SEISMICITY OF TEXAS PANHANDLE

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ABSTRACT

Seismicity of the Texas Panhandle has been examined to evaluate the earthquake hazard at a potential site for a high-level nuclear waste repository in the Palo Duro Basin. The Texas Panhandle is an area of low seismicity. The first earthquake report for the area dates back to 1907. Several earthquakes have been felt since then, although none of them have caused any damage. Most of the earthquakes occurred in the northern part of the Texas Panhandle and have been assigned locations of felt reports.

A sixteen-station seismographic network was installed in the Texas Panhandle so earthquakes occurring in the area could be accurately located. The network became fully operational in October 1984 and has recorded a few small earthquakes occurring in the northern part of the Panhandle. These earthquakes range in magnitude up to about 3.1, but were not felt.

The earthquakes appear to be associated with either the Amarillo Uplift or the Oldham Nose. The limited data do not permit fault plane solutions or associate the earthquakes with specific faults in these two structures. The Palo Duro Basin appears to be nearly aseismic. Although historical reports indicate association of earthquakes with Amarillo Uplift, the occurrence of microearthquakes in the Oldham Nose area was unknown until the microearthquake monitoring network was installed.

INTRODUCTION

The seismicity of the Texas Panhandle has been examined as part of an ongoing effort by U.S. Department of Energy to investigate potential sites for storage of high level radioactive waste. The Texas Panhandle is an area of low seismicity. Most seismicity information to date is from felt reports and is, therefore, subject to the uncertainties inherent in such data. A microearthquake monitoring network is now operating in the area in order to enlarge the data base and provide better understanding of the region's seismicity.

HISTORICAL SEISMICITY

The seismicity of the Texas Panhandle has been examined by Northrop and Sanford (1), Pennington and Davis (2), and Acharya (3). The seismicity of central United States including the Texas Panhandle and vicinity has been examined by Docekal (4), Coffman and von Hake (5), Nuttli (6), and Gordon (7) among others. Figure 1 shows the seismicity of the Texas Panhandle and vicinity based on felt reports and instrumental data from Acharya (3). Historical seismicity of the area has been described primarily using reports of earthquakes felt in the area. The Texas Panhandle was settled in the later part of the nineteenth century. The earliest report of an earthquake in this area dates back to 1907 when an earthquake was felt in Amarillo. Earthquakes in 1917, 1925, 1936, 1948, and 1966 were also felt in Amarillo. The instrumental coverage of the area was poor. There was no seismographic station operating in the Texas Panhandle until 1983. The coverage of earthquakes in the area was, therefore, dependent on regional seismographic stations operating outside the local area. Figure 2 shows the location of stations in the area operating continuously since their installation.

The station nearest the Palo Duro Basin is at Lubbock (LUB). This station began operation in 1948 and operated intermittently until 1963, when it was upgraded to become part of the World Wide Standardized Seismographic Network (WWSSN). Other stations in Texas, Oklahoma, New Mexico, and Colorado also provide some coverage for seismicity in the Texas Panhandle. Figure 2 shows very few stations operating in the south central United States before the Palo Duro Basin seismographic network was installed. The seismographic coverage of the Texas Panhandle was, therefore, poor. Nuttli (6) estimated that earthquakes occurring in this area with magnitude $<$ 3.5 mb were not detected and located because only regional stations were available in 1979.

The Texas Panhandle area appears to exhibit a low rate of seismicity, and only low intensities have been observed. Most earthquakes reported in the area are small, varying in intensity from III to VI (MM). There is no report of damage in the area from any historical earthquake.

