ONWI/SUB/84/E512-05000-T33

Historical Seismicity of the Texas Panhandle From an Examination of Lubbock Station Records

Topical Report

December 1984

by

H. Acharya

Stone & Webster Engineering Corporation
245 Summer Street
Boston, MA 02107

This report was prepared by Stone & Webster Engineering Corporation under Contract E512-05000 with Battelle Memorial Institute, Project Management Division, under Contract DE-AC02-83-CH10140 with the Department of Energy. The Contract was administered by the Battelle Project Management Division.

ABSTRACT

Seismicity data concerning the Texas Panhandle area have been compiled from two general sources: instrumental data and felt reports. Felt reports date back to 1907 in this area. However, instrumental coverage has been poor and the station at Lubbock is the only seismic monitoring station within 100 miles of the Palo Duro Basin. Due to the lack of any adequate instrumental seismic monitoring of the area, it is conceded that many earthquakes in this area may have gone undetected or unreported.

Film chips from Lubbock Station for the period 1963-1980 were examined to identify all earthquakes that had occurred in the Texas Panhandle. Film chips of known events were also used to aid investigators in identifying characteristics of signals from earthquakes occurring in the Panhandle. This examination identified 40 earthquakes that occurred within approximately 360 km of Lubbock during 1963-1980. These 40 earthquakes were not recorded by many stations and were, therefore, not located earlier. First motion amplitude and direction on all three components were measured for these earthquakes. Earthquakes which occurred north of Lubbock were identified on the basis of azimuth computation and were then approximately located using the time interval between the arrival of P and S phases. The study shows that the area north of Lubbock Station, including the Texas Panhandle, is an area of low seismicity.

The examination of records of Lubbock Seismographic Station suggests two to three earthquakes per year within about 360 km of Lubbock. An examination of seismicity of the salt areas of Texas, Louisiana, Oklahoma, and Kansas by Racine and Klouda (1980) suggested a rate of one earthquake a day. The rate of activity in the vicinity of Lubbock Station is clearly much lower than in the salt areas of Texas, Louisiana, Oklahoma, and Kansas.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1 INTRODUCTION

Seismograms of the Lubbock Station, covering the period 1963-1980, have been examined in order to determine the level of seismicity in the Texas Panhandle on the basis of instrumental data. It is hoped that the results of this study will provide a framework for the interpretation of available pre-1963 historical information as well as data to be obtained from the operation of the Department of Energy's microearthquake network in the Palo Duro Basin area.

Earliest reports of earthquakes in the Texas Panhandle date back to 1907, when an earthquake was reported near Amarillo. Since that time approximately 21 earthquakes have been reported to have occurred in the Texas Panhandle, either on the basis of felt reports or instrumental records. Fifteen additional earthquakes are reported to have occurred in neighboring parts of the states of Oklahoma and New Mexico. Historical reports of felt earthquakes, therefore, indicate a very low rate of earthquake activity in the Texas Panhandle. Table 1 lists earthquakes which are reported to have occurred in the Panhandle and vicinity (SWEC, 1983). Magnitude specified in Table 1 is body wave magnitude m_b unless otherwise indicated. Figure 1 shows the seismicity of the Texas Panhandle and vicinity.

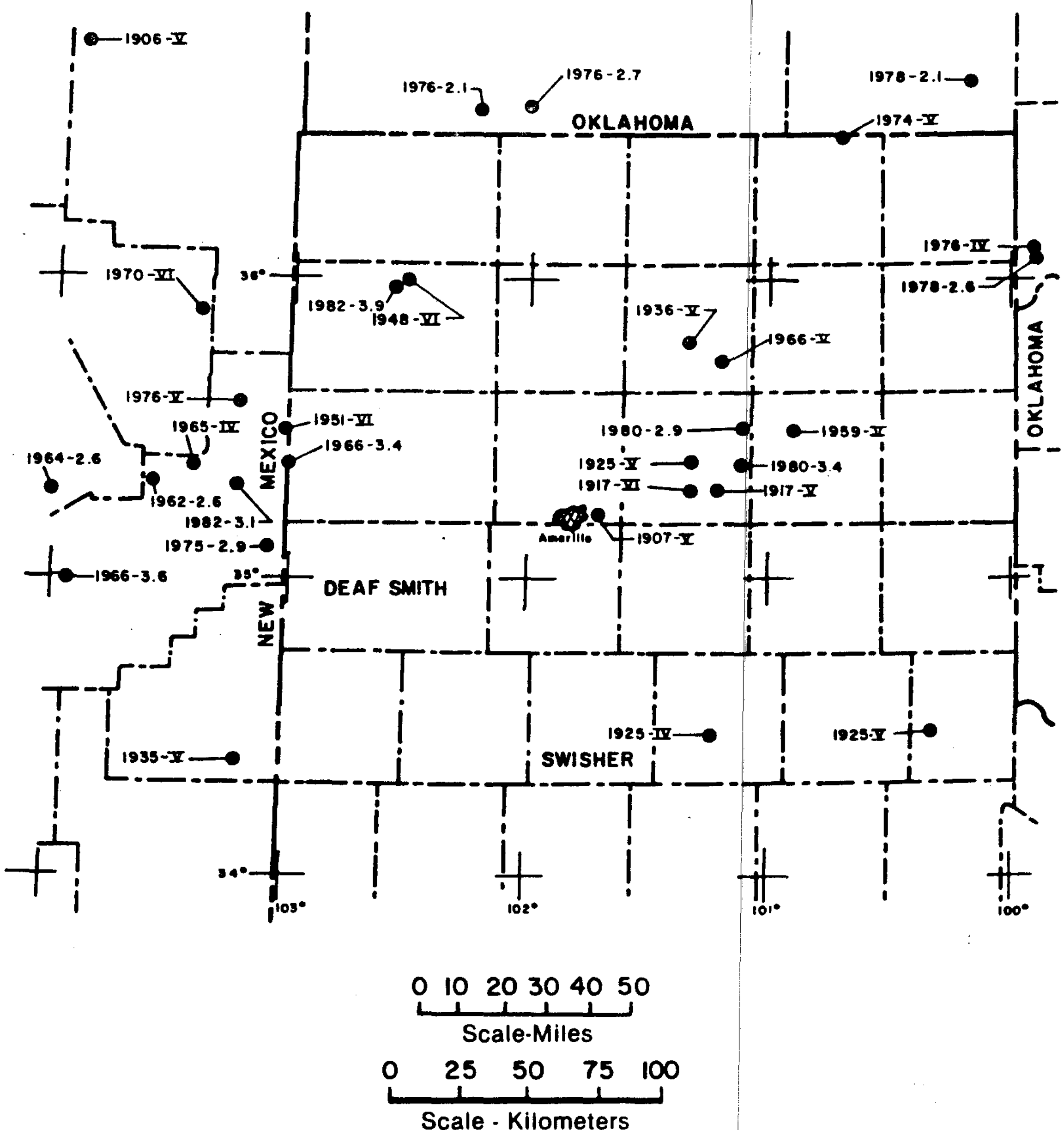
Table 1. Earthquake Catalog for the Texas Panhandle and Vicinity, 1900-1982

