The New Madrid Earthquakes of 1811 - 1812

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http://web.ics.purdue/~braile
http://web.ics.purdue.edu/~braile/new/NewMadridEQs.ppt
http://web.ics.purdue.edu/~braile/new/NewMadridEQs.pdf

Links to Earthquake Education Information:

- Earth Science Education Activities
- Earth Science Education Links
- AS-1 Seismograph Information
- Seismic/Eruption Teaching Modules
- EAS 100 • EAS 309
- EAS 509 • EAS 553
- Research Papers

http://web.ics.purdue.edu/~braile/new/NewMadridEQs.pdf

Quick Links: | braile@purdue.edu | Purdue Univ. | Purdue EAS | IRIS | Seismic Monitor | Earthquake – USGS |
| USGS tsunami calculator | USGS LSS | AS-1 MagCalc | Alan Jones’ Site | SAGE | IRIS Seismographs in Schools |
| WLIN AS-1 Seismograph near real time display | IRIS Educational Seismograph Records | What’s New |
| USGS Earthquake Search | USGS M7+ EQ List | USGS M2.5+ List | IRIS Event Search | Miscellaneous Links |
Outline

The 1811-1812 New Madrid earthquakes
Earthquake statistics
  Foreshocks, main shocks, aftershocks
  Frequency-Magnitude relationship
  Forecasting earthquakes
Central United States earthquake history
  The 4/18/2008 M5.2 SE IL earthquake & aftershocks
  Seismic-Eruption software
Causes of Central United States Earthquakes
Efficient wave propagation in eastern North America
  Felt area and damage
  Comparison of CUS and CA seismograms
References/Resources

The 1811-1812 New Madrid Earthquakes

The “New Madrid Earthquakes”

Series of 3 major earthquakes (~M7-7.5, most recent study suggests M~7.0 for all)

December 16, 1811
  (and “Dawn Aftershock” Dec. 16, 1811)
January 23, 1812
February 7, 1812

"The Great Earthquake of New Madrid 1811–1812." Published with permission of the State Historical Society of Missouri, Columbia, Mo.
The first earthquake of December 16, 1811 caused only slight damage to man-made structures, mainly because of the sparse population in the epicentral area. The extent of the area that experienced damaging earthmotion, which produced Modified Mercalli Intensity greater than or equal to VII, is estimated to be 600,000 square kilometers. However, shaking strong enough to alarm the general population (intensity greater than or equal to V) occurred over an area of 2.5 million square kilometers.

A notable area of subsidence that formed during the February 7, 1812, earthquake is Reelfoot Lake in Tennessee, just east of Tiptonville dome on the downdropped side of the Reelfoot scarp. Subsidence there ranged from 1.5 to 6 meters, although larger amounts were reported.

Large waves (seiches) were generated on the Mississippi River by seismically-induced ground motions deforming the riverbed. Local uplifts of the ground and water waves moving upstream gave the illusion that the river was flowing upstream. Ponds of water also were agitated noticeably.


1811, December 16, 08:15 UTC Northeast Arkansas - the first main shock
2:15 am local time
Magnitude ~7.7 (Revised to ~7.0, Hough and Page, 2011)

This powerful earthquake was felt widely over the entire eastern United States. People were awakened by the shaking in New York City, Washington, D.C., and Charleston, South Carolina. Perceptible ground shaking was in the range of one to three minutes depending upon the observers location. The ground motions were described as most alarming and frightening in places like Nashville, Tennesse, and Louisville, Kentucky. Reports also describe houses and other structures being severely shaken with many chimneys knocked down. In the epicentral area the ground surface was described as in great convulsion with sand and water ejected tens of feet into the air (liquefaction).

