under the aegis of the National Cooperative Geologic Mapping Program (NCGMP). If Congress appropriates adequate funding for the NCGMP, the Coalition will be able to move dynamically forward in its mapping. Already, the USGS has contributed to the Coalition effort by providing training in three-dimensional, surficial-materials mapping through a program called "Surfschool." Several of our geologists attended that training during 1997.

A mapping program that will involve a three-year start-up phase, followed by an 11-year intensive mapping phase, is being finalized by the state surveys and the USGS. Our readers will hear more about this ambitious program in future issues of *Ohio Geology.*

Billie Long named Division Employee of the Year

Billie Long received the 1997 Employee of the Year award at the Survey's annual Christmas luncheon. This award recognizes superior efforts and contributions by an employee and has special significance because awardees are selected from nominations submitted by Division staff.

Billie's primary responsibility is to record and process all publication orders received by the Survey so that a proper accounting is kept within the intricate state system and to insure that the monies are deposited in the proper accounts. These tasks must be done in a timely manner so that the Survey can adhere to our goal of sending requested publications out within 24 hours of receipt of an order. This goal can be challenging at times when large numbers of publication orders are received in a short period. It was particularly challenging in the spring of 1997 when hundreds of orders were received daily for Bulletin 70, *Fossils of Ohio*.

Billie also keeps track of the inventory of furniture, equipment, computers, and the numerous other items belonging to the Survey. She is always ready to help out in the Survey's sales office (Geologic Records Center) when needed and frequently fills in for Geologic Records Center staff who are away because of illness, meetings, or vacations.

Efficiency, dependability, and a willingness to take on new tasks and help where needed are characteristics that have earned Billie the respect of her colleagues. Most people only see the results of Survey research in the form of publications, reports, maps, and data files. Few realize the behind-the-scenes efforts that are necessary to maintain the business and administrative efforts of the Survey. Since coming to the Survey in 1977, Billie has been a vital person in maintaining these efforts, which are recognized and admired by Survey staff.

Ohio Geology

A quarterly publication of the

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Division of Geological Survey
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Columbus, Ohio 43224-1362

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Ohio Geology is a free publication. To become a subscriber please contact the Division of Geological Survey at the above address, phone numbers, or e-mail.

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until 1817. The four great shocks of 1811 and 1812 are estimated to have had body-wave magnitudes of between 7.0 and 7.4, surface-wave magnitudes of between 7.8 and 8.3, and Modified Mercalli intensities of XI to XII. In addition to these major events, there were at least six shocks of estimated magnitude 6.2-7.0, and 197 shocks of 5.2-6.2. More than 1,800 individual earthquakes large enough to be felt were noted by Louisville, Kentucky, resident Jared Brooks.

The biggest shocks were felt throughout the eastern United States and Canada from the Gulf Coast to the Atlantic shore to Quebec, an area encompassing about 2 million square miles. An area of 250,000 square miles experienced strong shaking and Modified Mercalli intensities of VII. An area of 50,000 square miles in the epicentral region experienced extensive uplift, ground fissuring, bluff collapse, and liquefaction. Reelfoot Lake in Tennessee, and a number of other lakes, were formed by disruption of the ground.

These effects and many more were recorded in journals, diaries, newspaper articles and letters, and other contemporary accounts. However, communications were poor and the sparsely populated region from Missouri to Ohio had few newspapers to document events. Indeed, it was several months before it was confirmed in eastern cities that had felt the earthquakes that the quakes had originated in the Missouri region. For many years, the eyewitness accounts from the epicentral region were regarded by some to be fanciful and greatly exaggerated. Therefore, it is difficult to fully ascertain the precise distribution and intensity of the shaking during the New Madrid sequence. The first serious scientific study of the earthquakes did not take place until a century later when, in 1912, Myron L. Fuller of the U.S. Geological Survey published a detailed report on his field studies of the region and a summary of the contemporary accounts he could locate. It was not until the 1970's, however, that modern studies of the New Madrid events and the geology of the region began to receive serious attention, primarily through the efforts of Dr. Otto W. Nuttli of St. Louis University.

Nuttli and other geologists realized that the New Madrid events could recur, and the region that was a sparsely populated wilderness in 1811 was now densely populated and could be subject to tremendous devastation. Nor had the region been seismically quiet since the New Madrid events. In 1843, an earthquake having an estimated magnitude of 6.4 occurred near Marked Tree, Arkansas, and in 1895 a 6.7-magnitude event, which was felt in 23 states, occurred near Charleston, Missouri. In addition, many other smaller earthquakes had been felt in the region. There was little doubt earthquake risk in the New Madrid region posed a major threat to the Midwest. Some estimates suggest that a repeat of the 1811-1812 events could cause $50 billion in damage and that thousands of lives would be lost.