Date	Time (GMT)	Lat.	Long.	Inten. (Modified Mercalli)	Mag.	Location	Felt Area (sq km)	Ref.
4.20.06	AM	36.8	103.9	V	-	Folsom, NM		3
4.21.06	AM	36.8	103.9	V	-	Folsom, NM		3
4. .07		35.2	101.8	V	3.0	TX, North		6
3.24.17	1930	35.3	101.2	V	4.2	TX, North		7
3.27.17	1956	35.3	101.3	VI	3.8	TX, North	5,000	7
3.28.17	2338	35.3	101.3		3.0	TX, North		10
7.29.25	1130	34.5	101.2	IV	3.8	TX		7
7.30.25	0800	34.5	100.3	V	4.2	TX		7
7.30.25	1217	35.4	101.3	V	4.8	TX, North	500,000	7, 10
7.30.25	1222	35.4	101.3	IV	-			10
7.30.25	1227	35.4	101.3	IV	-			10
12.20.35	0530	34.4	103.2	V	-	Clovis, NM		14
6.20.36	0318	35.8	101.3	III	3.0	Borger, TX		10
6.20.36	0324	35.8	101.3	V	4.7	Borger, TX	110,000	10
3.12.48	0459	36.0	102.5	VI	4.8	Dalhart, TX	300,000	6
6.20.51	193710	35.5	103.0	VI	-	TX, North	103,600	2
2.10.59	2005	35.5	100.9	V	4.5	TX, North	120,000	7
1.03.62	232952	35.32	103.64		2.6	Tucumcari, NM		14
3.02.64	0126	35.3	104.0		2.6	Tucumcari, NM		6

B4-1369708-30J

Table 1. (Continued)

Date	Time (GMT)	Lat.	Long.	Inten. (Modified Mercalli)	Mag.	Location	Felt Area (sq km)	Ref.
2.03.65	113235	35.4	103.4	IV	2.9	Logan, NM	13,700	14
4.21.66	1414	35.4	103.0		3.4	Logan, NM		6
7.20.66	090458	35.7	101.2	V	3.9	TX, North	60,000	10
9.17.66	2130	35.0	103.9		3.6	Tucumacari, NM		7
1.12.70	112115	35.89	103.4	VI	3.5	Amistad, NM	9,600	14
2.15.74	133349	36.5	100.69	V	4.5	OK-TX Border		10
2.02.75	203922	35.10	103.10		2.9	NM		14
3.30.76	065316	36.68	102.25	V	2.1 MBLG			13
3.30.76	092701	36.61	102.08	V	2.7 MBLG			13
4.19.76	044242.2	36.13	99.88	IV	3.5	OK, West		13
6.24.76	152732	35.62	103.28	V	3.5	NM, Eastern		14
8.03.78	003537.1	36.69	100.16		2.1 MBLG	Beaver Co., OK		5
8.06.78	042856.8	36.07	99.94		2.6	Ellis Co., OK		5
2.21.80	204200.9	35.281	101.076	Felt	2.9 MBLG	Carson, Co., TX		12
6.09.80	223709.9	35.513	101.082	IV	3.4 MBLG	Carson Co., TX		12
3.16.82	110302.4	35.335	103.25	III	3.1 MBLG	Logan, NM		15
10.14.82	125245.4	35.999	102.596		3.9 MBLG	Dalhart, TX		16



Explanation:

- Seismic Event

  (Refer to Table 1)

