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EARTHQUAKES OF NORTHEASTERN NEW MEXICO AND THE TEXAS PANHANDLE

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INTRODUCTION

This paper includes earthquakes recorded 1907-1971 in northeastern New Mexico, the Texas Panhandle, and southeastern Colorado, between latitudes 34° and 38° N. and longitudes 100° and 106° W. The Oklahoma Panhandle and the southwestern corner of Kansas are in this area, which extends 280 miles north-south, 330-350 miles east-west, and embraces about 95,000 square miles.

A total of 31 earthquakes have had their epicenters within this area; see Figure 1. Of these, 2 are in Colorado, 8 are in Texas, and 21 are in New Mexico. Noninstrumental observations are available for 15 quakes (1907-70) and instrumental records are at hand for 21 quakes (1962-71). In addition, information is given in a concluding section on a few earthquakes whose epicenters were located outside the area but which were reported felt within the area.

From 1849 until 1960, practically all knowledge of New Mexico earthquakes was based on noninstrumental observations. In the summer of 1960 two high-magnification seismographs were installed in two abandoned mine tunnels west of the New Mexico Institute of Mining and Technology campus at Socorro. Late in 1961 the U.S. Coast and Geodetic Survey started operating instruments at the Albuquerque Seismological Center, at the west base of the Manzano Mountains southeast of Albuquerque. According to Shurbet (1969), practically all knowledge of Texas earthquakes from 1882 until 1948 was also based on noninstrumental observations. The Texas Technological College Seismological Observatory operated instruments sporadically from 1948 to 1956; since 1956 it operated continually and since 1961 it has been a World Standard Seismograph Station.

Shurbet notes that from 1882 until 1967, about 20 earthquakes had been clearly felt by people in Texas. "However, some of the quakes actually occurred in the neighboring states of New Mexico, Oklahoma, and Arkansas."

By contrast, hundreds of quakes have been felt in New Mexico since 1849. The great majority of these have had their epicenters in the Rio Grande rift zone of central New Mexico, extending from the Colorado line down through Santa Fe, Albuquerque, Socorro, and Las Cruces to El Paso, Texas. For these New Mexico quakes, see Sanford and others (1972); also Bagg (1904), Northrop (1942, 1945, 1947, 1961), Reid (1911), Sanford (1963, 1965), Sanford and Cash (1969), Sanford and Holmes (1961a, 1961b, 1962), and Toppozada and Sanford (1972). Relatively few earthquakes have occurred in northeastern New Mexico.

Richter's (1959, fig. 4) seismic regionalization map of the United States shows that northeastern New Mexico, the Texas Panhandle, and adjoining parts of Colorado, Kansas, and Oklahoma might occasionally expect earthquakes of intensity VIII. Our study shows no shock of intensity VIII or even VII for this area.

Algermissen's (1969, fig. 8) seismic risk map shows that maximum expectable intensities in this area are only V to VI. The Modified Mercalli Intensity Scale is given in Table 2.

EARTHQUAKES ORIGINATING WITHIN THE AREA

The accompanying Table 1 summarizes information on 31 earthquakes with epicenters located within the area of northeastern New Mexico, southeastern Colorado, and the Texas Panhandle, 1907 to 1971. Given are the number used on the map (Fig. 1), year, month, day, origin time (either Mountain or Central Standard Time), location of epicenter, Modified Mercalli Intensity based on noninstrumental observations, and Magnitude (either local or body wave) based on instrumental records. The area over which the earthquake was felt is given for 11 shocks.

Notable aseismic spans during which no important earthquake was recorded include one of 11 years (1937-47), one of 10 years (1952-61), one of 9 years (1908-16), and one of 6 years (1918-23). During the entire span of 65 years, 1907-71, earthquakes occurred in 19 different years. Greatest frequency was 1966, during which year 9 quakes occurred.

Mercalli intensities of 15 earthquakes can be ranked as follows: 6 of VI, 3 of V-VI, 2 of V, 1 of IV-V, 2 of IV, and 1 of III-IV. It seems likely that most of the remaining 16 quakes had an intensity of IV.

Magnitudes are known for 21 shocks, beginning in 1962. One had a magnitude of 4.8; one was 4.5; most ranged from 3.0 to 3.9; four were less than 3.0.

The magnitude rating (often called the Richter Magnitude) is a measure of the energy release at the focus; it is estimated by analysis of seismograph records. On the other hand, the intensity rating of an earthquake is expressed on the Modified Mercalli Intensity Scale of 1931 (Table 2); it is a local measure of the effects of people and objects. The observed intensity is a result of many factors, including the energy released (magni-

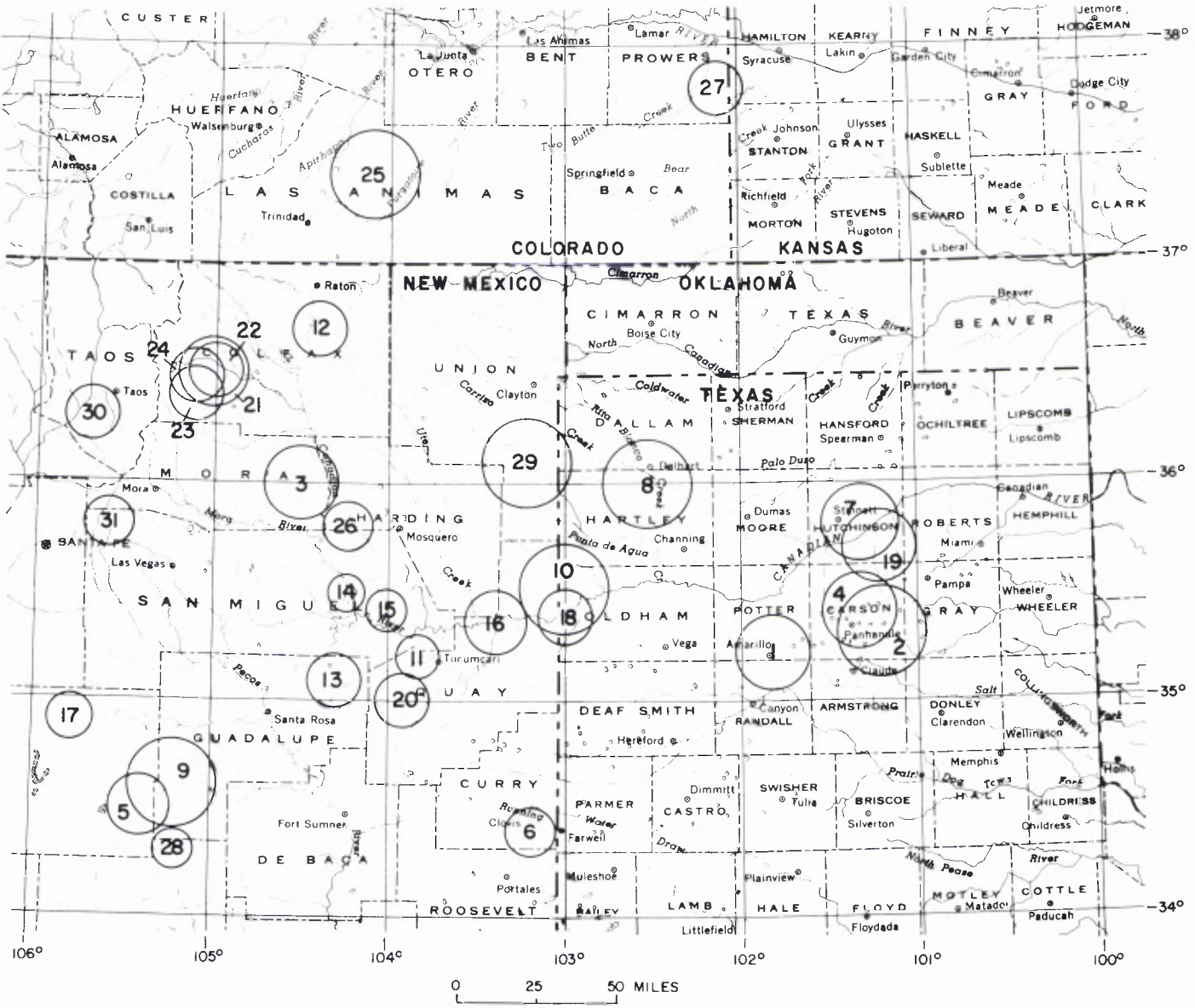

Figure 1. Map of northeastern New Mexico, Texas Panhandle, and adjoining States, showing epicenters of earthquakes, 1907-1971. Diameters of circles proportional to intensity, if known, or magnitude.

tude), depth of focus, distance from the epicenter, geological conditions, topography, and structural properties of buildings.

Intensity ratings and magnitude ratings cannot be correlated exactly but a rough approximation is attempted in Table 2.

For five shocks, both the intensity and the magnitude are available.

