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Assessing the Felt Reports of the 1811-12 New Madrid Earthquakes in the Central United States

Ron Street
University of Kentucky

John D. Kiefer
University of Kentucky, john.kiefer@uky.edu

Jerry L. Raisor
Fort Boonesborough State Park

Kentucky Geological Survey
James C. Cobb, State Geologist and Director
University of Kentucky, Lexington

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Ron Street, John D. Kiefer, and Jerry Raisor

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Ron Street[1], John D. Kiefer[2], and Jerry L. Raisor[3]

Abstract

The damage and felt reports describing the New Madrid, Mo., earthquakes of 1811-12 need to be assessed in the historical context in which the events occurred. Log cabins in the frontier settlements along the lower Ohio River Valley, for example, were built with a rudimentary form of base isolation, and their response to the earthquakes should not be evaluated in the same way that a modern wood-frame or brick building would be.

Also, inaccuracies have crept into the databases used for estimating the epicenters and magnitudes of the earthquakes. For example, the magnitude of the December 16, 1811, earthquake has been based, in part, on the lack of damage to buildings built well after the occurrence of the 1811-12 events, and the locations and circumstances of some of the people who described their observations of earthquakes and aftershocks in December 1811 while traveling down the Mississippi River on flatboats have been incorrectly used to estimate modified Mercalli intensities.

This study indicates that the damage areas for the 1811-12 earthquakes have been underestimated, and favors an epicenter for the January 23, 1812, earthquake in the northern end of the New Madrid Fault Zone, and that the three aftershocks that some have suggested were triggered events centered in northeastern Kentucky or south-central Ohio were in fact centered in the New Madrid Seismic Zone.

Introduction

The New Madrid earthquakes of 1811-12 are the largest historical or instrumental events known to have occurred in the central United States, and as such they have a profound impact on all aspects of the seismic hazard in the area. It is generally agreed that most, if not all, of the epicenters of the earthquakes in the sequence were centered in the seismically active area referred to as the New Madrid Seismic Zone, located in northeastern Arkansas, western Tennessee, and southeastern Missouri (Fig. 1). Of the four largest events (Table 1), the epicentral locations of the first two on the morning of December 16, 1811, and the final one on February 7, 1812, can be somewhat constrained by the damage that resulted to frontier settlements along the Mississippi River, and by changes in the elevation of landforms, such as subsidence, uplift, and the creation of temporary falls along the Mississippi River (Johnston and Schweig, 1996). The settlement at Little Prairie, Mo. (Fig. 1), for example, was damaged as a result of the earthquake on December 16 at 2:15 a.m., but it was the earthquake on December 16 at 8:15 a.m. that resulted in the destruction of the settlement and caused the settlers to abandon it (Anonymous A, 1812; Foster, 1812). The settlement at New Madrid was damaged by the earthquakes of December 16 and further damaged by the earthquake on January 23, 1812, but it was the earthquake on the morning of February 7 that resulted in the greatest damage (Anonymous B, 1812; Bryan, 1848).

Johnston and Schweig (1996) proposed the fault model for the New Madrid Seismic Zone shown in Figure 1. The model consists of seven segments, which they identified as the Blytheville Arch (BA), the Blytheville Fault Zone (BFZ), the Bootheel Lineament (BL), New Madrid West (NW), New Madrid North (NN), the Reelfoot Fault (RF), and Reelfoot South (RS). Johnston and Schweig's (1996) preferred sequence of events is that the earthquake at 2:15 a.m. on December 16 was strike-slip movement along the fault segments BA and BL of Figure 1, and that the earthquake at 8:15 a.m. on December 16 was the result of strike-slip movement along fault segment BFZ of Figure 1. In

[1]University of Kentucky Department of Earth and Environmental Sciences, retired, Hermosa, S.D.
[2]Kentucky Geological Survey, University of Kentucky, Lexington, Ky.
[3]Curator, Fort Boonesborough State Park, Richmond, Ky.

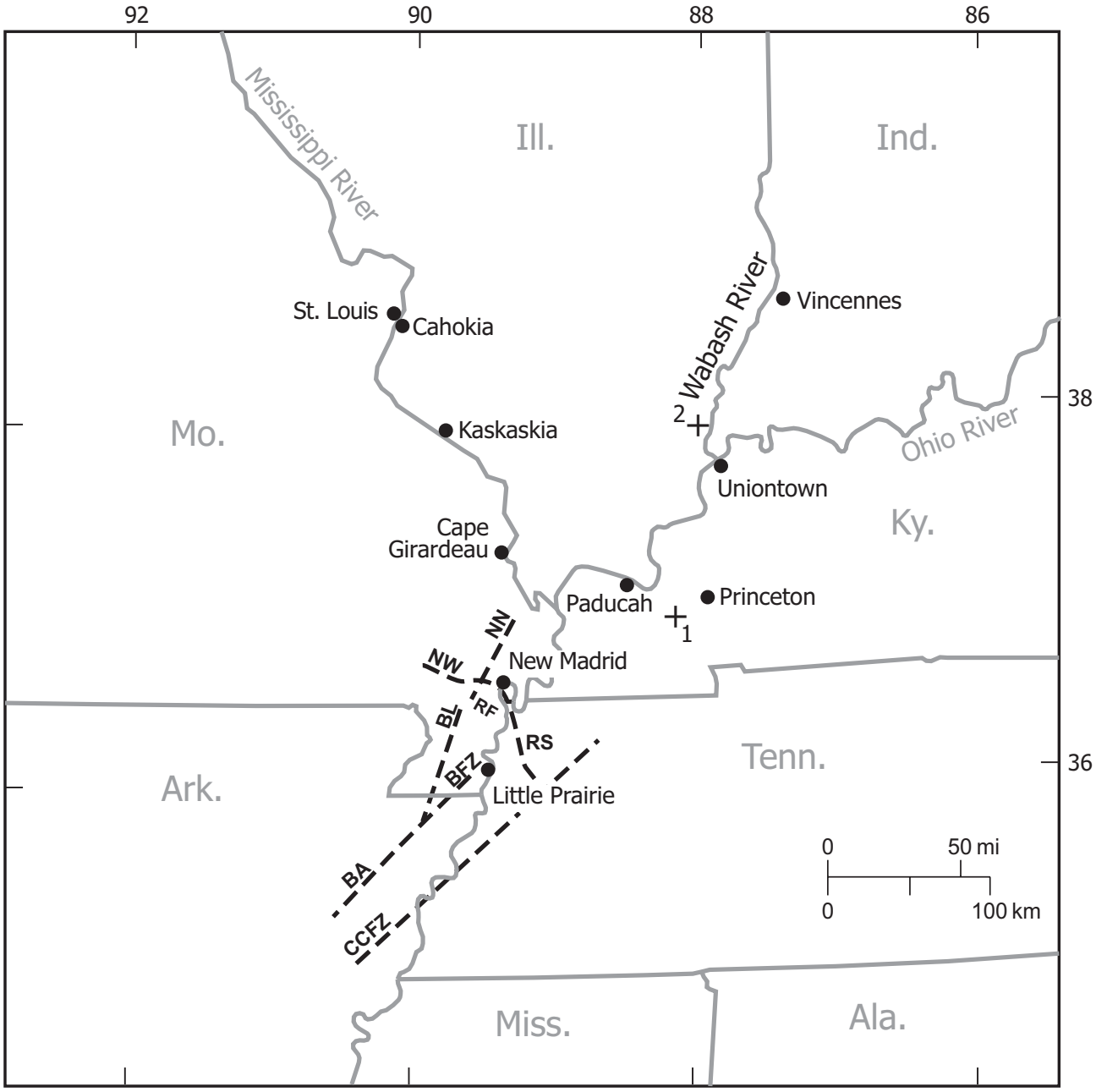

Figure 1. Segmentation of the New Madrid Fault Zone according to Johnston and Schweig (1996). BA=Blytheville Arch. BFZ=Blytheville Fault Zone. BL=Bootheel Lineament (which Guccione and others [2005] suggested should be renamed the Bootheel Fault). NW=New Madrid West. NN=New Madrid North. RF=Reelfoot Fault. RS=Reelfoot Scarp. The location of the Crittenden County Fault Zone, proposed by Chiu and others (1997), is indicated by the dashed line with the abbreviation "CCFZ." The "+" symbols in western Kentucky and southeastern Illinois show the alternative epicentral locations for the January 23, 1812, earthquake that were suggested by Mueller and others (2004).

a recent study, Guccione and others (2005) concluded that the Bootheel Lineament is a Holocene fault with predominantly right-lateral displacement that may or may not have moved horizontally during the 1811-12 earthquakes.

As for the major earthquakes on January 23 and February 7, Johnston and Schweig's (1996) preferred scenario is that the former event was the result of strike-slip motion along the fault segment identified in Figure 1 as NN, and that the latter event was the result of a combination of strike-slip movement along the NW segment and thrusting along the RF segment of their fault model. Hough and others (2003) and Mueller and others (2004), on the other hand, have proposed that

Table 1. Moment magnitude estimates of the four largest earthquakes.

	December 16, 1811 (2:15 a.m.)	*December 16, 1811 (8:15 a.m.)*	*January 23, 1812 (9:00 a.m.)*	*February 7, 1812 (4:00 a.m.)*
Nuttli (1973a)[1]	7.7		7.5	8.0
Street (1982)[1]	7.7	7.4	7.5	7.8
Johnston (1996)	8.1 ±0.3	7.2 ±0.3	7.8 ±0.3	8.0 ± 0.3
Hough and others (2000)	7.2–7.3		7.0	7.4–7.5
Atkinson (2001)	8.0		7.8	8.0
Hough and Martin (2002)		7.0		
Bakun and Hopper (2004)	7.6		7.5	7.8
Kochkin and Crandell (2004)[2]	7.2			
Street and others (2004)[2]		7.2+		

[1]The $m_{b,Lg}$ magnitudes, based on the magnitude scale suggested by Nuttli (1973b), were converted to **M** using the $m_{b,Lg}$ to M_o relationship suggested by Johnston (1996) and the M_o to **M** relationship given by Hanks and Kanamori (1979).

[2]Kochkin and Crandell (2004) estimated the magnitude of the earthquake at 2:15 a.m. on December 16, 1811, as being **M** 7.2 on the basis of the damage at St. Louis. Street and others (2004) suggested that the damage was more likely the result of one of the earthquakes that occurred on the morning of December 16, 1811, such as the event at 8:15 a.m. Street and others (2004) also suggested that the magnitude of the event investigated by Kochkin and Crandell (2004) is greater than **M** 7.2 because of a lower site amplification than assumed by Kochkin and Crandell.

the January 23 event was a triggered event centered somewhere in western Kentucky or southeastern Illinois (Fig. 1).

Since the 1811-12 earthquakes are historical events, and the bedrock in the New Madrid Seismic Zone is overlain by up to 3 km of sediments, obscuring any direct evidence of faulting, their epicentral locations, displacements, and magnitudes are uncertain. The best evidence we have for estimating the magnitudes of the earthquakes is the effects as reported by eyewitnesses at the time of the events. Based on these accounts, various magnitudes have been estimated for the 1811-12 earthquakes (Table 1). Differences in the magnitude estimates are the result of differences in the databases used, differences in the interpretation of the eyewitness accounts in the context of the modified Mercalli intensity scale, and, in some instances, errors made either in the interpretation of the account or in the database used.

This report addresses the historical context in which the 1811-12 earthquakes occurred, to correct some of the errors that have crept into the databases, and to express our conclusions about the locations of the four main shocks listed in Table 1 and some of the larger aftershocks.

Assessing the Felt Reports

To interpret the felt reports of the New Madrid earthquakes in terms of the modified Mercalli intensity scale, the demographics of the United States in 1811-12 must be taken into account, as well as the circumstances of the person who wrote the account, the extent and lack of newspaper coverage, the means by which newspapers acquired the material for their stories, the materials and type of construction in the area where the account originated, and various other things, such as the specificity of the account and the context in which the account was written.

Demographics

In 1811-12, the central United States was a sparsely populated area consisting of three states (Kentucky, Ohio, and Tennessee) and four territories (Indiana, Illinois, Missouri, and Mississippi) (Fig. 2). According to the U.S. census of 1810, the most populated state in the central United States was Kentucky, with a population of 406,511, and its largest settlement was Lexington, with a population of 4,326. The populations of the other states and territories in 1810, along with the populations of the districts in the Missouri Territory and the two counties that made up Illinois, are shown in Figure 2. Table 2 lists the populations of several of the communities and settlements whose locations are shown in Figure 2. Latitudes and longitudes of the settlements shown in Figure 2, as well as for settlements mentioned elsewhere in this report, are given in Table 3. Not shown in Figure 2 or listed in Table 3 is Vicksburg, Miss. (32.353°N/90.878°W), which is mentioned in some of the literature on the 1811-12 earthquakes. Vicksburg, which is named after the Methodist missionary Bewit Vicks, who established a mission at the location in 1817, was not founded until 1825 (George

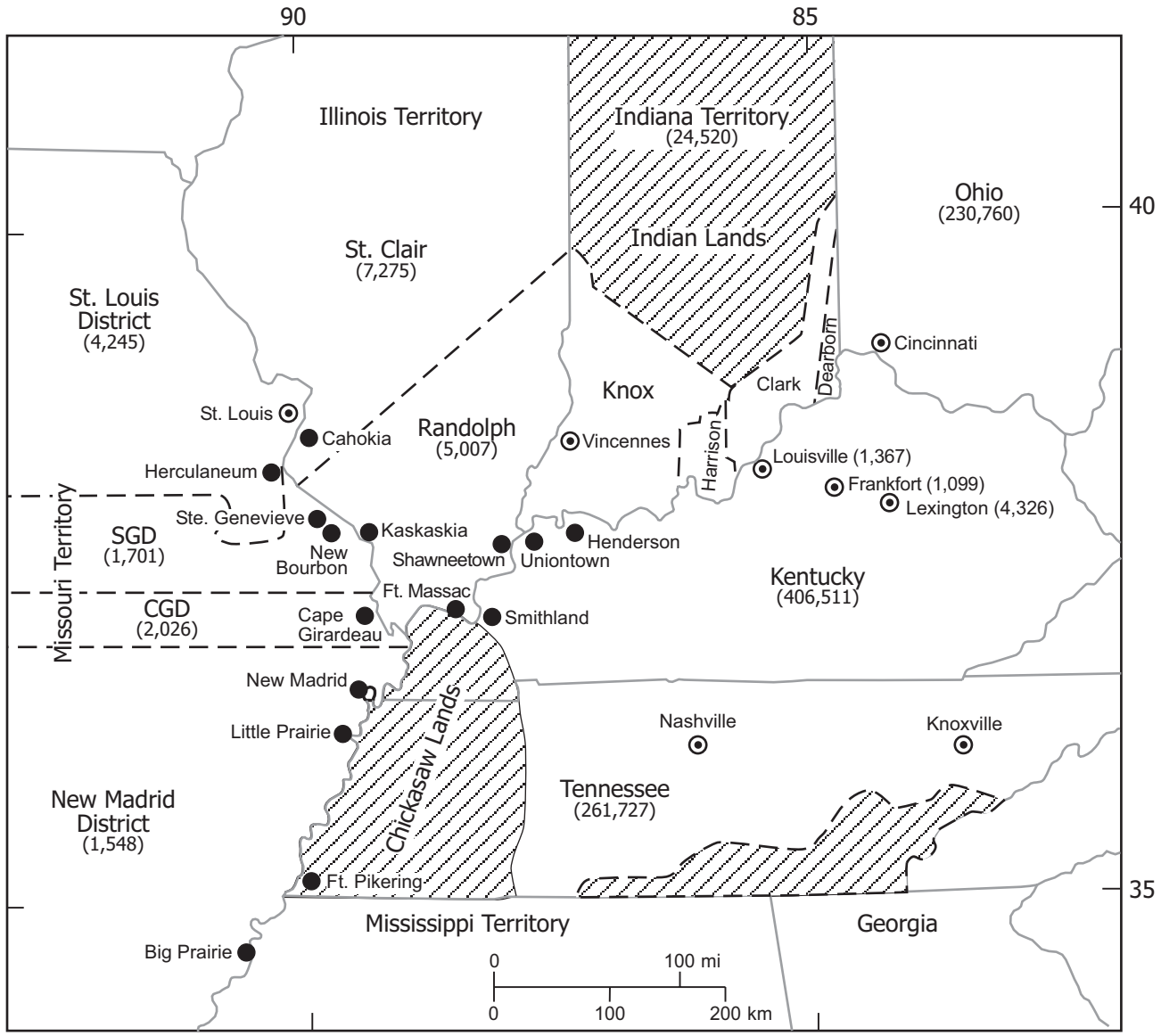

Figure 2. The geographical boundaries of the three states (Kentucky, Ohio, and Tennessee) and four territories (Illinois, Indiana, Mississippi, and Missouri) that made up what is now the central United States in December 1811. Numbers in parentheses are the populations of the state, territory, district, or county indicated in 1810. Western settlements that had a weekly newspaper are indicated with the symbol "⊙"; there were no daily newspapers in the central United States in 1811. Diagonal patterns indicate designated tribal lands.