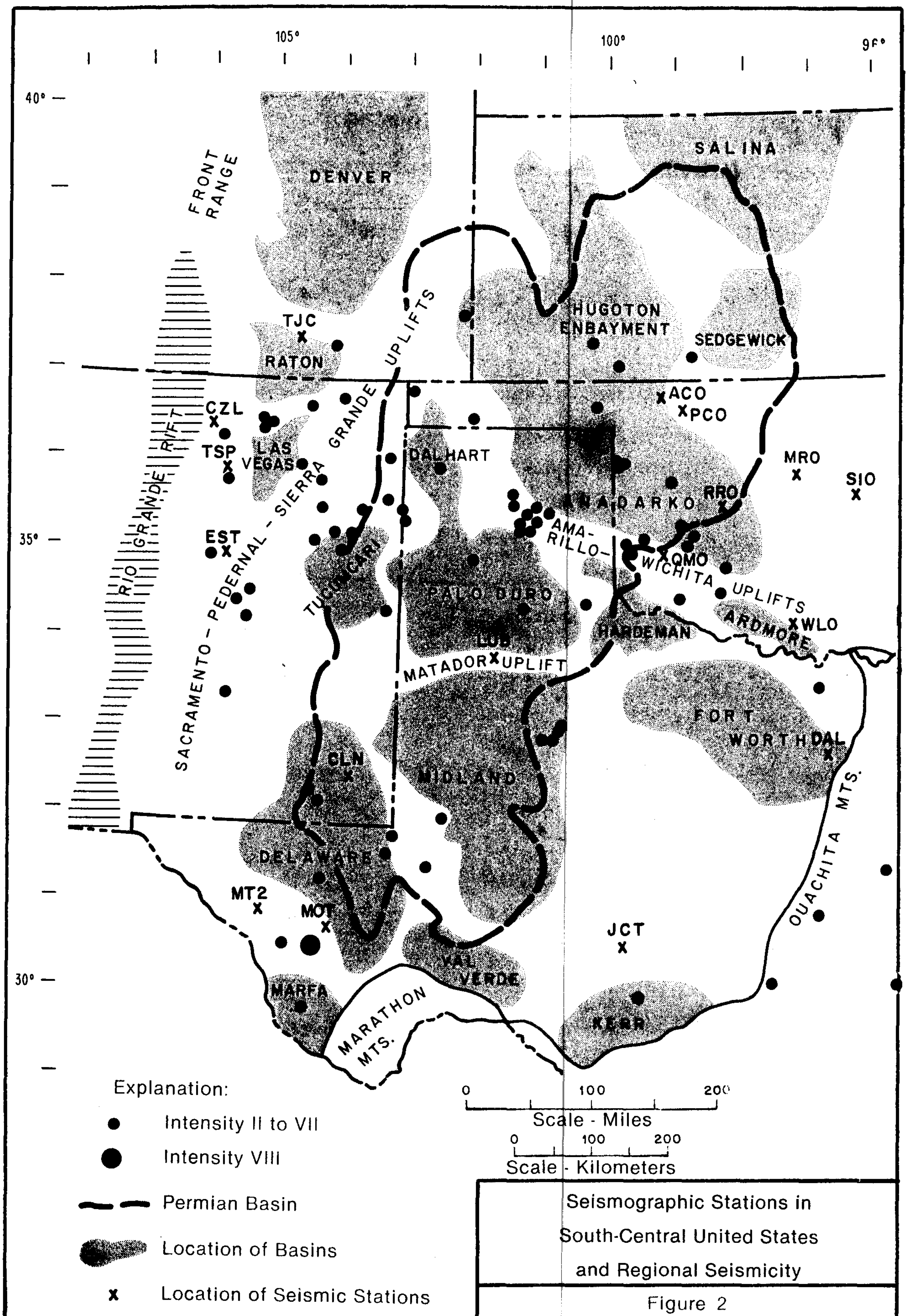
Historical Earthquakes in
the Texas Panhandle Area
Intensity ≥ III(MM)

Figure 1

2 SEISMIC MONITORING OF THE TEXAS PANHANDLE AREA

Although instrumental recording became widespread around 1962, only seven earthquakes in the Panhandle have been located on the basis of instrumental data during the last two decades. Earthquakes recorded ranged in magnitude from 2.1 to 4.7. It is possible that the small number of events recorded in this period within this magnitude range results from poor instrumental coverage of the area. Figure 2 shows the poor coverage by seismographic stations operating in the vicinity of the Texas Panhandle. There is no station in the Panhandle itself (north of 34°). The station at Lubbock is the only station within 100 miles of the Palo Duro Basin. Characteristics of stations operating in the area around the Texas Panhandle are tabulated in Table 2.

It is, therefore, possible that because of the poor coverage of the area, earthquake catalogs are extremely incomplete even at present. Pennington and Davis (1984) note that a magnitude 3.4 event in 1983 would not have been detected by conventional procedures had there been no specific interest in modern day seismicity related to the possible siting of a high level nuclear waste repository. Since this interest did not exist until recently, it is probable that many earthquakes of a magnitude up to approximately 3.5 have gone unrecognized, and it is possible that some larger events have also been missed (Pennington and Davis, 1983). Racine and Klouda (1980) examined the seismicity of salt areas of Texas, Oklahoma, Kansas, and Louisiana utilizing records of the Long Range Seismic Monitoring Station, Wichita Mountain Seismological Observatory (WMSO), which operated in Lawton, Oklahoma from 1961 to 1968. During this period, they examined records obtained only on Sundays in order to avoid any possible confusion with quarry blasts. Based on this study, Racine and Klouda (1980) concluded that earthquakes occur in the salt basins of Texas, Oklahoma, Kansas, and Louisiana at the rate of one event a day. Racine and Klouda (1980) contrasted this with five events a year demonstrated by the catalogs for the area. Table 1 suggests about one event every three years in the Texas Panhandle and vicinity during 1961 to 1980. The rate observed by Racine and Klouda (1980) is clearly several times higher than the rate to be obtained from an examination of standard earthquake catalogs. This suggests that stations operating now may be recording a larger number of events than are (1) felt, or (2) recorded at a sufficient number of stations to determine their location. The seismographic station at Lubbock has been operating since 1963 as part of the World Wide Seismograph Station Network (WWSSN), and records from the Lubbock Station are available on film chips. These film chips were examined to identify earthquakes that may have occurred in the Panhandle during this period but were not reported in any of the catalogs.



