DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY

MISCELLANEOUS FIELD STUDIES
MAP MF-1011
SHEET 2 OF 2

PRELIMINARY SEISMOTECTONIC MAP OF CENTRAL MISSISSIPPI VALLEY AND ENVIRONS

By A. V. Heyl and F. A. McKeown

The purpose of this map is to make readily available a compilation of geological and seismological data that are relevant to the assessment of seismic hazards in the most seismically active part of the central United States. The data shown on the map include gross time-stratigraphic units; faults and lineaments; seismicity; location of mafic rocks and diatremes; locations of sand blows, which were very likely associated with the 1811-12 sequence of earthquakes; and lineations and scarps. A compilation of gravity and aeromagnetic-survey data at the same scale (1:500,000) for part of the area of this preliminary seismotectonic map has recently been open-filed by Hildenbrand and others (1977). Integration of gravity and aeromagnetic data from this and other sources with the geological and seismological data provides considerable insight into geologic features that may possibly be genetically related to the seismicity. Discussion of two interpretations of the integrated data is included in this brief report.

Faults and lineaments

The map shows faults as reported in the literature, some of which have been slightly modified, and a few faults mapped by the authors. The amount and quality of fault information shown on the map vary greatly. The lack of faults in some areas is more likely attributable to the lack of information than to the lack of faults. For example, many faults are shown along Kentucky Lake in Kentucky, where detailed mapping has been done, but very few faults are shown along this lake in Tennessee, where detailed maps are not available. Also, many more faults have been indicated in southeastern Illinois than in southwestern Illinois. This is very likely due to the fact that much detailed mapping has been done in southeastern Illinois because it includes part of a fluorite-lead-zinc mining district. Because fault information is incomplete, the map should not be used for detailed tectonic analysis.

Several prominent fault trends are evident on the map. Of these, the northeast trend of the faults in western Kentucky and southeastern Illinois, which encompasses the Kentucky-Illinois fluorspar district, is most prominent. These faults are part of the New Madrid fault zone as originally defined by Heyl and Brock (1961). Since 1961, when the zone was defined, new information and ideas have become known; and the term "zone" is no longer a suitable description of the northeast-trending faults. We therefore tentatively propose that these faults be called the New Madrid fault system. The principal reasons for the suggested change in terminology is that the faults occur over a very great width (more than 60 km) and are complexly associated with the Cottage Grove-Shawneetown-Rough Creek fault zone, Hicks Dome, and the Ste. Genevieve fault zone. Further, the areal extent of the system cannot yet be clearly defined. It may extend farther west than shown; because detailed mapping has not been done west of the Kentucky-Illinois fluorspar district, a western boundary cannot be defined. Conclusive evidence that it extends unbroken southward past New Madrid, Mo., into the subsurface of the Mississippi embayment is partly lacking. The eastern boundary of the system may be defined along a line where northeast-trending faults in western Kentucky curve to the east.

The authors of this map do not agree on the continuity and character of the New Madrid fault system. Heyl believes that the additional seismic, geophysical, and geologic data that have been obtained since the New Madrid fault zone was defined in 1961 (Heyl and Brock) support the interpretation of a major structural feature (the New Madrid fault system) extending from about Vincennes, Ind., to Memphis, Tenn., and possibly farther. McKeown, on the other hand, believes that the northeast-trending faults exposed in the fluorspar district and Wabash Valley, which constitute the principal surface evidence of the system, do not represent major structural features that extend deep into the crust where the earthquakes occur. Heyl's arguments for the system as originally defined are outlined in the following paragraphs; McKeown's viewpoint follows.

The New Madrid fault zone, hereafter called a system, was originally named and defined by Heyl and Brock (1961) as the 60-km-wide "zone" of northeast-trending faults (including connecting segments of other trends) that make up the complex zone of grabens and horsts crossing the Illinois-Kentucky fluorspar district. In addition, they proposed that the system extends southwestward into the Mississippi River embayment in the Paleozoic rocks, and, to a lesser extent, in the overlying Mesozoic and Tertiary rocks to form the part of a tensional fault system having a strike-slip component. They proposed that the northeastward-trending zone (also about 80 km wide) of earthquake epicenters within the embayment, which extends from west of Memphis, Tenn., to Paducah, Ky., and a few faults described near New Madrid, Memphis, and Cape Girardeau, Mo., were evidence that the fault system is "tectonically active today" and that it extends at least as far south as Memphis. In addition, they suggested that the fault system may extend northeastward across the Rough Creek-Shawneetown fault zone and the moderately seismically active area of the northeastward-trending Wabash Valley fault zone to about Vincennes, Ind.

