MICROEARTHQUAKES IN KANSAS AND NEBRASKA 1977-89

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ABSTRACT

The Kansas Geological Survey operated a microearthquake seismograph network from August 1977 to August 1989 . The network originally consisted of nine stations and was expanded to fifteen stations in 1982. All stations were located in the eastern half of Kansas and Nebraska. Locatable microearthquakes with duration magnitudes less than 3.2 occur at the rate of roughly 20 per year in the two-state area, with most of the events ranging from 1.4 to 2.5 in local magnitude. The microearthquake pattern observed during the 12 years of recording is consistent with the pattern of historical earthquakes reported since 1867. Much of the activity occurs along the Nemaha Ridge, a buried Precambrian uplift that runs from roughly Omaha, Nebraska, southward across Kansas to near Oklahoma City. This geological structure has been the site of several earthquakes of MM Intensity VII over the past 125 years. Some seismicity is observed along the northwest flank of the Midcontinent Geophysical Anomaly in Kansas, but little is observed in the Nebraska or Iowa portions of this Precambrian feature. The Central Kansas Uplift, which is a buried anticline similar in age to the Nemaha Ridge, has been the site of several felt earthquakes since 1982. A trend of earthquakes extending northeastward across central Nebraska is not associated with any prominent known geologic structure. All the seismicity in central and eastern Kansas can be roughly correlated to known geologic structures.

This report also includes previously unpublished felt reports from two earthquakes that were not listed in DuBois and Wilson (1978) and for which no information was previously available. These data were kindly supplied to us by John M. Peterson of Lawrence, Kansas, who conducted the library search at his own expense. One earthquake occurred near Stockton, Kansas, on April 27, 1879, with Modified Mercalli intensities of at least VI and possibly VII. This new information and the relatively high degree of seismicity noted along the central Kansas uplift in comparison to the Nemaha ridge/Humboldt fault zone leads us to conclude that the earthquake risk associated with the central Kansas uplift has been underestimated.

The other newly discovered earthquake occurred on January 19, 1871 near Lawrence, Kansas, with MM Intensity III or possibly IV. The felt reports for these events are listed in Appendix I.

INTRODUCTION

At least 30 felt earthquakes with epicenters in Kansas were documented between 1867 and 1978 (DuBois and Wilson, 1978). For comparison, historical earthquakes are shown in Figure 1 and microearthquakes from 12 years' recording are shown in Figure 2. The largest of the historical earthquakes in Kansas were Modified Mercalli Intensity VII events that occurred in 1867 and

1906 in the vicinity of Manhattan, although the Stockton event of April 27, 1879, was larger than previously realized. Although the geologic structure or structures responsible for the two Manhattan earthquakes have not been positively identified, the following paragraphs outline the tectonic setting and provide some insight into the probable geologic structure or structures involved.

The proximity of several MM Intensity VII/VIII earthquake epicenters in Kansas, Nebraska, and Oklahoma to the Nemaha Ridge (a buried Precambrian granitic uplift) or the Humboldt Fault (the eastern boundary of the Nemaha Ridge, Fig. 3) led early investigators (Lugn, 1935; Lee, 1954) to ascribe the source of seismic activity to movement on these structures. This view is also reflected in the Seismic Risk Map of the United States (Algermissen, 1969) which shows a zone two (moderate damage expected) designation in the vicinity of the Nemaha Ridge.

The Stockton area lies on the northeast flank of the Central Kansas Uplift, which is geologically similar to the Nemaha Ridge in many respects, including age, lithology, and size. In addition to the Stockton event of 1879, a group of earthquakes with MbLg of between 3.0 and 4.0 occurred southeast of Palco, Kansas, in June and July of 1989. These events were located about 35 km south-southwest of Stockton.

REGIONAL SEISMOTECTONIC SETTING

Docekal (1970) analyzed the isoseismal patterns of Intensity VII/VIII historical earthquakes in the Midcontinent and related them to basement configuration, structure, and lithology. From this he delineated the Midcontinent Seismic Trend with earthquake occurrence in central Texas, central Oklahoma, northeast Kansas, southeast Nebraska, southeast Minnesota, and the Keweenaw Peninsula, Michigan. He concluded that the stronger earthquakes of the region were genetically related to the Arbuckle, Nemaha/Humboldt, and Midcontinent Geophysical Anomaly (MGA) structures or combinations of them. However, we doubt that earthquakes in central Texas and central Oklahoma are genetically related to earthquakes in Kansas, Nebraska, and Minnesota because late Paleozoic structures in central Oklahoma (such as the Arbuckle mountains) separate the Precambrian features of the north from those in the south.

The MGA has been recognized as representing an important structural feature in the Midcontinent (Ocola and Meyer, 1973). The MGA extends from the Lake Superior region southwestward at least to central Kansas and into Oklahoma (King and Zietz, 1971; Chase and Gilmer, 1973). Yarger (1981) has shown that the MGA extends southward beyond the Kansas-Oklahoma border. Data presented by Guinness et al. (1982) suggest that the MGA extends as far south as 32.5°N, 99.6°W near Abilene, Texas.

The MGA is the largest positive gravity anomaly in North America with a length of more than 1000 km, a width of 50 to 100 km, and a maximum peak-to-peak amplitude of 160 Mgal. It marks a thick sequence of mafic igneous rocks emplaced along a zone of major late Precambrian rifting (Ocola and Meyer, 1973). The structure is bounded by faults at the surface in the Lake Superior region, and similar bounding faults are inferred from geophysical data in the area to the south where the structure is deeply buried below younger sediments (King and Zietz, 1971). An offset of 50 to 60 km to the northwest in the Nebraska section of the MGA (near the Kansas-Nebraska border) is interpreted by Chase and Gilmer (1973) as a transform fault associated with the Precambrian rifting (Fig. 4).

There are surface structures associated with the MGA in the Manhattan, Kansas, area. The Abilene anticline (Jewett, 1941) parallels its southeast flank and the Riley County kimberlite intrusives (Brookins, 1970) lie along the same structural trend. Emplacement of the kimberlites has been associated with right lateral strike-slip movement on a buried fault at the east flank of the Abilene anticline (Chelikowsky, 1972). The direction of movement is inferred from rotation of rock joints in the area of the possible fault. The relation of the kimberlites to this strike slip fault hypothesis is in doubt because the long axes of the intrusions are oriented northwest-southeast, perpendicular to the Abilene anticline (Cook, 1955). This indicates that the direction of least horizontal compressive stress was perpendicular to the Abilene anticline at the time the kimberlites were emplaced, a condition incompatible with strike slip parallel to the Abilene anticline. The Elk Creek, Nebraska, carbonatite (Brookins et al., 1975) also lies along the southeast flank of the MGA not far from the Kansas-Nebraska border. It appears from aeromagnetic evidence (Yarger, 1981) that all of these ultramafic intrusions are controlled or at least influenced by the faults bounding the MGA.

Recently, deep seismic reflection data have been gathered by the Consortium for Continental Reflection Profiling (COCORP) across the MGA in Kansas. These data ultimately will go far in assisting in regional interpretation of the relationship of the MGA to the Nemaha Ridge (Serpa et al., 1984) and in constructing a geologic cross-section of the MGA itself. Data from the eastern section of the COCORP line show the relatively flat-lying sediments in the Forest City basin and complex structures within the Precambrian basement at depths of 10 to 20 km (Brown et al., 1983). The deep Precambrian reflections become more shallow in the vicinity of the MGA and the Nemaha Ridge, suggesting 2 to 3 km of uplift since 1.65 By ago which is the U/Pb Zircon-age of basement granites in the area (Bickford et al., 1979). The age of the uplift may well be Keweenawan (1.1 By ago), associated with the rifting.