Seismographic Stations in South-Central United States and Regional Seismicity

Figure 2

Table 2. Seismographic Stations Operating in and Around the Texas Panhandle

(30-36°N, 96-106°W)

Station	Code	Latitude (°N)	Longitude (°W)	Installation Date
Texas				
Lubbock	LUB	33.5833	101.8667	1948
Dallas	DAL	32.8461	96.7839	1953
McDonald Obs.	MOT	30.6797	104.0082	1975
Eagle Mt.	MT2	30.8992	105.0146	1977
Junction	JCT	30.4794	99.8022	1965
Oklahoma				
Wilson	WLO	34.0648	97.3695	1977
Albaster Cavern St. Pk	ACO	34.0648	97.3695	1977
Ponca City	PCO	36.6912	96.9782	1977
Quartz Mt. St. Pk.	QMO	34.8929	99.3071	1977
Meridian	MRO	35.8356	97.2265	1978
Slick	SIO	35.7463	96.3071	1978
Red Rock Canyon St. Pk.	RRO	35.4569	98.3584	1978

Table 2. (Continued)

Station	Code	Latitude (°N)	Longitude (°W)	Installation Date
Colorado				
Trinidad	TJC	37.2169	104.6912	1965
New Mexico				
Estancia	EST	34.8645	105.7228	1976
Cerro Azul	CZL	36.2833	105.9103	1976
Tesuque Peak	TSP	35.7853	105.7814	1973
Carlsbad	CLN	32.4027	103.7318	1974

3 CHARACTERISTICS OF LUBBOCK STATION

The seismographic station at Lubbock has been operating as part of the WWSSN since 1963. The equipment at the station includes short period (1-second) Benioff and long period (15-second) Sprengnether vertical and two horizontal (N-S and E-W) components. The timing at the station is WWSSN standard and recording is on photographic paper. The station operates at a gain of 25 K for short periods and 1.5 K for long-period components. The station foundation is caliche of Pleistocene Age. Records obtained are routinely sent to the World Data Center in Boulder for microfilming, storage, and distribution. These records are available for purchase from:

World Data Center A for Solid Earth Geophysics
Environmental Data Service
National Oceanic and Atmospheric Administration
Boulder, CO 809302

4 EXAMINATION PROCEDURE

Film chips of seismograms from the Lubbock Station covering the period 1963-1980 were purchased from the National Oceanic and Atmospheric Administration Data Center in Boulder, Colorado, and were examined. The identification of earthquakes which may have occurred in the Texas Panhandle was carried out on the basis of (1) time interval between the arrival of longitudinal wave (P wave) and transverse wave (S wave), and (2) examination of the direction of first motion. Examination of film chips began by reviewing records of earthquakes which occurred in the Texas Panhandle and vicinity in 1974 and 1980 (Table 1) in order to ascertain the characteristics (frequency, amplitude, and duration) of signal from these known earthquakes as recorded at Lubbock. Unfortunately, the equipment was malfunctioning at the time of the 1974 Earthquake (Magnitude 4.7), and, consequently, no record was obtained for that earthquake. Records for the two 1980 earthquakes were available for examination. Film chips from Lubbock were also examined for several earthquakes in Texas and Oklahoma, which were identified by Racine and Klouda (1980) as a result of their examination of the WMSO records. This review was carried out in order to familiarize the investigators with the characteristics of signals from local events so that other earthquakes that may have occurred in the Panhandle can be identified and examined.

In order to increase the usefulness of the analysis, and thereby minimize picking up a false event, the following criteria were used to identify local earthquakes as recorded at Lubbock:

(1) Impulsive first arrival - sharp P-wave group.

(2) S minus P arrival times less than 45 seconds. This time interval corresponds to an epicentral distance from Lubbock of approximately less than or equal to 360 km and will include all earthquakes occurring in the Texas Panhandle and surrounding parts of Oklahoma, New Mexico, and central Texas. (S minus P times for the 1980 earthquakes were approximately 22-30 seconds.)

(3) Event recorded by horizontal components also (to facilitate S-wave picks).

(4) No significant ground motion recorded by long-period instruments. (There was no significant ground motion on long-period seismograms for the 1980 earthquakes.)

(5) Total signal duration less than approximately 7 minutes. (The duration of the 1980 earthquakes was approximately 4 minutes.) Duration is measured from the first motion until the amplitude can no longer be distinguished from the background level. On the basis of magnitude-duration relationship published for Oklahoma (Lawson, 1978), a duration of five minutes corresponds to a magnitude of approximately 3.1. Since several earthquakes of this size are included in published catalogs (Table 1), it can be concluded that earthquakes with higher magnitude have already been detected and located.

A number of events satisfying these criteria were identified from Lubbock Station records during the period 1963-1980. The dates and times of these events were then checked with the International Seismological Center (ISC) Bulletins to eliminate any mistaken reading of other phases for S-phase. A few events were eliminated on that basis. The dates and times of the remaining 40 events are listed in Table 3.

In order to locate an earthquake on the basis of the records of a single station, it is necessary to determine the epicentral distance and azimuth. Epicentral distance can be computed from the difference in arrival times of S and P waves. Azimuth to the epicenter can be approximately determined from P wave first motion on all three component records (Byerly, 1942). The apparent angle of incidence α, as computed from the recorded horizontal amplitude u_1 and vertical amplitude u_3 by

$$\tan \alpha = \frac{u_3}{u_1},$$

does not give the direction of approach of the wave. However, the horizontal amplitude u_1 does lie in the great circle joining epicenter and station and its direction may be obtained by compounding as vectors the amplitudes of the first wave of P on E-W and N-S components (Byerly, 1942). Information on which way along the great circle the epicenter lies is obtained from the vertical component of the first motion. If it is up, the first wave is a compression and the horizontal motion is away from the

Table 3. Additional Local Earthquakes Detected by Lubbock Station During 1963 - 1980

