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MAP SHOWING SEISMICITY IN THE VICINITY OF THE LOWER WABASH VALLEY, ILLINOIS, INDIANA, AND KENTUCKY

By

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INTRODUCTION

This is one of a series of seismotectonic maps of the lower Wabash Valley area, including southeastern Illinois, southwestern Indiana, part of western Kentucky, and a small part of northwestern Tennessee (table 1). Immediately to the southwest is the more seismically active New Madrid area. The threat posed by earthquakes in and near New Madrid and the lower Wabash Valley makes the combined region the focus of many investigations. Most studies have concentrated on the New Madrid area. Recently we summarized many of the New Madrid geological and geophysical results on maps that help investigators to understand seismogenesis and assess the seismic hazard (Rhea and Wheeler, 1994a, b; Rhea and others, 1994; Wheeler and Rhea, 1994; Wheeler and others, 1994; Rhea and Wheeler, 1995). Our New Madrid data base is available digitally (Rhea, 1995). The present Wabash Valley map series is a similar summary of available results for the lower Wabash Valley (table 1).

Seismotectonic maps show some of the geologic and geophysical information needed to assess seismic hazard (Hadley and Devine, 1974; Pavoni, 1985). A previous regional seismotectonic map of the central Mississippi River valley (Heyl and McKeown, 1978) has been widely used for planning field surveys and as a base map for plotting or compiling data. Since 1978, numerous studies have greatly advanced our knowledge of the geology and geophysics of the central Mississippi Valley, including the New Madrid and Wabash Valley map areas. The Wabash Valley seismotectonic maps update approximately the northeastern fifth of the central Mississippi Valley seismotectonic map of Heyl and McKeown (1978).

SEISMOTECTONIC DATA

We used the ARC/INFO geographic information system (GIS) software to compile and edit the maps in this series (table 1). Rhea and others (1991) pointed out that the digital data bases that we compiled for the New Madrid and Wabash Valley areas can be used to produce diverse products in addition to the seismotectonic maps. The digital data bases are available separately (Tarr, 1991; Rhea, 1995). Table 2 describes construction of the base map for the Wabash Valley map series.

GEOLOGIC SETTING

Most of the map area is underlain by flat-lying or gently dipping Paleozoic platform strata of the midcontinent (Willman and others, 1967; McDowell and others, 1981; Gray and others, 1987; Noger, 1988). The Paleozoic rocks generally dip toward the central part of the map area, which overlies the deepest part of the Illinois basin (Kolata, 1991). In the southwestern corner of the map area an unconformity atop the Paleozoic rocks dips southwestward under Mesozoic and Cenozoic sediments and sedimentary rocks of the Mississippi embayment. Much of the geologic and geophysical information available for the map area was produced during, or in support of, exploration for coal in Pennsylvanian rocks, oil and gas in the Illinois basin, and minerals in the Illinois-Kentucky fluorspar district between the Mississippi embayment and the Wabash River.

We show the edge of the embayment within the map area to be the contact between exposed Paleozoic rocks on the northeast and younger strata on the southwest. R. L. Dart (written commun., 1992) digitized the contact from state geologic maps (Willman and others, 1967; McDowell and others, 1981) and then generalized it. We used the generalized version, which ignores Cretaceous and Cenozoic outliers and Paleozoic inliers in southern Illinois and especially in western Kentucky.

SEISMOGRAPH NETWORK

The map area includes the northeastern part of the central Mississippi Valley seismograph network. Most stations in this part of the network are operated by Saint Louis University and the University of Kentucky. Operational details, data, and other results are available in the quarterly or semiannual "Central Mississippi Valley Earthquake Bulletin," distributed by Saint Louis University. Four-letter names, except that of station WCK, identify the 15 stations listed in the issue for the second half of 1993 (Herrmann and others, 1993). Station locations are reported to the nearest 0.001° (about 100 m). The eight stations shown in Illinois and Indiana were closed in October 1992 and June 1993 (Herrmann and others, 1993), whereas the seven shown in Kentucky were still in operation on December 31, 1995 (Herrmann and Whittington, 1995).