The probability of a recurrence of the 1811-1812 sequence is low for the immediate future, perhaps only 10 percent or less in the next 50 years. It is estimated that earthquakes of such magnitude occur in the New Madrid zone only about every 500-600 years. This recurrence interval seems to be supported by paleoseismic studies of the area, which document strong earthquakes at about 800-1,000 AD and 1,200-1,400 AD. However, such events do not necessarily follow regular patterns. Of more immediate concern is a repeat of an earthquake in the 6.5-magnitude range, similar to the 1895 Charleston, Missouri, event. Earthquakes of this magnitude seem to repeat about every century in the New Madrid zone and there is a high probability that an event of this size will occur in the near future.

It is an interesting thought to speculate on the consequences if the New Madrid events of 1811-1812 had occurred a century earlier or a century later. It is very probable that had they occurred in the early 1700's, we would not regard the region with the same trepidation. Most certainly, there would be few, if any, eyewitness accounts of the devastation. Had the events occurred in the early 1900's, the devastation would have been catastrophic and may have changed the way the region has developed.

The extent and severity of ground motion associated with the 1811-1812 sequence is of interest to emergency planners in any state affected by the

MODIFIED MERCALLI INTENSITY SCALE

I	Detected only by sensitive instruments
II	Felt only by a few persons at rest, especially on upper floors of buildings; delicately suspended objects may swing
III	Felt noticeably indoors, especially on upper floors of buildings, but not always recognized as earthquake; standing autos may rock slightly; vibrations like a passing truck
IV	During the day, felt indoors by many, outdoors by few; at night, some awakened; dishes, windows, doors disturbed; walls make creaking sound; sensation like heavy truck hitting building; standing autos rock noticeably
V	Felt by most people; some breakage of dishes, windows, and plaster; unstable objects overturned; disturbance of trees, poles, and other tall objects
VI	Felt by all, many frightened and run outdoors; some heavy furniture may move; falling plaster and chimneys, damage slight
VII	Everyone runs outdoors; damage to buildings varies depending on quality of construction; noticed by people driving autos
VIII	Panel walls thrown out of frames; walls, monuments, chimneys fall; sand and mud ejected; drivers of autos disturbed
IX	Buildings shifted off foundations, frame structures thrown out of plumb; ground cracked; underground pipes broken
X	Most masonry and frame structures destroyed; ground badly cracked, rails bent, landslides; sand and mud shift; water splashes over river banks
XI	Few structures remain standing; bridges destroyed; broad fissures in ground, pipes broken, landslides, rails bent
XII	Damage total; waves seen on ground surface, lines of sight and level distorted, objects thrown up into the air

Dr. Daniel Drake (1785-1852), Cincinnati physician and scientific observer.

events, and Ohio is no exception. The Central United States Earthquake Consortium (CUSEC), based in Memphis, Tennessee, is represented by emergency management agencies and state geological surveys from the seven states surrounding the New Madrid seismic zone (Arkansas, Illinois, Indiana, Kentucky, Mississippi, Missouri, and Tennessee) and associate members in states on the periphery of the zone (such as Ohio).

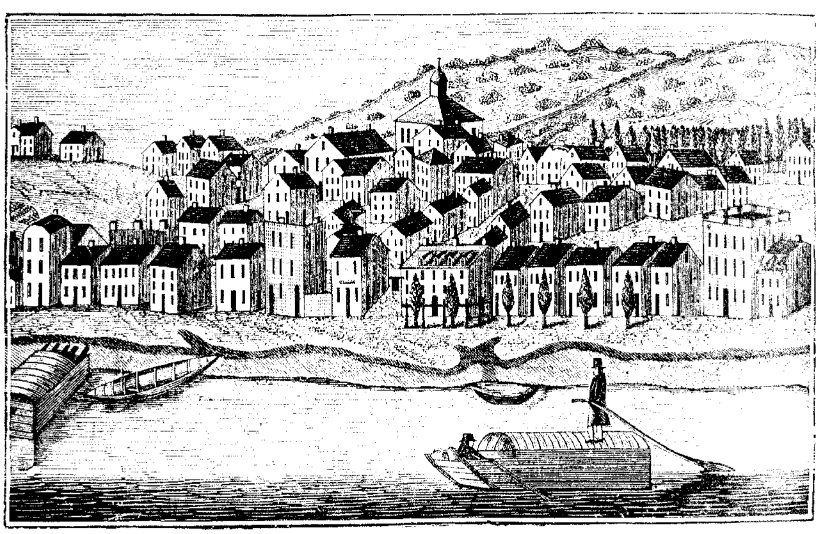
Although Ohio is certainly on the fringe of the New Madrid seismic zone, it is obvious from contemporary accounts that damage occurred in southwestern Ohio, particularly in Cincinnati. A recurrence of the 1811-1812 sequence would have direct and significant influence on the state. Dr. Ronald Street of the University of Kentucky undertook an extensive investigation in 1984 of all existing accounts of the New Madrid sequence. He compiled a remarkably detailed list of newspaper articles and other forms of documentation for an unpublished U.S. Geological Survey report; this information was the basis for interpretations made in a 1990 publication by Street and Nuttli (see Further reading). More recently, Dr. Carl Albrecht of the Ohio Historical Society has begun searching for additional New Madrid accounts from Ohio.