Bolm, Vicksburg and Warren County Historical Society, personal communication, November 30, 2006).

The populations and settlements in these states and territories were not evenly distributed. Mountainous areas, such as eastern Kentucky and eastern Tennessee, were not settled and, as indicated in Figure 2, parts of western Kentucky, western Tennessee, southeastern Tennessee, and northern Indiana were Indian territory and not open to settlement. Furthermore, the populations in the areas that were open for settlement tended to be concentrated. For example, in Kentucky most of the population was centered along an east-west corridor stretching from just east of Lexington to Louisville. In Tennessee, much of the population was centered around Nashville, with a smaller population center around Knoxville. In the Illinois and Missouri Territories, the only population centers were along the Ohio and Mississippi Rivers.

The importance of the demographics in 1811-12 is twofold. First, given the distances between the settlements and the lack of communications and convenient transportation, the record of the damage result-

Table 2. Census and site conditions at various locations in the central United States in 1810-11.			
Location	*Coordinates (°N/°W)*	*Census or Size*	*Site Conditions (V_{30} is the time-averaged shear-wave velocity to a depth of 30 m)*
American Bottoms, Ill.	See Table 3	unknown	V_{30}=195 m/s; limestone bedrock at 33 m (Robert Bauer, Illinois State Geological Survey, personal communication, February 24, 2005).
Cincinnati, Ohio[1]	39.11/84.51	2,540	V_{30}=260 m/s; bedrock is a soft shale with interbedded limestone at 30 m (Edward Woolery, University of Kentucky, personal communication, May 17, 2005).
Frankfort, Ky.	38.20/84.87	1,099	
Henderson, Ky.[2]	37.79/87.59	159	V_{30}=280 m/s near Audubon's store; the depth to bedrock in the Henderson area varies from outcrop to several tens of meters. Depending on the location, bedrock might be a sandstone, shale, limestone, or coal (Higgins, 1997).
Herculaneum, Mo.	38.27/90.38	20 cabins	On rock (Cramer, 1811); location on bluffs along the Mississippi River.
Knoxville, Tenn.	35.96/83.92	730	
Lexington, Ky.	38.33/84.50	4,326	Lexington Limestone (V_s=965 m/s); depth to bedrock < 5 m (Edward Woolery, University of Kentucky, personal communication, January 24, 2005).
Little Prairie, Mo.	36.19/89.65	~20–26 cabins	V_{30}=185 m/s; depth to bedrock is ~800 m; S-wave velocity from two sites near where Little Prairie was located.
Louisville, Ky.	38.22/85.74	1,367	V_{30}=250 m/s; a 3- to 4-m layer of surficial soils overlying glacial outwash; bedrock is > 30 m (Zhenming Wang, Kentucky Geological Survey, personal communication, March 23, 2005).
Nashville, Tenn.	36.16/86.78	1,100	
New Bourbon, Mo.[3]	37.98/90.05	unknown	Depth to bedrock is ~30 m (David Hoffman, Missouri Geological Survey, personal communication, March 19, 2004).
New Madrid, Mo.	36.57/89.53	~1,000	V_{30}=160 m/s; depth to bedrock is ~500 m (James Harris, Millsaps College, Jackson, Miss., personal communication, July 12, 2004).
Old Shawneetown, Ill.	37.70/88.14	~30 cabins	Depth to bedrock is ~36 m; so sandy that sand boils that form inside of old levee are not even muddy, just pure sand (Linda Davis, U.S. Army Corps of Engineers, personal communication, September 21, 2004).
Ste. Genevieve, Mo.	37.90/90.20	unknown	Depth to bedrock is ~30 m (David Hoffman, Missouri Geological Survey, personal communication, March 19, 2004).
St. Louis, Mo.[4]	38.65/90.25	1,200	Six meters of clayey residuum with some chert gravel; bedrock is hard to very hard St. Louis Limestone (David Hoffman, Missouri Geological Survey, personal communication, March 25, 2004). Cramer (1811) stated that most of the houses were built on limestone.

Table 2. Census and site conditions at various locations in the central United States in 1810-11.

Location	*Coordinates (°N/°W)*	*Census or Size*	*Site Conditions (V_{30} is the time-averaged shear-wave velocity to a depth of 30 m)*
Uniontown, Ky.[5]	37.77/87.94		V_{30}=344 m/s; depth to bedrock is ~20 m and the V_s of the bedrock is 825 m/s (Edward Woolery, University of Kentucky, personal communication, September 21, 2004).
Vincennes, Ind.[6]	38.68/87.51	670	Depth to bedrock is ~45 m; soils consist primarily of fine to medium sands near the surface to sand and gravel (not very coarse) at depth (John Hill and Robert Bauer, Illinois State Geological Survey, personal communication, June 9, 2004).

[1]Ford and Ford (1881) described Cincinnati in 1810 as a place of about 360 dwellings, with about two-thirds of the houses in the Bottom (i.e., between the river and Third Street), and the rest upon the Hill (i.e., between Third and Seventh Streets). They described the streets as not being paved, noted the lack of alleys, and stated that the dwellings were chiefly brick and frame, with some stone.

[2]The first settlers in the area, a group of Pennsylvania Dutch, referred to the settlement as "Red Banks."

[3]A community established in either 1787 or 1793 by French expatriots who had fled the French Revolution. The settlement was atop the bluffs along the Mississippi River, and the most likely type of construction used in the houses was the vertical-post construction that was characteristic of French Colonial architecture.

[4]At the time of the 1811-12 earthquakes, dwellings in St. Louis consisted of a few stone buildings and wooden vertical-post and framed houses. The first brick structure in St. Louis was built in 1813 (stlouis.missouri.org/heritage/History69/).

[5]In 1811-12, Uniontown was not so much a settlement as it was a landing site for travelers going down the Ohio. It is described as a frontier outpost where settlers came to take up land and till the soil, not to build towns or engage in manufacturing and commerce (American Guide Series, 1941).

[6]Hempstead (1804) described Vincennes in 1804 as a settlement of "upwards of a hundred houses, most of them in a battered situation, poorly constructed and wretched in appearance." Most of these houses were probably constructed with upright posts with mud and straw in between. By 1816, Thomas (1819) described the settlement as having several good buildings of frame and brick, a majority being of log and plaster. At the time of the 1811-12 earthquakes, there were two brick structures in Vincennes: Gov. Harrison's home (Grouseland) and Vincennes University (a grammar school). The brick walls in Gov. Harrison's home were cracked by the earthquakes of 1811-12 (Vincennes *Western Sun,* August 2, 1873, p. 1). There is no information about the effects of the earthquakes on the building that housed Vincennes University; the building was demolished in 1883 (Cauthorn, 1902).

ing from the earthquakes of 1811-12 is almost certainly incomplete. Second, since many of the settlements were small, typically less than a few tens of cabins, the number of structures susceptible to earthquake damage was small, and it is not always possible to determine the average level of damage. An example of the latter situation is the damage to a brick house in Mortons Gap, Ky. Gordon (1958) stated that the force of the earthquake left a crack in the front brick wall of the Thomas Morton dwelling (Brown, 1976). By itself, a crack in the brickwork of one building does not appear to be too damaging. But the building was new (built in 1810) and it was the only brick building in the area at the time of the earthquakes. No other information, such as chimney damage, the loss of chinking in log cabins, etc., is known about the damage in the Mortons Gap area, and, in fact, very little is known about Mortons Gap in 1811. Consequently, if a modified Mercalli intensity is to be interpreted for Mortons Gap, it must be on the basis of the one and only brick building in the area; there can be no average or medium level of damage.

A final point about the demographics in the central United States is that after the War of 1812 there was a large influx of settlers into the area because of the defeat of the British and their Indian allies in the Old Northwest Territories (i.e., Illinois, Indiana, Michigan, Ohio, and Wisconsin) and the subsequent treaties with the various Indian nations. For this reason, we have used U.S. census numbers for 1810 wherever possible (Fig. 2, Table 2).

Table 3. Locations of settlements mentioned in text.			
Locality	*Coordinates Lat (°N)/Long(°W)*	*Locality*	*Coordinates Lat (°N)/Long(°W)*
American Bottoms, Ill.[1]		Lexington, Ky.	37.989/84.478
Atlanta, Ga.	33.749/84.388	Little Prairie, Mo.	36.193/89.656[2]
Augusta, Ga.	33.471/81.975	Louisville, Ky.	38.254/85.759
Baltimore, Md.	39.290/76.613	Madisonville, Ohio	39.158/84.391
Bardstown, Ky.	37.809/85.467	Marietta, Ohio	39.415/81.455
Beaufort, S.C.	32.431/80.670	Maury County, Tenn.	35.633/87.067
Bethel, Mo.	39.877/92.024	Maysville, Ky.	35.641/83.744
Big Prairie, Ark.	34.568/90.573[2]	Meadville, Pa.	41.641/80.152
Birdsville, Ky.	37.221/88.448	Milledgeville, Ga.	33.080/83.232
Cahokia, Ill.	38.571/90.190	Mortons Gap, Ky.	37.237/87.475
Cape Girardeau, Mo.	37.306/89.518	Nashville, Tenn.	36.166/86.784
Carthage, Tenn.	36.252/85.952	Natchez, Miss.	31.560/91.403
Charleston, S.C.	32.776/79.931	Natchitoches, La.	31.761/93.086
Chillicothe, Ohio	39.333/82.983	Newberry, S.C.	34.274/81.619
Cincinnati, Ohio	39.162/84.457	New Bern, N.C.	35.108/77.044
Circleville, Ohio	39.601/82.946	New Bourbon, Mo.	37.950/90.021
Clarksville, Tenn.	36.530/87.359	New Madrid, Mo.	36.586/89.528
Columbia, S.C.	34.001/81.035	Newport, Ky.	39.091/84.496
Coshocton, Ohio	40.272/81.860	New York, N.Y.	40.714/74.006
Dayton, Ohio	39.759/84.192	Ozark Village, Ark. (Arkansas Post)	34.020/91.349
Detroit, Mich.	42.331/83.046	Paris, Ky.	38.210/84.253
Dorena, Mo.	36.616/89.237	Pittsburgh, Pa.	40.441/79.996
Edenton, N.C.	36.045/76.614	Portage des Sioux, Mo.	38.925/90.342
Fort Hawkins (Macon), Ga.	32.841/83.633	Princeton, Ky.	37.109/87.882
Fort Massac, Ill.	37.143/88.712	Raleigh, N.C.	35.772/78.639
Fort Osage, Mo.	39.188/94.192	Richmond, Ky.	37.748/84.295
Fort Pikering (Memphis), Tenn.	35.125/90.070[2]	Richmond, Va.	37.554/77.461
Fort Stephens, Ala.	31.540/88.055	Russellville, Ky.	36.845/86.887
Fort Wayne, Ind.	41.131/85.129	St. Charles, Mo.	38.784/90.481
Frankfort, Ky.	38.201/84.873	Ste. Genevieve, Mo.	37.980/90.045
Franklin, Tenn.	35.925/86.869	St. Louis, Mo.	38.627/90.198
Georgetown, S.C.	33.377/79.295	Savannah, Ga.	38.083/81.100
Greenville, Ky.	37.201/87.179	Shawneetown, Ill.	37.697/88.137[3]
Henderson (Red Banks), Ky.	37.836/87.590	Smithland, Ky.	37.139/88.403
Herculaneum, Mo.	38.268/90.380	South Union, Ky.	36.876/86.656
Hodgenville, Ky.	37.574/85.740	Uniontown, Ky.	37.775/87.931
Jackson, Mo.	37.382/89.666	Vincennes, Ind.	38.677/87.529
Kaskaskia, Ill.	37.921/89.913	Washington, Ga.	33.737/82.739
Knoxville, Tenn.	35.961/83.921	Washington, Ky.	37.767/85.183
Lancaster, Ohio	39.714/82.599	Wheeling, W.Va.	40.064/80.721
Laurens, S.C.	34.499/82.014	Wilmington, N.C.	34.226/77.945

Table 3. Locations of settlements mentioned in text.			
Locality	*Coordinates Lat (°N)/Long(°W)*	*Locality*	*Coordinates Lat (°N)/Long(°W)*
Zanesville, Ohio	39.940/82.013		

[1]American Bottoms is a name given to the strip of alluvial ground along the east side of the Mississippi River between Kaskaskia and Cahokia, Ill. (Fig. 2).
[2]The locations for these sites are approximate. The location of Big Prairie, Ark., is based on Cramer's (1811) description. The location given for Little Prairie, Mo., is that of present-day Caruthersville, Mo., which is close to where Little Prairie was located.
[3]This location is referred to as Old Shawneetown today. The town was moved shortly after the flood of 1835.

Firsthand Accounts along the Mississippi River between the Mouth of the Ohio River and Fort Pikering, Tenn. (near Present-Day Memphis)

There are only a few firsthand accounts of the 1811-12 earthquakes in the epicentral area between the junction of the Mississippi and Ohio Rivers and Fort Pikering. The lack of reports from along this stretch of the Mississippi River is because there were only two settlements in the area (Little Prairie and New Madrid, Mo.), no newspapers were being published in the area (Fig. 2), and from the end of December through January, travel on the Mississippi River downriver from the junction with the Ohio River was halted because of extensive ice jams on the Ohio River (Johnston and Schweig, 1996). Furthermore, Little Prairie was destroyed and abandoned as a result of the earthquakes on December 16 (Cummings, 1847). New Madrid, on the other hand, though severely damaged as a result of the earthquakes, was never completely abandoned.

Two people are known to have experienced all of the earthquakes in the New Madrid region, beginning with the events on December 16 through February 1812. One of the two, Bryan (1848), described the earthquakes on December 16 at sunrise and on January 23 at 9:00 a.m. as being the most violent earthquakes felt, until the event of February 7. The other person, Anonymous B (1812), stated that he was in Little Prairie on the morning of December 16 and at New Madrid from mid-day December 16 through February 7. He described the earthquakes of December 16 and January 23 as being equal, and the event of February 7 as being the most severe.