Heyl believes that the faults and linears mapped by many investigators since 1961 extend into the Cretaceous and Tertiary rocks of the north end of the embayment. The newer earthquake data showing lines of epicenters of northeast, west, and northwest trends (Stauder and others, written commun., 1975-76) and the mantle-derived mafic alkalic intrusives in the Wabash Valley fault-zone segment partly substantiate the New Madrid fault system. The most recent gravity and aeromagnetic data by Hildenbrand and others (1977) suggest that a 2-km-deep graben about 80 km wide lies in the center of the embayment. The inferred graben is defined on the aeromagnetic map of Hildenbrand and others (1977) as a northeast-trending zone having a very low amplitude, nondescript magnetic field bounded rather sharply on the northwest and southeast by areas containing many moderate- to high-amplitude anomalies. The inferred graben clearly extends northeastward to about New Madrid and extends southwestward beyond the limits of aeromagnetic and gravity data. The gravity and aeromagnetic data suggest that the graben continues northeastward from the vicinity of New Madrid but becomes progressively more shallow and less well defined as it approaches Cairo, Ill., where it ends. Northeast of Cairo many northeast-trending linears occur in the gravity data that may reflect the graben and horst system of the fluorspar district with which they may join. Several northwest-trending linears intersect the northeast system, the largest of which appears to be the southeast extension of the Ste. Genevieve fault zone. The northeast system is also crossed by a strong linear south of a buried pluton whose center approximately underlies Bloomfield, Stoddard County, Mo. The inferred graben in aeromagnetic and gravity data of Hildenbrand and others (1977) and the occurrence, as shown on the map, of alkalic and alkalic mafic rocks in drill holes support the interpretation made by others (for example, Ervin and McGinnis, 1975; Kumarapeli and Saull, 1966) that the Mississippi embayment is underlain by a rift zone. Much of the rapidly accumulating data is still unclear, particularly in the segment of the New Madrid fault system between New Madrid and Cairo, Ill., and eastward to Paducah, Ky.

McKeown's arguments against a relatively continuous structural system with which seismic activity is associated are outlined in the following paragraphs.

The recent seismic activity reported by William Stauder, Stephen Schaefer, John Best, and S. T. Morrisey (written commun., 1975) shows alinements of epicenters that transect as well as parallel the inferred northeast-trending New Madrid fault system. Furthermore, focal mechanisms (Street and others, 1974) for earthquakes in the Mississippi embayment as well as in the surrounding region show diverse mechanisms that indicate great differences in geologic structure within short distances.

Study of the aeromagnetic data of Lidiak and Zietz (1976) and of the gravity and aeromagnetic data of Hildenbrand and others (1977) suggests that the northeast-trending faults may not extend southwestward as a continuous system. Strong northwest-trending lineations on the gravity and aeromagnetic maps, one of which is coextensive with the Ste. Genevieve fault zone, transect southwest projections of the faults in the fluorspar district. If the system is assumed to extend northeastward so as to include the Wabash River faults, an explanation of the system's relationship to the Cottage Grove-Shawneetown-Rough Creek fault zone is required. No satisfactory explanation of this relationship is known to the authors, and the outcrop and subsurface evidence at the join is particularly poor. Some evidence indicates that the Wabash River faults extend to only shallow depths and may not be genetically part of the system if the system is of deep-seated origin. The evidence is found in the work of Bristol (1975). For example, in figures 4, 5, and 6 of Bristol, the maximum vertical displacement on the Inman East fault decreases from about 450 feet (150 m) on top of the Pennsylvanian Brereton Limestone Member of Kosanke and others (1960) of the Carbondale Formation to less than 200 feet (60 m) at the base of the Upper Mississippian Beech Creek Limestone Member of the Golconda Formation. Several other faults shown in these figures also have less displacement on the deeper horizons than on the shallowest horizon. Apparently these faults are tensional features associated with domes and anticlines.

It should be noted, however, that northwest-striking dikes of mafic alkalic rocks, which by modern geologic interpretation are derived from the mantle, occur along the Cottage Grove-Shawneetown-Rough Creek fault zone. Mafic alkalic rocks also have been penetrated in the Omaha Dome near Omaha, Gallitin County, Ill., and reportedly in Indiana. Thus some faults in the Wabash Valley may extend through the Earth's crust.

Additional arguments by either Heyl or McKeown are inappropriate within the limited scope of this report. We believe, however, that the readers should be aware of some of the problems associated with defining a major structural system with which the seismic activity in the central Mississippi Valley can be associated.

The Cottage Grove-Shawneetown-Rough Creek fault zone and the Ste. Genevieve fault zone are prominent zones and form part of the 38th parallel lineament (Heyl, 1972). Their great length, their coincidence with aeromagnetic lineations (Lidiak and Zietz, 1976), and the abundance of ultramafic rocks and diatremes along or near them indicate that these faults are deep-seated and of major tectonic importance. Further, even though no evidence of Quaternary movement is known on them, the occurrence of seismic events near them suggests the possibility that some parts of these faults may be earthquake source zones. A considerable amount of additional detailed geological and seismological data are required to assess the earthquake potential of these faults.

