EARTHQUAKE STATISTICS FOR OHIO[1]

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Although Ohio cannot be classified as an area of unusually high amounts of seismic activity, it has experienced several earthquakes of small to moderate intensity. The seismically most active region is near the city of Anna where approximately 36 earthquakes have been experienced in a span of 188 years. The seismic data for 1900–1964 are considered to be reasonably complete, and if these data are analyzed, several conclusions may be drawn. The seismic activity of Anna has taken place in several distinct episodes or swarms primarily during the years of 1925–1933 and 1936–1940. The logarithm of the frequency of earthquake occurrence for all of Ohio and for the Anna region is inversely related to the intensity of the earthquake. The mean recurrence time, the average time between earthquakes of intensity I or greater, ranges from approximately 0.7 to 10 years for all of Ohio, and from 1.7 to 15 years for Anna.

Ohio, though not an area of unusually high seismic activity, has experienced several earthquakes of small to moderate intensity. Many of these earthquakes have taken place near the city of Anna, located about 45 miles north of Dayton. Data of some Ohio earthquakes are catalogued in the reports of Bradley and Bennett (1965) and of the Department of Commerce (1973).

Several analyses of these data have been made; but none are generally available in the scientific literature. Instead, it is common to find in reports by site investigators, city planners, etc., general statements about the low level of seismicity, the infrequent occurrence of damaging earthquakes, and the maximum size of a future earthquake in the area. Instead of basing major planning decisions on such vague statements, it would be more useful to examine the historical records in order to arrive at more precise statements describing the nature of the seismic activity of Ohio. The purpose of this paper is to examine the statistics of the earthquake data, construct recurrence relations, and estimate the mean period of earthquake recurrence as a function of earthquake intensity for Ohio and for the Anna region.

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DISTRIBUTION OF EARTHQUAKES

Table 1 is a list of earthquake epicenters in Ohio for the period 1776–1964 from the paper by Bradley and Bennett (1965). Although their data are generally in agreement with the data compiled by the Department of Commerce (1973), slight differences in estimates of intensity existed. Wherever such a discrepancy was detected, the Department of Commerce data were considered to be more accurate, and slight modifications of the information catalogued by Bradley and Bennett were made accordingly.

Ohio earthquakes do not occur in a uniform distribution across the state, but in a number of definite belts or zones of activity. By far the most seismically active portion of the state is near the city of Anna, where approximately 36 earthquakes have been experienced over a span of 188 years. In addition, the Anna area has suffered the most intense (up to VIII on the Modified Mercalli Scale) and, consequently, the most damaging earthquakes. The earthquake of March 8, 1937 of intensity VIII, for example, damaged numerous buildings in Anna and was felt as far away as Chicago, Milwaukee and Toronto.

Broader zones of less frequent and less intense seismic activity are located across the northern, western and southern sections of the state, but activity there isn't quite as severe or concentrated as near Anna (Fig. 1). Although Bradley and Bennett (1965) have summarized the earthquake history of Ohio for the years 1776 through 1964, they consider only data for the period 1900–1964 to be reasonably complete. Only seismic data for this 64-year span will be considered and analyzed in the remainder of this paper.

TABLE 1

List of Ohio Earthquakes, 1776 through 1961.
(Modified from Bradley and Bennett, 1965)