1811, December 16, 13:15 UTC Northeast Arkansas - the "Dawn" Aftershock
7:15 am local time
Magnitude ~7.0 (Revised to ~7.0, Hough and Page, 2011)

A large event felt on the East Coast that is sometimes regarded as the fourth principal earthquake of the 1811-1812 sequence. The event is described as "severe" at New Bourbon, Missouri, and was described by boatman John Bradbury, who was moored to a small island south of New Madrid, as "terrible, but not equal to the first". Hough believes that this large aftershock occurred around dawn in the New Madrid region near the surface projection of the Reelfoot fault.


1812, January 23, 15:15 UTC, New Madrid, Missouri
9:15 am local time (7:15 am LT, Hough, 2009)
Magnitude ~7.5 (Revised to ~7.0, Hough and Page, 2011)

The second principal shock of the 1811-1812 sequence. It is difficult to assign intensities to the principal shocks that occurred after 1811 because many of the published accounts describe the cumulative effects of all the earthquakes and because the Ohio River was iced over, so there was little river traffic and fewer human observers. Using the December 16 earthquake as a standard, however, there is a general consensus that this earthquake was the smallest of the three principals. The meizoseismal area was characterized by general ground warping, ejections, fissuring, severe landslides, and caving of stream banks.

1812, February 7, 09:45 UTC, New Madrid, Missouri
3:45 am local time (3:00 am LT, Hough, 2009)
Magnitude ~7.7 (Revised to ~7.0, Hough and Page, 2011)

The third principal earthquake of the 1811-1812 series. Several destructive shocks occurred on February 7, the last of which equaled or surpassed the magnitude of any previous event. The town of New Madrid was destroyed. At St. Louis, many houses were damaged severely and their chimneys were thrown down. The meizoseismal area was characterized by general ground warping, ejections, fissuring, severe landslides, and caving of stream banks.


New Madrid, Territory of Missouri, March 22, 1816

On the 16th of December, 1811, about two o'clock, A.M., we were visited by a violent shock of an earthquake, accompanied by a very awful noise resembling loud but distant thunder, but more hoarse and vibrating, which was followed in a few minutes by the complete saturation of the atmosphere, with sulphurous vapor, causing total darkness. The screams of the affrighted inhabitants running to and fro, not knowing where to go, or what to do - the cries of the fowls and beasts of every species - the cracking of trees falling, and the roaring of the Mississippi - the current of which was retrograde for a few minutes, owing as is supposed, to an irruption in its bed -- formed a scene truly horrible.
At first the Mississippi seemed to recede from its banks, and its waters gathering up like a mountain, leaving for the moment many boats, which were here on their way to New Orleans, on bare sand, in which time the poor sailors made their escape from them. It then rising fifteen to twenty feet perpendicularly, and expanding, as it were, at the same moment, the banks were overflowed with the retrograde current, rapid as a torrent - the boats which before had been left on the sand were now torn from their moorings, and suddenly driven up a little creek, at the mouth of which they laid, to the distance in some instances, of nearly a quarter of a mile. The river falling immediately, as rapid as it had risen, receded in its banks again with such violence, that it took with it whole groves of young cotton-wood trees, which ledged its borders. They were broken off which such regularity, in some instances, that persons who had not witnessed the fact, would be difficultly persuaded, that is has not been the work of art. A great many fish were left on the banks, being unable to keep pace with the water. The river was literally covered with the wrecks of boats, and 'tis said that one was wrecked in which there was a lady and six children, all of whom were lost.

In all the hard shocks mentioned, the earth was horribly torn to pieces - the surface of hundreds of acres, was, from time to time, covered over, in various depths, by the sand which issued from the fissures, which were made in great numbers all over this country, some of which closed up immediately after they had vomited forth their sand and water, which it must be remarked, was the matter generally thrown up. In some places, however, there was a substance somewhat resembling coal, or impure stone coal, thrown up with the sand. It is impossible to say what the depths of the fissures or irregular breaks were; we have reason to believe that some of them are very deep. The site of this town was evidently settled down at least fifteen feet, and not more than a half a mile below the town there does not appear to be any alteration on the bank of the river, but back from the river a small distance, the numerous large ponds or lakes, as they are called, which covered a great part of the country were nearly dried up. The beds of some of them are elevated above their former banks several feet, producing an alteration of ten, fifteen to twenty feet, from their original state. (End of Excerpts)
New Madrid 1811-1812 Earthquakes (Magnitudes revised, Hough, USGS web page)


Sand Blows (white spots; sand "volcanoes"; liquefaction effects) in the bootheel area of SE Missouri from the 1811-1812 New Madrid earthquakes.