Shock No.	Intensity	Magnitude
16	IV	3.9
19	V	4.8*
21	IV-V	3.8*
25	VI	4.5*
29	VI	4.0

*Body wave magnitude may be higher than local magnitude.

These few cases suggest the following relation between intensity and magnitude.

Intensity	Magnitude
V	4.0
VI	4.5

For "ordinary ground conditions in metropolitan centers in California," Richter (1958, p. 353) suggests the following relation.

Intensity	Magnitude
I-II	2
III	3
V	4
VI-VII	5

Table 3 ranks the areas of perceptibility in square miles of 11 shocks; the number of the shock is given in parentheses.

A glance at this table reveals that the Texas Panhandle earthquakes have been felt over much larger areas than the

Table 1. Earthquakes originating within the area of latitude 34°-38° N. and longitude 100°-106° W., 1907 to 1971

No.	Year	Month	Day	Origin Time*	Epicenter Lat. N.	Epicenter Long. W.	Location and Felt Area	Mercalli Intensity	Magnitude**
1.	1907	Apr.	?	18(?) CST	35.2°	101.8°	Near Amarillo, Texas	V	
2.	1917	Mar.	27(?)	13:56 CST	35.3°	101.2°	Near Panhandle (City), Texas	VI	
3.	1924	Aug.	12	21:23 MST	36.0°	104.5°	Between Wagon Mound and Roy, New Mexico. Felt over area of 5,000+ sq. mi.	V-VI	
4.	1925	Jul.	30	06:17 CST	35.4°	101.3°	Northeast of Amarillo, Texas. Area = 200,000+ sq. mi.	V-VI	
5.	1930	Oct.	3	20:25 MST	34.5°	105.4°	Duran, New Mexico	IV	
6.	1935	Dec.	19	22:30 MST	34.4°	103.2°	Clovis, New Mexico	III-IV	
7.	1936	Jun.	19	21:24:06 CST	35.8°	101.3°	Borger, Texas. Area = 40,000-50,000 sq. mi.	V+	
8.	1948	Mar.	11	22:29:00 CST	36.0°	102.5°	Dalhart, Texas. Area = 50,000 sq. mi.	VI	
9.	1949	May	23	00:22 MST	34.6°	105.2°	Vaughn, New Mexico. Area = 1,300 sq. mi.	VI	
10.	1951	Jun.	20	13:37:10 CST	35.5°	103.0°	Probably in Texas near Nara Visa, New Mexico. Area = 40,000+ sq. mi.	VI	
11.	1962	Jan.	3	16:29:54 MST	35.2°	103.8°	Near Tucumcari, New Mexico		3.0 (1)
12.	1963	Jun.	6	01:05:33 MST	36.7°	104.4°	South of Raton, New Mexico		3.7 (1)
13.		Dec.	19	09:47:30 MST	35.1°	104.3°	Between Santa Rosa and Tucumcari, New Mexico		>3.6 (2)
14.	1964	Feb.	11	02:24:38 MST	35.5°	104.2°	Northwest of Tucumcari, New Mexico		2.4 (1)
15.		Mar.	2	18:26:30 MST	35.3°	104.0°	Northwest of Tucumcari.		2.6 (1)
16.	1965	Feb.	3	04:32:35 MST	35.4°	103.4°	Near Logan, New Mexico. Area = 5,300 sq. mi.	IV	3.6 (2) 4.2 (1)
17.		Dec.	28	17:50:24 MST	34.9°	105.8°	Northeast of Estancia, New Mexico		2.6 (2) 3.1 (1)
18.	1966	Apr.	21	08:14:12 CST	35.4°	103.0°	Probably in Texas, east of Logan, New Mexico		3.4 (2) 3.8 (1)
19.		Jul.	20	03:04:58 CST	35.7°	101.2°	North of Lake Meredith, Texas. Area = 60,000 sq. mi.	V	4.8 (3)
20.		Sep.	17	14:30:15 MST	35.0°	103.9°	Southwest of Tucumcari, New Mexico		3.6 (1)
21.		Sep.	24	00:33:46 MST	36.5°	105.0°	Near Cimarron, New Mexico. Area = 7,500 sq. mi.	IV-V	3.8 (3)
22.				01:27:10 MST	36.5°	105.0°	Cimarron, New Mexico		3.4 (3) 3.6 (1)
23.		Sep.	25	03:10:41 MST	36.4°	105.1°	Cimarron, New Mexico		3.8 (3)
24.				05:22:41 MST	36.5°	105.1°	Cimarron, New Mexico		3.6 (3) 3.7 (1)
25.		Oct.	2	19:26:02 MST	37.4°	104.1°	Northeast of Trinidad, Colorado. Area = 15,000+ sq. mi.	VI	4.5 (3)
26.		Oct.	5	23:29:53 MST	35.8°	104.2°	West of Mosquero and northwest of Tucumcari, New Mexico		3.1 (2) 3.8 (1)
27.	1968	Apr.	21	00:08:07 MST	37.8°	102.1°	Southeast of Lamar, Colorado		3.8 (3)
28.	1969	Jun.	8	04:36:02 MST	34.3°	105.2°	Southeast of Duran and south of Vaughn, New Mexico		2.6 (2) 2.8 (1)
29.	1970	Jan.	12	04:21:15 MST	36.1°	103.2°	Near Amistad, north of Nara Visa, New Mexico. Area = 3,700 sq. mi.	VI	3.5 (3) 3.9 (2) 4.2 (1)
30.	1971	Feb.	18	04:28:14 MST	36.3°	105.7°	Southwest of Taos, near Picuris, New Mexico		3.3 (1) 3.7 (3)
31.		Apr.	28	04:36:53 MST	35.8°	105.6°	Near Cowles, northwest of Las Vegas, New Mexico		2.9 (1) 4.0 (3)

*Origin time is given to nearest second; see text for tenths of a second.

**The numbers in parentheses after the magnitudes indicate the following:

(1) Local magnitude based on SNM records: seismograph station at Socorro, N.M.

(2) Local magnitude based on ALQ records; seismograph station at Albuquerque, N.M.

(3) Body wave magnitude assigned by ERL, NOAA; can be higher than local magnitude.

Originally we had planned to make longitude 105° W. the western limit of the area to be considered in this paper; later we extended the area to longitude 106° W. Four earthquakes were inadvertently omitted: a slight shock at Santa Fe on August 2, 1873, a slight shock at Cimarron on June 14, 1878, a feeble shock at Las Vegas on February 12, 1931, and a shock of intensity V at Cimarron on August 3, 1952. These four shocks are not included in either Figure 1 or Table 1.

Table 2. Comparison of intensities and magnitudes.

RICHTER MAGNITUDE	MODIFIED MERCALLI INTENSITY SCALE OF 1931 (Abridged)
2	I. Not felt except by a very few under especially favorable circumstances. (I Rossi-Forel Scale.)
	II. Felt only by a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing. (I to III Rossi-Forel Scale.)
3	III. Felt quite noticeably indoors, especially on upper floors of buildings, but many people do not recognize it as an earthquake. Standing motorcars may rock slightly. Vibration like passing truck. Duration estimated. (III Rossi-Forel Scale.)
	IV. During the day felt indoors by many, outdoors by few. At night some awakened. Dishes, windows, and doors disturbed; walls make creaking sound. Sensation like heavy truck striking building. Standing motorcars rocked noticeably. (IV to V Rossi-Forel Scale.)
4	V. Felt by nearly everyone; many awakened. Some dishes, windows, etc., broken; a few instances of cracked plaster; unstable objects overturned. Disturbance of trees, poles, and other tall objects sometimes noticed. Pendulum clocks may stop. (V to VI Rossi-Forel Scale.)
	VI. Felt by all; many frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster or damaged
5	chimneys. Damage slight. (VI to VII Rossi-Forel Scale.)
	VII. Everybody runs outdoors. Damage negligible in buildings of good design and construction; slight to moderate in well built
6	ordinary structures; considerable in poorly built or badly designed structures. Some chimneys broken. Noticed by persons driving motorcars. (VIII Rossi-Forel Scale.)
	VIII. Damage slight in specially designed structures; considerable in ordinary substantial buildings, with partial collapse; great in poorly built structures. Panel walls thrown out of frame structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Persons driving motorcars disturbed. (VIII+ to IX Rossi-Forel Scale.)
	IX. Damage considerable in specially designed structures; well designed frame structures thrown out of plumb; great in
7	substantial buildings, with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken. (IX+ Rossi-Forel Scale.)
	X. Some well built wooden structures destroyed; most masonry and frame structures destroyed with foundations; ground badly cracked. Rails bent. Landslides considerable from river banks and steep slopes. Shifted sand and mud. Water splashed (slopped) over banks. (X Rossi-Forel Scale.)
8	XI. Few, if any (masonry), structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipelines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly.
	XII. Damage total. Waves seen on ground surfaces. Lines of sight and level distorted. Objects thrown upward into the air.