No.	Year	Description
1	1776	Summer; 13h; VI. Epicenter near Muskingum River. Furniture was overthrown. People and animals were frightened. A rumbling noise accompanied the earthquake. Duration of shock estimated as two or three minutes.
1A	1810	Night; III. Reported as occurring in Ohio. Many people roused from sleep. This shock was referenced in a 1918 newspaper and possibly was the New Madrid earthquake in 1811.
2	1845	Earth slump or some type of displacement occurred on a farm in Putnam County. Ridge of ground was shifted approximately four feet. No report of any shock being felt.
3	1872	July 23; III. Felt around Elyria and Lorraine. Felt over several counties. Was either the result or cause of a rockslide.
4	1875	June 18; 12h 43m; 40.2N, 84.0; VII. Felt over an area of 40,000 sq. mi. Most severe damage at Urbana and Sidney, where walls were cracked and chimneys thrown down.
5	1876	June. Intense shock near Anna.
6	1877	January 23; 21h; III. Shock primarily felt in Brown and Adams counties in south central Ohio. Accompanied by a rumbling noise. Also felt in northern Kentucky.
7	1882	February 9; 20h; V. Two distinct shocks felt at Swanders and Botkins, near Anna. Windows and dishes rattled. People rushed into streets. Ground reportedly moved toward northeast.
8	1884	September 19; 19h 14m; 40.7N, 84.1W; VI. Felt over an area of 125,000 sq. mi. Slight damage occurred at Lima. Two distinct shocks felt in several places. Direction of motion reported from north to south. Felt in all of the states bordering Ohio.
9	1884	December 23; 23h; III. Distinct shock felt at Anna. Ground seemed to move from northwest to southeast. Duration of shock several seconds.
10	1889	September. Slight earthquake near Anna.
11	1892	Summer. Intense earthquake near Anna.
12	1896	March 15; 07h; IV. Shock awakened some from sleep. Accompanied by rumbling noise. Reported strongest at Sidney. Motion lasted about 1 minute and seemed to travel from northwest to southeast.
13	1901	May 17; 06h 00m; 39.3N., 82.5W.; V. Shock felt over 7000 sq. mi. Center near Wellston and Portsmouth. Felt as far as West Virginia.
14	1906	June 27; 21h 10m; 41.4N., 81.6W.; V. Felt over a 400 sq. mi. area. Most intense at Fairport and Put-in-Bay. Doors slammed and windows rattled. Two shocks felt along southern shore of Lake Erie for about 100 mi.
15	1914	Slight earthquake near Anna; II(?).
16	1925	March 27; 04h 06m; V. A distinct earthquake was felt over southwestern Ohio. Furniture was moved and dishes rattled but there was no report of damage.
17	1925	April 4. Earthquake near Cincinnati.
18	1925	October. Slight earthquake near Anna; II(?).
19	1926	October 28; 07h 40m; III. Vibration similar to explosion felt in East Toledo and suburbs. Not thought to be a blast.
20	1926	October 28; 10h 00m; IV. Second shock within four-hour period. Houses jarred and windows rattled in suburbs of Toledo.
21	1926	November 5; 14h 53m; 39.1 N, 82.1 W; VI. Felt over 350 sq. mi. Strongest at Pomeroy where chimneys were thrown down and a stove overturned. Some objects were knocked from shelves.
22	1927	February 17; 05h; IV. A series of slight earth tremors was felt between 05h and 06h 30m near Mansfield.
23	1928	September 9; 20h 00m; 41.5N, 82.0W; V. Felt over 1500 sq. mi. along southern shore of Lake Erie. Most intense in East Cleveland, where some people rushed from houses. Sounds resembling thunder were heard. Three distinct shocks were felt.
24	1928	October 27; III. Felt over a 100 sq. mi. area. Center at Jackson Center (close to Anna).
25	1929	March 8; 09h 06m; 40.4 N, 84.2 W; V. Felt over 5000 sq. mi. Most intense around Sidney and Bellefontaine. Windows and dishes rattled, furniture shifted, and many sleepers were awakened. Rumbling noise accompanied the earthquake. Two distinct tremors were felt.
26	1929	June 10; Daytine; III. Buildings in suburbs in east side of Cleveland were shaken. Possibly due to an explosion.