Various investigators agree on the locations of most earthquakes shown on Fig. 1. There is, however, some disagreement about the locations of three events (3). For example, the earthquake in 1959, northeast of Amarillo, is assumed by Pennington and Davis (2) to be a sonic boom. A careful examination of the data (3) indicates that the evidence for a sonic boom is inconclusive. Newspaper accounts of the event report there were no airplanes in the area at that time. Many people over a wide area of the Texas

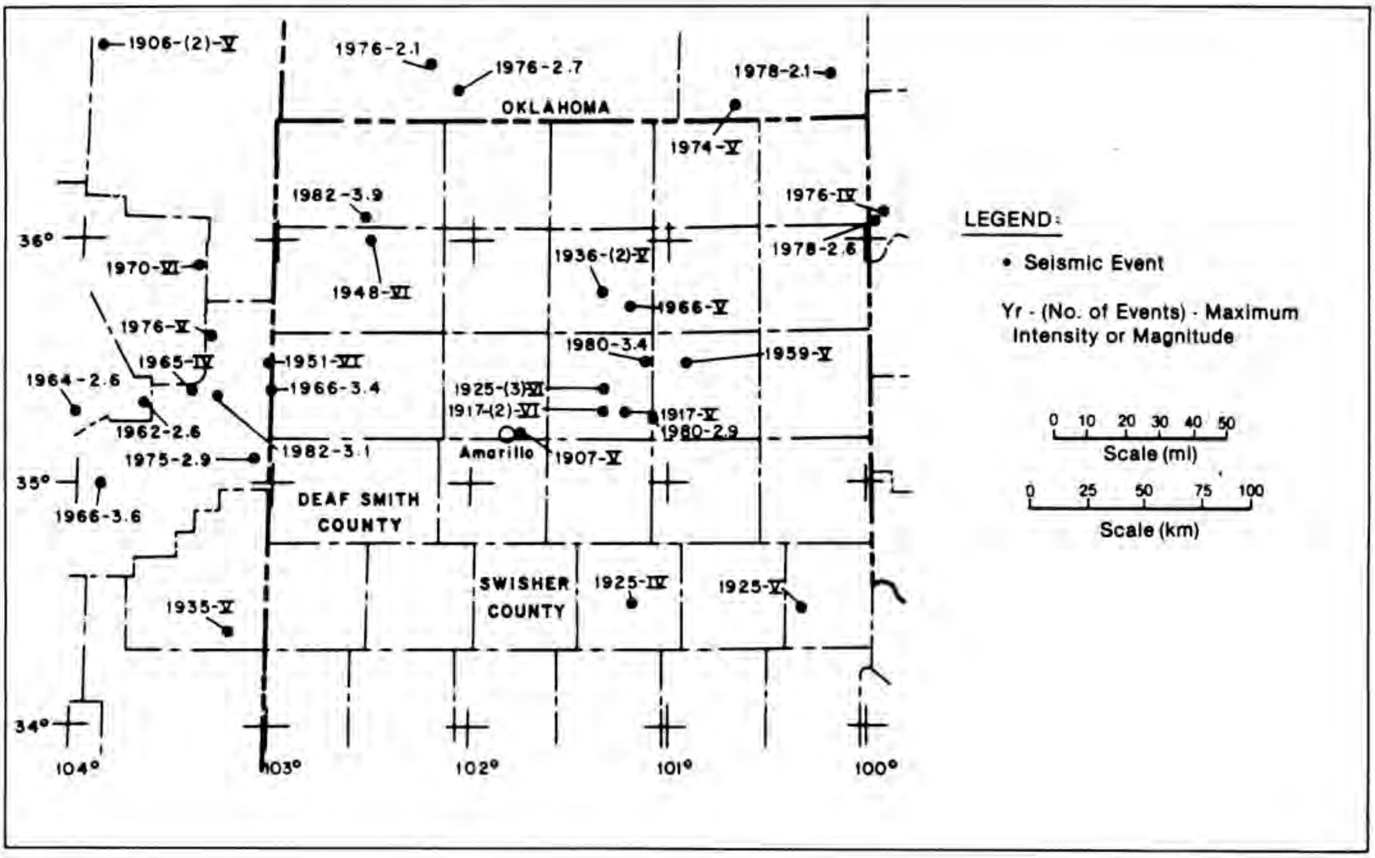

Fig. 1. Epicenters of Historical Earthquakes in the Texas Panhandle Area (1900-1982).

Panhandle reported feeling a disturbance at the reported time but there was no damage. The event is shown at the location on Fig. 1 as an earthquake by several investigators.