Figure 10 — Aerial photograph of Bootheel linearism (arrows) and dense sand blows (white patches over entire photograph), show the difference in the shapes and extent of sand blows on opposite sides of the linearism. Also shown are County Highway C, Perrysville County Road 42S, and Highway H.

Earthquake fissure filled with intruded sand, formed at the time of the New Madrid earthquake. Mississippi County, Arkansas, 1904.
Earthquake Statistics

<table>
<thead>
<tr>
<th>Year</th>
<th>Magnitude</th>
<th>Type</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>2002</td>
<td>M7.9</td>
<td>Foreshock, Mainshock, Aftershocks, M 2.5+</td>
<td>Nov. 3, 2002 M7.9 Denali foreshock, mainshock, aftershocks</td>
</tr>
</tbody>
</table>

Exploring Planet Earth
Denali aftershocks

M7.9 Denali Earthquake, Foreshock, Mainshock, Aftershocks Sequence

"Normal earthquake activity"

2002 Denali Foreshock/Mainshock/Aftershock Sequence, 10/1/02 - 3/23/03

Most of these events were not on the Denali fault

Number of Earthquakes

Maximum Magnitude

Days (beginning 10/1/02)
Earthquake Statistics

Magnitude of earthquake is controlled by fault length (or area) that ruptures

Magnitude versus fault length

Alaska, 1964
Sumatra, 2004
Denali, 2002
Landers, 1992
Loma Prieta, 1989
Northridge, 1994

Fault rupture area controls magnitude

Results were quickly obtained using Seismic/Eruption views.
**Worldwide earthquakes per year (from USGS):**

<table>
<thead>
<tr>
<th>Descriptor</th>
<th>Magnitude</th>
<th>Average Annually</th>
</tr>
</thead>
<tbody>
<tr>
<td>Great</td>
<td>8 and higher</td>
<td>1 (^1)</td>
</tr>
<tr>
<td>Major</td>
<td>7 - 7.9</td>
<td>17 (^2)</td>
</tr>
<tr>
<td>Strong</td>
<td>6 - 6.9</td>
<td>134 (^2)</td>
</tr>
<tr>
<td>Moderate</td>
<td>5 - 5.9</td>
<td>1319 (^2)</td>
</tr>
<tr>
<td>Light</td>
<td>4 - 4.9</td>
<td>13,000 (est.)</td>
</tr>
<tr>
<td>Minor</td>
<td>3 - 3.9</td>
<td>130,000 (est.)</td>
</tr>
<tr>
<td>Very Minor</td>
<td>2 - 2.9</td>
<td>1,300,000 (est.)</td>
</tr>
</tbody>
</table>

\(^1\) Based on observations since 1900.
\(^2\) Based on observations since 1990.

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**Worldwide earthquakes per year:**

![World Frequency-Magnitude Plot](image-url)
Worldwide earthquakes per year:

How many M6+ earthquakes each year?

~150
Putting the earthquake risk in the U.S. into perspective... (Data from Stein and Wysession)

### Causes of death in the U.S., 1996

<table>
<thead>
<tr>
<th>Cause of death</th>
<th>Number of deaths</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heart attack</td>
<td>733,834</td>
</tr>
<tr>
<td>Cancer</td>
<td>544,278</td>
</tr>
<tr>
<td>Motor vehicle accidents</td>
<td>43,300</td>
</tr>
<tr>
<td>Falling</td>
<td>14,100</td>
</tr>
<tr>
<td>Bicycle accidents</td>
<td>695</td>
</tr>
<tr>
<td>Severe weather</td>
<td>514</td>
</tr>
<tr>
<td>Football</td>
<td>18</td>
</tr>
<tr>
<td>Skateboards</td>
<td>10</td>
</tr>
<tr>
<td>Earthquakes (1811-1983), ave. per year</td>
<td>9</td>
</tr>
<tr>
<td>Earthquakes (1984-98), ave. per year</td>
<td>9</td>
</tr>
</tbody>
</table>