Of the four main earthquakes in the 1811-12 sequence, the two events on December 16 and their effects in the epicentral area are the best documented, although in some instances it is difficult to distinguish which effects were the result of which earthquake. In addition to the accounts of Anonymous B (1812) and Bryan (1848), there are other firsthand accounts of the events, such as the one by Fletcher (1812) and accounts written by people floating down the Mississippi River. Of the accounts written by travelers going down the Mississippi River on December 16, the most informative ones are by Bedinger (1812), Foster (1812), Pierce (1812), and Bradbury (1819). On the morning of December 16, Bedinger and Foster, who were traveling together, were on a flatboat tied up to Island 13 on the Mississippi River, which was a little over half the distance downriver from New Madrid to Little Prairie (Fig. 3). Pierce was on a flatboat that was tied up to an island about 25 km downriver from Little Prairie, and Bradbury was on a flatboat that was tied up to Island 34, which was about halfway between Little Prairie and Fort Pikering (Fig. 3).

Bedinger (1812), Foster (1812), and Pierce (1812) stated that there were two significant earthquakes on the morning of December 16: one event shortly after 2:00 a.m. and another between 7:00 and 7:30 a.m. Bedinger and Pierce described the earthquake on the morning of December 16 at 7:30 a.m. as being more severe than the event at 2:00 a.m. Foster, on the other hand, described the event at 7:30 a.m. as having been as severe as the event at 2:00 a.m., but not as long. Bradbury (1819) described an earthquake on the morning of December 16 near daylight as having been nearly equal in violence to the first event, but did not give a time for the morning event. It is important to note that these accounts are from people on flatboats tied up to islands at the time of the first event (2:00 a.m.) , and that Bedinger, Foster, and Pierce were on flatboats floating down the Mississippi River at the time of the 7:00 to 7:30 a.m. event. Bradbury was on a flatboat that was in the process of casting off from Island 34 when the earthquake at daylight was felt. People such as Bedinger, and others who were floating down the Mississippi River, were in the wilderness and not in a position to observe architectural or structural damage such as broken windows, damaged chimneys, etc.

The only firsthand accounts of the January 23 event for the area between the mouth of the Ohio Riv-

er and Fort Pikering are the accounts by Anonymous B (1812) and Bryan (1848), who were in New Madrid. For the earthquake on February 7, however, there are the accounts by Anonymous B (1812) and Bryan (1848) at New Madrid, as well as accounts by Speed (1812) and Shaler (1815), who were traveling down the Mississippi River on flatboats.

Newspaper Coverage of the Earthquakes

Newspaper articles at the time of the 1811-12 earthquakes are the primary source of information about the effects of the events. In 1811-12, newspaper articles were based on firsthand accounts of the editor, letters written to the editor, word of mouth from travelers passing through the settlement where the newspaper was published, articles copied from other newspapers that found their way into the settlement, and extracts of letters written to local residents from outside the settlement. Settlements west of the Appalachian Mountains that had a local newspaper were small (Fig. 2), and the pool of potential customers was also small (Table 2). As a result, the newspapers were weeklies, and did not always report local events. For example, *The Louisiana Gazette* (St. Louis) did not report on the extensive damage known to have occurred in nearby settlements such as New Bourbon and Herculaneum, Mo., and Kaskaskia, Cahokia, and the American Bottoms in Illinois. (The American Bottoms is the name given to the

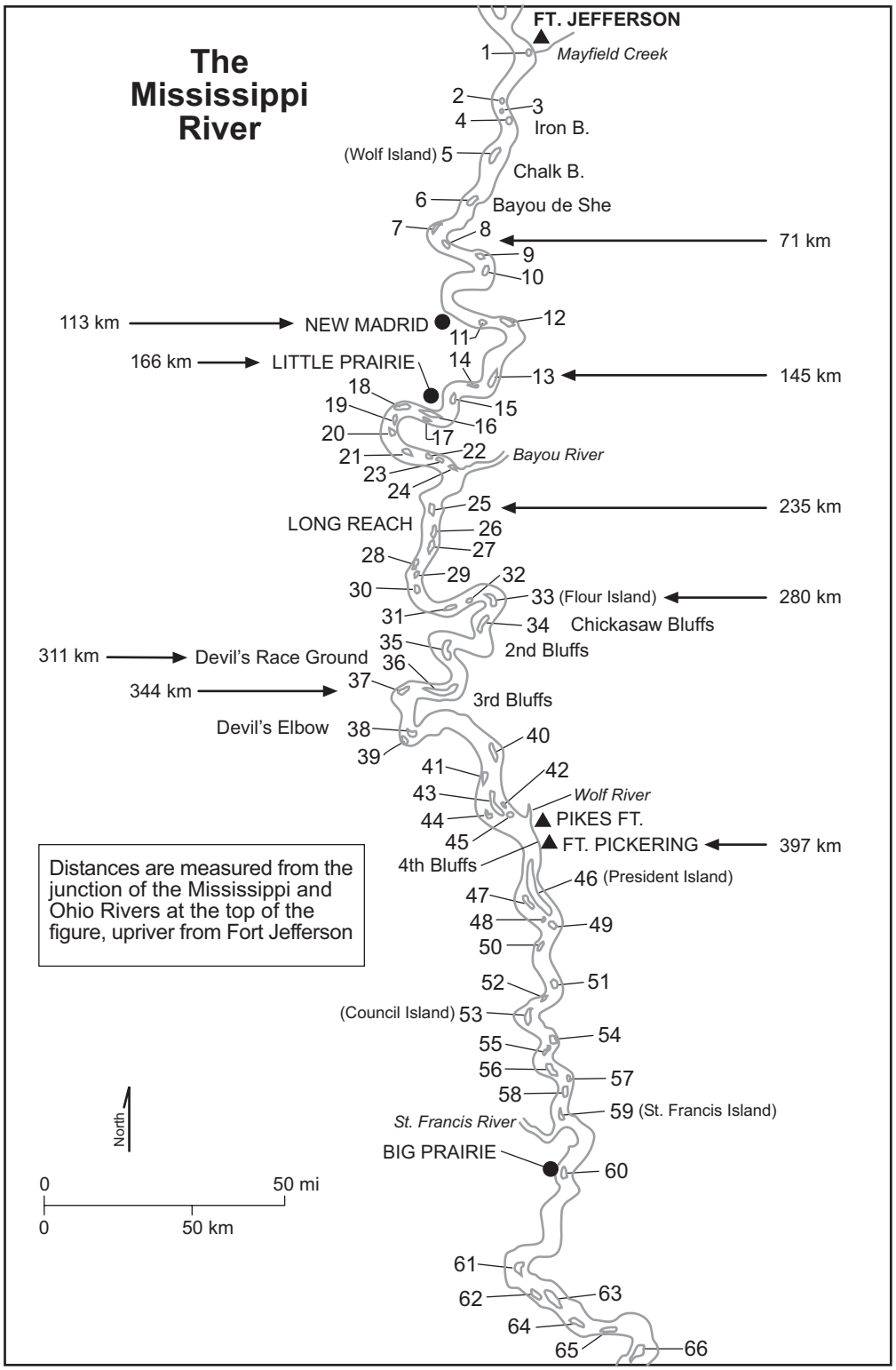

Figure 3. Channel morphology of the Mississippi River from Island 1 through Island 66 (Cramer, 1814) in the early part of the 19th century. Measurements in original accounts were in miles, but converted to km for this report.

strip of alluvial land along the eastern edge of the Mississippi River between Kaskaskia and Cahokia.)

Because the newspapers were weeklies and the populations of the settlements were small, in many instances the local news would have been disseminated by word of mouth long before it could have been printed. We conclude, therefore, that just because something was not mentioned in a local newspaper does not mean that it did not happen.

Many of the aftershocks of the 1811-12 earthquakes were, in their own right, significant earthquakes; that is, they were felt as far away as the East Coast of the United States. The locations and magnitudes of these events are difficult to estimate, however, because of the previously discussed lack of settlements in the epicentral area, the lack of newspaper coverage of the events in general, and, in the case of the aftershocks, the lack of coverage of the specific events. If a newspaper mentioned anything about the aftershocks, it often was a vaguely worded statement to the effect that some earthquakes had been felt over the past however many days. For example, in Columbia, S.C., the local paper stated that several slight shocks were felt between January 23 and 28 (Anonymous C, 1812). The *Natchez Gazette* (Natchez, Miss.) of February 13, 1812, stated that "several shocks, though not violent, have been felt in this city, within 8 or ten days past." The *Louisiana Gazette* (St. Louis) of February 8, 1812, stated that "few hours pass without feeling slight vibrations of the earth," and *Wilson's Knoxville Gazette* (Knoxville, Tenn.) of February 10, 1812, stated that "in the opinion of many that not one day has passed, since the 16th December, unmarked by this phenomena [earthquake]."

Another difficulty in determining the magnitudes of the aftershocks is that some of the descriptions of the effects are in vague terms relative to other events. For example, *The Times* (Charleston, S.C., February 14, 1812) stated that "at 35 minutes past 8 P.M. there was a second; and at 11 p.m., a third, more violent than the second, but not so much so as the first." The article is referring to the main earthquake on February 7 at 4:00 a.m., and the aftershocks at 8:35 and 11:00 on the evening of the same day. Although it is clear that there were three events felt in Charleston on February 7, there is insufficient information in the statement to interpret modified Mercalli intensities.

Types of Construction in 1811-12

Houses and chimneys in 1811-12, particularly in the frontier areas of the central United States, were not built in the same manner or with the same materials as the houses and chimneys found in the central United States today. A good example of this difference is the log cabins that were found in the frontier settlements of Tennessee, Kentucky, Ohio, and elsewhere. Log cabins of the period were basically all joinery. The foundation of the typical log cabin was stone, usually dry-laid, or stone pillars. The bottom log (sill) was placed directly on top of the foundation and held in place by the weight of the logs above it in the walls. The logs were held together by the notching at the four corners of the building. Such structures were fairly earthquake-resistant since the sills were not attached to the foundations and the cabins could shift horizontally or move vertically on their foundations without being structurally damaged. In other words, log cabins in 1811-12 had what today would be referred to as a form of base isolation, and as such they were not very vulnerable to ground motions resulting from an earthquake. Log cabins were damaged if a corner of the cabin shifted off its support, since the notching along the corner of the walls would most likely split, causing the logs in that corner to unravel. This in turn would have stressed the other corners and resulted in the cabin being pulled over to one side.

Berry (1908) gave the dimensions of a "typical" log cabin in the southern Illinois area as being "fifteen feet square and seven feet high." He stated that the walls were built of small logs fitted in dovetailed joints at the corners, and that long logs were used to hold the gable ends in place and to support the roof. He concluded that such buildings were ideal for resisting the shock of an earthquake since, like a basket, they were flexible and yielding.

The resiliency of log cabins compared to brick and stone houses in an earthquake is also demonstrated by an account of the effects of the earthquakes in Cahokia, Ill., and Cape Girardeau, Mo. McDermott (1949, p. 317) stated that the effects of the earthquakes on houses in Cahokia were such that some of the stone and brick houses had to be abandoned because of the damage resulting from the earthquakes, but that cabins made of undressed logs and sand were able to withstand a great deal of shaking without much damage. The *Louisiana Gazette* (St. Louis, December 22, 1811) stated that two brick buildings and five brick chimneys were damaged by the earthquakes of December 16, but made no mention of any damage to the log cabins known to have existed in Cape Girardeau at the time of the earthquakes. Nowhere in the descriptions of the damage in Cape Girardeau is there any mention of damage to the log cabins in the settlement. In fact, the only settlements in which log cabins are known to have been destroyed by any of the earthquakes are Big Prairie, Little Prairie, and New Madrid (Fig. 3).

In settlements whose origins dated back to the French and Spanish colonial days, post-on-sill and

post-in-ground construction were common. Buildings of this type were common in such settlements as St. Louis and Ste. Genevieve, Mo., Cahokia, Ill., and Vincennes, Ind., and examples are shown in Kochkin and Crandell (2004). How this type of structure responded to the earthquakes is not well documented, but based on the lack of comments to the contrary, such structures in St. Louis, Ste. Genevieve, or Vincennes apparently sustained only minimal damage. An article in the December 21, 1811, issue of the *Western Sun* (Vincennes) mentioned that the roofs of several post-in-ground houses were thrown off as a result of the earthquakes on December 16. The article also mentions that the earthquakes cracked two or three brick chimneys, but makes no mention of any other damage to the structures in that settlement.

Elsewhere in the central United States by 1811, homes in the more well-established settlements, such as Lexington and Frankfort, Ky., and Cincinnati, Ohio, were brick and wood-framed structures (Cramer, 1811). In settlements nearer the frontier, such as Nashville, Tenn., and Chillicothe, Ohio, housing generally consisted of a mix of brick, stone, and wood-frame houses and log cabins *(Raleigh Star,* Raleigh, N.C., February 12, 1812; Cramer, 1814; Houck, 1908; www.historicalnashville.org/history).

Chimneys

Chimneys in the frontier settlements of 1811-12 were constructed of a variety of materials, including packed earth (clay), stone, and brick, and typically did not have flue liners. So-called "dirt chimneys" were constructed using packed earth that may or may not have been strengthened by a mesh of young tree limbs. Berry (1908) described the fireplaces in southern Illinois as being a 6-ft-square pen at one end of the cabin, about a foot deep, with half of the pen in the cabin, and the other half outside of the cabin, which served as the base for the chimney. The chimney itself was built up of a mesh of white oak sticks, the sticks overlapping at the corners of the chimney and being forced down into the clay, after which another 2-in. layer of clay was placed upon the previous layer. The walls of the chimneys constructed in this manner were more than a foot thick. In other areas along the frontier, such as in Kentucky, a chimney might be built of packed clay, but the fireplace itself would be built of stone. Because of the variety of methods and materials used in the construction of dirt chimneys, it is reasonable to assume that they responded to ground motions in a variety of different ways.

Dirt chimneys were constantly in need of repair, and typically thought of as a temporary arrangement. Such chimneys were generally replaced within a short time with a stone or brick chimney. Stone chimneys were constructed with and without mortar. For brick chimneys, and if the stone chimney was constructed with mortar, the quality of mortar mix used depended on the local materials from which it was made. For example, the mortar mix in northeastern Kentucky was of an inferior quality. It was high in lime content and sandy, and as a result easily weathered. On the other hand, the materials for mixing a high-quality mortar in the St. Louis area were locally available (David Hoffman, Missouri University of Science and Technology, written communication, April 15, 2004), and likely this resulted in a relatively better quality of mortar than that used in northeastern Kentucky.

Windows

One type of damage that occurs as a result of present-day earthquakes, but that was apparently not a common occurrence during the earthquakes of 1811-12, is broken windows. A review of the accounts describing the effects of the 1811-12 earthquakes revealed only two instances of windows being broken. The *Savannah Republican* (Savannah, Ga., February 18, 1812), in an article titled "Augusta, Georgia, February 13," stated that 15 squares of glass windows were broken in a house about 15 km south of Augusta. Glass windowpanes were also reported to have been broken in Maury County, Tenn. This lack of broken glass windows is seemingly inconsistent with the fact that the windows of that era were made of rolled glass, which is fairly brittle and would generally be thought of as being highly vulnerable to breakage during an earthquake. Windowpanes in 1811-12 were typically small, however, 15 x 20 cm being about the largest size, and window sashes were made of wood that only loosely fitted in the window frame. Because the windows were relatively small and the sashes had the degree of freedom to rattle around during an earthquake, such windows were less apt to break than windows in modern structures.