There is considerable disagreement about the location of the 1951 earthquake. Pennington and Davis (2) and Nuttli (6) specify the origin of this earthquake slightly east of Deaf Smith County near Amarillo because of felt reports. Northrop and Sanford (1), Coffman and von Hake (5), and Gordon (7) specify the location at the border of Texas and New Mexico based on instrumental data. The location by Gordon (7) is based on reevaluation of available data with better estimates of crustal velocities in the area.

There is also some disagreement about the location of the 1925 earthquake of intensity V in Childress County in the southeastern part of the Texas Panhandle. Pennington and Davis (2) specify the location of this earthquake in the area northeast of Amarillo, whereas newspaper reports suggest its location near Childress. This confusion may have arisen because another earthquake occurred in the northern part of the Panhandle that same day.

Historical seismicity can be loosely correlated with the region's major tectonic features. Tectonic elements in the Texas Panhandle include faulting associated with basin development, Tertiary Quaternary volcanics in northeastern New Mexico, and small scale low amplitude folding. The major basins are the Palo Duro, Dalhart, and Anadarko Basins (Fig. 2). The borders of these basins are formed in part by the Amarillo, Cimarron, and Matador uplifts and Oldham Nose. These uplifts include high-angle faults, some of which may have a strike slip component (8). Most of these basin and uplift structures were formed by tectonic activity from late Mississippian to late Pennsylvanian or early Permian, and all major development was completed by early Permian (9). Stratigraphic evidence indicates that regional subsidence continued through the Permian and intermittently through the Mesozoic era.

The Amarillo Uplift is the most prominent structure in the study area and separates the Palo Duro Basin from the Anadarko Basin. The uplift consists of prominent steep-sided peaks bounded by faults parallel with the trend of the uplift and cut in the saddles by cross faults of lesser magnitude (9). The Cimarron Uplift is a relatively low feature that separates the Dalhart Basin from the Anadarko Basin. The Matador Arch forms the southern border of the Palo Duro Basin. The few faults that have been recognized in the Palo Duro and Dalhart Basins have no surface expression, and apparently do not affect strata more recent than early Permian (9, 8), but little is known about these faults. Normal faulting predominates; however, the main fault bordering the Amarillo Uplift on the north appears to show reverse offset. Most faulting in the area appears to be contemporaneous with basin development during the late Mississippian to early Pennsylvanian episode and may be parallel to or coincident with Pre-cambrian structural trends (8).