TABLE 1. *Continued.*

No.	Year	Description
27	1929	September 17; 19h 16m; II. In Cleveland suburb of Euclid; man reported house violently shaken.
28	1930	June 26; 21h 45m; 40.5 N, 84.0 W; IV. A rocking and rumbling of the ground was observed. Most pronounced near Bellefontaine and Lima where dishes and windows were rattled. Was accompanied by a noise similar to a blast. Two shocks were felt by many.
29	1930	June 27; 07h 23m; 40.5 N, 84.0 W; IV. Very similar to earthquake of day before, perhaps slightly weaker. Buildings were shaken and beds moved, waking many sleepers.
30	1930	July 11; 00h 15m; 40.7 N, 83.2 W; IV. Small buildings were shaken. Some movement of furniture and vibration of dishes.
31	1930	September 20; VI. Earthquake experienced in the Anna area.
32	1930	September 29; 22h 50m; 40.3 N, 84.2 W; III. A brief earthquake shock was felt by many people at Sidney and Anna. The tremor lasted only a few seconds and was accompanied by a rumbling sound.
33	1930	September 30; 20h 40m; 40.3 N, 84.3 W; VII. A brief but strong shock was generally felt over a wide area, with the strongest intensity at Anna. The earthquake was strong enough to knock down the chimney on the school and cause plaster to crack and fall. The tremor was again accompanied by a rumbling noise.
34	1930	October. Moderate earthquake at Anna; IV?.
35	1931	March 21; 15h 48m; III. A feeble earthquake shock was felt at Sidney and Jackson Center.
36	1931	April 1; 00h 15m; III. Buildings at Jackson Center were shaken by the shock. A rumbling noise was heard by many. No damage reported.
37	1931	June 10; 08h 30m; V. A strong shock was experienced in Malinta, Ohio and surrounding regions. Windows were broken and trees knocked down. Many people were awakened. Buildings were shaken in several nearby cities. There was some speculation that the shock may have been caused by a meteor.
38	1931	September 20; 23h 05m; VII. Felt over an area of 40,000 sq. mi. Most damage done at Anna, where two cornices were thrown down, plaster was shaken from the walls and several chimneys were toppled. In nearby cities chimneys also fell and several windows were broken.
39	1931	October 8; 14h 30m; III. A slight earth tremor was felt by a large number of the residents of Anna.
40	1932	January 21; P.M.; IV. Shock was felt along the west side of Summit Lake near Akron. Windows were cracked, furniture moved, and pictures and chandeliers jolted by the vibration.
41	1933	February 23; 03h 20m; III. Shock felt over four counties. Center of disturbance seems to have been near Sidney, where windows rattled and houses shook. A low rumbling noise accompanied the tremor.
42	1936	January 31; 06h 30m; III. A heavy rumbling awakened many in the Tiffin area.
43	1936	October 8; 16h 30m; III. A slight earthquake was experienced by many persons in the downtown areas of Cincinnati and Middletown. Plates and chairs were moved by the vibration which lasted about five seconds.
44	1936	December 26; 01h 15m; III. Houses in the Cincinnati area were shaken by a slight earthquake. The tremor which lasted ten or fifteen seconds vibrated chairs and was accompanied by a rumbling noise.
45	1936	December 26; 02h 05m; III. A second shock very similar to the one above was felt by residents in the Cincinnati area.
46	1937	March 2; 14h 48m; 40.7 N, 84.0 W; VII. This earthquake was felt over an area of 110,000 sq. mi. in Ohio, Indiana, Michigan, West Virginia, Kentucky, and Canada. Greatest damage was done at Anna, but the shock was also strong at Sidney and Wapakoneta. Several chimneys were toppled, walls cracked, and plaster thrown down.
47	1937	March 3; 09h 50m; V. Felt in Anna, Sidney, Jackson Center, and Botkins. Windows rattled and bricks were shaken from chimneys. Many were awakened from sleep. The earthquake was accompanied by a rumbling sound.
48	1937	March 3; 09h 55m; III. A second distinct shock occurred about 5 minutes after the one above.
49	1937	March 9; 05h 45m; 40.6 N, 84.0 W; VIII. Earthquake felt over a 150,000 sq. mi. area. Region around Anna experienced greatest damage. Chimneys were thrown down, walls were badly cracked and some organ pipes were twisted. Shock accompanied by deep rumbling noise.
50	1937	April 23; 17h 15m; III. Slight earth tremor felt at Anna, Sidney, Jackson Center, and Botkins.