Date	P-Time (GMT)	S-Time (GMT)	S-P (sec)	Duration
1.05.63	10:02:40	10:03:02	22	
6.06.63	08:06:40	08:07:25	45	3.5 min
9.02.63	10:45:08	10:45:30	22	
10.17.63	05:30:10	05:30:35	25	
11.30.63	02:39:30	02:39:45	15	
11.08.64	09:26:35	09:27:00	25	90 sec
2.03.65	11:33:13	11:33:40	27	2.25 min
8.30.65	05:18:04	05:18:28	24	
4.21.66	14:14:57	14:15:25	28	2 min
7.15.67	18:47:52	18:48:08	16	
2.28.68	05:05:15	05:05:30	15	1.5 min
3.20.68	22:12:15	22:12:45	30	
7.14.69	07:50:55	07:51:20	25	
1.12.70	11:22:03	11:22:35	32	
5.17.70	19:27:40	19:28:07	27	
8.05.70	05:34:30	05:34:47	17	
12.14.70	04:13:15	04:13:20	5	
12.19.70	23:45:40	23:46:12	32	
7.03.71	23:55:25	23:55:50	25	
7.30.71	01:46:25	01:46:50	25	
7.31.71	14:54:25	14:54:55	30	
10.21.71	11:40:40	11:40:42	2	

Table 3. (Continued)

Date	P-Time (GMT)	S-Time (GMT)	S-P (sec)	Duration
3.24.72	06:51:12	06:51:48	36	
9.04.72	04:43:45	04:44:12	27	
3.25.74	20:32:00	20:32:20	20	
9.01.74	13:54:35	13:54:53.5	18.5	
11.12.74	02:32:30	02:32:58	28	
11.12.74	07:15:03	07:15:25	22	
12.30.74	08:06:18	08:06:50	32	
5.16.75	07:27:30	07:28:08	38	
3.05.76	02:58:50	02:59:20	30	1.5 min
9.17.76	02:48:40	02:49:10	30	
10.25.76	00:27:35	00:28:05	30	
3.14.77	10:10:45	10:10:55	10	
6.07.77	23:01:41	23:01:55	14	2.25 min
6.17.77	03:37:25	03:37:50	25	1.5 min
7.22.77	04:02:02	04:02:08	6	
3.02.78	10:05:25	10:05:55	30	3.0 min
7.05.79	01:05:15	01:05:27	12	
9.13.79	00:50:07	00:50:37	30	

epicenter. Conversely, if the first vertical motion is down, the wave is a rarefaction, and the horizontal movement is toward the epicenter. The direction of the epicenter can be obtained in this manner.

In order to determine which of these 40 events occurred within the Texas Panhandle, the P-wave first motion was examined on all three components for all 40 events. It was difficult to determine the direction of first motion on many of the records and, in most cases, it was difficult to determine the amplitude of first motion, given the poor quality of the records. Table 4 lists the first motion direction and amplitude recorded for all 40 events. Earthquakes believed to have occurred in the Panhandle and vicinity based upon first motion data are identified in Table 5. The table includes estimated parameters of these earthquakes along with epicentral distance. Approximate locations of these earthquakes are shown on Figure 3.

Table 5 also lists magnitude of these earthquakes on the basis of the magnitude duration relationship,

$$M_c = 1.86 \text{ Log (DUR)} -1.49,$$

developed by Lawson (1978) for Oklahoma. M_c in this relationship is coda magnitude and DUR is signal duration in seconds.

Table 4. Direction and Amplitude of a P-Wave First Motion for Earthquakes Listed in Table 3

		P - First Motion					
		Vert		N - S		E - W	
Date	P - Time (GMT)	Dir	Amp (cm)	Dir	Amp (cm)	Dir	Amp (cm)
1.05.63	10:02:40	-	-	-	0.05	-	0.05
6.06.63	08:06:40	U	0.225	D	0.175	U	0.175
9.02.63	10:45:08	-	0.05	U	0.20	U	0.10
10.17.63	05:30:10	U	0.15	D	0.125	-	0.10
11.30.63	02:39:30	-	0.10	-	0.10	-	0.10
11.08.64	09:26:35	D	0.05	U?	0.025	U?	0.025
2.03.65	11:33:13	D	0.20	D	0.10	U	0.075
8.30.65	05:18:04	U	0.05	U	0.075	D	0.05
4.21.66	14:14:57	U	0.15	D	0.25	U	0.125
7.15.67	18:47:52	-	0.10	U	0.10	D	0.10
2.28.68	05:05:15	U	-	U	-	-	-
3.20.68	22:12:15	D?	0.20	U?	0.10	D?	0.10
7.14.69	07:50:55	-	0.10	D	0.05	-	0.05
1.12.70	11:22:03	D	0.275	U?	0.15	D	0.125
5.17.70	19:27:40	D	0.10	U	0.05	-	-
8.05.70	05:34:30	D	0.375	D	0.10	U	0.075
12.14.70	04:13:15	D	0.40	U	0.125	U	0.10
7.03.71	23:55:25	D	0.30	U	0.10	U	0.075
7.30.71	01:46:25	U	0.60	D	0.65	D	0.55
7.31.71	14:54:25	U	0.30	D	0.35	-	0.30
10.21.71	11:40:40	U	0.30	U	0.55	U	0.50
3.24.72	06:51:12	U	0.10	U?	0.075	U?	-
9.04.72	04:43:45	D	0.075	D	0.225	-	0.125
3.25.74	20:32:00	-	-	-	-	-	-
9.01.74	13:54:35	D	0.075	U	0.125	D	0.175
11.12.74	07:15:03	U	0.15	D	0.05	U	0.05
12.30.74	08:06:18	D	0.225	D?	0.10	D	0.225
5.16.75	07:27:30	D?	0.10	D	0.075	U	0.05

Table 4. (Continued)

