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Pasadena, California 91125

USGS CONTRACT NO. 14-08-0001-18322
Supported by the EARTHQUAKE HAZARDS REDUCTION PROGRAM

CALIFORNIA INSTITUTE OF TECHNOLOGY

PASADENA, CALIFORNIA

SEISMICITY STUDIES FOR EARTHQUAKE PREDICTION IN SOUTHERN CALIFORNIA USING A MOBILE SEISMOGRAPHIC ARRAY

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OPEN-FILE NO.81-282

U.S. Geological Survey
OPEN FILE REPORT

FINAL TECHNICAL REPORT

1 October 1979 - 30 September 1980

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Contract Number:	U. S. Geological Survey No. 14-08-0001-18322
Name of Contractor:	Seismological Laboratory California Institute of Technology
Principal Investigators:	Hiroo Kanamori Seismological Laboratory, 252-21 California Institute of Technology Pasadena, California 91125 Karen McNally Seismological Laboratory, 252-21 California Institute of Technology 91125
Government Technical Officer:	Gordon W. Greene U. S. Geological Survey 345 Middlefield Road Menlo Park, California 94025
Short Title of Contract:	Seismicity Studies for Earthquake Prediction in Southern California Using A Mobile Seismographic Array
Effective Date of Contract:	1 October 1979
Contract Expiration Date:	30 September 1980
Date of Report:	30 October 1980

Sponsored by the
U. S. Geological Survey
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I. USE OF EXPLOSIONS FOR MEASURING TEMPORAL CHANGES OF P VELOCITY

Since 1973, the Califonia Institute of Technology has been monitoring large quarry blasts which occur in Southern California.

During the period from 1 October 1979 to 30 September 1980, monitoring of quarry blasts at Mojave, Gorman, Victorville, and Corona was continued. Current results are summarized in the following tables and shown in Figures 1 to 6. The locations of the blast sites and the stations are shown in Figure 6.

a. Mojave Blast (Figures 1 and 6)

In most cases, the shot time and the first arrival were timed with an accuracy of 10 msec and the spread of the shot points was about 300 m or less. Since the Mojave quarry is a cement quarry and the in situ velocity is about 4.5 km/sec (limestone), the source term is probably very small.

Except for somewhat unreliable measurements (owing to instrumental malfunctioning) prior to 1974, most measurements fall within $\pm$ 0.06 sec about the average. Although the fluctuation about the average, $\pm$ 0.06 sec, is very small, it is larger than our measurement accuracy. At the present time, the cause of this fluctuation is unknown, but because of its proximity to the Palmdale area, monitoring of this quarry blast is extremely important for investigating whether there is any long-term change assocated with the migration of the Palmdale uplift.

b. Victorville Blast (Figures 2 and 6)

In general, the fluctuation about the average is larger for the Table Mt. path than for the SBB and Mt. Emma paths.

c. Corona Blast (Figures 3 and 4)

The average velocity for the Corona-Riverside path decreased from 1973 to 1976. However, the measurement taken in 1978 indicated an increase. It is interesting to note that the USGS geodolite measrements of a line close to the Corona-Riverside path showed an increase sometime in 1978 (J. Savage, written communication).

Figure Captions

Figure I-1. Temporal variation of the average P velocity (Mojave quarry). For the locations of the quarry and stations, see Figure 6.

Figure I-2. Temporal variation of the average P velocity (Victorville quarry).

Figure I-3. Temporal variation of the average P velocity for the Corona-Riverside path.

Figure I-4. Temporal variation of the average P velocity for the Corona-Riverside path.

Figure I-5. Temporal variation of the average P velocity for the Gorman quarry.

Figure I-6. Temporal variation of average velocity for the Mojave, Victorville, and Gypsum Canyon blasts.

Blast Location: Mojave, 35° 02.27' N; 118° 18.94' W

Date: April 25, 1980

Time: $22^h 46^m 06.03^s$ GMT*

Yield: 12.3 KLB; 1 delay 17 msec

Travel Time Data

Station	Δ (km)	Azimuth (Deg.)	P time $22^h 46^m \sim$	T (sec)	T-Δ/6 (sec)	$\bar{v}$ (km/sec)	Quality**
Lake Hughes 2	41.67	195.0	13.88	7.85	0.91	5.308	B
SWM	42.99	214.5	14.23	8.20	1.04	5.243	A
SWM (t)	42.99	214.5	14.21	8.18	1.02	5.256	CEDAR
FTC	55.83	251.1	15.90	9.87	0.57	5.657	B (noisy)
SBB (t)	59.37	130.6	16.53	10.50	0.61	5.654	CEDAR
PYR (t)				no data			

* Determined at the shot point, accurate to ±10 msec.

** A = ±10 msec; B = ±30 msec.

Auxiliary station (noisy onset)

Blast Location: Mojave, 35° 02.39' N; 118° 19.16' W

Date: June 25, 1980

Time: $21^h 47^m 47.55^s$ GMT*

Yield: 33.9 KLB; 8 rows, 9 msec between rows

Travel Time Data

Station	Δ (km)	Azimuth (Deg.)	P time $21^h 47^m$∿	T (sec)	T−Δ/6 (sec)	$\bar{v}$ (km/sec)	Quality**
Lake Hughes 2	41.68	194.7	55.28	7.73	0.78	5.392	A
SWM	42.98	214.0	55.62	8.07	0.91	5.326	A
FTC	55.59	250.8	57.38	9.83	0.57	5.655	A (noise)
SBB (t)	59.77	130.6	58.06	10.51	0.55	5.687	B

Auxiliary Station 35° 01.97' N; 118° 19.06' W

P time $21^h 47^m 47.67^s$ GMT

* Radio failed, estimated from the P time at the auxiliary station by subtracting 120 msec; probably accurate to ±20 msec.

** A = ±10 msec

B = ±30 msec

Blast Location: Victorville, 34° 37.88' N; 117° 06.80' W

Date: May 23, 1980

Time: $18^h52^m54.20^s$ GMT*

Yield: 36.9 KLB; 123 holes, no delays

Travel Time Data

Station	Δ (km)	Azimuth (Deg.)	P time $18^h53^m\sim$	T (sec)	T-Δ/6 (sec)	$\bar{v}$ (km/sec)	Quality**
CSP (t)							
Table Mt	59.00	242.2	4.74	10.54	0.71	5.598	A
SBB (t)	65.44	275.8	5.73	11.53	0.62	5.676	A
RVR (t)							
GSC (t)							
PEC (t)							
Mt. Emma			record masked by noise				

* Determined at shot point, accurate to ±10 msec

** A = ±10 msec

Blast Location: Gorman, 34° 49.97' N; 118° 45.44' W

Date: February 12, 1980

Time: $22^{h}47^{m}15.82^{s}$GMT*

Yield: 10.83 KLB; 30 holes (2 rows), 25 msec delay between rows

Travel Time Data

Station	Δ (km)	Azimuth (Deg.)	P time $22^{h}47^{m}$	T (sec)	T-Δ/6 (sec)	$\bar{v}$ (km/sec)	Quality**
FTC	13.225	289.9	18.79^{s}	2.97	0.77	4.453	A
SWM			no record				
Lake Hughes 2			noisy				

* Determined at the shot point, accurate to ±10 msec.

** A = ±10 msec.

Blast Location: Gorman, 34° 50.19' N; 118° 45.45' W

Date: July 29, 1980

Time: $21^h36^m41.33^s$GMT*

Yield: 23.262 KLB; 73 holes, 4 rows, 100 msec delay between rows

Travel Time Data

Station	Δ (km)	Azimuth (Deg.)	P time 21^h36^m	T (sec)	T-Δ/6 (sec)	$\bar{v}$ (km/sec)	Quality**
Fort Tejon	13.08	288.2	44.30^s	2.97	0.79	4.404	A
SWM	20.76	129.1					
PYR	29.82	177.2					
Lake Hughes				no data			

* Determined at shot point, accurate to ±10 msec.

** A = ±10 msec.

Blast Location: Corona, 33° 50.24' N; 117° 30.25' W

Date: April 16, 1980

Time: $23^h00^m28.68^s$GMT*

Yield: 13.116 KLB; Twelve delays

Travel Time Data

Station	Δ (km)	Azimuth (Deg.)	P time $23^h00^m\sim$	T (sec)	T-Δ/6 (sec)	$\overline{v}$ (km/sec)	Quality**
RVR	21.028	34.6	32.48	3.80	0.30	5.534	A
RVR (t)	21.028	34.6	32.48		same		B

* Determined at the shot point, accurate to 10 msec

** A = ±10 msec, B = ±30 msec

Auxiliary Station, 33° 51.06' N; 117° 30.42' W, $23^h00^m29.01^s$GMT*

Blast Location: Corona, 35° 50.24' N, 117° 30.24' W

Date: June 20, 1980

Time: $20^h 05^m 40.41^s$ GMT*

Yield: 11.2 KLB, Complex pattern

Travel Time Data

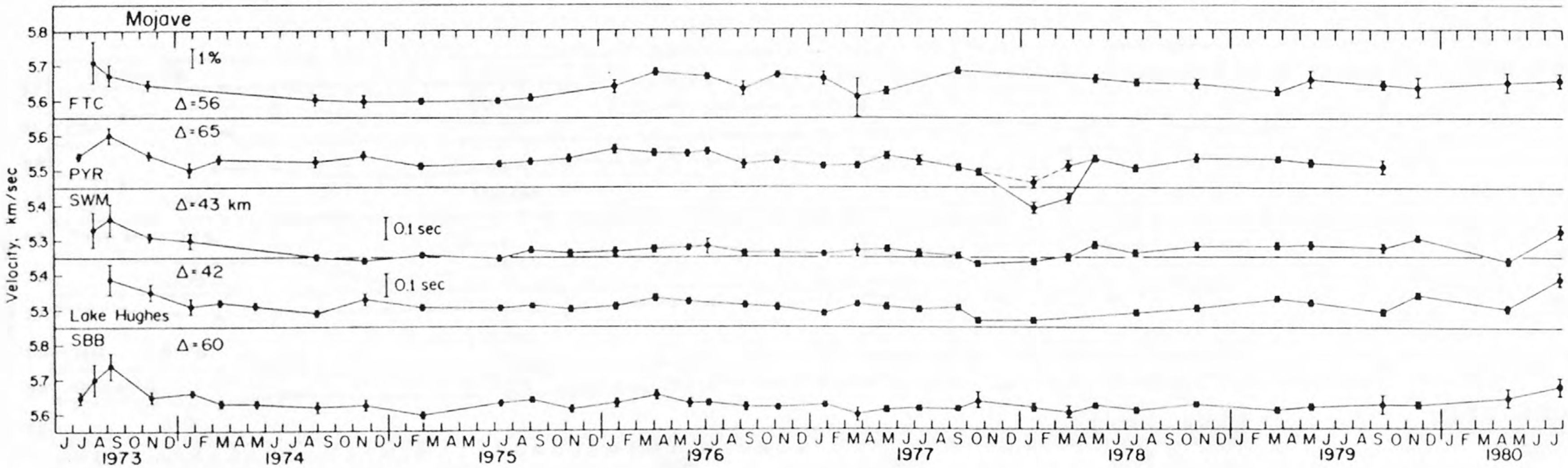
Station	Δ (km)	Azimuth (Deg.)	P time $20^h 05^m \sim$	T (sec)	$T-\Delta/6$ (sec)	$\bar{v}$ (km/sec)	Quality**
RVR	21.02	34.5	44.20^s	3.79	0.29	5.546	A

Auxiliary Station

P time 40.74^s

* Determined at shot point, accurate to ±10 msec

** A = ±10 msec



Mojave
1%
FTC
Δ=56
Δ=65
PYR
SWM
Δ=43 km
0.1 sec
Δ=42
0.1 sec
Lake Hughes
SBB
Δ=60
Velocity, km/sec
1973
1974
1975
1976
1977
1978
1979
1980

Fig. 1

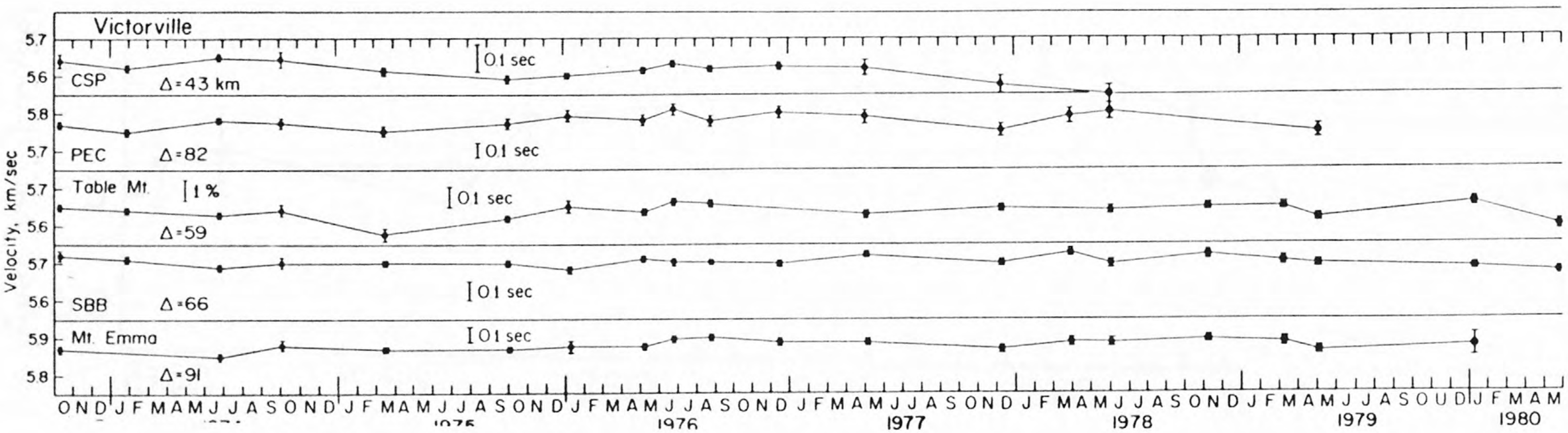

Victorville
CSP
Δ=43 km
0.1 sec
PEC
Δ=82
0.1 sec
Table Mt.
1%
0.1 sec
Δ=59
SBB
Δ=66
0.1 sec
Mt. Emma
0.1 sec
Δ=91
Velocity, km/sec
5.7
5.6
5.8
5.7
5.7
5.6
5.7
5.6
5.9
5.8
O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O U D J F M A M
1976
1977
1978
1979
1980

Fig. 2

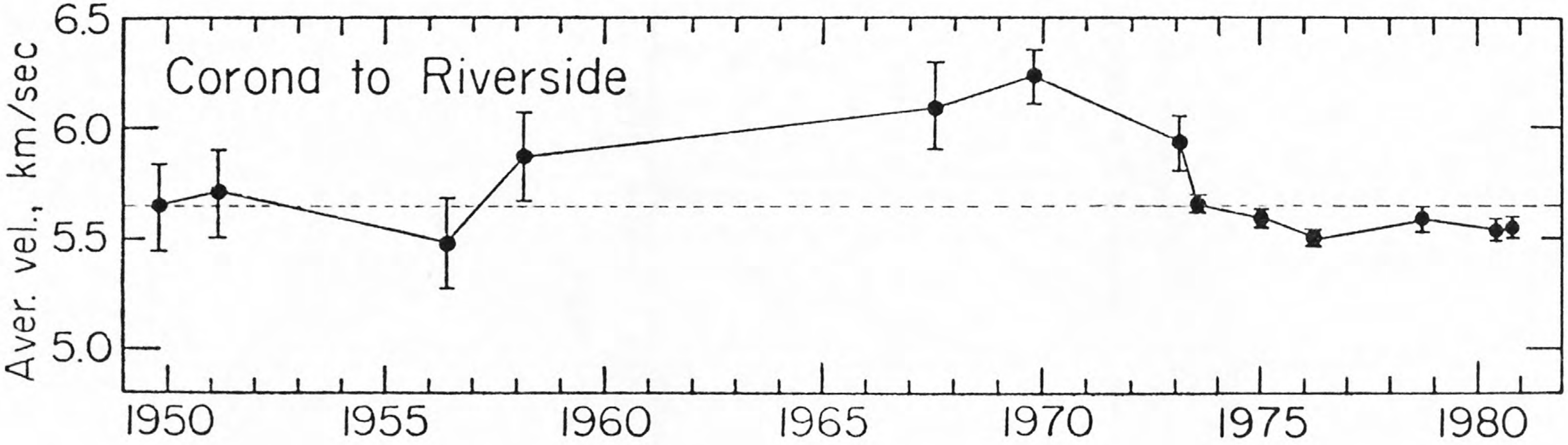

Corona to Riverside
Aver. vel., km/sec
6.5
6.0
5.5
5.0
1950
1955
1960
1965
1970
1975
1980

Fig. 3

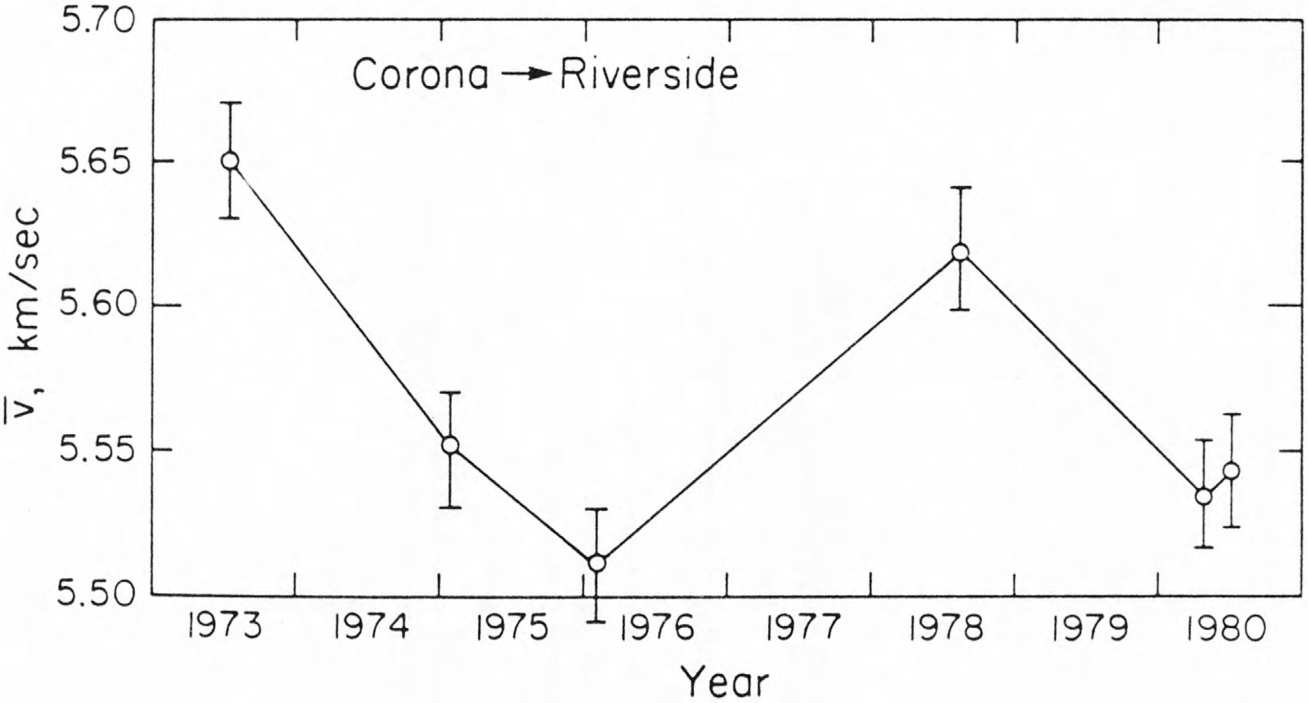

5.70
5.65
5.60
5.55
5.50
$\overline{v}$, km/sec
Corona → Riverside
1973
1974
1975
1976
1977
1978
1979
1980
Year

Fig. 4

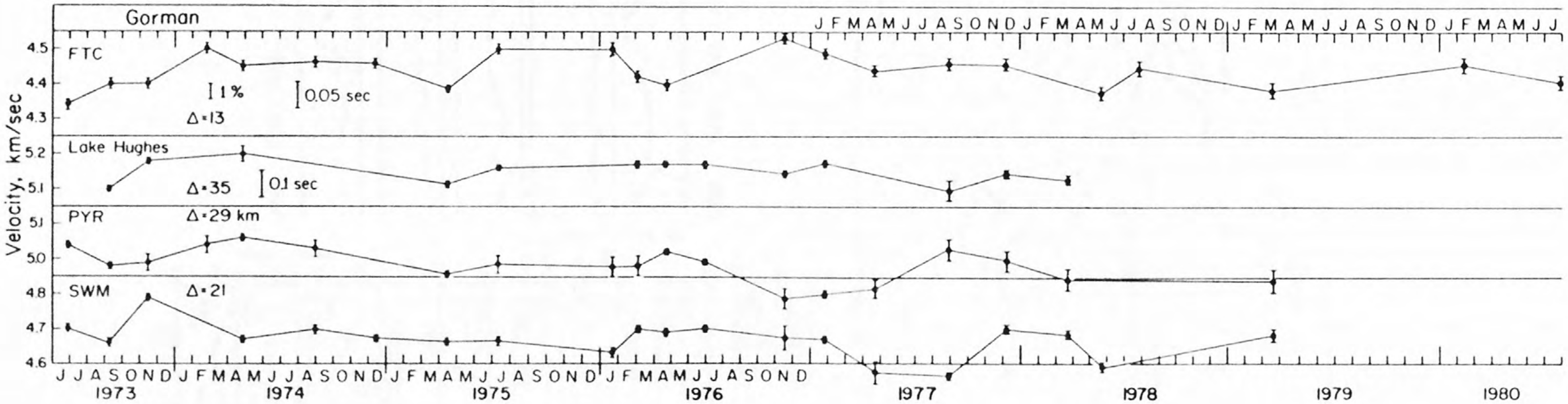
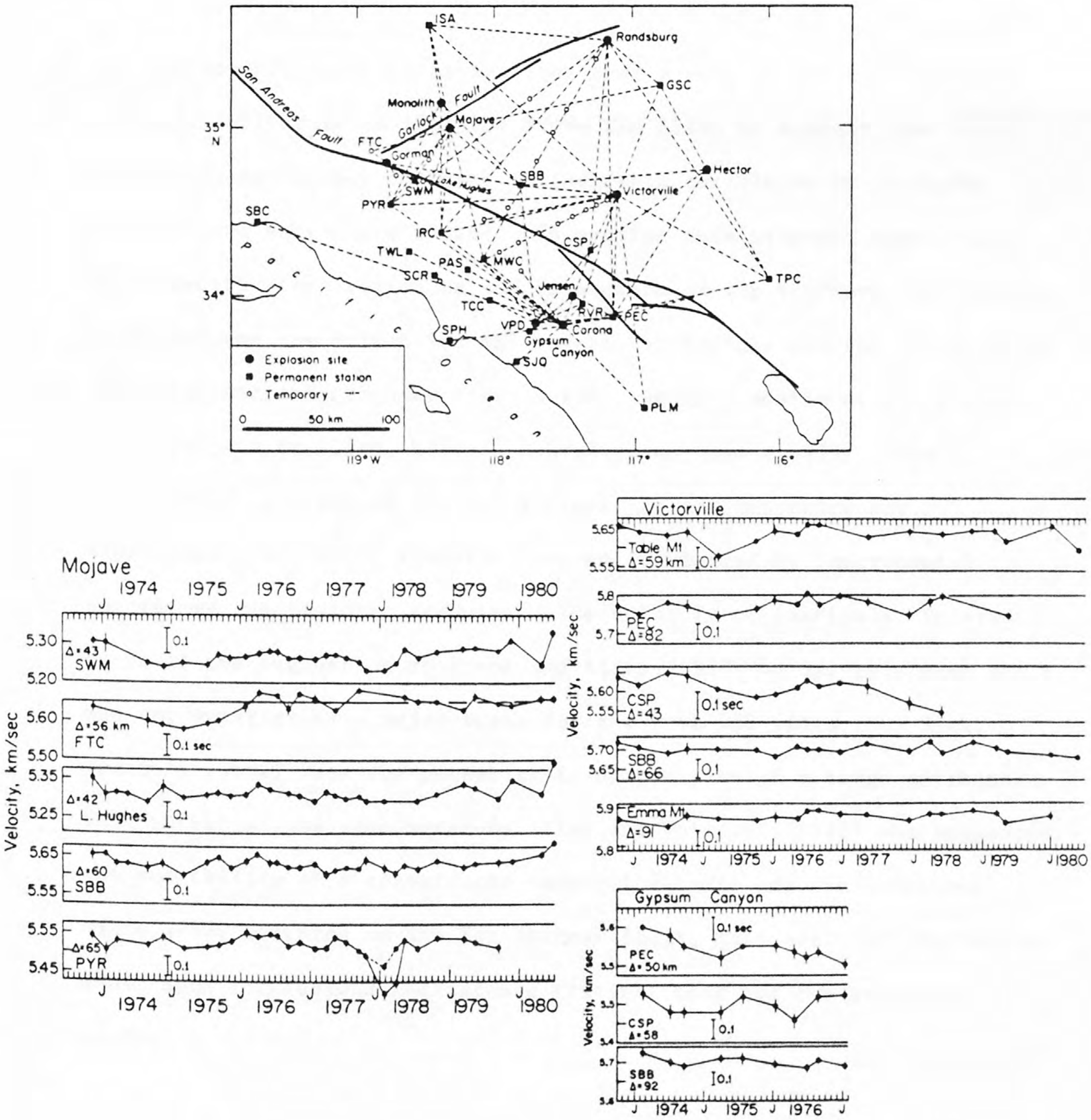

Gorman
FTC
1%
0.05 sec
Δ=13
Lake Hughes
Δ=35
0.1 sec
PYR
Δ=29 km
SWM
Δ=21
Velocity, km/sec
4.5
4.4
4.3
5.2
5.1
5.1
5.0
4.8
4.7
4.6
J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J
J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D
1973
1974
1975
1976
1977
1978
1979
1980

Fig. 5



ISA
Randsburg
GSC
San Andreas Fault
Garlock Fault
Monolith
Mojave
FTC
Gorman
SWM
L. Hughes
SBB
Hector
Victorville
PYR
SBC
IRC
TWL
PAS
MWC
CSP
SCR
TPC
Jensen
TCC
RVR
PEC
SPH
VPD
Corona
Gypsum Canyon
SJQ
PLM
Explosion site
Permanent station
Temporary
0 50 km 100
35° N
34°
119° W
118°
117°
116°
Mojave
1974 1975 1976 1977 1978 1979 1980
Δ=43 SWM
Δ=56 km FTC
0.1 sec
Δ=42 L. Hughes
Δ=60 SBB
Δ=65 PYR
Velocity, km/sec
Victorville
Table Mt Δ=59 km
PEC Δ=82
CSP Δ=43
SBB Δ=66
Emma Mt Δ=91
Gypsum Canyon
PEC Δ=50 km
CSP Δ=58
SBB Δ=92

Fig. 6

II. MICROEARTHQUAKE SURVEY FOR SOUTHERN CALIFORNIA

1. Investigations of seismic quiescence and microearthquakes along the southern San Andreas fault: Coachella Valley, California

Micro-earthquake investigations over a wide geographic region of southern California in 1967 led Brune and Allen to suggest that short term micro-earthquake activity is inversely correlated to longterm activity and earthquake hazard. To examine this proposal more closely in a specific test region, a 100 km section of the southern San Andreas fault between the Salton Sea and Desert Hot Springs was the focus if an intensive micro-earthquake field survey, using a mobile array of eight seismographic trailers, between February and August 1979. This southernmost portion of the San Andreas has not undergone any significant rupture in historic time as documented by instrumental recordings and historic accounts. The quiet is of particular interest since if the suggestion of Brune and Allen (1967) holds, this area which has not experienced a major break for the past 230 years (K. Sieh, personal comm.) has the potential to be the site of a large earthquake. This potential was also noted by Allen and Whitcomb (1978) who suggested the possibility of a conspicuous temporal seismic gap, in existence since 1950, centered on the San Andreas fault, just north of the Salton Sea. Such conclusions indicated a critical need for our intensive study.