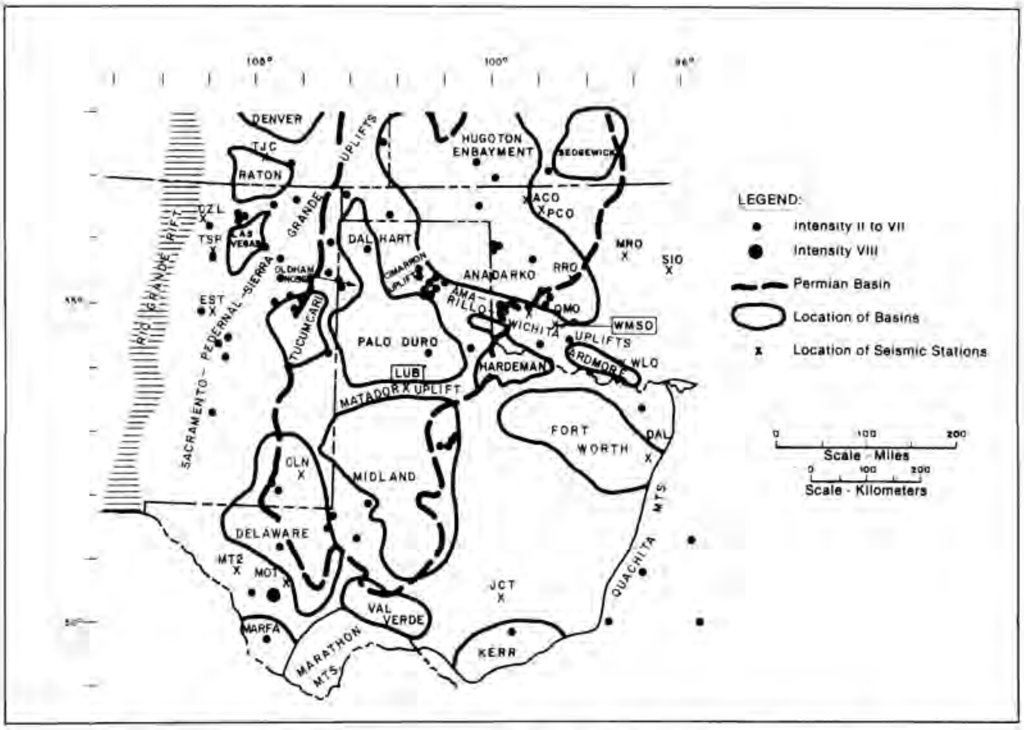

Fig. 2. Seismographic Stations in South-Central United States and Regional Seismicity (1907-1982).

Most of the earthquakes reported in the Texas Panhandle area occurred in the northern part (Fig. 1), in the vicinity of the Amarillo Uplift. The locations shown are determined from felt reports, as mentioned earlier, and therefore, earthquakes cannot be correlated with confidence to specific faults on the Uplift. Nevertheless, it is reasonable to conclude that the Amarillo Uplift shows seismic activity at a low level. The Palo Duro Basin exhibits very little seismicity. The remaining activity appears to be on structures that bound the Palo Duro and Dalhart Basins.

COMPLETENESS OF HISTORICAL RECORD

Although instrumental recording became widespread in the region around 1962, only seven earthquakes in the Panhandle have been located using instrumental data during the last two decades (2). Earthquakes recorded ranged in magnitude from 2.1 to 4.7. The small number of events recorded in this period within this magnitude range is probably influenced by the limited instrumental coverage of the area until recently.

Pennington and Davis (2) noted that a magnitude 3.4 event in 1983 would not have been detected by conventional procedures had there been no specific interest in the seismicity of the area around the Palo Duro Basin. Since this interest did not exist until recently, it is probable that many earthquakes with magnitudes up to approximately 3.5 may have gone unrecognized. Some larger events also may have been missed (2). Racine and Klouda (10) examined the seismicity of salt basin 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. For this period, they examined only records obtained on Sundays in order to avoid any possible confusion with quarry blasts. Based on this study, Racine and Klouda (10) concluded that microearthquakes occur in the salt basins of Texas, Oklahoma, Kansas, and Louisiana at the combined rate of one event per day for all these basins. They contrasted this rate with five events per year listed in the catalogs for the area. Historical reports suggest about one event every three years in the Texas Panhandle and vicinity during 1961 to 1980. The rate estimated by Racine and Klouda (10) is clearly several times higher than the rate derived from earthquake catalogs. In part, this difference arises because modern seismographic instruments are much more sensitive to microearthquakes that do not appear in catalogs prepared from felt reports.

The seismographic station at Lubbock has been operating since 1963 as part of the World Wide Standardized Seismographic Network (WWSSN). Records from the Lubbock station are available on film chips. These film chips were examined by Acharya (3) to identify any earthquakes that may have occurred in the Texas Panhandle from 1963 to 1980 but had not been reported in any catalogs.