Site Effects

Site effects are known to play a significant role in damage from modern-day earthquakes, and it is reasonable to assume that they played a significant role in historical earthquakes, such as the 1811-12 events. Although site effects are most generally associated with thick layers of sediments with low shear-wave velocity, they are difficult to predict and may also result from such things as surface and subsurface topography and weathered rock (Joyner, 1995; Steidl and others, 1996). Site effects were noted by some of

the observers at the time of the 1811-12 earthquakes. Brownsville, Pa., and Carthage, Tenn., accounts specifically mentioned that effects of the earthquakes were more pronounced near the rivers than on the nearby hills (Anonymous A, 1812, p. 57; Mitchill, 1815, p. 292) and a Richmond, Va., account mentioned that the effects of the earthquakes were felt more on the hill than below it, and were more pronounced in upper stories of a building than in the lower stories *(Ohio Centinel,* Dayton, February 27, 1812). The *New York Evening Post* (January 29, 1812) stated that in Annapolis, Md., "in the lower part of the city, it [the earthquake] appears to have been more forcible, some people being in the act of abandoning their houses, for the purpose of seeking safety in the open air."

Hough and others (2000) argued that since many of the settlements in 1811-12 were established along major rivers on alluvium-filled valleys, the magnitudes estimated by previous researchers for the New Madrid 1811-12 earthquakes were biased upward because they had not taken into consideration site effects. Although it is true that many of the settlements in 1811-12 were located near major rivers and some were built on alluvial-fill valleys, it is also true that settlements such as Bardstown, Georgetown, Lexington, Paris, Smithland, and Washington, Ky., and Herculaneum and St. Louis, Mo., were located where the depth to bedrock is only a few meters (less than 10). At other settlements, such as Louisville, Nashville, Cape Girardeau, New Bourbon, and Ste. Genevieve, the settlements in 1811-12 were located on bluffs well above the alluvial floodplains.

Hough and others (2000) concluded that in the hills above Cincinnati, the modified Mercalli intensity for the earthquake on December 16 at 2:00 a.m. was IV. The basis for this conclusion is a remark by Drake (1815), who stated that families living on the ridges of Kentucky, not more than 32 km from the river, were not awakened by the earthquake (i.e., a modified Mercalli intensity of IV). Drake did not give any specifics as to how many families, where they lived, or the source of his information for this comment, but by itself it implies that the Mercalli intensity somewhere along the ridges in Kentucky south of Cincinnati was IV, as suggested by Hough and others (2000). But in the hills above and to the north of Cincinnati, the soils are glacial tills that vary in thickness from a couple of meters to more than 10 m. In contrast, the soils on the ridges in Kentucky 32 km south of Cincinnati are typically covered with loess, and the depth to bedrock is typically less than 1 or 2 m (Potter, 1996). Given these differences in site effects, the effects of the earthquakes along the ridges of Kentucky would be expected to be different from the hills on the northern side of Cincinnati. In fact, based on ongoing research, we now know that in Madisonville (formerly Madison), Ohio, the foundation of the first framed house in the area was cracked by the earthquake of December 16 (Nelson and Runk, 1894). Madisonville is located in the hills north of Cincinnati, in an area that was very sparsely populated in 1811. In 1810, Cincinnati was described as a village of about 360 dwellings within an area bounded by present-day Race, Seventh, and Broadway streets and the Ohio River. Elevations from benchmarks in that area range from 150 m along the riverfront to 166 m along Seventh Street. The elevation of Madisonville, the only settlement that we are aware of in the hills north of Cincinnati at the time of the 1811-12 earthquakes, is 182 m. Therefore, the modified Mercalli intensity in the hills north of Cincinnati must have been significantly higher than the IV interpreted for the ridgetops south of Cincinnati in Kentucky.

Extent of Damage

Estimating the extent of the damage resulting from the 1811-12 earthquakes is difficult because of the above-mentioned lack of settlements and newspapers in the central United States, errors in damage reports, and the types of construction in the frontier settlements. Table 4 lists the damage currently known to have resulted from the 1811-12 earthquakes. The locations where damage resulted from the earthquakes are shown in Figure 4. The damage is indicated in a manner similar to that used by Kochkin and Crandell (2004), except that in Figure 4 we have included a separate category for settlements where houses were badly damaged. The area of the damages differs from that shown in Kochkin and Crandell (2004) for a number of reasons. The primary source of information for the map by Kochkin and Crandell (2004) was the accounts of the earthquakes included in Street and Green (1984). For Figure 4, we have used the expanded database of information maintained by the University of Memphis (www.ceri.memphis.edu/compendium/main.shtml), as well as other accounts that we have been able to find.

Figure 4 also differs from that shown in Kochkin and Crandell (2004, Fig. 15) because we have been able to determine that several of the structures investigated by them were in fact constructed after the earthquakes of 1811-12. Table 5 lists the buildings cited in Kochkin and Crandell (2004, Table 1) that are known to have been built after 1812. Of the buildings used by Kochkin and Crandell (2004) in their investigation of damage in the St. Charles, Mo., area, the only structure that existed prior to the earthquakes was the Kibby house, which was built in 1809 or 1810 (Olson, 1998). According to Olson and Sperandino (1967), the earthquakes caused

Table 4. Locations that reported damage.		
Rating[1]	*Locality*	*Summary and Date of Damage; Source of Information*
□	American Bottoms, Ill.[2]	Many chimneys thrown down (date not specified); Reynolds (1855).
○	Atlanta, Ga.	Displaced brick chimneys and threw down chimneys composed of wood and dirt (December 16, 1811); *Georgia Journal* (Atlanta), January 3, 1812.
n	Bardstown, Ky.	Damage to some log cabins, poorly built cabins collapsed (December 16, 1811); G.H. Crist, www.ceri.memphis.edu/compendium.
□	Beaufort, S.C.	Walls of house cracked in several places (February 7, 1812); Anonymous C (1812).
H	Big Prairie, Ark.	Log house shaken down (December 16, 1811); Street and Green (1984).
□	Birdsville, Ky.	Overturned coarse and heavy back wall composed of rock and clay (December 16, 1811); Rankin (1837).
n	Cahokia, Ill.	Some stone and brick houses had to be abandoned, log cabins not damaged (no date given); McDermott (1949).
n	Cape Girardeau, Mo.	Split two brick homes and damaged five brick chimneys (December 16, 1811); *Louisiana Gazette* (St. Louis), December 22, 1811. Did considerable damage, demolishing chimneys and cracking cellar walls (February 7, 1812); *Louisiana Gazette*, February 29, 1812.
○	Champaign County, Ohio	Cracked chimney (December 16, 1811); M'Farlan (1881).
□	Charleston, S.C.	Houses were cracked and bricks thrown from foundation of Capitol (December 16, 1811); *Charleston Courier,* December 21, 1811, and *Lexington American Statesman* (Lexington, Ky.), February 18, 1812.
□	Chillicothe, Ohio	One chimney broken, several houses were considerably cracked (February 7, 1812); *The Supporter* (Chillicothe), February 8, 1812.
□	Cincinnati, Ohio	Shook down the chimneys of several houses (December 16, 1811); Ford and Ford (1881). Convulsive shock far more violent than any before experienced resulted in damage to walls and chimneys of some houses (February 7, 1812); *The Western Spy* (Cincinnati), February 8, 1812.
○	Circleville, Ohio	Some chimneys suffered (cracked?) (February 7, 1812); *Lexington American Statesman* (Lexington, Ky.), February 18, 1812.
□	Clarksville, Tenn.	Several chimneys collapsed (December 16, 1811); Fuller (1912).
○	Columbia, S.C.	Shook top off one chimney, and partially affected other buildings (February 7, 1812); *New York Spectator,* March 11, 1812.
○	Coshockton, Ohio	Cracked stone chimney, and considerably damaged one or more brick chimneys (January 23, 1812); *Kline's Weekly Carlisle Gazette* (Carlisle, Pa.), February 14, 1812.
H	Dorena, Mo.	Brick portion of house collapsed, wood portion remained standing (December 16, 1811); Shaw (1856).

Table 4. Locations that reported damage.		
Rating[1]	*Locality*	*Summary and Date of Damage; Source of Information*
n	Fort Massac, Ill.	Damaged the buildings of the fort, some houses very damaged (date not specified); Mansberger (2001). The chimneys, plaster, and daubing of the houses were shaken down (December 16, 1811); *Natchez Gazette* (Mississippi), February 13, 1812.
○	Fort Osage, Mo.	One chimney shaken out, all others more or less cracked (December 16, 1811); *Philadelphia Aurora and General Advertiser*, February 29, 1812.
□	Frankfort, Ky.	One chimney of the courthouse was thrown down (December 16, 1811); *The Western Spy* (Cincinnati), January 4, 1812. Some bricks thrown from tops of chimneys, some small cracks in a few walls, part of one or two gable ends of houses thrown down (February 7, 1812); *American Republic* (Frankfort), February 14, 1812.
○	Franklin, Tenn.	Stone chimney was split (date not specified); www.Tarkington.com.
○	Greenville, Ky.	Cracked brick chimneys of house (~14 km east of Greenville) from top to bottom (date not specified).
□	Henderson (Red Banks), Ky.	Several chimneys thrown down, many others wrecked or cracked (December 16, 1811); *The Weekly Register-Chronicle* (Washington, D.C.), January 25, 1812.
□	Herculaneum, Mo.	Several chimneys cracked to their bases, some broken off (December 16, 1811); Mitchill (1815).
□	Jackson, Mo.	Door hinges loosened, back wall shaken down, large trees broken (December 16, 1811); Thompson (1867).
n	Kaskaskia, Ill.	Stone and brick chimneys fell down, houses cracked (date not specified); Brown (1906). Great number of chimneys thrown down and houses injured, many people left town as a result of some cracks in the earth (date not specified); *The Western Spy* (Cincinnati), March 7, 1812.
○	Laurens, S.C.	Cracked and started some of the chimneys from their houses (December 16, 1811); *The Enquirer* (Richmond, Va.), January 4, 1812.
□	Lexington, Ky.	Brick walls are known in some instances to have been cracked (December 16, 1811); *Lexington American Statesman*, February 7, 1812.
H	Little Prairie, Mo.	Destroyed log cabins (December 16, 1811); *The Reporter* (Lexington, Ky.), February 1, 1812.
□	Louisville, Ky.	Several chimneys broken off, damage to gable ends (December 16, 1811); *Poulson's American Daily Advertiser* (Philadelphia), January 11, 1812. Injured a few chimneys and part of some parapet walls were broken off (February 7, 1812); *Muskingum Messinger* (Zanesville, Ohio), February 12, 1812.
NR	Madisonville, Ohio	Cracked foundation of wood-frame house; www.heritagepursuit.com/Hamilton/HamiltonChapXXXVII.htm.
□	Maury County, Tenn.	Chimneys crumbled and cracks formed in buildings; www.tngenweb.org/maury/history/historyindex.htm.
○	Maysville, Ky.	Chimneys damaged, some small cracks in a few walls, two gable ends of houses thrown down (February 7, 1812); *Frankfort American Republic* (Frankfort, Ky.), February 14, 1812.

Table 4. Locations that reported damage.		
Rating[1]	*Locality*	*Summary and Date of Damage; Source of Information*
□	Mortons Gap, Ky.	Cracked front brick wall (date not specified); Gordon (1958), Brown (1976).
□	Nashville, Tenn.	Threw down chimneys and cracked brick walls (February 7, 1812); Williams (1930).
○	Newberry, S.C.	Cracked some of the chimneys (December 16, 1811); *The Enquirer* (Richmond, Va.), January 4, 1812.
□	New Bourbon, Mo.	Chimneys collapsed (December 16, 1811); *Otsego Herald* (Cooperstown, N.Y.), March 28, 1812.
H	New Madrid, Mo.	Destroyed log cabins (December 16, 1811; January 23, 1812; February 7, 1812); *Philadelphia Aurora and General Advertiser*, June 4, 1812.
○	Newport, Ky.	Threw down the tops of two chimneys (December 16, 1811); *Liberty Hall* (Cincinnati), December 18, 1811.
n	Ozark Village, Ark.	Chimneys demolished, and some houses injured (December 16, 1811); *Farmer's Repository* (Charleston, Va.), February 28, 1812.
□	Paris, Ky.	Some chimneys and brick houses slightly damaged (February 7, 1812); *Kentucky Gazette* (Lexington, Ky.), February 11, 1812.
○	Piney River, Tenn.	A few bricks shaken off chimneys (date not specified); Fuller (1912).
H	Portage des Sioux, Mo.	Many of the cottages thrown down (date not specified); Flagg (1838).
NR	Princeton, Ky.	Dirt chimney collapsed (February 7, 1812); home.hiwaay.net/~woliver/WC_Love.html.
○	Richmond, Va.	A chimney was tumbled (February 7, 1812); *Farmer's Repository* (Charleston, Va.), February 21, 1812.
□	St. Charles, Mo.	Chimneys felled, and gable end collapsed on the only brick building in the settlement; Olson (1998).
□	St. Louis, Mo.	Many houses damaged and several chimneys thrown down (February 7, 1812); *Louisiana Gazette* (St. Louis), February 8, 1812.
□	Savannah, Ga.	Cracked several brick buildings (February 7, 1812); *New York Evening Post,* March 5, 1812.
□	Shawneetown, Ill. (present-day Old Shawneetown)	Stone chimneys thrown down (date not specified); Berry (1908). *Natchez Gazette* (Natchez, Miss.), February 13, 1812, indicates that chimneys were thrown down in Shawneetown during the earthquakes of December 16, 1811.
□	Smithland, Ky.	Chimneys, plastering, and daubing of cabins shaken down (December 16, 1811); *Natchez Gazette* (Natchez, Miss.), February 13, 1812.
□	South Union, Ky.	Cracking of some chimneys, and plastering (December 16, 1811); Tommy Hines, Director, South Union Shaker Village, Ky., personal communication, April 28, 2005. At the time of the earthquakes, the buildings at South Union were log or frame structures; the foundations for the larger stone structures seen at South Union today were in the process of being dug (Tommy Hines, personal communication, April 22, 2005).

Table 4. Locations that reported damage.

Rating[1]	*Locality*	*Summary and Date of Damage; Source of Information*
□	Uniontown, Ky.	Every brick chimney in the county shattered (December 16, 1811); *Martinsburgh Gazette* (Martinsburgh, Va.), February 21, 1812.
□	Vincennes, Ind.	Cracked the brick walls of Grouseland (date not specified); *The Vincennes Weekly Western Sun,* October 25, 1873.
○	Washington, Ga.	Tops of several chimneys fell off (December 16, 1811); *Liberty Hall* (Cincinnati), March 18, 1812.
□	Washington, Ky.	Some chimneys were thrown down (December 16, 1811); *Natchez Gazette* (Natchez, Miss.), February 13, 1812.
□	Wheeling, W.Va.	Stone house was much cracked; also cracked chimneys (February 7, 1812); Anonymous C (1812).