THE OHIO RECORD

The Ohio record of the New Madrid earthquakes consists of a series of newspaper accounts from a few cities in the state and the astute observations of Daniel Drake of Cincinnati. Drake published his observations in 1815 in his book, *Natural and statistical view, or a picture of Cincinnati*. These observations, sparse as they are, constitute the primary basis for evaluating the potential risk to Ohio's populace should there be a repeat of the 1811-1812 events.

Of the initial New Madrid event of December 16, 1811, Drake wrote:

At 24 minutes past 2 o'clock A.M. mean time, the first shock occurred. The motion was a quick oscillation or rocking, by most persons believed to be west and east; by some south and north. Its continuance, taking the average of all the observations I could collect, was six or seven minutes. Several persons assert that it was preceded by a rumbling or rushing noise; but this is denied by others, who were awake at the commencement. It was so violent as to agitate the loose furniture of our rooms; open partition doors that were fastened with falling latches, and throw off the tops of a few chimnies in the vicinity of the town. It seems to have been stronger in the valley of the Ohio, than in the adjoining uplands. Many families living on the elevated ridges of Kentucky, not more than 20 miles from the river, slept during the shock; which cannot be said, perhaps of any family in town.



View of Cincinnati in 1810 from the Kentucky side of the Ohio River (from Howe, Henry, 1907, Historical collections of Ohio, State of Ohio, v. 1, p. 768). The official census for that year listed the population at 2,540. It is apparent in this view that most of the city was built on thick outwash and alluvium along the river—sediments that are prone to amplification of ground motion during strong earthquakes.

Drake's observations make two important points. First, architectural damage such as chimney tops being shaken off suggest Modified Mercalli intensities of VII. Secondly, the observation that the shock awakened everyone in Cincinnati, a town built on unconsolidated sediment along the Ohio River, but not those families whose homes were built on bedrock ridges, points out the phenomenon of amplified ground motion by thick, unconsolidated sediment. Such observations are important in assigning risk categories to geologic units.

Of the large shock on January 23, 1812, Drake wrote:

About 9 o'clock A.M. a great number of strong undulations occurred in quick succession. They continued 4 or 5 minutes, having two or three distinct exacerbations during that time. An instrument constructed on the principle of that used in Naples, at the time of the memorable Calabrian earthquakes, marked the direction of the undulations from south-south-east to north-north-west. This earthquake was nearly equal to that which commenced the series on the 16th ultimo.

The January 23 event shook Chillicothe as well. The Chillicothe *Supporter* reported "On Thursday morning last, about nine o'clock, another considerable shock of an Earthquake was felt at this place. Its continuance was near two minutes, and appeared to come from the southwest."

Perhaps surprisingly, Coshocton, in east-central Ohio, experienced intensities from the January 23 event that were in the VII range. A correspondent to *Kline's Weekly Carlisle* (PA) *Gazette* (14 February, 1812) wrote:

Coshockton, Jan. 23rd, 1812. Mr. Editor. This morning, at seventeen minutes past eight o'clock a severe shake of an earthquake was felt at this place. It lasted nearly a minute: it shook so as to nearly half empty a bucket, standing on the floor, full of water; and the river being frozen over, it caused the ice to crack considerably. A stone chimney in the house of Col. Williams in this place, seven by five feet square, solid and well built, was so severely shaken so as to cause it to crack in several places; and one or more brick chimneys in this place have been considerably injured by the shock. I have been informed that several houses in the neighborhood of this place were so shook that much of the chinkin dropt out; and the commotion of the trees and bushes was so great as to cause persons in the woods to observe the phenomenon.