Table 3. Areas of perceptibility (square miles).

Northeastern New Mexico	Southeastern Colorado	Texas Panhandle
1,300 (9)		
3,700 (29)		
5,000+ (3)		
5,300 (16)		
7,500 (21)		
	15,000+ (25)	40,000+ (10)
		40,000+ (7)
		50,000 (8)
		60,000 (19)
		200,000+ (4)

northeastern New Mexico ones. Shocks 3 and 4 had the same intensity (V-VI) but drastically different areas of perceptibility (5,000+ vs. 200,000+ square miles). Shocks 25 and 19 had nearly the same magnitude (4.5 and 4.8) but drastically different areas of perceptibility (15,000+ vs. 60,000 square miles). In general, shocks of a given strength are felt over much greater areas when located east of New Mexico than when located in New Mexico or southeastern Colorado.

Information about the earthquakes is given below, in chronological sequence.

1. 1907, April : 18:00 (about) CST. Amarillo, Texas. Lat. 35.2° N., long. 101.8° W. Intensity V.

Although the approximate hour is known, the day of the month is not. The only record of this shock is Udden's (1926, p. 32) note that the PANHANDLE DAILY NEWS, Amarillo, Texas, July 31, 1925 reported that "Mrs. C. R. Warren, 1101 Lincoln Street, declared a tremblor [sic] hit Amarillo about 6 o'clock one Saturday afternoon in April, 1907, breaking a window in her home. People living along Madison Street said it shook their dishes."

2. 1917, March 27(?): 13:56 CST. Near Panhandle (City), Texas. Lat. 35.3° N., long. 101.2° W. Intensity VI.

Curiously, there is some uncertainty as to the date of this shock; March 24, 27, and 28 have all been reported. Sellards (1939, p. 704) and Udden (1926, p. 13, 32) give March 24. Pratt (1926, p. 147) gives March 27 at 13:57; Eppley (1965, p. 33, 42) also gives March 27, but at 13:56. Heck (1938, p. 37, 47) and Eppley (1958, p. 32, 40) give March 28 at 13:56. Most press accounts had given the date as March 24 (and the hour as about 13:30), and it is difficult to understand how the 27th and 28th got into the literature. The following newspaper excerpts are from Udden (1926, p. 32).

"NEWS, Amarillo, Texas, July 31, 1925.—An earthquake shock [was] felt throughout the Panhandle on March 24, 1917. . . . . The shock felt at the time was felt about 1:30 o'clock in the afternoon. Cement on walls of many buildings was cracked, and the school building was severely shaken. However, it suffered no damage. The children became excited, and school was dismissed at once. People who were riding in cars at that time declared they could hardly remain in their seats due to the intensity of the shock.

"DAILY NEWS, Amarillo, July 31, 1925.—A quake was reported as

felt in the Panhandle, March 24, 1917, but did little damage. Plastering on walls of several buildings in Panhandle were cracked.

"HERALD, Panhandle, Texas, July 30, 1925.—The quake recalls a similar shakeup that was distinctly felt in Panhandle (City) and through the northern portion of Carson County and the southern portion of Hutchinson County at 1:30 P.M. on the 24th day of March, 1917. At that time particles of the ceiling plaster of the Panhandle Bank building were shaken loose and fell to the floor."

3. 1924, August 12: 21:23 MST. Between Wagon Mound and Roy, New Mexico. Lat. 36.0° N., long. 104.5° W. Intensity V-VI. The shock was strongest at Valmora, Abbott, and Roy. Felt over an area of more than 5,000 square miles.

Press reports and information from the U.S. Weather Bureau are summarized by Neumann (1927, p. 69-70). Because this seems to be northeastern New Mexico's first recorded important earthquake, information from ten towns is given in some detail. Intensity assignments were given on the Rossi-Forel scale.

Abbott (N.E. of epicenter).—Intensity V. Felt by many; ground trembled, east-west direction; rumbling sound heard.

Colmor (N.W. of epicenter).—III. Felt by many sitting on 1st floor; several alarmed; abrupt bumping; one very short shock; direction southwest to northeast.

Levy (N.W. of epicenter).—III. People awakened by rattling of windows and dishes; underground noises.

Mills (N.E. of epicenter).—III. Windows broken.

Nolan (N.W. of epicenter).—III. Same as reported at Levy.

Raton (62 miles N. of epicenter).—II. Felt by a few persons.

Roy (S.E. of epicenter).—V. Somewhat more distinct. Windows and buildings shaken; underground rumbling heard. Several alarmed.

Springer (N. of epicenter).—III. Sudden sharp shock; zigzag quick motion, about 1 second. Felt by several.

Valmora Sanitarium (S.W. of epicenter).—VI. Very severe. Some damage.

Wagon Mound (W. of epicenter).—III. Felt by several.

It is curious that this shock was not reported at Las Vegas. The area over which it was felt was a little more than 5,000 square miles; theoretically, it might have been as great as 10,000 to 12,000 square miles.

4. 1925, July 30: 06:17 CST. Northeast of Amarillo, Texas; in the vicinity of Cuyler, Plemons, Borger, and Panhandle. Lat. 35.4° N., long 101.3° W. Intensity V-VI. Felt over an area of more than 200,000 square miles. See Figures 2 and 3.

More has been published on this earthquake than on any other in the region. Udden (1926) gave a detailed account of 32 pages and a map (see Fig. 2); Pratt (1926) discussed the geologic setting and presented another map (see Fig. 3).

In an abstract, Neumann (1926b) described an isoseismal map which apparently was never published. This map showed two distinct areas of intensity IV, separated by an approximately equal area of intensity II. Furthermore, the epicenter did not lie within the intensity VI zone, but on the intensity IV curve next to the quiet zone.

The shock was felt throughout the Texas Panhandle and in parts of four adjoining states: New Mexico, Colorado, Kansas, and Oklahoma. As a result of his campaign to gather information, Udden (1926, p. 5) received more than 300 clippings. "A perusal of the material shows that there were at hand some 500 separate items from which in most cases inferences could be made on the intensity or nature of the disturbance in seventy-five localities. Of these thirty-five were in Texas, nineteen in Oklahoma, nine in New Mexico, nine in Kansas, two in Colorado, and one in Missouri."

It was felt as far away as Leavenworth, Kansas, and Kansas City, Missouri. If the felt area had been circular, with a diameter extending from Roswell, New Mexico to Kansas City, Missouri (679 miles), the area might have been 360,000 square miles.

Udden (1926, p. 8) concluded that the intensity was VI on both the Rossi-Forel and Mercalli scales. "The greatest intensity appears to be reported from Amarillo, Canyon, Claude, Miami, Pampa, Clarendon, Panhandle, and White Deer. These localities lie in a belt running from southwest to northeast, their geographical center being not far from midway between Groom and Panhandle City" (Udden, 1926, p. 9). Pratt (1926, p. 146) fixed the epicenter as "in the vicinity of the towns of Cuyler, Panhandle, and Plemons." In two towns practically all persons asleep were awakened. Many people were startled; some became frightened and excited. A number of individuals fled from their homes. Many buildings swayed; houses shook and trembled; furniture was displaced; windows and dishes rattled.

The quake was reported from ten localities in New Mexico, including Raton (200 miles northwest of the epicenter), Roswell (225 miles southwest), and a locality 15 miles southeast of Mountainair (280 miles west-southwest). Neumann (1926a, p. 9-10) assigned higher intensities than Udden (1926) for several of the New Mexico localities. In the following summary, Neumann's intensities are designated (N), and Udden's (U).

Clayton.—II (N). Felt by one in bed; rapid gentle tremor N-S, 5 seconds.

Clovis.—IV (U), V (N). Two distinct shocks in 30 seconds. Buildings badly shaken; dishes jarred from shelves.

Dillon (2 miles south of Raton).—II (U), V (N). A railroad cistern under construction was badly damaged.

Melrose.—III (U). An adobe house was shaken.

Mosquero.—III (U). Several people awakened.

Mountainair.—II (U). It is difficult to believe that fissures in the earth reported 15 miles southeast of Mountainair were caused by this quake. The JOURNAL, Clovis, New Mexico reported that fissures 2 feet wide traversing a distance of more than half a mile were discovered three days after the quake. An exploring party found that fissures were "arranged in zigzag formation, like a chain of lightning, and run in an east-west direction. The openings start with a crack of only a few inches, and in a distance of fifty feet widen out to between two and three feet. Each fissure branches off from another, but at an angle. Some of the openings were so deep that the bottom could not be seen. Members of the exploring party dropped lighted matches in them, but after falling a short distance the matches disappeared on one side or the other of the main fissure. . . . ."

Raton.—II (U), III (N). Two slight shocks were felt.

Roswell.—II-III (U), IV (N). "Several people were awakened by tremors shaking beds." Windows shaken and dishes rattled.

Texico.—IV (U).

Tucumcari.—III (U), IV (N). Rattled windows and shook dishes. The clock in the Rock Island offices was stopped, but only a few persons felt the shock.