TABLE 1. *Continued.*

No.	Year	Description
51	1937	April 27; 17h; III. Slight shock felt in Sidney and Anna.
52	1937	May 2; 17h 05m; III. Shock felt at Sidney, Anna, Jackson Center and surrounding communities. The tremor lasted a few seconds and no damage was reported.
53	1937	October 17; 04h 25m; III. Shock felt by many people in suburbs of Cincinnati.
54	1939	March 18; 11h 00m; II. A number of persons in Sidney reported they felt and heard an earthquake.
55	1939	March 18; 13h 03m; III. Shock felt at Anna, Sidney, Botkins, and Jackson Center. Tremor described as being similar to an explosion.
56	1939	June 18; 02h 20m; IV. Felt at Botkins, Jackson Center, and Wapakoneta. Strongest at Anna. Caused much excitement but no damage. Bottles and dishes rattled. Rumbling noise reported.
57	1939	July 9; 11h 50m; II. Slight shock at Anna.
58	1940	May 31; 17h 30m; II. Slight tremor felt by a few people in the vicinity of Akron.
59	1940	June 16; 02h 30m; III. On a farm north of Nankin a series of tremors, thought to be of seismic origin continued at intervals for several months. This event was the strongest. People were awakened by the shock.
60	1940	July 28; 09h 30m; II. Second of series of shocks at Nankin.
61	1940	August 15; 10h 35m; II. Third in series of shocks at Nankin.
62	1940	August 19; 03h 30m; II. Final in series of shocks at Nankin.
63	1943	March 9; 04h 26m; 42.2 N, 80.9 W; IV. Felt over a 40,000 sq. mi. area, in Ohio, Michigan, Pennsylvania, New York, and Canada. Epicenter in Lake Erie about 60 mi. northeast of Cleveland. Reports of cracked plaster, broken windows and dishes.
64	1944	November 13; 11h 48m; III. Epicenter apparently near Anna and Botkins. No damage was caused by shock, which lasted 7 seconds. Earthquake reportedly felt as far away as Indianapolis, Indiana.
65	1948	January 18; night; III. One family awakened by tremor in suburbs of Toledo. Another reported sound similar to explosion. A cement floor was reportedly cracked and cracks were found in the ground.
66	1950	April 20; III. Sudden earth tremors were felt in Dayton and surrounding area. Some dishes and windows were broken. Possibly an earthquake, but more probably low flying aircraft.
67	1951	December 3; 07h 02m; IV. Most intense in Willoughby, but felt in other suburbs of Cleveland. Many thought their furnaces had exploded, as homes were shaken and windows rattled.
68	1951	December 7; 21h 00m; II. Shock at Willoughby, recorded on seismographs of John Carroll University, Cleveland.
69	1951	December 21; 20h 00m; II. Another Willoughby shock recorded at John Carroll University.
70	1952	June 20; 09h 38m; 39.8 N, 82.2 W; VI. Shock felt over a 20 mile radius, with strongest effects at Zanesville. The tremor awoke most of the people in the area, as dishes were rattled, pictures shaken and doors thrown open. Disturbance lasted from five to ten seconds.
71	1953	May 5; 23h 32m; IV. Shock centered near Crooksville, where windows and dishes rattled and buildings shook in the downtown area. A sound similar to an explosion accompanied the event.
72	1953	June 12; 04h 45m; IV. Earthquake felt in Toledo and suburbs, where houses were shaken and pictures knocked off of walls. Tremors reportedly lasted for several minutes.
73	1955	May 26; 18h 09m; V. Shock seems to have been centered in southeastern suburbs of Cleveland, near Aurora. Houses were jolted, doors, windows and dishes rattled and pictures were shaken from walls. A rumbling noise accompanied the tremor.
74	1955	June 29; 01h 16m; V. Second earthquake occurred in suburbs of Cleveland, near Aurora. Many were alarmed as houses rattled and a rumbling sound was heard.
75	1956	January 27; 16hr 03m; V. Felt over large area in west-central Ohio. Strongest at Anna, Sidney, and Lima. Buildings were shaken and windows and dishes were rattled by the tremor.
76	1957	July 23; 13h 03m; III. Shock at Ripley was recorded by John Carroll University. Two distinct shocks jarred buildings, but no damage was reported.
77	1958	May 1; 21h 47m; V. Shock felt by and alarmed many in the Cleveland area. Houses were rocked and dishes and windows rattled.
78	1961	February 22; 08h 44m; V. Shock felt in Findlay, where citizens reported a mild shaking which lasted about two minutes. Recorded at John Carroll University.