The quiet portion of the San Andreas of interest to us is located between the Salton Sea and Desert Hot Springs. Just north of the study area, the San Andreas fault was broken by the 1857 Ft. Tejon earthquake. South of the Salton Sea is the seismically active Imperial Valley. Since 1932, when the catalogue of instrumentally recorded earthquakes in southern California begins, two major earthquakes have occurred near the region of our interest, at Desert Hot Springs (1948) and at Borrego Mountain (1968). Neither of these earthquakes is associated with the main trace of the San Andreas. The largest historic earthquake in the study area, the 1948 Desert Hot Springs earthquake ($M_L = 6.5$), has no surface displacement associated with it (Richter, et al., 1952). Until October 1979, the only historic displacement on the San Andreas fault in the Salton trough was one centimenter of right-slip in the Mecca Hills which was dynamically triggered by the May 1968, Borrego Mountain earthquake ($M_L = 6.0$), (Allen, et al., 1972). Following the 15 October 1979 Imperial Valley earthquake ($M_L = 6.6$), a similar amount of slip occurred in the same region (Sieh, 1979).

Prior to instrumental recordings, in May 1868 a severe earthquake of Rossi-Forel intensity IX or X, is reported to have occurred along the San Andreas fault near the northern end of the Salton Sea. This event which was not felt in northern or central California, is described by the Townley and Allen (1939) and Wood and Heck (1951) catalogues. The earthquake reportedly occurred at a hot springs in the desert, and is said to have opened a long fissure in the earth at Dos Palmas on the Southern Pacific Railroad line (Townley and Allen, 1939). However, these reports are contradicted by geologic work by K. Sieh (personal comm.) which indicate that no major rupture has occurred in the area since about 1750 A. D.

The southernmost portion of the San Andreas, just north of the Salton Sea has been in a period of relative quiescence since 1932 as determined from the catalogue of seismicity for the Southern California region (Hileman, et al., 1973, and later editions), for events of $M_L \geq 4.0$ (see Figure 1). This quiescence extends over 65 km of the San Andreas. Some aspects of the apparent quiescence could have been due to the poor seismic coverage afforded the area by the SCARLET array during much of this time. Permanent seismographic coverage for the area is now provided by two stations, INS, installed in April 1974, and CTW, installed in August 1977 (see map of permanent and temporary stations in Figure 1). During the period of our study, supplementary information was provided by eight mobile seismographic trailer stations. The mobile stations were first installed at the southern end of the study area, straddling the San Andreas fault. After an initial stationary configuration to establish detection characteristics of the mobile array, the southernmost stations were sequentially removed and reinstalled to the north, as the array leapfrogged along the fault. The locations and periods of operation of these temporary stations are listed in Table 1.

a. Seismicity

Until this work, the only information available on micro-earthquake activity along this portion of the San Andreas is for a 42 hour period in February 1966 when a temporary site in the middle of the study area at station PAC was occupied by Brune and Allen (1967). During the 42 useful recording hours of their work, no events were observed. However, this result is not inconsistent with the results of our study, as there were blocks of time characterized by little or no activity during our work, and it would have been possible to identify 42 consecutive hours at that rate.

Use of the mobile array of seismographic trailers gives us a uniform detection threshold for events of $M_L \geq 1.4$ within the study area. Certain characteristics of earthquake occurrence in the Coachella Valley can be identified from seismicity plots of microearthquake activity between January and June 1979 (see Figure 2) which appear to be consistent with our knowledge of previous activity observed at higher magnitude levels. Events located during this time period by the Caltech Southern California automated detection and recording system are shown in Figure 2. Figure 3 plots only those events located during the same time period through the use of data from the trailer station array employed in this work. In this figure, earthquakes have been located using the standard southern California velocity model of Hadley and Kanamori. A catalogue of the events on which both of these figures are based is contained in Table 2. In examining the nature of the seismicity, first it is observed that earthquakes tend to be located along east-west lineations to the northeast of the mapped trace of the San Andreas. These features, from north to south are named the Blue Cut (mapped lineation near station INS), Porcupine Wash and Cottonwood Pass (see Figs. 2 and 3). Secondly, activity appears to happen in "clusters" of closely related events which occur in very localized areas along these east-west trends. A scan of the temporal history of the clusters indicates that they occur over time periods of one to several days duration. The third major observation is that during the microearthquake study essentially no activity is observed to the southwest of the San Andreas. As will be shown in a later discussion of the long-term patterns of seismic activity in this region, this quiet has persisted since 1950.

CEDAR events and events located in this work are shown together in Fig 4. Locations of events from the microearthquake study as plotted in Figure 4 (open circles) are based on an average crustal velocity model worked out for the Coachella Valley by G. Humphreys (personal comm.) on the basis of other regional studies (Hadley and Kanamori, 1977, Biehler, 1964, and Johnson and Hadley, 1976). The model used differs from the standard Caltech velocity model, by

1) having a slightly lower velocity at the surface

2) using a series of thin layers of increasing velocity between 5 and 6 km to approximate a velocity gradient

3) thinning of the crust by 6 km from 32 to 26 km.

The general effect of the revised velocity model is to slightly reduce scatter around east-west lineations and to "tighten" localized clusters of events. In addition, one feature of a velocity gradient which was indicated in the Imperial Valley study of Johnson and Hadley (1976), is its ability to help stabilize calculations of focal mechanisms which we are continuing to examine for the Coachella Valley region.

Focal mechanisms for ten events of $M_L \geq 2.2$ which occurred in the Coachella Valley before the installation of our microearthquake array (1977, 1978) are shown in Figure 5. The solutions plotted in Figure x are for earthquakes selected from activity along the Blue Cut and Porcupine Wash and from a cluster near the San Andreas at the northeastern shore of the Salton Sea. The events selected were chosen to be representative of the spatial characteristics of the local seismicity. Focal mechanism solutions for each event of $M_L \geq 2.2$ which occurred during the operation of the trailer array are shown in Figure 6. Event A (2.16.79) located on the Blue Cut near station INS is shown on both Figures 5 and 6 for continuity. In both figures, focal mechanism solutions were computed with the assistance of the FOC.PLOT program (Whitcomb and Garmany, 1973). Generally the mechanisms obtained are consistent with the regional tectonics, although the results show some variability and can not be rigidly constrained in some cases.

<u>b. Special microearthquake study in the Coachella Valley following the 1979 Imperial Valley earthquake</u>

On 15 October 1979, shortly after the temporary trailer stations had been removed from the Coachella Valley portion of the San Andreas fault, an earthquake of M_L = 6.6 struck the Imperial fault near the international border. Seismic activity immediately following the mainshock was relatively high at the ends of the aftershock zone, indicative of stress redistribution during the main event (Johnson and Hutton, 1980). Further evidence of the effect of the mainshock at large distance, was Kerry Sieh's (1980) identification of "sympathetic slip" along the portion of the San Andreas which we had been studying. This slip was found just north of the northern end of 15 October 1979 aftershock activity (see Fig 7), and occurred in the same region that had seen slip following the 1968 Borrego Mountain earthquake. This indication of stress redistribution caused us to once again investigate micro-earthquake activity in this portion of the San Andreas.

For a one week period following the mainshock, we re-occupied five temporary sites on both sides of the San Andreas. Sprengnether MEQ800 smoked paper recorders were employed in this work. The sites occupied are noted as stations ORF, PAC, TRR, FSH, and BRD in Fig. 7. Four of these sites are in the same location as stations of the mobile trailer array which had operated in the previous months immediately prior the the shock. Station ORF was located at a new site on the eastern side of the fault, in order to provide a uniform station distribution for this work.

During the one week long micro-earthquake study in late October 1979, activity was high but at a rate not unusual for this area. Specifically on the 3rd and 4th days of our occupation of these sites, a large, localized cluster of activity occurred along an east-west lineation known as Porcupine Wash. This cluster contained about 85 events and was located within 24 km of station PAC. Although this activity occurs just after the Mexicali event, it does not appear to represent a change from normal activity, since clusters are quite common along the east-west lineations in this region and five others had been observed during our earlier study (see Fig 7). Other activity during the time period of this special study also appeared to be similar to that observed during our earlier micro-earthquake study. Small numbers of events occurred along the San Jacinto and the Mission Creek faults and at the edges of the San Jacinto Mountains. The events ranged in magnitude from $1.0 \leq M_L \leq 2.5$. Two events observed do appear to possibly be related to the observed slip of Sieh's work. These events near Sieh's observed slip, occur within 4 km of the mapped surface trace of the San Andreas, making them among the closest to the fault of any events observed during our entire micro-earthquake work in this area.

c. Patterns of longer term seismic activity based on instrumentally recorded data since 1932

In order to examine the instrumentally recorded seismic history of the study region, we have constructed a cumulative plot of activity since 1932 at the level of $M_L \geq 3.0$ from the Caltech southern California earthquake catalogue. This is used as a basis for comparison to current activity in order to determine what fraction of the seismicity represents a change in the nature of the activity as opposed to a change in seismic detection levels.

The cumulative number of events since 1932 has been plotted in two parts, events prior to the Desert Hot Springs earthquake (Figure 8a) and events from 1950 to date (see Fig. 8b). Activity just after the Desert Hot Springs earthquake is omitted, since it represents an order of magnitude change in the seismicity for a short period of time due to the occurrence of aftershocks. Two curves are shown, one containing all events and a second curve in which only the first event of any clustered sequence is included. The criteria for clustering is temporal. Events occurring within 24 hours of a previous event are grouped in a cluster, provided their locations are within one minute of latitude or longitude. The lines fit to the cumulative event plots are approximate slopes and do not represent a fit to a regression curve.

For the past ten years, no obvious change in the rate of seismic activity in the area can be seen (See Figs. 8a and 8b). Since 1932, however, there are fluctuations in the rate of activity. In two cases, before the Imperial Valley earthquake of 1940, and again before the Borrego Mountain earthquake of 1968, there is a decrease in the rate of activity, which appears to be associated with the large events nearby. However, for the Desert Hot Springs event in 1948, the only event which occurred within the region of interest to this work, no change in the rate of activity is observed prior to the mainshock (see Figure 8a).

Seven straight line segments, which are approximate slopes and do not represent the fitting of a regression curve, can be used to indicate changes in the rates of activity along the southern San Andreas fault between 1932 and 1979 (see Figures 8a and 8b). Maps of earthquake epicenters for each of six of these segments of time are shown in Figures 9a - f. Rates of activity in each time period are calculated for a region centered on the fault just north of the Salton Sea, outlined by the dashed line of Figures 9a - f. The time period from just after the 1948 Desert Hot Springs event through 31 December 1951 is omitted since it represents an order of magnitude increase in the seismicity for a short period of time due to aftershocks of the $M_L = 6.5$ earthquake in 1948.

The first time period considered is 1932 through 1937. During these four years, activity at the level of $M_L \geq 3.0$ occurs at the rate of 3.2 events per year (see Figure 9a). In this time period, in contrast to presently observed patterns of earthquake location, six events of $3.0 \leq M_L \leq 5.0$ are observed to the southwest of the main trace of the San Andreas between station PSP at Palm Springs and the Salton Sea, while only two events occur in the currently more active region to the northeast of the fault. Location error can not be held accountable as the only cause of this distribution of activity. Perhaps these events are related to the occurrence of the 1937 Terwilliger Valley earthquake ($M_L = 6.$, indicated by the open star along the San Jacinto fault in Figure 9a). This correlation is suggested by the repeated coincidence of events to the southwest of the San Andreas and a large event on the San Jacinto again in the period of time covered by the 1942 Carrizo Mountain $M_L = 6.$ event (see Fig. 9c). However, such a coincidence occurs for neither the 1954 Rabbit Peak earthquake of $M_L = 6.$ or the 1968 Borrego Mountain earthquake of $M_L = 6.0$ which also occurred along the San Jacinto (see Figs. 8a and 8b).

A very low rate of activity characterizes the two years just prior to the 1940 Imperial Valley earthquake (see Fig. 9b). During these two years and three months, 0.9 earthquakes of $M_L \gtrsim 3.0$ occur per year, primarily near the edges of the study region. This rate indicates a period of marked quiescence prior to the large, Imperial Valley event ($M_L = 6.7$) located 100 km to the south. A similarly noticeable quiescence along the southernmost San Andreas fault is seen again just prior to the 1968 Borrego Mountain earthquake.

The time interval from just after the 1940 Imperial Valley event until just before the Desert Hot Springs event in Dec. 1948 ($M_L = 6.5$) is characterized by an activity rate of 5.7 events per year (see Fig. 9c). In contrast to the previous time segment, earthquakes are scattered throughout the study area and there is no observable decrease in the seismicity rate just prior the 1948 Desert Hot Springs earthquake which occurs within the study area. In addition, a relatively high number of events (ten or twelve) locate in the currently active block on the southwest side of the San Andreas between Palm Springs and the Salton Sea. As mentioned earlier, these events occur during a time period co-incident with the occurrence of a major ($M_L = 6.5$) earthquake along the San Jacinto at Carrizo Mountain (located just south of the limit of the seismicity map of Fig. 9c).

Following the Desert Hot Springs event activity appears to "shut off" for the ten years between 1952 and 1962 as if in response to stress redistribution by the 1948 earthquake (see Fig 9d). Activity over this ten year period occurs at a rate of 2.9 events per year, and is located to the north and northeast of the San Andreas. Once again the region between Palm Springs and the Salton Sea is quiet, despite continuing activity along the San Jacinto.

The next time segment for which a uniform rate of activity applies is from 1963 through 1967, during which period activity is very low occurring only at the rate of 0.8 events per year (see Fig 9e). This rate is the lowest of any we have documented for the study region. As discussed, this low rate applies to a time period just prior to the occurrence of a large (M_L = 6.4) event nearby at Borrego Mountain in 1968 (located just south of the southern limit of the seismicity plot in Fig. 9e). It also was during this period of extremely low activity (0.8 events per year) in which the only other micro-earthquake survey we have available for direct comparison to our work was made. Using the same mobile seismographic trailers as used in our work, Brune and Allen (1967) occupied the PAC site, located in the center of our array, for a period of 42 hours of useful recording time. During this time, they observed no events with S - P times $\leq$ 3 seconds or that would be located within 24 km of site PAC. In contrast, for the same location, we observe a relative increase in the number of events, finding on the average, one event every 42 hours. Based on the seismic history of the study region, it appears that the Brune and Allen work is an accurate representation of the activity in the sudy area at that time, and that the increase we observe documents a real change in the seismic activity of this area.

Following the Borrego Mountain earthquake, seismic activity takes on the presently observed configuration (see Fig 9f). Activity occurs at an even pace of 2.9 events per year throughout the 10 year time period. The spatial distributions of the events are also what we have observed in our intensive microearthquake study, being characterized by an absence of activity to the south and west of the San Andreas fault; a general absence of activity along the fault itself; and the occurrence of the major part of the activity to the north and east of the San Andreas.

This examination of the longer term history of seismic activity, using almost 50 years of instrumentally recorded earthquakes along the southernmost San Andreas, indicates a changing nature of activity levels over time. We document 6 levels of activity, all of which occur without major rupture along the San Andreas within the study region. However, several of these changes can also be temporally associated with the occurrence of a large earthquake in a neighboring area. This indicates a very reflective nature of the seismic activity in the Coachella Valley portion of the San Andreas fault. In accord with this is the similarly reflective or sympathetic nature of the geologically observed slip in the Mecca Hills area following the Borrego Mountain and Imperial Valley 1979 earthquakes as discussed in the previous sections.

d. Results and conclusions

The results of our intensive microearthquake study in the Coachella Valley support the consideration of this region as a seismically unique portion of the San Andreas fault, characterized by low rates of earthquake occurrence at the present time, and a tendency to reflect the nature of large earthquake activity in bordering areas. Activity along the San Andres fault through the Coachella Valley is very low compared to other regions for which microearthquake activity levels are known. Of particular interest is the fact that even with mobile seismographic trailer stations auqmenting the permanent network coverage, we do not see activity along the San Andreas.

Earthquake activity in the Coachella Valley exhibits very marked patterns of occurrence. Events tend to be aligned along east-west trending features to the north and east of the San Andreas; essentially no activity is observed to the southwest of the San Andreas; and earthquakes commonly occur in "clusters" of closely related events which occur as very local features along the east-west lineations. Twelve days following the Imperial Valley earthquake of 15 October 1979, the most recent large event near the Coachella Valley, a cluster of 85 events is observed as part of an investigation of "sympathetic slip" noted by geologists. We conclude that although this activity occurs just after the Mexicali event, it does not appear to represent a change from normal seismic activity.

In contrast to the "Big-Bend" region of the San Andreas fault near Palmdale, microearthquake activity in the Coachella Valley does not appear to be exhibiting changes in either the rate of activity or the nature of the clustered activity in response to changes in the regional strain pattern. However, without the microearthquake data of this work, we would have been unable to document this "non-response" since supplemental coverage by the temporary array was necessary in order to make true comparisons between the earthquake data sets.

For the past 10 years, the seismicity of the study area appears to be fairly constant at the level of $M_L \geq 3.0$. However, since 1932, rates of seismic activity in the Coachella Valley have fluctuated from 0.8 events per year to 10.0 events per year. It can be inferred that earthquake activity along this portion of the San Andreas is strongly "sympathetic" to the occurrence of larger events nearby. In two cases, prior to the large events in 1940 and in 1968, a decrease in the rate of seismic activity is observed in the Coachella Valley. In contrast, for the Desert Hot Springs event in 1948, which occurred on the northern edge of the Coachella Valley, no change in the rate of activity is observed prior to the mainshock. However, if a decrease had occurred, it might well have been obscured by the effects of increased seismicity following the 1942 Carrizo Mountain event on the San Jacinto fault. The "sympathetic" reaction of the the southernmost San Andreas fault has also been documented geologically following the Borrego Mountain earthquake of 1968 (Allen, et al., 1972) and again by Sieh (1980) after the recent Imperial Valley shock.

2. Earthquake mechanisms and patterns of seismic activity concurrent with the short-term strain changes in Palmdale, California

Since 1932 when the California Institute of Technology began to catalog instrumental locations of earthquakes in southern California, the section of the San Andreas fault from the Carrizo Plains to Cajon Pass has been seismically quiet. This section of the fault is particularly important because of its known capability for rupture in great earthquakes, such as the 1857 Fort Tejon earthquake of surface magnitude 8 1/4 (McNally et al, 1978). This area has, therefore, been the focus of considerable scientific attention. In addition to the extensive permanent network operated by the U.S.G.S. and the California Institute of Technology, a mobile array of seismographic

trailers was operated in 1976 to 1978 along the "locked big bend" portion of the San Andreas. This year, beginning in February, Caltech again installed the mobile trailers in this area. These are shown in Figure 10 and listed in Table 4. The data obtained from the permanent array and the mobil trailer array have been used in this study to examine seismicity patterns and to determine focal mechanisms from P-wave first motions of the larger events (ML>2.0).

Frequently repeated strain measurements have been obtained since

1971 using the trilateration networks shown in Figure 11. From the Palmdale network it has been found that in addition to the uniform accumulation of right-lateral shear strain, there have been significant flucuations in the N-S strain measurements and since 1978 some significant flucuations in the E-W strain measurements. The focal mechanisms determined in this study have been used to check for any correlation with these strain changes.

Of additional interest is to further document and to look for systematic changes in focal mechanisms from the same source region as reported by McNally et al, 1978.

a.Seismicity

Figures 12,13,14, and 15 show epicenters of all earthquakes located by the California Institute of Technology (C.I.T.) on a yearly basis for the years 1977-1980 which occurred within the boxed area shown in Figure 16. The 1980 catalog is still preliminary; meaning that hypocentral locations are subject to slight modification, quarry blasts have not been removed, and magnitude determinations for the smaller events are incomplete. For this same time period a time/distance plot of epicenters located in box A and box B (given in Figure 16) have been projected onto a line which begins at 34 ,116 55′ (Figure 16).

The seismicity data during this time period shows two interesting features. One feature is the dispersion of earthquake activity away from the initial locations of a swarm in the Juniper Hills area. The dispersion of microearthquake activity has been documented by Drowley and Mcnally, 1980, and is shown in Figure 18 and 19. Southeast migration of the larger events along the San Andreas is additionally suggested by the time/distance plot (Figure 17). The second feature of interest is the quiescence which is observed NW and SE of the Juniper Hills area at the beginning of 1979. This quiescence seems to coincide with rapid extension observed in the Palmdale network (Figure 20). Quiescence in the Lake Hughes area is still being observed.

As one of the primary aims of this study was to examine focal mechanisms through the observed stain changes, events in the central Juniper Hills region were initially determined. Focusing on this area was a first priority as earthquake activity ceased to the NW and SE. Focal mechanisms for events of ML>2.0 were determined for the area shown in Figure 15 with the exception of 4 events which occurred on December 13, 1976, March 7, 1977, March 12, 1977 and December 11, 1977.

Focal Mechanisms

To determine the focal mechanisms, arrival times and first motions were first read from computer-stored seismographic traces from the

Caltech Earthquake Detection and Recording (CEDAR) system or from 16mm/develocorder film viewed at a scale of 1 sec/cm (events which occurred before the June 1978 event). These data were supplemented in many cases by readings from the MOBILE TRAILER ARRAY and helicorder paper records.

The events in this study were located using the computer program HYPO78 with a horizontally-layered crustal model. The model used was; 5.5km/sec for depths 0 to 5.5km, 6.3km/sec for depths of 5.5 to 16.0 km and 6.7km/sec for depths 16.0 to 37.0 km (Hadley and Kanamori, 1977). Only stations within 60 kms of the epicenter were used in order to maximize the depth resolution. Reduced travel time ($T-\Delta/6.0$) was then plotted versus distance, Δ, using the program QBLAST (a Caltech program developed by Victor Lamanuzzi). An interpretation of each plot was made in terms of the Hadley-Kanamori model and station corrections from Reiches,1978 were applied using the method given by Pechmann, 1980. Travel time information was then used to individually assign take-off angles for each station.

From the P-wave first motion information nodal planes were determined with the aid of the computer program FOCPLT developed by Whitcomb and Garmany (Whitcomb, 1973). This program computes the number of stations in error for all possible solutions spaced at approximately 5 intervals using linear weighting taper on all stations within 3 of the nodal plane. Mechanisms determined in this study along with Palmdale area mechanisms from Pechmann, 1978 are shown in Figures 21, 22, 23, and 24 with the events listed in Table 5.

Focal mechanism associated with the San Andreas fault or conjugate faults do not show consistent right-lateral mechanisms. Instead mechanisms vary from strike slip to strike slip with a thrust component to pure thrust and dip slip. Additionally for event #14 a left-lateral event was found.

Focal mechanisms, also vary in the temporal domain for events from the same source region. As initially reported by McNally et al,1978, the Juniper Hills swarm (#'s 3,4,5,6,7,8,9,10,12) occurred within a 1-2km source region from December 13,1976 to April 27,1980. The early events in this sequence have right-lateral strike slip mechanisms. The mechanisms then systematically change to pure thrust starting with event #7, March 5,1977. The April 27, 1980 event which occurs 2 years later in this same region shows a right-lateral mechanism.

A similar temporal pattern of change in mechanism from strike slip to thrust was observed in events 15 to 19. Station polarities for this mainshock- aftershock sequence were examined to determine if the apparent change in mechanism could be verified on individual stations. Station polarities for the August 28,29, and 30 events were similar but a change in polarity for several stations occurred during the September 3 event.

c. Discussion

If we assume consistent locations for the Juniper Hills swarm events and August-October 1979 mainshock-aftershock sequence, the temporal change in the mechanims may reflect changes in the local stress field. To check this hypothesis horizontal strain measurements from the Palmdale and Cajon Trilateration networks were examined (Savage et al, 1980). These are plotted along with representative focal mechanisms on a time/distance plot. Because events in this focal mechanism study are located between the two networks, the local stress field can only be approximated by what is observed to the NW and SE. Additionally, since only horizontal strain at the surface has been measured the stress fields at depths of 6-10km may be significantly different. Because more frequent measurements have been made on the Palmdale network the focus of temporal strain changes will be examined there.

During the period of this study, shear strain (γ_1') showed fairly uniform right-lateral accumulation (Savage et al, 1980) as is shown in Figure 19 for the Palmdale network. Although the along strike component of strain shows some marginally significant flucuations especially after 1978 the observed strains all remain within two standard deviations of a mean value The anomalous strain accumulation is shown principally in the

N-S component normal to the fault (ε_{22}). From 1974-1978 there is a steadily increasing contraction, then from February - November 1979 an apparent sudden extension was followed by contraction in late 1979 and early 1980. In general, dilatation (Δ') mimics this component; thus, illustrating the importance of this component. The fault mechanisms were therefore compared to the N-S component which varies most significantly with time.

During periods of relative N-S contraction it is possible the stress field would be more favorable to thrust type mechanisms with roughly E-W axial planes (see events #9,11,12 & 19). With a lessening of the normal component during periods of relative N-S extension a stress field which is more favorable to strike slips events may exist (see events #13,14,15, & 20).

d. Conclusions

In summary, results of a study of focal mechanisms from the Juniper Hills, California region suggest a relationship between temporal changes in N-S strain observed at the U.S.G.S. Trilateration Network at Palmdale, California for the time period of 1977-1980. The temporal changes of fault mechanism from strike-slip to thrust which has been observed for the swarm sequence at Juniper Hills (and back to strike slip for this sequence) and the August - October 1979 mainshock-aftershock sequence which occurred about 25 km to the ESE may also be related to these strain changes. Dispersion to the SE of the larger events (ML>2.0) along the San Andreas has additionally been observed.

3. Investigation of the spatial and temporal characteristics of aftershock sequences following $M_L > 6.0$ earthquakes in Southern California

In major earthquake sequences, Richter (1958) has suggested that relatively large, late-occurring aftershocks are not uncommon. When aftershocks have apparently subsided, what appears to be an unusually large event occurs unexpectedly. Such an event often has its own aftershock series. We have evaluated time, space and magnitude relationships of mainshock-aftershock patterns for twelve large, ($M_L \geq 6.0$) earthquakes which have occurred in Southern California since 1932 in order to establish a firm empirical basis for this evaluation. We then consider the discernible patterns and regularities, in the study of an ongoing mainshock-aftershock sequence in Southern California, that of the 15 October 1979 ($M_L = 6.6$) Imperial Valley earthquake.

Several examples of earthquakes followed by large, late occurring aftershocks were suggested by Richter (1958). These include the Santa Barbara earthquake of 29 June 1925 (Rossi-Forel intensity IX $M_L = 6.3$, according to Townley and Allen, 1939, see Figure 26) which was followed by a large, late aftershock (intensity VII to VIII), which occurred one year later to the day and was called the "anniversary shock". The Long Beach earthquake (1933, $M_L = 6.3$), was followed by two large aftershocks to the north at Signal Hill ($M_L = 5.4$) and Torrance ($M_L = 5.4$), occurring at intervals of 7 and 108 months, and 30 and 33 km away, respectively. In the large Kern Co. series in 1952, ($M_L = 7.7$, 6.4, 6.1, 6.1) there were no shocks of $M_L \geq 5.0$ from August 22, 1952 to

January 12, 1954 at which time an earthquake of M_L = 5.9 occured almost precisely at the epicenter of the main earthquake of 21 July 1952. A similar aftershock pattern was observed for the Hawkes Bay, New Zealand earthquake of 2 February 1931 (M_L = 7.9), which was followed by the Wairoa earthquake of 15 September 1932 (M_L = 6.8), some distance away (Richter, 1958).