Clocks in the early 1800's were not synchronized, and many kept poor time. However, it is interesting that the observation from Coshocton was 43 minutes earlier than other observations that placed the January 23 earthquake at 9:00 a.m. There is the possibility that this was another earthquake, perhaps centered in Ohio, that coincidentally occurred on January 23; however, it is more likely that the earlier time attributed to this event was a mistake.

After several days of small shocks being felt in Ohio, on February 7, 1812, the largest of the New Madrid events occurred in the early morning hours. Drake observed in Cincinnati:

At 45 minutes past 3 o'clock A.M. several alarming shocks in rapid succession. The instrument already mentioned indicted the three principal heaves to be from the south-west, the south-south-west and south-south-east. The last greatly surpassed any other undulation ever known at this place. It threw *down the tops of more chimnies, made wider fissures in the brick walls, and produced vertigo and nausea in a greater number of people, than the earthquakes of either the 16th of December or the 23rd of January. It was said by some, that this earthquake was preceded by a light and a noise; but this was denied by others, who were awake, and collected in mind and senses.*

The *Liberty Hall* newspaper in Cincinnati (12 February, 1812) gave the following account:

. . . on the morning of the 7th, at 32 minutes past 3 o'clock, apparent time, a strong vibration occurred and was followed without intermission by two others; the whole occupying, according to the best observations that were made, about six minutes. They raised those sides of houses which face S.S.E. and W.S.W. One of them threw a plum, hung by a line 7 feet long, three inches to the N.W. from the point over which it ordinarily rested. This was not only the strongest vibration that occurred at that time, but by far the most powerful that has been experienced here. It however, did less damage than was expected, by those who witnessed it. It threw down part of the top of one chimney in town, and of two in the vicinity of the town. It also widened the cracks that previously existed in some brick houses; and is said to have injured the Court-house. As that building, however, was already cracked, over several of the arches, from the bad execution of the masonry it is altogether uncertain to what extent it was injured by this shock. These strong vibrations, are said by some, to have been preceded by a light and noise, but others who were awake and collected in mind and senses, observed neither.

Another detailed account of the February 7 earthquake was printed in the Chillicothe *Supporter*:

Yesterday morning, about half past 3 o'clock the inhabitants of this place were very much alarmed by another tremendous shock of an Earthquake. About a minute before the shock commenced a loud subterraneous noise was heard resembling that made by a heavy loaded wagon running over frozen ground. The concussion began moderately, but soon became extremely violent, continuing with sudden jerks. The houses continued to shake about 25 minutes, sometimes with such extreme violence that many were apprehensive of their falling down. One chimney was thrown down and several bricks shook off of others; and several houses in town, were considerably cracked. The morning was perfectly calm; and had truly an awful appearance: the moon shone dimly, being surrounded by a circle, and cast a shade as if apparently eclipsed, which, together with the noise made by the trees in the woods, created in the minds of some, sensations totally indescribable.

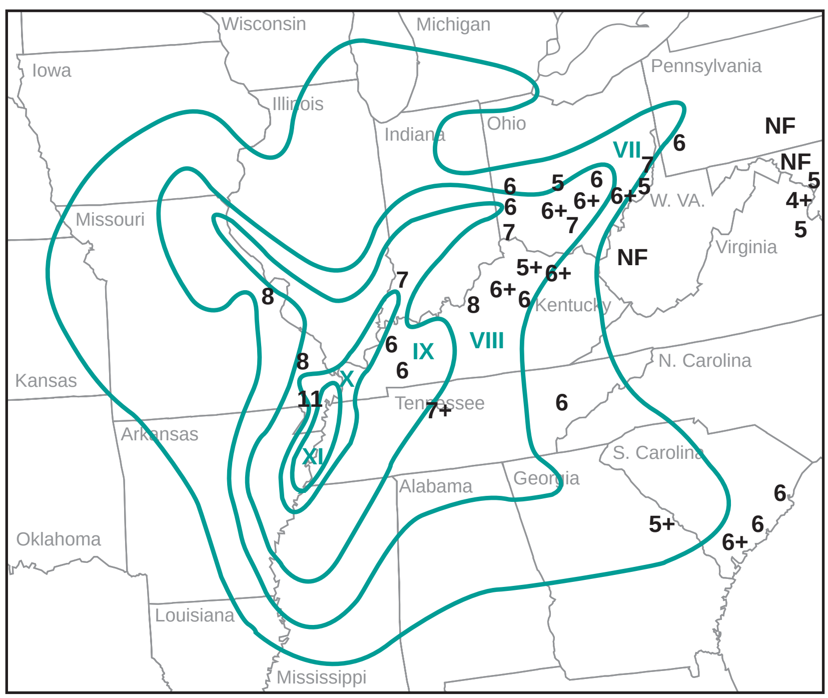
Similar effects, including damaged chimneys, were reported at Circleville. Dr. Street has assigned an intensity of VII to these communities for this shock.