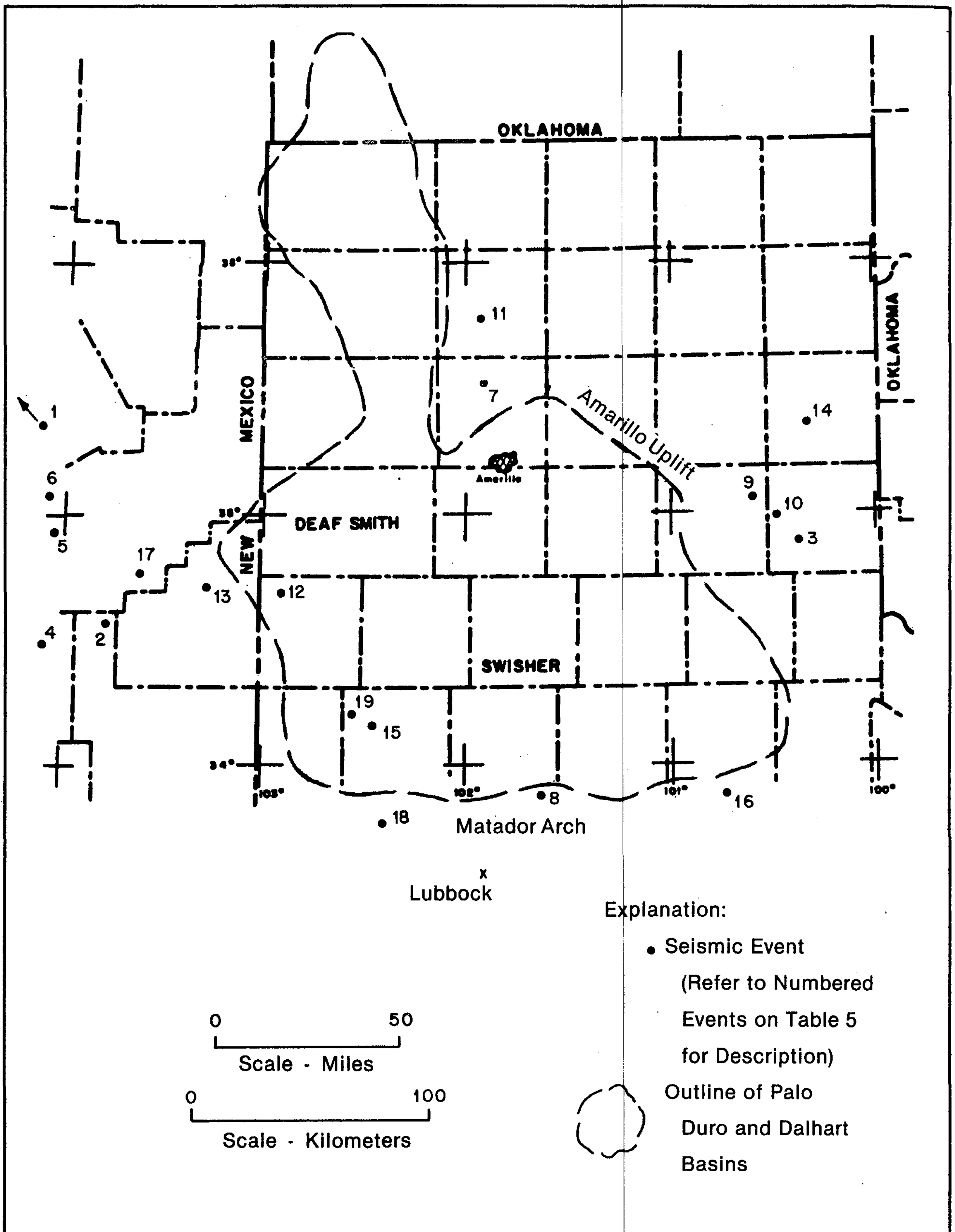
Date	P - Time (GMT)	P - First Motion: Vert Dir	Vert Amp (cm)	N - S Dir	N - S Amp (cm)	E - W Dir	E - W Amp (cm)
10.21.75	06:42:03	U	0.15	U?	0.15	D	0.20
3.05.76	02:58:50	U	0.175	U	0.15	D?	-
9.17.76	02:48:40	U	0.40	D	0.40	D	0.30
3.14.77	10:10:45	D	0.25	U	0.10	D	0.125
6.07.77	23:01:41	U	0.10	D	0.03	D	0.10
6.17.77	03:37:25	U	0.225	D	0.175	U	0.15
7.22.77	04:02:02	D?	0.175	U	0.25	D	0.10
3.02.78	10:05:25	U	0.30	U	0.40	D	0.15
7.05.79	00:05:15	U	0.25	D	0.125	D	0.175
9.13.79	00:50:07	U	0.35	U	0.40	U	0.425

Table 5. Earthquakes North of Lubbock During 1963-1980

No.	Date	P-Time	S-P (sec)	Distance	Duration	Magnitude	Azimuth
1.	06.06.63	08:06:40	45?	360 km	3.5 min	2.8	315°
2.	10.17.63	05:30:10	25	200 km	85.0 sec	2.1	303°
3.	11.08.64	09:26:35	25	200 km	90.0 sec	2.2	45°
4.	04.21.66	14:14:57	28	224 km	2.0 min	2.9	296°
5.	03.20.68	22:12:15	30?	240 km	45.0 sec	1.6	308°
6.	01.12.70	11:22:03	32	256 km	4.75 min	3.1	310°
7.	05.17.70	19:27:40	27	216 km	2.25 min	2.5	0°
8.	12.14.70	04:13:15	5	40 km	3.5 min	2.8	39°
9.	07.03.71	23:55:25	25	200 km	5.25 min	3.2	37°
10.	07.30.71	01:46:25	25	200 km	7.25 min	3.4	40°
11.	07.31.71	14:54:25	30	240 km	4.5 min	3.0	0°
12.	09.01.74	13:54:35	18.5	148 km	3.5 min	2.8	324°
13.	11.12.74	07:15:03	22	176 km	1.5 min	2.1	315°
14.	09.17.76	02:48:40	30	240 km	2.5 min	2.55	37°