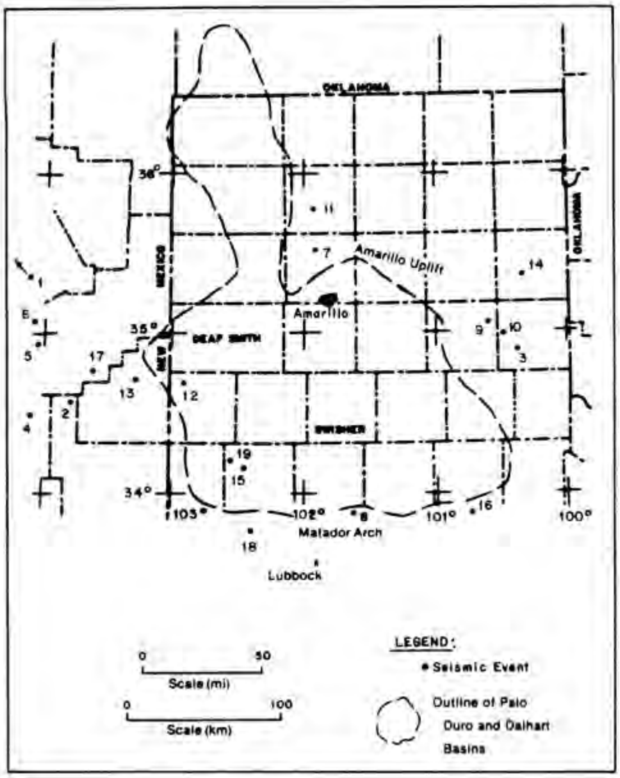

Fig. 3. Historical Earthquakes Located on the Basis of Lubbock Data.

EXAMINATION PROCEDURE FOR LUBBOCK RECORDS

To estimate an earthquake location using only records from a single station, both the epicentral distance and azimuth must be determined. Epicentral distance can be computed from the difference in arrival times of S and P waves. Azimuth to the epicenter can be estimated from P wave first motion on all three component records (11). Vector composition of the two horizontal components (E-W or-N-S) of the first motion gives two possible azimuths, 180° apart, for the ray path. The sense of first motion on the vertical component resolves the correct ray path because the ray path must arrive through the earth, and all these components together must have motion consistent with either a compressional or dilatational wave. If it is up, the first wave is a compression and the horizontal motion is away from the 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.

RESULTS OF LUBBOCK STUDY

Many events with S minus P intervals of $\leq$ 45 sec, corresponding to an epicentral distance of $\leq$ 360 km were identified on the Lubbock station records for the period 1963 to 1980. The dates and times of these events were 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 this basis. The magnitudes of these earthquakes were estimated using the magnitude duration relationship

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

developed by Lawson (12) for Oklahoma. M_c in this relationship is coda magnitude and DUR is signal duration in seconds.

This study suggests that the Lubbock station detects, on an average basis, about two events per year occurring within approximately 360 km of the station and independent of direction. These events are not detected at a sufficient number of other stations so that they can be located. Analysis of the first-motion pattern has identified 19 earthquakes that occurred north of Lubbock. These earthquakes are shown on Fig. 3. Approximately seven of these 19 events occurred in New Mexico, at some distance from the Palo Duro Basin. Three earthquakes appear to have occurred along the Matador Uplift. 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 seismicity. Three events (Nos. 12, 19, and 15 on Fig. 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 events, first-motion data were insufficient for azimuth determination purposes. All the locations have uncertainties on the order of 30 to 50 km.

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. This activity rate is almost twice the rate computed from felt reports and instrumental data from regional seismographs.

INSTALLATION OF MICROEARTHQUAKE NETWORK

A microearthquake monitoring network has been installed in Texas Panhandle in order to detect and locate small earthquakes occurring in the area.

The Palo Duro Basin microearthquake monitoring network consists of 16 permanent stations of which 14 have been operational since April 1984. The remaining two stations became operational in September 1984. The locations of the seismic stations are shown on Fig. 4. The locations were chosen to obtain (1) accurate information on the seismicity of central Palo Duro Basin, (2) information on earthquakes occurring in the entire Palo Duro Basin, and (3) information on earthquakes occurring on the Amarillo Uplift. Five of these stations are on national wildlife refuges, recreation areas, or state parks. Eleven other stations are on private property. The availability of permits for installing the instruments and access were also factors in choosing these locations under the guidelines mentioned above. The installation and operation of the microearthquake monitoring network is described in detail in Acharya and Tyrala (13).