All earthquake sequences associated with events of M_L > 6.0 which are listed in the Caltech southern california catalogue and which occur in California are considered in this observational study (see Figure 26). These include the Long Beach 1933, Terwillinger Valley 1937, Imperial Valley 1940, Carrizo Mountain 1942, Walker Pass 1946, Manix 1947, Desert Hot Springs 1948, Kern County 1952, Rabbit Peak 1954, Borrego 1968, San Fernando 1971 and Mexicali 1979 earthquake sequences. Our results indicate that large, late aftershocks have occurred in 64 percent, or 7 out of 11, of the sequences associated with M_L > 6.0 earthquakes since 1932 and prior to 15 October 1979. The magnitudes of all large, late aftershocks appear to be M_L - 5.0, although we have examined Omori-type decay curves for all events in order to verify that sequences which apparently lack large, late aftershocks are not actually disturbed by late events of M_L < 5.0.

As tabulated by Table 6, the average separation in time between the mainshock and the large, late aftershock is 38 months, with a range of 7 months to 108 months. Both of these extreme values were observed for the Long Beach 1933 sequences. The mean distance separating a mainshock and its large, late aftershock is 34 km. The average difference in magnitude between the mainshock and its large, late aftershock is 1.5

units of magnitude. The large magnitudes of the Kern Co. sequence cause this value to be high; if the Kern Co. values are removed, the average difference in magnitude is 1.2. This agrees well with the average difference in magnitude between a mainshock and its largest aftershock found by Båth and Benioff (1952).

Thus, it appears that the phenomenon of large, late aftershocks is significant in southern California and must be considered in the development of models of aftershock occurrence. Other $M_L > 6.0$ events which have occurred in the surrounding regions of Mexico, Nevada and central California are also reviewed. However, only limited data are available from the Caltech catalogue for these events, making it difficult to obtain truly comparable results.

a. Southern California Data Events with Large, Late Aftershocks

We have considered every event with $M_L \geq 6.0$ in the southern California region defined by Hileman et al. (1973), which has occurred from 1932 to date in establishing an empirical base with which the occurrence of other large, late aftershocks can be compared (see Figure 25). Major features of aftershock activity observed for these sequences are discussed in the following paragraphs. A catalogue of specific mainshock and aftershock data is contained in Table 6. Aftershock areas in each case are based on seismicity maps from the Caltech southern California catalogue for the years immediately following the mainshock, and are considered to be those regions about each mainshock which experienced an increase in activity in response to the main event. For each of the mainshock-aftershock series studied, a number of representations of the aftershock data were examined including: 1) seismicity maps of the mainshock-aftershock areas (see Figures 26a-g, 30a-d, 10a); 2) time-distance plots of earthquakes along the rupture zone (see Figures 27a-g, 30a-d, 10b); 3) changes in the seismic moment of the aftershock area as a function of time (see Figures 28a-f, 33); and 4) cumulative plots of the numbers of events occurring in the aftershock area for up to 10 years following the main event (see Figures 29a-g and 32a-d).

a.1 Long Beach, 1933

Two large, late occurring aftershocks are a part of the Long Beach earthquake sequence. This destructive shock on 10 March 1933 (M_L = 6.3, M_{KJ} = 6.3; where used, M_{KJ} indicates a Kanamori and Jennings, 1978, magnitude calculation) was followed immediately by aftershocks along the Inglewood fault zone. The Long Beach sequence is illustrated in Figure 26a, which indicates the relative positions of the mainshock and the two aftershocks. The mainshock was followed by two events to the north, which we suggest as large, late aftershocks. The first of these, at Signal Hill (M_L = 5.4), occurred 7 months later at a distance of 30 km from the mainshock. A second large, late aftershock (M_L = 5.4) occurred near Torrance 33 km away, 108 months after the mainshock. The temporal and spatial relationships of the mainshock and the two large, late aftershocks are illustrated by the time vs. distance plot of Figure 27a. Moment plotted as a function of time for the Long Beach series illustrates that significant changes in the moment can be observed in association with each of these aftershocks (see Figure 28a). We have also compared the numbers of aftershocks in each of our sequences to expected rates of aftershock activity as described by Omori (1900), the graph of which is a hyperbolic decay curve. In the Long Beach series, a smooth decay curve is disturbed by an increase in the number of events assocated with the large, late aftershock (see Figure 29a). In these figures, both the importance in size of the two large, late aftershocks and their separation in time relative to immediate aftershocks of the Long Beach 1933 event are made apparent.

a.2 <u>Terwilliger Valley, Imperial Valley, Carrizo Mountain 1937, 1940, 1942</u>

The mainshock and aftershock distributions of the Imperial Valley 1940, Terwilliger Valley 1937, and Carrizo Mountain 1942 earthquakes are complex due to the close spatial and temporal relationship of these events. Therefore, difficulties are encountered in separating these sequences in time and space. Seismicity plots of each of these series are shown in Figures 26b, c, d.

One potential, large, late aftershock to the Terwilliger Valley earthquake (25 March 1937, $M_L = 6.0$), occurs 62 months later and 53 km to the southeast elong the San Jacinto fault zone (see Figures 26b and 27b). However, this event ($M_L = 5.0$, 23 May 1942) occurs almost at the epicenter of and only 5 months prior to the Carrizo Mountain 1942 mainshock. The total moment of the aftershock area of the 1937 event is increased by this event as shown by Figure 28b. It is difficult, if not impossble, to identify this event as an aftershock or a foreshock to either of these series. Given that no information requires otherwise, we consider it reasonable to suggest this event is an aftershock to the Terwilliger Valley mainshock.

The most destructive event in the aftershock sequence of the 19 May 1940 Imperial Valley occured at Brawley, one and one-half hours after the mainshock. Despite problems with their spatial and temporal proximity to the 1937 and 1942 events along the San Jacinto fault, two earthquakes could be suggested as large, late aftershocks of the Imperial Valley 1940 mainshock (see Figure 26c). The earliest of these occurs 23 May 1942, but as discussed above, this earthquake could better be considered an aftershock of the 1937 Terwilliger Valley event. A second candidate large, late aftershock is located in the Salton Sea (22 October 1942, M_L = 5.5), 71 km northwest of the Imperial Valley mainshock (see Figure 27b). This suggestion is made on the basis of the currently recognized seismic connection between the Imperial and the San Andreas faults. However, the choice of this event in 1942 as a large, late aftershock to the Imperial Valley 1940 mainshock is ambiguous due to the temporal coincidence between this aftershock and the Carrizo Mountain mainshock, i.e., 1 day apart (see Figure 27c). The effect of the 22 October event on the cumulative moment released by the Imperial Valley 1940 earthquake and subsequent aftershocks is also obscured by this temporal coincidence (see Figure 28c).

The 21 October 1942 (M_L = 6.5) Carrizo Mountain sequence shares the above mentioned difficulties in distinguishing separate features. This event, the latest of the three earthquakes in the region at that time, appears to have two large, late occurring aftershocks (see Figures 26d and 27d). An aftershock occurs to the north of the mainshock at a distance of 30 km within 3 years. A second aftershock occurs 16 km to the east of the mainshock in 3 years and 3 months (see Figure 26d). These two earthquakes sharply increase the total moment in the aftershock area as illustrated by Figure 28d. A large shock in the Salton Sea occurs one day after the 1942 mainshock, however, as discussed in the previous paragraph, this event is being considered as a lage, late aftershock of the Imperial Valley 1940 event.

Normal patterns of the decay of aftershock activity which could be indicated by the nmbers of events following each of the 1937, 1940 and 1942 mainshocks (see Figures 29b-d) are also indistinguishable because of the close spatial and temporal occurrence of these earthquakes.

a.3 <u>Kern County 1952</u>

The largest sequence studied is the Kern County 1952 series. In this series, (see Table 1 for complete details), the first event M_L = 7.7 occurs at the southern end of the main rupture zone. It is followed shortly by two events also of M_L - 6.0 at the northern end of the zone (see Figure 26e and Table 5). The aftershock responsible for most of the damage at the city of Bakersfield occurred 7 weeks after the first Kern Co. event. This "Bakersfield shock" on 22 August 1952 has a M_L = 5.8. Three aftershocks of $M_L > 5.0$ occur late, from 1954 through 1961. The largest, late aftershock which is located more than 8 km from the mainshock occurs on 27 January 1954 (M_L = 5.0) 40 km northeast of the first shock (see Figure 27e). This aftershock occurs midway between the endpoints of the rupture area, in a region which is not the site of other major activity. Following this aftershock, activity is observed to "shut off" in this area while the northern and southern ends of the rupture zone remain active (see Figure 27e), as if the large, late aftershock had relieved stress along this part of the fault.

Also in January 1954, an event of M_L = 5.9 occurs at the site of the M_L = 7.2 mainshock. This event does not occur away from the mainshock, however, both it and the mainshock occur at the south end of the original aftershock area. The effect these two events in January 1954 have on the total seismic moment of the Kern Co series is shown in Figure 27b. In this plot of moment released per month during 10 years after the mainshock, the largest addition to the original energy released during July and August 1952 is the increase of January 1954 (see Figure 28e).

a.4 <u>Rabbit Peak 1954</u>

The Rabbit Peak (19 March 1954, M_L = 6.2) sequence occurs along the San Jacinto fault in the same general region as the Terwilliger Valley 1937, and Carrizo Mountain 1942 events, but is sufficiently isolated in time for two, large, late aftershocks to be clearly identified (see Figure 26f). Both occur in 1957. The first late, large aftershock occurs 33 km away along an extension of one segment of the San Jacinto from the mainshock (25 April 1957, M_L = 5.1). This event is followed a month later by a second aftershock (26 May, 1957, M_L = 5.0), located midway along the same extension of the San Jacinto fault between the mainshock and the first, large, late aftershock (see Figures 26f and 27f). The disturbance those two events cause to the decay of aftershock activity is seen by the sharp increase in the number of aftershocks in 1957, shown in Figure 29f.

a.5 Borrego Mountain 1968

The large, late aftershock pattern is strongly developed in the Borrego Mountain 1968 earthquake series (see Figure 26g). Extensive investigation of the relationships between the mainshock and the larger of two late aftershocks has been made by Thatcher and Hamilton (1973). Following the mainshock, an aftershock occurred 26 km to the northwest at Coyote Mountain, after an interval of 12 months (28 April 1969, M_L = 5.8). This has been identified as an abrupt northwesterly extension of the Borrego Mountain 1968 aftershock zone by Thatcher and Hamilton (1973). The Coyote Mountain event was located in an area where aftershock activity of the 1968 event was low (Thatcher and Hamilton, 1973). These authors consider that microearthquake recordings of Coyote Mountain aftershocks indicate that this large, late event resulted primarily from sudden growth of the zone involved in the Borrego Mountain shock. Two and one-half years later, a second break (30 September 1971, M_L = 5.1), occurred 34 km to the southeast, 41 months after the mainshock. A time-distance plot of this series clearly indicates the separation in time and distance of these breaks to the northwest and southeast, away from the mainshock (see Figure 27g). The relationship of these two aftershocks to the space-time and moment-time history of the Borrego Mountain sequence is illustrated by Figures 27g and 28f. The later aftershock of 1971, most perturbs the decay of aftershock activity as shown in Figure 29g.

b. Sequences Without Large, Late Aftershocks

Large, late aftershocks are not associated with all of the earthquakes of M_L > 6.0 which have occurred since 1932 in the southern California region. In this section we describe the mainshock-aftershock patterns of these events and describe, where possible, why large, late aftershocks are not observed. Additional data for these events can be found in Table 6.

b.1 Walker Pass 1946

On 15 March 1946 a shock of M_L = 6.3 occurred along the Sierra Nevada fault, north of its intersection with the Garlock fault (see Figure 30a). Five aftershocks of M_L > 5.0 followed within 4 days, after which no further aftershcks with M_L > 5.0 occur. A time-distance plot of this sequence (see Figure 31a) indicates that aftershock activity continues through 1951 in this region, with an event in 1948 occurring some distance away from the mainshock. However, the largest of these late aftershocks is M_L = 4.6, and as observed in Figure 32a, a normal decay curve for aftershock activity is not significantly disturbed by these events.

b.2 Manix 1947

No large, late occurring aftershocks are observed in the seismicity patterns of the 10 April 1947, Manix event (M_L = 6.2, see Figure 30b). Three aftershocks of $M_L > 5.0$ occur, all within 24 hours of the mainshock. Of these immediate aftershocks, none are located more than 5 km from the mainshock (see Figure 31b). As is shown by Figure 32b, the number of aftershocks to the Manix event decays by 1951 without being perturbed by late occurring events.

b.3 Desert Hot Springs 1948

The Desert Hot Springs earthquake (4 December 1948, M_L = 6.5) and its aftershock series do not contain a large, late aftershock of the type we have been studying (see Figures 30c, 31c and 32c). Overall, the sequence is smaller than the others examined, and no aftershocks with magnitudes greater than 5.0 are observed. Neither do any earthquakes of M_L - 5.0 disturb the graph of normal aftershock decay (see Figure 32c). Richter et al. (1958) report that in contrast to what is shown in Figure 31c for events of $M_L < 4.0$, when considered at all magnitude levels, aftershock activity appears to concentrate toward the ends of the aftershock area.

b.4 San Fernando 1971

No large, late aftershock appears as part of the San Fernando earthquake activity (9 February 1971, M_L = 6.4, see Figures 30d, 31d, 32d, and 33). In the five years following the mainshock, only one aftershock of M_L = 5.0 occurs at any distance from the mainshock. This event, at a distance of 10 km, occurs only 40 minutes after the mainshock (9 February 1971, M_L = 5.2). Three other aftershocks of $M_L \geq$ 5.0 occur within 10 minutes of the mainshock, but, unfortunately, the exact positions of these events are questionable as they are given D quality locations and placed at the mainshock epicenter (Hileman, et al., 1973). Analysis of the source spectrum of the San Fernando mainshock by Das and Aki (1977) indicates that this event has barriers which were not broken in the mainshock. However, there is no indication of a large, late aftershock in this sequence to date, as indicated by the plot of cumulative energy release in the mainshock-aftershock area (see Figure 33).

c. Results, Applications and Discussion

These examples indicate that late, large aftershocks are observed for a significant number of mainshock-aftershock sequences in southern California. It is important, then, to consider the empirical regularities and patterns established in our seismicity studies as a factual basis for the development of theoretical models of earthquake occurrence. In addition, these regularities and patterns should be considered in the evaluation of ongoing earthquake sequences, particularly in southern California where their significance has just been shown.

Comparison of these characteristics of large, late occurring aftershocks to the 15 October 1979, M_L = 6.6, earthquake along the international border near Mexicali has been a major goal of this study. All aftershocks through the end of 1979 with $M_L > 4.0$ from the CIT catalogue are plotted in Figure 10. In addition, an event which occurred on the San Jacinto fault on 25 February 1980 is shown. We have attempted to determine whether this event is the large, late aftershock which might be expected in this series. When comparisons are made to the characteristics observed for other large, late aftershocks, the 25 February 1980 event, also known as the Turkey Track or Hemet event, is rejected and not believed to be the expected large, late aftershock. This rejection is based on: a) timing, the event occurs too early in comparison to the other examples, b) distance, the Hemet event at some 120 km distance is much further away than others observed in southern California, although a large, late aftershock occurred nearly 124 km away from the 1956 mainshock in northern Mexico, and c) the occurrence of this aftershock on the San Jacinto rather than on the Imperial or the San Andreas faults.

In southern California, two additional events of $M_L > 6.0$ provide ongoing experiments to test the regional significance of large, late occurring aftershocks although these recent events near Mammoth Lakes (25 May 1980, M_L = 6.5) and in the Cerro Prieto region (9 June 1980, M_L = 6.1) occur near the border of the study region. Our review of the nature of earlier sequences in both locations, indicates that large, late aftershocks occurred in each region in the past and can be expected in the current series.

d. Conclusions

The high quality and large quantity of data contained in the southern California catalogue (Hileman et al., 1973 and subsequent editions) demonstrate that in at least one seismically active area for which an extensive 50 year data set is available, 7 out of 11 aftershock sequences or 64 percent of those for earthquakes of $M_L > 6.0$ contained large, late occurring events of $M_L > 5.0$. Thus, in southern California, the occurrence of large, late aftershocks is considered significant throughout the region. It follows that such shocks can be identified as particularly likely in those local areas which have previously exhibited such patterns, e.g., the Imperial Valley, the southern San Jacinto fault, and northern Mexico. For this reason, three areas in southern California merit special consideration at this time with regard to expected aftershocks. These include the aftershock regions of the 15 October 1979 ($M_L = 6.6$) earthquake, the Mammoth Lakes earthquake aftershock area (25 May 1980, $M_L = 6.5$), and the region of the 9 June 1980 ($M_L = 6.1$) earthquake in northern Baja along the Cerro Prieto fault.

Analyses such as ours provide a firm empirical basis against which the models suggested in theoretical works on aftershock occurrence can be tested. In this light, further study of the rupture patterns of these three events should be undertaken in a specific effort to predict the approximate location and size of the expected aftershocks.

Figure Captions

Figure II- 1. Seismicity of the southernmost portion of the San Andreas fault and surrounding regions at the level of M_L - 4.0. (Data from Hileman et al., 1973 and later editions).

Figure II- 2. Earthquakes located between January and June 1979 by the Caltech Southern California automated detection and recording system.

Figure II- 3. Earthquakes located between January and June 1979 through use of data from the mobile seismographic trailer station array. Earthquakes are located using the standard southern California velocity model of Hadley and Kanamori.

Figure II- 4. CEDAR events and events from the microearthquake study. Earthquakes from our study are located using an average crustal velocity model worked out for the Coachella Valley in this work.

Figure II- 5. Focal mechanisms for selected events of M_L - 2.2 in the Coachella Valley before the installation of our microearthquake array (1977 and 1978).

Figure II- 6. Focal mechanism solutions for all events of M_L - 2.2 occurred in the Coachella Valley during the the operation of the trailer array. Shaded quadrants are compressional.

Figure II- 7. Seismic activity observed during a one week special study subsequent to the 15 October 1979 earthquake. Seismicity patterns closely follow those observed in the previous microearthquake work. Data from both MEQ800 stations (elongated X's) and the standard Caltech operating system (smaller x's) are indicated.

Figure II- 8a. Cumulative plot of activity in the Coachella Valley between 1932 and 1948 from the Caltech southern California earthquake catalogue. Two curves are shown, one containing all events (upper curve) and a second curve (lower curve) in which only the first event of any clustered sequence is included. Approximate slopes are fit to the unclustered curve with associated rates of activity indicated for each fluctuation.

Figure II- 8b. Cumulative plot of activity in the Coachella Valley between 1950 and 1979.

Figure II- 9a. Earthquakes of M_L - 3.0 located along the southern San Andreas fault for the years 1932-1937. The dashed box outlines the area on which the rates of activity for Figures 8a and 8b are based. See text for a discussion of the seismicity patterns observed.

Figure II- 9b. Seismicity map for 1938 - Mar 1940. Other details same as Figure 9a.

Figure II- 9c. Seismicity map for April 1940 - Oct 1948. Other details same as Figure 9a.

Figure II- 9d. Seismicity map for 1952 - 1962. Other details same as Figure 9a.

Figure II- 9e. Seismicity map for 1963 - 1967. Other details same as Figure 9a.

Figure II- 9f. Seismicity map for 1968 - 1979. Other details same as Figure 9a.

Figure II-10. Location of the mobile trailers, Palmdale, Ca.

Figure II-11. Map of southern California showing the locations of the seven trilateration networks and the average principal strain rates measured at each. Each network is identified by name, period covered by the surveys, and the principal strain rates (extension reckoned as positive) in microstrain/a. The directions of the principal strains are indicated by the diagram beside each label. The heavy sinuous lines represent the major faults.

Figure II-12. Distributions of epicenters for the Big-Bend section of the San Andreas fault in 1977.

Figure II-13. Epicenters for 1978.

Figure II-14. Epicenters for 1979.

Figure II-15. Epicenters for 1980.

Figure II-16. Index map of the Big-Bend section of the San Andreas. Box "A" is used for figures 12 through 15. Box "B" is used for the map projection of figure 17. Also shown is the area of the focal mechanism study.

Figure II-17. Spatio-temporal variation of seismicity in the area of Box "A" and "B" as shown in Fig. 16.

Figure II-18. Relocations of microearthquake seismicity using linear velocity gradient over dipping half space model (from Drowley and McNally, 1980). Line AB is used for the time-distance projection in Figure 19.

Figure II-19. Time-distance seismicity projection along line AB (Fig. 18) Nov. 1976-Nov. 1978. Juniper Hills swarm occurs near center of figure and subsides with time as activity disperses along the fault east and west.

Figure II-20. Spatio-temporal variation of seismicity for an area along the San Andreas from 50km SE of Cajon Pass to 50km NW of station LHU. Representative focal mechanisms for the larger events are given by the numbers listed in Table 2. Three components of strain for the Palmdale geodolite network (above mechanisms) and one component for the Cajon geodolite network are plotted against time.

Figure II-21. Focal mechanism solutions for events at locations shown on map.

Figure II-22. Focal mechanisms for events plotted.

Figure II-23. Focal mechanisms for events plotted.

Figure II-24. Focal mechanisms for events plotted.

Figure II-25. Earthquakes of magnitude 6.0 and greater in the southern California region 1912-1971.

Figure II-26. Seismicity maps for mainshock-aftershock sequences with large, late aftershocks.

Figure 1.