Collectively, there are only about a dozen Ohio communities that published one or more accounts of the New Madrid earthquakes. All of these communities are in the southern half of the state and most of the accounts are brief. These communities were small and construction practices and materials differed greatly from those employed today. It is therefore difficult to assess the potential damage to Ohio communities if the 1811-1812 earthquakes were to be repeated. There can be little doubt that cities such as Cincinnati would suffer damage, especially in older, unreinforced masonry buildings, and especially in those structures built on thick, unconsolidated sediments that could amplify ground motion. For most Ohio communities, however, there is no historical basis for evaluation of the potential ground motion and damage from a New Madrid-type event. The widely published isoseismal maps for the New Madrid events are broad generalizations of potential Modified Mercalli intensities that might occur in a particular area. However, as Drake noted for the December 16, 1811, event, intensities in the Cincinnati area varied widely; significant damage occurred in structures built on terraces along the Ohio River, but residents living on bedrock hills were not even awakened by the shock. This information tells us that ground motion from an earthquake can differ considerably within a small geographic area, depending on the amplification characteristics of the underlying geologic materials.

WHAT NEXT?

In the foreseeable future it is improbable that we will be able to predict the magnitude or the timing of the next large New Madrid earthquake. Available data suggest that the probability of a magnitude-8 event in the next 50 years ranges from about 2.7 percent to 11 percent, depending on which model is used. Probability of a 6.0 to 6.5 event in the next 50 years is between 45 and 97 percent. The best we can do is to prepare for the next Great New Madrid Earthquake, whenever it may occur.

For a realistic assessment of the potential damage from a significant earthquake, it is necessary to map the extent of individual geologic units and to assign them to particular risk categories based upon their potential for amplification of ground motion and their potential for liquefaction. The Ohio Geological Survey, the Indiana Geological Survey, and the Kentucky Geological Survey are nearing completion of a joint project to produce a map of the Cincinnati area at a scale of 1:250,000 that depicts the susceptibility of surface materials to amplification and liquefaction during a significant earthquake. These surface materials consist of unconsolidated sediments of glacial origin and bedrock. The map does not predict when, how big, or where an earthquake will occur, but does suggest how surface materials will react if a significant event would occur. This map is being prepared for, and is funded by, the Federal Emergency Management Agency (FEMA) through the Central United States Earthquake Consortium (CUSEC). An expanded



Composite map showing Modified Mercalli intensities (arabic numerals) calculated from historical accounts of the February 7, 1812, New Madrid earthquake (from Street and Nuttli, 1990) and isoseismal lines showing composite intensity that would hypothetically result from a magnitude 8.6 earthquake throughout the length of the New Madrid seismic zone (from Hopper, M. G., 1985, U.S. Geological Survey Open-File Report 85-457). NF = *not felt.*

version of the map will be available in the near future for public distribution from the participating state geological surveys. Similar maps are being prepared through CUSEC for other 1:250,000-scale quadrangles in the New Madrid seismic zone. Such maps will be important to planners, government officials, emergency-response agencies, insurance underwriters, the building industry, and a host of other groups because they will be able to target specific areas that have the highest susceptibility to earthquake damage, in contrast to previous assumptions that broad regions will experience the same level of ground motion at all locations.

Major earthquakes in Ohio and adjacent areas are low-probability events, but the consequences could be extraordinarily high when such an event does occur. The destruction and chaos that would result from a repeat of the 1811-1812 New Madrid earthquakes probably cannot be fully comprehended, even by those who have studied these events and are planning for their recurrence. Society is slowly beginning to realize that we must be prepared for them.

ACKNOWLEDGMENTS

We thank Dr. Ronald L. Street of the University of Kentucky and Dr. Carl Albrecht of the Ohio Historical Society for information used in this article.

FURTHER READING

Atkinson, William, 1989, The next New Madrid earthquake: a survival guide for the Midwest: Carbondale, Southern Illinois University Press, 210 p.

Drake, Daniel, 1815, Natural and statistical view, a picture of Cincinnati and the Miami County, illustrated by maps, with an appendix, containing observations on the late earthquakes, the aurora borealis, and the south-west wind: Cincinnati, Looker and Wallace, 251 p.