[1]Key to rating: H=houses collapsed; n=some houses badly damaged; □=chimneys collapsed or houses cracked; ○=chimneys cracked; **NR**=not rated and not plotted in Figure 4.
[2]The American Bottoms is the name that was given to the strip of alluvial ground along the east side of the Mississippi River between the settlements of Kaskaskia and Cahokia, Ill. (Fig. 2).

two of the five chimneys of the house to fall, and a gable end to collapse; the house was either extensively repaired or rebuilt in 1820. As for the two structures Kochkin and Crandell (2004) listed in Kentucky as being built before the 1811-12 earthquakes, the Ashburn-Jeffress house was not built until sometime after 1833, when the first owners of the property, the Ashburns, moved from Virginia to Kentucky (David Liveingston, secretary, Fulton County Genealogical Society, written communication, September 20–24, 2004), and construction on the Gower house, located in Smithland (Fig. 2), was not started until 1824 (Julie Ruggles, www.gowerhouse.com/_wsn/page2.html).

No damage is listed in Table 4 or indicated in Figure 4 for Ste. Genevieve, Mo., because there are no accounts of damage or, in fact, any firsthand accounts of the effects of the earthquakes in Ste. Genevieve. The absence of such an account is sometimes taken as an indication that Ste. Genevieve did not suffer any damage as a result of the earthquakes. Kochkin and Crandell (2004) found evidence of repairs to brick chimneys at the "Old Brick" house in Ste. Genevieve (Fig. 2), but concluded that it would be speculative to attribute that damage to the 1811-12 earthquakes since, according to the secondhand account by Rozier (1890), buildings in the settlement did not sustain any damage. Although we agree with Kochkin and Crandell's assessment that attributing the evidence of damage in Ste. Genevieve to the 1811-12 earthquakes is speculative, it is also highly unlikely that the chimneys in the settlement were not damaged as a result of the earthquakes. Brick and stone chimneys in the settlements of New Bourbon and Herculaneum, which are south and north of Ste. Genevieve (Fig. 2), respectively, were badly damaged by the earthquakes on December 16 (Table 4). Furthermore, New Bourbon is located only 3 km south of Ste. Genevieve along the same bluff, and the depth to bedrock at both settlements is approximately 30 m (David Hoffman, Missouri University of Science and Technology, written communication, March 15, 2004). Given the proximity of New Bourbon to Ste. Genevieve, the similarity in site conditions, as well as the extensive chimney damage in New Bourbon and Herculaneum on the morning of December 16, most probably there was chimney damage in Ste. Genevieve as a result of the 1811-12 earthquakes.

Locations of the Main Shocks

The various magnitudes that have been estimated for the four main shocks of the 1811-12 sequence are listed in Table 1. As has been previously discussed, the epicentral area for the January 23 earthquake is difficult to pinpoint because of the lack of firsthand accounts. Most researchers (e.g., Nuttli, 1982; Johnston and Schweig, 1996; Bakun and Hopper, 2004) have favored an epicenter near or along what Johnston and Schweig (1996) referred to as the New Madrid North segment of the New Madrid Seismic Zone (Fig. 1). Hough and others (2003) and Mueller and others (2004), on the other hand, have suggested that the January 23 earthquake occurred well east of the New Madrid Seismic Zone, perhaps in western Kentucky or southeastern Illinois (Fig. 1). This suggestion is not supported by anecdotal accounts of the earthquake in southeastern Missouri, western Kentucky, southern Illinois, and southwestern Indiana, however.

The only settlement in the area outlined above that reported the January 23 earthquake as being more

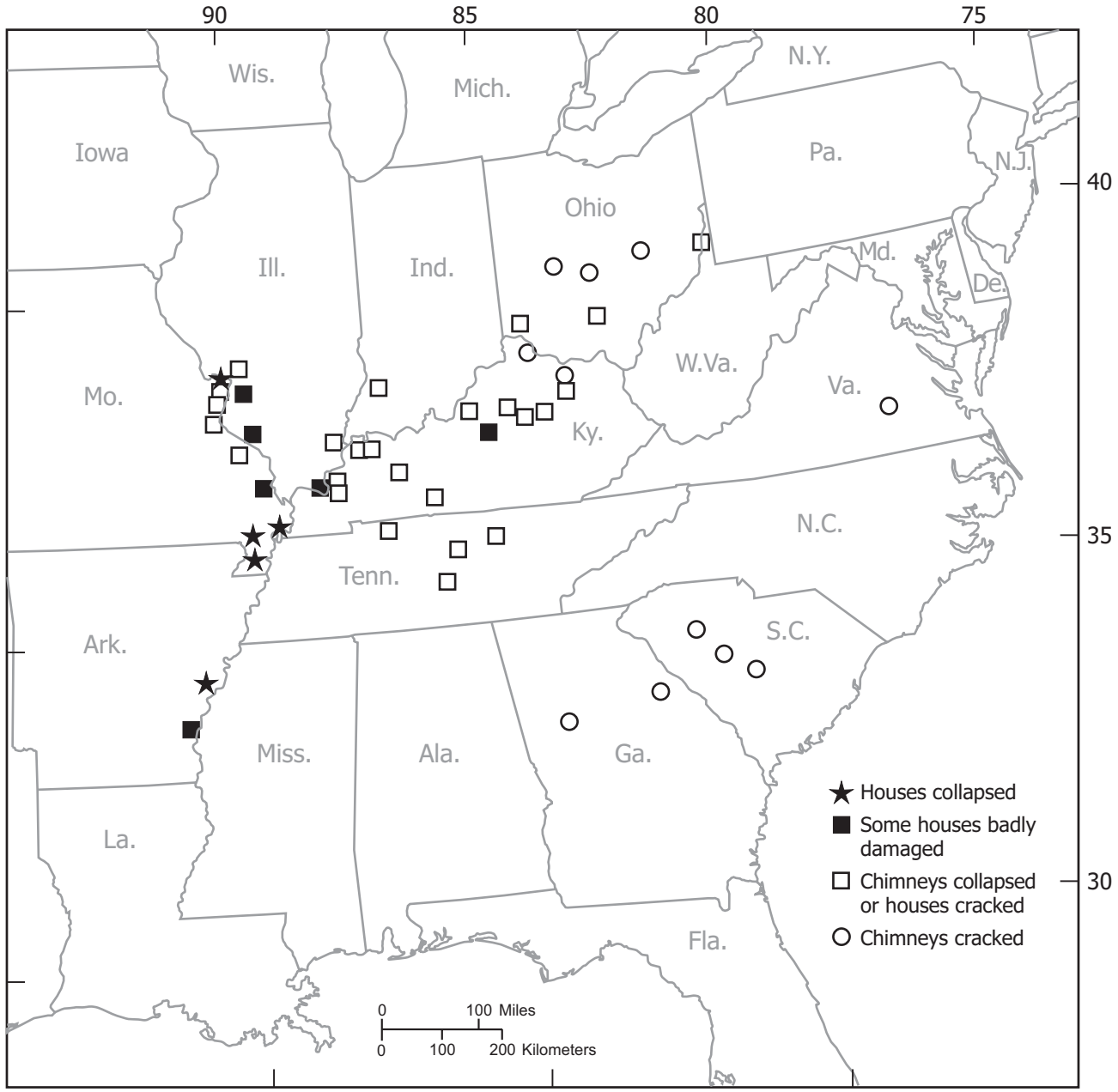

Figure 4. Location of damage resulting from the New Madrid earthquakes of 1811-12, as well as the type of damage reported. Damage classification and symbols modified from Kochkin and Crandell (2004).

severe than the earthquakes on the morning of December 16 is Cape Girardeau, Mo., and the only log cabins known to be damaged by the January 23 earthquake were in New Madrid, Mo. (Table 6). In contrast, Yearby Land (Berry, 1908), who lived in southeastern Illinois, stated that with the exception of the dirt chimneys, the log cabins in southeastern Illinois were not damaged by the earthquakes, and Love (no date), who lived near present-day Princeton, Ky., stated that the dirt chimney in his family's cabin was knocked down by "one of the hardest shakes" one morning, a while before daybreak. Based on Love's description of the sequence of the events, and the time of day for the event that knocked down the chimney ("a while before daybreak"), we believe the earthquake that knocked down his chimney was the main event on February 7. The fact that Love's chimney was not knocked down until February 7 seemingly rules out an epicenter for the January 23 event in western Kentucky. At Vincennes, in southwestern Indiana, the December 16 earthquakes

Table 5. Structures used by Kochkin and Crandell (2004) to evaluate the 1811-12 earthquakes, but which in fact were built after the New Madrid earthquakes of 1811-12.

Building Name	*Location*	*Construction Date*	*Reference*
Goellner Printers	St. Charles, Mo.	1819	1
Piker's Club	St. Charles, Mo.	1820	1
McNair's House	St. Charles, Mo.	1820's	1
Millington House	St. Charles, Mo.	1821	1
Cooperage Building	St. Charles, Mo.	1820's	1
Ashburn-Jeffress House	Near Cacey, Ky.	1833	2
Gower House	Smithland, Ky.	1824–36	3
Tayon House	St. Charles, Mo.	1820	1

1. Olson (1998). See editor's comments on inside of the front cover.
2. David Liveingston, Secretary, Fulton County (Ky.) Genealogical Society, written communication, September 20–21, 2004.
3. Julie Ruggles, www.gowerhouse.com.

Table 6. Accounts from settlements in the epicentral area for the earthquake of January 23, 1812.

Cape Girardeau, Mo.
"The concussions of the earthquakes still continue, the shock on the 23rd ult. was more severe and larger than that of the 16th December and the shock of the 7th inst. was still more violent than any preceding, and lasted longer than perhaps any on record."—*Louisiana Gazette,* February 29, 1812, "Cape Girardeau, Feb. 15th, 1812"

New Madrid, Mo.
"The shocks of the 16th December and 23rd of January had done much injury to the houses (though all frame and log) in the town and township of New Madrid."—Anonymous B (1812)
"About sunrise a number of lighter shocks occurred, at which time one more violent than the rest [December 16, 1811; 2:15 a.m.] took place."
"The 23rd of January, 1812, when one occurred as violent as the severest of the former ones."—Bryan (1848)

Uniontown, Ky.
"They [earthquakes] have been extremely severe in this neighborhood. Thirty miles below this [Uniontown] there is a crack in the earth 3 miles in length, several inches wide; and thence down perhaps 150 miles below in New Madrid, the earth (particularly the river bottom and islands) is dreadfully torn to pieces and sunk."—*Martinsburgh Gazette,* February 21, 1812, "Extract of a Letter from a Gentleman in Uniontown, Kentucky, to His Friend in This Place," dated January 31, 1812

Vincennes, Ind.
"No damage done that we have heard of, except two or three brick chimneys that were cracked, and the roofs of several houses thrown off."—*The Western Sun,* December 21, 1811
"On Thursday last about 8 o'clock we had another severe shock of an earthquake, which shook off the top of some chimneys, but no other damage was sustained."—*The Western Sun,* January 25, 1812

were at least as severe as, and most likely more severe than, the January 23 event (Table 6). We interpret these accounts, along with the descriptions of the December 16 and January 23 events in Cape Girardeau, Mo., and the lack of damage to log cabins in southeastern Illinois, to indicate that the epicenter of the January 23 earthquake was not in southeastern Illinois or western Kentucky, but more likely north-northwest of the events on December 16; that is, in southeastern Missouri.

The liquefaction feature that Hough and others (2003) and Mueller and others (2004) cited as evidence for the January 23 event being centered in southeastern Illinois can be readily explained by the February 7 event that is generally believed to have been centered near New Madrid, Mo. The distance between New Madrid and the liquefaction feature in southeastern Illinois is no greater than the distance in the accounts of liquefaction in Cahokia and Kaskaskia, Ill. (Fig. 5). If Ambraseys's (1988) limiting liquefaction curve is assumed (Street and others, 2004; Olson and others, 2005), and if the moment magnitude (**M**) of the February 7 event was 7.6 (or greater, as suggested by most researchers) (Table 1), then the liquefaction in southeastern Illinois, Kaskaskia, and Cahokia can be explained by that event. Another possibility is higher

than expected ground motions in southeastern Illinois as a result of unilateral rupture within the New Madrid Fault Zone, as suggested by Cramer and others (2006). Yearby Land did not specify the date the liquefaction occurred in southeastern Illinois, so attributing the feature to the February 7 event is reasonable.

The final argument we offer as to why we do not believe the epicenter of the January 23 earthquake was in southeastern Illinois is the lack of liquefaction evidence in the Wabash and Ohio River Valley areas (Fig. 1). Obermeier and others (1993), Munson and others (1997), and others described the sediment in the Wabash River Valley as having a high liquefaction susceptibility, which is consistent with the low average blow-count data for the sediments in Uniontown, Ky., listed in Table 2. If an **M** 6.8 earthquake had occurred in southeastern Illinois, as proposed by Mueller and others (2004), there should be other liquefaction evidence of the event besides the one site described by Yearby Land to Berry (1908); but no such evidence was found by Obermeier and others (1993). In addition, a letter written in Uniontown, Ky., on January 31, 1812 *(Martinsburgh Gazette,* February 21, 1812), describes what was lateral spreading along the banks of the Ohio River beginning 48 km downriver from Uniontown and continuing to New Madrid. If the January 23 earthquake had occurred near location 2 in Figure 1, the lateral spreading or other liquefaction phenomena should have been observed in the soft sediments at Uniontown since the distance between Uniontown and location 2 in Figure 1 is less than 40 km. Despite the extensive geotechnical investigation done for the siting of the J.T. Myers Lock and Dam on the Ohio River at Uniontown, no evidence of liquefaction was found at the site by the U.S. Army Corps of Engineers (Ken Henn, U.S. Army Corps of Engineers, written communication, September 21, 2004).