The COCORP data from the MGA vicinity (Serpa et al., 1984; Somanas et al., 1989) indicate that the Rice Formation (Precambrian sedimentary rocks that appear to be genetically related to the rift) reaches a thickness of as much as 3 to 4 km along the flanks of the MGA. The basalt flows within the MGA itself reach a thickness of about 8 km. The Serpa et al. (1984) interpretation of COCORP data suggest that the Humboldt fault zone dips about 20°-30° to the east and that the Humboldt may be a Pennsylvanian-Permian-aged reactivation of late Precambrian faults associated with the formation of the MGA. Faults with similar dips are present on both sides of the central portion of the MGA.

RESULTS FROM TWELVE YEARS RECORDING

Historical earthquakes can often be linked to specific geologic features by inference from the recording of present-day microearthquakes. The microearthquake pattern shown in Figure 2 bears a good resemblance to that shown by historical earthquakes in Figure 1 with the exception of northwestern Nebraska where there are no seismograph stations (see station map in Fig. 3). This result in conjunction with other geological and geophysical studies of the past few years allows us to make useful observations about earthquake activity in Kansas. While Cole (1976) showed a single long Humboldt Fault in the basement, more recent geophysical evidence (Steeples, 1982, 1989) indicates that a zone of faulting perhaps tens of kilometers wide exists along both sides of the Nemaha Ridge. This conclusion is drawn in part from the scatter in both the historical and microearthquake seismicity and in part from other geological and geophysical evidence. Seismic-reflection surveys, including unpublished proprietary data, indicate a myriad of faulting along both sides of the Nemaha Ridge. Gravity and aeromagnetic data are consistent with a multitude of unmapped subsurface faults. Drawing on these data and LANDSAT lineaments, Berendsen (1984) has examined cuttings from hundreds of wells on both sides of the Nemaha and has hypothesized faulting between basement crustal blocks.

The earthquakes located using the Kansas-Nebraska network can be grouped into four distinct seismic trends. A large portion of the events lie astride the Nemaha Ridge and indicate low levels of seismicity on faults associated with or bounding the ridge. A trend of events roughly parallel to the ridge, but about 100 km to the west of it is associated with northwest flanking boundary fault of the MGA. Intersecting these trends from the northwest is a belt of earthquake activity that during the first five-to-six years of network operation had only sparse activity; however, recently a marked increase in earthquake activity has been observed. This northwest-southeast trend is related to the faults flanking the Central Kansas Uplift. Lastly, and least understood geologically, is a band of earthquakes that is oriented northeast-southwest across central Nebraska. This trend of earthquakes has no named geologic structure associated with it, but there are a pair of normal faults shown on the USGS/AAPG tectonic map of the United States that are coincident with the trend. The central Nebraska trend intersects the Central Kansas Uplift at nearly a right angle. There is a strong concentration of seismicity at that intersection (Evans and Steeples, 1987).

The occurrence of microearthquakes along the approximate trace of the Humboldt Fault zone implies the possible occurrence in the past and in the future of earthquakes with body-wave magnitudes up to 5 1/2 which was the probable approximate magnitude of the 1867 "Manhattan" earthquake. Fault segments in the basement are easily long enough to accommodate infrequent earthquakes up to at least magnitude 6. Felt reports from the 1867 earthquake (Modified Mercalli Intensity VII) suggest that the epicenter may have been east of Manhattan near the known Humboldt Fault trace (DuBois and Wilson, 1978) rather than "22 miles northwest of Manhattan" (Merriam, 1956).

The series of felt earthquakes in the Manhattan vicinity in 1929 are no longer enigmatic in regard to their structural source. Isoseismal patterns clearly indicate that the epicenters were 20 to 40 km west of the main trace of the Humboldt Fault. As detailed earlier, however, there are other structures in the Manhattan area that may be responsible for some of the historical earthquakes. The pattern of microearthquakes along the Nemaha Ridge is diverse, suggesting that several faults are capable of producing small-to-moderate earthquakes. At least one microearthquake has occurred in the area south of Junction City, 20 km west of the Humboldt Fault.

The recent increase in earthquake activity along the Central Kansas Uplift has been documented on earthquake seismograms and by earthquake-felt reports. The majority of the felt reports prior to 1989 were from 8 events located in Rooks, Graham, and Ellis counties. The felt reports from 1989 come from the earthquakes near Palco in Rooks County, where dozens of earthquakes were felt, including several that occurred after seismograph network operations ceased.

This group of events in north-central Kansas can be clearly identified on the microearthquake epicenter map (Fig. 2) as the densest cluster of earthquakes in the two-state area. A large majority of the felt reports prior to 1989 were from people whose homes are built on alluvial deposits along the Saline River in the northeast corner of Ellis County.

While the earthquake risk associated with the Nemaha ridge/Humboldt fault zone is appropriately addressed in building codes and earthquake risk papers such as Algermissen (1969) and Algermissen and Perkins (1976), the central Kansas uplift has not been properly recognized for its earthquake activity. On the basis of new information about the 1879 Stockton event and the concentration of seismicity along the central Kansas uplift in the 1980's, we believe the risk is probably equivalent to that associated with the Nemaha ridge. The isoseismal Modified Mercalli Intensity map of the 1879 event is shown in Figure 4, and its felt reports are listed in Appendix I of this report. Cole (1976) documents faults in the Precambrian basement that have lengths of at least 100 km (see Figure 2). These segments are at least as long as comparable segments along the Nemaha ridge. Furthermore, they may be oriented in the right direction to accommodate strike-slip motion associated with east-west tectonic compression in the Midcontinent (Zoback and Zoback, 1980). Armbruster et al., (1989) noted a component of strike-slip on some of the smaller Palco earthquakes in August of 1989.

One of the most important seismic observations in western Kansas and central Nebraska is the relatively high level of seismicity at the intersection of the northwest/southeast trend through central Kansas and the northeast/southwest trend through central Nebraska. Although this intersection is coincident with the Sleepy Hollow oil field, we believe that a series of microearthquakes in this region (at least some of them) are tectonic in nature rather than induced by water-flood operations in the oil field. Pleistocene and/or recent tectonic upwarping centered along the Chadron-Cambridge arch (Fig. 3) is suggested by anomalous stream gradients and knick-points where rivers cross the arch in south-central Nebraska (Stanley and Wayne, 1972), indicating tectonic activity was present before oil production began. Woollard (1958) also suggested on the basis of the historical seismicity record that the Central Kansas Uplift-Chadron-Cambridge arch system, was tectonically active (Fig. 1.) It is worth noting that hundreds of other water-flood operations within oil fields along the Central Kansas Uplift do not cause earthquake activity, although the events near Palco and in northeast Ellis County occurred not far from ongoing water-flood operations.

A single event recorded with an epicenter near Lakin, Kansas, was of sufficient size (M_{DUR}=3.0) to be felt by people over a relatively small area. The lack of any located epicenters below M_{DUR}=3.0 in the area is not surprising considering the lack of sensitivity of the network that far from the primary monitoring area.

Recent earthquake analysis has involved both digital data and standard drum-recorded analog data. Refraction-type crust/mantle studies (Miller, 1983; Steeples and Miller, 1989) have included both earthquake data from the Kansas-Nebraska network and explosion refraction data. The general seismicity (Evans and Steeples, 1987) and an estimation of the source parameters of earthquakes in the Sleepy Hollow oil field in Red Willow County, Nebraska (Wallace, 1986), have been derived from analysis of microearthquake data.

The regional network in eastern Kansas and eastern Nebraska had a typical station spacing of about 200 km. It has not been possible to develop social mechanisms for microearthquakes because almost all readings are made near the edges of the focal sphere.

Location parameters and arrival times for all Kansas and Nebraska microearthquakes from 1977 through 1984 are given in Steeples et al., 1988.

CONCLUSIONS

1. The microearthquake pattern established over a twelve-year period in the Kansas vicinity bears good resemblance to the historical pattern established over the past 125 years of recorded history.

2. The vast majority of the microearthquakes in Kansas can be related directly to the Nemaha Ridge/Humboldt Fault zone, the Midcontinent Geophysical Anomaly and its southward extension into Oklahoma, and the Central Kansas Uplift.