Two- and three-letter names identify stations of a temporary network of 20 three-component, digital seismographs that were deployed from November 1995 to June 1996 (Bear and others, 1996). The temporary network straddles the Wabash River. Ten of the stations, A0-A3 and B1-B6, form a small-aperture array at a single site. Epicenters and other results from the temporary network were not available in time to show here.

ACCELEROGRAPHS

The map area lies astride the northeast edge of a network of digital accelerographs that is centered on the New Madrid seismic zone to the southwest. Two of these strong-motion stations are within the map area (N. Barstow and R. L. Street, oral and written communs., 1994 and 1995). The two accelerograph locations bracket the Ohio River in the southwestern part of the map area, and are reported to the nearest 0.001° (about 100 m). Further details of most stations in the accelerograph network, and data from the stations, are in the digital database STRONGMO, which is maintained by the National Center for Earthquake Engineering Research (NCEER) Strong Ground Motion Group at the Lamont-Doherty Earth Observatory (Friberg and Barstow, 1994).

A third digital accelerograph is on the dam at the south end of Rend Lake, near the western edge of the map area (R. F. Ballard, Jr., oral commun., 1995). The location is reported to the nearest 0.1 minute (about 170 m). The instrument owner, the U.S. Army Corps of Engineers, is upgrading its analog accelerographs to digital capability. Details are available from the manager of the Strong Motion Instrumentation Program at the Corps' Waterways Experiment Station in Vicksburg, Mississippi.

EARTHQUAKE EPICENTERS

Earthquakes in the map area are located routinely using data from the permanent seismograph network. The epicenters shown here are from the Saint Louis University catalog (Taylor and others, 1991; Melanie Whittington, written commun., 1994). The events occurred between July 29, 1974, and July 29, 1993. Ninety-five percent of the 168 events have calculated horizontal precisions (ERH values) of 10 km or less; most have ERH values of 1.5 km or less. Total locational uncertainty, however, includes inaccuracies and perhaps imprecisions from other sources, such as velocity models, and probably exceeds the calculated precision.

The earthquakes recorded by the network are generally small and scattered, without the tight epicentral alignments that characterize the New Madrid area to the southwest. Magnitudes of the 168 events shown here are m_{bLg} (defined in footnote 1 of table 3 below; Herrmann and others, 1994) 0.0 or greater. Fifty-six percent of the magnitudes were between 2.0 and 2.9, inclusive, and only 17 magnitudes exceeded 2.9. The only earthquake larger than magnitude 3.8 was that of June 10, 1987, east of Olney, Richland County, Illinois, with a magnitude of m_{bLg} 5.2. The cluster of epicenters east of Olney is dominated by aftershocks of the 1987 earthquake. The loose cluster of epicenters west of Paducah, Kentucky, between and near Mayfield Creek and the Ohio River, is part of a diffuse halo of seismicity that surrounds the New Madrid seismic zone (Rhea and others, 1994; Rhea and Wheeler, 1995). Of the remaining events within the map area, slightly more were located in Illinois and Indiana than in Kentucky and Tennessee.

Several earthquakes in the nineteenth and twentieth centuries were larger than any recorded by the network. Table 3 lists historical earthquakes known or interpreted to have caused MMI (Modified Mercalli Intensity) of at least VI within the map area. Most preceded installation of the permanent seismograph network, so they are known mainly from intensity reports. We chose MMI VI because it represents the onset of light damage (Wood and Neumann, 1931).

EARTHQUAKE INTENSITIES

The map shows that damaging historical earthquakes have tended to occur more frequently in the Indiana and Illinois parts of the map area than in most of the Kentucky part. However, there are too few of these epicenters to support more geographically specific statements. Intensity isoseismals provide greater spatial resolution because they represent more control points per earthquake.