Seismicity

Epicenters of earthquakes listed in two catalogs are plotted on the map. Nuttli's (1974) catalog of earthquakes that occurred during the period from 1833 to 1972 was used to show the regional distribution of earthquakes over a long period of time. The accuracy of the location of many of these epicenters is poor, however, because of the lack of any seismographic stations before 1909 and the scarcity of seismographic stations until 1974.

The data from Nuttli's (1974) catalog include earthquake locations estimated from seismic effects noted before any seismograph stations were established, as well as instrumental locations using an assortment of stations whose operating periods and magnifications varied widely. This spatial and temporal nonuniformity makes it difficult to assess the relative number of earthquakes from location to location or to delineate trends in the data.

Epicenters of earthquakes detected by the seismic network operated by St. Louis University during the period from July 1975 through June 1976 are also shown. Although this network operated before and after this period, to maintain cartographic clarity, only the results of 1 year of recording are shown on the map; also, prior to July 1975 the network was incomplete. The results of greatly increased accuracy of locations and detection capability of the St. Louis network compared with former seismographic facilities are evident on the map in the distinct trends in seismic activity. The width of the seismically active area between Marked Tree, Ark., and Cairo, Ill., is about the same as the known width of the Illinois-Kentucky fluorspar fault system to the north, and these systems are elongated in the same direction. Most of the seismic activity in the last few years trends north-northwest from near Bogota, Dyer County, Tenn., to about Howardville, New Madrid County, Mo. The second most prominent trend is northeast, parallel to segments of the New Madrid fault system. Discussion of the significance of these trends should include all geologic and geophysical data available and is therefore not within the scope of this report.

Mafic rocks and diatremes

The location of mafic rocks and diatremes is plotted on the map because (1) they are indicative of deep ruptures in the crust of the earth, and (2) much seismic activity in central and southeastern United States appears to be associated with mafic rocks. The significance of the association is not yet completely understood. The mafic rocks range in age from Precambrian to Tertiary. Diabase dikes and sills in the St. Francois Mountains are of Precambrian age. The mafic diatremes west of long $90^{\circ}30'$ are geologically dated as Cambrian age (Snyder and Gerdemann, 1965). Diatremes and alkalic ultramafic rocks in the vicinity of lat $37^{\circ}45'$ N., long $90^{\circ}15'$ W., centered near Avon, Mo., are geologically and isotopically dated as Devonian age (Zartman and others, 1967). In the Kentucky-Illinois fluorspar district, some of the diatremes and alkalic ultramafic rocks are isotopically dated as Permian age, as is one of the mafic intrusions in northwest Tennessee (Zartman and others, 1967; Zartman, 1977).

Possibly the youngest igneous rock occurrence shown on the map is in the drill hole indicated by a question mark near it, 7 km northwest of New Madrid, Mo. Cuttings from depths of 795 to 825 feet (239-284.2 m) in this hole contain elements and minerals commonly diagnostic of igneous rock. The rock also lacks some diagnostic criteria and, therefore, its classification is uncertain. That the rock may be associated with a large mafic pluton is indicated by its location on the nose of a large gravity and aeromagnetic anomaly whose center is near Bloomfield in Stoddard County, Mo. In the drill hole the rock occurs between the Paleocene Porters Creek Formation of the Midway Group and the Eocene Wilcox Formation.

Sand blows

The map shows the distribution of sand blows that are identifiable on 1:80,000-scale aerial photography. Reentrants into the sand-blow pattern along the St. Francis River and the Right Chute of Little River do not necessarily indicate a lack of sand blows. The area is heavily forested along parts of these rivers; and sand blows, which are very likely present, are not visible through the trees. Heavy forest cover is also the reason that sand-blow areas west of Dyersburg, Tenn., are in patches. The boomerang-shaped area immediately east of Malden, Mo., appears mottled on aerial photographs. Sand blows probably occurred in this area, but they do not have the clearcut outlines typical of most sand blows. The cause of the mottled ground, therefore, is somewhat uncertain. That this pattern is the result of sand blows is supported by the fact that patches of similarly mottled ground occur around New Madrid, where sand blows were observed in 1811 and 1812. These patches are few and not mappable at the scale of the map. From mapping of the sand blows on aerial photographs and searching for them in the field, it appears that New Madrid was at about the northern limit of their occurrence in 1811-12. The limits of the sand blows shown on the map are approximately the same as the limits mapped by Fuller (1912). Perhaps one of the most significant aspects of the distribution of sand blows is that they form a generally northeastward-trending linear pattern that crosses most present-day drainage features and that elongate pattern could be interpeted as being an indication of a buried fault zone.