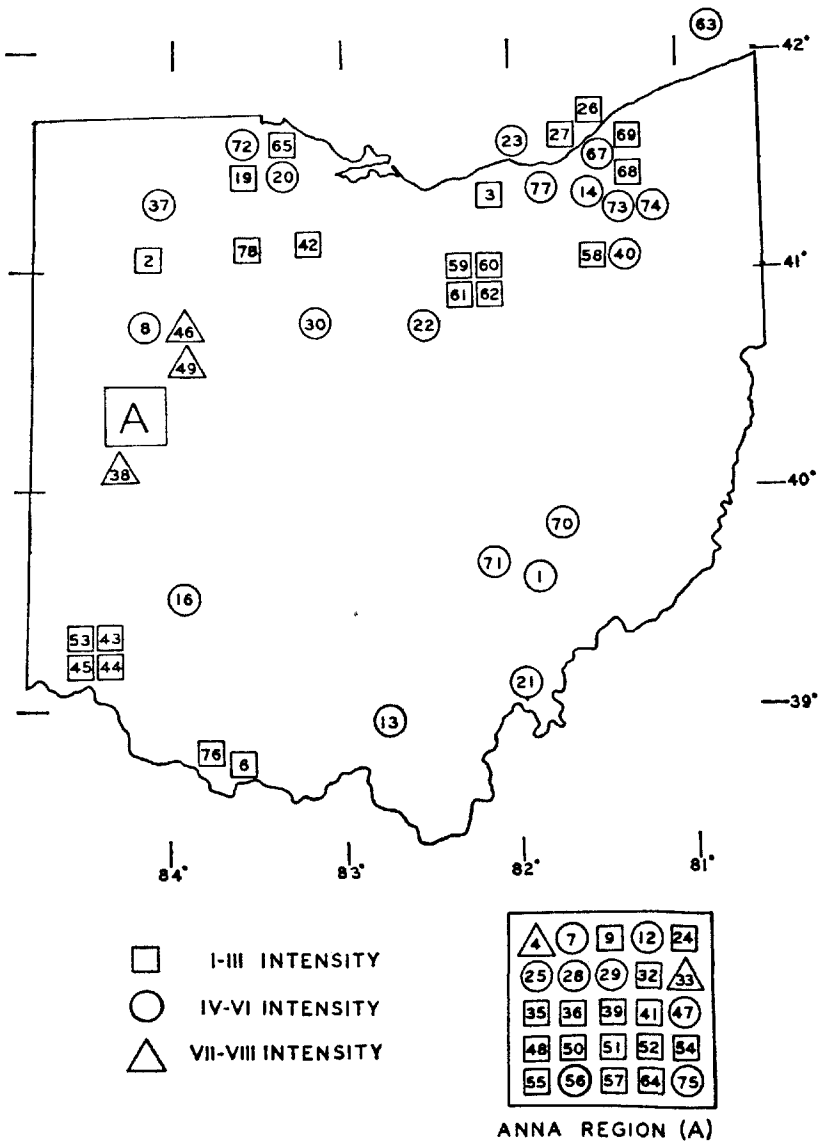

FIGURE 1. Earthquakes in Ohio, 1776 through 1964 (From Bradley and Bennett, 1965). The numbers in circles, triangles and squares refer to table 1.

FREQUENCY OF EARTHQUAKE OCCURRENCE

The temporal distributions of earthquakes for Ohio, for the Anna region, and for Ohio less the Anna region are illustrated in figs. 2–4. The seismic activity of the Anna region (fig. 3) was not distributed uniformly with time, but occurred in several distinct episodes or swarms. Two periods of unusually high amounts of activity are evident: 1925–1933 and 1936–1940. Of the total number of 28 earthquakes recorded over the 64 year period, 14 earthquakes (50%) and 11 earthquakes (39%) took place during 1925–1933 and 1936–1940 respectively

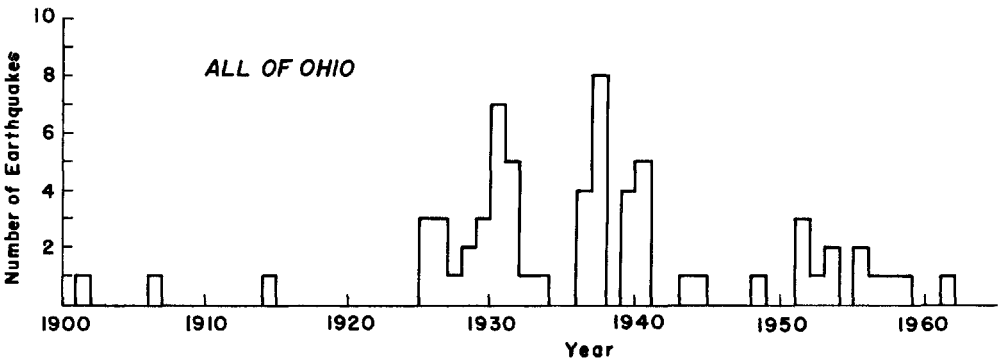

FIGURE 2. Temporal distribution of earthquakes for all of Ohio.