3. A large number of faults exist in the vicinity of these major structures. These faults are likely capable of generating earthquakes in the body-wave magnitude range of 5 to 5 1/2, with possible rare events ranging to the magnitude 6-6.5 category with average return periods on the order of a thousand years.

4. While the earthquake risk associated with the Nemaha ridge/Humboldt fault zone has been appropriately addressed by previous authors such as Algermissen (1969) and Algermissen and Perkins (1976), the central Kansas uplift has not been properly recognized for its earthquake activity. On the basis of new information about the 1879 Stockton event and the concentration of seismicity along the central Kansas uplift in the 1980's, we believe the risk is probably equivalent to that associated with the Nemaha ridge.

5. Correlation of the Sleepy Hollow oil field with the intersection of seismic trends and geomorphic evidence of tectonic uplift in Pleistocene and/or recent time suggests that at least some of the earthquakes in the oil field are tectonic in nature.

REFERENCES

Algermissen, S. T.,1969, Seismic risk studies in the United States; in Proc. of Fourth World Conf. on Earthquake Engr., Santiago, Chile, 1, 14-27.

Algermissen, S. T., and Perkins, D. M., 1976, A probabilistic estimate of maximum acceleration in rock in the Contiguous United States: *U.S. Geological Survey,* Open-file Report no. 76-416.

Armbruster, J.G., Steeples, D.W., and Seeber, L., 1989, The 1989 earthquake sequence near Palco, Kansas: A possible example of induced seismicity [Abs.]: *Seismological Research Letters,* 60, no. 4, p. 141.

Berendsen, P. and Blair, K, 1986, Subsurface structural maps over the CNARS with discussion: *Kansas Geological Survey,* over-size maps, scale 1:250,000, 20 p..

Bickford, M. E., Harrower, K. L., Nusbaum, R. L., Thomas, J. J., and Nelson, R. E., 1979, Preliminary geologic map of the Precambrian basement rocks of Kansas: Kansas Geological Survey Map M-9, Scale 1:500,000.

Brookins, D. G., Treves, S. B., and Bolivar, S. L., 1975, Elk Creek, Nebraska, carbonatite: *Strontium Geochemistry, Earth and Planetary Science Letters,* 28, 79-82.

Chase, C. G. and Gilmer, T. H., 1973, Precambrian plate tectonics: The Midcontinent gravity high: *Earth and Planetary Science Letters,* 21, 70-78.

Chelikowsky, J. R., 1972, Structural geology of the Manhattan, Kansas, area: *Kansas Geological Survey Bull.* 204, pt. 4.

Cole, V. B., 1976, Configuration of the top of the Precambrian rocks in Kansas: *Kansas Geological Survey Map* M-7, scale 1:5000,000, 1 sheet.

Cook, K. L., 1955, Magnetic surveys over serpentine masses, Riley County: *Kansas, Mining Engineering,* 7, no. 5, 481-488.

Docekal, J., 1970, Earthquakes of the Stable Interior with emphasis on the Midcontinent: *Ph.D. thesis*, University of Nebraska.

DuBois, S. M. and Wilson, F. W., 1978, List of earthquake intensities for Kansas, 1867-1977: *Kansas Geological Survey, Environmental Geology Series* 2.

Evans, D. G. and Steeples, D. W., 1987, Microearthquakes near the Sleepy Hollow oil field, southwestern Nebraska: *Seismological Society of America Bull.,* 77, 132-140.

Guinness, E. A. et al., 1982, Identification of a Precambrian rift through Missouri by digital image processing of geophysical and geologic data: *Journal Geophysical Research*, 87, no. B10, 8532.

Hildebrand, G. M., Steeples, D. W., Knapp, R. W., Miller, R. D., and Bennett, B. C., 1988, Microearthquakes in Kansas and Nebraska 1977-87: *Seismological Research Letters.*, 59, no. 4, p. 159-163.

Jewett, J. M., 1941, The geology of Riley and Geary counties, Kansas: *Kansas Geological Survey Bull.* 39.

King, E. R. and Zietz, I., 1971, Aeromagnetic study of the Midcontinent gravity high of central United States: *Geol. Soc. Am. Bull.* 82, 2187-2208.

Lee, W. H. K., 1954, Earthquakes and Nemaha anticline: *Am. Assoc. Petr. Geol. Bull.* 38, no. 2, 338-340.

Lugn, A. L., 1935, The Nebraska earthquake of March 1, 1935: *Science*, 81, no. 2102, 338-339.

Merriam, D. F., 1956, History of earthquakes in Kansas: *Seismol. Soc. Am. Bull.* 46, 87-96.

Miller, R. D., 1983, Crustal structure in Kansas from regional earthquake seismograms, M.S. thesis, Dept. of Physics, University of Kansas, Lawrence: *Kansas Geological Survey* Open-file Report 83-21.

Ocola, L. C. and Meyer, R. P., 1973, Central North American Rift System 1: Structure of the axial zone from seismic and gravimetric data: *Jour. Geophysical Research*, 78, 5173-5194.

Serpa, L., Setzer, T., Farmer, H., Brown, L., Oliver, J., Kaufman, S., Sharp, J., and Steeples, D. W., 1984, Structure of the southern Keweenawan rift from COCORP surveys across the Midcontinent Geophysical Anomaly in northeastern Kansas: *Tectonics*, 3, 367-384.

Somanas, C., Knapp, R. W., Yarger, H. L., and Steeples, D. W., 1989, Geophysical model of the Midcontinent Geophysical Anomaly in northeastern Kansas; in Proc. of Symposium on Geophysics in Kansas, D. W. Steeples, ed.: *Kansas Geological Survey Bull.* 226, p. 215-228.

Stanley, K. O. and Wayne, W. J., 1972, Epeirogenic and climatic controls of early Pleistocene fluvial sediment dispersal in Nebraska: *Geol. Soc. Am. Bull.* 83, 3675-3690.

Steeples, D. W., 1982, Structure of the Salina-Forest City interbasin boundary from seismic studies: University of Missouri-Rolla, Journal 3, 55-81.

Steeples, D. W., 1989, Structure of the Salina—Forest City interbasin boundary from seismic studies; in Symposium on Geophysics in Kansas, D. W. Steeples, ed.: *Kansas Geological Survey Bull.* 226, p. 31-52.

Steeples, D. W., Hildebrand, G. M., Bennett, B. C., Miller, R. D., Chung, Y.,Knapp, R. W., 1988, Kansas-Nebraska seismicity studies using the Kansas-Nebraska microearthquake network: U.S. Nuclear Regulatory Commission, Washington, D.C., Final Report NUREG/CR-5045-RA, NRC FIN B8272, Contract no. NRC-04-82-006-02.

Steeples, D. W. and Miller, R. D., 1989, Kansas refraction profiles; in Geophysics in Kansas, D. W. Steeples, ED.: *Kansas Geological Survey Bull.* 226, 133-168.

Wallace, K. D., 1986, Estimation of source parameters for microearthquakes near the Sleepy Hollow oil field, Red Willow County, Nebraska: University of Kansas Masters Thesis, 96 p.

Yarger, H. L., 1981, Aeromagnetic survey of Kansas: *EOS Am. Geophys. Union Trans.*, 62, 173-178.