SEISMICITY 1932-1979 M≥4.0

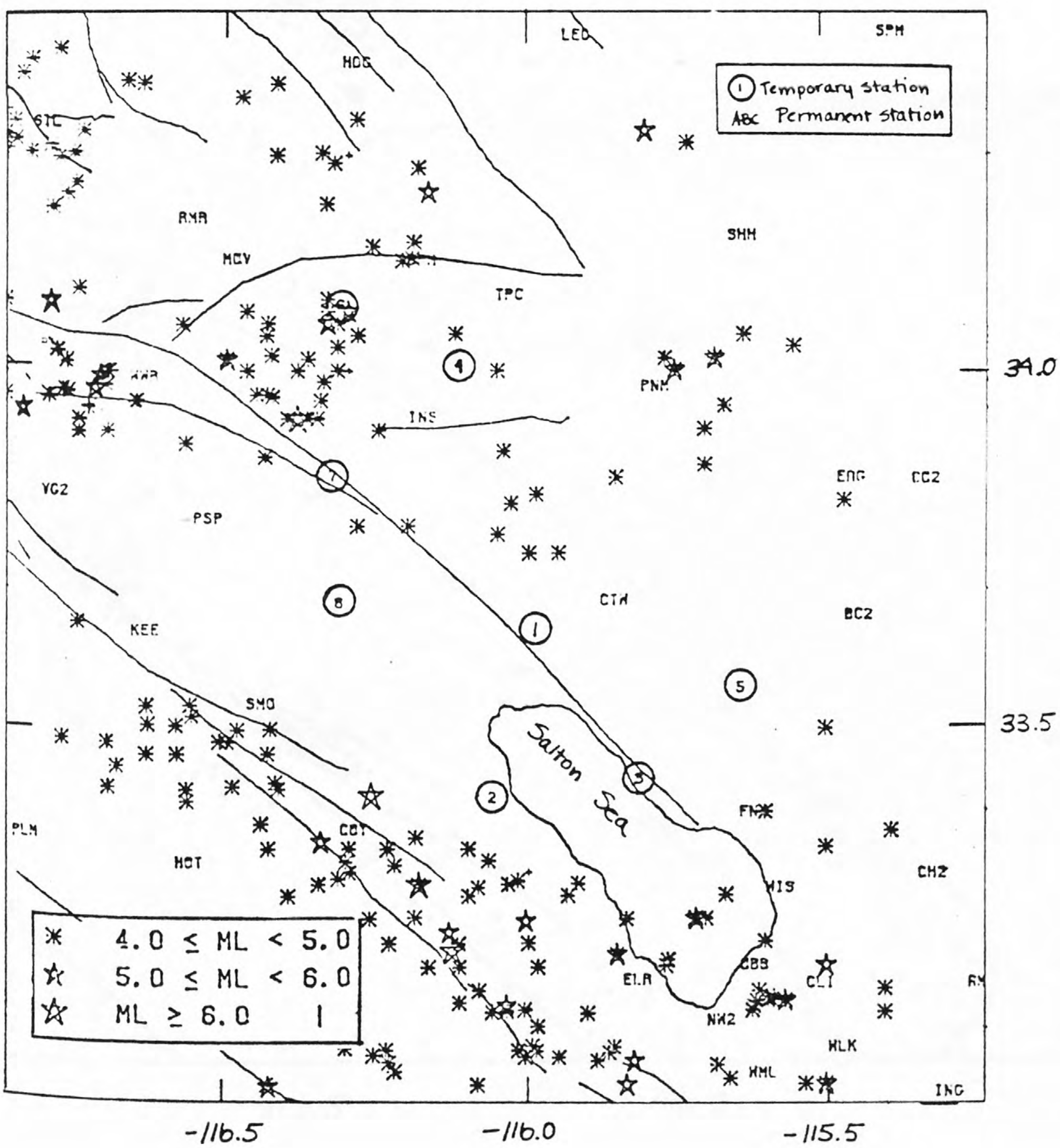


Figure 2

1 January – 30 June 1979

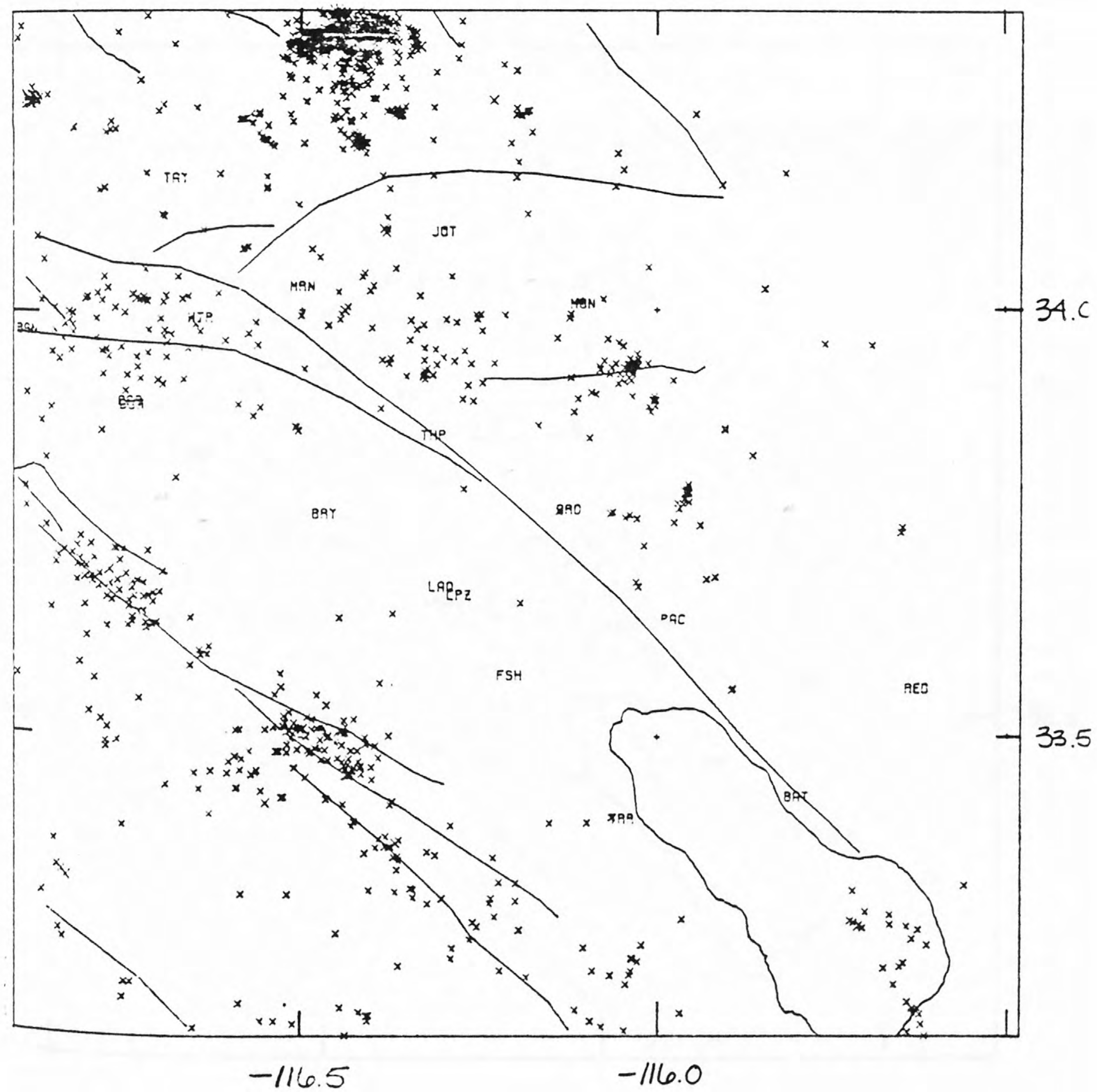


Figure 3

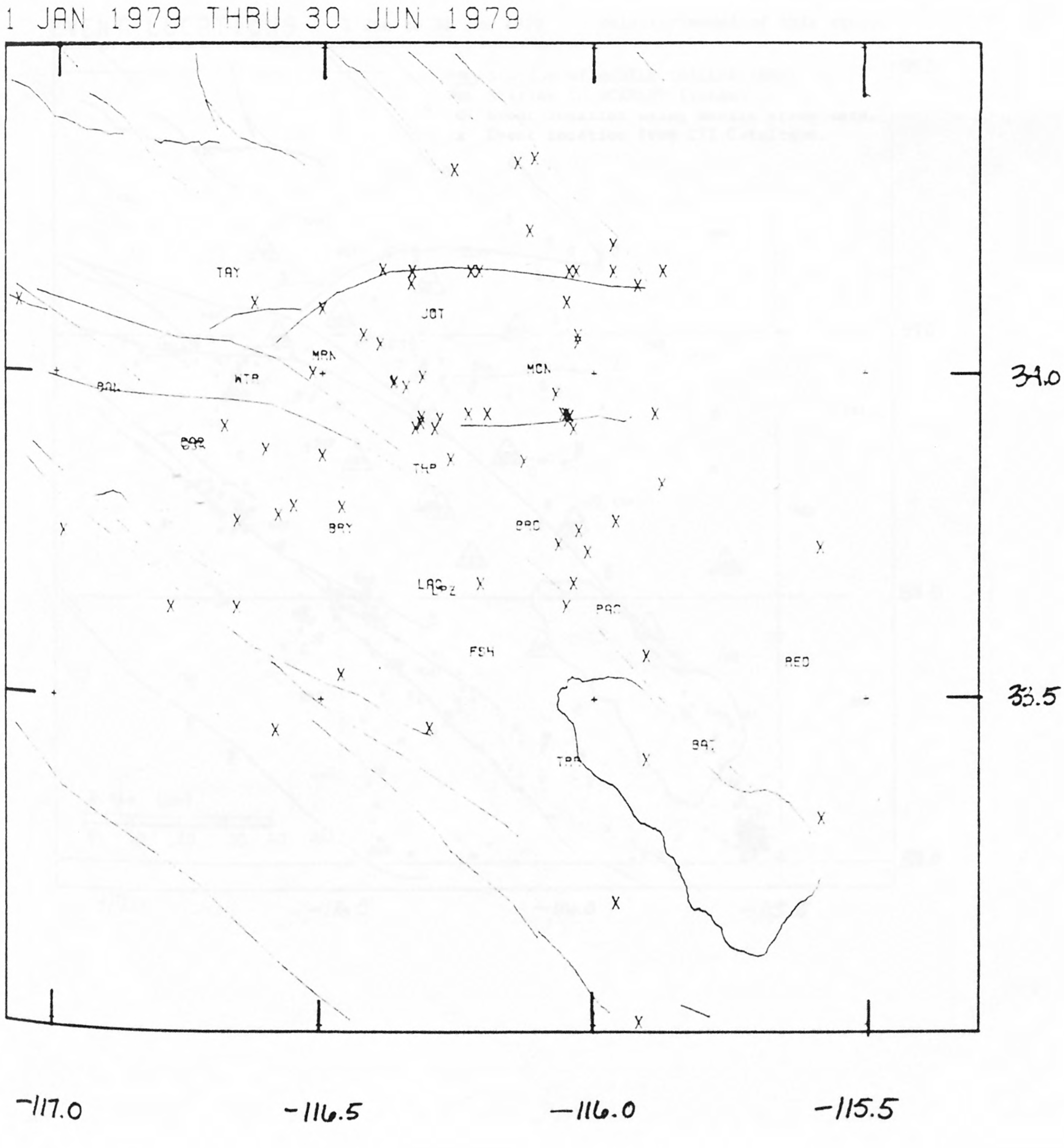

1 JAN 1979 THRU 30 JUN 1979
TAY
JOT
MRN
MCN
WTR
THP
BRY
FSH
RED
34.0
33.5
-117.0
-116.5
-116.0
-115.5

Figure 4

EVENT LOCATIONS 1 Jan to 31 Jun 1979 Velocity model of this study.

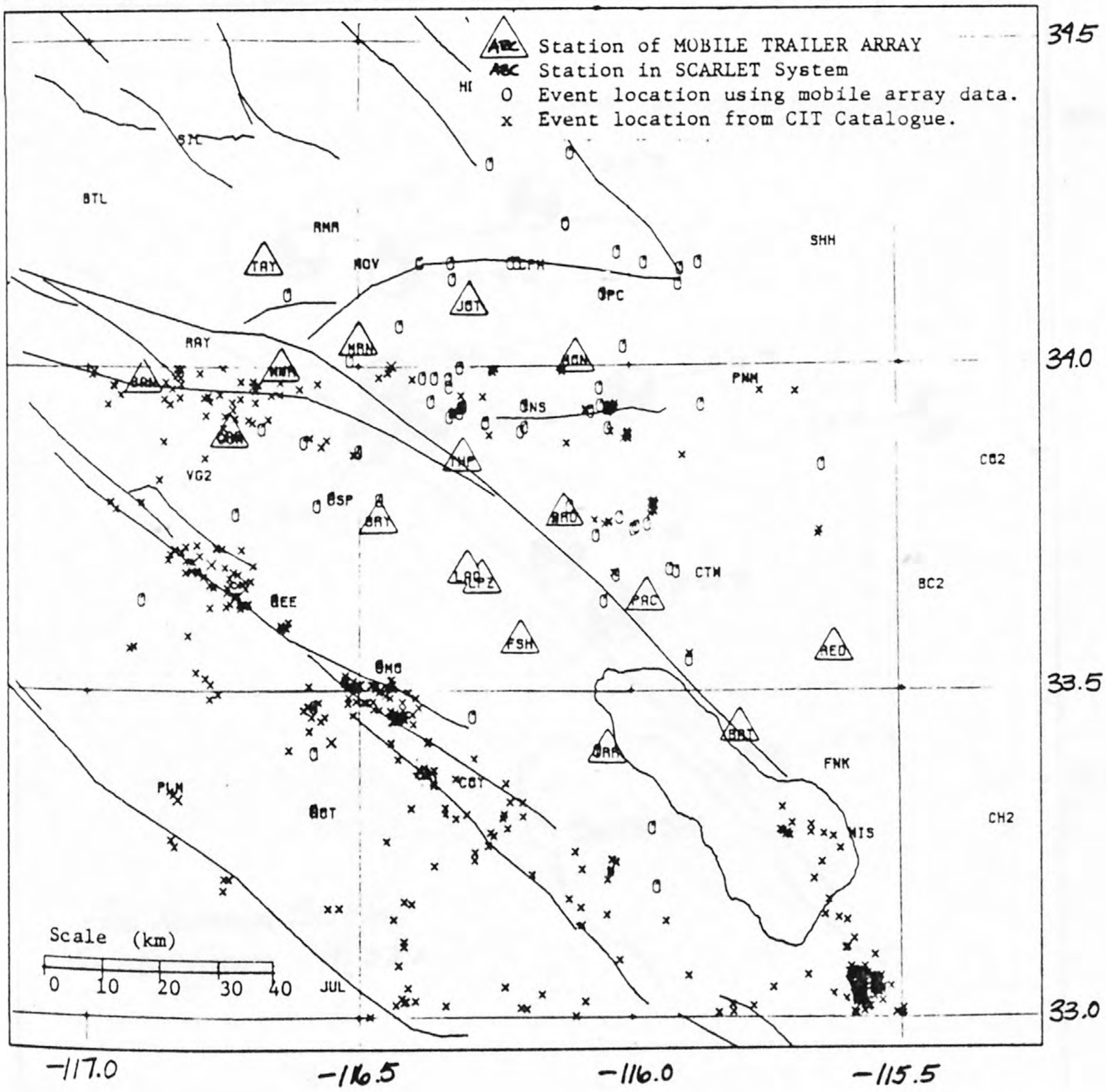
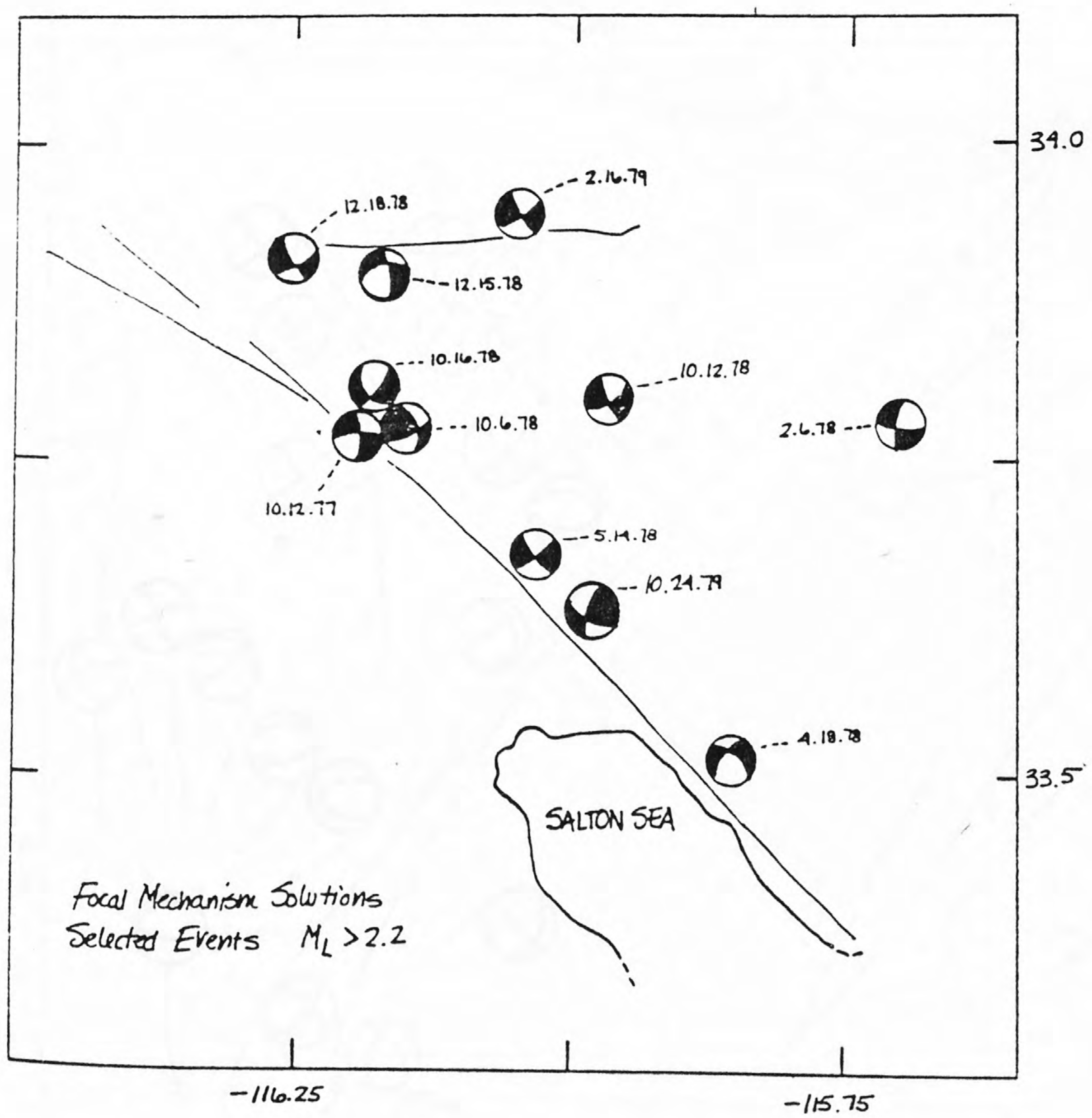


Figure 5


34.0
33.5
-116.25
-115.75
12.18.78
2.16.79
12.15.78
10.16.78
10.12.78
10.6.78
2.6.78
10.12.77
5.14.78
10.24.79
4.18.78
SALTON SEA
Focal Mechanism Solutions
Selected Events $M_L > 2.2$

CIT LOCATIONS 2/79 -- 9/79

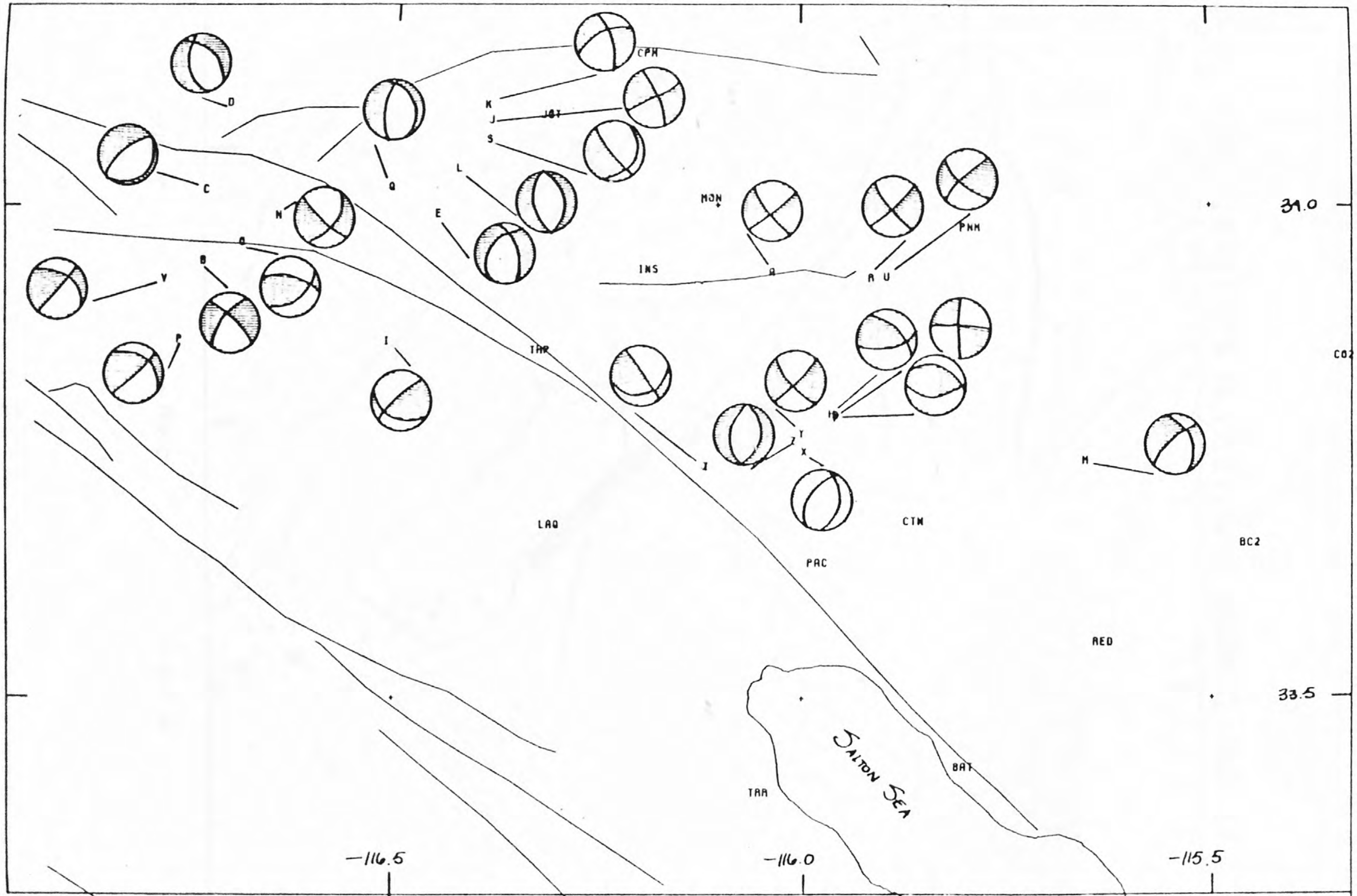


Figure 6

Figure 7

10-24-79 THRU 10-31-79 ALL EVENTS MEQ800 AND CIT

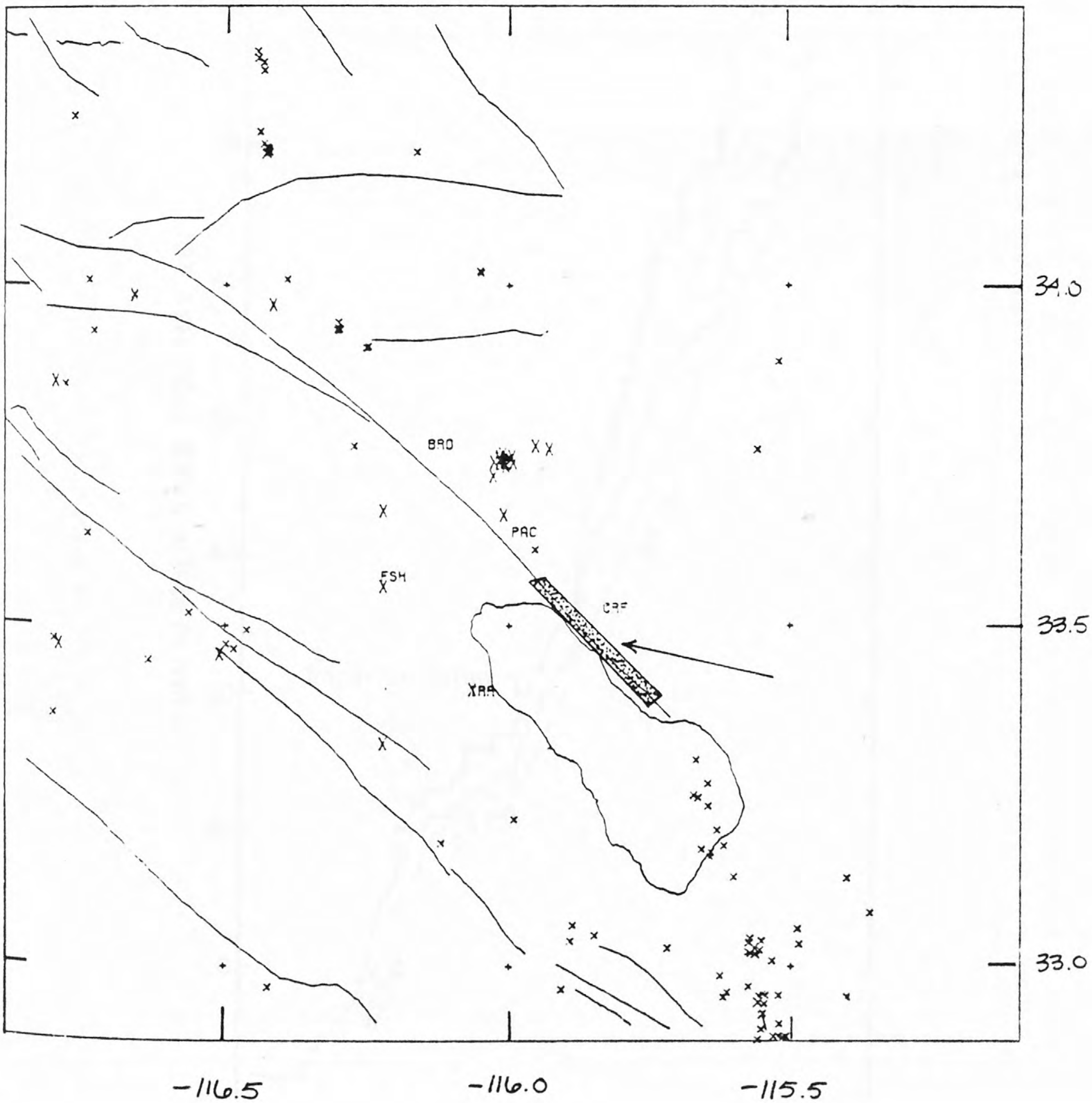
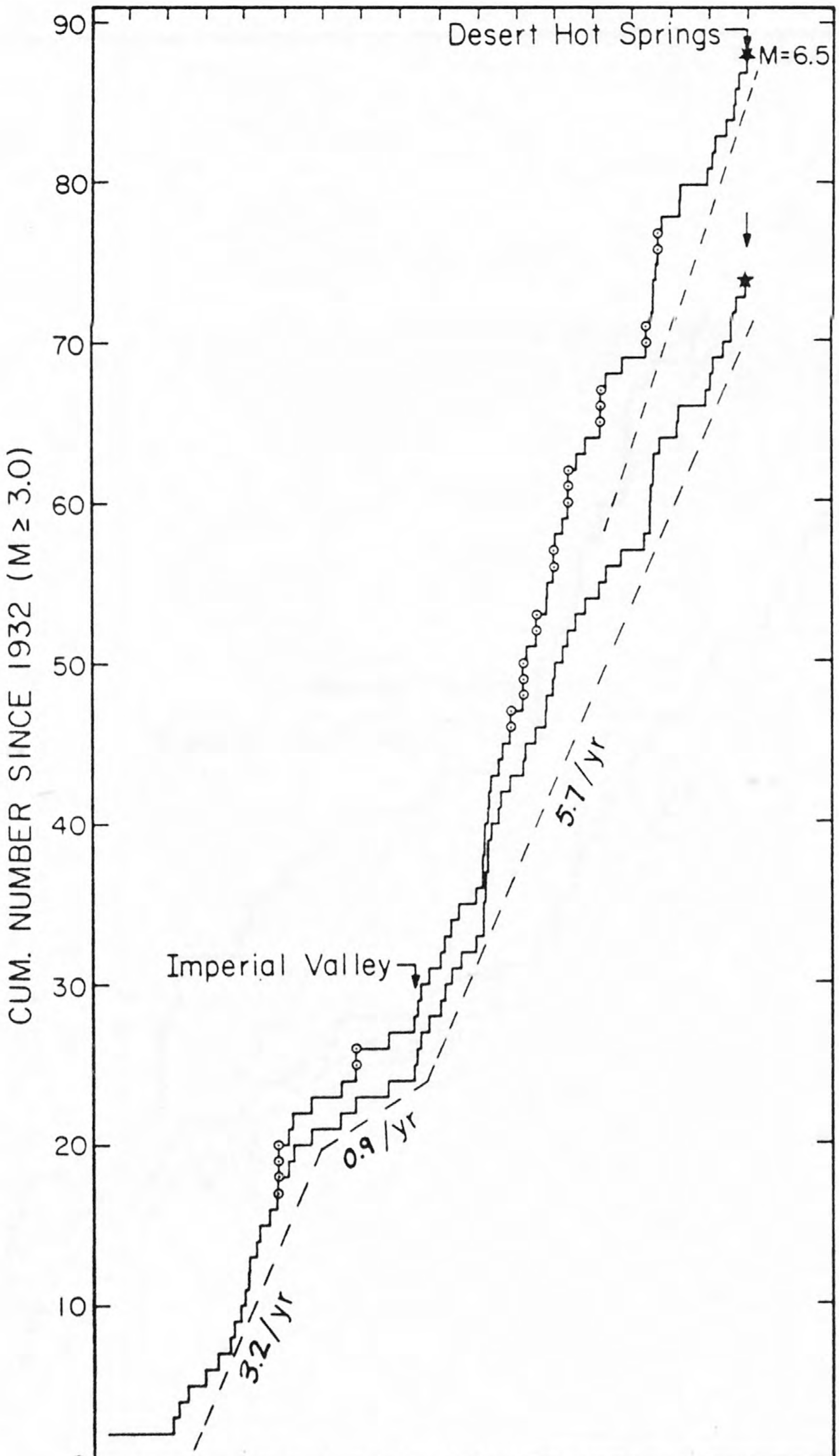


Figure 8a



Desert Hot Springs
M=6.5
Imperial Valley
3.2/yr
0.9/yr
5.7/yr
CUM. NUMBER SINCE 1932 (M ≥ 3.0)
0
10
20
30
40
50
60
70
80
90
1932
4
6
8
40
2
4
6
1948
TIME (YEAR)

Figure 8a

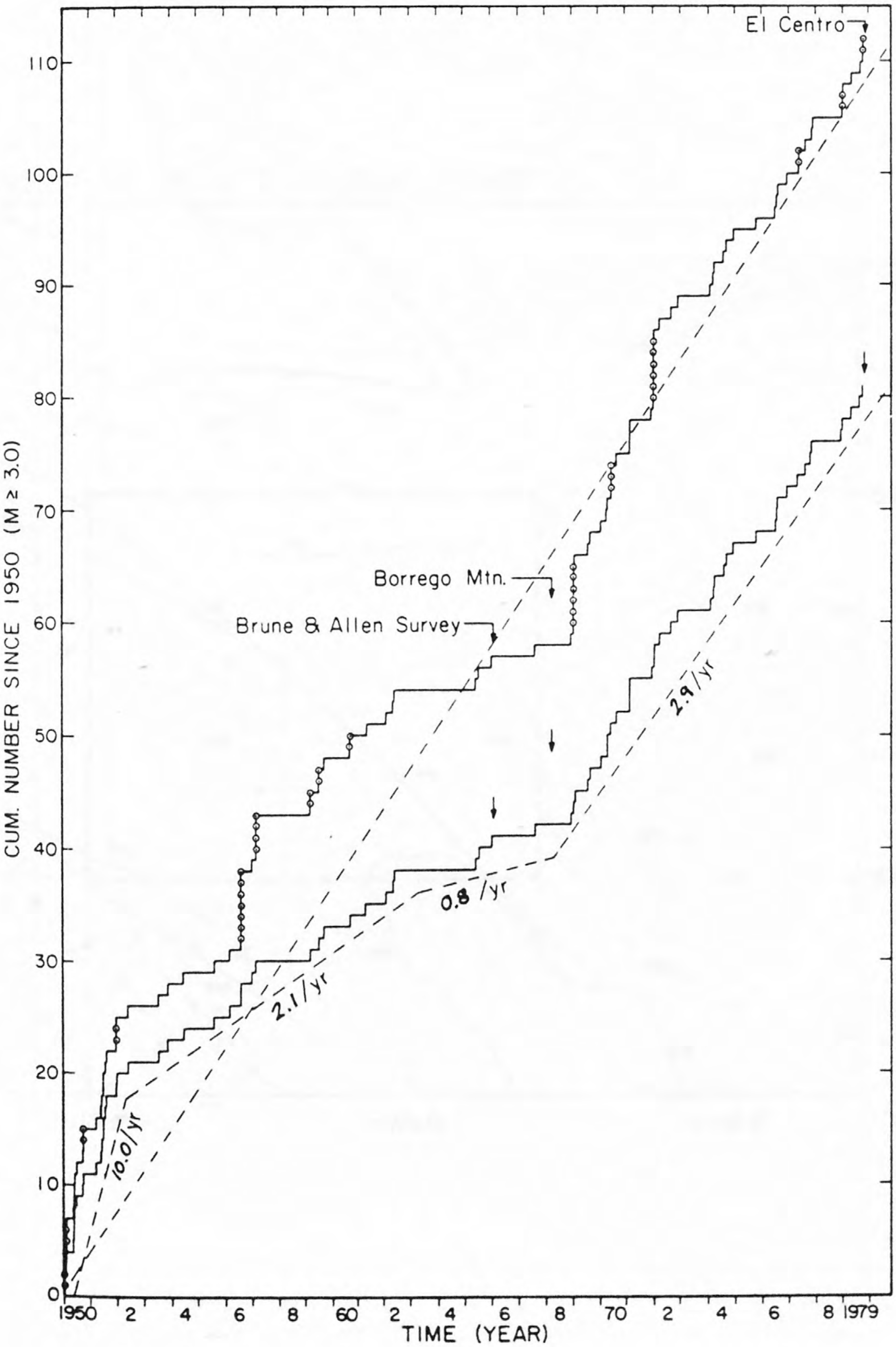

El Centro
Borrego Mtn.
Brune & Allen Survey
10.0/yr
2.1/yr
0.8 /yr
2.9/yr
CUM. NUMBER SINCE 1950 (M ≥ 3.0)
0
10
20
30
40
50
60
70
80
90
100
110
1950
2
4
6
8
60
2
4
6
8
70
2
4
6
8
1979
TIME (YEAR)