The temporal distribution of earthquakes for the rest of Ohio (fig. 4), on the other hand, reflects a different pattern. The time period 1900–1924 could be termed as a seismically "quiet" period with only two earthquakes recorded, while 1925–1964 reflects a period of much greater amounts of activity (95% of all earthquakes with epicenters outside of the Anna region).

There is no adequate explanation for the sporadic nature of the earthquake activity for the Anna area. More data on the nature of source mechanisms, focal depths, and subsurface and basement geology need to be accumulated before proposing an hypothesis.

The frequency of earthquake occurrence for many regions follows a logarithmic equation of the form (Chinnery and Rogers, 1973)

$$\log N = A - BI \quad (1)$$

where N = number of earthquakes per year of intensity greater than, or equal to I, and

A, B = scale constants.

An analysis of the seismic data of Ohio for 1900–1964 (Bradley and Bennett, 1965; Department of Commerce, 1973) using the method of least-squares error

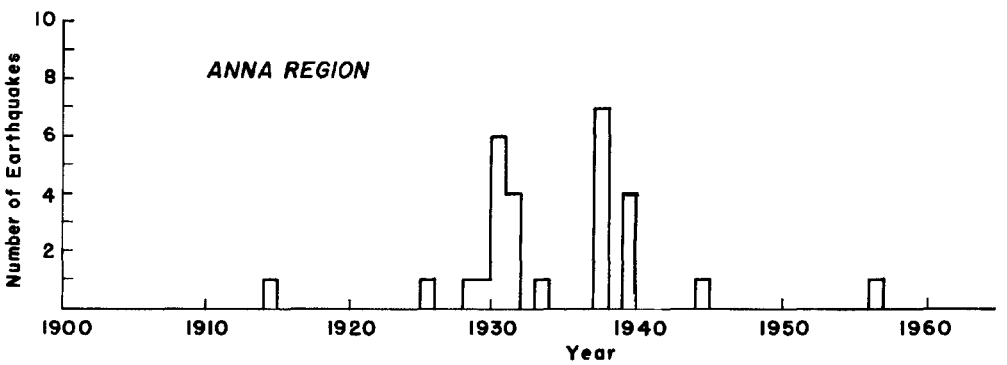

FIGURE 3. Temporal distribution of earthquakes for the Anna region.

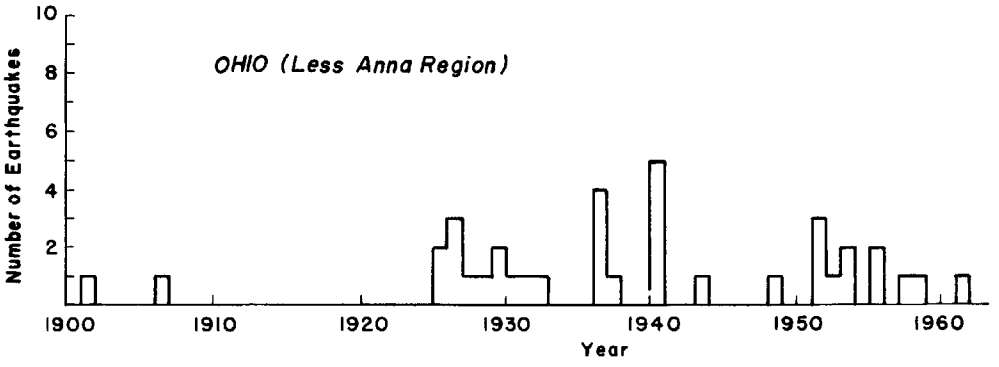

FIGURE 4. Temporal distribution of earthquakes for Ohio less the Anna region.

to obtain the best fit of the curve to the data indicates that earthquakes in Ohio follow a relation of the form

$$\log N = 0.62 - 0.25I, \quad \text{for } II \leq I \leq VIII. \tag{2}$$

The same analysis performed on the data of the Anna area for the same range of intensities yield the relationship

$$\log N = 0.04 - 0.25I. \tag{3}$$

Richter (1958) determined that the seismic activity of Southern California follows an equation of the form

$$\log N = 4.77 - 0.85\ M \tag{4}$$

where M = magnitude of the earthquake. Gutenberg and Richter (1956) derived a relationship between magnitude and intensity for the same area as

$$M = 1\ 2/3\ I, \text{ so} \tag{5}$$

equation 4 can be modified to relate the frequence of earthquake occurrence, N, directly to intensity, I, or

$$\log N = 3.9 - 0.57\ I. \tag{6}$$

This equation for Southern California, and the corresponding relationships for the East Coast (Algermissen, 1969) and Ohio (equations 2, 3) are plotted on fig. 5.