The principal components of the microearthquake network are seismometers, signal amplifying and

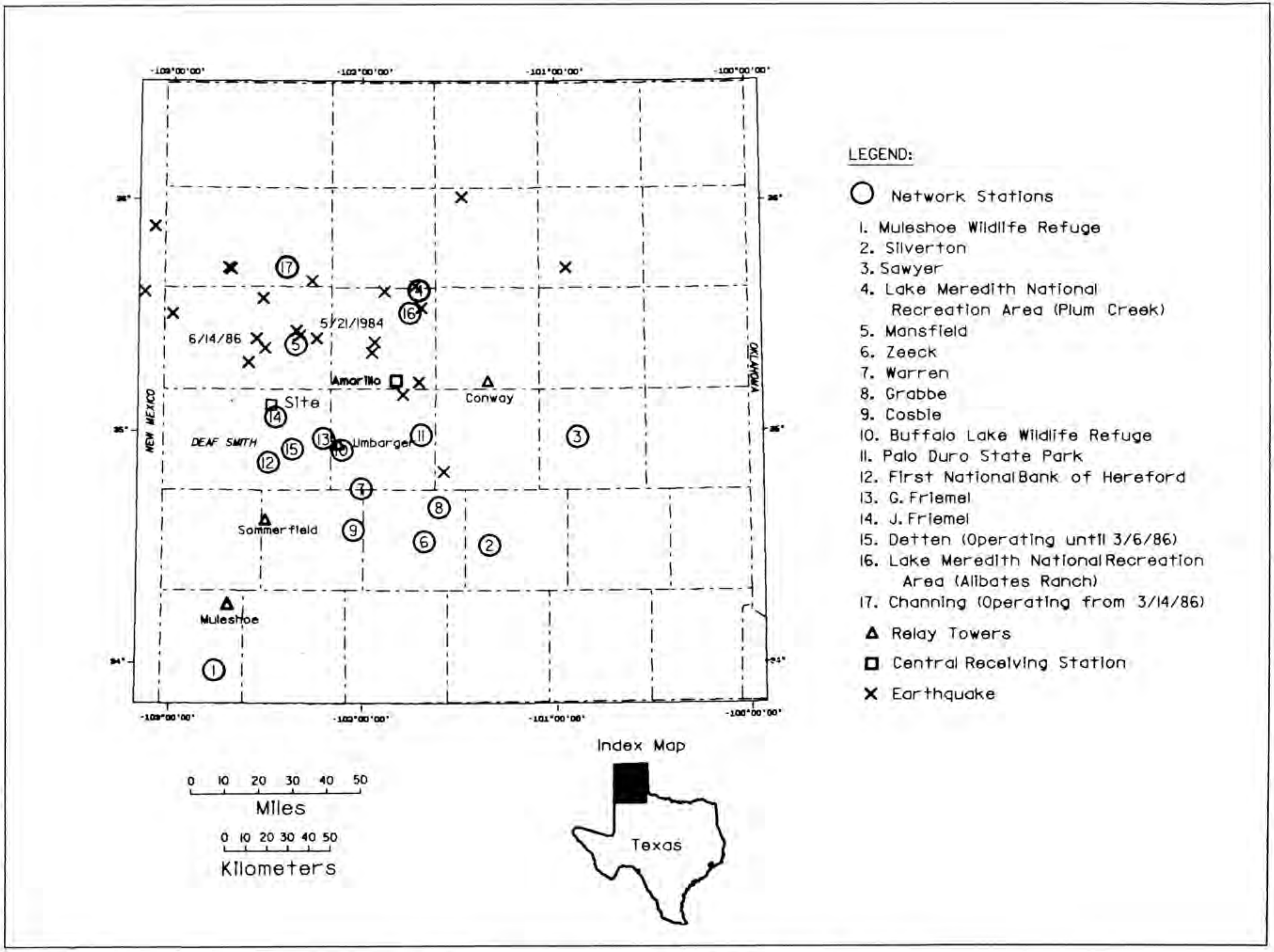

Fig. 4. Microearthquakes in Texas Panhandle (1984-1986).

conditioning devices, signal transmission and receiver circuitry, recording media, an accurate clock, and a power supply. The output signal from a seismometer is conditioned and amplified at the field station and converted for telemetry transmission to the central recording station. Telemetry transmission and centralized recording systems are commonly used for operating microearthquake monitoring networks. The principal advantage in using a centralized recording system is that a common time base can be established easily for the entire network. At many stations, the seismometer is placed in a borehole at a depth of 50 ft to reduce wind generated, high-frequency noise and thus increases the ability to detect weak seismic signals.