The fact that New Madrid, Mo., was the only settlement in the upper Mississippi embayment during the 1811-12 sequence of earthquakes has led to mistaken concepts (excluding Fuller, 1912) of the location of the area of greatest disturbance produced by these earthquakes. Judging from the current appearance of the sand blows and their distribution, ground disturbance appears to have been greatest between Marked Tree, Ark., and Caruthersville (formerly Little Prairie), Mo., and not in the immediate area around New Madrid. An apparent offset in the pattern of sand blows occurs from south of Reelfoot Lake to the latitude of Dyersburg, Tenn., and has a northerly trend. This belt of sand blows, along with the subsidence that apparently caused Reelfoot Lake, may be a separate but contiguous area of great disturbances.

Lineations and scarps

Lineations and scarps are common features in the floodplain of the Mississippi River. Perhaps all of them are the result of various river processes such as lateral corrasion, crevassing of natural levees, point-bar deposition, and channel filling. A few lineations and scarps, however, appear to have alternative interpretations. Those shown on the map have been selected to illustrate how their orientations, dimensions, and locations appear suggestive of Quaternary deformation. For example, Sikeston Ridge was considered part of an anticline by Fuller (1912), and is nearly coextensive with the Tiptonville dome (Fuller, 1912) immediately west of Reelfoot Lake, Tenn. The ridge and bounding scarps, however, are considered by geologists knowledgeable of the area to be an erosional remnant of a Holocene terrace. The scarp extending from Dexter in Stoddard County, Mo., south past Malden in New Madrid County, Mo., is also believed to separate terrace levels. The fact that it is so straight for more than 50 km suggests the possibility that it may be structurally controlled. The lineation about 2 km east of Ridgely, Dyer County, Tenn., may reasonably be interpreted as a fault. If so, it probably had displacement on it during the 1811-12 earthquakes. Exploration is planned to prove or negate whether this lineation is a fault. Although the lineations and scarps shown on the map are all speculative structural features, it seemed best in the judgment of the authors to show them on this preliminary map.

Selected references

Amos, D. H., 1965, Geology of parts of the Shetlerville and Rosiclare quadrangles, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-400, scale 1:24,000.

______1966, Geologic map of the Golconda quadrangle, Kentucky-Illinois, and part of the Brownfield quadrangle in Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-546, scale 1:24,000.

______1967, Geologic map of part of the Smithland quadrangle, Livingston County, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-657, scale 1:24,000.

______1970, Geologic map of the Blackford quadrangle, western Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-873, scale 1:24,000.

______1974, Geologic map of the Burna quadrangle, Livingston County, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-1150, scale 1:24,000.

Amos, D. H., and Desborough, G. A., 1970, Mafic intrusive rocks of Precambrian age in southeast Missouri (Contribution to Precambrian geology no. 3): Missouri Division of Geological Survey and Water Resources Report of Investigations 47, 22 p.

Amos, D. H., and Finch, W. I., 1968, Geologic map of the Calvert City quadrangle, Livingston and Marshall Counties, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-731, scale, 1:24,000.

Amos, D. H., and Hays, W. H., 1974, Geologic map of the Dycusburg quadrangle, western Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-1149, scale 1:24,000.

Amos, D. H., and Wolfe, E. W., 1966, Geologic map of the Little Cypress quadrangle, Kentucky-Illinois: U.S. Geological Survey Geologic Quadrangle Map GQ-554, scale 1:24,000.

Anderson, R. E., 1970, Ash-flow tuffs of Precambrian age in southeast Missouri (Contribution to Precambrian geology no. 2): Missouri Division of Geological Survey and Water Resources Report of Investigations 46, 50 p.

Baker, L. N., 1963, Geology of New Madrid SE and Hubbard Lake quadrangles in Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-292, scale 1:24,000.

Baxter, J. W., and Desborough, G. A., 1965, Areal geology of the Illinois fluorspar district--Part 2, Karbers Ridge and Rosiclare quadrangles: Illinois State Geological Survey Circular 385, 40 p.

Baxter, J. W., Desborough, G. A., and Shaw, C. W., 1967, Areal geology of the Illinois fluorspar district--Part 3, Herod and Shetlerville quadrangles: Illinois State Geological Survey Circular 413, 41 p.

Baxter, J. W., Potter, P. E., and Doyle, F. L., 1963, Areal geology of the Illinois fluorspar district--Part 1, Saline mines, Cave-In-Rock, Dekoven and Repton quadrangles: Illinois State Geological Survey Circular 342, 43 p.

Blade, L. V., 1963, Geology of the Hazel quadrangle in Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-203, scale 1:24,000.

______1964, Geology of the Cuba quadrangle, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-322, scale 1:24,000.

______1965, Geologic map of the Hickory quadrangle, Graves County, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-457, scale 1:24,000.

______1966, Geologic map of parts of the Hamlin and Paris Landing quadrangles, western Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-498, scale 1:24,000.

Boswell, E. H., Moore, G. K., MacCary, L. M., and others, 1965, Cretaceous aquifers in the Mississippi Embayment, in Water resources of the Mississippi Embayment: U.S. Geological Survey Professional Paper 448-C, p. C1-C37.

