Observed Seismicity (Earthquake Activity) in the Jackson Purchase Region of Western Kentucky: January through June 2003

Zhenming Wang

Edward W. Woolery

Baoping Shi

Kentucky Geological Survey

University of Kentucky

Lexington, Kentucky

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For further information contact:
Manager, Communications & Technology Transfer
Kentucky Geological Survey
228 Mining & Mineral Resources Building
University of Kentucky
Lexington, KY 40506-0107

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Mission Statement

Our mission is to increase knowledge and understanding of the mineral, energy, and water resources, geologic hazards, and geology of Kentucky for the benefit of the Commonwealth and Nation.

Earth Resources—Our Common Wealth

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Executive Summary

Although it has not been proven that the active faults of the New Madrid Seismic Zone extend into the Jackson Purchase Region of western Kentucky, such extension was considered to be the case in many seismic hazard assessments, including those by the U.S. Geological Survey and Risk Engineering, Inc., of Boulder, Colo. This is one of the reasons that western Kentucky, the Jackson Purchase Region in particular, has high estimates of seismic hazard. The issue of whether or not the active faults of the New Madrid Seismic Zone extend into the Jackson Purchase Region is also extremely important with regard to the siting of critical facilities.

In the central United States, the best information for determining seismogenic faults (faults that are capable of generating earthquakes) is seismicity (earthquake activity). Until recently, the lack of seismic stations in the area has precluded any definitive determination of the northeastern extension of the active faults of the New Madrid Seismic Zone. In order to better monitor and locate earthquakes, a temporary seismic network was deployed in the Jackson Purchase Region between late December 2002 and early January 2003, with support from the Kentucky Consortium for Energy and the Environment. The Kentucky Geological Survey continues to maintain and operate the network.

Since January 2003, the network has recorded many local, regional, and worldwide earthquakes. An evaluation of the recorded data showed that the network is working properly. Only one earthquake, the June 6, 2003, Bardwell earthquake, with magnitude M4.0, occurred in the Jackson Purchase Region between January 1 and June 30, 2003. Analysis of the recorded data from the event revealed that the Bardwell earthquake was quite shallow, only about 2.3 km beneath the surface, which is significantly shallower than the focal depth (23.7 km) of the Blytheville, Ark., earthquake (magnitude M4.0) on April 30, 2003, which was located about 135 km southeast of Bardwell in the central New Madrid Seismic Zone.

Although 6 months of seismic monitoring is not long enough to make a scientifically defensible conclusion, the observed seismicity suggests that the active faults of the New Madrid Seismic Zone may not extend into the Jackson Purchase Region of western Kentucky. A much longer time is needed for seismic monitoring in the area to reach a definite conclusion. Continuous seismic monitoring is important for the economic development of western Kentucky.

Introduction

The Federal government uses seismic hazard maps produced by the U.S. Geological Survey (Frankel and others, 1996) for seismic safety design. The maps currently being used show the ground motion with 2 percent probability of being exceeded (PE) in 50 years, or once in about 2,500 years. The maps predict very high ground motion for western Kentucky, the Jackson Purchase Region in particular. They show peak ground acceleration (PGA) of about 1.0g (or 1 times the acceleration due to gravity) near Paducah. The maps were used for seismic design in the 2000 International Building Code and the 2000 International Residential Code. IBC-2000 and IRC-2000 use a design ground acceleration near Paducah of about 0.6g. Currently, the highest building design acceleration used in California is 0.4g. Thus, the use of the USGS hazard maps has resulted in higher seismic design in the Paducah area than anywhere in California, even though it is well documented that California has higher seismic hazard and risk.

More than 20 years of observation and research at the University of Kentucky have shown that using the ground motion with 2 percent PE in 50 years results in a seismic hazard prediction for western Kentucky, especially the Jackson Purchase Region, that is too high. One of the reasons for such high ground-motion estimates for the Jackson Purchase Region is the postulated extension of the northern boundary of the New Madrid Seismic Zone. Although it has not been proven that the active faults of the New Madrid Seismic Zone extend into the Jackson Purchase Region, such extension was considered to be the case in many seismic hazard assessments, including the ones by the U.S. Geological Survey (Frankel and others, 1996) and Risk Engineering, Inc. (1999). The postulated northeast extension of the active faults of the New Madrid Seismic Zone also has a significant impact on siting of critical facilities in the Jackson Purchase Region. For the central United States, the best information for determining seismically active zones and faults is seismicity. Until recently, the lack of a dense seismic network in the area has precluded any definitive determination of the northern boundary of the New Madrid Seismic Zone.

With partial support from the Kentucky Consortium for Energy and the Environment, a preliminary seismic hazard assessment for the Jackson Purchase Region was conducted between October 1 and December 31, 2002, in order to provide information for policy- and decision-makers (Wang and Woolery, 2003; Appendix A). Seven sites in the Jackson Purchase Region were also selected for installation of new seismic stations (Wang and Woolery, 2003). These new seismic stations, combined with previously installed seismic stations, were designed to better monitor and locate earthquakes that occur in the area. These data will allow researchers to accurately characterize seismogenic depths and geologic structures. Furthermore, the results obtained so far demonstrate why it is vitally important to install and operate a *dense seismic network* covering the northern boundary of the New Madrid Seismic Zone. A dense network has a number of seismometers closely spaced to collect data from an area of special scientific interest.

The Kentucky Geological Survey continues to fund the maintenance, operation, monitoring, and dissemination of information from the Kentucky Seismic and Strong-Motion Network. Maintenance and data archiving at the new stations are performed monthly. This report summarizes the data recorded by the new and previously installed seismic stations between January 1 and June 30, 2003, and interprets these data.

Seismic Network

Figure 1 shows locations of the new and previously installed seismic stations in western Kentucky. In the Jackson Purchase Region, bedrock is covered by thick unconsolidated and semiconsolidated sediments. In order to obtain high-quality records, all seismometers were placed in holes that penetrate into the semiconsolidated sediments. The depths of the holes range from 24 to 61 m, and were determined by a geophysical site investigation. Table 1 lists detailed information on the seismic stations.

Data Collection

Since January 2003, the new and previously installed seismic stations in western Kentucky have recorded many earthquakes from the central United States and the world. Table 2 lists some of the earthquakes in the central United States that were recorded by the network between January 1 and May 31, 2003. Figures 2 through 4 show some of the recordings from the new seismic stations.

The most significant records were from the June 6, 2003, earthquake near Bardwell, Ky. (Fig. 5). Ten seismic and strong-motion stations, all within 80 km epicentral distance, recorded the quake (Table 3). The magnitude of the earthquake was M4.0. The quake was felt in western Kentucky and parts of Alabama, Indiana, Missouri, and Tennessee, and caused some damage and shook up the Carlisle County Courthouse in Bardwell. The closest stations to the epicenter are DEKY and WIKY, at about 13 km each. Figure 6 shows the strong-motion recordings from WIKY in Wickliffe, Ky. Peak ground acceleration recorded in Wickliffe was about 0.02g (20 cm/s^2 or 2 percent of gravity). PGA recorded at Columbus-Belmont State Park (COKY) was also about 0.02g (Fig. 7). Figures 8 and 9 show the recordings at seismic stations DEKY and BLKY.