Figure 9a

SEISMICITY ML > 3 1932 - 1937

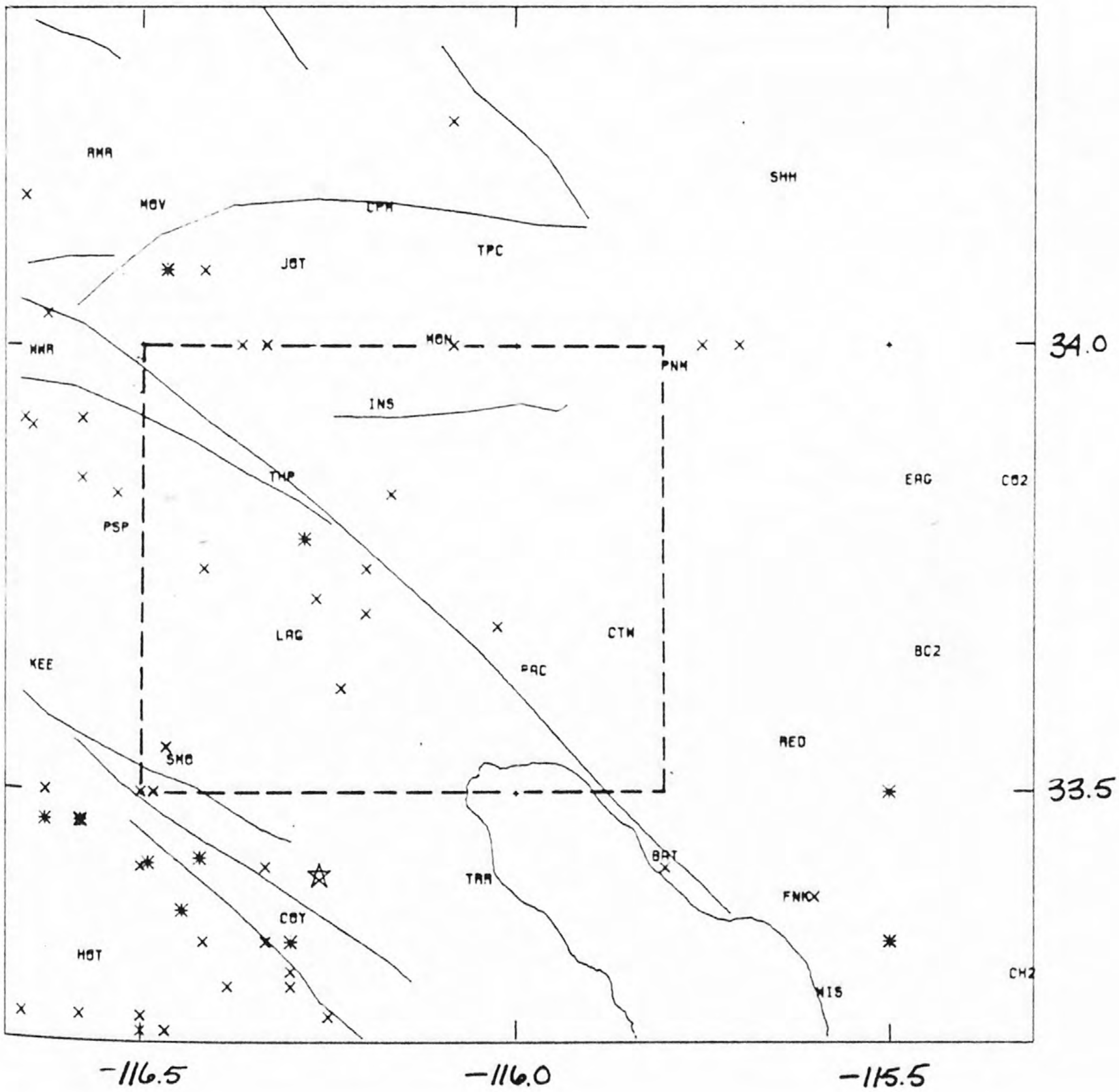


Figure 9b

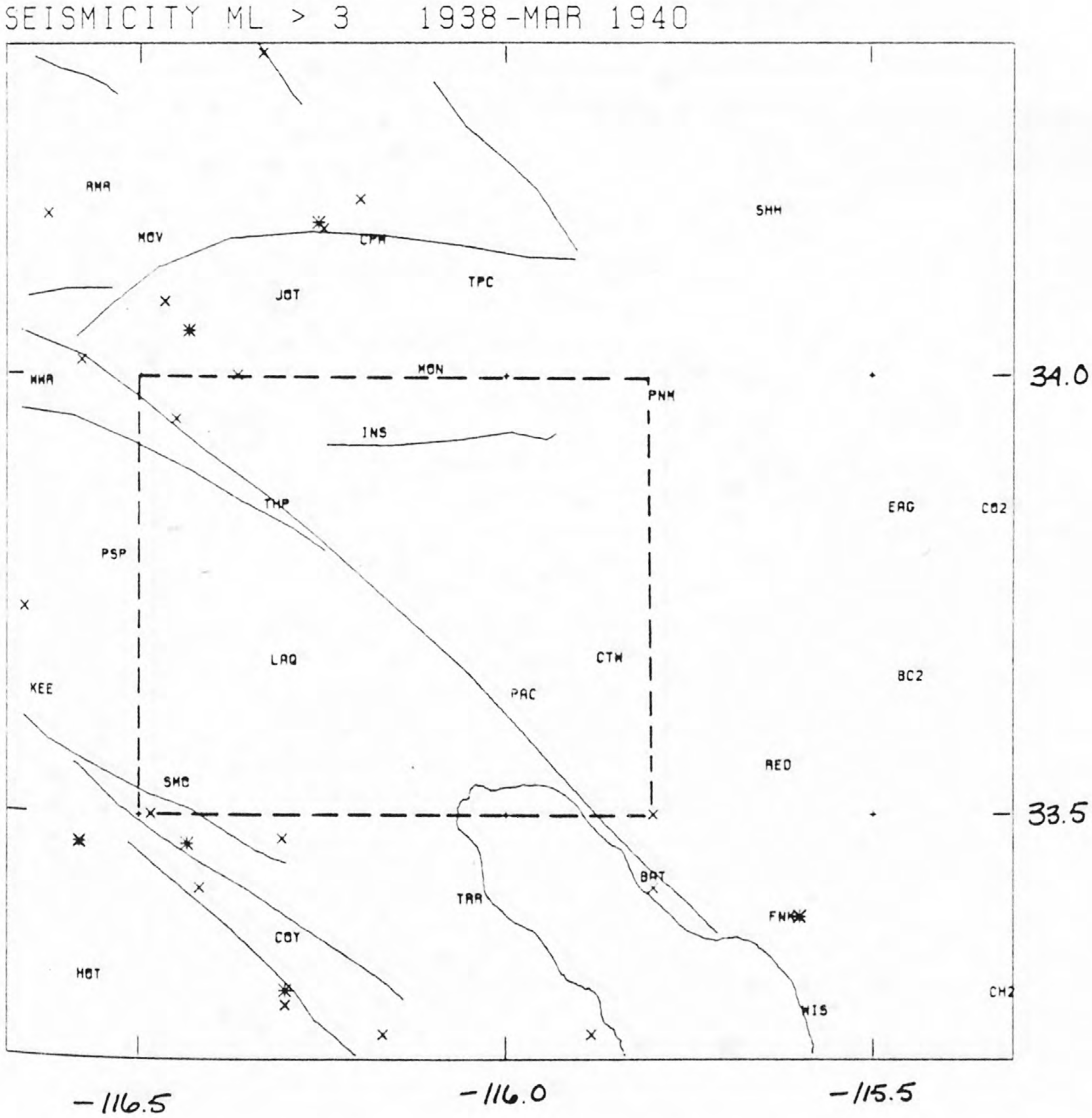

SEISMICITY ML > 3 1938-MAR 1940
AMA
MOV
CPM
JOT
TPC
SHH
MON
WWA
PNM
INS
THP
EAG
CO2
PSP
LAQ
CTW
KEE
PAC
BC2
SMC
RED
BAT
TRA
FNK
COY
HOT
WIS
CH2
34.0
33.5
−116.5
−116.0
−115.5

Figure 9c

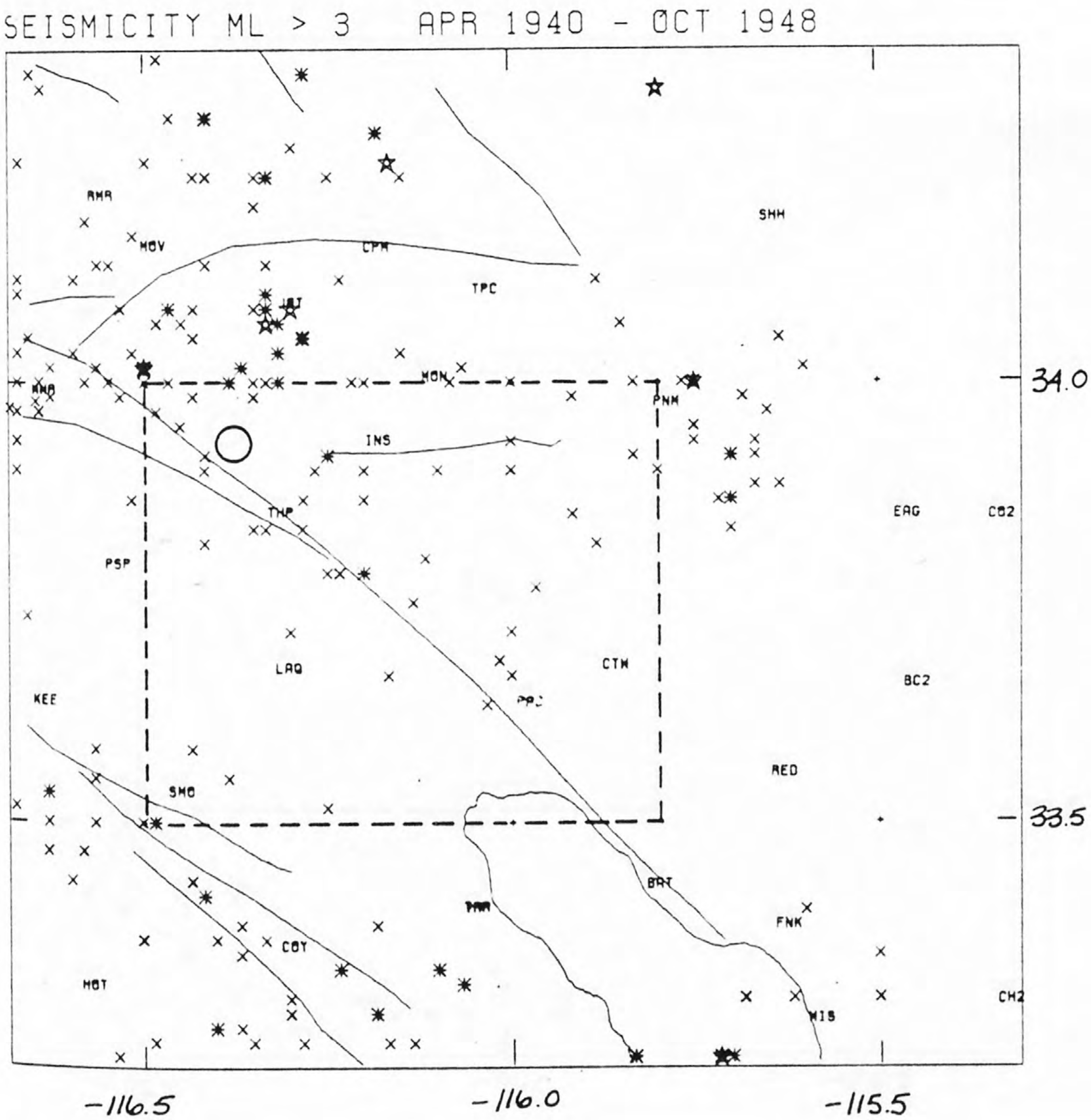

SEISMICITY ML > 3 APR 1940 - OCT 1948
RMR
HOV
CPM
TPC
SHH
JBT
RMA
MON
PNM
INS
THP
EAG
CB2
PSP
LAQ
CTM
BC2
KEE
RED
SMO
BRT
FNK
COY
HOT
CH2
34.0
33.5
-116.5
-116.0
-115.5

Figure 9d

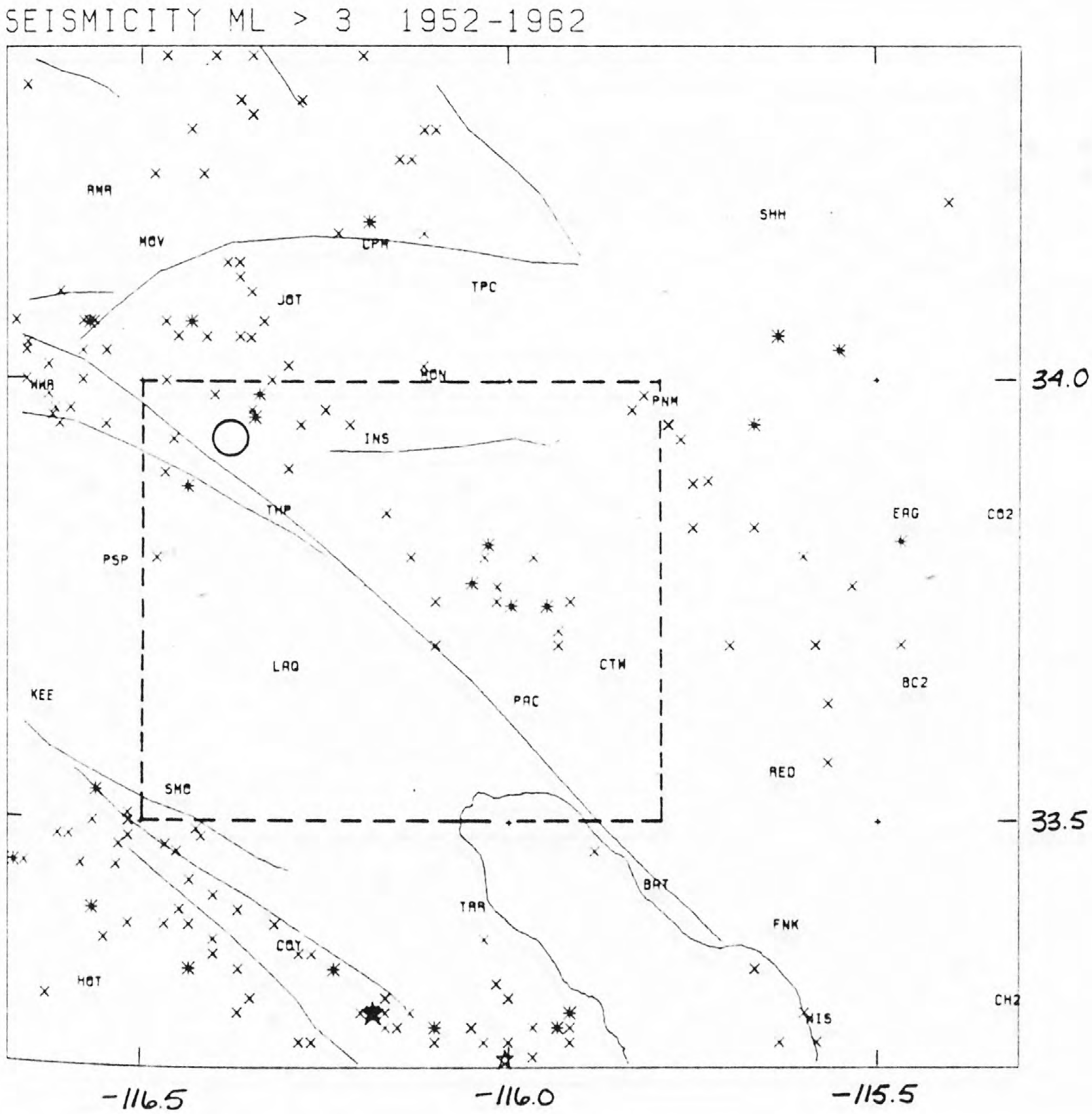

SEISMICITY ML > 3 1952-1962
AMA
MGV
CPM
TPC
JOT
SHH
34.0
AMA
PNM
INS
THP
ERG
CO2
PSP
LAQ
CTW
BC2
KEE
PAC
RED
SMC
33.5
BAT
TAA
FNK
COT
HOT
CH2
NIS
-116.5
-116.0
-115.5

Figure 9e

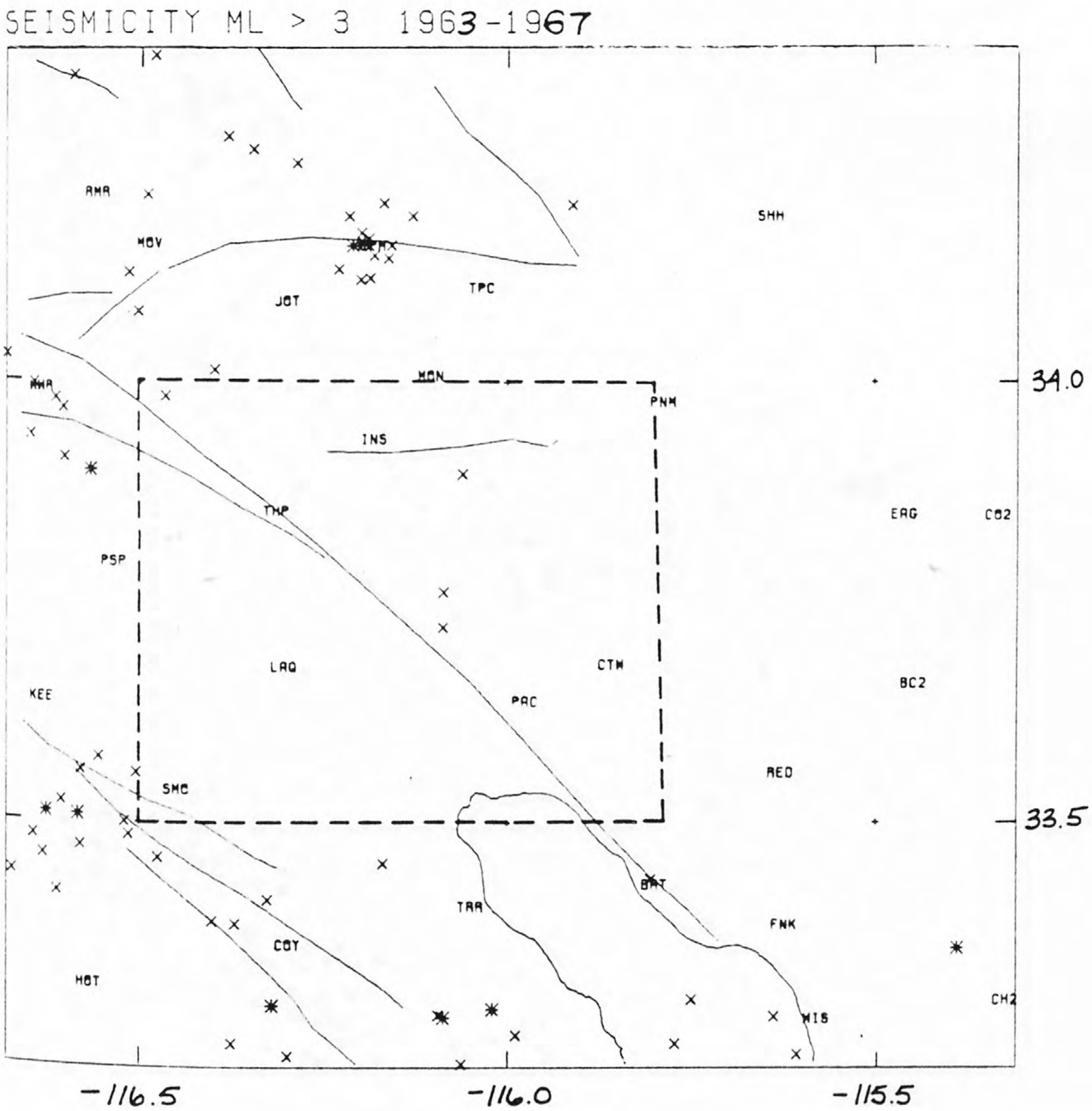
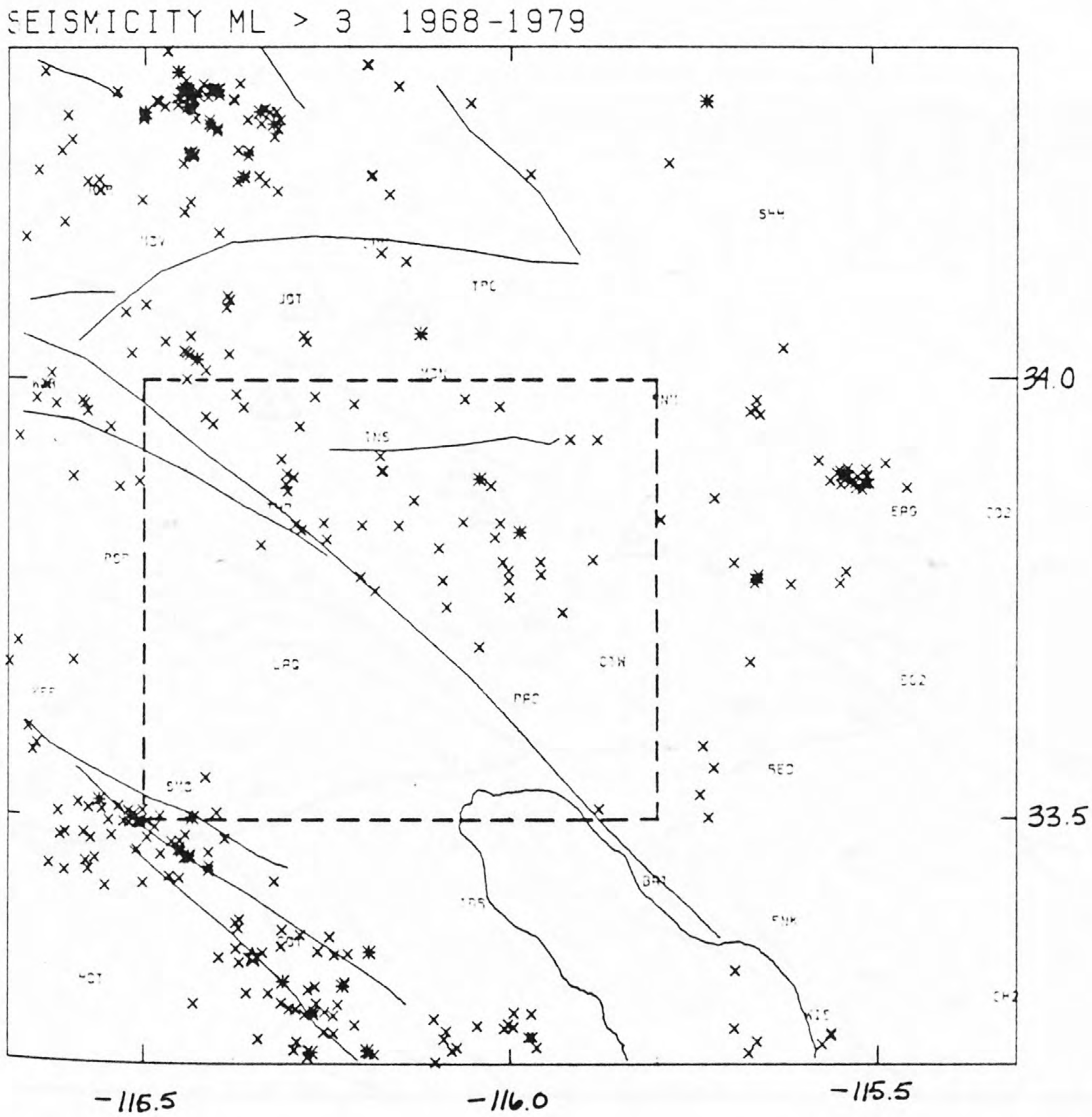

SEISMICITY ML > 3 1963-1967
AMA
MOV
JOT
TPC
SHH
MON
PNM
INS
THP
PSP
EAG
CG2
LAQ
CTM
PAC
BC2
KEE
RED
SMC
BAT
TAA
FNK
COY
HOT
CH2
NIS
34.0
33.5
-116.5
-116.0
-115.5