The intensity reported at a particular site varies with (1) the incoming ground motion at the interface between hard bedrock and overlying soil or soft sediment; (2) the site conditions; (3) the structures, persons, and natural features at the site; and (4) the investigator who evaluates earthquake effects and assigns intensity values (Hopper, 1985). Of these factors, the most subjective is investigator variability. Accordingly, we selected earthquakes for table 3 according to the maximum intensities listed in Stover and Coffman (1993), because they and their colleague M. G. Hopper (1994; oral and written communs., 1994-96) reevaluated the original reports, reassigned maximum intensities, and redrew isoseismal maps, all according to uniform criteria. The uniformity minimized investigator variability. Table 3 is generally consistent with older U.S. Geological Survey catalogs of earthquakes in individual states (Stover and others, 1979, 1987a, b, c), the Decade of North American Geology catalog (Engdahl and Rinehart, 1988, 1991), the National Center for Earthquake Engineering Research catalog (Seeber and Armbruster, 1991), the Electric Power Research Institute catalog (Johnston, 1994), and a catalog of central U.S. earthquakes that is in preparation by M. G. Hopper (written communs., 1994-96). We attribute the few differences to investigator variability.

Epicenters estimated from intensity reports can be inaccurate because of the geological and human factors listed in the preceding paragraph. We can estimate this inaccuracy as follows. We have only epicenters estimated from isoseismal maps for the 1934 and older earthquakes of table 3, whereas we have both isoseismal maps and instrumental epicenters for the 1958 and subsequent shocks (Gordon and others, 1970; Herrmann, 1979; Dewey and Gordon, 1984; Stover, 1988; Taylor and others, 1989; Stover and Coffman, 1993). For the 1958 and subsequent earthquakes, no epicenter was estimated from intensity data. Therefore, we make two simplifying assumptions about these five most recent earthquakes: that the instrumental epicenters are perfectly accurate, and that an epicenter derived from the intensity data would fall at the center of the highest-valued isoseismal. With these two assumptions, we measured the distances between the instrumental and intensity-based epicenters for the 1958 and subsequent earthquakes of table 3. The distances can be taken as estimates of the accuracies of the intensity-based epicenters of pre-1958 shocks in the map area. In chronological order of their earthquakes, the distances are 31, 9, 19, 9, and 4 km. Thus, we suggest that intensity-based locations of the 1934 and older earthquakes of table 3 are probably accurate to within a few tens of kilometers. The older pre-1934 earthquakes generally have sparser intensity reports, more poorly constrained isoseismals, and therefore poorer epicentral accuracy.

Stover and Coffman (1993) and M. G. Hopper (1994; oral and written communs., 1994, 1995) reevaluated intensities reported for all the earthquakes listed in table 3 except that of June 10, 1987. Accordingly, we used their isoseismal maps and intensity assignments in preference to previous interpretations from other authors in order to minimize investigator variability. For the 1987 shock we used an unpublished isoseismal map drawn by C. W. Stover for the planned publication "United States Earthquakes, 1987" (L. Brewer, oral and written communs., 1995).

Most shocks listed in table 3 were reported to have caused effects within the map area that were classified as MMI VI or greater, even though some of the epicenters were outside the map area. However, four of the earthquakes that occurred outside the map area have MMI VI isoseismals that were drawn so as to extend into the map area, even though no reports from within the map area described effects exceeding MMI V from these shocks. The earthquakes occurred in 1838, 1843, 1857, and 1934. The interpretation that they might have caused MMI VI within the map area depends on the manners in which isoseismals were drawn between comparatively sparse control points. Therefore, because the focus of this map is the lower Wabash Valley, we list these four earthquakes in table 3 but do not show them on the map.

The four earliest, largest earthquakes of table 3 dominated the New Madrid, Missouri, earthquake sequence during the winter of 1811-12. The smallest of the four, earthquake 1811b, occurred six hours after 1811a and is generally regarded as the largest aftershock of the sequence. All four earthquakes occurred in the New Madrid seismic zone southwest of the Wabash Valley map area. All four caused reports of MMI VI or greater within the map area. However, intensity reports of these four shocks were few from within the then-sparsely settled map area. Consequently, existing isoseismals for the four shocks show little variation across the map area. If we were to include their MMI VI and higher-valued isoseismals on the map, they would obscure the intensity patterns of the smaller, more recent, better reported earthquakes that occurred within the map area and that we discuss in the last paragraph of this section. Therefore, the map shows pointers to the four 1811-12 epicenters but does not show their isoseismals.