### Earthquake Forecasting

#### Frequency-Magnitude Comparisons

- Alaska
- N. California
- New Madrid
Earthquake Forecasting

Large New Madrid earthquakes do not occur very frequently

<table>
<thead>
<tr>
<th>Frequency-Magnitude Comparisons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Earthquakes per Year of M+</td>
</tr>
<tr>
<td>1000</td>
</tr>
<tr>
<td>100</td>
</tr>
<tr>
<td>10</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>1/10</td>
</tr>
<tr>
<td>1/100</td>
</tr>
<tr>
<td>1/1000</td>
</tr>
<tr>
<td>0.001</td>
</tr>
<tr>
<td>M7+ earthquakes</td>
</tr>
<tr>
<td>~1 per 1000 years</td>
</tr>
<tr>
<td>~1 per 100 years (last one was 1895)</td>
</tr>
<tr>
<td>~0.01/year or 1 per 100 years</td>
</tr>
<tr>
<td>~0.7/year or 7 per year</td>
</tr>
<tr>
<td>~0.7/year or 7 per year</td>
</tr>
</tbody>
</table>

Magnitude, M

Central United States Earthquake History

The "New Madrid Earthquakes"

Series of 3 major earthquakes (~M7-7.5, most recent study suggests M~7.0 for all)

December 16, 1811
(and "Dawn Aftershock" Dec. 16, 1811)
January 23, 1812
February 7, 1812

*The Great Earthquake of New Madrid 1811–1812.* Published with permission of the State Historical Society of Missouri, Columbia, Mo.
The April 18, 2008 M5.2 SE Illinois earthquake and aftershocks

April 18, 2008 M5.2 earthquake

Exploring Planet Earth
## April 18, 2008 M5.2 earthquake and aftershocks

### Earthquake Details

<table>
<thead>
<tr>
<th>Date</th>
<th>Time (GMT)</th>
<th>Depth (km)</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008/04/18</td>
<td>10:04:00</td>
<td>8.74</td>
<td>B 3.28 km SE of Gards Point, IL</td>
</tr>
<tr>
<td>2008/04/18</td>
<td>10:06:00</td>
<td>8.77</td>
<td>B 3.28 km SE of Gards Point, IL</td>
</tr>
<tr>
<td>2008/04/18</td>
<td>10:09:00</td>
<td>8.78</td>
<td>B 3.28 km SE of Gards Point, IL</td>
</tr>
<tr>
<td>2008/04/19</td>
<td>03:55:30</td>
<td>8.79</td>
<td>A 4.25 km W of Odgen, IL</td>
</tr>
</tbody>
</table>

### Aftershocks

April 18, 2008 M5.2 earthquake and aftershocks

### Map

- [Link to Map](http://news-info.wustl.edu/tips/page/normal/11630.html)

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**Note:** The map shows the locations of the earthquakes and aftershocks at April 18, 2008.
Reflection Seismic Profiling of the Wabash Valley Fault System in the Illinois Basin
U.S. Geological Survey
Professional Paper 1538-O
by R.M. René and F.L. Stanonis

http://igs.indiana.edu/geology/structure/seismicProfiling/index.cfm

Seismic reflection profiling studies of a buried Precambrian rift beneath the Wabash valley fault zone; by John L. Sexton, L.W. Braile, W.J. Hinze, and M.J. Campbell; 1986; in Geophysics, Volume 51, Number 3 (March 1986).
Interpretive profile over the Wabash Valley faults

M5.2 Eq (projected)

Seismic reflection profiling studies of a buried Precambrian rift beneath the Wabash valley fault zone; by John L. Sexton, L.W. Braile, W.J. Hinze, and M.J. Campbell; 1986; in Geophysics, Volume 51, Number 3 (March 1986).