Fuller, M. L., 1912, The New Madrid earthquake: U.S. Geological Survey Bulletin 494, 119 p.

Hamilton, R. M., and Johnston, A. C., eds., 1990, Tecumseh's prophecy: preparing for the next New Madrid earthquake: U.S. Geological Survey Circular 1066, 30 p.

Johnston, A. C., and Schweig, E. S., 1996, The enigma of the New Madrid earthquakes of 1811-1812: Annual Review of Earth and Planetary Sciences, v. 24, p. 339-384.

Penick, J. L., Jr., 1981, The New Madrid earthquakes: Columbia, University of Missouri Press, 176 p.

Platt, C. V., 1993, Nightmare on the Mississippi: the New Madrid earthquakes: Timeline, September-October, p. 18-31.

Street, R. L., and Nuttli, O. W., 1990, The great central Mississippi Valley earthquakes of 1811-1812: Kentucky Geological Survey Special Publication 14, Series XI, 15 p.

Digital data on the Web

As part of the Survey's continuing effort to provide data to the public in the most useful format at the lowest cost, the Division has recently placed many digital files on our Web site, where they can be downloaded at no cost. The files are available via the Survey's File Transfer Protocol (FTP) site, which is easily accessible from the Internet. Connect directly to the FTP site from a web browser at <ftp://ftp.dnr.state.oh.us/geological_survey> or link to the FTP site from the Survey's home page at <http://www.dnr.state.oh.us/odnr/geo_survey/>. New digital files are periodically posted to this site. These digital files also may be obtained on CD-ROM from the Survey at $25.00 per disk (plus tax and handling). Questions concerning the data files should be addressed to Joe Wells at 614-265-1030; questions concerning graphics files should be directed to Jim McDonald at 614-265-6601.

AVAILABLE DIGITAL DATA FILES

Be sure to read the **README** or **txt.file** associated with each product for complete information concerning the files.

BASEMAP—Digital graphics files for each county in Autocad (.DWG) format. Files contain recenty digitized land-subdivision boundaries from the Division of Geological Survey, as well as roads, streams, and other features digitized by the Ohio Department of Transportation (ODOT).

BEDROCK—ARC/INFO coverage of new bedrock-geology and bedrock-topography maps. Coverage is available for the areas of the following 30 x 60 minute (1:100,000) U.S. Geological Survey quadrangles: Lancaster, Lorain, Mansfield, Newark, and Wellston.

CORPSCON—National Geodetic Survey coordinate conversion program (converts State Plane x, y coordinates to latitude/longitude).

DDF 1-4—Division of Geological Survey Digital Data Files (DDF).

DDF1—749 wells in NW Ohio—includes tops and basic header data.

DDF2—Complete header information for 2,843 wells in the eastern two-thirds of the state that reach the Knox or deeper units (868 wells have formation tops).

DDF3—Miscellaneous support files/lookup files that assist in creating database systems. Files include all common names and codes used in Division databases, including counties, townships, and quadrangles; formations; oil and gas fields; and oil-and gas-well status codes.

DDF4—Selected oil- and gas-well production records for 11,955 wells drilled between 1972 and 1986.

DEV_SHALE—Data gathered during the 1985-1987 Gas Research Institute (GRI) study of Devonian shales in southeastern Ohio. Contains 4,460 well-header records, 3,817 wells with formation tops, and 898 wells with production records.

GAS ATLAS—Summary information on nearly 5,000 gas fields in the Appalachian Basin.

GEOPHYSICAL LOGS—Log ASCII Standard (LAS) files of geophysical-log suites from 26 wells in Ohio, Indiana, Kentucky, and West Virginia. More will be added soon.

MAGNETIC DATA— Data from the U.S. Geological Survey used to create magnetic contour maps of Ohio. The data set is suitable for use in computer-contouring programs.

WELL_DB—County-by-county data files containing all oil- and gas-well locations digitized from Division of Geological Survey and Division of Oil and Gas township well-spot maps. This database is currently being revised to create consistent well identifiers which will comply with standards of the American Petroleum Institute (API).

Sherry Weisgarber is new Ohio Aggregates Association Director

Sherry L. Weisgarber

Sherry L. Weisgarber, Survey geologist and mineral statistician, left the Division after 14 years of service to become Managing Director of the Ohio Aggregates Association (OAA). In her new position, Sherry will be the lead person in lobbying and legislative activities for the Ohio aggregates industry. She also will serve as a spokesperson for the industry and be involved with educational programs highlighting the mining industry. The Survey has long worked with the OAA on many issues involving Ohio's limestone and sand and gravel industries.