Other, smaller aftershocks in the 1811-12 sequence might also have been large enough to produce MMI VI or higher effects in the map area (Nuttli, 1973; Johnston and Schweig, 1996). However, the intensity data from these smaller aftershocks are not yet sufficiently analyzed to identify their intensity distributions in the map area (M.G. Hopper, oral commun., 1996), so we excluded these smaller earthquakes from table 3 and the map.

Our map identifies, with light shading, the parts of the map area that fall within a MMI VI isoseismal for any of the earthquakes of table 3, except the earthquakes that were excluded as described previously . Similarly, darker shading indicates areas within any of the MMI VII isoseismals. The result shows that since 1812, earthquakes shook most of the map area at least once at intensity VI or VII. In particular, all parts of the area from southern Lawrence County, Illinois, southward to Webster and Daviess Counties, Kentucky, have been shaken at least once at MMI VII since 1812. In contrast, the western half of the map area shows comparatively narrow bands of MMI VII shaking. However, examination of the intensity data shows that some of these narrow bands span scattered locations of MMI VII effects that are separated by MMI V or VI effects. Thus, the largest area of repeated MMI VII effects is in the northeastern part of the map area, between Lawrence, Webster, and Daviess Counties.

PREHISTORIC LIQUEFACTION

The northern part of the map area and large adjacent regions to the north, east, and west have been shaken severely by one or more moderate to large prehistoric earthquakes. The evidence of these prehistoric earthquakes takes the form of paleoliquefaction features, mostly shaking-induced dikes and the prehistoric sand blows that they fed. Since the summer of 1990 investigators have examined hundreds of kilometers of river cutbanks, and the walls of numerous man-made ditches and sand and gravel pits; hundreds of dikes and sand blows are exposed in the cutbanks and walls (Obermeier and others, 1991, 1993, 1996; Munson and others, 1992, 1993, 1994, 1995; Munson and Munson, 1996; Hajic and others, 1994a, b, 1995, 1996; Tuttle and others, 1996). The map shows the streams or parts of streams that were searched for evidence of paleoliquefaction, and the sites at which dikes were found. At comparatively few paleoliquefaction sites, sand blows, craters, and other features were found, but no dikes. We do not show these comparatively few sites, because the dikes provide the main constraint on the estimated locations and magnitudes of the prehistoric earthquakes (Obermeier and others, 1993; Pond and Martin, 1996). The most widespread paleoliquefaction is attributed to a mid-Holocene earthquake near what is now Vincennes, Indiana, with an estimated moment magnitude of about 7.5 (Obermeier and others, 1993). Stratigraphic, geomorphological, pedological, archaeological, and geochronologic evidence indicates that probably some of the paleoliquefaction was caused by several additional, smaller earthquakes during the Holocene and late Pleistocene (Munson and others, 1994; Hajic and others, 1995; Munson and Munson, 1996; Pond and Martin, 1996). Paleoliquefaction work continues, and the map shows its status as of the end of the summer-fall field season of 1995.

STRESS ORIENTATIONS

Ellis (1994) compiled published estimates of the orientations of greatest horizontal compressive stress for a large region that includes the map area. We updated and expanded his compilation to produce table 4. The table includes stress orientations from well-bore breakouts at depths from 0 to 1.4 km, but generally exceeding 0.3 km (Dart 1985; Plumb and Cox, 1987), and from single-earthquake focal mechanisms at depths from 10 to 25 km (Herrmann, 1979; Wheeler and Johnston, 1992).