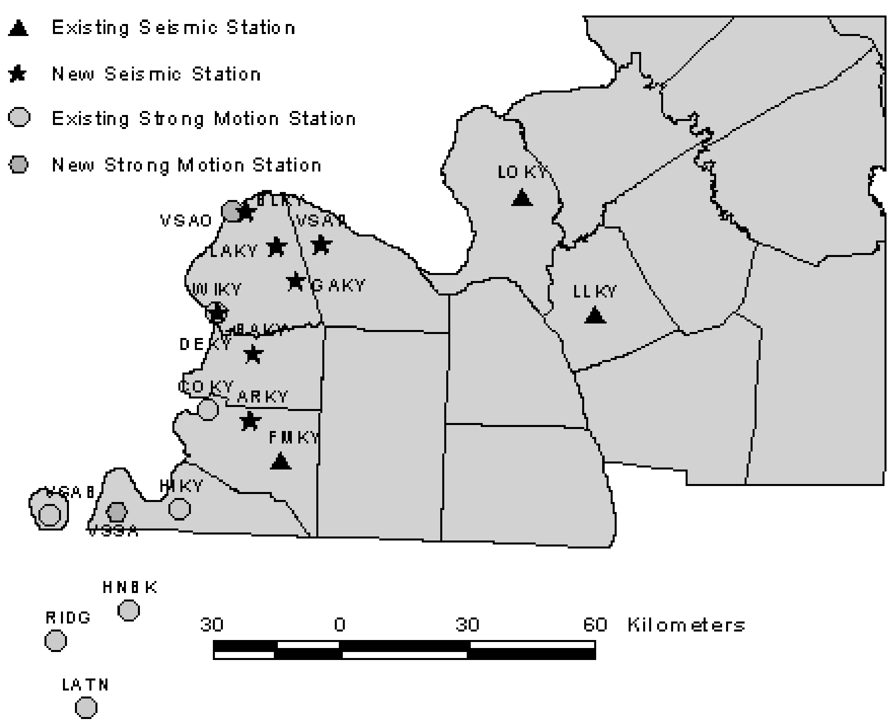

Figure 1. Seismic and strong-motion stations in western Kentucky.

Data Evaluation and Analysis

First, we evaluated the seismic data recorded between January and May 2003. The purpose was to check the instrument functions and parameters that were set at the stations. The evaluation showed the new stations were working properly. The sensitivity parameters at the stations were adjusted based on the evaluation. Further analysis, such as determination of location, was not performed because all the recorded earthquakes

Table 1. Seismic stations in western Kentucky.

Station	Longitude (degrees)	Latitude (degrees)	Depth (m)	Recorder	Sensor	Location
FMKY	–88.909	36.664	100	KEWS	L-4C	Flugham, Ky.
LLKY	–88.097	36.992	36	KEWS	L-4C	Land-Between-the-Lakes, Ky.
LOKY	–88.295	37.237	5	KEWS	L-4C	Lockhart Bluff, Ky.
BLKY	–89.015	37.184	24	NetDAS	L-4C	Ballard Wildlife Management Area
LAKY	–88.969	37.079	48	NetDAS	L-4C	La Centre, Ky.
GAKY	–88.897	37.044	48	NetDAS	L-4C	Gage, Ky.*
ARKY	–88.997	36.748	48	NetDAS	VLF-3	Arlington, Ky.
DEKY	–89.084	36.974	61	NetDAS	VLF-3	Ballard Detention Center
BAKY	–88.997	36.886	45	NetDAS	L-4C	Bardwell, Ky.
VSAP	–88.822	37.124	30	NetDAS	VLF-3	Paducah Gaseous Diffusion Plant, Ky.*

*Installation not yet complete

Table 2. Central U.S. earthquakes recorded between January 1 and May 31, 2003.

Magnitude	Date	Time (UTC)	Latitude	Longitude	Depth	Location
3.0	05/02/03	08:10:13	37.970	88.650	0.6	Macedonia, Ill.
4.0	04/30/03	04:56:22	35.940	89.920	23.8	Blytheville, Ark.
4.6	04/29/03	08:59:38	34.508	85.612	15.0	Menlo, Ga.

occurred far from the new seismic stations. The new seismic stations are designed to capture data on earthquakes in western Kentucky, the Jackson Purchase Region in particular, that are significant for seismic-hazard assessment of that area.

The June 6, 2003, Bardwell, Ky., earthquake occurred at about 8:30 a.m. (EDT), with a magnitude of M4.0. The initial location and focal depth determined by the U.S. Geological Survey were 36.890N/89.010W and 0.1 km, respectively. The recordings from the earthquake were collected from the stations on June 12, 2003. The data were evaluated and analyzed immediately. We determined the location of the earthquake to be 36.88N/88.98W, which put the quake near Bardwell (Fig. 5). Detailed parameters are listed in Table 4. The focal depth was only about 2.3 km beneath the surface; such a shallow earthquake, with a magnitude of M4.0, is very unusual in the central United States. In comparison, another earthquake with a magnitude of M4.0, occurring on April 30, 2003, near Blytheville, Ark., had a focal depth of about 23.8 km.

Discussion

Figure 10 shows the locations of earthquakes recorded in the central United States since 1974. Earthquakes occur sporadically over a large region, with the exception of the New Madrid Seismic Zone, where earthquakes concentrate along the known faults (Fig. 10). Many earthquakes occurred in the Jackson Purchase Region (Fig. 10), but the pattern of seismicity does not show that the earthquakes in western Kentucky are directly connected to the New Madrid faults (Fig. 10). It has been long suspected that

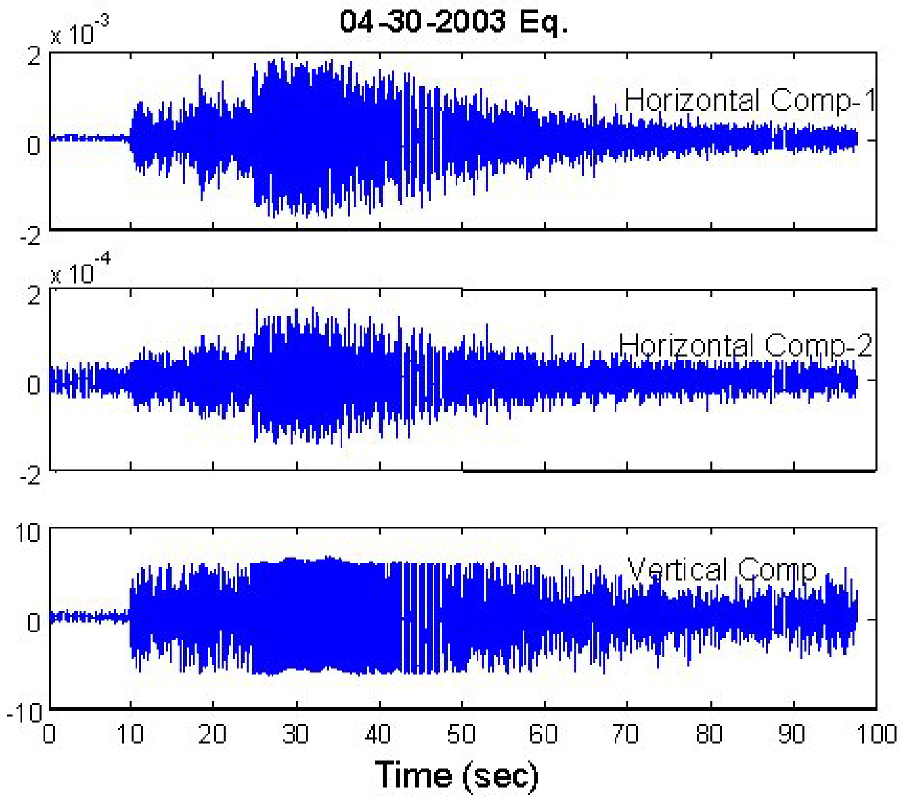

Figure 2. Recordings of the Blytheville, Ark., earthquake at station ARKY.