Figure 9f



Station of MOBILE TRAILER ARRAY

ABC Station in SCARLET System

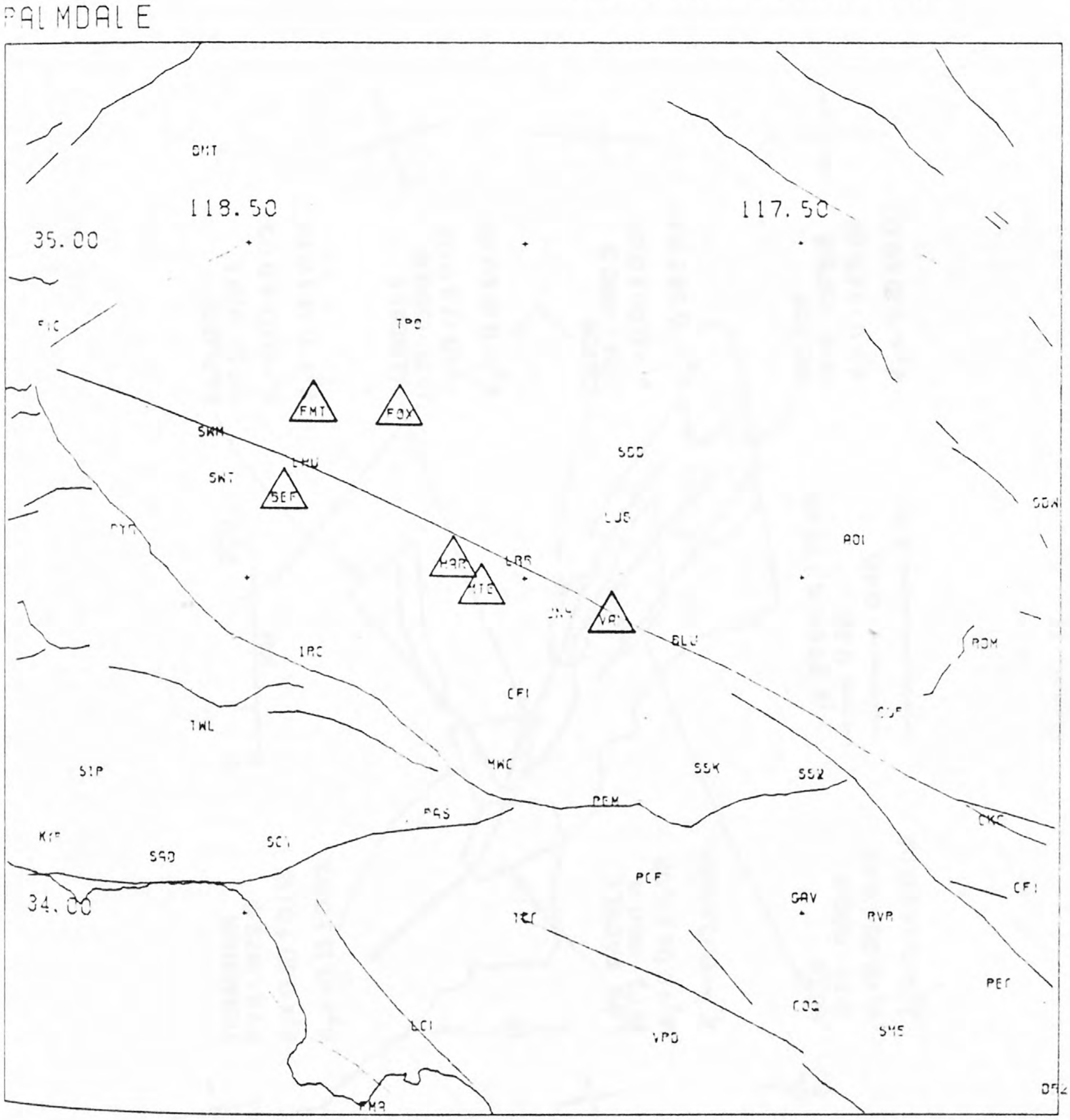


Figure 10

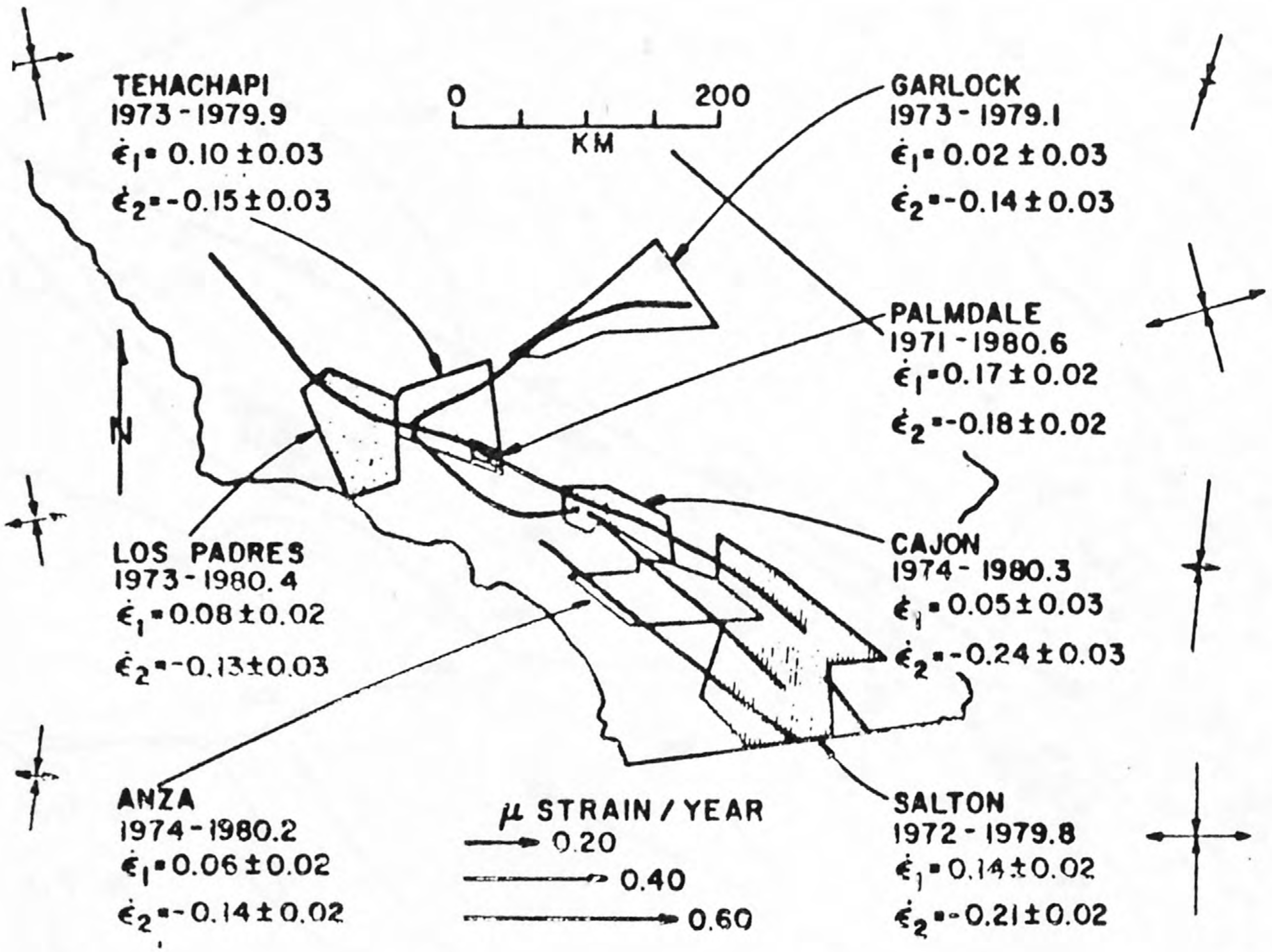

TEHACHAPI
1973 - 1979.9
$\dot{\epsilon}_1 = 0.10 \pm 0.03$
$\dot{\epsilon}_2 = -0.15 \pm 0.03$
0
200
KM
GARLOCK
1973 - 1979.1
$\dot{\epsilon}_1 = 0.02 \pm 0.03$
$\dot{\epsilon}_2 = -0.14 \pm 0.03$
PALMDALE
1971 - 1980.6
$\dot{\epsilon}_1 = 0.17 \pm 0.02$
$\dot{\epsilon}_2 = -0.18 \pm 0.02$
N
LOS PADRES
1973 - 1980.4
$\dot{\epsilon}_1 = 0.08 \pm 0.02$
$\dot{\epsilon}_2 = -0.13 \pm 0.03$
CAJON
1974 - 1980.3
$\dot{\epsilon}_1 = 0.05 \pm 0.03$
$\dot{\epsilon}_2 = -0.24 \pm 0.03$
ANZA
1974 - 1980.2
$\dot{\epsilon}_1 = 0.06 \pm 0.02$
$\dot{\epsilon}_2 = -0.14 \pm 0.02$
μ STRAIN / YEAR
0.20
0.40
0.60
SALTON
1972 - 1979.8
$\dot{\epsilon}_1 = 0.14 \pm 0.02$
$\dot{\epsilon}_2 = -0.21 \pm 0.02$

Figure 11

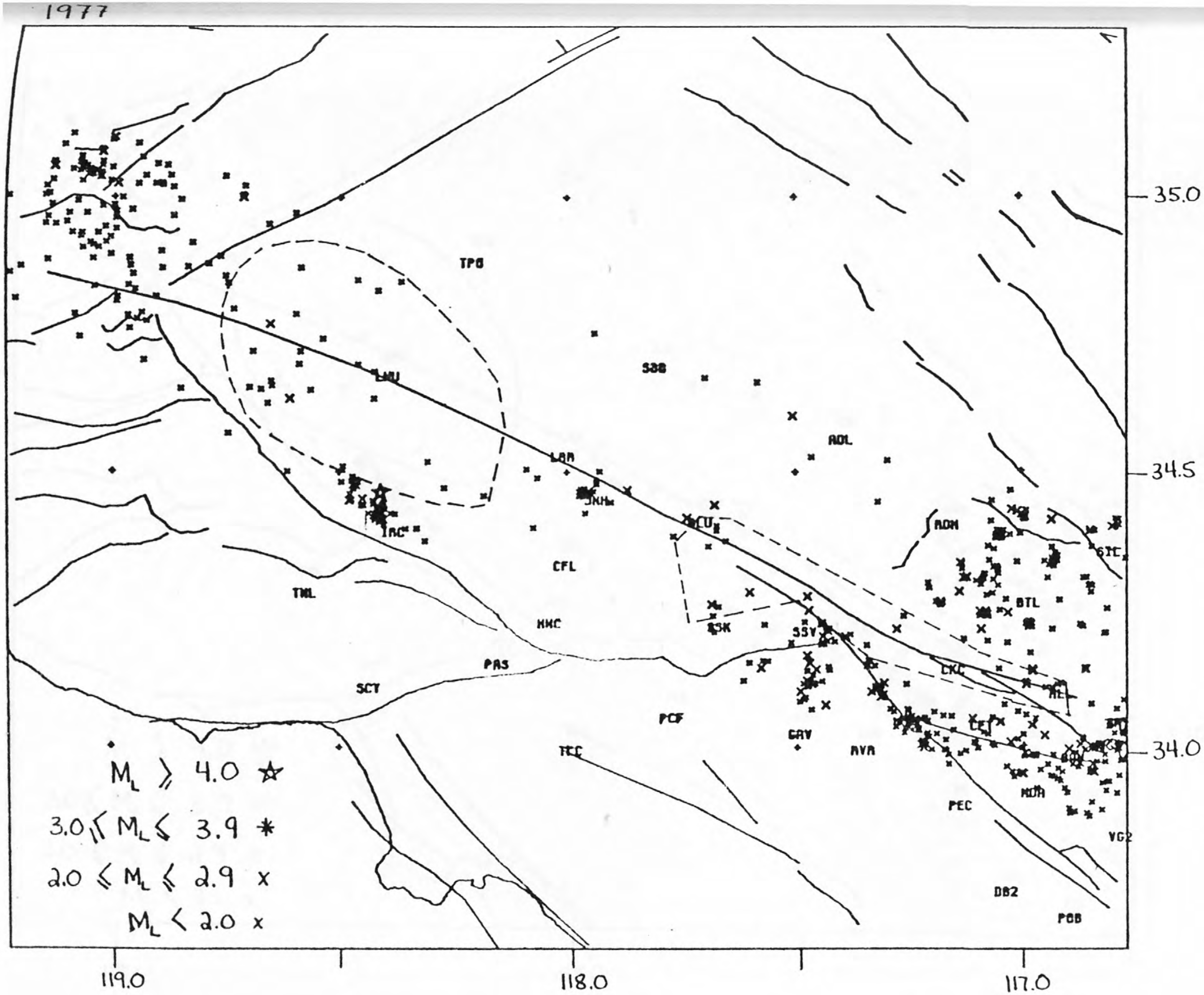
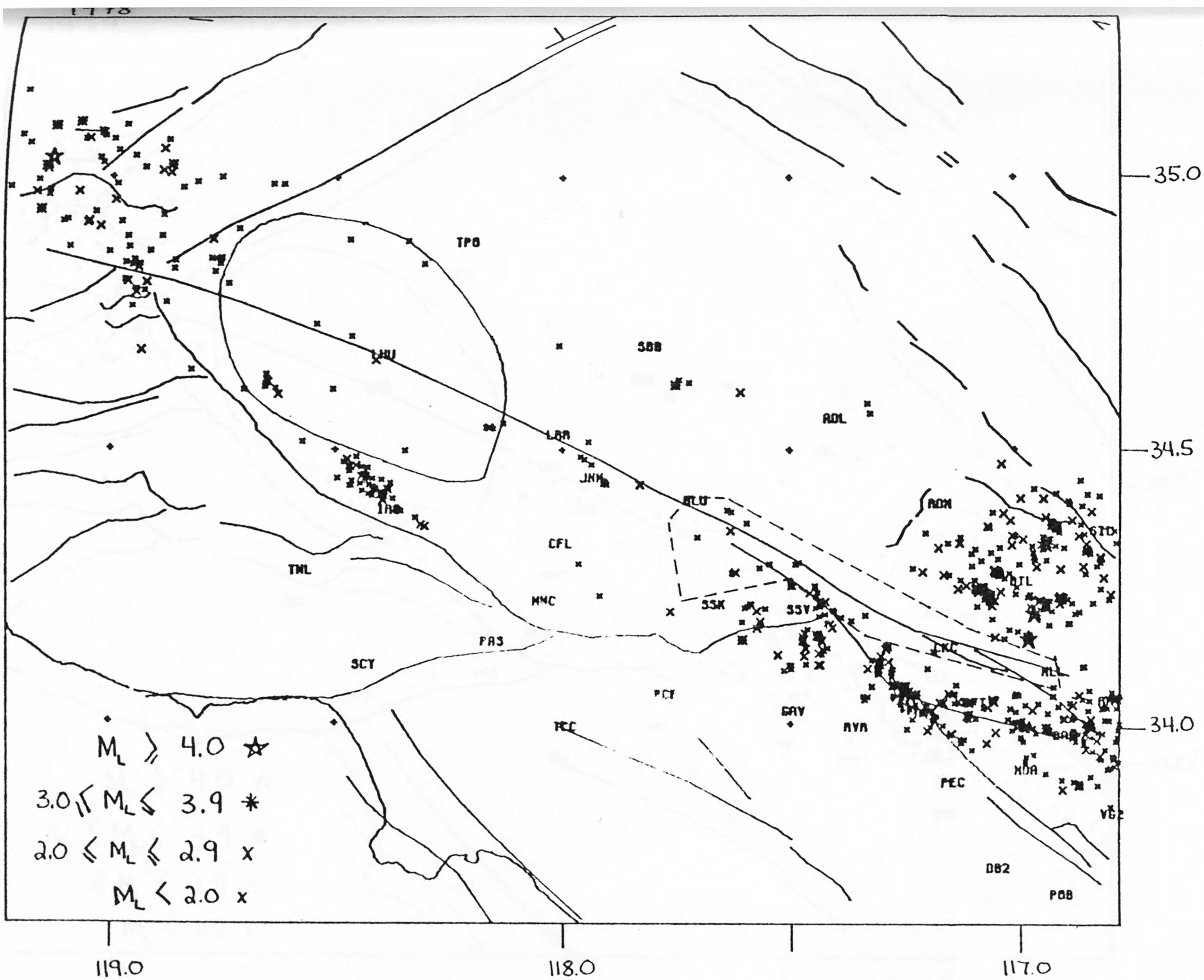
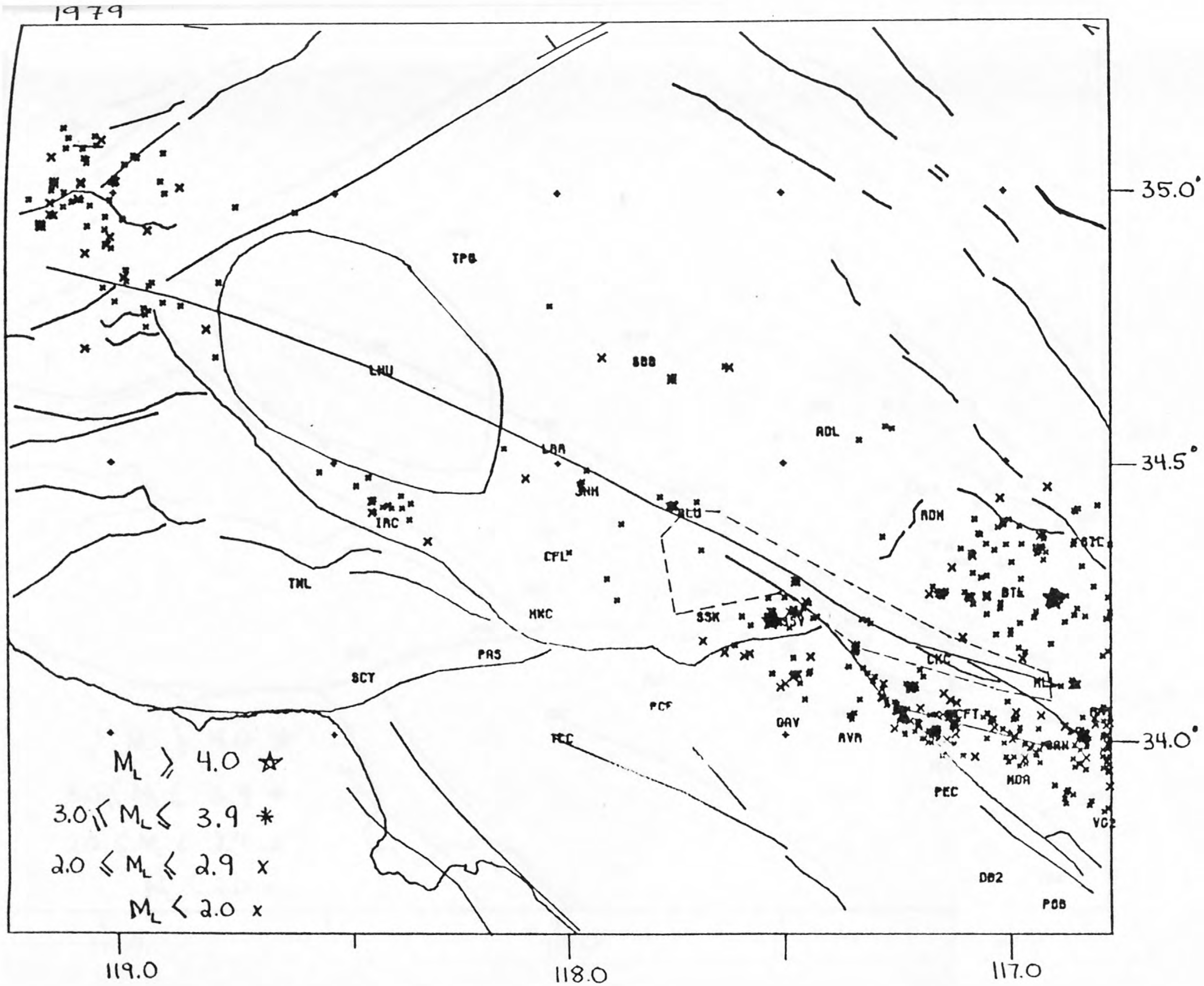

1977
TPO
SBB
LWU
ADL
LAR
JNH
TRC
CFL
ADN
BTL
TWL
HMC
SSK
SSV
PAS
SCY
CKC
PCF
GAV
AVA
TCC
PEC
MDA
VG2
DB2
PBB
$M_L \geq 4.0$ ☆
$3.0 \leq M_L \leq 3.9$ *
$2.0 \leq M_L \leq 2.9$ x
$M_L < 2.0$ x
35.0
34.5
34.0
119.0
118.0
117.0

Figure 12



TPO
SBB
LHU
ADL
LBR
JNH
ALU
ADN
CFL
TWL
MNC
SSK
SSV
PAS
SCY
PCF
GAV
RVA
TCC
PEC
MDA
VG2
DB2
PBB
35.0
34.5
34.0
119.0
118.0
117.0
M_L ≥ 4.0 ☆
3.0 ≤ M_L ≤ 3.9 *
2.0 ≤ M_L ≤ 2.9 x
M_L < 2.0 x

Figure 13



1979
35.0°
34.5°
34.0°
119.0
118.0
117.0
TPG
LHU
SBB
ADL
LBA
JNH
ALU
IRC
ADN
CFL
BTL
TNL
HKC
SSK
PAS
CKC
SCT
PCF
DAV
CFT
AVA
FEC
PEC
MDA
DB2
PSB
VC2
$M_L \geq 4.0$ ☆
$3.0 \leq M_L \leq 3.9$ *
$2.0 \leq M_L \leq 2.9$ x
$M_L < 2.0$ x

Figure 17

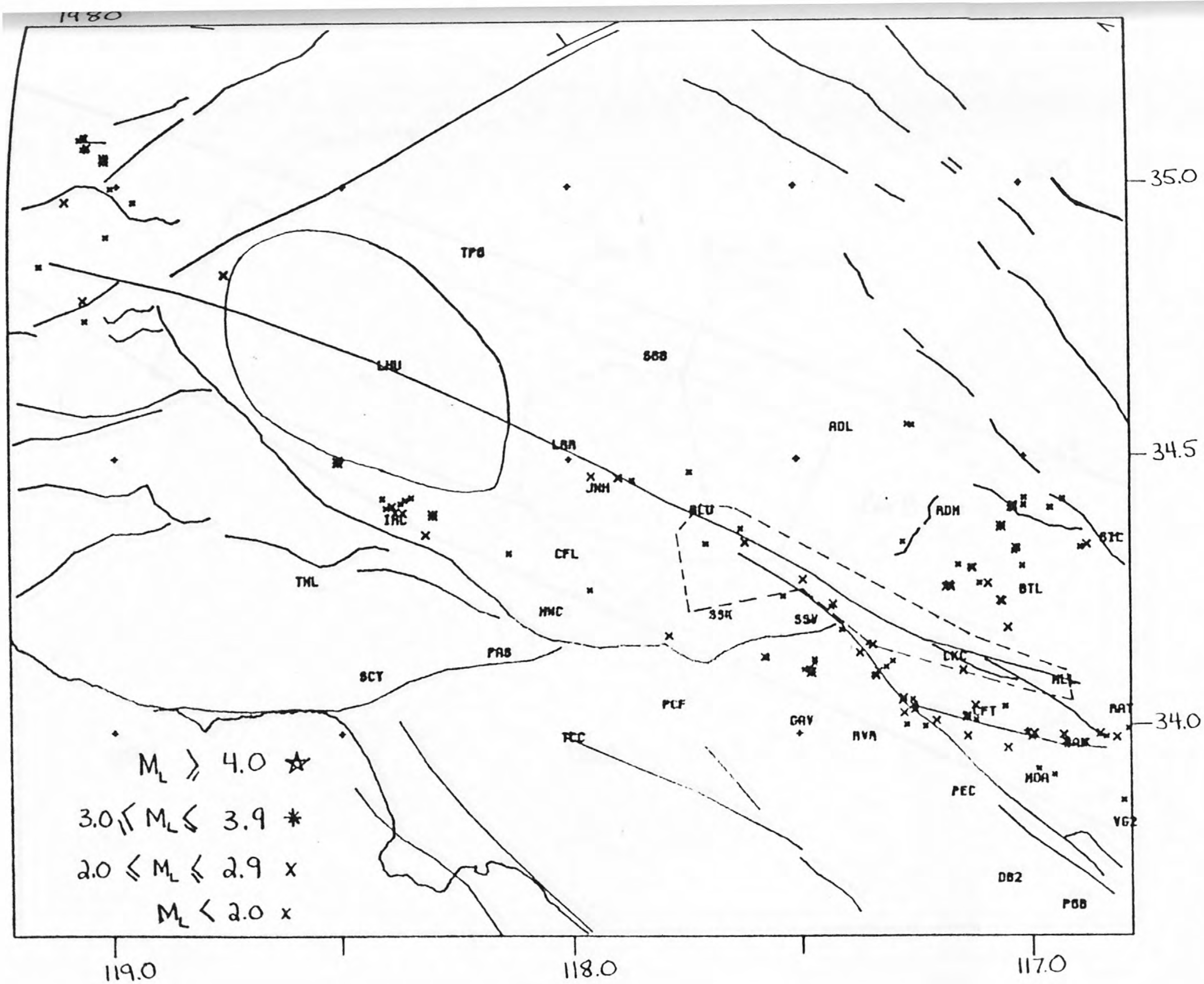

1980
35.0
34.5
34.0
119.0
118.0
117.0
TPG
SBB
ADL
LBR
JNH
ADH
CFL
STC
BTL
THL
SSR
SSV
PAS
SCT
CKC
PCF
CAV
RVA
CFT
RAT
TCC
PEC
VG2
DB2
PSB
$M_L \geq 4.0$ ☆
$3.0 \leq M_L \leq 3.9$ *
$2.0 \leq M_L \leq 2.9$ x
$M_L < 2.0$ x

Figure 15

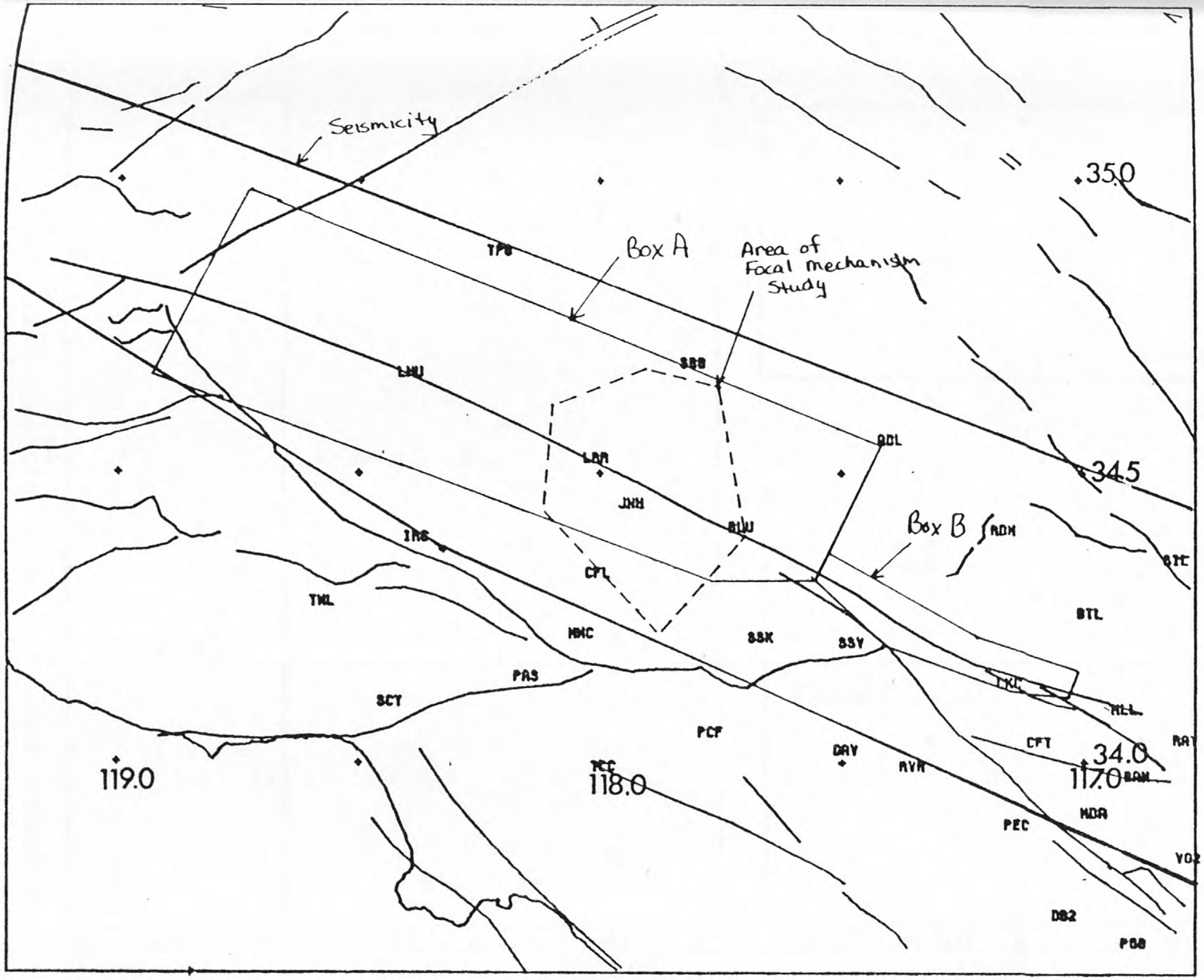

Seismicity
Box A
Area of Focal mechanism Study
Box B
35.0
34.5
34.0
119.0
118.0
117.0