We exclude stress orientations from other kinds of data that might not reflect contemporary regional stresses at hypocentral depths. We exclude composite focal mechanisms, because their construction requires the generally untestable assumption that the composited earthquakes ruptured parallel planes. We exclude P axes that Taylor (1991) determined for two small earthquakes that occurred on June 3, 1983, and June 29, 1984, because the P axes are poorly constrained. We exclude joint orientations, because rarely can one determine that the joints are young enough that they must have formed in the modern stress field, instead of in some ancient stress field that might parallel the modern field locally but not regionally. We exclude small faults that offset the walls of excavations and mines, because they might record either distorted stresses within the weathering zone or stress relief by expansion into the newly opened void. Finally, we exclude results of shallow overcoring, strain gage, and strain relaxation measurements, because of the difficulty in showing that the measured stresses parallel deeper stresses.

The 17 stress orientations from breakouts and single-earthquake focal mechanisms are mostly in the northern half of the map area, where earthquakes are more abundant and petroleum exploration in the Illinois basin has provided numerous dipmeter logs from which to measure breakout orientations. The three focal mechanisms show both reverse and strike-slip faulting. Fifteen of the 17 stress orientations are of A or B quality on a scale from A (best) to D (worst). The two D-quality orientations are nearly parallel to the mean of the better-quality estimates, and are surrounded and separated by the better estimates. Therefore, the following observations would not change much if the D-quality orientations were excluded. The 17 stress orientations are roughly normally distributed about a mean of 085° with a standard deviation of 15°. The three orientations from the southern half of the map area (nos. 3, 5, and 14) trend about 10 degrees more southerly than the mean but are within one standard deviation of it. The four orientations that trend more than one standard deviation away from the mean (nos. 1, 2, 6, and 8) are scattered across the northern and northwestern parts of the map area. Thus, overall, the greatest horizontal compressive stress trends a few degrees north of east throughout the map area, similar to stress orientations in the New Madrid map area to the southwest (Rhea and others, 1994).

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Table 1. *Maps in the U.S. Geological Survey seismotectonic folio of the lower Wabash Valley and vicinity*

Map	Theme: features shown	Reference
I-2583-A	Seismicity: earthquake epicenters, areas most intensely shaken, focal mechanisms, seismograph and accelerograph locations, and locations of prehistoric earthquake-induced liquefaction.	This map
I-2583-B	Modified Mercalli intensities.	Rhea and others (in press)
I-2583-C	Geophysical survey and modeling lines, wells, and global positioning system monuments.	Wheeler and others (unpub. compilation)
I-2583-D	Faults, basement structure, igneous rocks, and geophysical and neotectonic features.	Wheeler and others (unpub. compilation)

In addition, as many as two other maps may be published in this folio. In August, 1996 these two compilations of surficial and cultural information were in too preliminary a form to list them as we have maps A-D, but the reader should be aware of their possible inclusion in the folio.

Table 2. *Geographic and cultural features selected for base map*

Feature	Selection criteria[1]
Streams	Streams whose flood plains contain young, water-saturated materials that might liquefy or amplify shaking during a large earthquake, as shown on geologic maps at scales of 1:250,000 or 1:500,000. In Kentucky and Tennessee, streams with Holocene or Quaternary alluvium mapped along their courses (Miller and others, 1966; McDowell and others, 1981; Noger, 1988). In Illinois, streams with modern flood plain, channel, or alluvial fan deposits of Wisconsinan to Holocene age, or with slack-water lake deposits of Wisconsinan age in river valleys (Lineback, 1979). In Indiana, streams with Holocene alluvium, or with valley-filling, lacustrine clay, silt, and sand of Illinoian or Wisconsinan age (Gray and others, 1970).
Lakes	Lakes large enough to serve as regional geographic references. Each of the six lakes shown is dammed, and the impoundments are large enough that dam failure during seismic shaking could be hazardous (Wheeler and others, 1994).
Roads	Class 1 (primary) and class 2 (secondary) roads only. Topographic maps at 1:100,000 scale show that class 1 includes limited-access roads (Interstate highways, some U.S. routes, and Kentucky toll parkways), most unlimited-access U.S. routes, and some unlimited-access state routes. Class 2 roads have unlimited access, and include some U.S. routes and most state routes.
Railroads	All are shown.
Towns and cities	Twelve cities with 1990 populations of at least 10,000 are named on the map with large type. Smaller type identifies smaller towns or cities that are commonly used by earth scientists as geographic references.