As one would expect, the seismic activity of Ohio is considerably less than that of Southern California and generally less than that of the East Coast. Ohio, for example, experiences an average of 0.5 earthquakes per year. One earthquake occurs every two years of intensity IV or greater in Ohio, whereas Southern California experiences approximately 45 earthquakes per year of this or a greater intensity (fig. 5). Note that the curves converge as earthquake intensity increases, which indicates the seismic histories of the various regions have become progressively similar as intensities increase. Earthquakes in Ohio of intensity VII or greater have taken place about as often as earthquakes along the East

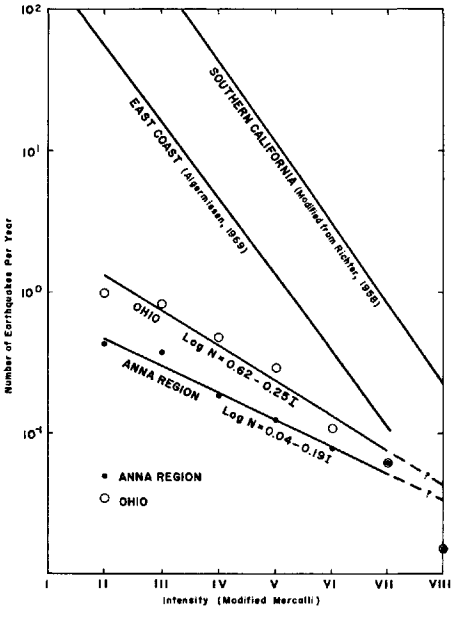

FIGURE 5. Frequency of earthquake occurrence versus earthquake intensity for various regions.

Coast with the same intensity. A similar observation is noted if the seismic activity of Ohio is compared with that of the St. Lawrence River Valley, a region having the highest incidence of earthquakes of any part of eastern North America. Though earthquakes of small intensity take place in this region much more frequently than do earthquakes of comparable intensity in Ohio, large earthquakes, those of intensity VII or greater, occur with nearly equal frequencies in both regions (Howell, 1973).

In considering the statistics of Ohio earthquakes, instead of using the quantity N for the number of earthquakes per year, it is more convenient to define the mean recurrence time (MRT). MRT is simply the average time between earthquakes with a given intensity I, or greater, and is equal to 1/N time periods. Therefore, it is an easy matter to calculate MRT for various intensities from equations 2 and 3, and the results are given in table 2. It should be noted that the values of MRT were determined from the cumulative event frequencies. Thus the first entry in table 2 states that the mean interval between earthquakes with a range of intensities of I–III *or greater* in all of Ohio is about 0.7 years, or about 8 months.

TABLE 2
Mean recurrence times.[1]

Intensity	Ohio (all)	Anna region
II-III	0.7	1.7
IV-V	2.5	5
VI-VIII	10	15

[1]Years.

These earthquake statistics for Ohio must be viewed with caution due to the incompleteness of seismic data for Ohio compared with many other regions. In the analyses of the seismic data presented in this paper, only information for a span of sixty-four years was considered because these data are considered reliable and complete. In contrast, seismic data for portions of the East Coast, sufficient for statistical analyses, dates back to 1534 (Chinnery and Rogers, 1973). In addition, since earthquakes of large intensity are (fortunately) rare events in Ohio, the recurrence relationships for these large earthquakes are necessarily less precise and should be interpreted with appropriate skepticism.