In his discussion of the geologic setting, Pratt (1926, p. 147-148) observed that "the region in which these earthquakes occurred would not generally be suspected of crustal instability," but "oil-well records have established, however, the presence of a former range of granite mountains [Amarillo Mountains] now completely submerged and covered over by the Permian Red Beds, so that the highest peaks are buried about 2,500 feet beneath the present surface. The axis of this buried mountain range trends west-northwest through a point about fifteen miles north of Panhandle. . . . . Along the southern margin of this buried granite ridge in the vicinity of the town of Panhandle, that is, near the epicenter of the recent earthquake, the relief of the former mountain surface is extreme. Differences of 1,500 to 2,000 feet in elevation of the old surface are proven over horizontal distances of only a few miles [See Fig. 3]. . . . . The suggestion is that the south margin of these Pre-Cambrian rocks is marked by a fault plane, with profound Pre-Cambrian displacement, and that the earthquakes in this region have been caused by a renewed, sudden movement along this old line of weakness."

It is worthwhile, we think, to append one more paragraph from Pratt (1926, p. 148). "A number of statements have been made by local people that the earthquake affected the behavior of the wells in the Panhandle oil field. Some wells are said to have been sheared off, others ceased to flow, and still others increased their flow. There is also a general impression that the earthquake may have been caused by the oil field operations. No evidence supporting either of these contentions was established. Probably the earthquake had but little effect on the oil wells, and certainly there is no reason to suspect that the removal of oil contributed to the forces which caused the earthquake."

This disclaimer of Pratt's is of considerable historical interest in light of recent study and discussion of the swarm of quakes that started in 1962 near Denver, Colorado. See Major and Simon (1968) for a study of the Derby–Commerce City swarm of 1,500 quakes during 1962-67. Some workers speculated that the disposal of wastes from the Rocky Mountain Arsenal either caused or triggered this swarm.

Shurbet's (1969, fig. 1) map shows another earthquake in 1925 near Childress, Texas. We have not been able to find details of this quake.

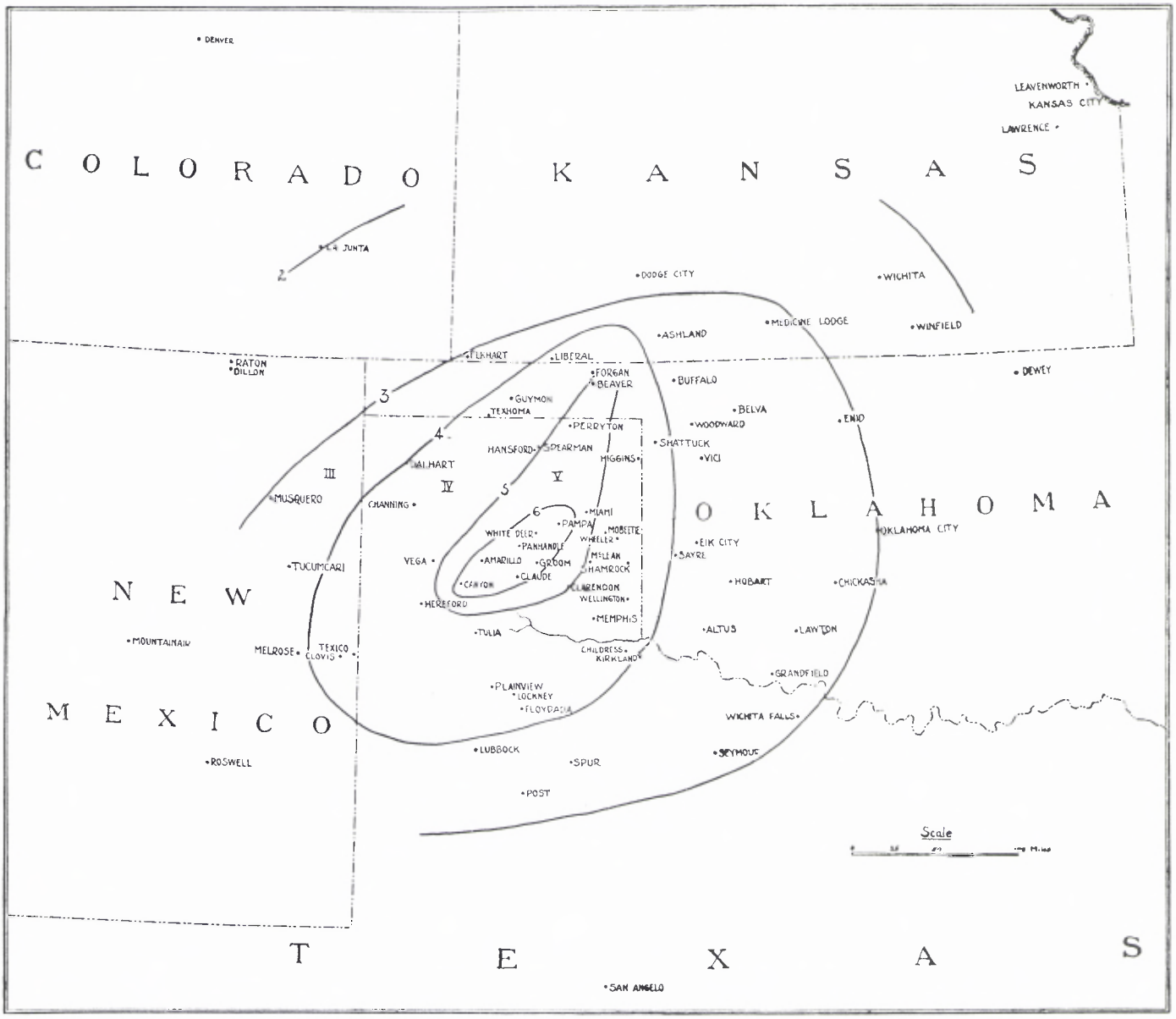

Figure 2. Map showing places where the Amarillo, Texas earthquake of July 30, 1925 was felt and reported and also the approximate location of isoseismals (Udden, 1926).

5. 1930, October 3: 20:25 MST. Duran, New Mexico. Lat. 34.5° N., long. 105.4° W. Intensity IV. A moderate shock felt by many. Rolling motion, rumbling sound, rattled windows. No damage (U. S. E., 1930, p. 7).

6. 1935, December 19: 22:30 MST. Clovis, New Mexico. Lat. 34.4° N., long. 103.2° W. Two shocks. Intensity III-IV. A tile wall in a creamery was cracked. Another report of wallpaper being split (AP news item).

7. 1936, June 19: 21:24:06 CST. Borger, Texas. Lat. 35.8° N., long. 101.3° W. Intensity V+. Felt over an area of 40,000 square miles, possibly as much as 50,000 square miles.

According to Sellards (1939, p. 699), there were three shocks, at 21:13:37, 21:18:27, and 21:24:06 (CST). The third shock was apparently the strongest; it was felt most widely over the Texas Panhandle, the Oklahoma Panhandle, the southeastern corner of Colorado, and the southwestern corner of Kansas. Although no reports were received from New Mexico, it may have been felt by a few persons along the New Mexico-Texas line. See Figure 4, which is Sellard's map; this same map is reproduced in U. S. E. 1936 (fig. 4, p. 10), along with another map (fig. 3, p. 9).

8. 1948, March 11: 22:29:00 CST. Near Dalhart, Texas. Lat. 36.0° N., long. 102.5° W. Intensity VI. Felt over an area of 50,000 square miles in five states: Texas, New Mexico, Colorado, Kansas, and Oklahoma. See Figures 5 and 6.

The time was originally given as 21:31 MST, later corrected to 21:29:00 MST or 22:29:00 CST. It was thought at first that the epicenter was in northeastern New Mexico. As State Collaborator in Seismology for the Seismological Field Survey (U.S. Coast and Geodetic Survey), Northrop started a questionnaire-card survey. As reports began coming in, the net of coverage had to be expanded several successive times. The shock was reported felt at 82 localities and not felt at 79 other localities. The Seismological Field Survey had some difficulty in locating the epicenter; note that no epicenter is shown in Figure 5. Later, it was picked near Dalhart, Texas (see Fig. 6).

The shock was felt over at least 18,000 square miles in Texas and over at least 13,000 square miles in northeastern New Mexico. Details are given in U. S. E. 1948 (p. 8-9) and at greater length in MSA-57 (p.