[1] Linework was modified from U.S. Geological Survey digital line graph (DLG) data, which in turn had been digitized from standard 1:100,000-scale planimetric and topographic maps (U.S. Geological Survey, 1989).

Table 3. *Earthquakes in the vicinity of the lower Wabash Valley that are known or interpreted to have caused Modified Mercalli intensity of VI or higher in the map area*

[Source: Stover and Coffman (1993) unless stated otherwise in footnotes]

Date (Year shown on map)	Highest intensity	Epicenter		Magnitude[1]
		lat N. (°)	long W. (°)	
Dec. 16, 1811a[2]	XI	35.6	90.4	**M** 8.1
Dec. 16, 1811b[2]	X	35.6	90.4	**M** 7.2
Jan. 23, 1812a[2]	XI	36.3	89.6	**M** 7.8
Feb. 7, 1812b[2]	XII	36.5	89.6	**M** 8.0
July 5, 1827	VI	38.0	87.5	Mfa 4.8
June 9, 1838[3]	VII	38.5	89.0	**M** 5.1
Jan. 4, 1843[3]	VII	35.5	90.5	**M** 6.5
Oct. 8, 1857[3]	VII	38.7	89.2	**M** 5.1
Sept. 25, 1876	VII	38.5	87.8	Mfa 4.8
Jan. 11, 1883	VI	37.0	89.0	Mfa 4.6
Feb. 6, 1887a	VI	38.7	87.5	Mfa 4.6
Aug. 2, 1887b	VI	37.2	88.5	Mfa 4.9
July 27, 1891a	VI	37.9	87.5	Mfa 4.1
Sept. 27, 1891b	VII	38.25	88.5	**M** 5.5
Oct. 31, 1895	VIII	37.0	89.4	**M** 6.8
Apr. 30, 1899	VII	38.5	87.4	**M** 4.3
Feb. 9, 1903	VII	37.8	89.3	Mfa 4.9
Nov. 27, 1922	VII	37.8	88.5	**M** 4.4
Apr. 27, 1925a	VI	38.2	87.8	**M** 4.9
Sept. 2, 1925b	VI	37.8	87.5	Mfa 4.6
Aug. 20, 1934[3]	VII	36.95	89.2	Mfa 4.7
Nov. 8, 1958	VI	38.436	88.008	Mfa 4.4
Nov. 9, 1968	VII	37.96[4]	88.46[4]	**M** 5.4
Apr. 3, 1974	VI	38.6[4]	88.1[4]	**M** 4.3[4]
June 29, 1984	VI	37.700	88.470	m_{bLg} 4.1
June 10, 1987	VI	38.71[4]	87.95[4]	**M** 5.0

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[1] **M** is moment magnitude; unless stated otherwise, from Johnston (1994) or Johnston (in press), with preference given to the latter. m_{bLg} is body-wave magnitude calculated from Lg waves with 1 s periods. Mfa is estimate of m_{bLg} calculated from the area over which an earthquake was felt before the deployment of seismographs from which m_{bLg} could be calculated. If more than one of these magnitudes is available for an earthquake, the order of their preference is as listed in this footnote.

[2] Epicenters but not isoseismals shown on map (see text, "Earthquake Intensities").

[3] Neither epicenters nor isoseismals shown on map (see text, "Earthquake Intensities").

[4] From sources cited in table 4.