Bridge, Josiah, 1930, Geology of the Eminence and Cardareva quadrangles: Missouri Bureau of Geology and Mines, 2d ser., v. 24, 228 p.

Bristol, H. M., 1975, Structural geology and oil production of northern Gallatin County and southernmost White County, Illinois: Illinois State Geological Survey, Illinois Petroleum 105, 20 p.

Brock, M. R., and Heyl, A. V., Jr., 1961, Post-Cambrian igneous rocks of the central craton, western Appalachian Mountains and Gulf Coastal Plain of the United States, in Geological Survey Research 1961: U.S. Geological Survey Professional Paper 424-D, p. D33-D35.

Butts, Charles, 1925, Geology and mineral resources of the Equality-Shawneetown area (parts of Gallatin and Saline Counties): Illinois State Geological Survey Bulletin 47, 76 p.

Cady, G. H., and others, 1951, Subsurface geology and coal resources of the Pennsylvanian system in certain counties of the Illinois Basin (Clay, Edwards, Gallatin, Hamilton, and Richmond Counties): Illinois State Geological Survey Report of Investigations 148, 123 p., with appendix, 151 p.

Clark, S. K., and Royds, J. S., 1948, Structural trends and fault systems in Eastern Interior Basin: Bulletin of the American Association of Petroleum Geologists, v. 32, no. 9, p. 1728-1749.

Dake, C. L., 1930, The geology of Potosi and Edgehill quadrangles: Missouri Bureau of Geology and Mines, 2d ser., v. 23, 233 p.

Desborough, G. A., 1961, Geology of the Pomona quadrangle, Illinois: Illinois State Geological Survey Circular 320, 16 p.

English, R. M., and Grogan, R. M., 1948, Omaha pool and mica-peridotite intrusives, Gallatin County, Illinois, in Howell, J. V., ed., Structure of typical American oil fields, Volume 3: Tulsa, Okla., American Association of Petroleum Geologists, p. 189-212; also issued as Illinois State Geological Survey Report of Investigations 130.

Ervin, C. P., and McGinnis, L. D., 1975, The Reelfoot rift--reactivated precursor of the Mississippi embayment: Geological Society of America Bulletin, v. 86, no. 9, p. 1287-1295.

Fairer, G. M., 1975, Geologic map of the Waverly quadrangle, Union and Henderson Counties, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-1220, scale 1:24,000.

Fairer, G. M., Norris, R. L., and Johnson, W. D., Jr., 1975, Geologic map of the Beech Grove quadrangle, western Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-1230, scale 1:24,000.

Farrer, Willard, and McManamy, Lyle, 1937, The geology of Stoddard County, Missouri: Missouri Geological Survey 59th Biennial Report 1935-36, Appendix 6, 92 p.

Fenneman, N. M., 1911, Geology and mineral resources of the St. Louis quadrangle, Missouri-Illinois: U.S. Geological Survey Bulletin 438, 73 p.

Finch, W. I., 1963, Geology of the Water Valley quadrangle in Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-269, scale 1:24,000.

______1964, Geology of the Symsonia quadrangle, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-326, scale 1:24,000.

______1965, Geology of the Mayfield quadrangle, Graves County, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-372, scale 1:24,000.

______1966, Geologic map of the Paducah West and part of the Metropolis quadrangles, Kentucky-Illinois: U.S. Geological Survey Geologic Quadrangle Map GQ-557, scale 1:24,000.

______1967, Geologic map of part of the Joppa quadrangle, McCracken County, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-652, scale 1:24,000.

______1968, Geologic map of the Lovelaceville quadrangle, western Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-763, scale 1:24,000 [1969].

______1971, Geologic map of part of the Hickman quadrangle, Fulton County, Kentucky and Mississippi County, Missouri: U.S. Geological Survey Geologic Quadrangle Map GQ-874, scale 1:24,000.

Finch, W. I., and Minard, J. P., 1966, Geologic map of the Farmington quadrangle, Graves County, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-530, scale 1:24,000.

Flint, R. F., 1926, Thrust faults in southeastern Missouri: American Journal of Science, 5th series, v. 12, p. 37-40.

Fox, K. F., Jr., 1965, Geology of the Cadiz quadrangle, Trigg County, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-412, scale 1:24,000.

Fox, K. F., Jr., and Olive, W. W., 1966, Geologic map of the Birmingham Point quadrangle, western Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-471, scale 1:24,000.

Fox, K. F., Jr., and Seeland, D. A., 1963, Geology of the Canton quadrangle, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-279, scale 1:24,000 [1964].

Freeman, L. B., 1945, Paleozoic structure and stratigraphy [of the Jackson Purchase region, Kentucky]: Kentucky Department of Mines and Minerals, Geologic Division Bulletin, series 8, no. 8, p. 12-43.

______1950, Paleozoic structure and stratigraphy, in Roberts and Gildersleeve, Geology and mineral resources of the Jackson Purchase region, Kentucky: Kentucky Geological Survey Bulletin, series 9, no. 4, p. 12-36.