CONCLUSIONS

Although Ohio cannot be classified as a seismically active region, it has historically experienced limited activity particularly near the city of Anna. The seismic history of Ohio has been catalogued in publications by Bradley and Bennett (1965) and the Department of Commerce (1973) and if these data are analyzed, several conclusions about the nature of the seismic activity can be drawn:

1. The seismic activity in the Anna region was not distributed uniformly with time, but occurred in several distinct episodes or swarms. In the periods 1925–1933 and 1936–1940 the region had unusually high amounts of activity. No similar pattern of earthquake activity is observed for the remainder of the state.
2. The frequency of earthquake occurrence for all of Ohio follows the equation $\log N = 0.65 - 0.23I$ where N is the number of earthquakes per year of an intensity greater than or equal to II. An analysis of the seismic data for the Anna region yields the relationship $\log N = 0.14 - 0.19I$. A comparison of the recurrence equations for Ohio with those of Southern California and the East Coast illustrates quantitatively the lack of comparable seismic activity in Ohio. However, the difference in activity between Ohio and the East Coast becomes progressively less as the intensities of the earthquakes increase.
3. The mean recurrence time between earthquakes of intensity I or greater, for Ohio ranges from 0.7 years when I is greater than or equal to about II (on the Modified Mercalli Scale) to 10 years when I is greater than or equal to about VIII. For the same range of intensity, an analysis of seismic data for the Anna region yields mean recurrence times of 1.7 to 15 years.

Commonly, persons dealing with problems such as site selection and evaluation need to base their decision on general and, occasionally, vague descriptions of the seismicity of areas in Ohio. The information contained in this paper, however, provides a more precise definition of the degree and nature of the seismic hazards in the state.

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APPENDIX

Modified Mercalli Intensity Scale (Richter, 1958)

I. Not felt. Marginal and long-period effects of large earthquakes.

II. Felt by persons at rest, on upper floors, or favorably placed.

III. Felt indoors. Hanging objects swing. Vibration like passing of light trucks. Duration estimated. May not be recognized as an earthquake.

IV. Hanging objects swing. Vibration like passing of heavy trucks; or sensation of a jolt like a heavy ball striking the walls. Standing motor cars rock. Windows, dishes, doors rattle. Glasses clink. Crockery clashes. In the upper range of IV wooden walls and frame creak.

V. Felt outdoors; direction estimated. Sleepers wakened. Liquids disturbed, some spilled. Small unstable objects displaced or upset. Doors swing, close, Shutters, pictures move. Pendulum clocks stop, start, change rate.

VI. Felt by all. Many frightened and run outdoors. Persons walk unsteadily. Windows, dishes, glassware broken. Knickknacks, books, etc., off shelves. Pictures off walls. Furniture moved or overturned. Weak plaster and masonry D cracked. Small bells ring (church, school). Tree, bushes shaken visibly, or heard to rustle.

VII. Difficult to stand. Noticed by drivers of motor cars. Hanging objects quiver. Furniture broken. Damage to masonry D, including cracks. Weak chimneys broken at roof line. Fall of plaster, loose bricks, stones, tiles, cornices, unbraced parapets and architectural ornaments. Some cracks in masonry C. Waves on ponds; water turbid with mud. Small slides and caving in along sand or gravel banks. Large bells ring. Concrete irrigation ditches damaged.

VIII. Steering of motor cars affected. Damage to masonry C; partial collapse. Some damage to masonry B; none to masonry A. Fall of stucco and some masonry walls. Twisting, fall of chimneys, factory stacks, monuments, towers, elevated tanks. Frame houses moved on foundations if not bolted down; loose panel walls thrown out. Decayed piling broken off. Branches broken from trees. Changes in flow or temperature of springs and wells. Cracks in wet ground and on steep slopes.

IX. General panic. Masonry D destroyed; masonry C heavily damaged, sometimes with complete collapse, masonry B seriously damaged. General damage to foundations. Frame structures, if not bolted, shifted off foundations. Frames racked. Serious damage to reservoirs. Underground pipes broken. Conspicuous cracks in ground. In alluviated areas sand and mud ejected, earthquake fountains, sand craters.

X. Most masonry and frame structures destroyed with their foundations. Some well-built wooden structures and bridges destroyed. Serious damage to dams, dikes, embankments. Large landslides. Water thrown on banks of canals, rivers, lakes, etc. Sand and mud shifted horizontally on beaches and flat land. Rails bent slightly.

XI. Rails bent greatly. Underground pipelines completely out of service.

XII. Damage nearly total. Large rock masses displaced. Lines of sight and level distorted. Objects thrown into the air.