Table 4. *Orientations of greatest horizontal compressive stress in the vicinity of the lower Wabash Valley*
[Data updated and expanded from Ellis (1994)]

Well-bore breakouts

Index[1], well	lat N., long W.[2]	S_{Hmax}[3]	Q[4]	References
1. TRW Systems/Henderson No. 2	38°41'03", 88°21'22"	057	B	Dart (1985), Ellis (1994)
2. Marathon Oil Co./Effie Barrie No. 1 and E.G. Shipman No. 1[5]	38°54'54", 87°49'05"[6]	065	B	Dart (1985), Ellis (1994)
3. M.W.C. Oil Co./Ramsey No. 1	37°30'23", 87°40'52"[6]	092	A	Dart (1985), Ellis (1994)
4. Marathon Oil Co./J. B. Lewis No. 79	38°45'13", 87°46'09"	086	B	Dart (1985), Ellis (1994)
5. M.W.C. Oil Co./Duncan No. 1 and Brown No. 1[5]	37°42'22", 87°31'38"[6]	093	A	Dart (1985), Ellis (1994)
6. Great Plains Resources, Inc./Tuck Rice No. 8F and Old Ben No. 2-F[5]	38°00'08", 88°56'51"[6]	102	B	Dart (1985), Ellis (1994)
7. Sandy Ridge Oil Co., Inc./Emerson et. al. No. 1	38°15'59", 87°42'56"	088	B	Dart (1985), Ellis (1994)
8. Gruy Federal, Inc. (D. O. E.)/ Simpson No. 1	38°15'42", 88°20'27"	050	B	Dart (1985), Ellis (1994)
9. Sandy Ridge Oil Co., Inc./Charles Young No. 1	38°17'20", 87°48'26"	099	B	Dart (1985), Ellis (1994)
10. H. B. and Y. Associates /Bessie Carneal Est. No. 1	38°59'46",[7] 88°39'13"	074	B	Dart (1985), Ellis (1994)
11. C. E. Brehm/Roser No. A-1	38°08'02", 88°15'12"	090	D	Dart (1985), Ellis (1994)
12. Marathon Oil Co./W. A. Gould No. W1-2	38°39'03", 87°42'48"	086	D	Dart (1985), Ellis (1994)
13. name not given	38°19'12", 87°27'36"	096	A	Plumb and Cox (1987)
14. name not given	37°19'12", 87°30'00"	099	B	Plumb and Cox (1987)

Single-earthquake focal mechanisms

Index[1], date	Moment magnitude	lat N., long W.[2]	P axis[8]	Q[4]	References
15. Nov. 9, 1968	**M** 5.4	37°57'36", 88°27'36"	097/01	B	Stauder and Nuttli (1970), Gordon and others (1970), Johnston (in press)
16. Apr. 3, 1974	**M** 4.3	38°36'00", 88°06'00"	267/14	C	Herrmann (1979)
17. June 10, 1987	**M** 5.0	38°42'36", 87°57'00"	089/04	B	Taylor and others (1989), Johnston (in press)

[1] Index number is keyed to symbol on map.

[2] Locations originally reported to nearest section (entries 1-12), nearest 0.01° (about 1 km; entries 13-15 and 17), or 0.1° (about 10 km; entry 16). Converted locations are reported here to nearest second in order not to add round-off error to original uncertainty.

[3] Stress orientation, taken as the azimuth, in degrees, of maximum horizontal compressive stress, and calculated as the normal to the preferred orientation of breakouts.

[4] Quality, graded from A (best) to D (worst), according to criteria of Zoback and Zoback (1991). A stress orientation calculated from breakouts measured in a well bore is graded according to number and length of breakouts and the standard deviation of their orientations. Orientation inferred from a focal mechanism is graded according to earthquake magnitude, degree of constraint on the mechanism's orientation, and method used to calculate the mechanism.

[5] Breakout data combined from two wells drilled by same company in same or adjacent sections (Dart, 1985). Tabulated location is average of the two individual locations.

[6] Locations differ slightly from those given by Dart (1985) because we obtained more precise locations from the state geological surveys.

[7] Note added in proof: stress indicator 10 is plotted 0.5 degree too far north on the map. The latitude is correct in this table.

[8] Azimuth/plunge, in degrees. Stress orientation is taken as the azimuth.

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