Shaking of the ground - Seismogram playback

April 21, 2008 M4.0 SE Illinois aftershock
New Madrid 1811-1812 Earthquakes (Magnitudes revised, Hough, USGS web page)


Seismic/Eruption includes up-to-date earthquake and volcanic eruption catalogs and allows the user to display earthquake and volcanic eruption activity in “speeded up real time” on global, regional or local maps that also show the topography of the area in a shaded relief map image. Seismic/Eruption is an interactive program that includes a number of tools that allow the user to analyze earthquake and volcanic eruption data and produce effective displays to illustrate seismicity and volcano patterns.

http://bingweb.binghamton.edu/~ajones/
http://web.ics.purdue.edu/~braile/edumod/svintro/svintro.htm
Pattern of epicenters correlates with prominent positive gravity anomaly (caused by high density rocks in crust beneath sediments in the Mississippi Embayment). Gravity anomaly (smoothed) shown by colors and contours.

Gravity anomaly and pattern of epicenters has been interpreted as being caused by an ancient buried rift complex.
Observed gravity anomalies (indicating that higher density rocks are beneath the surface below the Mississippi Embayment) and interpretive cross section of ancient rift structure.


Figure 11. Block diagram illustrating the present configuration of the buried New Madrid Rift Complex. The structurally controlled rivers, Paleozoic rocks in cratonic sedimentary basins, and the Mississippi Embayment, all associated with the buried rift complex, are also shown. Dark areas indicate intrusions near the edge of the buried rift. An uplifted and possibly anomalously dense lower crust is suggested as the cause of the linear positive gravity anomaly associated with the upper Mississippi Embayment.
Cause(s?) of Central U.S. Earthquakes

1. The correlation of significant ancient geologic structures (mostly identified with geophysical data) with contemporary earthquake activity argues strongly for a causative relationship.

2. However, due to the lack of recent deformation, several other mechanisms have been suggested, including, post glacial rebound. One theory is that the current activity is actually just the result of aftershocks of the 1811-1812 events.

Geologic Hazards Fact Sheet
Earthquake Hazard in the Heart of the Homeland
U.S. Geological Survey FS-131-02


http://pubs.usgs.gov/fs/fs-131-02/fs-131-02.html
Efficient wave propagation in eastern North America

Intensity (areas of damage) for San Fernando 1971 (M~6.2) and Charleston, MO 1895 earthquakes (~M6.2-6.5). Maps plotted at same scale.
Intensity maps comparing intensity of shaking and expected damage for New Madrid and California earthquakes.

Figure 6. Comparison of areas of minor ($I = VI$-$VII$) and major ($I > VII$) damage for the 1906 San Francisco earthquake ($M_s = 8.3$) and the 1811 New Madrid earthquake ($m_b = 7.2$) and for the 1971 San Fernando earthquake ($m_b = 6.2$) and 1868 Charleston earthquake ($m_b = 7$). The damage area for the western half of the 1811 New Madrid earthquake (outlined by dashed lines) is inferred, because there were no settlements in the area at that time.

Intensity maps comparing intensity of shaking and expected damage for New Madrid and California earthquakes (http://geopubs.wr.usgs.gov/factsheet/fs017-03/)
Shake map (from S. Hough, USGS) intensity data for the Dec. 16, 1811 earthquake.

When large New Madrid earthquakes do occur, the effects will be significant and very widespread (due to low attenuation of seismic wave propagation in eastern N. America)

Shake map (from S. Hough, USGS) comparison for New Madrid and Landers earthquakes.
Efficient wave propagation in eastern North America - Comparison of seismograms (~600 km) from CUS and CA EQs

Note efficient high frequency wave propagation

M5.2 April 18, 2008 SE IL earthquake - unfiltered

M5.2 June 12, 2005 So. CA earthquake - unfiltered

M5.2 April 18, 2008 SE IL earthquake - Low pass filtered 1 Hz

Accelerograms from M6.7 1994 Northridge earthquake

The horizontal directions of ground shaking are often significantly larger than the vertical direction due to the motion of shear and surface waves. Also note duration of strong shaking.