earthquakes in the Jackson Purchase Region tend to be shallow (< 5.0 km), but this could not be proven because of the lack of a *dense seismic network*.

Earthquakes occurring in the New Madrid Seismic Zone between January 1 and June 30, 2003, are shown in Figure 11. Appendix B lists detailed parameters of the earthquakes. Except for the June 6, 2003, Bardwell earthquake, all are concentrated along the New Madrid faults. The largest earthquakes are the April 30, 2003, Blytheville, Ark., and the June 6, 2003, Bardwell, Ky., earthquakes, both with magnitude M4.0. The focal depths for the two

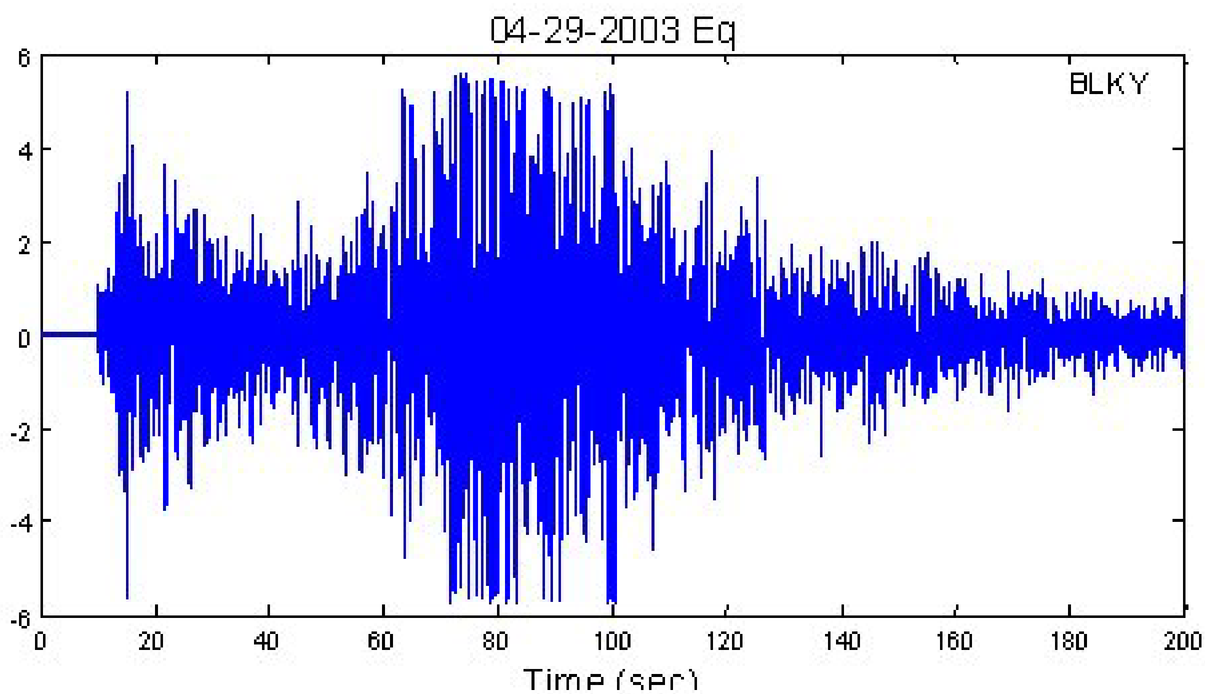

Figure 3. Recording of the Menlo, Ga., earthquake at station BLKY.

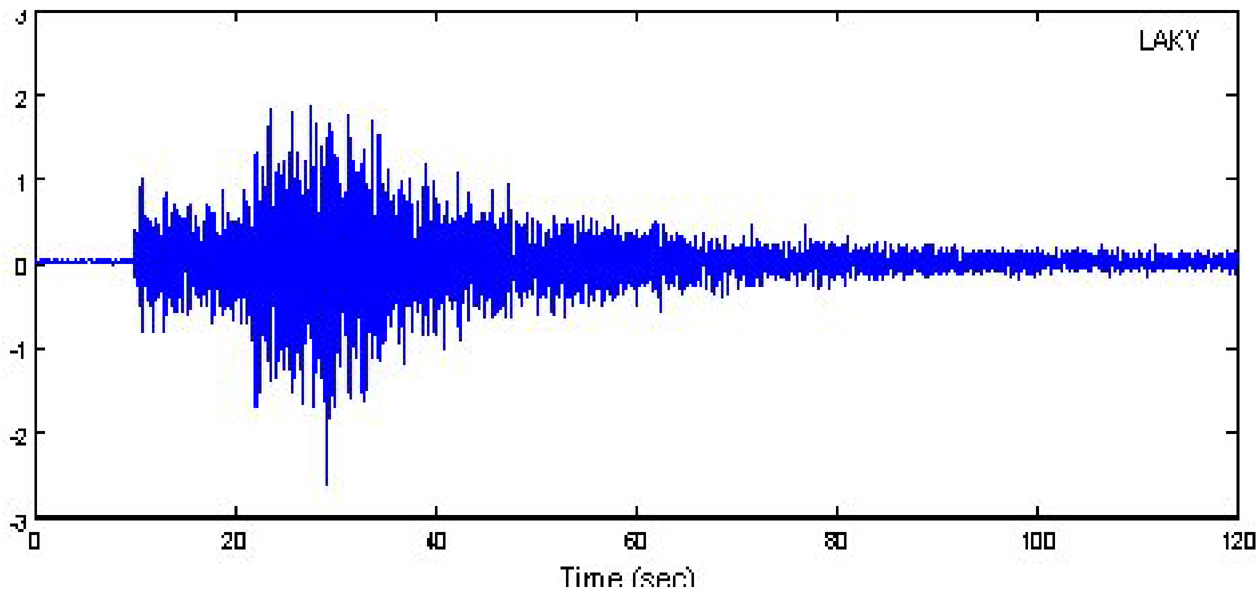

Figure 4. Recording of the Macedonia, Ill., earthquake at station LAKY.