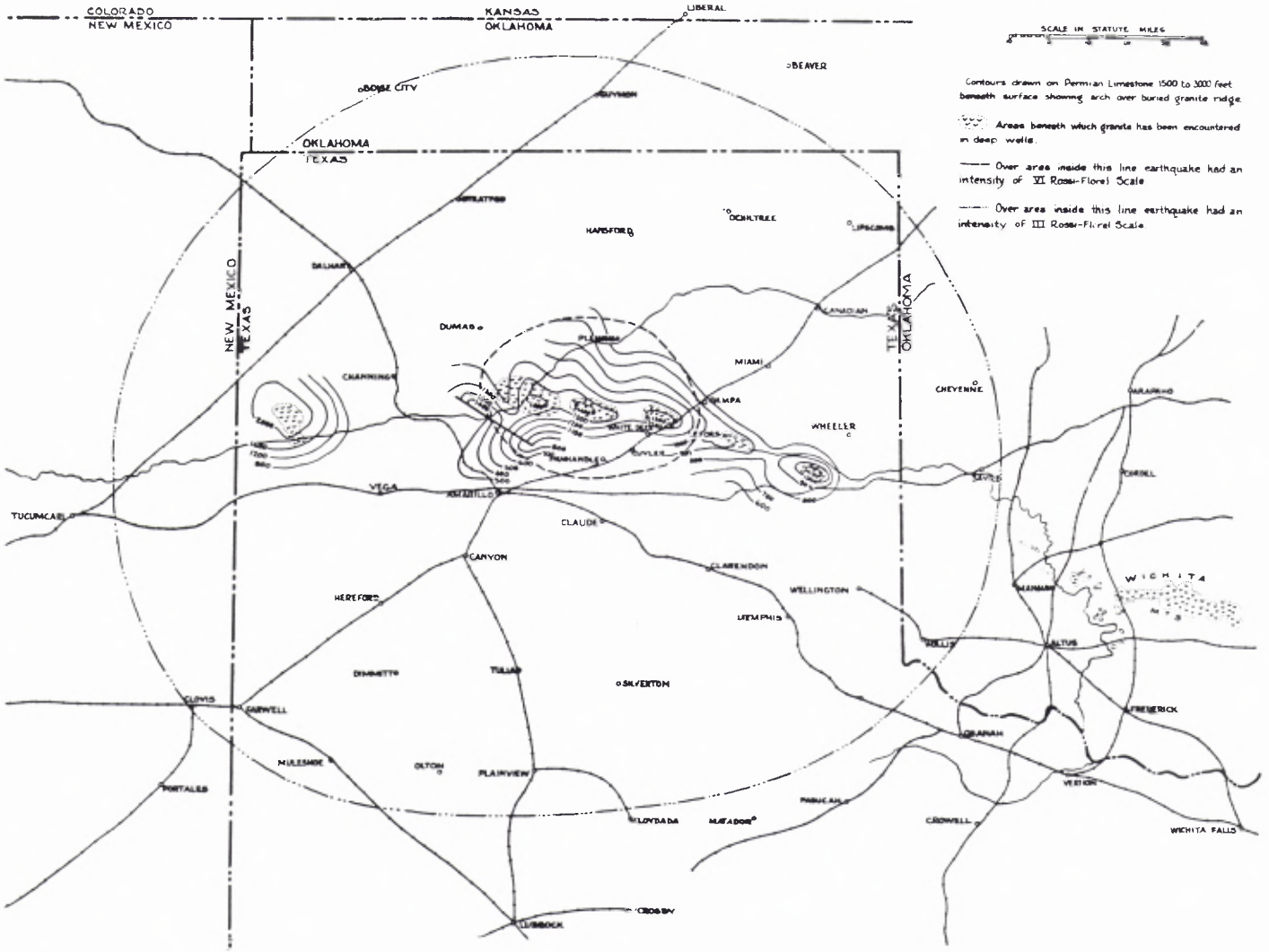

Figure 3. Pratt's (1926) map of the Amarillo, Texas earthquake of July 30, 1925.

30-40). Damage was minor, consisting chiefly of cracked plaster; some adobe walls were cracked. Intensity VI was reported in Texas at Amarillo, Channing, Dalhart, Electric City, Panhandle, Perico, and Perryton. In New Mexico, VI was reported at Bell Ranch, Bueyeros, Gladstone, Ione, Logan, Mount Dora, and Seneca. In Colorado, VI was reported at Kim and Trinchera; in Oklahoma, VI was reported at Boise City, Felt, Kenton, and Regnier. Intensity V was reported at 8 places in Texas, 10 in New Mexico, 5 in Colorado, and 2 in Kansas.

In a press release, Northrop stated: "The same general region has experienced quakes in 1907, 1917, 1925, and 1936, or approximately one every eight to twelve years. The March 11 quake covered a greater area (50,000 square miles) than the 1936 quake, which covered only 40,000 square miles, but did not approach the 1925 quake which was felt over an area of 200,000 square miles.

"Beneath the level High Plains surface of the Texas Panhandle is a buried mountain range, the Amarillo Mountains, trending east-west just north of Amarillo. This ancient mountain range has steeply dipping flanks on which younger sediments were deposited. It is thought likely . . . that these younger sediments are undergoing compaction, thus setting up strains which are relieved by slight slips from time to time. Enough energy is released at the time of these adjustments to cause the earth tremors.

"Inhabitants of the region may take comfort in the fact that seismologists believe that these shocks of slight to moderate intensity act as a sort of safety valve, thus preventing long-time accumulation of strains which in other parts of the world sometimes result in disastrous shocks with much loss of life and property."

The above was written in 1948. Richter (1958, p. 367-368) doubts that "small earthquakes may operate as a 'safety valve' to release harmlessly the energy which might otherwise express itself in a large earthquake. . . . . The energy relations suggest that major strains are released only in major earthquakes. . . . . "

9. 1949, May 23: 00:22 MST. Vaughn and East Vaughn, New Mexico. Lat. 34.6° N., long. 105.2° W. Intensity VI. Felt over an area of only about 1,300 square miles.

U. S. E. 1949 (p. 7): "Results of a questionnaire coverage indicated the felt area to be a 20-mile strip connecting Pastura with Vaughn and East Vaughn. Maximum intensity VI at the last-named place where a few things fell from shelves, loose objects rattled, and buildings creaked. Deep rumbling and grinding sounds were heard before and during shock." Pastura is about 20 miles northeast of Vaughn.

Many people were awakened and many were frightened. One person felt the shock while driving a car 20 miles southeast of Vaughn on the highway to Roswell (MSA-62, p. 73-74).

10. 1951, June 20: 13:37:10 CST. Probably in Texas near Nara Visa, New Mexico. Lat. 35.5° N., long. 103.0° W. Intensity VI. Apparently felt over an area of more than 40,000 square miles.

This quake was felt from Boise City, Oklahoma to Lubbock, Texas, a distance of 220 miles. Note the westward projection of the Amarillo Mountains shown in Figure 3.

"Felt from Lubbock to Borger, Vega, and Groom. Dishes, walls, and loose objects rattled throughout the area, switchboards were jammed with calls. Houses shook in the western part of Amarillo, in Canyon, and in Groom. At Borger, residents reported a noise 'like snow falling