Sherry began her career with the Survey in 1984 and in 1986 assumed the duties of compiler of the annual *Report on Ohio mineral industries*. She built this report into a vital document that is greatly admired and emulated. In addition to this responsibility, Sherry was very active in the Survey's educational programs, including the annual Ohio Mineral Industries Teachers Workshops. Fortunately, she plans to continue her participation in the workshops.

Sherry was also the compiler of the Hands On Earth Science series for *Ohio Geology*. This popular feature will continue. If any of our readers have activities to submit, please contact Merrianne Hackathorn, telephone: 614-265-6590, e mail: <merrianne.hackathorn@dnr.state.oh.us>.

Sherry's expertise, enthusiasm, and energy will not be easily replaced at the Survey. We wish her well in her new position and look forward to working with her in the future. She can be contacted at: The Ohio Aggregates Association, 20 S. Front Street, Columbus, OH 43215; telephone: 614-224-2717; email: <sherryw@netexp.net>.

Report on Cambrian oil and gas possibilities

The Ohio Geological Survey, as part of a joint project with the Kentucky Geological Survey, has issued Information Circular 60, *Cambrian pre-Knox Group play in the Appalachian Basin*. This 26-page report was authored by David C. Harris of the Kentucky Survey and Mark T. Baranoski of the Ohio Survey.

Harris and Baranoski discuss the potential for exploration in deeply buried rocks of Cambrian age below the Knox Group. They suggest that, although production from these reservoirs has been limited and is largely untested, the large number of gas shows in the Appalachian Basin indicate future exploration potential. The area of highest potential is that portion of the basin stretching from northeast Kentucky and adjacent parts of western West Virginia northward across eastern Ohio, northwest Pennsylvania, and western New York. They suggest that this area may hold as much as 460 billion cubic feet of recoverable gas resources.

Anyone interested in oil and gas exploration in the Appalachian Basin will find this report to be of value. Information Circular 60 is available for $4.00 plus $2.00 handling and $0.23 tax if shipped to an Ohio address. (This report also was published by the Kentucky Geological Survey as KGS Information Circular 58, Series XI, and is available from that agency as well.)

Pennsylvanian cephalopods of Ohio

The Survey has released Bulletin 71, *Pennsylvanian cephalopods of Ohio*, a comprehensive 260-page report on these fossils from marine limestones and shales of the coal-bearing rocks of eastern Ohio. Cephalopods are mollusks represented in modern South Pacific seas by the chambered nautilus. These invertebrate animals were much more abundant and diverse in the ancient Paleozoic seas that once covered Ohio. Fossil forms had either coiled or straight shells.

Bulletin 71 is the latest in a series on Pennsylvanian-age fossils from Ohio that have been published by the Survey. Others in the series are on brachiopods (Bulletin 63), bivalves (Bulletin 67), and trilobites (RI 142). These reports were initiated by Dr. Myron T. Sturgeon of Ohio University and Dr. Richard D. Hoare of Bowling Green State University and are based on the 50-year collection of Pennsylvanian fossils from eastern Ohio gathered by Sturgeon and his students. This massive collection is now reposited at the Orton Geological Museum at The Ohio State University.

The cephalopod volume was authored by Sturgeon, Hoare, Royal H. Mapes of Ohio University, and Delbert L. Windle of Midland, Texas, a former student of Sturgeon's at Ohio University. The report is divided into two parts: part 1, with Sturgeon as principal author, is on nautiloid cephalopods; and part 2, with Mapes as principal author, is on ammonoid cephalopods.

The book has 47 photographic plates of nautiloid cephalopods and seven plates of ammonoids, plus 32 figures and 34 tables. The morphology of each species known from Ohio is described in detail. The report includes a summary of the Pennsylvanian rock units that have yielded cephalopod fossils, an extensive bibliography, and a list of collecting localities from which Pennsylvanian cephalopods have been found in the state.

Most of the collecting localities listed in the book have yielded a diverse assemblage of marine invertebrates and some fishes. Although many of the localities may no longer be accessible, some of them have produced excellent fossils for decades. Most of these localities are on private property and permission of the landowner must be obtained. Fossil cephalopods are not common but are among the specimens most highly prized by collectors.

Bulletin 71 is available from the Survey for $12.00 plus $3.00 mailing and $0.69 sales tax if mailed to an Ohio address. Please order from the Ohio Division of Geological Survey, 4383 Fountain Square Drive, Columbus, OH 43224-1362. Credit-card orders may be placed by calling 614-265-6576.