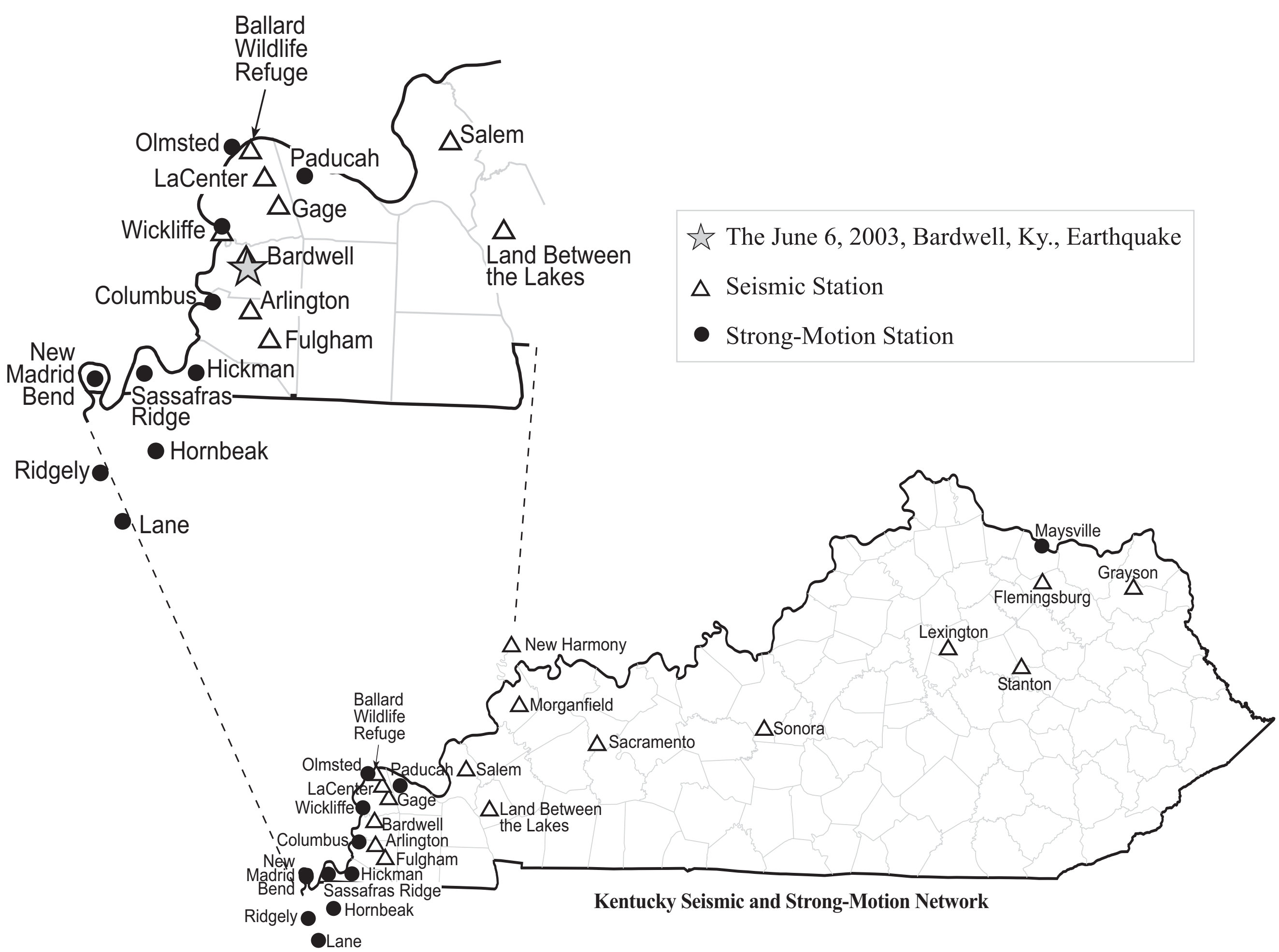

Figure 5. The Kentucky Seismic and Strong-Motion Network and location of the June 6, 2003, Bardwell, Ky., earthquake.

Table 3. Seismic and strong-motion stations in western Kentucky that recorded the Bardwell event.

Station	Type	Channels	Distance (km)
DEKY	seismic	3	13.2
WIKY	strong-motion	3	13.4
ARKY	seismic	3	14.3
COKY	strong-motion	3	16.0
LAKY	seismic	1	22.6
FMKY	seismic	1	25.0
BLKY	seismic	1	34.2
VSAB	strong-motion	3	59.8
LOKY	seismic	1	74.1
LLKY	seismic	1	81.1

quakes are significantly different: 23.8 km for Blytheville and 2.3 km for Bardwell. The focal depths of smaller earthquakes (< M4.0) in the New Madrid Seismic Zone are generally much deeper than 5.0 km (Appendix B). If the Bardwell earthquake is truly representative of earthquakes in the Jackson Purchase Region, it could mean a zone of seismic activity significantly different from that along the New Madrid faults (Fig. 11).

Although the stations recently installed by KGS have only 6 months of data, the observed seismicity in the New Madrid Seismic Zone indicates that (1) seismicity reflects the zone's active faults and (2) in the Jackson Purchase Region, characteristics of earthquakes, such as focal depth, are different from those of earthquakes along the New Madrid faults. This suggests that the active faults of the New Madrid Seismic Zone may not extend into the Jackson Purchase Region. This could mean a different seismic source for the Jackson Purchase Region.

Conclusion

Data recorded by the Kentucky Seismic and Strong-Motion Network between January and May 2003 showed that the newly installed seismic stations are working properly. Only one earthquake, the June 6, 2003, Bardwell earthquake (M4.0), occurred in the Jackson Purchase Region between January 1 and June 30, 2003. Analysis of the recordings from the new and previously installed seismic stations revealed that the Bardwell earthquake was a shallow one, about 2.3 km beneath the surface. This focal depth is significantly different from the focal depth of 23.8 km for the Blytheville, Ark., earthquake (M4.0), which occurred in the central New Madrid Seismic Zone.