Table 5. (Continued)

No.	Date	P-Time	S-P (sec)	Distance	Duration	Magnitude	Azimuth
15.	03.14.77	10:10:45	10	80 km	1.5 min	2.1	321°
16.	06.07.77	23:01:41	14	112 km	3.5 min	2.8	75°
17.	06.17.77	03:37:25	25	200 km	1.5 min	2.1	310°
18.	07.22.77	04:02:02	6	48 km	2.0 min	2.9	292°
19.	07.05.79	00:05:15	12	96 km			317°



Historical Earthquakes Located on the Basis of Lubbock Data

Figure 3

5 RESULTS

Table 1 shows that 18 earthquakes are reported to have occurred in the Texas Panhandle and vicinity since 1963, within approximately 300 km of Lubbock. Table 3 shows that approximately 40 events, which satisfy the criteria discussed in Section 3, have been recorded by Lubbock Station since 1963. This suggests that the Lubbock Station records, on an average basis, two events per year occurring within approximately 360 km of the station. These events are not detected, however, at a sufficient number of stations so that they can be located. If all 40 recorded events occurred north of the station, then the number of events occurring in the area and recorded at Lubbock is about 58, almost three times the number of known events (Table 1). This rate is considerably less, however, than the rate of one event per day, estimated by Racine and Klouda (1980) for the salt areas of Texas, Oklahoma, Kansas, and Louisiana. This huge difference in estimated rates of activity can occur for the following reasons:

(1) Racine and Klouda (1980) examined a very large salt area as compared to the restricted area investigated in this study. Spatial variations in seismicity may account for this difference in estimated activity rates as shown by the following examples:

Racine and Klouda (1980) noted that the standard earthquake catalogs for the salt areas of the four states considered suggest the occurrence of 39 earthquakes in the area or a rate of about five earthquakes per year. Most of this activity is located in either central Oklahoma or the Texas-Louisiana border. The standard earthquake catalog shows only one earthquake in the Texas Panhandle. Therefore, standard earthquake catalogs suggest that the larger area is about 40 times as active as the Texas Panhandle.

An examination of the locations of earthquakes identified by Racine and Klouda (1980) shows that most of these earthquakes occurred in central Oklahoma and north-central Texas. Only about four earthquakes were located in the Texas Panhandle or an activity rate of about 1/16 per day. Of these, three were located near the Oklahoma border (one near the northern end and two near the eastern end of the Texas Panhandle). The activity rate for the larger area estimated by Racine and Klouda (1980) is about 16 times the activity rate for the Texas Panhandle.

(2) WMSO consisted of 13 seismometers operating as a double polygon array with outer and inner rings of six instruments and one instrument in the center. The observatory operated at a magnification of 500,000. The short period seismographs at Lubbock operated, however, at a magnification of 25,000. It would, therefore, appear that high magnification and array configuration at WMSO can result in recording of many more earthquakes at WMSO than at Lubbock. This may explain the difference between activity computed using WMSO records and Lubbock records.

The earthquake activity rate for the Texas Panhandle, estimated on the basis of the study of Lubbock seismograms, is not very different from the activity rate computed on the basis of the earthquake catalog in Table 1. In view of the demonstrated low rate of seismic activity for the Texas Panhandle in the Racine and Klouda (1980) study, there is no reason to believe that the rate of one earthquake per day they calculated for the larger area is valid for the Texas Panhandle.

Analysis of first motion pattern has identified 19 earthquakes that have occurred north of Lubbock. These earthquakes are shown on Figure 3 and are listed in Table 5. Approximately seven out of these 19 events occurred in New Mexico, at some distance from the Palo Duro Basin. Three earthquakes appear to have occurred in the Matador Uplift area. This result is somewhat surprising because there is no report of any activity associated with the Matador Uplift in any of the historical earthquake catalogs. Six of the events appear to be associated with the Amarillo Uplift, a feature with low to moderate seismicity. Three events (Nos. 12, 19, and 15 on Figure 3) appear to have occurred in the southwestern part of the Palo Duro Basin. Most of the activity appears to be located near structural features which bound the Palo Duro Basin. For seven or eight events, first motion data were insufficient for azimuth determination purposes.

The results of this study show that the area north of Lubbock (which includes the Texas Panhandle and parts of New Mexico and Oklahoma) is an area of low seismicity. The average rate of activity within approximately 360 km north of Lubbock is about two events per year in the magnitude range of 2.1 to 3.4.

6 SOURCES OF UNCERTAINTY

There are several sources of uncertainty in this type of investigation. The two most important sources are correct identification of S-phase, and measurement of first motion amplitude.

In a few instances, phases from moderate size earthquakes at teleseismic distances were incorrectly identified as S-phase. This error was discovered as a result of a comparison of events identified on the basis of S-P times with the earthquakes listed in the ISC Bulletins.

Errors in the proper identification of S-phase, or in the determination of arrival time of S-phase, can affect the computation of epicentral distance considerably.

Although earthquakes which occurred north of Lubbock can be identified on the basis of the direction of first motion, the computation of azimuth depends on the amplitude of first motion. Any error in the measurement of first motion amplitude on the two horizontal components will effect the computation of azimuth.