Data from the 16 remote stations are telemetered by radio to the central recording station located in Amarillo. At many stations the antenna for transmission of radio signal is attached to the top of a 50-ft tower, so that the signal is received at the central recording station with $\geq$ 95 percent reliability. Modifications carried out in January 1986 to improve the quality of recorded data have resulted in increased detection capability by the network. As a result, several local earthquakes have now been detected and located. For example, the Mansfield Station frequently recorded earthquakes similar to the June 14, 1986, earthquake. However, these earthquakes were not recorded by other stations and could not be located. Modifications at several stations increased the quality of data so that the June 14, 1986, shock was recorded at four stations and subsequently located.

At the central recording station, incoming data are monitored by a Multichannel Digital Recorder (MDR). This real time, digital processing system continuously monitors the network signals, automatically detects events, and records the entire digital time series, including pre-event and post event context on IBM compatible (ASCII) nine-track computer tape. Recorded data are therefore available for direct input to a data analysis computer. The MDR is a triggered recording system and uses the Berkeley algorithm for monitoring long-term averages and short-term averages of trace amplitudes. Data can be sampled at rates from 1/sec to 200/sec.

Data are sampled at rate of 100/sec per channel and digital records include 15 sec of pre-event and post event data. Radio signals from NBS broadcasts are used to calibrate the clock in the MDR. Trigger parameters for recording local earthquakes are stored in the MDR computer. An uninterrupted power supply (UPS) attached to MDR ensures that power failure will not affect the trigger parameters and local earthquake data can be recorded.

Data from any eight stations are also recorded on four dual channel VR-60 helical recorders. These are ink writing drum recorders with a wide range of sensitivities and recording rates. Twenty-four hours of data are normally recorded on one sheet of paper. A patch panel is used to select desired channels. Currently, stations are selected either for location or sensitivity. These paper records provide back up data in the event of failure of the MDR and also serve as a means for rapid computation of local earthquake epicenters.

RESULTS

The operation of the microearthquake monitoring network is beginning to provide accurate information on the location and frequency of occurrence of microearthquakes and will help define the earthquake hazard in Deaf Smith County. A number of small local events have been detected and located. Figure 4 shows the locations of these earthquakes and were computed using the U.S. Geological Survey program HYPOELLIPSE/VAX (14). The magnitudes of earthquakes shown on Fig. 4 were computed using Lawson's (12) magnitude coda relationship and range between 1.0 and 3.1. Computed focal depths vary between 1 and 30 km.

The computed locations include considerable uncertainty, because the stations of the network are generally to the south of the earthquake epicenters and at considerable distances from epicenters as can be seen on Fig. 4. Azimuthal gaps range from 110 to 345°. Therefore, the azimuthal coverage for these earthquakes is poor, and the error estimates are large. The computed locations should be considered as only an indication of earthquake activity in that part of the Texas Panhandle. The installation of a station at Channing replacing the Detten station has, to some extent, improved the azimuthal coverage for some events. Focal depth estimates are not very meaningful, because in most cases the minimum epicental distance is greater than the estimated focal depth.

All the microearthquakes detected and located have occurred outside the network except for one very small earthquake near Amarillo. None of these earthquakes was felt. Many of these earthquakes appear to be associated with the Amarillo Uplift or the Cimarron Uplift, which bound the Palo Duro Basin to the northeast. Uncertainties in epicentral determinations preclude association of these earthquakes with specific faults in these broad structures. There was no report of any activity in Oldham County prior to the installation of the microearthquake monitoring network. Results to date suggest that Oldham County is even more active than the Amarillo Uplift area. The Mansfield Station in Oldham County has recorded many events with signatures similar to the magnitude 2.7 shock of May 21, 1984, or its smaller aftershocks (13). These very small earthquakes were recorded only by the Mansfield Station. In all cases, the time interval between the arrival of the S and P phases is about 1.0 to 1.5 sec, suggesting that these earthquakes are located 8 to 12 km from the Mansfield Station.

To date, the operation of the 16-station network indicates the need to expand the areal coverage of the network by increasing the number of stations in the network. The distribution of microearthquakes located so far also clearly points out the need for more closely spaced stations in the northern part of the Panhandle so earthquakes occurring in the area can be more accurately located.

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