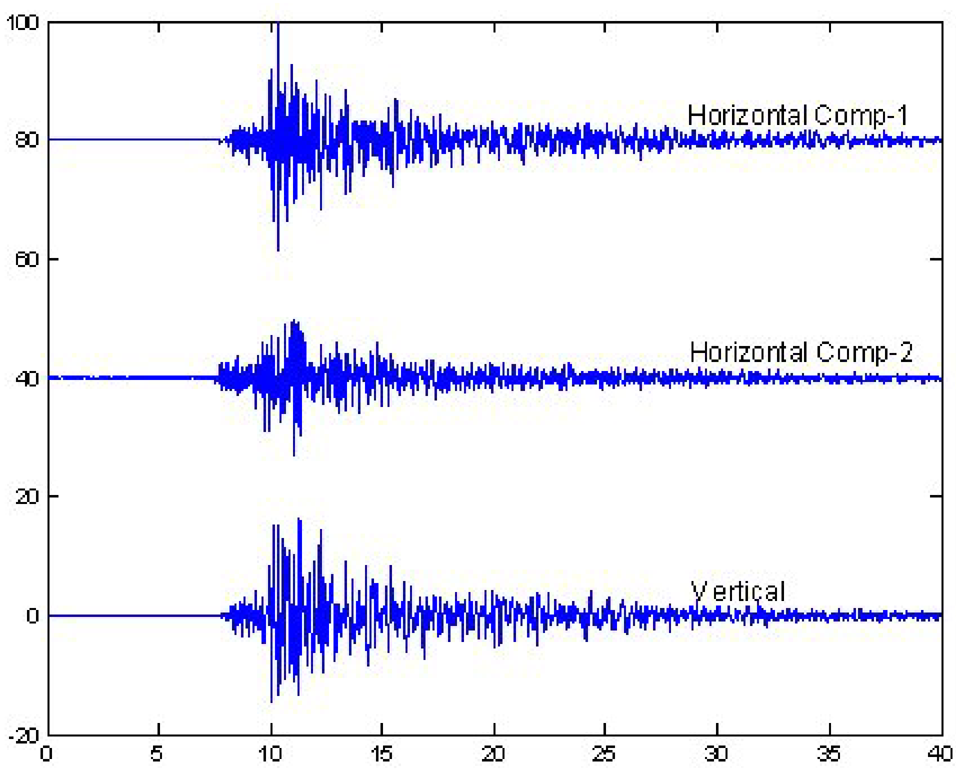

Figure 6. Strong-motion recordings of the Bardwell event from station WIKY.

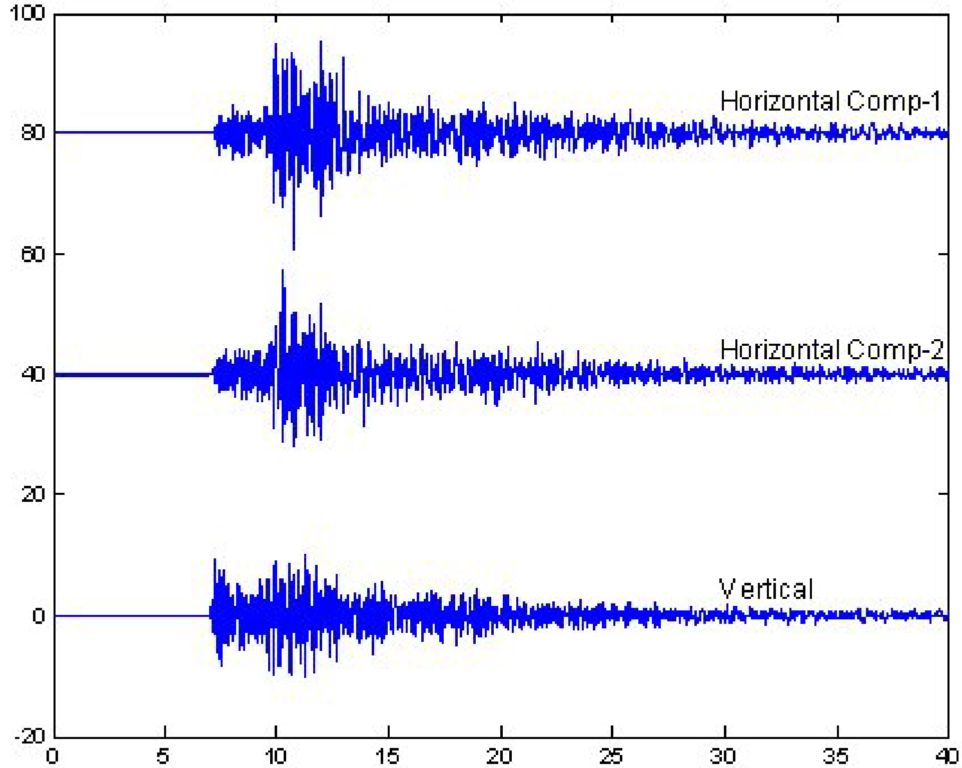

Figure 7. Strong-motion recordings of the Bardwell event from station COKY.

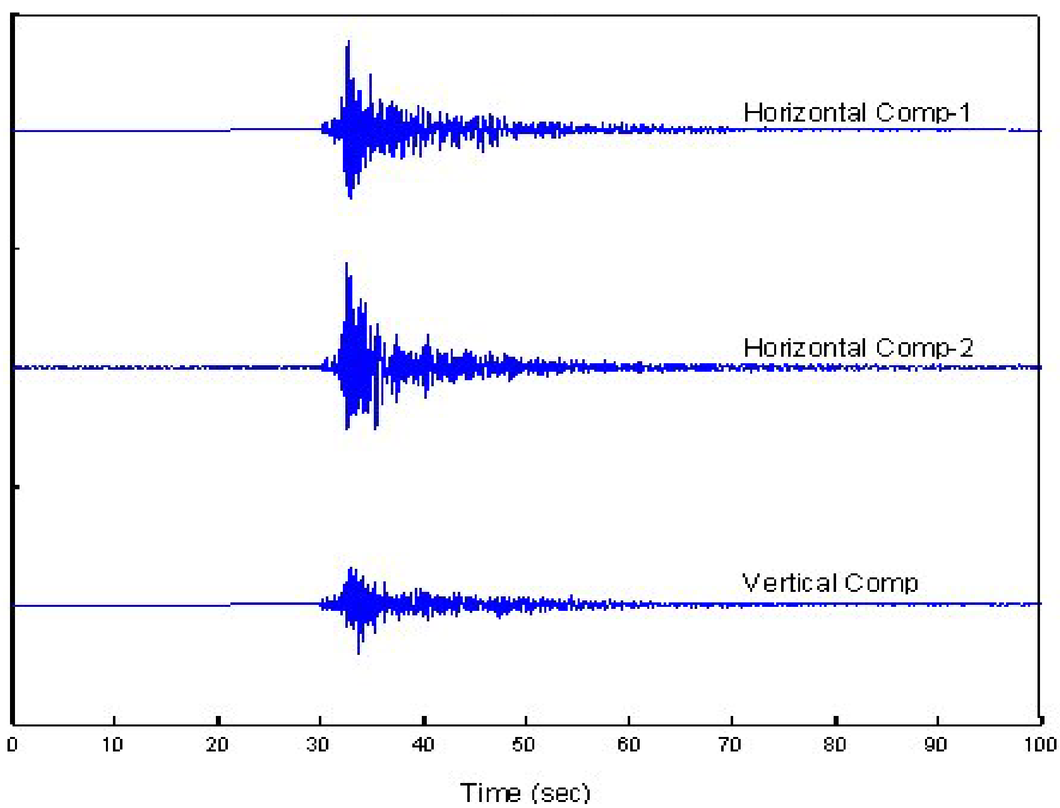

Figure 8. Seismic recordings of the Bardwell event from station DEKY.