Figure 16

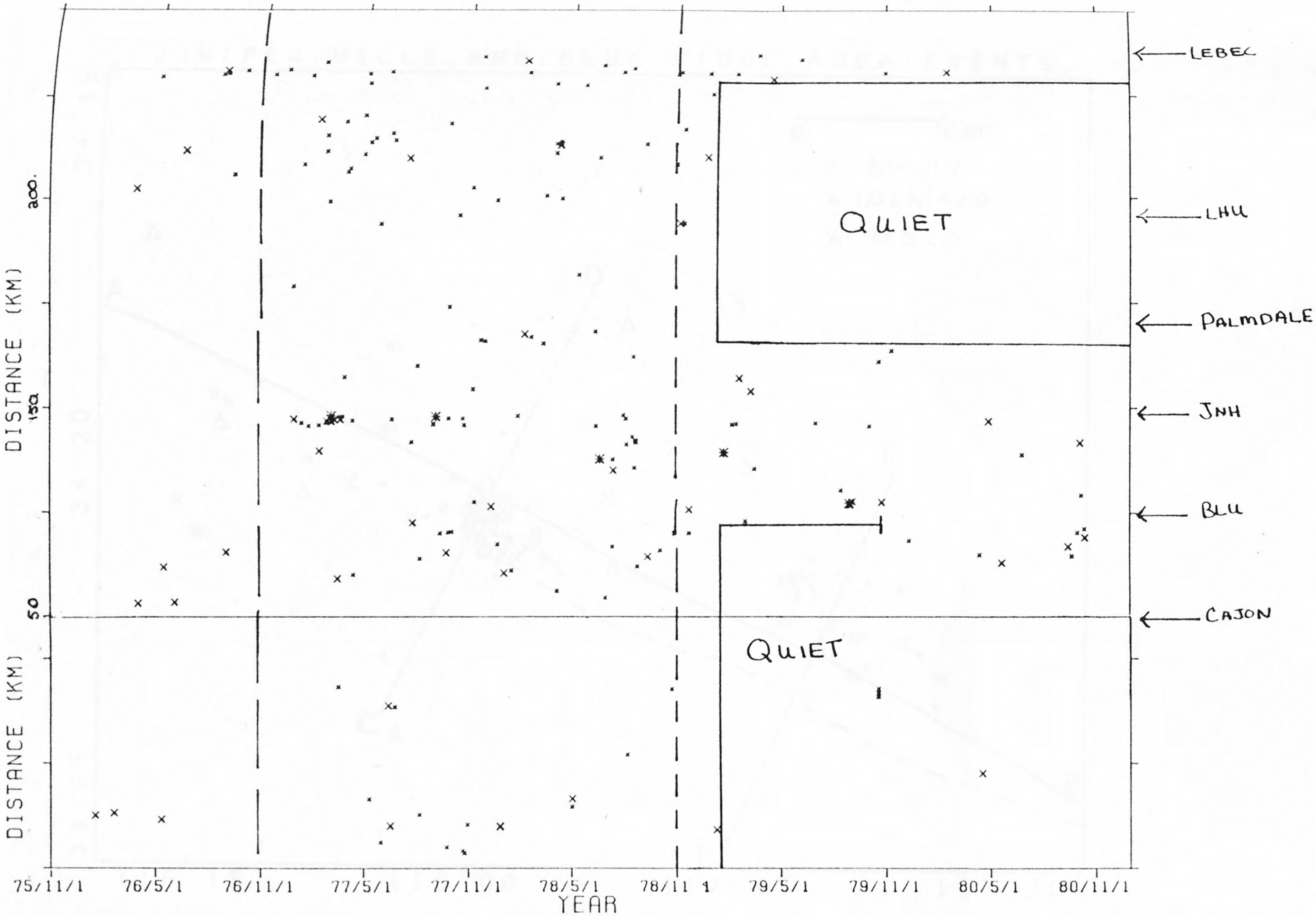

LEBEC
LHU
PALMDALE
JNH
BLU
CAJON
QUIET
QUIET
DISTANCE (KM)
DISTANCE (KM)
200.
150
50
75/11/1
76/5/1
76/11/1
77/5/1
77/11/1
78/5/1
78/11/1
79/5/1
79/11/1
80/5/1
80/11/1
YEAR

Figure 17

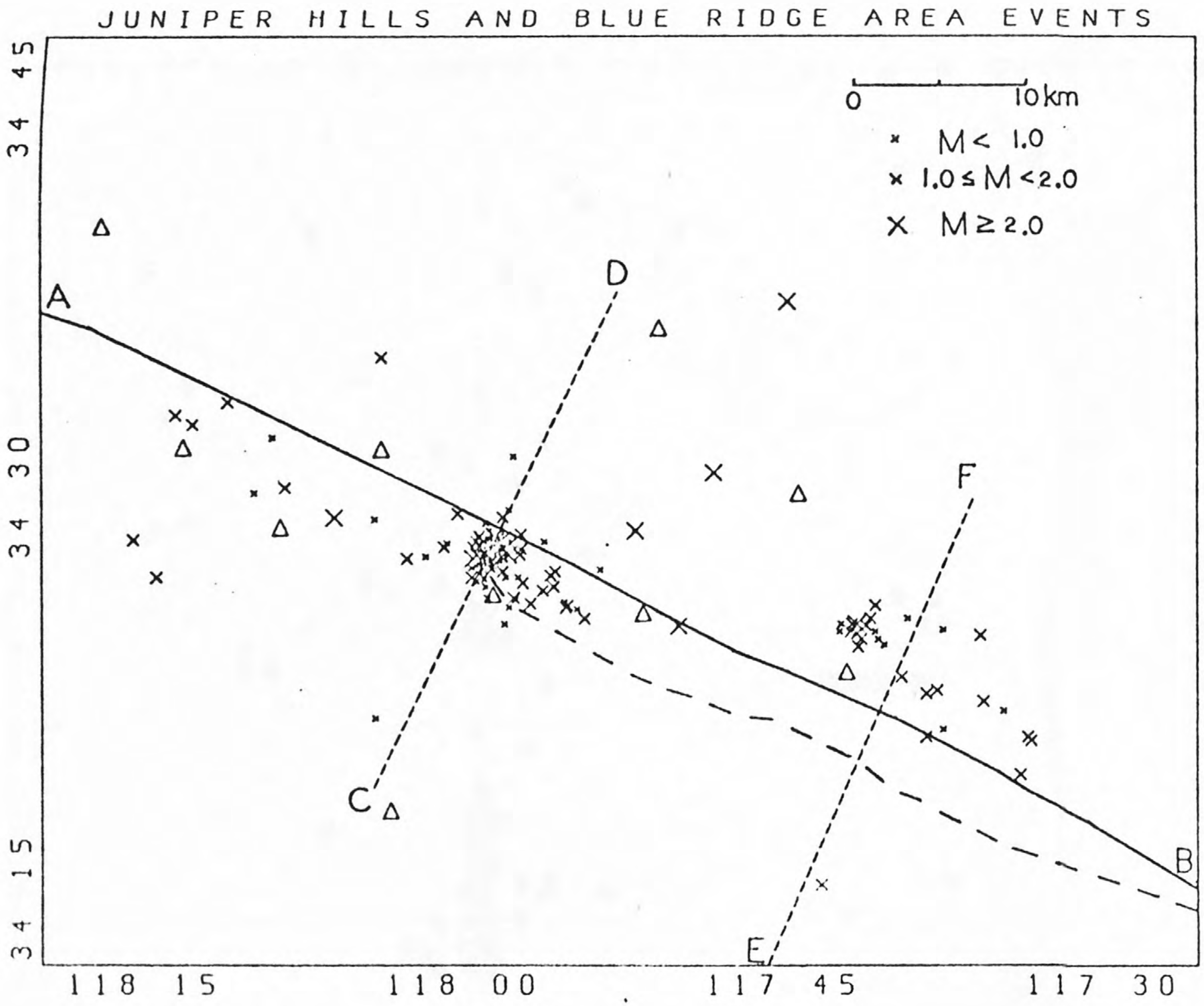
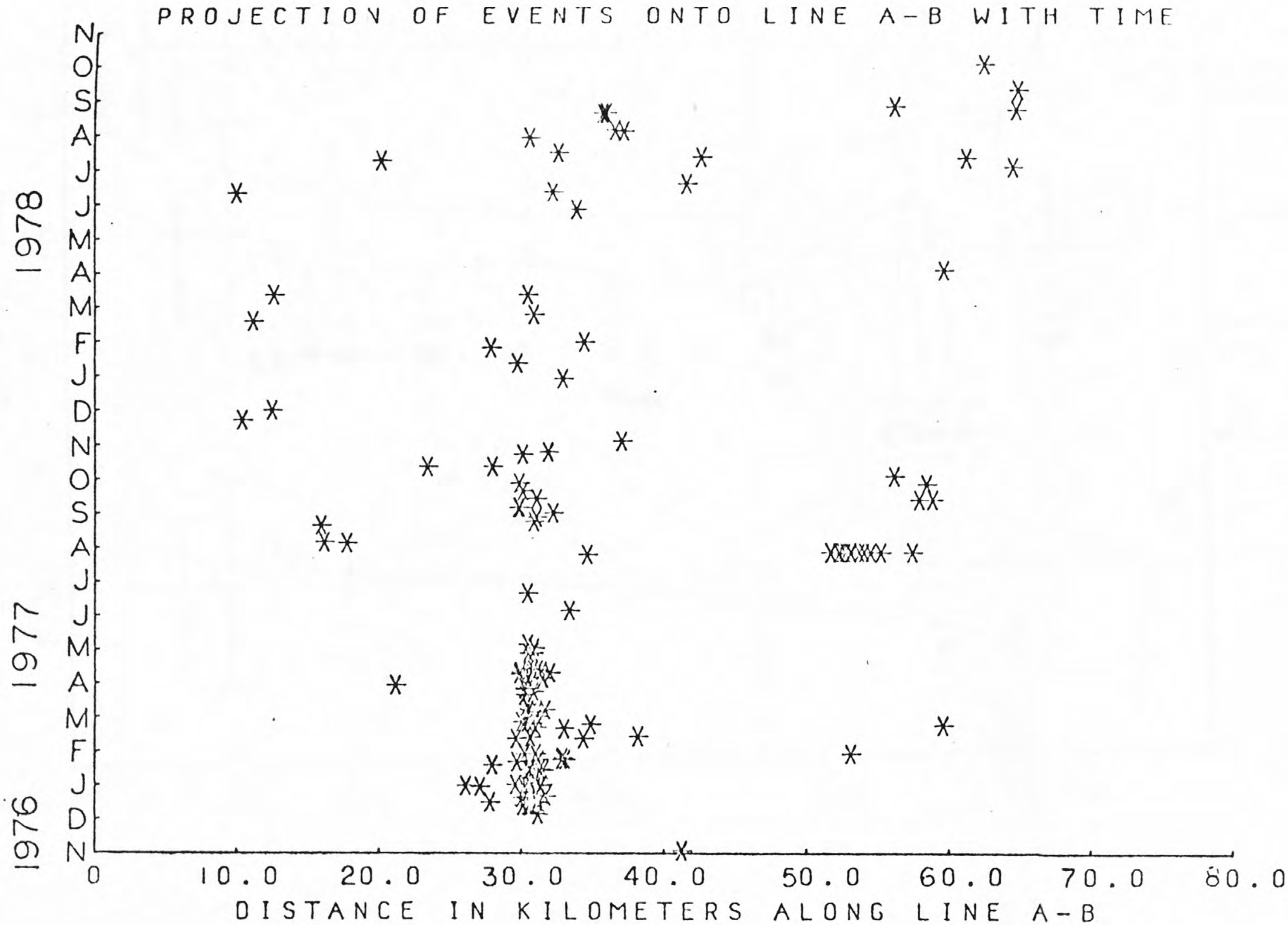

JUNIPER HILLS AND BLUE RIDGE AREA EVENTS
0
10 km
M < 1.0
1.0 ≤ M < 2.0
M ≥ 2.0
A
B
C
D
E
F
34 45
34 30
34 15
118 15
118 00
117 45
117 30

Figure 18



PROJECTION OF EVENTS ONTO LINE A-B WITH TIME
N
O
S
A
J
J
M
A
M
F
J
D
N
O
S
A
J
J
M
A
M
F
J
D
N
1978
1977
1976
0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
DISTANCE IN KILOMETERS ALONG LINE A-B

Figure 19

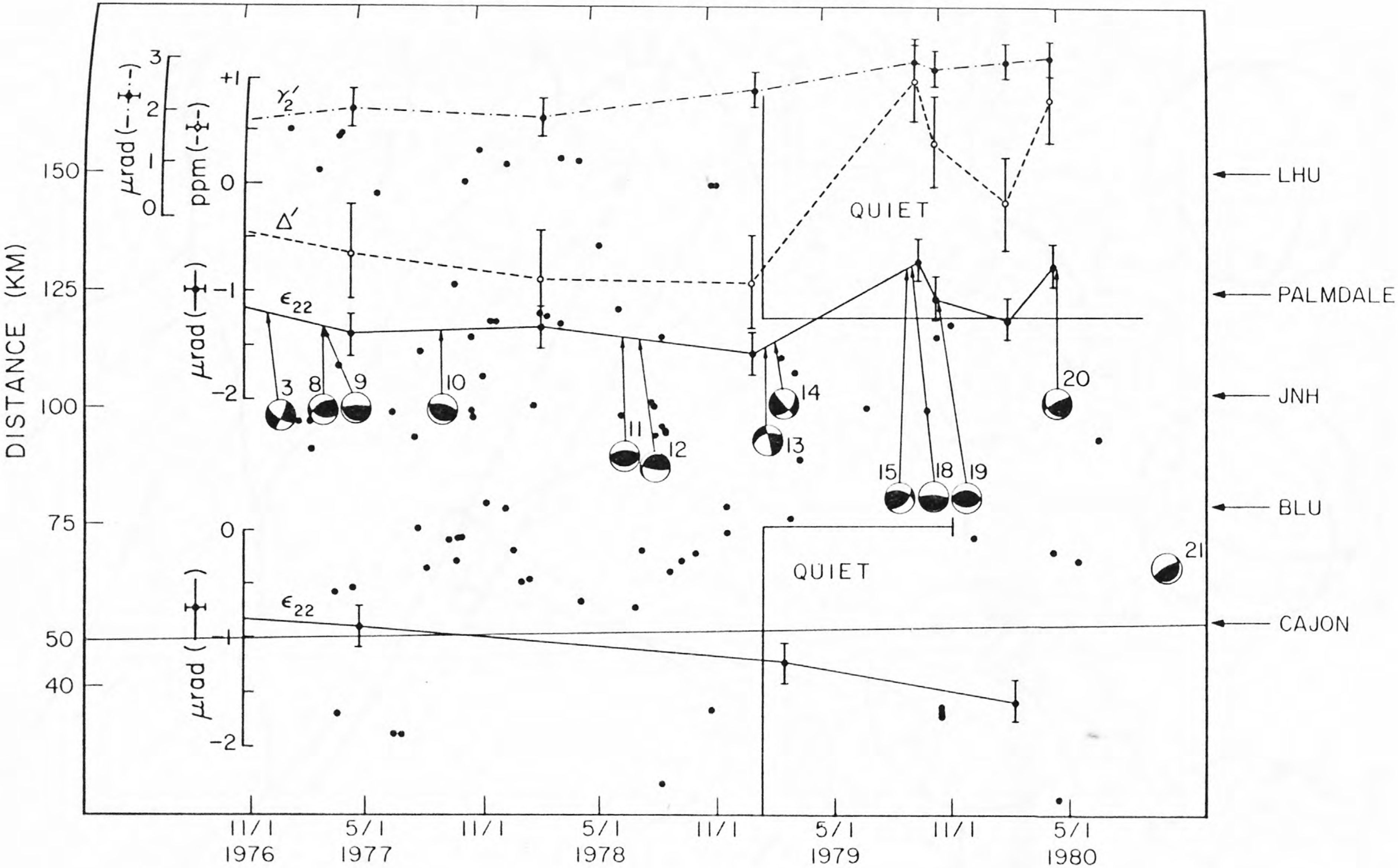

DISTANCE (KM)
150
125
100
75
50
40
μrad (-·-♦-·-)
ppm (-◊-)
3
2
1
0
+1
0
-1
-2
μrad (—♦—)
μrad (—)
γ_2'
Δ'
ϵ_{22}
ϵ_{22}
QUIET
QUIET
3
8
9
10
11
12
13
14
15
18
19
20
21
LHU
PALMDALE
JNH
BLU
CAJON
11/1
1976
5/1
1977
11/1
5/1
1978
11/1
5/1
1979
11/1
5/1
1980

Figure 20

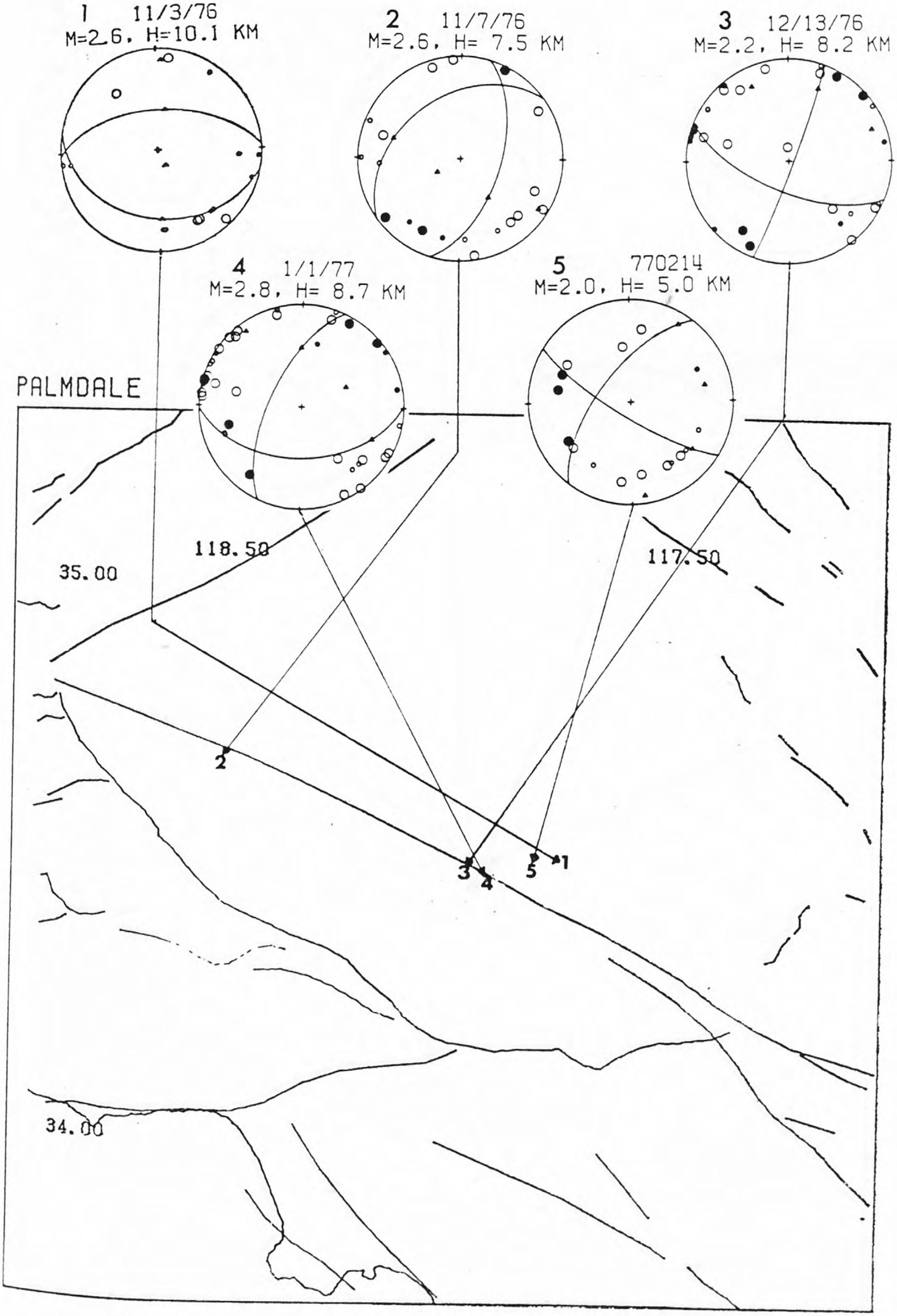

1 11/3/76
M=2.6, H=10.1 KM
2 11/7/76
M=2.6, H= 7.5 KM
3 12/13/76
M=2.2, H= 8.2 KM
4 1/1/77
M=2.8, H= 8.7 KM
5 770214
M=2.0, H= 5.0 KM
PALMDALE
118.50
117.50
35.00
34.00
2
3
4
5
1

Figure 21

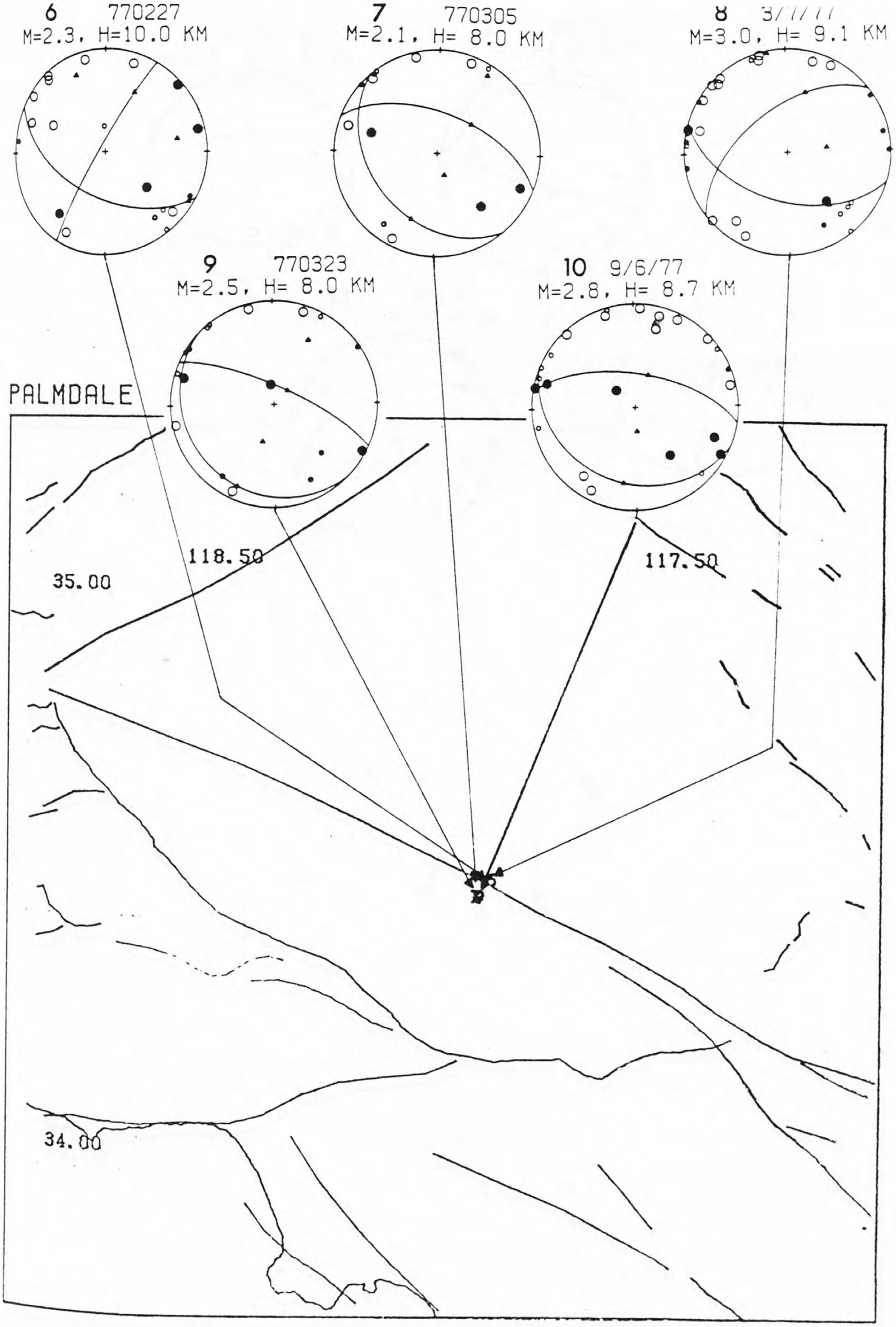

6 770227
M=2.3, H=10.0 KM
7 770305
M=2.1, H= 8.0 KM
8 3/7/77
M=3.0, H= 9.1 KM
9 770323
M=2.5, H= 8.0 KM
10 9/6/77
M=2.8, H= 8.7 KM
PALMDALE
118.50
117.50
35.00
34.00

Figure 22

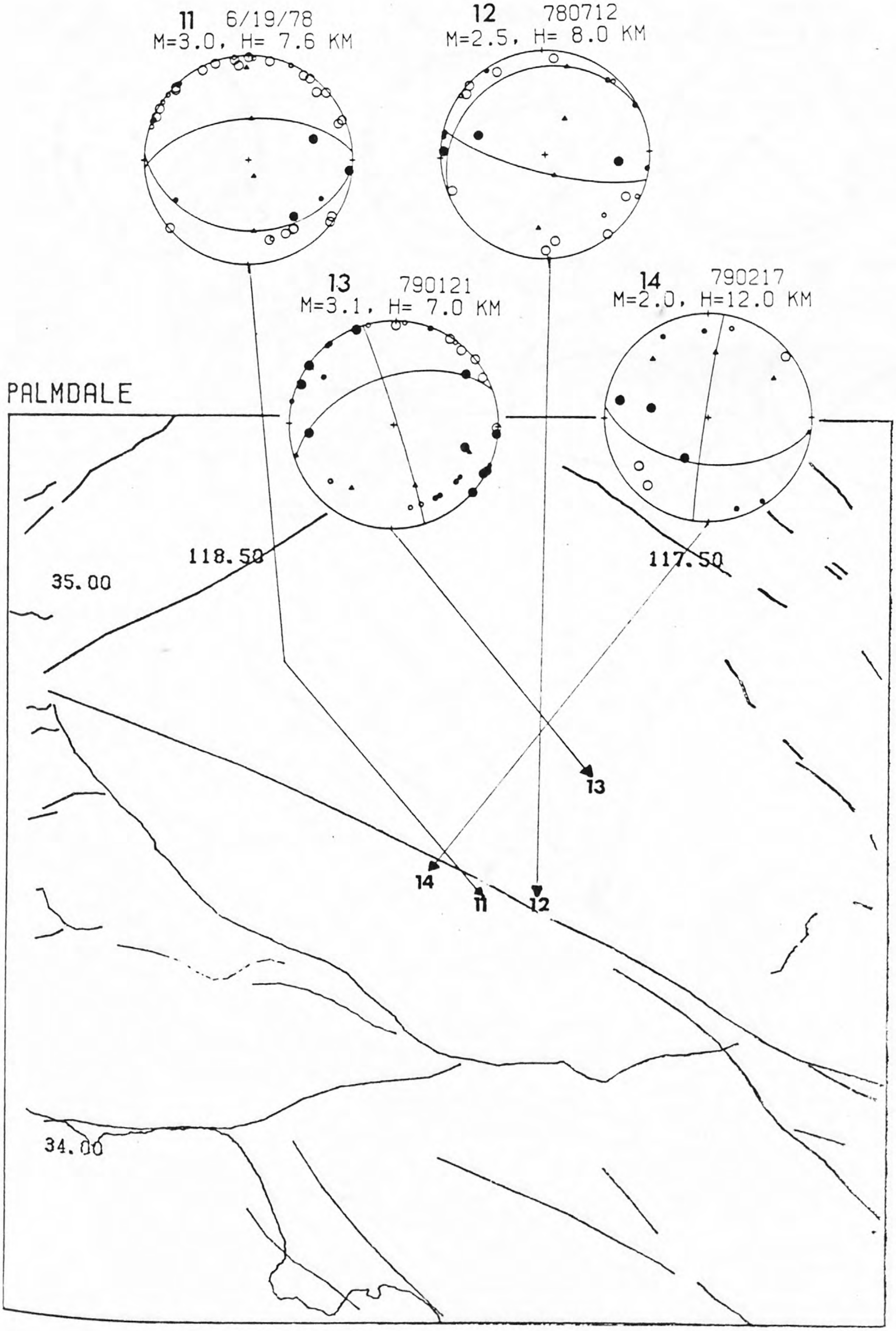

11 6/19/78
M=3.0, H= 7.6 KM
12 780712
M=2.5, H= 8.0 KM
13 790121
M=3.1, H= 7.0 KM
14 790217
M=2.0, H=12.0 KM
PALMDALE
118.50
117.50
35.00
34.00
13
14
11
12