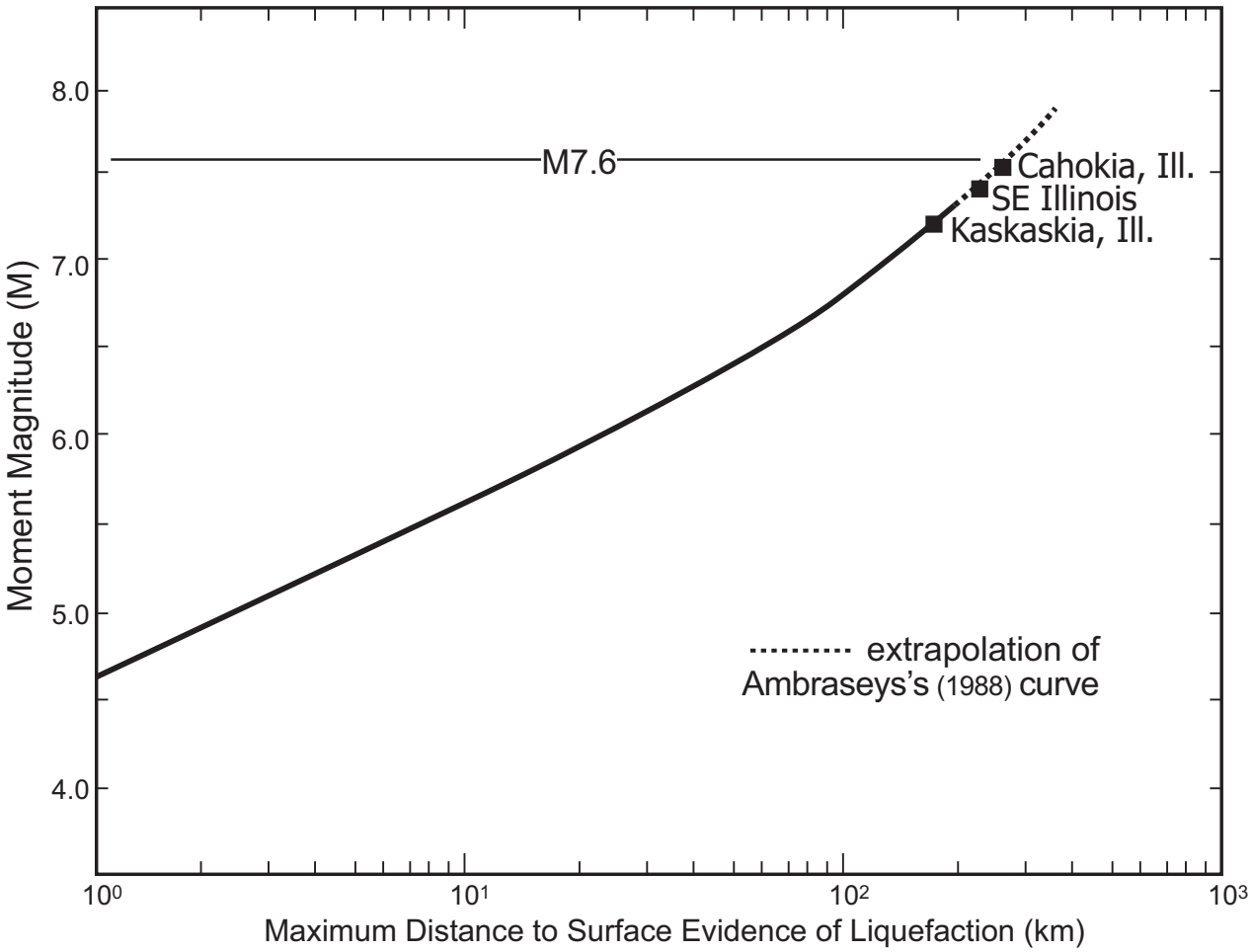

Figure 5. Upper-bound moment magnitude versus maximum distance to surface: evidence of liquefaction relationship for shallow-focus earthquakes (Ambraseys, 1988). Solid squares shown for the liquefaction that occurred at Cahokia, southeastern Illinois, and Kaskaskia, Ill., as a result of the 1811-12 earthquakes are plotted at their respective distances from New Madrid, Mo.

Locations of Selected Aftershocks

As previously stated, many of the aftershocks were significant events in that they were felt throughout much of the central and eastern United States. Table 7 lists the aftershocks of the 1811-12 main events for which magnitudes have been estimated. In general, the aftershocks are believed to have occurred within the general area of the main events in 1811-12. Hough (2001) suggested, however, that the aftershock of January 27 at 9:00 a.m. and those on February 7 at approximately 8:15 and 10:40 p.m. were triggered events whose epicenters were somewhere in northeastern Kentucky or south-central Ohio, a conclusion we disagree with. Figures 6 through 8 show the distribution of the felt reports for the three events, as well as the locations for which there is a general statement that aftershocks were felt when one of the three aftershocks in question occurred. Table 8 summarizes the accounts of the earthquakes for the locations shown in Figures 6 through 8.

Hough (2001) argued that the aftershocks were not centered in New Madrid, in part because of the lack of felt reports from that area. But, as previously discussed, no newspapers were being published in the New Madrid area in 1811-12 (Fig. 2), and few travelers were on the Mississippi River from late December 1811 through the end of January 1812 because of ice on the lower Ohio River, where most of the riverboat trade originated (Johnston and Schweig, 1996). Furthermore, by January 27, the settlement at Little Prairie had been abandoned, and New Madrid was heavily damaged by the earthquakes of December 16. There were two newspapers along what was then the western frontier: The *Louisiana Gazette* (St. Louis) and the *Western Sun* (Vincennes, Ind.) (Fig. 2). Although neither paper published specific accounts about the earthquakes at 8:15 or 10:40 p.m. on February 7, both newspapers reported that several shocks had been felt between the main event at 4:00 a.m. on February 7, when the main event occurred, and February 8, when the newspapers were published (Table 8).

Furthermore, contrary to Hough's (2001) assertion, there were reports of earthquakes being felt in the New Madrid area during the three aftershocks in question. Anonymous B (1812) and Bryan (1848) stated that earthquakes occurred frequently in the New Madrid area between January 23 and February 7, and *The Palladium* (Frankfort, Ky., March 4, 1812) reported that for 3 days after the earthquake at 4:00 a.m. on February 7, the quaking was so severe that a Mr. Veriner, who was at New Madrid when the main earthquake occurred, abandoned his boat and cargo. Shaler (1815) and Speed (1812), who were in New Madrid from February 7 to 12, stated that "the earth was constantly trembling, at intervals of about five minutes" and that "shocks of earthquakes were experienced every 15 to 20 minutes," respectively. Speed (1812) also told of a man trapped on one of the islands near New Madrid from the morning of February 7 through the evening of February 9, dur-

Table 7. Moment magnitude estimates of selected aftershocks.

	Date and Time[1]	*Street and Nuttli (1984)*[2]	*Johnston and Schweig (1996)*	*Hough (2001)*[3], *Hough and Martin 2002)*[4]
1.	December 16, 1811, 3:00 a.m.	5.9–6.3	6.6 ±0.4	
2.	December 16, 1811, 7:15 a.m.	5.3–5.9	5.9 ±0.55	
3.	December 16, 1811, 10:00 a.m.	5.9–6.3	6.2 ±0.55	
4.	December 17, 1811, noon	6.8	7.1 ±0.4	6.1 ±0.2[4]
5.	January 16, 1812, 11:00 p.m.	5.3–5.9	5.6 ±0.55	
6.	January 23, 1812, 11:00 p.m.	5.3–5.9	5.5 ±0.55	
7.	January 27, 1812, 9:00 a.m.	5.3–5.9	6.3 ±0.55	5[3]
8.	February 4, 1812, 5:00 p.m.	5.3–5.9	6.2 ±0.55	
9.	February 7, 1812, 8:15 p.m.	5.3–5.9	6.3 ±0.55	5[3]
10.	February 7, 1812, 10:40 p.m.	6.8	7.0 ±0.55	mid-5[3]
11.	February 10, 1812, 4:00 p.m.	6.2	6.5 ±0.55	
12.	February 11, 1812, 6:00 a.m.	6.2	6.5 ±0.55	

[1]Because of the lack of standardized timekeeping, all times are approximate.
[2]The $m_{b,Lg}$ magnitudes of Street and Nuttli (1984) were converted to **M** by use of the relationships referenced in Table 1.
[3]Hough (2001)
[4]Hough and Martin (2002)

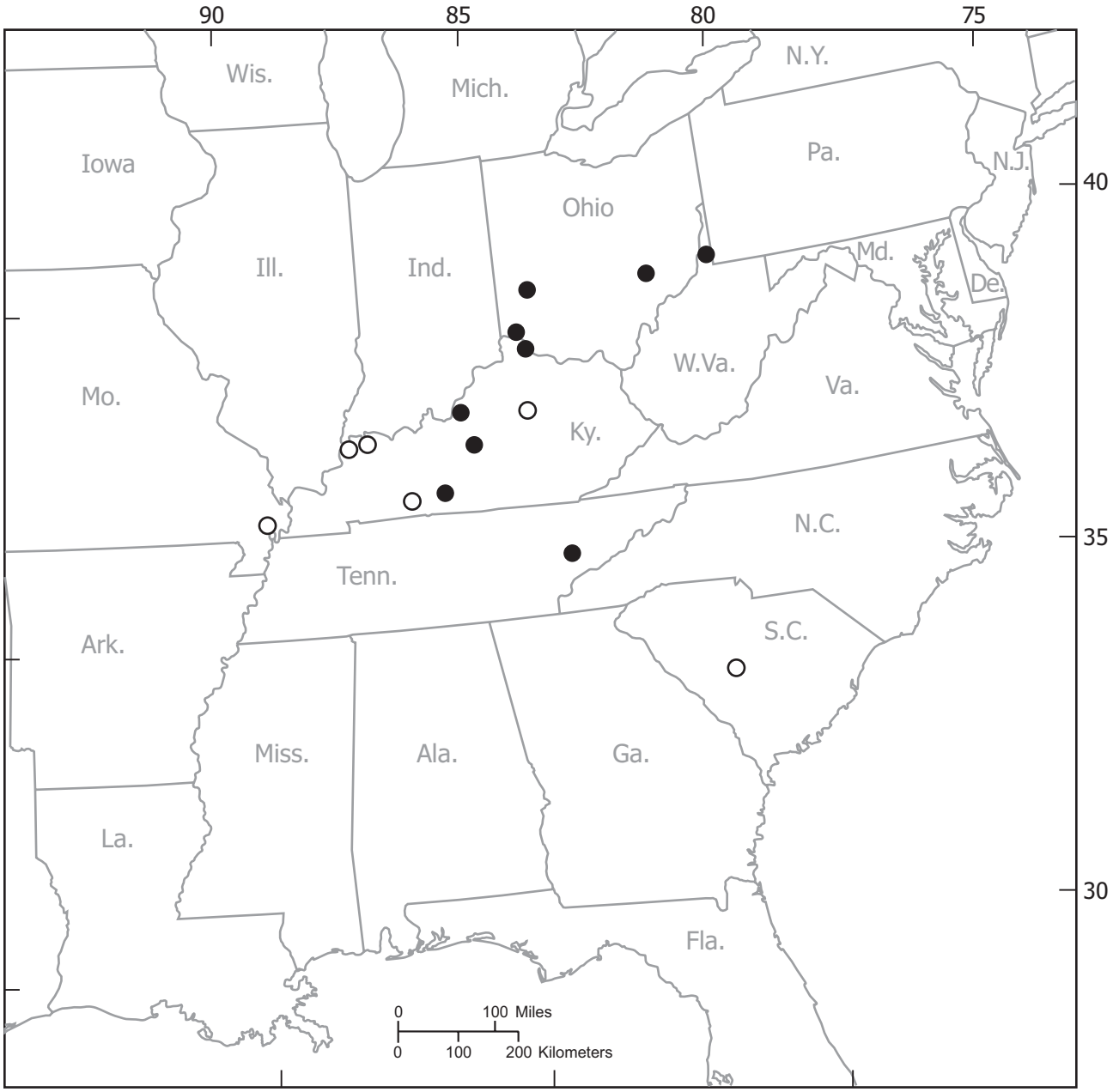

Figure 6. Locations that specifically reported the aftershock of January 27, 1812, at approximately 8:45 a.m. (local time) as being felt (●), and locations that reported earthquakes being felt during a time span that included the aftershock (○).

ing which time there were several earthquakes, some violent enough to cause eruptions of sandblows and, in one case, a deep fissure in the island. Consequently, severe earthquakes were occurring in the New Madrid area when the three aftershocks in question occurred, and some of the aftershocks in the New Madrid area between February 7 and 12 were large enough to induce liquefaction.

An earthquake large enough to induce liquefaction would have most likely been felt throughout the central and eastern parts of the United States. The **M** 5.9 to 6.2 Charleston, Mo., earthquake of October 31, 1895, induced liquefaction in an area about 35 to 45 km north-northeast of New Madrid, and was felt as far east as Charleston, S.C. (Hopper and Algermissen, 1980; Stover and Coffman, 1993; Street and others, 2004). The outer limit of the felt area for the 1895 event as estimated by Stover and Coffman (1993) is represented by the dashed-line contours in Figures 7 and 8. Judging by the fit of the felt reports (solid circles) for

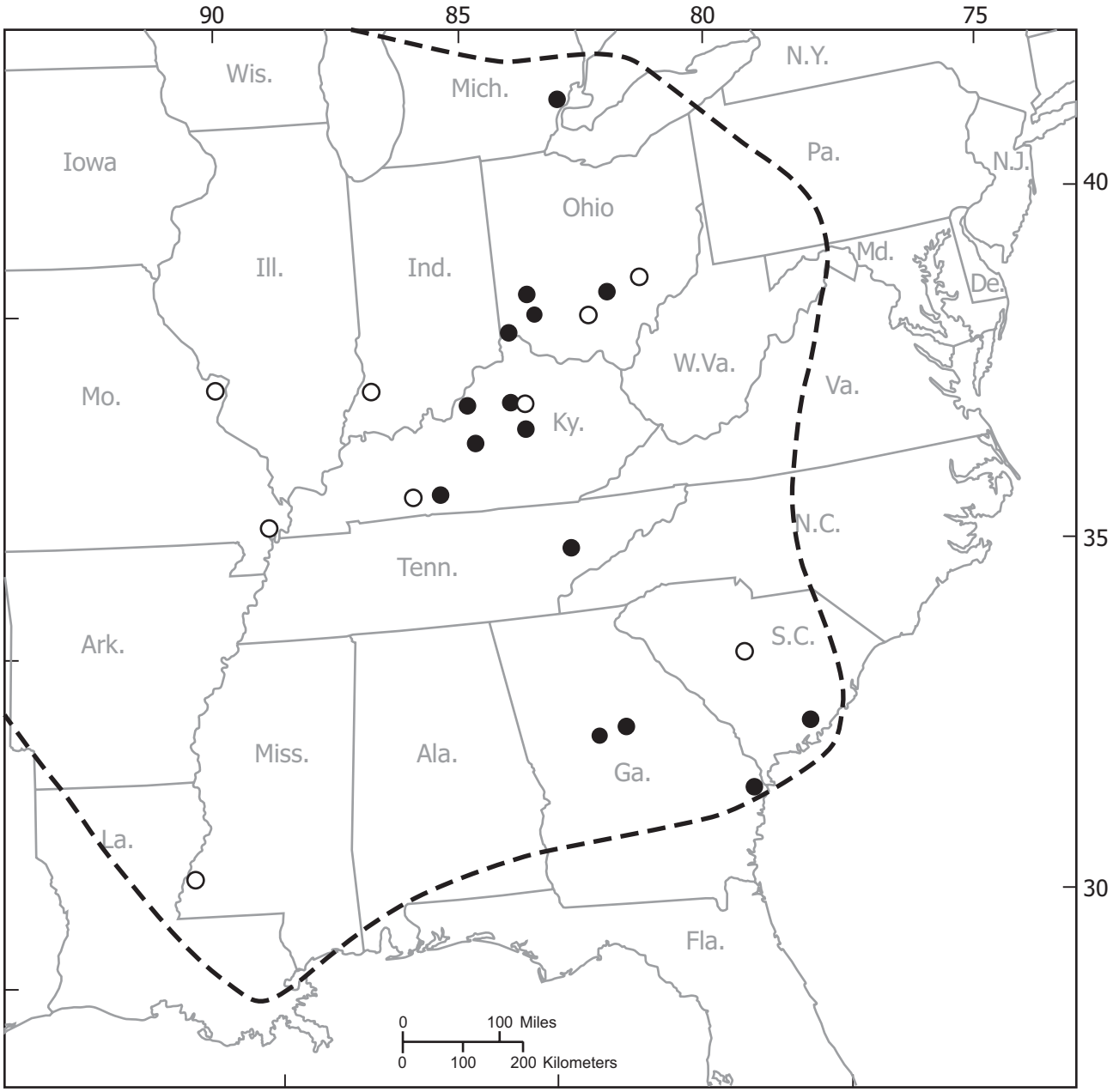

Figure 7. Locations that specifically reported the aftershock of February 7, 1812, at approximately 8:15 p.m. (local time) as being felt (●), and locations that reported earthquakes being felt during a time span that included the aftershock (○). The dashed line indicates the outer limit of the felt area of the October 31, 1895, Charleston, Mo., earthquake.

the February 7, 1812, event at 8:15 p.m. to the dashed-line contour in Figure 7, the 8:15 p.m. event was similar in magnitude to the 1895 event. For the earthquake at 10:40 p.m. on February 7, 1812, several of the felt reports for that earthquake lie outside of the limit of the felt area for the 1895 earthquake (Fig. 8). The fact that this earthquake was felt in New York as well as in several locations in North Carolina and Virginia leads us to conclude that it was a large event, somewhat larger than the 1895 event, and more comparable in size to the earthquake on December 17, 1811 (Fig. 9), that Johnston and Schweig (1996) estimated to be an **M** 7.1 $\pm$0.4 event. The two events on the evening of February 7, 1812, were large, and damaging or severe ground motions would have been noticeable at the epicenter of the event. The only reports of damaging or severe ground motions that we are aware of at about the time of the earthquakes at 8:15 and 10:40 p.m. on February 7, 1812, are the reports of liquefaction at New Madrid.