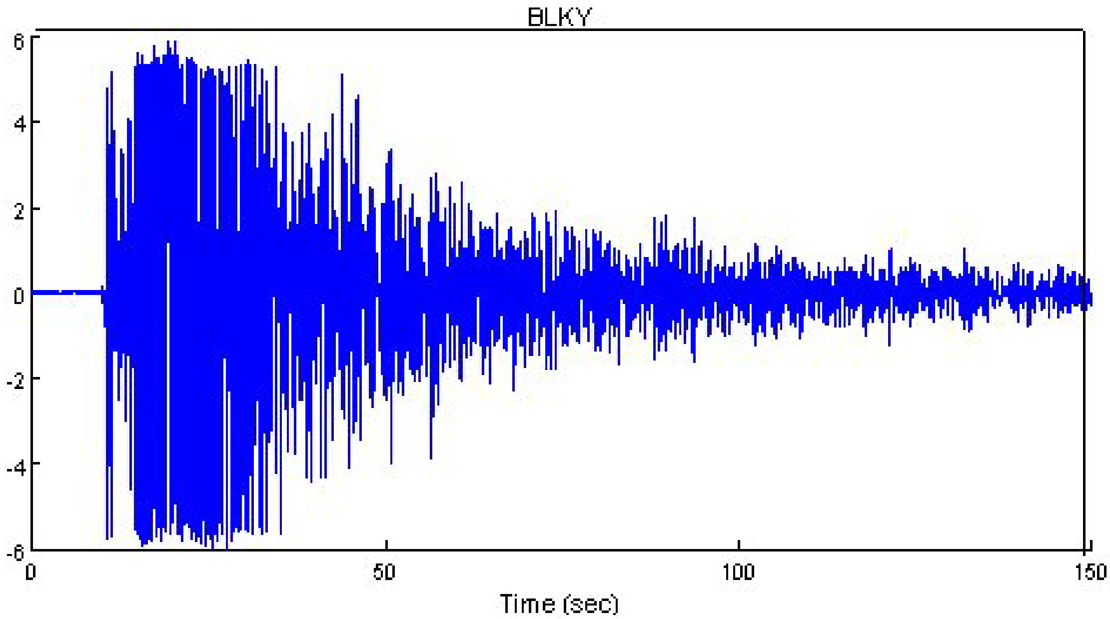

Figure 9. Seismic recordings of the Bardwell event from station BLKY.

Table 4. Comparison of parameters of the Bardwell, Ky., and Blytheville, Ark., earthquakes.

Date	Time (EDT)	Magnitude (M_w)	Location (La./Lo.)	Focal Depth (km)
06/06/2003	8:29:34 a.m.	4.0	36.88N/88.98W	2.3
04/30/2003	0:56:22 a.m.	4.0	35.92N/89.92W	23.8

The observed seismicity between January and June 2003 in the New Madrid Seismic Zone indicates that (1) most recorded seismicity in the central United States reflects the active faults of the New Madrid Seismic Zone and (2) in the Jackson Purchase Region, characteristics of earthquakes, such as focal depth, are different from those of earthquakes in the central New Madrid Seismic Zone. Six months of seismic monitoring is not enough time to make a scientifically defensible conclusion about the extent of the active faults into the Jackson Purchase Region. Much more time is needed for seismic monitoring in the area. The observed seismicity suggests, however, that the active faults of the New Madrid Seismic Zone may not extend into the Jackson Purchase Region. This could result in lower estimates of the seismic hazard in western Kentucky.

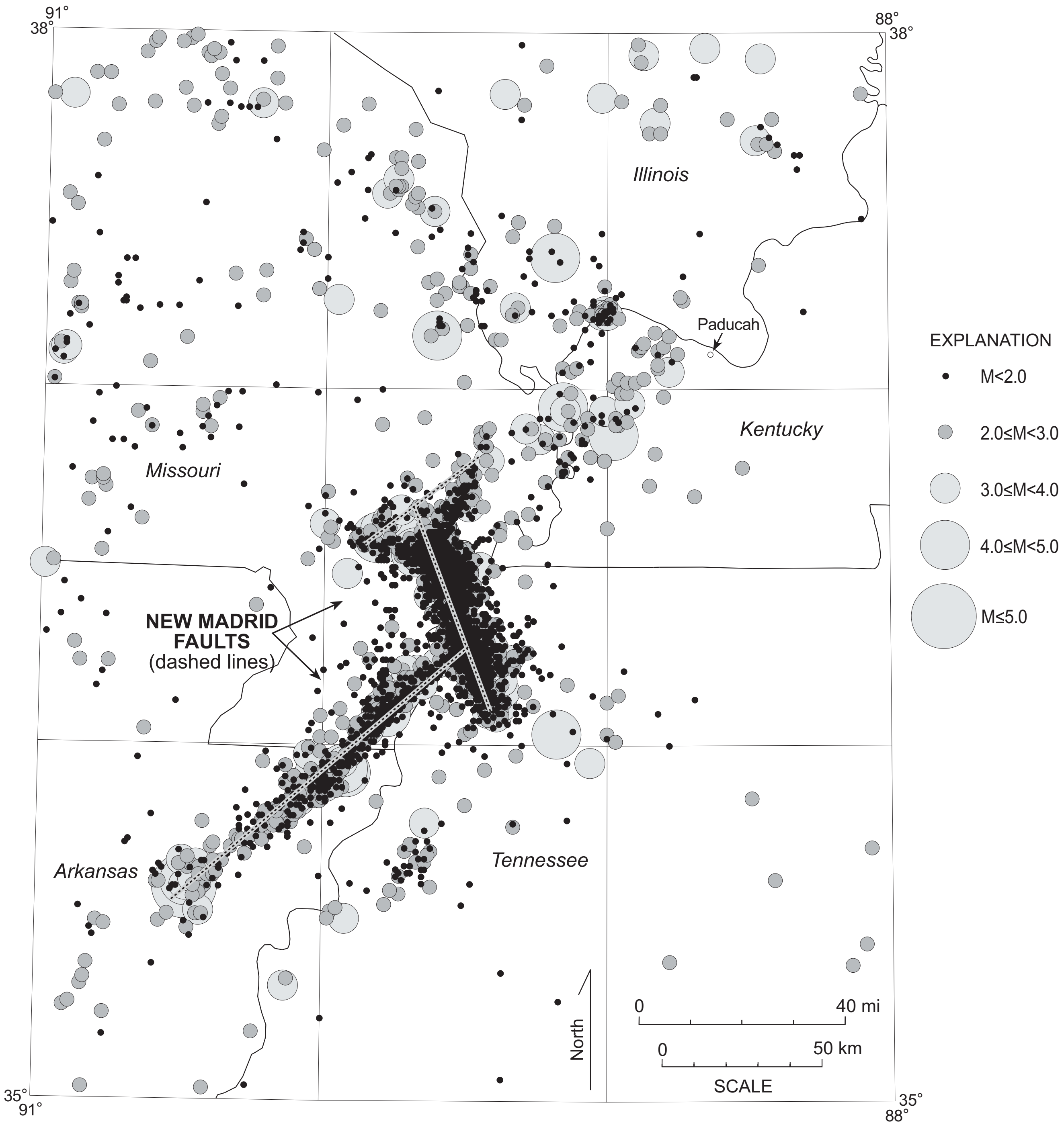

Figure 10. Locations of earthquakes in the central United States since 1974 (from the Center for Earthquake Research and Information).