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

Gildersleeve, Benjamin, 1968, Geologic map of Bee Spring quadrangle, Edmonson and Grayson Counties, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-757, scale 1:24,000.

Grohskopf, J. G., 1955, Subsurface geology of the Mississippi embayment of southeast Missouri: Missouri Division of Geological Survey and Water Resources [Report], 2d ser., v. 37, 133 p.

Haley, B. R., 1976, Geologic map of Arkansas: Reston, Va., U.S. Geological Survey.

Hardeman, W. D., 1966, Geologic map of Tennessee: State of Tennessee, Department of Conservation, Division of Geology.

Hays, W. H., 1964, Geology of the Grand Rivers quadrangle, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-328, scale 1:24,000.

Hendricks, H. E., 1954, The geology of the Steelville quadrangle, Missouri: Missouri Division of Geological Survey and Water Resources [Report], 2d ser., v. 36, 88 p.

Heyl, A. V., 1972, The 38th parallel lineament and its relationships to ore deposits: Economic Geology, v. 67, no. 7, p. 879-894.

Heyl, A. V., and Brock, M. R., 1961, Structural framework of the Illinois-Kentucky mining district and its relation to mineral deposits, in Geological Survey Research 1961: U.S. Geological Survey Professional Paper 424-D, p. D3-D6.

Heyl, A. V., Brock, M. R., Jolly, J. L., and Wells, C. E., 1966, Regional structure of the southeast Missouri and Illinois-Kentucky mineral districts: U.S. Geological Survey Bulletin 1202-B, 20 p.

Hildenbrand, T. G., Ervin, C. P., Hendricks, John, Keller, G. R., McGinnis, L. D., and Stearns, R. G., 1977, Bouguer gravity map of the northern Mississippi Embayment, parts of Missouri, Arkansas, Tennessee, Kentucky, and Illinois: U.S. Geological Survey Open-File Report 77-228.

Hildenbrand, T. G., and Johnson, R. W., 1977, Aeromagnetic map of the northern Mississippi Embayment, parts of Missouri, Arkansas, Tennessee, and Kentucky: U.S. Geological Survey Open-File Report 77-229.

Johnson, W. D., Jr., 1974, Geologic map of parts of the West Franklin, Caborn, and Mt. Vernon quadrangles, Henderson and Union Counties, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-1152, scale 1:24,000.

Johnson, W. D., Jr., and Harris, R. L., 1974, Geologic map of the Smith Mills quadrangle, Henderson and Union Counties, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-1215, scale 1:24,000 [1975].

Johnson, W. D., Jr., Smith, A. E., Fairer, G. M., 1975, Geologic map of the Morganfield quadrangle, Union County, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-1269, scale 1:24,000 [1976].

Kehn, T. M., 1966, Geologic map of the Providence quadrangle, western Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-491, scale 1:24,000.

______1974, Geologic map of parts of the Dekoven and Saline Mines quadrangles, Crittenden and Union Counties, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-1147, scale 1:24,000.

______1975, Geologic map of the Sturgis quadrangle, western Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-1273, scale 1:24,000 [1976].

Kidwell, A. L., 1947, Post-Devonian igneous activity in southeastern Missouri: Missouri Division of Geological Survey and Water Resources Report of Investigations 4, 83 p.

______1951, Mesozoic igneous activity in the northern Gulf Coastal Plain: Gulf Coast Association of Geological Societies Transactions, 1st Annual Meeting, p. 182-199.

Kiilsgaard, T. H., Heyl, A. V., and Brock, M. R., 1963, The Crooked Creek disturbance, southeast Missouri, in Geological Survey Research 1962: U.S. Geological Survey Professional Paper 450-E, p. E14-E19.

Klemic, Harry, Ulrich, G. E., and Moore, S. L., 1968, Geologic map of part of the Johnson Hollow quadrangle, Trigg County, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-722, scale 1:24,000.

Kosanke, R. M., and others, 1960, Classification of the Pennsylvanian strata of Illinois: Illinois State Geological Survey Report of Investigations 214, 84 p.

Kumarapeli, P. S., and Saull, V. A., 1966, The St. Lawrence Valley system--a North American equivalent of the East African rift system: Canadian Journal of Earth Sciences, v. 3, no. 5, p. 639-658.

Lamar, J. E., 1925, Geology and mineral resources of the Carbondale quadrangle: Illinois State Geological Survey Bulletin 48, 172 p.

Lambert, T. W., 1965, Geology of Lynnville quadrangle in Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-414, scale 1:24,000.

Lambert, T. W., and MacCary, L. M., 1964, Geology of the Briensburg quadrangle, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-327, scale 1:24,000.

Lee, K. Y., 1974, Geologic map of the Oakton and part of the Wolf Island quadrangle, Hickman and Fulton Counties, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-1187, scale 1:24,000 [1975].