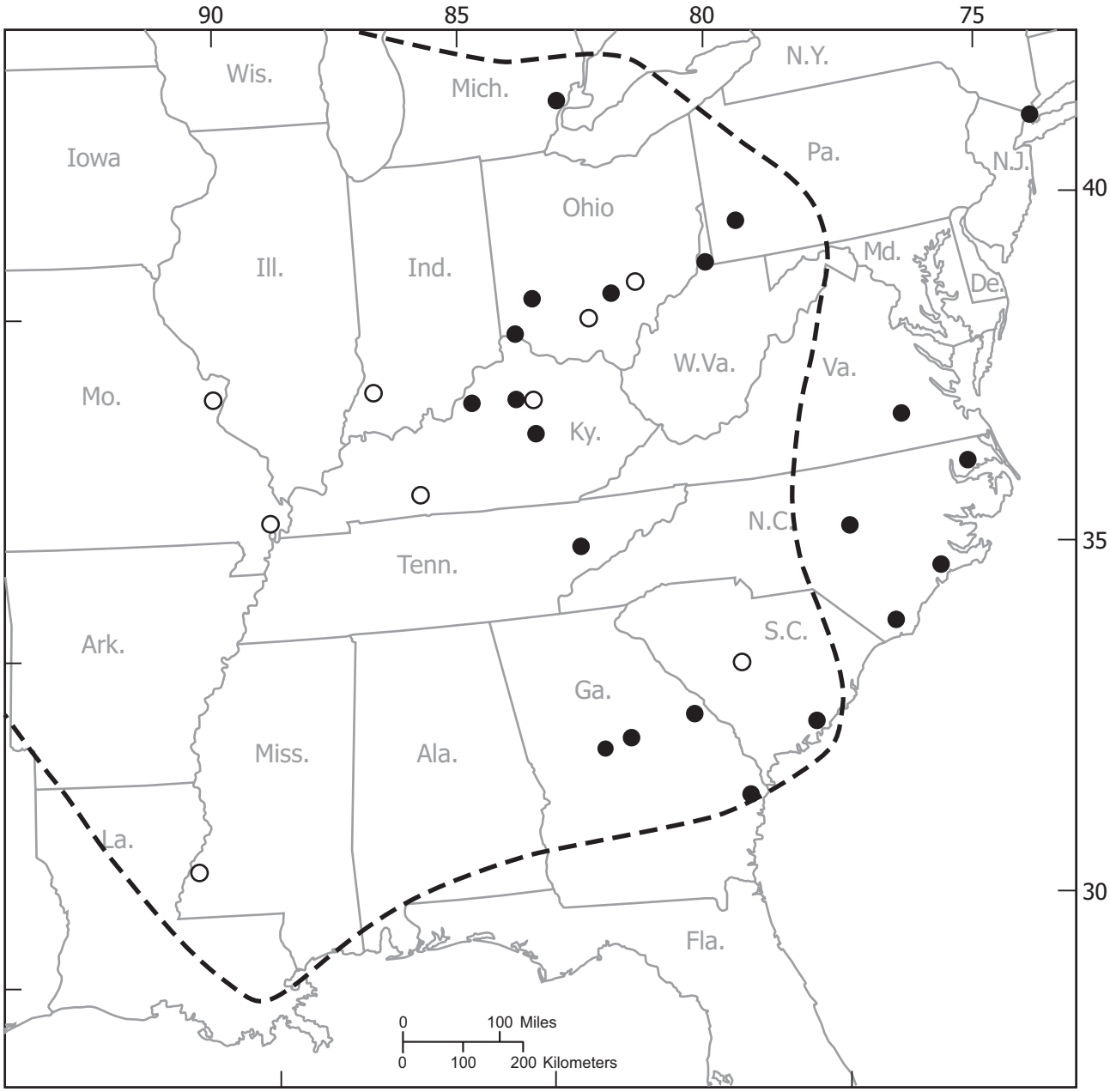

Figure 8. Locations that specifically reported the aftershock of February 7, 1812, at approximately 10:30 p.m. (local time) as being felt (●), and locations that reported earthquakes being felt during a time span that included the aftershock (○). The dashed line indicates the outer limit of the felt area of the October 31, 1895, Charleston, Mo., earthquake.

For this reason, we believe that the epicenters of the two earthquakes were in the New Madrid area.

Hough (2001) also suggested that the earthquake on January 27, 1812, at 9:00 a.m. was centered somewhere in northeastern Kentucky or south-central Ohio. As part of her argument, she cited the descriptions of how the events were felt in Cincinnati and Louisville by Drake (1815) and Brooks (1819), respectively. Hough (2001) correctly cited Drake (1815) as describing the event in Cincinnati as "a single vibration of only a few seconds duration," and Brooks (1819) describing the event in Louisville as a "violent shock, as sudden as the arrival of a cannon shot, it gave but one blow, as it were, and was for an instant severe." But Brooks went on to state that the earthquake "gradually subsided and trembled away in about one minute; in two minutes strengthened to a threatening pitch (slow motion) but soon eased away." Brooks's complete description suggests that the January 27 event was a distant event, and in fact his description of the January 27 event is

Table 8. Sources of information on felt reports for the earthquakes at noon on December 17, 1811, at 8:45 a.m. on January 27, 1812, and at 8:30 and 10:40 p.m. on February 7, 1812.	
December 17, 1811 (noon) (●) Localities for which there is a report that specifically states the event was felt.	
Augusta, Ga.	*Mirror of the Times* (Augusta), December 23, 1811
Charleston, S.C.	*New York Spectator,* January 4, 1812
Chillicothe, Ohio	*The Supporter* (Chillicothe), December 21, 1811
Cincinnati, Ohio	*Liberty Hall* (Cincinnati), December 18, 1811
Chickasaw Bluffs, Tenn.	*Liberty Hall* (Cincinnati), January 5, 1812
Columbia, S.C.	*The Enquirer* (Richmond, Va.), January 4, 1812
Fort Massac, Ill.	Anonymous C (1812)
Fort St. Stephens, Ala.	*The Western Intelligencer* (Worthington, Ohio), December 17, 1811
Fort Wayne, Ind.	*The Western Spy* (Cincinnati), February 22, 1812
Georgetown, S.C.	*Kentucky Reporter* (Lexington, Ky.), January 11, 1812
Louisville, Ky.	Brooks (1819)
Marietta, Ohio	*The Western Spectator* (Marietta), December 21, 1811
Meadville, Pa.	*Pittsburgh Gazette*, December 27, 1811
Natchez, Miss.	*Louisiana Gazette* (St. Louis), December 31, 1811
Natchitoches, La.	*Philadelphia Aurora and General Advertiser,* February 29, 1812
New Bourbon, Mo.	*Otsego Herald* (Cooperstown, N.Y.), March 28, 1812
Pittsburgh, Pa.	*Hampshire Federalist* (Springfield, Mass.), January 23, 1812
Raleigh, N.C.	*Raleigh Minerva,* December 27, 1811
St. Louis, Mo.	*Louisiana Gazette* (St. Louis), December 21, 1811
Savannah, Ga.	*The Ohio Centinel* (Dayton, Ohio), February 6, 1812
Wheeling, W.Va.	Anonymous C (1812)
Zanesville, Ohio	*Muskingum Messinger* (Zanesville), February 6, 1812
(○) Accounts from localities that are reported to have felt earthquakes on or about the time of the December 17, 1811, noon event.	
Carthage, Tenn.	Mitchill (1815): “There were two or more shocks every twenty-four hours, from the first mentioned one [December 16], until the night of Jan. 1, 1812.”
Clarksville, Tenn.	*The Times* (Charleston, S.C.), January 29, 1812: “On Saturday night, the 15th, we experienced the effects of an alarming earthquake—the shocks which continue to be felt at this time [December 20].”
Dayton, Ohio	*The Ohio Centinel* (Dayton), December 19, 1811: “The earth must have been in a constant tremor on Monday and Tuesday. A surveyor went out Monday for the purpose of surveying a road in the neighborhood of this place, but being unable to get the needle to settle, he was obliged to desist. He tried it again on Tuesday [December 17] with the same effect.”
Fort Osage, Mo.	*Philadelphia Aurora and General Advertiser,* February 29, 1812: “Since the 16th we have had various other shocks still less severe but very perceptible” [extract of a letter written on December 31].
Frankfort, Ky.	*American Republic* (Frankfort), December 18, 1811: “The shock has since [December 16] been repeated, on Monday, on Tuesday, with irregular impulses on Monday and Tuesday, as often as seven times.”
Lancaster, Ohio	Anonymous C (1812): “Since writing the above [accounts of the earthquakes on December 16], we have felt several slight shocks.”

Table 8. Sources of information on felt reports for the earthquakes at noon on December 17, 1811, at 8:45 a.m. on January 27, 1812, and at 8:30 and 10:40 p.m. on February 7, 1812.	
Nashville, Tenn.	*Mirror of the Times* (Augusta, Ga.), January 27, 1812, in an article with the dateline Nashville, Tenn., December 20, 1811: "Several slight shocks have been felt since [December 16]."
Vincennes, Ind.	*The Western Sun* (Vincennes), December 21, 1811: "Several shocks of an earthquake have been felt this week—Monday [December 16] morning last (3 o'clock) there were three within a few minutes of each other,—another was felt at sunrise and several more that day—more or less have been felt every day since."
January 27, 1812 (8:45 a.m.) (●) Localities for which there is a report that specifically states the event was felt.	
Cincinnati, Ohio	*Liberty Hall* (Cincinnati), January 29, 1812
Dayton, Ohio	*The Ohio Centinel* (Dayton), January 30, 1812
Hodgenville, Ky.	Pusey (1930)
Knoxville, Tenn.	*The Enquirer* (Richmond, Va.), February 6, 1812
Louisville, Ky.	Brooks (1819)
Newport, Ky.	*United States Gazette* (Philadelphia), February 7, 1812
Wheeling, W.Va.	Anonymous C (1812)
Zanesville, Ohio	*The Messenger* (Zanesville), January 29, 1812
(○) Accounts from localities that are reported to have felt earthquakes on or about the time of the January 27, 1812, 8:45 a.m. event	
Columbia, S.C.	Anonymous C (1812): "Several slight shocks have been felt since." Statement is referring to earthquakes felt between the main shock of January 23 and January 28, when the newspaper article cited was written.
Henderson, Ky.	Audubon (1897): "Shock succeeded shock day or night for several weeks." Statement is referring to earthquakes felt after the events on December 16.
Lexington, Ky.	*Kentucky Gazette* (Lexington), January 28, 1812: "Several other shocks are said to have been felt since." Statement is referring to the time between when the main shock of January 23 occurred and January 28, when the article was written.
New Madrid, Mo.	*Philadelphia Aurora and General Advertiser*, June 4, 1812: "The light and less frequent shocks, which had been felt since the 23rd January to that date [February 7] …." Bryan (1848): "From this time [January 23] until the 4th of February, the earth was in a continued state of agitation …."
Russellville, Ky.	Anonymous C (1812): "An earthquake equally as considerable as the one felt about five weeks since, was felt at this place on Thursday morning last, at eight o'clock, and several slight ones have been felt since" [written on January 29, 1812].
Uniontown, Ky.	*Martinsburgh Gazette* (Martinsburgh, Va.), February 21, 1812: "We have been ever and ever terrified with earthquakes since the 16th of December which are still felt every day more or less" [written on January 31].
February 7, 1812 (8:30 and 10:40 p.m. events) (●) Localities for which there is a report that specifically states the event(s) was felt.	
Augusta, Ga.	*New York Evening Post,* March 5, 1812. Article does not mention the event at 8:30 p.m.
Charleston, S.C.	*The Times* (Charleston), February 8, 1812
Cincinnati, Ohio	*The Western Spy* (Cincinnati), February 8, 1812 *Liberty Hall* (Cincinnati), February 12, 1812. Article does not mention the event at 10:40 p.m.
Dayton, Ohio	*The Ohio Centinel* (Dayton), February 13, 1812
Detroit, Mich.	Fuller (1912)

Table 8. Sources of information on felt reports for the earthquakes at noon on December 17, 1811, at 8:45 a.m. on January 27, 1812, and at 8:30 and 10:40 p.m. on February 7, 1812.	
Edenton, N.C.	*Edenton Gazette,* February 11, 1812. Article does not mention the event at 8:30 p.m.
Frankfort, Ky.	*The American Republic* (Frankfort), February 14, 1812
Goshen, Ohio	Mortimer (1812)
Hodgenville, Ky.	Pusey (1930)
Knoxville, Tenn.	*Wilson's Knoxville Gazette,* February 10, 1812
Lancaster, Ohio	Anonymous C (1812)
Louisville, Ky.	Brooks (1819)
Macon (Fort Hawkins), Ga.	www.rootsweb.ancestry.com/~gajones/hawkins.htm. No mention of the event at 8:30 p.m.
Milledgeville, Ga.	*The Georgia Journal* (Milledgeville), February 12, 1812
New Bern, N.C.	Anonymous C (1812). Article does not mention the event at 8:30 p.m.
New York, N.Y.	*New York Spectator,* February 8, 1812. Article does not mention the event at 8:30 p.m.
Pittsburgh, Pa.	*The Western Spy* (Cincinnati), February 22, 1812. Articles does not mention the event at 8:30 p.m.
Raleigh, N.C.	*Raleigh Register,* February 21, 1812. Article does not mention the event at 8:30 p.m.
Richmond, Ky.	*The Luminary* (Richmond), February 8, 1812
Richmond, Va.	*Raleigh Register* (Raleigh, N.C.), February 21, 1812. Article does not mention the event at 8:30 p.m.
Savannah, Ga.	*Savannah Republican,* February 8, 1812
South Union, Ky.	Tommy Hines, Director, Shaker Museum, South Union, Ky., personal communication, April 28, 2005. No mention of the event at 10:40 p.m.
Wheeling, W.Va.	Anonymous C (1812)
Wilmington, N.C.	*Charleston Courier* (Charleston, S.C.), February 14, 1812. Article does not mention the event at 8:30 p.m.
(○) Accounts from localities that are reported to have felt earthquakes on or about the time of the February 7, 1812, events at 8:30 and 10:40 p.m.	
Chillicothe, Ohio	*The Supporter* (Chillicothe), February 8, 1812: "Several shocks have been felt since our last publication [February 1]; but the one described above [February 7] was much severer than any hereto forth felt in this place."
Columbia, S.C.	*New York Spectator,* March 11, 1812: "In the early part of the night following [the evening of February 7], two single shocks were felt, which so alarmed the inhabitants of that place that they would not venture to bed at all, and those that did slept in their clothes."
Lexington, Ky.	*Kentucky Gazette* (Lexington), February 11, 1812: "On the morning of Thursday [should be Friday] last [February 7] about half past three o'clock, another violent shock of an earthquake was felt in this place…. Several shocks of less force have been noticed since."
Natchez, Miss.	*Natchez Gazette,* February 13, 1812: "Several shocks, though violent, have been felt in this city within 8 or 10 days past."
New Madrid, Mo.	*Pennsylvania Gazette* (Philadelphia), March 18, 1812: "I [Mathius Speed] remained at New Madrid from the 7th to the 12th [February 1812] during which time I think shocks of earthquakes were experienced every 15 to 20 minutes."
Russellville, Ky.	Anonymous C (1812): "On Friday night [February 7] there were three light ones and we have several times felt moderate shocks."