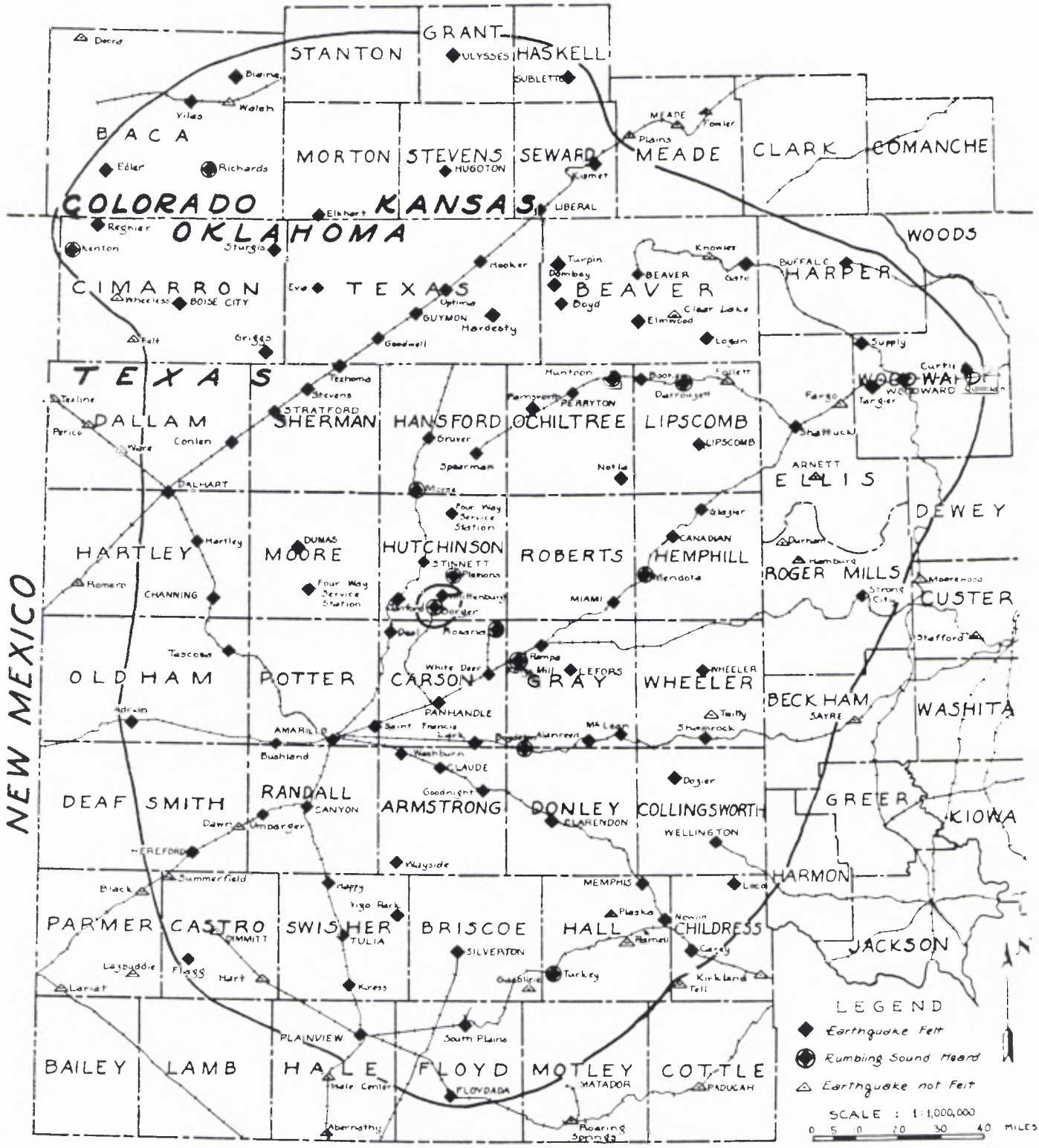

Figure 4. Area over which the Borger, Texas earthquake of June 19, 1936 was felt (Sellards, 1939).

off the roof.' Small furniture was moved in a house 2 miles west of Plainview. In Plainview and Bovina windows rattled; in Amarillo dishes rattled, houses creaked, and some plaster cracked; in Hereford, a piece of plaster fell in a furniture store. The tremors were reported as very slight in Boise City, Oklahoma" (U. S. E. 1951, p. 8).

The quake must have been felt at numerous localities in northeastern New Mexico, although apparently no reports were received from this State.

11. 1962, January 3: 16:29:54 MST. Near Tucumcari, New Mexico. Lat. 35.2° N., long. 103.8° W. Local magnitude 3.0 (SNM). Instrumental location by Sanford (1965, p. 7). The intensity may have been about III.

12. 1963, June 6: 01:05:33 MST. About 15 miles south of Raton, New Mexico. Lat. 36.7° N, long. 104.4° W. Local

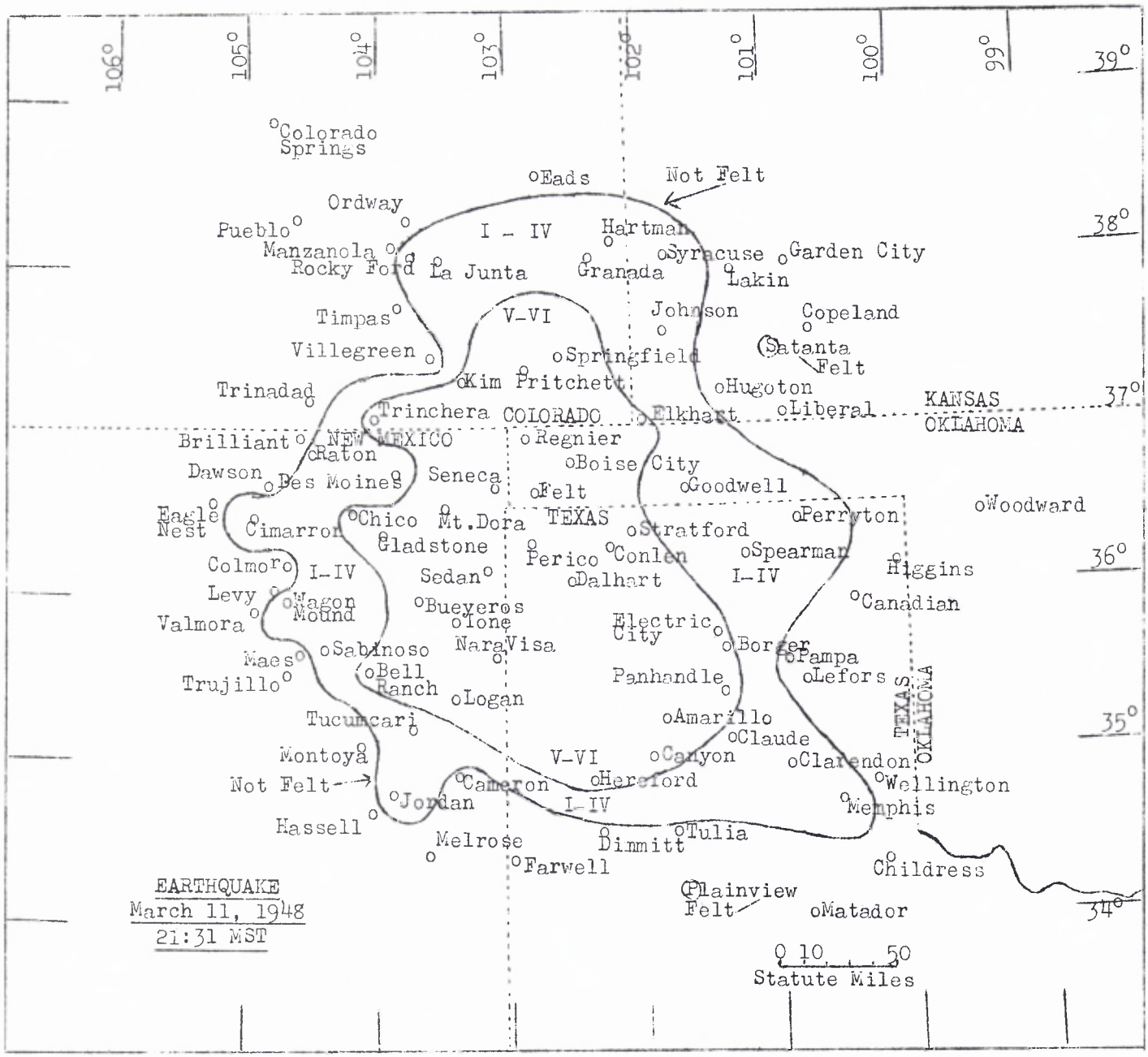

Figure 5. Isoseismal map of the Dalhart, Texas earthquake of March 11, 1948 (MSA-57, p. 40).

magnitude 3.7 (SNM). Instrumental location by Sanford (1965, p. 7). The intensity was probably at least IV.

13. 1963, December 19: 09:47:29.6 MST. Between Santa Rosa and Tucumcari, New Mexico. Lat. 35.1° N., long. 104.3° W. Local magnitude more than 3.6 (ALQ). Instrumental location by Sanford (1965, p. 7). The intensity may have been IV.

14. 1964, February 11: 02:24:38.4 MST. Near Bell Ranch and Conchas Lake, northwest of Tucumcari, New Mexico. Lat. 35.5° N., long. 104.2° W. Local magnitude 2.4 (SNM). Instrumental location by Sanford (1965, p. 6). Intensity may have been only II to III. This is the weakest shock included in this study.

15. 1964, March 2, 18:26:29.6 MST. Between Conchas Lake and Tucumcari, New Mexico. Lat. 35.3° N., long. 104.0° W. Local magnitude 2.6 (SNM). Instrumental location by Sanford (1965, p. 6). Intensity was probably II to III.

16. 1965, February 3, 04:32:35 or 04:33:10.5 MST. Near Logan, northeast of Tucumcari, New Mexico. Lat. 35.4° N., long. 103.4° W. Intensity IV. Felt over an area of about 5,300 square miles.

Sanford and Cash (1969, p. 6, no. 1) give time as 04:32:35 and local magnitude 3.6 (ALQ), 4.2 (SNM). The time was given as 04:33:10.5 by U. S. E. 1965 (p. 13). "Press reported the shock was felt at Logan, Nara Visa, and in the Gallegos area (about 30 miles north of Tucumcari). At the Bell Ranch (about 30 miles northwest of Tucumcari), windows and doors rattled; frame creaked. Motion slow, two shakes; each lasted about 1 second. At Logan, awakened and frightened few; windows rattled." See also MSA-125 (p. 19-20).

17. 1965, December 28: 17:50:24 MST. Northeast of Estancia, New Mexico. Lat. 34.9° N., long. 105.8° W. (an error of 0.3 degree in the latitude was originally reported). Sanford and Cash (1969, p. 6, no. 6) give local magnitude as 2.6 (ALQ), 3.1 (SNM). The intensity may have been III.