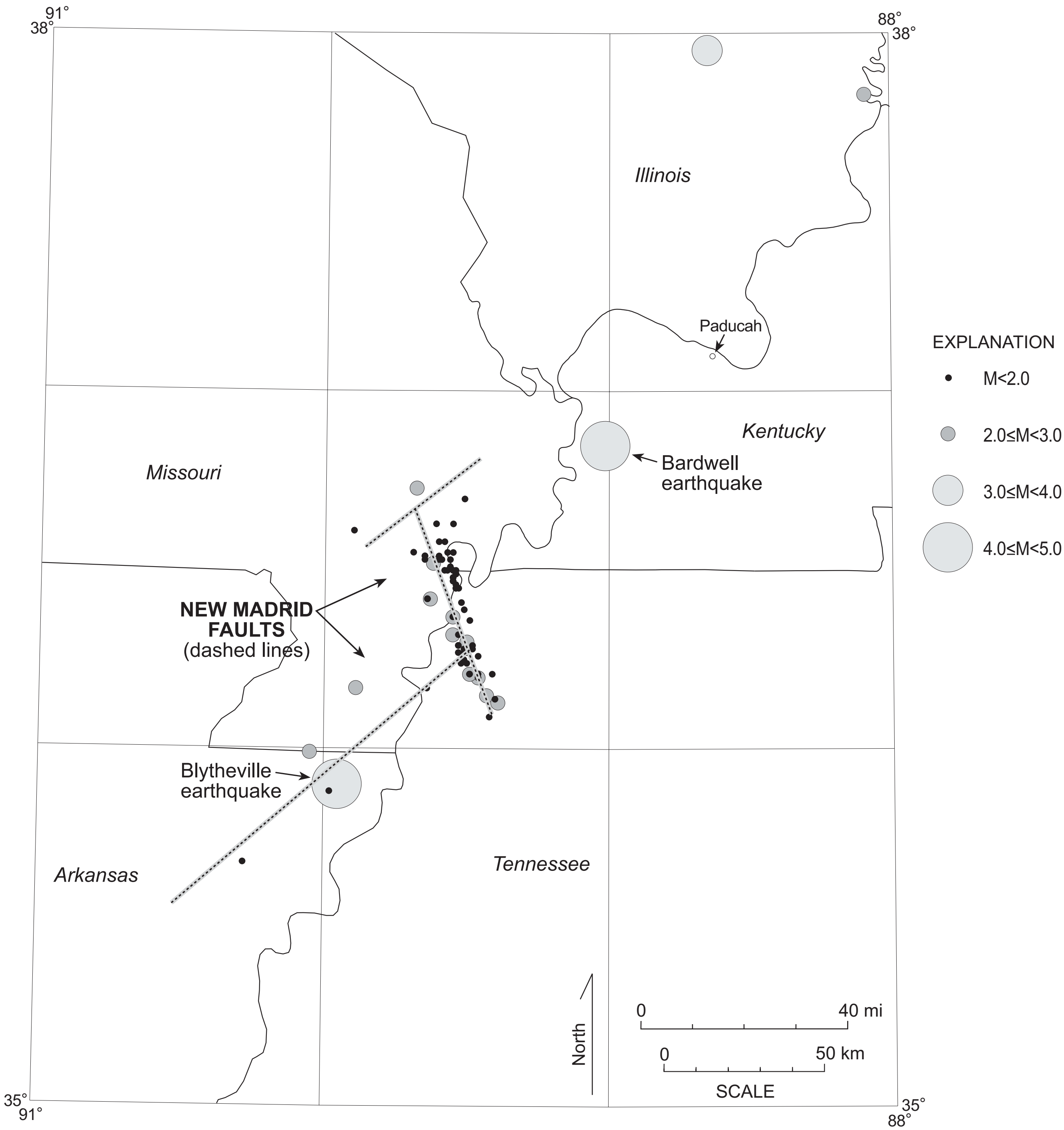

Figure 11. Locations of earthquakes in the New Madrid Seismic Zone between January and June 2003 (from the Center for Earthquake Research and Information).

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Appendix A: Providing Preliminary Seismic Hazard Assessment for Paducah Area of Western Kentucky—Executive Summary

Zhenming Wang
Kentucky Geological Survey
University of Kentucky
Lexington, KY 40506
zwang@kgs.mm.uky.edu
Phone: 859-257-5500

Edward W. Woolery
Department of Geological Sciences/Kentucky Geological Survey
University of Kentucky
Lexington, KY 40506
woolery@uky.edu
Phone: 859-257-3016

January 10, 2003

Federal government agencies, including the U.S. Nuclear Regulatory Commission, use the seismic hazard maps developed by the U.S. Geological Survey for seismic safety regulations. These maps are based on a 2 percent probability that a ground motion will be exceeded in 50 years (2,500-year return period). The maps predict very high ground motion for western Kentucky, the Jackson Purchase Region in particular. These high seismic hazard estimates for western Kentucky will have a significant impact on economic development in the region.

The type of analysis used by the U.S. Geological Survey to estimate the ground-motion hazard is called probabilistic seismic hazard analysis. Three data sets are needed for probabilistic seismic hazard analysis: earthquake sources (where and how big), earthquake occurrence frequencies (how often), and ground-motion attenuation relationship (how strong). All data sets contain a large amount of uncertainty because of a lack of understanding about the seismic setting in the central United States, and a lack of real data. The exact boundary of the New Madrid Seismic Zone is still difficult to define, even though it is the most active and well studied east of the Rocky Mountains. Although the U.S. Geological Survey has tried its very best to use the latest scientific information to estimate ground-motion hazards for the central United States, large uncertainties were inherent in the hazard maps.

One of the uncertainties that has a significant impact on the probabilistic seismic hazard analysis for western Kentucky is the northern boundary of the New Madrid Seismic Zone. The best way to define the boundary is by monitoring earthquake activity in the area. To this end, seven new seismic stations have been installed in the Jackson Purchase Region. Three previously installed seismic stations in western Kentucky have also been upgraded. These new and upgraded seismic stations, in combination with existing seismic networks, will provide better information on earthquake activity in the region and help reduce the uncertainty about the northern boundary of the New Madrid Seismic Zone. Because of the time-dependent nature of earthquake activity, a minimum of 2 years of observation is required.

A sensitivity analysis was conducted, based on the data sets used by the U.S. Geological Survey. This analysis showed that the seismic hazard in western Kentucky is dominated by the earthquakes from the New Madrid Seismic Zone. The analysis also showed that a large uncertainty was inherent in the ground-motion hazard for western Kentucky: the ground motion for western Kentucky, particularly the Jackson Purchase area, has been overpredicted by as much as a factor of two. A full-scale study is needed to provide a credible and defensible seismic hazard assessment for western Kentucky. Anticipated time for the full-scale study is 18 to 24 months.