Table 8. Sources of information on felt reports for the earthquakes at noon on December 17, 1811, at 8:45 a.m. on January 27, 1812, and at 8:30 and 10:40 p.m. on February 7, 1812.	
St. Louis, Mo.	*Louisiana Gazette* (St. Louis), February 8, 1812: "On Thursday [should be Friday] last between 2 and 3 o'clock, we experienced the most severe shock of an earthquake that we have yet felt, many houses injured, and several chimneys thrown down; few hours past without feeling slight vibrations of the earth."
Vincennes, Ind.	*The Western Sun* (Vincennes), February 8, 1812: "On Friday morning the 7th inst. [February 7] at 15 minutes after 2 o'clock, we experienced another heavy shock of an Earthquake, it shook off the tops of several chimneys, without doing any injury that we learnt—Since which several have been felt, though much lighter than the first."
Zanesville, Ohio	*The Muskingum Messenger* (Zanesville), February 12, 1812: "A number of slight shocks have been felt since, sometimes two or three a day" [refers to the time from when the main event was felt on February 7 to February 12, when the paper was published].

very similar to how some of the other shocks were described in the southern Ohio area. Williams (1811), for example, described the December 16 event at 2:00 a.m. in Chillicothe, Ohio, as being two shocks, with the first one being severe, followed by a second shock 2 or 3 minutes later that was more violent and seemed to threaten the tottering houses. Because earthquakes were occurring frequently in the New Madrid area in January 1812 (Anonymous B, 1812; Bryan, 1848) and because Brooks's (1819) complete description of the January 27 event suggests that it was a distant earthquake, we believe that the epicenter of the January 27 aftershock at 9:00 a.m. was most likely in the New Madrid area.

We also disagree with Hough and Martin's (2002) conclusion that the epicenter of the aftershock shortly before noon on December 17, 1811 (Fig. 9), was in western Tennessee or northeastern Arkansas along the southwest-trending band of seismicity identified by Chiu and others (1997) as the Crittenden County Fault Zone (Fig. 1). Hough and Martin (2002) based their conclusion in part on the descriptions of the event given by Pierce (1812), Bradbury (1819), and an unidentified person (Anonymous D, 1812) who posted a letter at Chickasaw Bluffs (Fig. 3) on December 21, 1811. But what Hough and Martin (2002) failed to take into consideration is that the accounts of the earthquake are from three people floating down the Mississippi River on flatboats at the time of the earthquake. Bradbury (1819) was at the head of Devils Channel (also referred to as Devil's Race Ground) (Fig. 3) on the morning of December 16. He floated down the river on the 16th, tied up for the night, and was again floating downriver on the 17th when the aftershock at noon occurred. Bradbury (1819) described the aftershock as being "a severe shock of long duration." Pierce (1812) stated that he had been tied up to an island 186 km below the mouth of the Ohio River on the morning of December 16, and floated down the river on the 16th until 3:00 p.m. At that time he "tied up to some willows at the extremity of some sunken land (an island)" and remained there for the next 2 days. He described the aftershock as being "a long and dreadful shock, that appeared threatening." As for Anonymous D, the person who posted the letter at Chickasaw Bluffs on December 21, and the source of Hough and Martin's (2002) modified Mercalli intensity of VII, he was in command of a barge that on the morning of December 16 was anchored 27 km below New Madrid. On the 16th he had floated downriver, and was again underway on December 17 when the aftershock shortly before noon occurred. He stated that "the first and second vibrations [those at 2:15 a.m. and daylight on December 16], and that between 11 and 12 o'clock on the 17th, were the most violent."

Two other people, Bedinger (1812) and Foster (1812), who were floating down the Mississippi River on a flatboat in December 1811 also wrote accounts of the aftershock at noon on December 17. Bedinger (1812) stated that the flatboat he was traveling on was just below Bayou River (Fig. 3) when he experienced an aftershock that was "severe and of a long duration." On the other hand, Foster (1812), who was traveling on the same flatboat as Bedinger, described the aftershock "as being heavy, but of only 5 or 6 seconds in duration."

Based on the descriptions of where they were on the Mississippi River on December 16, and the assumption that they floated downriver about 56 to 64 km, Anonymous D (1812), Bedinger (1812), Foster (1812), and Pierce (1812) were probably all within the general vicinity of Islands 25 to 27 (Fig. 3) at noon on December 17; Bradbury (1819) was probably in the general vicinity of Island 40 (Fig. 3). Regardless of where the travelers were, Hough and Martin's (2002) use of the modified Mercalli intensity scale to assess the accounts of Anonymous D (1812), Pierce (1812), and Bradbury (1819) is inappropriate because the people were on

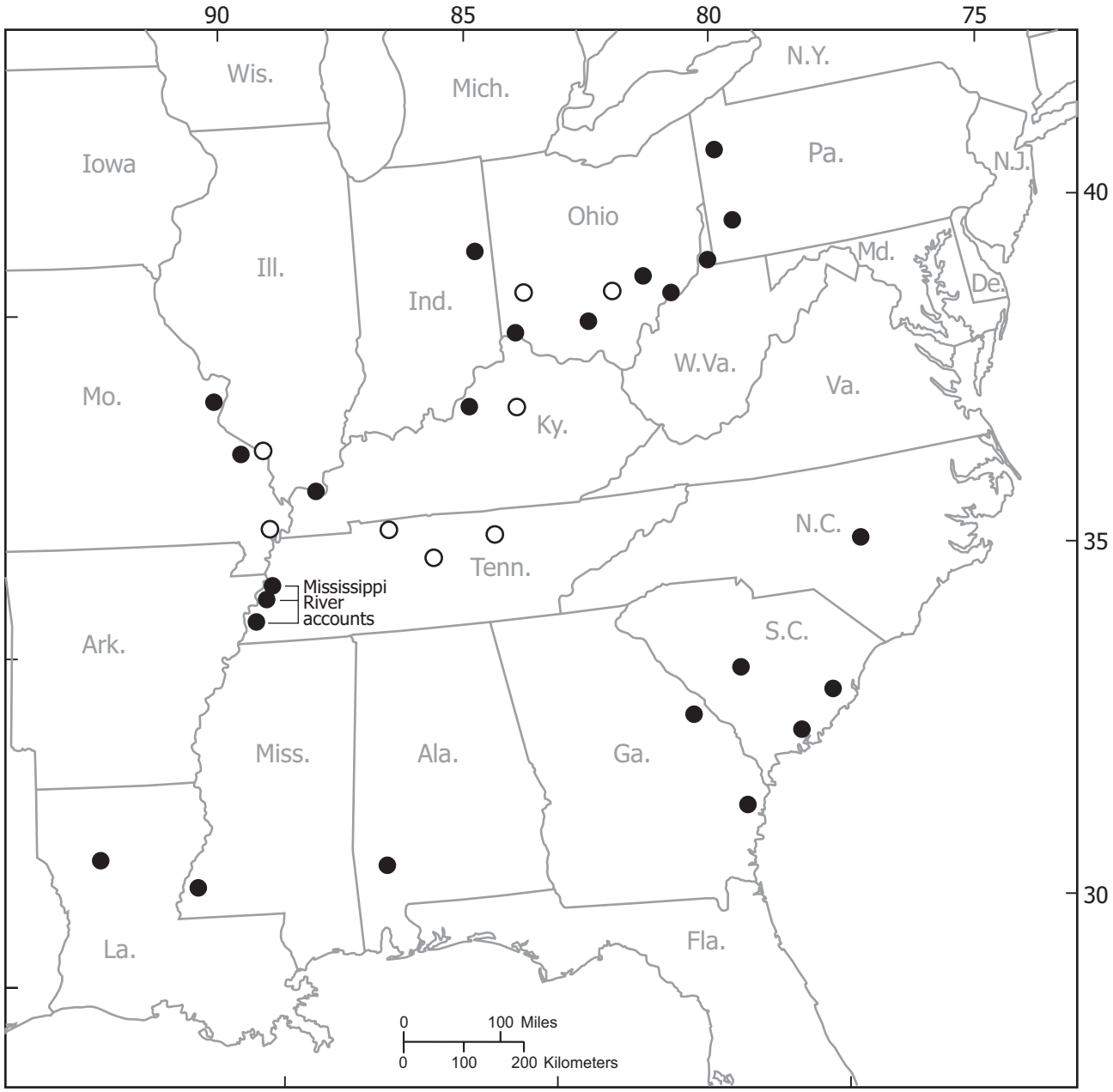

Figure 9. Locations that specifically reported the aftershock of December 17, 1811, at noon (local time) as being felt (●), and locations that reported earthquakes being felt during a time span that included the aftershock (○).

flatboats on the Mississippi River, which in 1811 was in a wilderness area, and they were not in a position to observe such things as the damage or lack of damage to chimneys.

The only two descriptions of the effects of the December 17 aftershock in the settlements along the Mississippi River are those by Moore (1811) of New Bourbon, Mo., and a mention of the event by the *Louisiana Gazette* that the event was felt in St. Louis. In New Bourbon (Fig. 2), Moore (1811) described the aftershock as lasting 2 minutes and being severe. In St. Louis, the *Louisiana Gazette* (December 21, 1811) stated that at about noon on December 17 a "smart shock" was felt there. No other accounts describe the effects of the aftershock in the settlements along the Mississippi River. Given the lack of information about the earthquake in these settlements, and the fact that the accounts by Anonymous D (1812), Bedinger (1812), Foster (1812), Pierce (1812), and Bradbury (1819) were written by people in a wilderness area while floating

down the Mississippi River, we conclude that there is insufficient information for suggesting a location for the aftershock at noon on December 17, other than to say that based on the presently available information, it most likely was centered in the New Madrid Seismic Zone, and most likely south of New Madrid.

Magnitudes of the Main Shocks

Estimating the magnitude of a historical event is always difficult because of the need to subjectively estimate the modified Mercalli intensities of what is usually a limited number of firsthand accounts, and to convert these estimates into a magnitude. Hough and others (2000) concluded that the magnitudes estimated for the 1811-12 earthquakes by Nuttli (1973a), Street (1982), and Johnston (1996) were biased upward because site effects had not been taken into consideration. Although site effects undoubtedly played a significant role in the damage resulting from the 1811-12 earthquakes, little attention has been given to the role that the types of construction played in the interpretation of the modified Mercalli intensities for the frontier settlements. For example, the modified Mercalli intensities at Henderson, Ky., were estimated by Bakun and Hopper (2003) as typically being 0.68 ($\pm$0.02) units higher than expected because of site effects. But the buildings in Henderson in 1811-12 were not the wood-frame and brick buildings of the latter half of the 19th and 20th centuries. In 1811-12, Henderson was a small frontier settlement with a population of 157 and a few log cabins, a type of construction that was not very susceptible to being damaged by an earthquake. Site effects were almost certainly a factor in the effects of the 1811-12 earthquakes at Henderson and the other frontier settlements along the lower Ohio River, such as Fort Massac, Old Shawneetown, and Uniontown (Fig. 2), since they are underlain by low shear-wave-velocity soils (Table 2). But site corrections are not the only thing that affected the modified Mercalli intensity estimates for the frontier settlements of 1811-12. The intensities were also a product of the log cabins in those settlements resisting damage from earthquake-induced ground motions.

Furthermore, if site effects are used to adjust the modified Mercalli intensities for the settlements affected by the 1811-12 earthquakes, they need to be determined for the areas occupied by the settlements in 1811-12. For example, St. Louis in 1811-12 was a small settlement of approximately 1,200 people living in post-on-sill and log cabins, and in an area where the foundation conditions consist of 6 m of clayey residuum and chert gravel overlying St. Louis Limestone (Table 2); site effects would have been minimal. Today, St. Louis is spread out over a much larger area than in 1811-12, and includes areas that are part of former floodplains of the Mississippi River. Thus, site effects would play a greater role in St. Louis today.

Based on ongoing research, we also know that the damage area of the 1811-12 earthquakes is larger than previously believed. Mistakes have been made in the documentation of damage and lack of damage to buildings that still exist from that time (Table 4), there has been a general lack of appreciation of how resistant log cabins in the frontier settlements were to ground motions (as noted above), and recently discovered evidence shows earthquake-related damage to buildings well outside the previously believed damage area associated with the 1811-12 earthquakes (e.g., Gov. Harrison's home in Vincennes, Ind., *The Vincennes Weekly Western Sun,* October 25, 1873; Gov. Garrard's home near Paris, Ky., www.shawhan.com/ruddlesprecinct.html. Damage at the two homes cannot be associated with a specific earthquake in the 1811-12 sequence, but nonetheless damage to those structures, as well as the other reports of damage listed in Table 4, indicates that the area of damage that resulted from the earthquake sequence is larger than previously believed.

Conclusions

We have attempted to point out the need to evaluate the 1811-12 New Madrid earthquakes in the historical context in which they occurred. Accounts of the effects of an earthquake by people floating on a flatboat down the Mississippi River in what was then a wilderness cannot be used to estimate a modified Mercalli intensity. Log cabins, which were common in the frontier settlements in the central United States in 1811-12, were not easily damaged by ground motions resulting from an earthquake, and the response of a log cabin to an earthquake is not part of the modified Mercalli intensity scale. Site effects did play a significant role in the felt and damage reports of the earthquakes, but such effects are site-specific and should not be extrapolated over any distance without taking changes in the site geologies into consideration. There were newspapers in what is now the central United States, but not many, and they were all weeklies with limited readership. Unlike today's newspapers, the newspapers in 1811-12 did not send out reporters to collect information and, in general, did not give detailed accounts of the local effects of the earthquakes or report on the effects of the earthquakes in nearby settlements. Most of the more detailed information on the effects of the earthquakes in various areas comes from letters written by people who lived in or were traveling through the area.

Based on the historical accounts, we conclude that the January 23, 1812, earthquake most likely occurred in the northern part of the New Madrid Seismic Zone in southeastern Missouri, and not in western Kentucky or southeastern Illinois, as suggested by Hough and others (2003) and Mueller and others (2004). We also conclude that the earthquake on January 27 and the two on February 7, which Hough (2001) suggested were triggered earthquakes in northeastern Kentucky or south-central Ohio, were centered in the New Madrid area, where severe aftershocks were regularly occurring at the same time earthquakes were felt in and about northeastern Kentucky, as well as elsewhere in the central and eastern parts of the United States.

As listed in Table 1, various magnitudes have been estimated for the main shocks of the 1811-12 earthquake sequence. We favor a magnitude more toward the higher end of the estimates, rather than the lower estimate of Hough and others (2000). This is because the modified Mercalli intensities for some of the frontier settlements are based on the lack of damage to log cabins, which are very resistant to earthquake ground motions, and because damage to Gov. Harrison's home in Vincennes, Ind., indicates the damage caused by the earthquakes extended farther than has been previously documented.

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