Zoback, M. L., and Zoback, M., 1980, 1980, State of stress in the conterminous United States: *Journal Geophysical Research*, 85, 6113-6156

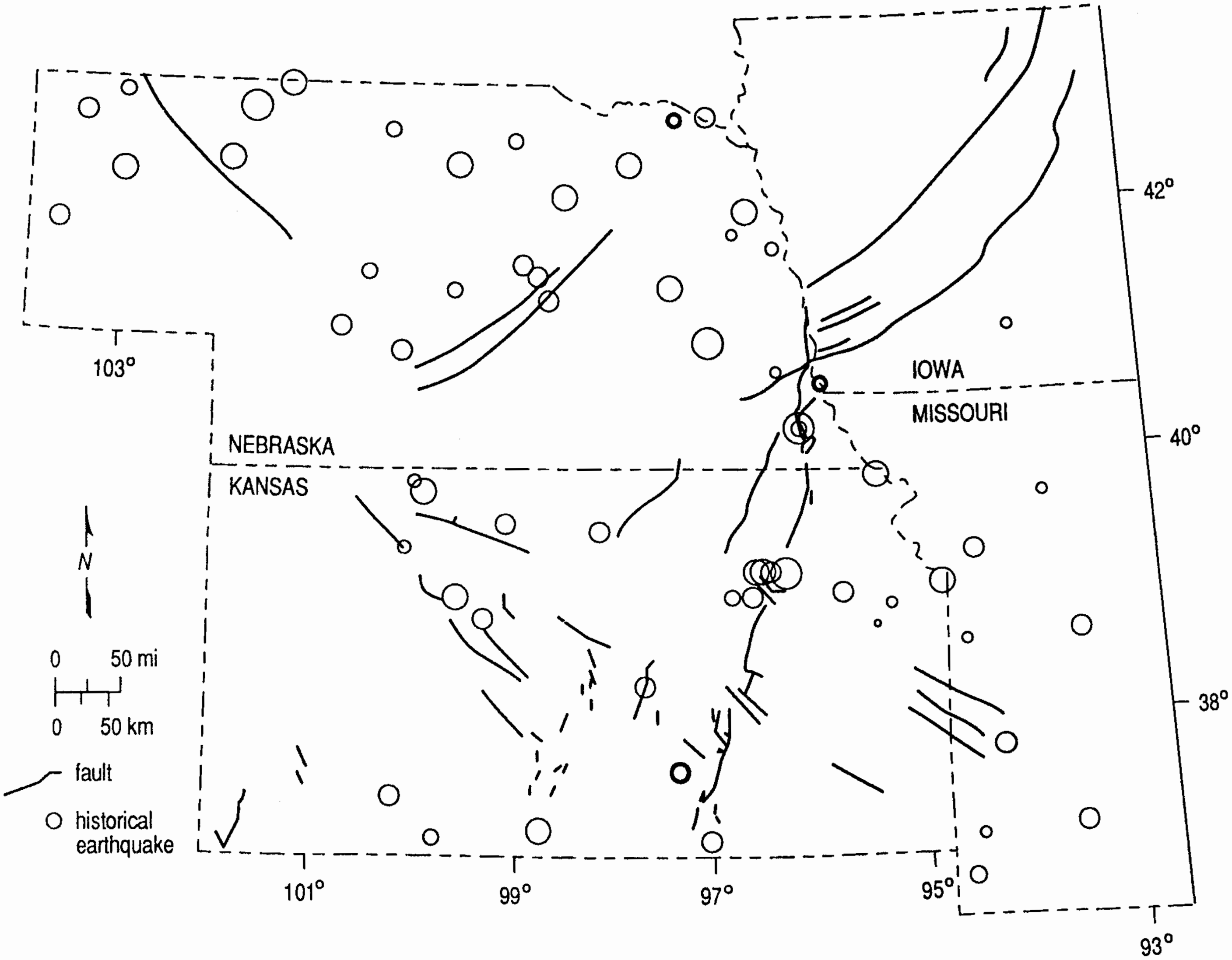

FIG. 1. Historical earthquakes are shown by size-coded circles of Modified Mercalli Intensity. Largest events are the MM VII shown by the largest circles and the smallest events are MM III shown by the smallest circles. Faults are depicted by lines and are taken from many sources in the literature, although Cole (1976) is the primary source.

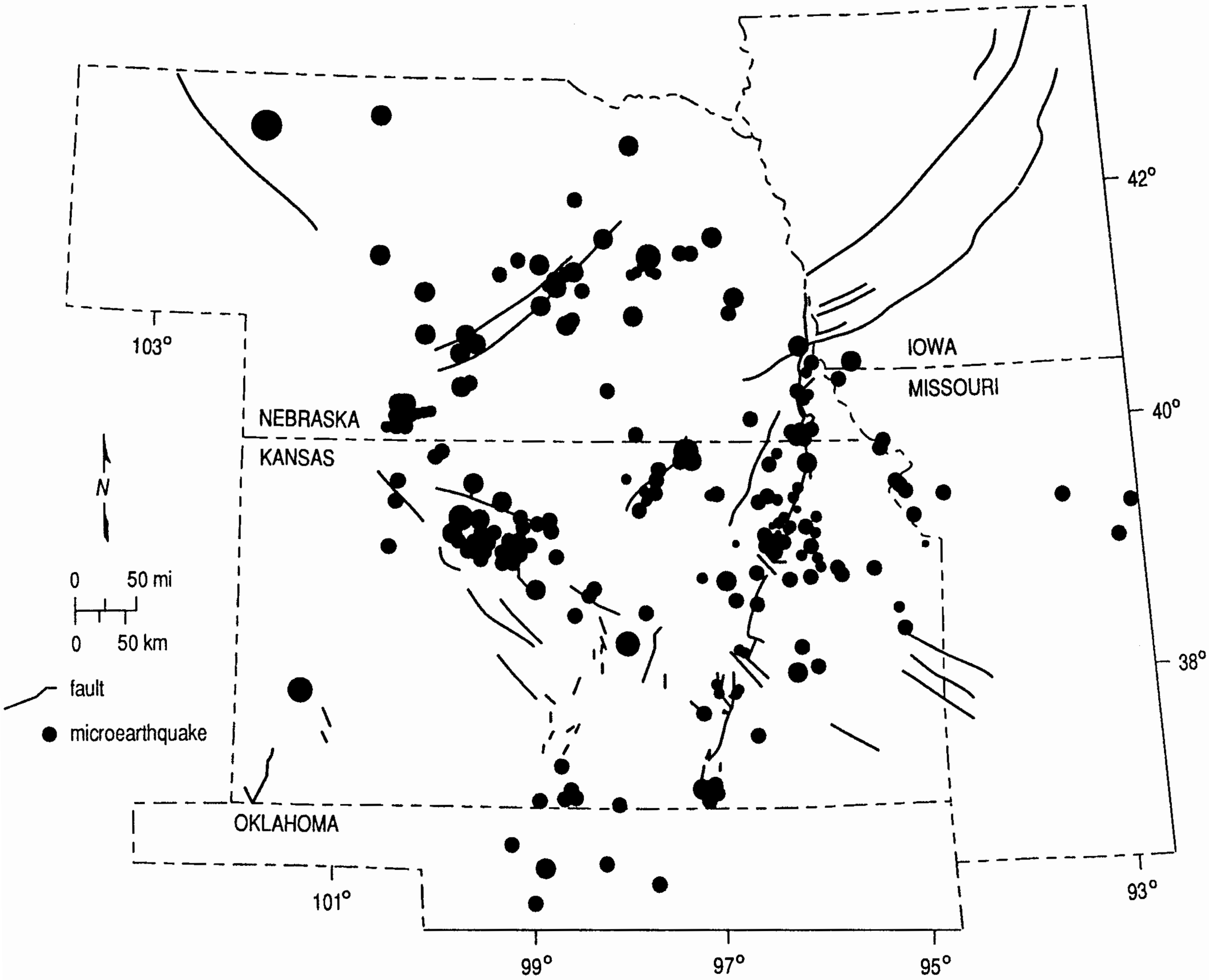

FIG. 2. Microearthquakes recorded by the Kansas Geological Survey between August 1977 and August 1989 are size-coded by local magnitude. The largest event has magnitude 4.0 and the smallest is local magnitude 0.8. Faults plotted are identical to Figure 1.