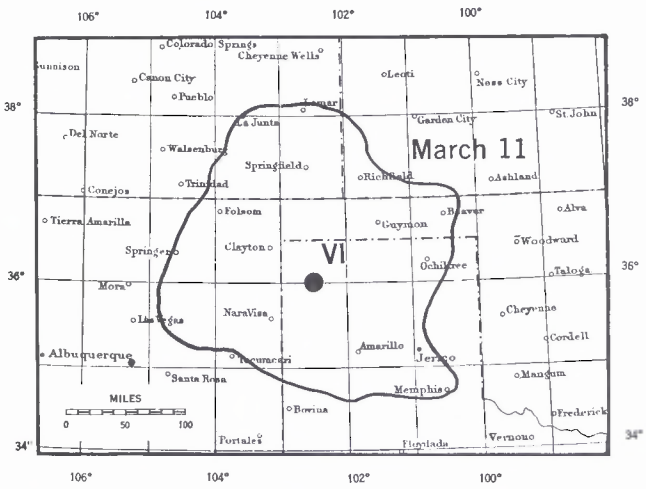

Figure 6. Area affected by the Dalhart, Texas earthquake of March 11, 1948, showing epicenter (U.S.E. 1948, p. 8).

18. 1966, April 21: 08:14:12 CST. Probably in Texas, a few miles east of the New Mexico–Texas line, northeast of Tucumcari and east of Logan, New Mexico. Lat. 35.4° N., long. 103.0° W. See Figure 3 for the westward projection of the buried Amarillo Mountains. Sanford and Cash (1969, p. 6, no. 7) give local magnitude as 3.4 (ALQ), 3.8 (SNM). Intensity probably IV.

19. 1966, July 20: 03:04:58.2 CST. North of Lake Meredith, Texas. Lat. 35.7° N., long. 101.2° W. Body wave magnitude 4.8 (ERL, NOAA). Intensity V. Felt over an area of about 60,000 square miles.

Intensity V at Amarillo and Borger; IV at Floydada, Fritch, Pampa, Sanford, and Sunray; I-III at a locality 15 miles east of Borger; also at Dimmitt, Dumas, and Hereford. According to U. S. E. 1966 (p. 13-14), "At Amarillo, an observer in the courthouse reported a chair moved 4 to 5 inches. Chairs also moved in the FAA Control Tower at the Municipal Airport. Observers thought a truck had hit the tower. Patients at the Amarillo Air Force Base Hospital were awakened. The Weather Bureau Station reported a barometer dial jumped at the time of the shock. Other observers noted that buildings creaked, windows rattled, and a rumbling noise accompanied the shock. Abrupt onset; swaying motion. At Borger, about 50 miles northeast of Amarillo, the earthquake was felt by nearly all. The press reported books fell from a shelf in one home, and that a loud rumble was heard. Others reported that buildings creaked and windows rattled. Abrupt onset; jarring motion. Duration, 3-4 seconds." The shock should have been felt in marginal parts of Oklahoma and Kansas.

Shurbet (1969, p. 39-40) notes that this earthquake "was located about 20 miles north of Lake Meredith by the U.S.C.G.S. network, however, standard errors in such a location make it logical to associate the earthquake with Lake Meredith and the newly completed Sanford Dam. The dam was closed and water storage began on 28 January 1965 and Lake Meredith was about one-half filled by 15 July 1967. The dam itself contains about 15 million cubic yards of earth and it is reasonable to assume that the seismic activity described above is a result of the increased crustal load in the area. It is common knowledge that the damming of rivers to form lakes does alter crustal loading sufficiently to cause earthquakes. For example the filling of Lake Mead was accompanied by the occurrence of numerous earthquakes."

20. 1966, September 17: 14:30:15 MST. Southwest of Tucumcari and southeast of Montoya, New Mexico. Lat. 35.0° N., long. 103.9° W. Sanford and Cash (1969, p. 6, no. 10) give local magnitude as 3.6 (SNM). Intensity may have been IV.

21. 1966, September 24: 00:33:46.4 MST. Near Cimarron, New Mexico. Lat. 36.5° N., long. 105.0° W. MSA-131 (p. 84) gives body wave magnitude as 4.1; Sanford and Cash (1969, p. 6, no. 11) give body wave magnitude as 3.8 (CGS). Felt over an area of about 7,500 square miles.

This was the first and main shock of a series of four shocks in two days. The intensity was IV-V.

A questionnaire-card survey was made by Northrop (MSA-131, p. 84). The shock was felt at Cimarron, Miami, Penasco, Red River, Shady Brook (east of Taos), Taos, Ute Park, and Valle Escondido, New Mexico; also at Weston and Trinidad, Colorado. At Weston, Colorado, about 45 miles north of Cimarron, it was felt by several and rattled windows doors, and dishes. Loose objects were thrown from a mantle at Valle Escondido, New Mexico.

22. 1966, September 24: 01:27:10 MST. Near Cimarron, New Mexico. Lat. about 36.5° N., long. 105.0° W. (epicenter determined from incomplete or less reliable data). Sanford and Cash (1969, p. 6, no. 12) give body wave magnitude as 3.4 (CGS) and local magnitude as 3.6 (SNM). Intensity was probably IV. This shock was not listed either by either MSA-131 or U. S. E. 1966.

23. 1966, September 25: 03:10:41 MST. Near Cimarron, New Mexico. Lat. about 36.4° N., long. 105.1° W. Sanford and Cash (1969, p. 6, no. 13) give body wave magnitude as 3.8 (CGS). Intensity may have been IV. According to MSA-131 (p. 84) and U. S. E. 1966 (p. 27), this shock occurred on September 24; Sanford and Cash (1969) give the date as September 25.

24. 1966, September 25: 05:22:40.5 MST. Near Cimarron, New Mexico. Lat. 36.5° N., long. 105.1° W. Sanford and Cash (1969, p. 6, no. 14) give body wave magnitude as 3.6 (CGS) and local magnitude as 3.7 (SNM). The intensity was probably about IV. MSA-131 (p. 84) and U. S. E. 1966 (p. 27) give the date of this shock as September 24; Sanford and Cash give the 25th.

25. 1966, October 2: 19:26:01.9 MST. Northeast of Trinidad, Colorado. Lat. 37.4° N., long. 104.1° W. Body wave magnitude 4.5 (CGS). Intensity VI. Felt over an area of more than 15,000 square miles of southeastern Colorado and northeastern New Mexico. See Figure 7.

This shock was felt by all and frightened many in Trinidad. Slight damage occurred at several localities in Colorado. It was felt as far south as Roy, New Mexico. Intensity VI at Aguilar, Segundo, Trinchera, and Trinidad, Colorado. Intensity V at Boncarbo, Branson, Hoehne, Model, Sopris, Starkville, Villegreen, and Walsenburg, Colorado. Intensity IV at many places in Colorado. Intensity I-III in New

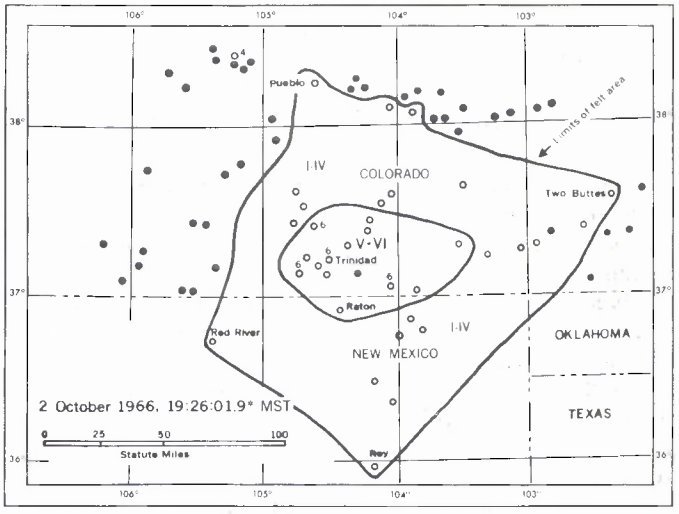

Figure 7. The Trinidad, Colorado earthquake of October 2, 1966 (MSA-132, p. 30).

Mexico at Capulin, Chico, Des Moines, Farley, Folsom, Point of Rocks, Raton, Red River, and Roy. See MSA-132 (p. 18-22, and map, p. 30) and U. S. E. 1966 (p. 27, and fig. 12, p. 28).

The felt area is curiously shaped; apparently the "negative control" (places where no shock was reported) was poor to the southwest, south, and southeast of the epicenter. It is possible that the felt area was somewhat larger than 15,000 square miles; it may have been as much as 20,000 square miles. However, Hadsell's (1968, p. 62) estimate of 60,000 square miles seems excessive.

26. 1966, October 5: 23:29:53 MST. West of Mosquero and northwest of Tucumcari, New Mexico. Lat. 35.8° N., long. 104.2° W. Sanford and Cash (1969, p. 6, no. 16) give local magnitude as 3.1 (ALQ), 3.8 (SNM). Intensity was probably III to IV.