HANDS-ON EARTH SCIENCE

by Richard G. Hansgen
Bluffton College

JUST HOW BIG IS THE SUN?

In *Life on the Mississippi*, Mark Twain remarks, "There is something fascinating about science. One gets such wholesale returns of conjecture out of such a trifling investment of facts." Such an example would be the old schoolboy method of measuring the diameter of the Sun. In that method, a pinhole is pricked in a card at one end of a closed cardboard box, and the image of the Sun is projected onto a small screen at the opposite end of the box (see diagram A). This same principle is involved in making a pinhole camera. By measuring, using a centimeter ruler, the diameter of the Sun's image and the distance from the pinhole to the screen (the length of the box), and by knowing the distance from the Earth to the Sun, you can calculate the actual diameter of the Sun.

This experiment describes an improved variation on that theme. We substitute a masked mirror for the pinhole and a darkened room for the box. The advantage of this technique is that the Sun's image is cast over a greater distance, thus enlarging the image. Also, because the experiment is done in a darkened room, the image appears brighter and an entire class can sit in comfort and participate in the measurements.

Procure a small, flat mirror and cover the front with masking tape, leaving a small opening about 0.5 cm x 0.5 cm near the center of the mirror. Using a piece of modeling clay, prop the edge of the mirror on the windowsill of a Sun-facing window. Close all the blinds except for the one where the mirror is, and adjust that one so that a minimum of light enters the room and strikes the mirror. Orient the mirror so that the image of the Sun is projected across the room to the opposite wall. A large piece of white paper can be taped to that wall to serve as a screen.

The image of the Sun is inverted because the two rays from the Sun (and any other rays you might wish to draw) crisscross as they pass through the pinhole or reflect from the small aperture in the mirror (see diagrams). The geometry is the same whether one uses a pinhole or a mirror. The mirror simply folds back the image and projects it onto the wall.

The geometry of similar triangles informs us that the diameter of the Sun is to the distance from the Earth to the Sun as the diameter of the image is to the distance from the mirror to the wall.

$$\frac{\text{diameter of Sun}}{\text{distance to Sun}} = \frac{\text{diameter of image}}{\text{distance from mirror to image}}$$

or,

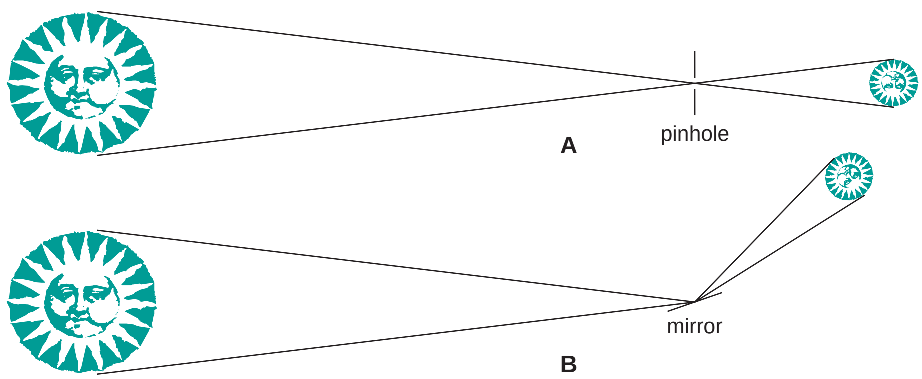
$$\text{diameter of Sun} = \frac{\text{diameter of image x distance to Sun}}{\text{distance from mirror to image}}$$

You can easily measure the diameter of the image and the distance from the mirror to the image. Knowing that the distance from the Earth to the Sun is 1.5×10^8 km, you can calculate our unknown, the diameter of the Sun. If your measurements are in centimeters, remember to convert them into kilometers.

This method of viewing the Sun also provides an excellent way of observing the next solar eclipse. Students can sit at their seats, eat popcorn, and watch the entire progress of the eclipse. Teachers should take advantage of this perfectly safe technique and allow their students to see these spectacular displays of nature. As you use this method, see if you can observe sunspots. If you can, they can be used to measure the rotational rate of the Sun, which is exactly what Galileo did 400 years ago.

One last question. The diameter of the Earth is 12,800 km. What is the diameter of the Sun in units of Earth diameters? That is, how many Earths could be placed side by side across the face of the Sun? [Answer: about 100, a remarkable number that will impress your students and one that is easy to remember.]

Mark Twain was right. So many returns for such little investment!



*Diagrams showing image formation by a pinhole (**A**) and a masked mirror (**B**). Diagrams not to scale.*

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