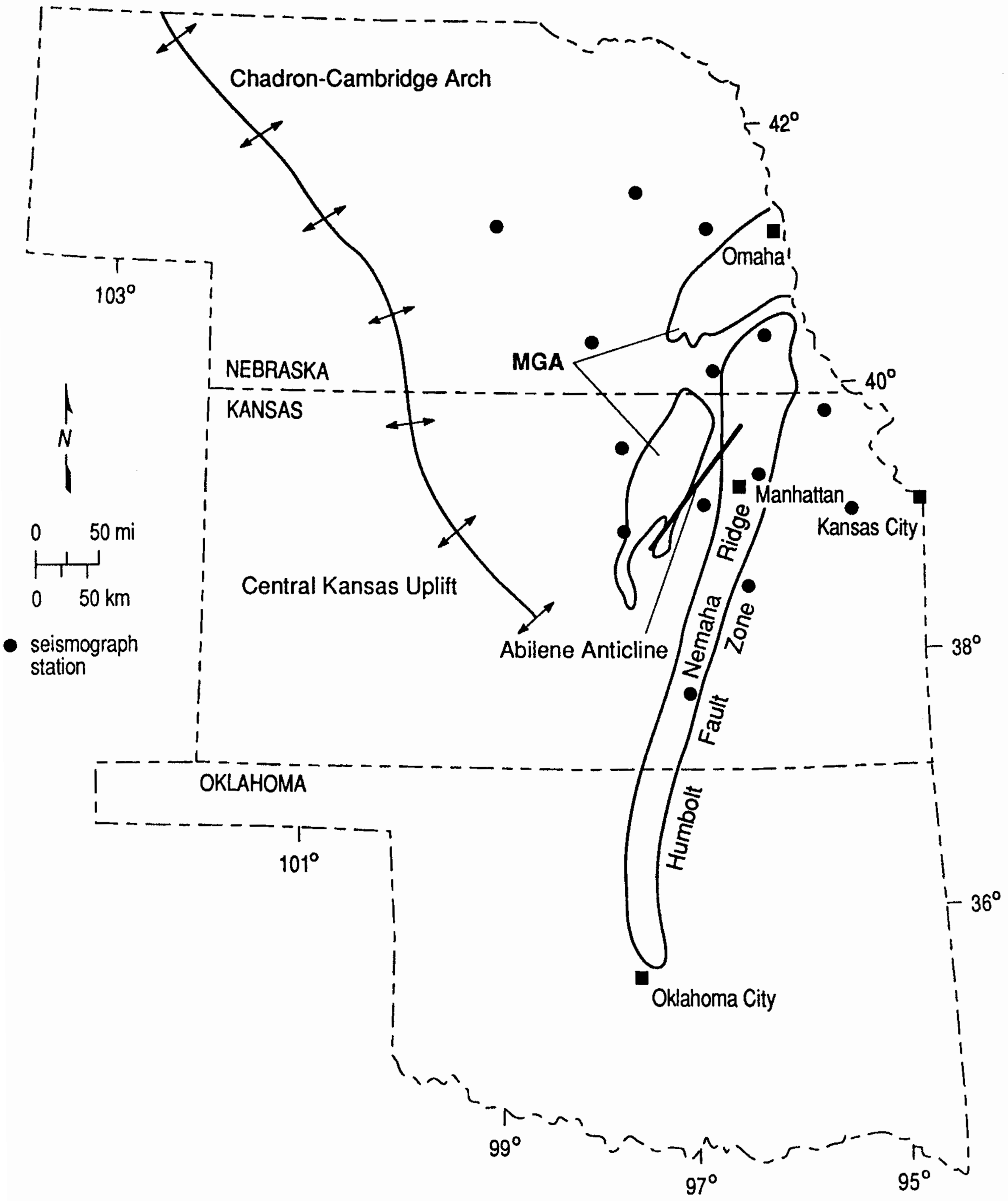

FIG. 3. Major regional tectonic features that are apparently related to earthquake activity.

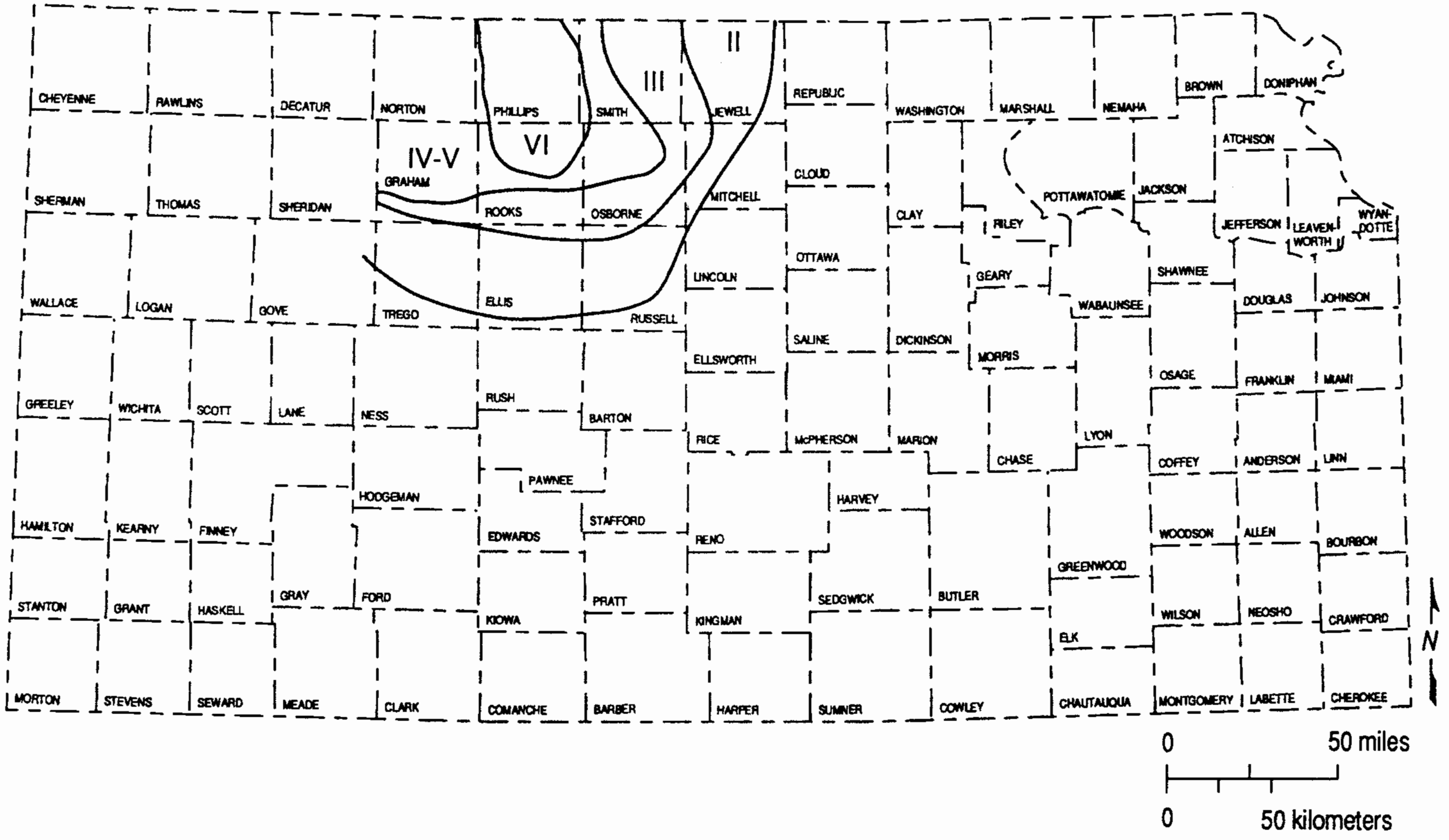

FIG. 4. Map of Modified Mercalli isoseismals of Stockton, Kansas, earthquake of April 27, 1879.