27. 1968, April 21: 00:08:07 MST. Southeast of Lamar, Colorado, near the Colorado-Kansas line. Lat. 37.8° N., long. 102.1° W. Body wave magnitude 3.8 (ERL,NOAA). Reference: PDE list. Intensity was probably at least IV.

28. 1969, June 8: 04:36:02.3 MST. Southeast of Duran and south of Vaughn, New Mexico. Lat. 34.3° N., long. 105.2° W. Toppozada and Sanford (1972, in press) give local magnitude as 2.6 (ALQ), 2.8 (SNM). The intensity may have been about III.

29. 1970, January 12: 04:21:15.4 MST. Near Amistad, north of Nara Visa, New Mexico. Lat. 36.1° N., long. 103.2° W. Body wave magnitude 3.5 (ERL, NOAA); local magnitude 3.9 (ALQ), 4.2 (SNM). Intensity VI. Felt over an area of about 3,700 square miles.

Intensity VI at Amistad, where some damage was reported; awakened all; loud earth noises. Intensity V at Clapham, Nara Visa (where plaster fell), Pasamonte, Sedan; IV at Bueyeros, Clayton, Gladstone, Hayden; I-III at Gladstone, a locality 8 miles east of Roy, and another locality 38 miles east of Roy; all localities in New Mexico. Intensity I-III at Texline, Texas. See MSA-145 (p. 6); Cloud (1970); Toppozada and Sanford (1972, in press). This shock must have been felt at several localities in Texas.

30. 1971, February 18: 04:28:14.1 MST. Southwest of Taos, near Picuris, New Mexico. Lat. 36.3° N., long. 105.7° W. Local magnitude 3.3 (SNM); body wave magnitude 3.7 (ERL, NOAA); Toppozada and Sanford (1972, in press). Intensity may have been IV. The epicenter of this shock was apparently in the Rio Grande rift zone.

31. 1971, April 28: 04:36:52.7 MST. Near Cowles, northwest of Las Vegas, New Mexico. Lat. 35.8° N., long. 105.6° W. Local magnitude 2.9 (SNM); body wave magnitude 4.0 (ERL, NOAA); Toppozada and Sanford (1972, in press). Intensity was probably III-IV.

EARTHQUAKES WITH EPICENTERS LOCATED OUTSIDE THE AREA

Brief mention is here made of a few earthquakes whose epicenters were located outside the area bounded by latitude 34°-38° N. and longitude 100°-106° W. but which were felt within the area.

Three of the 1906 Socorro, New Mexico, swarm of earthquakes were of intensity VIII and were felt over much of New Mexico. The July 12 shock had a radius of perceptibility of 160 miles and may have been felt over an area of 80,000 square miles. The July 16 shock was felt at Raton, New Mexico, 235 miles northeast of Socorro, and at Douglas, Arizona, 250 miles to the southwest of Socorro; it was felt over an area of 180,000 to 200,000 square miles, including adjoining parts of Arizona, Colorado, Texas, and Mexico. Another shock on November 15 was felt at Las Vegas and Raton. See Sanford and others (1972, p. 2), Northrop (1942, 1945, 1947, 1961), and Reid (1911).

On May 28, 1918 an earthquake at Cerrillos, southwest of Santa Fe, New Mexico, was of intensity VIII and was felt in parts of northeastern New Mexico.

The earthquake of August 16, 1931 near Valentine, Texas, was felt over an area of 450,000 square miles—about 200,000 square miles in Mexico and 250,000 square miles in Texas and New Mexico. See Figure 8. The intensity was VIII-IX Rossi-Forel or VIII Mercalli. The quake has been referred to in the literature as West Texas, Valentine, and Mount Livermore. Valentine was the locality of maximum destruction. Details are given in U. S. E. 1931 (p. 10-13) and by Sellards (1933); digests are given by Heck (1938, p. 57), Eppley (1958, p. 50), and Eppley (1965, p. 58). Byerly (1934) made an instrumental study.

"Adobe buildings suffered most, although cement and brick walls were in some cases badly cracked. . . . All but frame buildings were badly damaged and all brick chimneys toppled over or were badly damaged. . . . The population was more or less panic stricken, but there were no fatalities and only a few were slightly injured by falling adobe. This is accounted for by the fact that nearly everyone was sleeping outdoors." (U. S. E. 1931). It must have been a hot August night! Damage was reported from several places in Brewster, Jeff Davis, Culberson, and Presidio Counties, Texas. In New Mexico, walls were cracked at Artesia and Carlsbad, and several chimneys were damaged at Carlsbad. "The earthquake was accompanied by subterranean sounds described as rumbling and roaring and at some places terrifying. They were heard over practically the entire affected area."

The map (Fig. 8) shows that a considerable part of southeastern New Mexico and West Texas reported intensities V and IV. The III-II zone was extensive across New Mexico and the Texas Panhandle.

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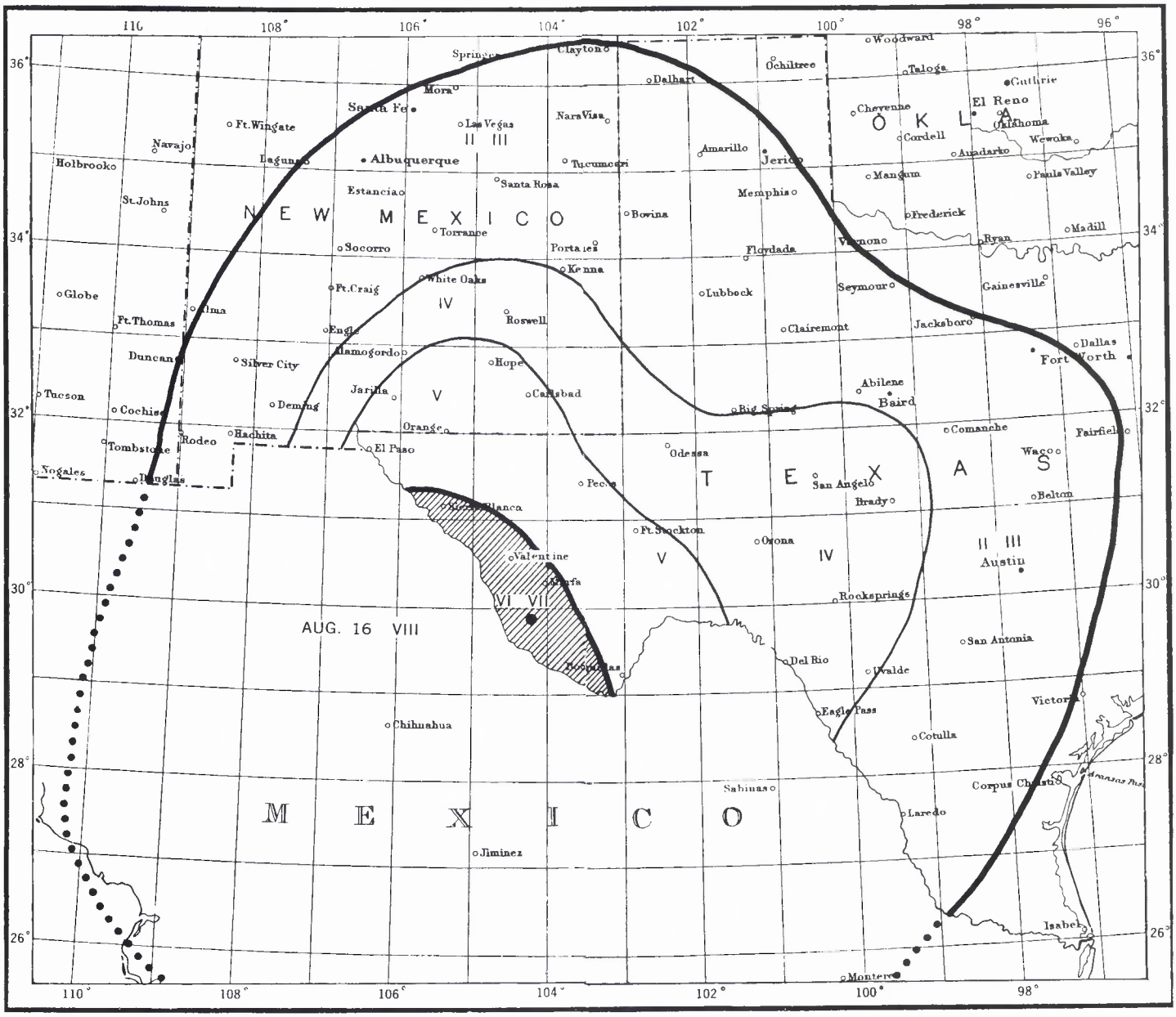

Figure 8. Area affected by the Valentine, Texas earthquake of August 16, 1931 (U.S.E. 1931, p. 12-13).

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