Lee, Wallace, 1914, Geology of the Rolla quadrangle: Missouri Bureau of Geology and Mines, 2d ser., v. 12, 111 p.

Lidiak, E. G., and Zietz, Isidore, 1976, Interpretation of aeromagnetic anomalies between latitudes 37° N. and 38° N. in the eastern and central United States: Geological Society of America Special Paper 167, 37 p.

McCracken, M. H., comp., 1961, Geologic map of Missouri: Rolla, Missouri Division of Geological Survey and Water Resources.

______1971, Structural features of Missouri: Missouri Division of Geological Survey and Water Resources Report of Investigations 49, 99 p.

Nuttli, O. W., 1974, Magnitude-recurrence relation for central Mississippi Valley earthquakes: Bulletin of the Seismological Society of America, v. 64, no. 4, p. 1189-1207.

Olive, W. W., 1963, Geology of the Elva quadrangle, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-230, scale 1:24,000.

______1963, Geology of the Lynn Grove quadrangle in Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-268, scale 1:24,000.

______1965, Geology of the Hico quadrangle, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-332, scale 1:24,000.

______1966, Geologic map of the Heath quadrangle, McCracken and Ballard Counties, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-561, scale 1:24,000.

______1966b, Geologic map of the Paducah East quadrangle in western Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-531, scale 1:24,000.

______1967, Geologic map of part of the Cayce quadrangle, Hickman and Fulton Counties, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-601, scale 1:24,000.

______1969, Geologic map of parts of the Bandana and Olmstead quadrangles, McCracken and Ballard Counties, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-799, scale 1:24,000.

______1971a, Geologic map of the Blandville quadrangle, Ballard and Carlisle Counties, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-938, scale 1:24,000.

______1971b, Geologic map of parts of the Cairo and Barlow quadrangles, Ballard County, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-885, scale 1:24,000.

______1972, Geologic map of the Clinton quadrangle, Hickman County, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-1030, scale 1:24,000.

______1974, Geologic map of the Wickliffe quadrangle, Kentucky-Missouri, and the part of the Wyatt quadrangle, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-1161, scale 1:24,000.

Olive, W. W., and Davis, R. W., 1968, Geologic map of the Oak Level quadrangle, western Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-744, scale 1:24,000.

Palmer, J. E., 1966, Geologic map of the Dalton quadrangle, western Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-490, scale 1:24,000.

Pryor, W. A., and Ross, C. A., 1962, Geology of the Illinois parts of the Cairo, La Center, and Thebes quadrangles: Illinois State Geological Survey Circular 332, 39 p.

Rogers, W. B., 1963, Geology of the Eddyville quadrangle, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-255, scale 1:24,000.

______1965, Geology of the Model quadrangle in Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-409, scale 1:24,000.

Rogers, W. B., and Hays, W. H., 1967, Geologic map of the Fredonia quadrangle, western Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-607, scale 1:24,000.

Ross, C. A., 1963, Structural framework of southernmost Illinois: Illinois State Geological Survey Circular 351, 28 p.

______1964, Geology of the Paducah and Smithland quadrangles in Illinois: Illinois State Geological Survey Circular 360, 31 p.

Rubey, W. W., 1952, Geology and mineral resources of the Hardin and Brussels quadrangles (in Illinois): U.S. Geological Survey Professional Paper 218, 179 p.

Sample, R. D., 1965, Geology of the Princeton West quadrangle, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-385, scale 1:24,000.

______1967, Geologic map of the Lamasco quadrangle, western Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-608, scale 1:24,000.

Scott, G. R., and MacCary, L. M., 1968, Geologic map of the Hardin quadrangle, Marshall County, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-759, scale 1:24,000.

Schnabel, R. W., and MacKallor, J. A., 1964, Geology of the Fenton quadrangle, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-317, scale 1:24,000.

Seeland, D. A., 1968a, Geologic map of the Cobb quadrangle, Trigg and Caldwell Counties, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-710, scale 1:24,000.

______1968b, Geologic map of part of the Repton quadrangle in Crittenden County, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-754, scale 1:24,000.

Seeland, D. A., and Wilshire, H. G., 1965, Geologic map of part of the Rushing Creek quadrangle in southwestern Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-445, scale 1:24,000.

Sims, J. D., 1972, Geologic map of the Dublin quadrangle, Graves and Hickman Counties, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-972, scale 1:24,000.

Snyder, F. G., and Gerdemann, P. E., 1965, Explosive igneous activity along an Illinois-Missouri-Kansas axis: American Journal of Science, v. 262, no. 6, p. 465-493.

Stearns, R. G., and Wilson, C. W., Jr., 1972, Relationships of earthquakes and geology in west Tennessee and adjacent areas: Nashville, Tennessee, Vanderbilt University, Report for Tennessee Valley Authority, 344 p.

Stonehouse, H. B., and Wilson, G. M., 1955, Faults and other structures in southern Illinois--a compilation: Illinois State Geological Survey Circular 195, 4 p.