The two possible sources of uncertainty discussed above can lead to considerable error in the locations of the 19 earthquakes shown on Figure 3. Although all 19 earthquakes occurred north of Lubbock, slight error in the computation of azimuth and epicentral distance can change the location of the earthquakes and, therefore, their tectonic significance. For example, on Figure 3, epicentral distance will determine whether earthquakes occurred on the Matador Uplift or in the Palo Duro Basin. Similarly, earthquakes in New Mexico, west of the Palo Duro Basin, may actually have occurred in the basin itself. Conversely, the Palo Duro Basin may be totally free of all earthquake activity, and the three earthquakes in the southwest part of the Basin may have occurred in either New Mexico or on the Matador Uplift.

7 CONCLUSIONS AND RECOMMENDATIONS

During the period 1963-1980, the Lubbock Seismographic Station recorded about 40 earthquakes within an epicentral distance of approximately 360 km. These earthquakes ranged in the magnitude (M_c) from 2.0 to 3.5. These earthquakes were not recorded at a sufficient number of stations for location purposes. If all of these earthquakes occurred north of Lubbock, then these results suggest that the rate of activity in the Texas Panhandle is about three times what is reported in the earthquake catalogs.

Poor record quality precludes determination of first motion for all events. In several cases first motion can be determined on only one horizontal component. Ground motion amplitude can be measured on only a few records. It is, therefore, not possible to carry out a comprehensive analysis of this data to identify all events which occurred in the Texas Panhandle. For events where estimation was possible, preliminary examination suggests that approximately 19 of these occurred north of Lubbock Station. Some of these events may be associated with the Matador Uplift or the Amarillo Uplift. Three of these events occurred in the Palo Duro Basin. Since it is not possible to determine first motion for all events, the number of earthquakes that occurred in the Panhandle and were detected but not located cannot be precisely estimated. The rate of earthquake activity in the Texas Panhandle is, therefore, between one and three events per year at a magnitude greater than 2.0. Most of the 40 events identified did not occur within the Palo Duro Basin.

In order to refine the source parameters of the 40 events listed in Table 3, it is proposed to examine the records of a station operating in Trinidad, Colorado. This station is part of the WWSSN and uses the same recording equipment as Lubbock. The Trinidad Station, however, operates at a magnification of 100 K. Records of Trinidad Station will be examined for the days on which these 40 events were recorded. Based on estimated epicentral distance and azimuth, it will then be possible to determine the number of events which occurred in the area of interest.

8 REFERENCES

1. Byerly, P., 1942. Seismology, Prentice Hall, New York, NY.

2. Coffman, J.L., and C.A. Von Hake, 1973. Earthquake History of the United States, Publication 41-1, U.S. Dept. of Commerce, Washington, DC, 208 pp.

3. Docekal, J., 1970. Earthquakes of the Stable Interior, with Emphasis on the Mid-Continent, Vols. 1 and 2, Ph. D. Thesis, University of Nebraska, Lincoln, NE, p. 169, p. 332.

4. Lawson, J.E., Jr., 1978. A Preliminary Duration Magnitude Scale for Local and Regional Earthquakes Recorded at Oklahoma Seismograph Stations, Oklahoma Geophysical Observatory Open File Report, 14 pp.

5. Lawson, J.E., K.V. Luza, R.L. DuBois, and P.M. Foster, 1979. Earthquake Map of Oklahoma - Inventory, Detection, and Catalog of Oklahoma Earthquakes, Oklahoma Geological Survey Map GM-19, University of Oklahoma, Norman, OK.

6. Northrop, S.A., and A.R. Sanford, 1972. "Earthquakes of Northeastern New Mexico and the Texas Panhandle", Guidebook of East-Central New Mexico, (23rd Field Conference, New Mexico Geological Society), Kelley, V.C. and F.D. Trauger, eds., pp. 148-160.

7. Nuttli, O.W., 1979. "The Seismicity of the Central United States", Geology in the Siting of Nuclear Power Plants, (Geological Society of America, Review in Engineering Geology), Vol. 4, pp. 67-93.

8. Pennington, W.D., and S.D. Davis, 1984. Historic Seismicity in and Around the Texas Panhandle, Open File Report OF-WTWI-1984-14, Bureau of Economic Geology, University of Texas, Austin, TX, 7 pp.

9. Racine, D., and P. Klouda, 1980. Seismicity of the Salt Areas of Texas, Louisiana, Oklahoma, and Kansas, Teledyne Geotech Report 2, Contract No. 5200609, AL-79-3, prepared for Lawrence Livermore Laboratory, University of California, Livermore, CA, 27 pp.

10. Reagor, B.G., S.W. Stover, and S.T. Algermissen, 1982. Seismicity Map of the State of Texas, Miscellaneous Field Studies Map - 1388, U.S. Geological Survey, Denver, CO.

11. Stone & Webster Engineering Corporation, 1983. Area Geological Characterization Report for the Palo Duro and Dalhart Basins, Texas, DOE/CH/10140-1, prepared for the Office of Civilian Radioactive Waste Management, U.S. Department of Energy, Washington, DC.

12. Stover, C.W., and C.A. Von Hake, 1982. United States Earthquakes, 1980, published jointly by the U.S. Geological Survey and National Oceanic and Atmospheric Administration, Golden, CO.

13. Stover, C.W., B.G. Reagor, S.T. Algermissen, and J.E. Lawson, Jr., 1981. Seismicity Map of the State of Oklahoma, Miscellaneous Field Studies Map - 1352, U.S. Geological Survey, Denver, CO.

14. Stover, C.W., B.G. Reagor, and S.T. Algermissen, 1983. Seismicity Map of the State of New Mexico, Miscellaneous Field Studies Map - 1660, U.S. Geological Survey, Denver, CO.

15. U.S. Geological Survey, 1982. Preliminary Determination of Epicenters, Monthly Listing for March 1982, U.S. Government Printing Office, Washington, DC.

16. U.S. Geological Survey, 1983. Preliminary Determination of Epicenters, Monthly Listing for October 1982, U.S. Government Printing Office, Washington, DC.