The seismic issue in western Kentucky also requires intensive communications with related government and nongovernment agencies. The principal investigators have actively communicated with personnel from Federal agencies, including the U.S. Geological Survey and Nuclear Regulatory Commission, and other national experts on seismic hazard assessment in the central United States, western Kentucky in particular. A workshop was held on November 18, 2002, in Lexington to discuss seismic hazards, risk, and design maps in the central United States, especially western Kentucky. It was attended by 110 geologists, seismologists, engineers, emergency managers, and others from the related Federal and State agencies. Three key problems were identified at the workshop:

1. The probabilistic ground-motion hazard with 2 percent probability of being exceeded in 50 years for the New Madrid region (including western Kentucky) is overly conservative.
2. There are many inconsistencies in the NEHRP 97 seismic design maps. These inconsistencies have resulted in very high seismic design for western Kentucky.
3. There is lack of communication between the map developers and the users in the central United States.

Appendix B: Earthquakes Occurring in the New Madrid Seismic Zone between January and June 2003

Date	Time (UTC)	Latitude (Degrees)	Longitude (Degrees)	Depth (km)	Magnitude
2003/01/02	06:18:36.00	36.32	–89.53	8.7	1.7
2003/01/02	11:29:40.00	36.24	–89.52	6.8	1.8
2003/01/03	16:17:07.00	37.83	–88.09	5	2.9
2003/01/04	04:16:42.00	36.24	–89.5	7.7	1.5
2003/01/06	06:45:06.00	36.58	–89.6	9.7	1.9
2003/01/07	03:24:59.00	36.2	–89.46	8.6	1.8
2003/01/09	10:27:03.00	36.3	–89.5	7.7	2
2003/01/14	05:09:34.00	36.48	–89.55	7.9	1.9
2003/01/20	06:47:09.00	36.47	–89.55	8.3	1.6
2003/01/26	07:58:56.00	36.28	–89.51	8.4	1.5
2003/02/03	12:44:33.00	36.17	–89.89	17.5	2.3
2003/02/03	22:27:23.00	36.5	–89.54	7	1.8
2003/02/08	05:51:06.00	36.5	–89.54	8.2	0.9
2003/02/08	05:52:43.00	36.5	–89.55	8.3	1.9
2003/02/09	12:24:03.00	36.42	–89.64	12	0.6
2003/02/09	12:24:12.00	36.42	–89.64	12.2	1.7
2003/02/09	21:13:34.00	36.42	–89.63	13	2.3
2003/02/10	04:23:10.00	36.42	–89.64	11.9	1.8
2003/02/14	02:41:05.00	36.55	–89.69	7.3	1.8
2003/02/14	03:53:31.00	36.45	–89.53	7.7	1.8
2003/02/19	10:56:39.00	36.42	–89.64	12.6	1.6
2003/02/20	12:06:15.00	36.25	–89.51	6.8	1.6
2003/02/24	08:29:27.00	35.99	–90.05	7.4	2.3
2003/02/28	08:15:12.00	36.53	–89.56	7.6	1.5
2003/03/04	07:00:27.00	35.88	–89.98	19.5	1.7
2003/03/04	10:51:52.00	36.26	–89.46	7.3	1.5
2003/03/09	07:45:18.00	35.68	–90.28	2.6	1.3
2003/03/13	13:43:32.00	36.29	–89.48	6.3	1.5
2003/03/17	13:03:21.00	36.53	–89.6	6.6	1.5
2003/03/18	17:19:42.00	36.27	–89.53	8.8	1.5
2003/03/18	22:00.56.00	36.37	–89.55	9.4	1.7
2003/03/21	00:49:50.00	36.53	–89.65	11	1.6
2003/03/23	08:05:13.00	36.58	–89.58	7.6	1.8
2003/03/23	09:46:40.00	36.49	–89.54	7.2	1.5
2003/03/28	03:19:10.00	36.5	–89.57	9.4	1.3
2003/03/28	09:01:22.00	36.39	–89.51	7.6	1.8
2003/03/29	08:52:55.00	36.51	–89.56	8.5	1.1
2003/03/31	04:11:37.00	36.5	–89.55	7.1	1.8
2003/04/01	04:20:16.00	36.61	–89.9	9.4	1.5

Date	Time (UTC)	Latitude (Degrees)	Longitude (Degrees)	Depth (km)	Magnitude
2003/04/05	10:18:41.00	36.48	–89.55	8.3	1.7
2003/04/05	11:13:17.00	36.7	–89.51	12.8	1.6
2003/04/07	05:30:27.00	36.14	–89.4	8.4	1.9
2003/04/09	19:54:46.00	36.55	–89.55	6.8	1.8
2003/04/17	07:40:19.00	36.2	–89.46	7.6	2.2
2003/04/18	05:32:15.00	36.54	–89.6	9	1.5
2003/04/21	16:22:27.00	36.52	–89.62	10.1	2.1
2003/04/24	23:08:50.00	36.46	–89.54	8.4	1.8
2003/04/30	04:56:22.00	35.92	–89.92	23.8	4
2003/04/30	18:42:00.00	36.63	–89.61	9.1	1.5
2003/05/01	04:56:19.00	36.63	–89.55	6.3	1.6
2003/05/02	00:36:13.00	36.54	–89.65	9.2	1.4
2003/05/02	03:25:03.00	36.73	–89.68	1.8	2.7
2003/05/02	08:10:13.00	37.96	–88.65	0.6	3.2
2003/05/07	01:49:33.00	36.54	–89.65	9.2	1.6
2003/05/13	23:58:31.00	36.21	–89.46	6.9	1.9
2003/05/15	11:12:21.00	36.17	–89.64	11.1	1.9
2003/05/16	05:33:33.00	36.41	–89.52	8.2	1.9
2003/05/19	16:23:42.00	36.55	–89.57	1.8	1.7
2003/05/21	05:11:13.00	36.45	–89.54	7.8	1.7
2003/05/25	17:30:03.00	36.21	–89.49	5.2	1.5
2003/05/26	05:21:55.00	36.29	–89.53	9.7	1.2
2003/05/26	08:06:48.00	36.29	–89.53	9.5	1.5
2003/05/27	05:50:55.00	36.21	–89.49	5.9	2
2003/05/27	07:09:06.00	36.21	–89.49	5.6	1.6
2003/05/27	20:22:31.00	36.36	–89.49	6.9	1.7
2003/05/29	03:40:41.00	36.32	–89.55	11.8	2.1
2003/05/29	05:32:16.00	36.47	–89.55	7.6	1.9
2003/05/30	02:18:24.00	36.13	–89.39	6.2	2.8
2003/06/03	09:40:07.00	36.21	–89.41	7.2	1.6
2003/06/06	12:29:34.00	36.87	–88.98	2.6	4
2003/06/07	03:44:05.00	36.5	–89.58	8.3	1.5
2003/06/08	02:03:10.00	36.37	–89.55	11.3	2
2003/06/13	05:41:55.00	36.45	–89.54	7.8	1.5
2003/06/15	03:22:27.00	36.09	–89.42	5.4	1.4
2003/06/17	09:31:59.00	36.28	–89.48	7.1	1.5
2003/06/17	11:46:34.00	36.53	–89.59	10	1.5
2003/06/18	09:37:50.00	36.49	–89.54	8.1	1.6
2003/06/18	10:43:57.00	36.27	–89.5	7.3	1.7
2003/06/26	11:03:20.00	36.27	–89.51	7.1	1.5
2003/06/28	05:47:48.00	36.15	–89.43	10	2