APPENDIX I

Earthquakes located by KGS seismograph network in Kansas and Nebraska
During 1987-1989

DATE	ORIGIN		LAT N	LONG W	DEPTH	MAG	NO	GAP	DMIN	RMS	ERH	ERZ	QM
870109	1852	3.80	39-46.82	97-34.34	5.00	2.03	16	124	32.6	.41	1.4	2.2	C1
870124	1035	24.03	41-41.37	98- 9.45	6.78	2.23	9	228	63.1	.28	3.4	1.8	D1
870202	9 1	25.13	41- 7.71	98-49.92	3.11	2.18	9	184	21.9	.29	2.1	1.8	C1
870210	2014	56.05	39- 7.38	94-44.59	.83	0.80	7	282	40.8	.58	16.0	16.1	D1
870213	233	45.32	37-56.98	96-47.50	5.00	1.55	4	181	19.5	.02			C1
870216	229	34.67	41-24.16	97-47.32	5.00	1.52	6	160	33.8	.15	1.3	2.9	C1
870219	1426	44.46	39-32.19	96-23.54	13.76	1.42	10	107	33.0	.20	1.1	4.3	C1
870315	1732	35.18	42- .44	98-27.73	5.00	1.62	7	274	87.2	.28	3.3	2.9	D1
870323	343	2.94	39-19.34	98-52.50	5.00	1.77	9	248	117.4	.48	5.3	4.2	D1
870610	1858	54.51	39-42.35	97-55.46	4.03	1.58	4	219	28.5	1.54			D1
870701	1042	32.17	39-38.28	95- .18	5.00	1.57	6	260	46.1	.54	4.4	6.6	D1
870704	23 5	13.47	39-17.41	99- 1.72	.68	2.02	6	288	128.9	.53	20.3	11.5	D1
870712	1732	6.12	41-32.25	100-35.82	5.00	2.48	7	326	141.0	.48	12.2	5.2	D1
870810	14 5	48.37	40- 1.21	96- 1.21	14.46	1.44	6	118	47.4	.32	2.6	13.0	C1
870816	910	4.90	39- 8.95	96-25.52	9.91	2.17	15	90	23.2	.25	.8	2.1	C1
871030	5 2	32.10	39-11.86	96-21.54	13.95	1.54	13	80	15.6	.25	.9	1.8	B1
871105	443	17.25	40-39.01	95-27.51	10.52	2.35	17	232	52.5	.47	2.5	2.4	D1
871129	339	3.55	41-16.89	98-41.06	5.00	2.06	8	291	106.9	.43	4.4	3.7	D1
871226	1659	45.39	39-10.23	96-14.70	5.00	1.72	9	164	11.0	.46	3.2	12.5	C1
880118	1347	24.66	41-20.69	98-43.63	.75	1.97	8	294	110.8	.59	8.2	5.5	D1
880228	113	57.39	39- 2.88	95-53.91	8.37	1.32	10	118	60.1	.27	1.03	30.7	D1
880317	940	19.85	38-53.33	97- 8.42	13.68	1.31	7	114	32.3	.38	2.3	9.4	C1
880329	1015	2.11	39- 7.43	99-14.75	1.04	1.67	7	306	138.9	.25	3.9	2.7	D1
880329	1233	35.17	39- 4.27	99- 6.00	5.00	2.01	14	274	129.1	.68	4.6	3.8	D1
880402	1743	11.89	38-58.26	95-41.87	8.79	1.92	9	137	43.6	.51	2.4	36.3	D1
880413	19 0	59.07	39- 6.57	99-14.93	5.00	1.95	10	299	139.7	.45	4.8	3.1	D1
880413	20 7	11.04	39- 4.93	99-15.41	14.12	2.17	10	300	141.3	.32	4.0	1.8	D1
880414	939	31.47	39- 7.69	99- 7.82	5.00	3.6	27	130	129.3	.63	2.3	2.7	D1
880418	516	44.83	39- 2.64	99- 8.16	.06	1.82	12	276	133.1	.84	7.5	2.5	D1
880424	1550	56.62	39-10.81	99-11.16	7.65	2.23	13	273	132.2	.63	6.0	3.9	D1
880428	17 3	4.24	39-39.37	95- 2.16	5.00	1.81	5	260	42.7	.38	1.5	2.8	D1
880505	213	27.34	39-54.17	96-17.92	5.00	1.51	6	136	43.4	.32	2.1	10.1	C1
880509	9 7	37.24	39-17.46	99- 2.79	1.93	1.90	9	272	117.4	.68	6.8	4.2	D1
880618	246	38.93	39- 6.78	99- 6.89	.77	1.98	13	266	128.6	.59	5.2	3.8	D1
880618	941	32.01	39- 7.36	99- 6.15	1.01	1.61	9	265	127.3	.56	5.9	4.1	D1
880618	1534	45.17	39- 9.53	99- 6.78	17.08	2.8	12	149	126.8	.36	3.4	2.6	D1
880621	1938	19.20	40- 1.68	96- 2.80	6.07	1.53	5	186	46.6	.02	.0	.1	C1
880714	1711	17.34	39-19.40	98-54.05	.47	1.80	7	249	104.4	.47	5.8	1.9	D1
880808	1749	4.96	40-34.79	95-56.55	5.00	1.15	7	249	16.1	.50	7.4	14.6	D1
880910	1041	3.22	39-11.40	98-57.73	.14	2.1	9	258	120.5	.77	6.6	2.2	D1
880915	624	1.50	39- 6.64	99-11.20	5.00	2.51	15	258	134.6	.63	3.9	3.3	D1
880925	1412	14.69	39-13.99	96-27.68	8.35	1.82	7	135	28.1	.23	2.5	14.8	C1
881015	1943	.65	41-31.06	99- 5.59	1.23	1.7	7	329	26.6	.64	14.5	4.5	D1
881016	1118	27.88	42-27.63	97-50.57	.82	2.2	6	289	157.0	.44	2.2	2.3	D1
881029	10 9	2.23	39-34.84	97- 1.64	13.21	1.69	9	172	34.1	.26	2.4	9.4	C1
890121	2311	14.08	39- .84	99-14.36	5.00	2.4	13	273	141.9	.86	8.2	5.4	D1
890127	0 0	13.93	39- 6.59	99-31.54	9.22	2.50	5	276	162.5	.12	7.9	3.6	D1
890127	056	48.73	39-13.51	99-31.54	1.16	2.70	15	103	159.3	.58	2.3	2.6	D1