Street, R. L., Herrmann, R. B., and Nuttli, O. W., 1974, Earthquake mechanics in the central United States: Science, v. 184, no. 4143, p. 1285-1287.

Swanson, R. W., and Wilshire, H. G., 1967, Geologic map of the Westplains quadrangle, Graves County, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-587, scale 1:24,000.

Tolman, C. F., and Robertson, Forbes, 1969, Exposed Precambrian rocks in southeast Missouri (Contribution to Precambrian Geology No. 1): Missouri Division of Geological Survey and Water Resources Report of Investigations 44, 68 p.

Trace, R. D., 1962, Geology of the Salem quadrangle, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-206, scale 1:24,000.

______1966, Geologic map of the Marion quadrangle, Crittenden and Caldwell Counties, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-547, scale 1:24,000.

______1972, Geologic map of the Princeton East quadrangle, Caldwell County, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-1032, scale 1:24,000.

______1974, Geologic map of part of the Cave In Rock quadrangle, Crittenden County, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-1201, scale 1:24,000 [1975].

Trace, R. D., and Kehn, T. M., 1968, Geologic map of the Olney quadrangle, Caldwell and Hopkins Counties, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-742, scale 1:24,000.

Trace, R. D., and Palmer, J. E., 1971, Geologic map of the Shady Grove quadrangle, Crittenden and Caldwell Counties, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-880, scale 1:24,000.

Ulrich, G. E., and Klemic, Harry, 1966, Geologic map of the Caledonia quadrangle, Trigg and Christian Counties, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-604, scale 1:24,000 [1967].

Weis, P. L., and Theobald, P. K., 1964, Geology of the Mont quadrangle, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-305, scale 1:24,000.

Weller, J. M., 1940, Geology and oil possibilities of extreme southern Illinois, Union, Johnson, Pope, Hardin, Alexander, Pulaski, and Massac Counties: Illinois State Geological Survey Report of Investigations 71, 71 p.

Weller, J. M., and Ekblaw, G. E., 1940, Preliminary geologic map of parts of the Alto Pass, Jonesboro, and Thebes quadrangles, Union, Alexander, and Jackson Counties [Ill.]: Illinois State Geological Survey Report of Investigations 70, 26 p.

Weller, J. M., Grogan, R. M., and Tippie, F. E., 1952, Geology of the fluorspar deposits of Illinois: Illinois State Geological Survey Bulletin 76, 147 p.

Weller, Stuart, and Krey, F. F., 1939, Preliminary geologic map of the Dongola, Vienna, and Brownfield quadrangles; Explanation and stratigraphic summary by James Marvin Weller: Illinois State Geological Survey Report of Investigations 60, 11 p.

Weller, Stuart, and St. Clair, Stuart, 1928, Geology of Ste. Genevieve County, Missouri: Missouri Bureau of Geology and Mines, 2d ser., v. 22, 352 p.

Weller, Stuart, and Sutton, A. H., 1951, Geologic map of the western Kentucky fluorspar district: U.S. Geological Survey Mineral Investigations Field Studies Map MF-2, scale 1:62,500.

Weller, Stuart, Butts, Charles, Currier, L. W., and Salisbury, R. D., 1920, The geology of Hardin County and the adjoining part of Pope County: Illinois State Geological Survey Bulletin 41, 416 p.

Weller, Stuart, and others, 1945, Geologic map of Illinois: Urbana, Ill., Illinois State Geological Survey.

Willman, H. B., and others, 1967, Geologic map of Illinois: Illinois State Geological Survey.

Wilshire, H. G., 1963a, Geology of the Crutchfield quadrangle in Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-270, scale 1:24,000.

______1963b, Geology of the Kirksey quadrangle, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-246, scale 1:24,000.

______1964, Geology of the New Concord quadrangle and part of the Buchanan quadrangle, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-313, scale 1:24,000.

Wolfe, E. W., 1963, Geology of the Dexter quadrangle, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-244, scale 1:24,000.

______1964, Geology of the Fairdealing quadrangle, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-320, scale 1:24,000.

Zartman, R. E., 1977, Geochronology of some igneous rock provinces in eastern and central United States: Annual Review of the Earth and Planetary Sciences, v. 5, p. 757-786.

Zartman, R. E., Brock, M. R., Heyl, A. V., and Thomas H. H., 1967, K-Ar and Rb-Sr ages of some alkalic intrusive rocks from central and eastern United States: American Journal of Science, v. 265, no. 10, p. 848-870.

PRELIMINARY SEISMOTECTONIC MAP OF THE CENTRAL MISSISSIPPI VALLEY AND ENVIRONS

By
A. V. Heyl and F. A. McKeown
1978

INTERIOR—GEOLOGICAL SURVEY, RESTON, VIRGINIA—REPRINTED 1988

For sale by Branch of Distribution, U.S. Geological Survey, Box 25286, Federal Center, Denver, CO 80225