Accelerograms ("acceleration seismograms") ~7.3 km from Northridge epicenter
Examples of Earthquake Damage

Soft first story failure

Loma Prieta earthquake, 1989, photo from USGS

Examples of Earthquake Damage

Dec. 26, 2003
M6.6 Earthquake, Bam, Iran, ~80% of buildings destroyed
Earthquake Shaking - Falling Objects

Shake table test of earthquake shaking (max. ~ 1 g acceleration) of two-story wood frame house, UCSD, July 2000. CUREE-Caltech Woodframe Project.

Background Information:
The video footage shows a two-story house being tested by a simulated earthquake on a shake table at the University of California at San Diego on July 11, 2000. The test matched-up very severe ground shaking with very strong construction. The goal was to verify that a new house that conforms to all building code regulations and in addition is specially engineered can escape with little damage from such an earthquake. The testing was part of the CUREE-Caltech Woodframe Project funded by the Federal Emergency Management Agency (FEMA) through a grant administered by the California Governors Office of Emergency Services. The earthquake shaking provided by the shake platform replayed the actual motion of the ground that occurred in an area where the shaking was most intense in the January 17, 1994 Northridge Earthquake (Los Angeles). The peak acceleration is about 1 g at the base, and the roof moved with an acceleration of over twice that. The precise record of the jolts, or accelerations, of the shaking in the Northridge Earthquake was obtained by a strong motion seismograph, and this computerized record was then played back on the shake table at UC San Diego the way a sound recording, when played on high-fidelity sound equipment, recreates very closely the original musical performance. Click for MORE INFO on the test.
http://www.abag.ca.gov/bayarea/eqmaps/fixit/videos.html
First floor – kitchen office – about 1 g peak acceleration.

Second floor – bedroom (upper level acceleration as great as 2 g).
Additional Resources:

File to print 11 x 17 size color maps:
http://web.ics.purdue.edu/~braile/edumod/CUSeqs/CUSeqsTwoMaps.doc
The U.S. Geological Survey shaking-hazard maps for the United States are based on current information about the rate at which earthquakes occur in Different areas and on how far strong shaking extends from earthquake sources. Colors on this particular map show the levels of horizontal shaking that have a 1-in-50 chance of being exceeded in a 50-year period. Shaking is expressed as a percentage of g (g is the acceleration of a falling object due to gravity).


References/Resources:

Midwest Earthquakes:
(includes many additional links and references)

Cataloging the 1811–1812 New Madrid, Central U.S., Earthquake Sequence:

Toward a consistent model for strain accrual and release for the New Madrid Seismic Zone, central United States:

The Magnitude of the Problem:
http://www.seismosoc.org/publications/SRL/SRL_82/srl_82-2_op.html

Wagon Loads of Sand Blows in White County, Illinois:

Analysing the 1811–1812 New Madrid earthquakes with recent instrumentally recorded aftershocks:
References/Resources: (continued)

Susan Hough (USGS) New Madrid website:
Putting Down Roots in Earthquake Country – Your Handbook for the Central United States:
Central U.S. Earthquake Guide:
New Madrid 1811-1812 Earthquakes (USGS):
Earthquake Hazard in the New Madrid Seismic Zone Remains a Concern:
The Enigma of the New Madrid Earthquakes of 1811-1812
http://www.ceri.memphis.edu/compendium/enigma.pdf

The New Madrid Earthquakes of 1811 - 1812

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http://web.ics.purdue.edu/~braile
http://web.ics.purdue.edu/~braile/new/NewMadridEQs.ppt
http://web.ics.purdue.edu/~braile/new/NewMadridEQs.pdf