890209	515	47.84	42-34.20	101-54.54	9.97	4.0	17	197	283.5	.41	4.2	4.8	D1
890223	2339	29.20	40- 4.08	96- .60	5.00	1.7	8	196	52.9	.59	5.1	17.1	D1
890314	1935	10.99	40- 4.05	96- 6.67	9.38	2.2	9	135	42.9	.28	1.8	23.0	C1
890502	2235	7.59	40- 2.19	96- 2.72	10.73	1.8	7	116	45.6	.32	1.2	12.1	C1
890506	2330	31.62	38-54.20	95-38.82	2.09	2.0	13	161	41.5	.26	1.0	6.7	C1
890508	1851	19.82	40- 2.25	96- 4.95	22.31	2.1	7	207	45.8	.42	4.5	14.2	D1
890510	1948	55.63	40- 1.07	96- 1.46	5.00	2.0	8	117	47.6	.24	1.4	12.5	C1
890530	1920	46.87	39-33.69	96-26.02	5.00	2.0	5	130	31.7	.17	25.8	137.1	D1
890531	1640	9.33	39- 8.56	95-57.14	29.76	2.1	5	168	65.6	.11	1.7	1.5	C1
890606	631	4.62	39-11.40	99-41.63	8.43	2.4	6	328	174.5	.21	8.1	2.2	D1
890606	634	20.86	39-11.40	99-29.80	5.00	2.4	6	272	157.9	.76	22.0	13.8	D1
890606	727	5.56	39-11.40	99-29.80	5.00	2.0	3	326	165.9	.39			D1
890608	11 4	1.48	39-11.40	99-29.80	5.00	2.0	4	326	157.9	.40			D1
890608	1726	59.46	39-11.40	99-25.05	5.00	2.1	5	270	151.2	.51	18.8	24.1	D1
890608	1749	36.12	39-11.40	99-25.60	5.00	2.4	3	271	152.0	.00			C1
890608	1757	55.65	39-13.97	99-29.80	5.00	2.3	3	271	156.6	.00			C1
890608	18 5	47.44	39- 3.72	99-29.80	5.00	1.7	3	299	161.6	.24			C1
890608	1818	43.36	39- 9.10	99-29.80	5.00	4.0	13	179	158.9	.62	4.4	4.4	D1
890616	1453	53.79	39-11.40	99-25.91	14.21	2.7	8	177	152.4	.25	3.6	2.9	D1
890617	013	57.38	39-15.96	99-47.34	1.48	2.6	4	328	180.8	.18			C1
890627	219	59.59	39-16.99	99-30.80	1.73	0.9	6	217	4.3	.14	9.1	32.2	D1
890627	1219	.10	39-18.29	99-29.80	5.00	1.7	5	209	7.1	.57	19.1	15.1	D1
890704	1444	42.43	39-11.40	99-29.80	5.00	2.0	11	229	8.5	.49	5.7	2.6	D1
890704	1511	25.89	39-11.40	99-29.80	5.00	1.5	4	229	8.5	.10			C1
890706	112	31.49	39-11.40	99-29.80	5.00	2.8	7	184	157.9	.57	12.4	6.7	D1
890709	323	12.83	39-11.40	99-30.96	2.38	1.0	4	254	4.4	.14			C1
890709	331	38.83	39-14.09	99-30.70	.83	1.0	4	130	1.6	.06			C1
890709	636	3.32	39-11.40	99-30.89	5.00	0.9	3	259	4.5	.02			C1
890709	638	41.61	39-11.40	99-30.71	2.30	0.5	4	257	4.7	.09			C1
890709	8 8	26.33	39-11.24	99-29.89	2.74	0.5	4	270	5.1	.12			C1
890709	1445	22.93	39-11.40	99-29.80	5.00	0.9	3	229	8.5	1.11			D1
890710	950	29.78	39-11.40	99-29.80	1.05	1.8	7	175	6.1	.33	3.8	4.0	C1
890711	1142	11.26	39-11.40	99-29.80	2.84	0.9	9	271	1.0	.15	1.6	.8	C1
890711	1156	42.39	39-11.40	99-29.80	2.96	1.3	9	271	1.0	.15	1.5	.8	C1
890711	1346	38.54	39-11.40	99-29.80	2.25	0.5	9	271	1.0	.15	1.4	.8	C1
890713	1835	22.46	39-11.40	99-28.20	5.00	3.0	19	172	3.3	.58	2.8	1.9	D1
890714	710	22.41	39-12.66	99-31.27	3.00	1.5	8	91	1.2	.19	1.4	2.7	B1
890714	711	49.31	39-13.10	99-31.77	1.38	1.5	5	108	2.3	.18	3.5	91.1	D1
890718	23 8	43.52	39-11.40	99-29.80	5.00	2.0	5	272	157.9	.67	26.2	14.7	D1
890720	249	47.05	36-13.74	98-54.00	5.00	2.3	6	313	365.1	.21	38.2	348.1	D1
890720	6 7	51.57	36-30.00	98-47.95	5.00	2.6	7	310	292.0	.44	54.0	661.7	D1
890731	1837	31.14	39-22.79	99-29.80	15.20	2.3	6	319	170.3	.16	39.4	38.2	D1
890801	1833	4.59	38-18.48	96- 5.44	.39	2.0	7	310	25.1	2.15	181.5	77.2	D1

Explanation of "Phase Lists" individual columns:

STN = Station name

PRMK = P-wave Remark
- I = Impulse
- E = Emergent
- P = Compressional wave or P-wave
- G = Direct wave
- N = Moho refracted wave

	Qualitative Values
Weighted least square value:	0 = fully weighted
	1 = three-quarters weighted
	2 = half weighted
	3 = quarter weighted
	4 = not used in solution

P-SEC = P-wave arrival-time in seconds.

Example:	yr	day	mo	hr	min	P-SEC	
	87	01	09	18	52	09.25	(870109185209.25)

S-SEC = S-wave arrival-time in seconds.

SRMK = S-wave Remark

Weighted least square value:	0 = fully weighted
	1 = three quarters weighted
	2 - half weighted
	3 - quarter weighted
	4 = not used in solution

DURATION = Duration of wave — time in seconds between P-arrival and end of noticeable coda.

Phase Lists for the earthquakes during 1987-1989

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STN PRMK  DATE      P-SEC        S-SEC SRMK DURATION

CNK IP 0 870109185209.25       12.00 S 4        73
MLK IP 1 870109185220.55       32.15 S 2        83
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LCNEEP 3 870109185237.70       60.95 S 4
BEK EP 1 870109185226.10       41.45 S 3
LAK EP 4 870109185240.35       66.35 S 3        76
HWK EP 2 870109185233.25       54.60 S 3        65
EMK IP 3 870109185234.15       55.35 S 4
EDK EP 4 870109185235.60       67.80 S 3
CCNEIP 1 870109185218.55       28.95 S 3        70
JHN IP 2 870109185229.55       47.85 S 3
RSOZ P 4 8701091852                  S 4
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CNK  P 4 870124103603.60
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JHN EP 3 870124103600.30       27.45 S 3
WHNEEP 4 870124103545.45       63.45 S 3
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PCNEIP 0 870124103535.05       43.20 S 2        83
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HWK  P 4 8702102015            25.30 S 3
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TCK EP 3 870216023013.15       43.75 S 4
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CNK IP 2 870816091025.20         39.30 S 2
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JHN EP 4 880428170321.00       39.20 S 4
TCK EP 2 880428170329.25             S 4
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ADDITIONS TO LIST OF KANSAS EARTHQUAKES

Attached are information sheets on two earthquakes with epicenters in Kansas which were not included in the Kansas Geological Survey publication, A Revised and Augmented List of Earthquake Intensities for Kansas, 1867-1977, by Susan M. DuBois and Frank W. Wilson, dated April 1978.

I found mention of these earthquakes several years ago while searching 19th century Kansas newspapers for information on historical subjects. Recently, after discussing the subject with Don Steeples, I have made a fairly intensive search for additional newspaper reports and summarized the results on the attached pages including the time, place, estimated Modified Mercalli intensity, and the effects mentioned in the newspaper reports.

The first of these earthquakes, one felt in a very limited area and of rather low intensity, occurred on the morning of January 19, 1871 in Lawrence. Even though I have found only one account, the description and the number of people who were aware of it convince me that it was an earthquake and qualifies for the list at least as well as those of 1903 and 1907.

The second earthquake was a much more considerable affair, being felt over at least eleven Kansas counties (roughly 10,000 square miles) and reaching intensities of at least VI, and possibly VII, on the Modified Mercalli scale. The area affected probably was considerably greater than 10,000 square miles as I made no attempt to determine how far it extended into Nebraska and there are no Kansas newspapers available for the area west of Norton. This earthquake took place about 9 p.m. on the evening of April 27, 1879 and probably was centered a little north of Stockton. I have drafted an isoseismal map of the Kansas portion of this earthquake, based on estimates of the Modified Mercalli intensities derived from the newspaper descriptions. I believe this is the same earthquake as that listed on page 21 of the Kansas Geological Survey publication mentioned above, but not considered authentic or included in the list of twenty-five Kansas earthquakes. Possibly a typographical error in the source report led to a search in March rather than May newspapers; although the earthquake took place late in April many of the weekly newspapers reporting it bear May dates.

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"Additions to list of Kansas earthquakes" were prepared by John M. Peterson. We appreciate his efforts.

EARTHQUAKE

January 19, 1871

	Locality	Intensity	Time	Reported Effects
1.	Lawrence (Douglas Co.)	III-IV	About 11:30 a.m.	Severe shock accompanied by a rumbling noise. Felt on Massachusetts Street and elsewhere in the city. Large number of persons rushed into the gas office to learn if there had been an explosion. Nothing learned of that could have caused the shock or rumbling so must have been an earthquake.

No report found in other Lawrence paper or papers from Topeka, Leavenworth, Paola, Ottawa, Burlingame, or Wyandotte.

Source:
Kansas Daily Tribune (Lawrence), January 20, 1871.

EARTHQUAKE

April 27, 1879

	Locality	Intensity	Time	Reported Effects
1.	Norton (Norton Co.)	IV	9:15 p.m..	General shaking and trembling of the earth followed by severe shock. Rumbling noise accompanied shaking in dugouts, dirt rattled down and dishes clattered. In frame houses, noise and trembling equally felt. Doors in bookcase rattled so hard that glass expected to break. Shock seemed as though two ton weight had been thrown against the house.
2.	Phillipsburg (Phillips Co.)	VI	About 9 p.m.	Severe shock. Buildings swayed, glass and doors jarred in violent manner, church congregations fled from building, dugouts abandoned by occupants, dugout walls and roofs gave way and crumbled down. Shock lasted 20 seconds but quivering of earth could be felt for minutes. Shock was felt throughout Phillips Co.
3.	Lenora (s. of Norton) (Norton Co.)	IV-V		A general shaking up. Terrific shock, rocking houses and jingling dishes. Sound resembled muttering of distant thunder.
4.	Stockton (Rooks Co.)	VI-VII	8:50 p.m.	Very perceptible, in fact, severe earthquake. People stampeded from meeting house, walls of stone buildings cracked, lamps and other furniture nearly overturned, stoves danced around. Many thought shock came from southwest and proceeded to the northeast.

EARTHQUAKE

April 27, 1879 (Cont'd.)

	Locality	Intensity	Time	Reported Effects
5.	Kirwin (Phillips Co.)	VI	9:00 p.m.	Subterraneous noise resembling distant thunder immediately followed by sharp quaking or oscillatory motion of the earth. Repeated twice with more violent shock. Shocks caused houses to sway, windows to rattle, piano strings to vibrate, and made it difficult to walk. Hotel guests, church congregation, others ran outside. Hardware stores shook up, wagons rocked. The three shocks lasted 15 seconds, course was from southwest to northeast.
6.	Bloomington (w. of Osborne) (Osborne Co.)	III-IV	About 9:30	Very audible shock of earthquake noticed in congregation at court house but no attention paid at time. Lasted 30 seconds, loudest at first, then diminished. At depot observers thought train was coming.
7.	Osborne (Osborne Co.)	IV	Precisely 9:00 p.m.	Dull rumbling sound as of distant thunder coming from southwest followed in 1/2 second by a jarring undulation which briskly rattled windows and doors and loose articles of furniture. Lasted half a minute with sensation increasing and diminishing gradually. Some people quite surprised or frightened; others did not observe at all. Slight shock, majority of observers thought it came from the west. (Monthly report of weather observer, R. B. Foster).

EARTHQUAKE

April 27, 1879 (Cont'd.

Locality	Intensity	Time	Reported Effects
8. Smith Center (Smith Co.)	III	About 9:00 p.m.	Three distinct shocks felt, lasted about thirty seconds.
9. Cawker City (Mitchell Co.)	III	About 9:00 p.m.	Slight shock of earthquake just sufficient to shake the buildings a little. Lasted but a few moments.
10. Mankato (Jewell Co.)	II	Between 8 & 9 o'clock	Slight shock accompanied by a rumbling noise. Startled a few; some did not hear it.
11. Corinth (near Mankato)	?		Earthquake made some Corinthians tremble. (Corinth items)
12. Plainville	III	About 9:00 p.m.	Low rumbling sound resembling thunder accompanied by quite perceptible trembling of the earth. Duration estimated from 3 seconds to several minutes.
13. Victor Township (sw of Osborne) (Osborne Co.)	?		Much glass broken by earthquake Sunday night and recent hail storm.
14. Gettysburg Township (w. of Hill City) (Graham Co.)	IV	Between 7 & 8 p.m.	Inhabitants frightened by shaking of earth. Houses shook so as to rattle dishes on shelves.
15. WaKeeney (Trego Co.)	II	About 8 o'clock	Editor did not hear or feel it but friends assure him there was an earthquake.
16. Hays (Ellis Co.)	II-III		Earthquake shock scared some. Young man seated on gallery rail of court room had sensation similar to riding bucking horse.
17. Russell (Russell Co.)	II	About 8:30	Slight shock felt by many. A number of citizens distinctly noticed the earthquake shock.

EARTHQUAKE

April 27, 1879 (Cont'd.)

Locality	Intensity	Time	Reported Effects

Beloit and Lincoln newspapers do not mention, or only mention reports from elsewhere. No newspapers available from Graham, Sheridan, Decatur, or Grove counties.

18. Nicodemus (Graham Co.)	IV?		Earthquake shock of more than passing notice felt by many. No damage other than frightening the timid.
19. Lost Creek	III?		Earthquake shook us up a little and caused quite an excitement.

SOURCES

1. Norton Advance, May 1, 1879.
2. Phillips County Herald (Phillipsburg), May 1, 1879.
3. Kirwin Chief, May 7, 1879, exchange item not further identified.
4. Stockton News, April 30, 1879.
5. Kirwin Chief, April 30, 1879.
6. Kirwin Chief, April 30, 1879, quoted from Bloomington Guard.
7. Osborne County Farmer (Osborne), May 1, 1879 and May 8, 1879.
8. Smith County Pioneer (Smith Center), May 2, 1879.
9. Free Press (Cawker City), May 3, 1879.
10. Free Press (Cawker City), May 10, 1879, quoted from Monitor-Diamond (Mankato).
11. Free Press (Cawker City), May 10, 1879, Corinth items.
12. Stockton News, April 30, 1879, news from Plainville.
13. Osborne County Farmer (Osborne), May 8, 1879, Victor Township items.
14. Stockton News, April 30, 1879, Gettysburg correspondent.
15. Wa-Keeney Weekly World, May 3, 1879.
16. Ellis County Star (Hays), May 1, 1879.
17. Russell Independent, May 1, 1879, and Russell Record, May 1, 1879.
18. Stockton News, May 7, 1879, letter from Nicodemus signed A. T. H., Jr.
19. Stockton News, May 7, 1879, Lost Creek correspondent.

APPENDIX II

SHALLOW SEISMIC REFLECTION SURVEY ACROSS THE MEERS FAULT, OKLAHOMA

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Abstract

A high-resolution seismic-reflection survey over part of the Meers fault scarp in Comanche County, Oklahoma, provides an improved understanding of the shallow structure associated with the fault zone. The objective of this survey was to detect and identify shallow faulting near the Meers fault and to appraise the resolving power of the shallow seismic-reflection technique in a structurally complex area. Three reflection profiles were acquired using a downhole .50-caliber rifle energy source and two 100-Hz geophones per channel connected in series. Field parameters were designed to optimize the recording of seismic reflections from geologic units in the 40 to 200-m depth range. Severe analog low-cut filters helped increase the dominant recorded reflection frequencies into the 100-250-Hz range, providing minimum bed resolution of about 6 m.. Lines 1 and 2 straddle and cross the scarp orthogonally, and line 3 was acquired approximately parallel to the scarp. Seismic data along line 2 show reverse faulting that extends from 250 m southwest to 200 m northeast of the scarp. The CDP stacked seismic data are sufficiently good to interpret an up-to-the-north, vertical to high-angle reverse displacement on the Meers fault. The amount of vertical displacement on the fault associated with the scarp cannot be determined with these seismic data. Maximum vertical displacement is less than 10 m on other secondary faults interpreted on seismic lines 1 and 2. Normal faulting is common on line 3. The major structural feature on line 3 is a graben with net displacement of between 5 and 30 m. The deformation on line 3 may be evidence of strike-slip motion along the main fault. The Meers fault was in a transpressive tectonic setting during Quaternary time as evidenced by strike-slip motion in conjunction with high-angle up-to-the-north reverse faulting. Evidence for angular unconformities within the Permian section exists on individual unprocessed field seismograms, suggesting that some complex bedforms (channel sands?) are present.