Figure 23

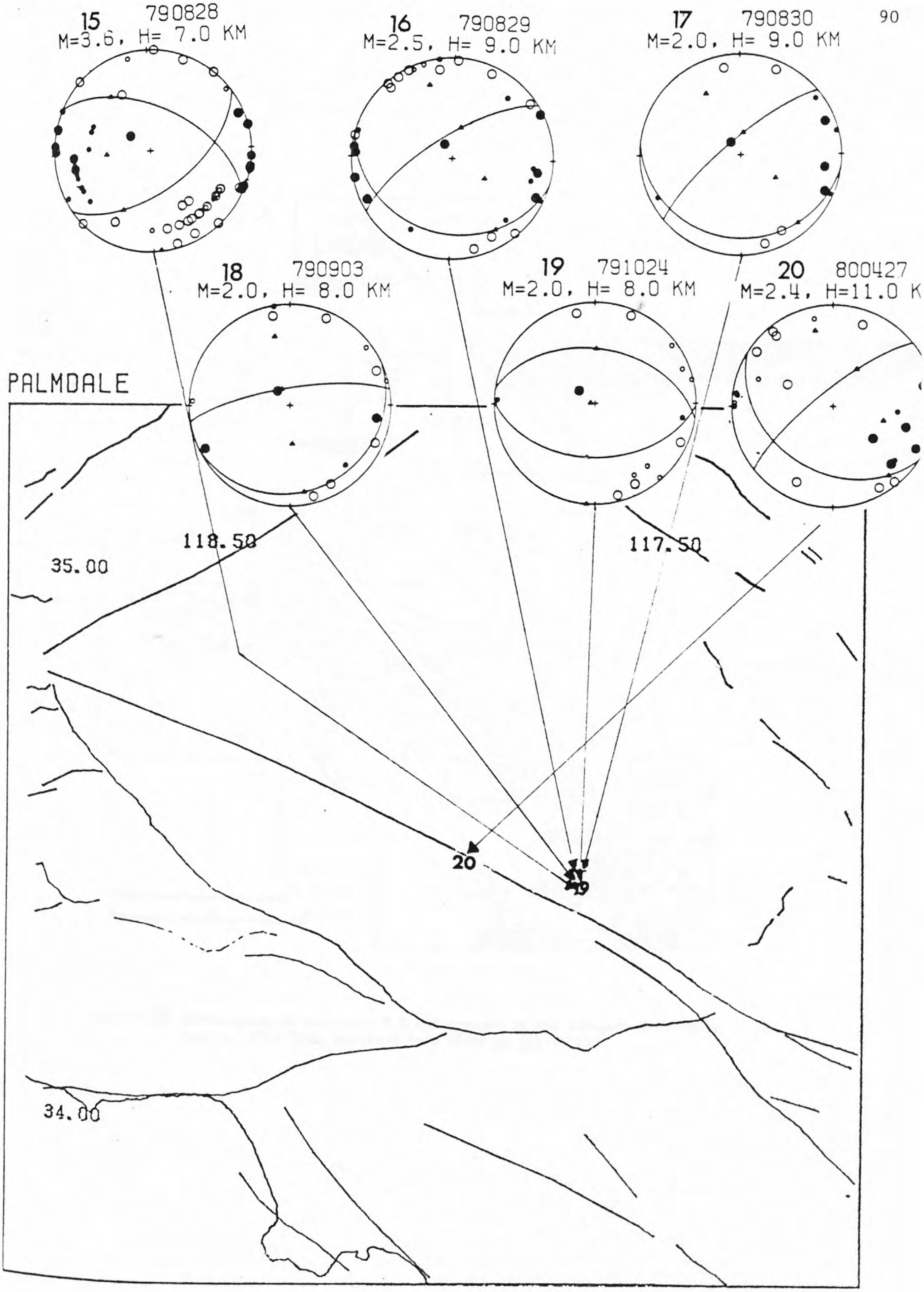

15 790828
M=3.6, H= 7.0 KM
16 790829
M=2.5, H= 9.0 KM
17 790830
M=2.0, H= 9.0 KM
18 790903
M=2.0, H= 8.0 KM
19 791024
M=2.0, H= 8.0 KM
20 800427
M=2.4, H=11.0 K
PALMDALE
118.50
117.50
35.00
34.00
20
19

Figure 24

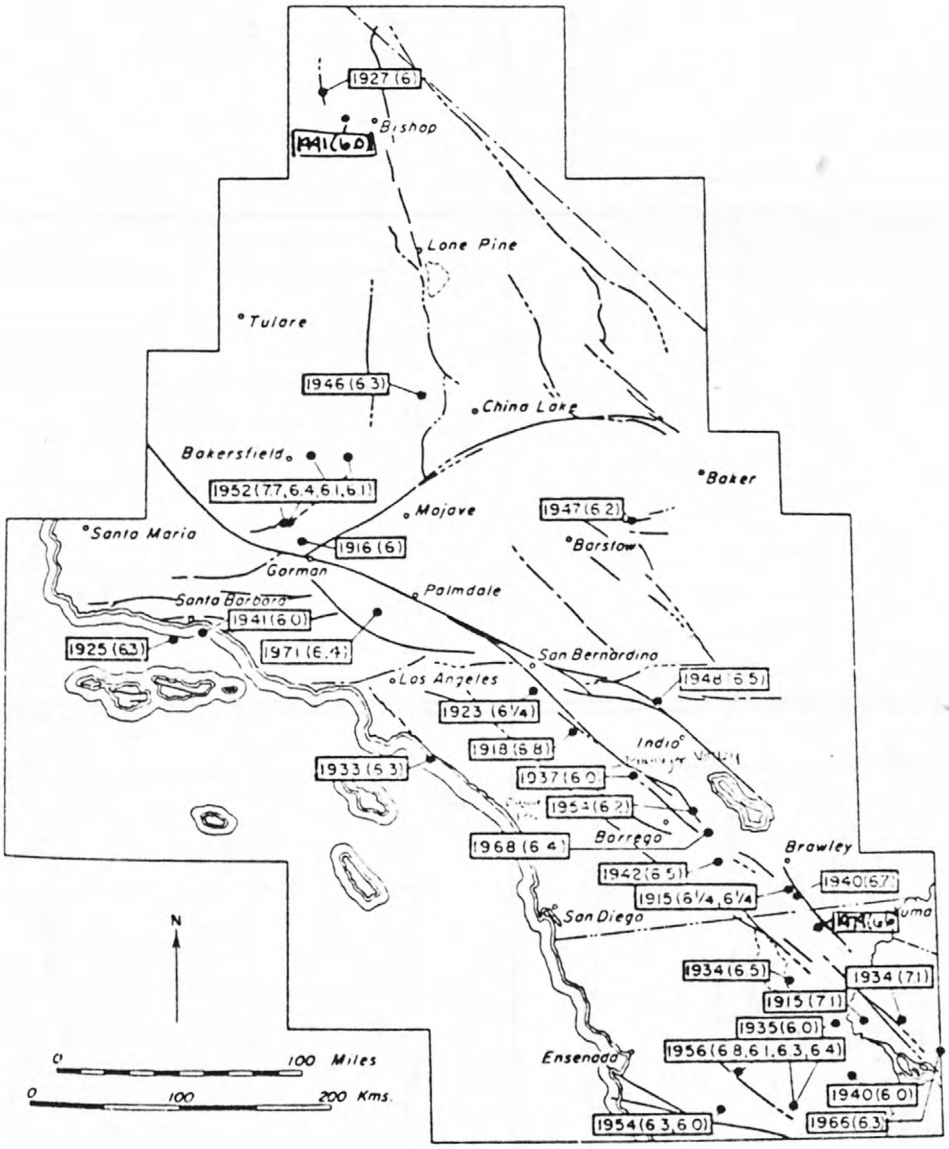


Figure 25. Earthquakes of magnitude 6.0 and greater in the southern California region, 1912-1972, modified from Allen et al. (1965).

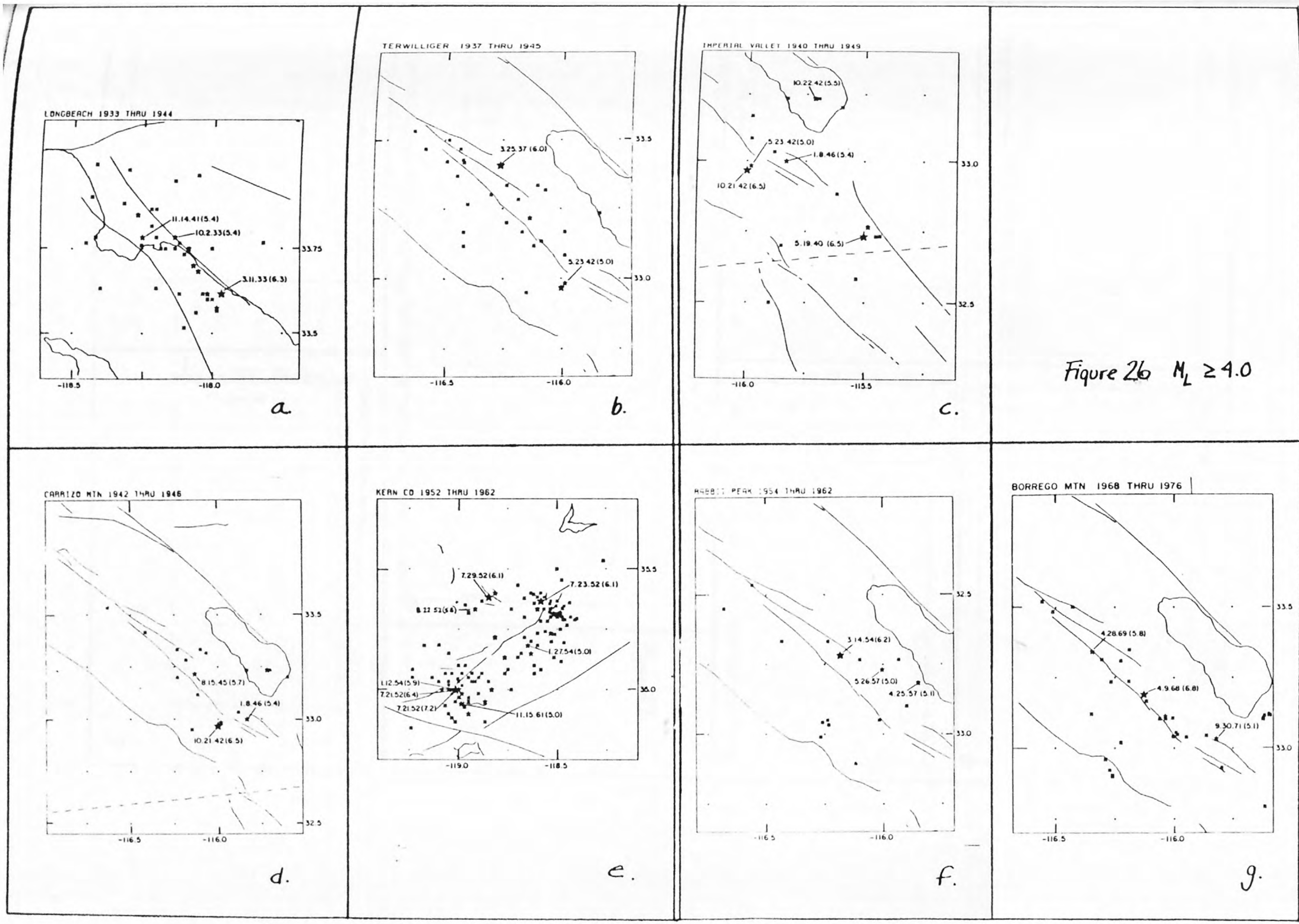


Figure 26 $M_L \geq 4.0$

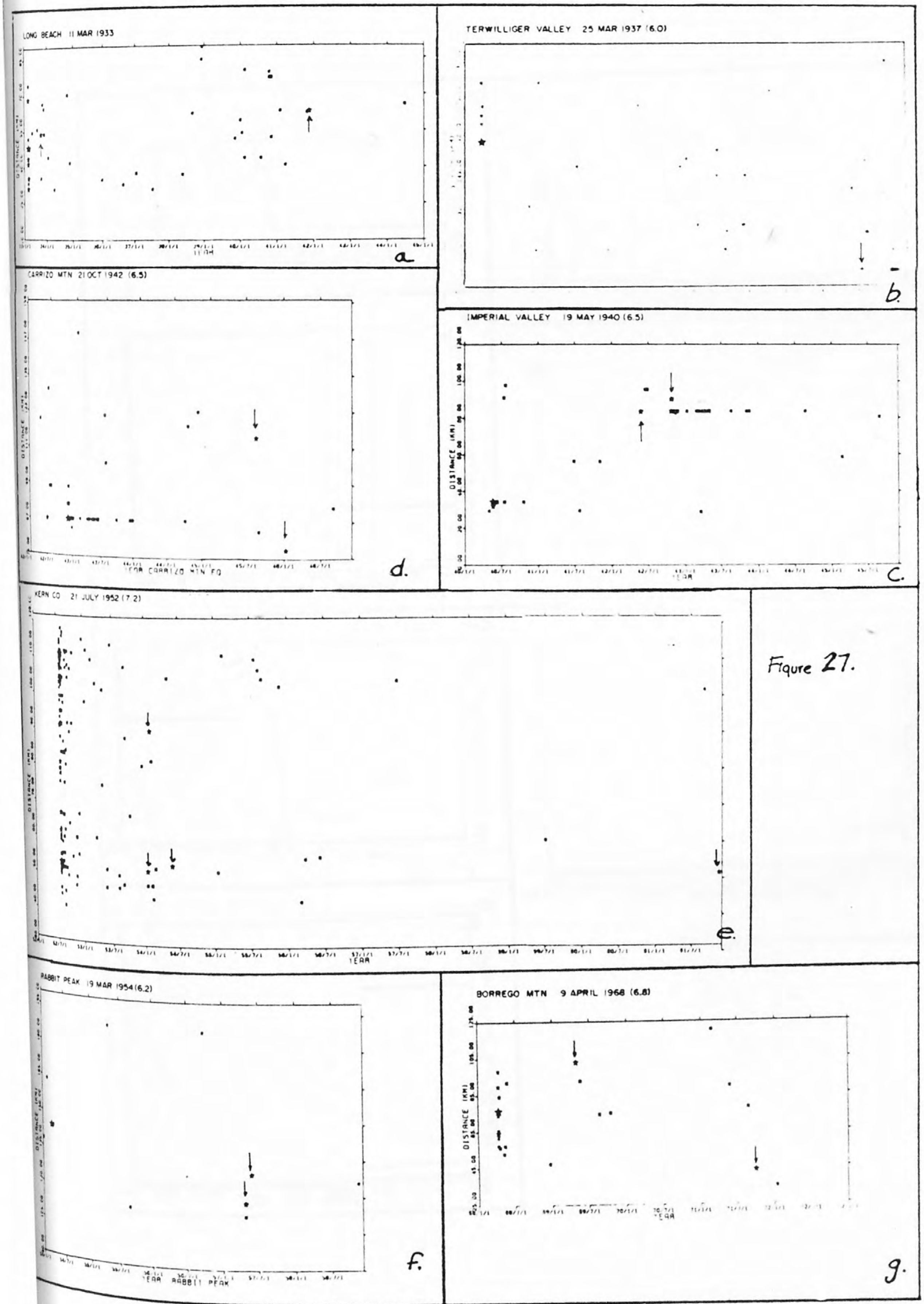

LONG BEACH 11 MAR 1933
DISTANCE (KM)
YEAR
a
TERWILLIGER VALLEY 25 MAR 1937 (6.0)
b.
CARRIZO MTN 21 OCT 1942 (6.5)
DISTANCE (KM)
YEAR CARRIZO MTN EQ
d.
IMPERIAL VALLEY 19 MAY 1940 (6.5)
DISTANCE (KM)
YEAR
c.
KERN CO 21 JULY 1952 (7.2)
DISTANCE (KM)
YEAR
e.
RABBIT PEAK 19 MAR 1954 (6.2)
DISTANCE (KM)
YEAR RABBIT PEAK
f.
BORREGO MTN 9 APRIL 1968 (6.8)
DISTANCE (KM)
YEAR
g.

Figure 27.

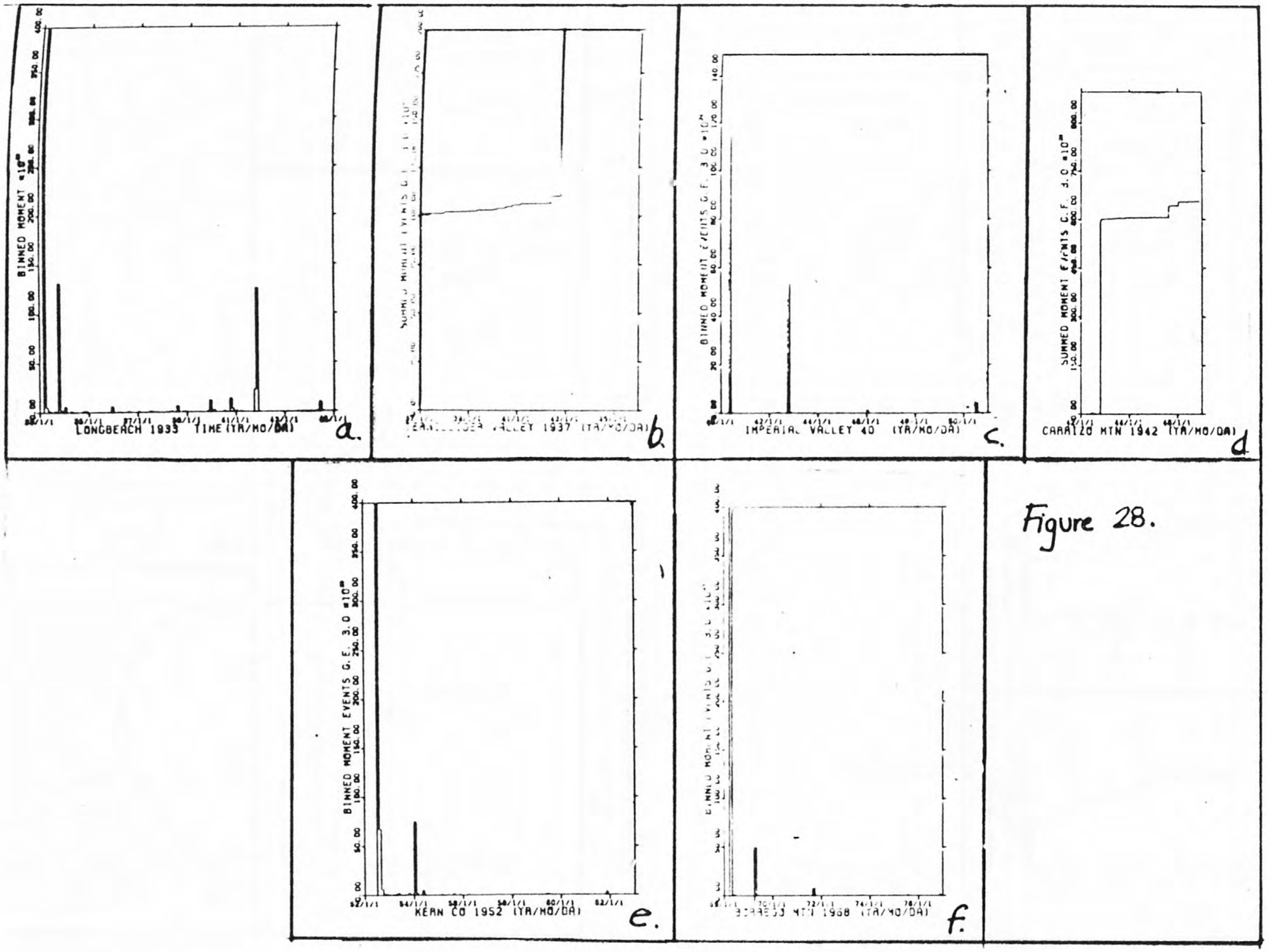

BINNED MOMENT
LONGBEACH 1933 TIME (YR/MO/DA)
a.
b.
BINNED MOMENT EVENTS G.E. 3.0
IMPERIAL VALLEY 40 (YR/MO/DA)
c.
SUMMED MOMENT EVENTS G.E. 3.0
CARRIZO MTN 1942 (YR/MO/DA)
d.
BINNED MOMENT EVENTS G.E. 3.0
KERN CO 1952 (YR/MO/DA)
e.
f.

Figure 28.

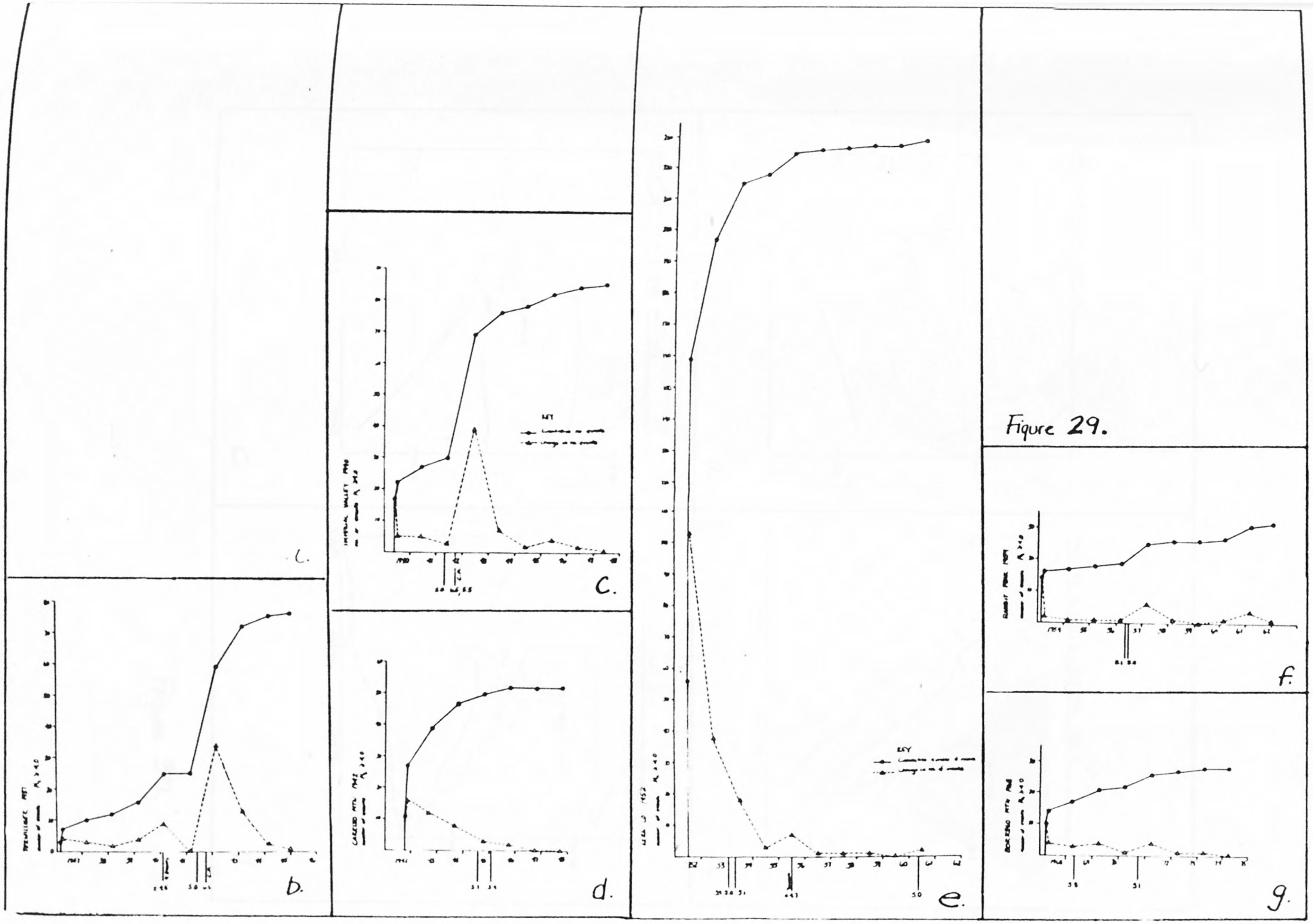


Figure 29.

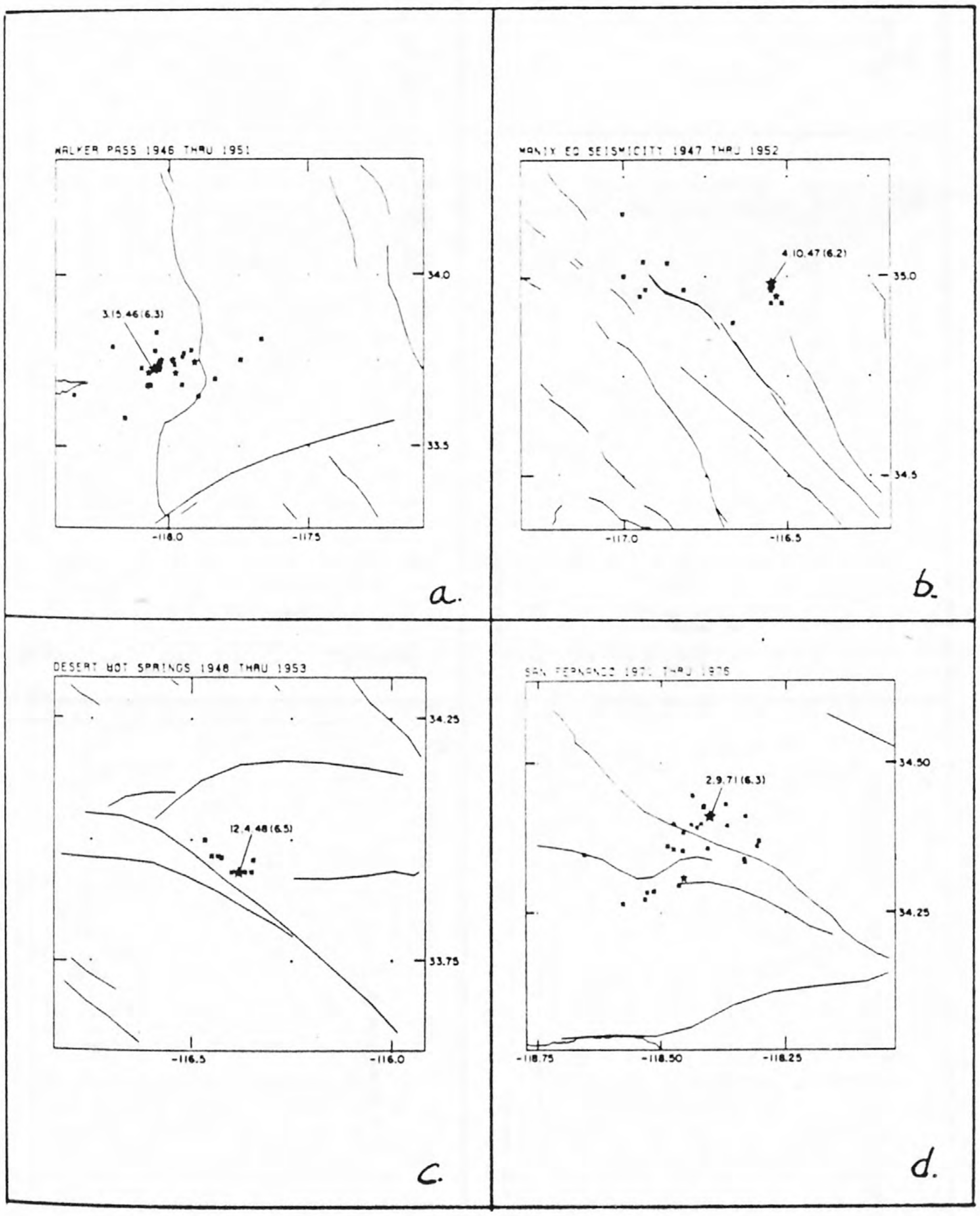

WALKER PASS 1946 THRU 1951
3.15.46 (6.3)
34.0
33.5
-118.0
-117.5
a.
MANIX EQ SEISMICITY 1947 THRU 1952
4.10.47 (6.2)
35.0
34.5
-117.0
-116.5
b.
DESERT HOT SPRINGS 1948 THRU 1953
12.4.48 (6.5)
34.25
33.75
-116.5
-116.0
c.
2.9.71 (6.3)
34.50
34.25
-118.75
-118.50
-118.25
d.

Figure 30.

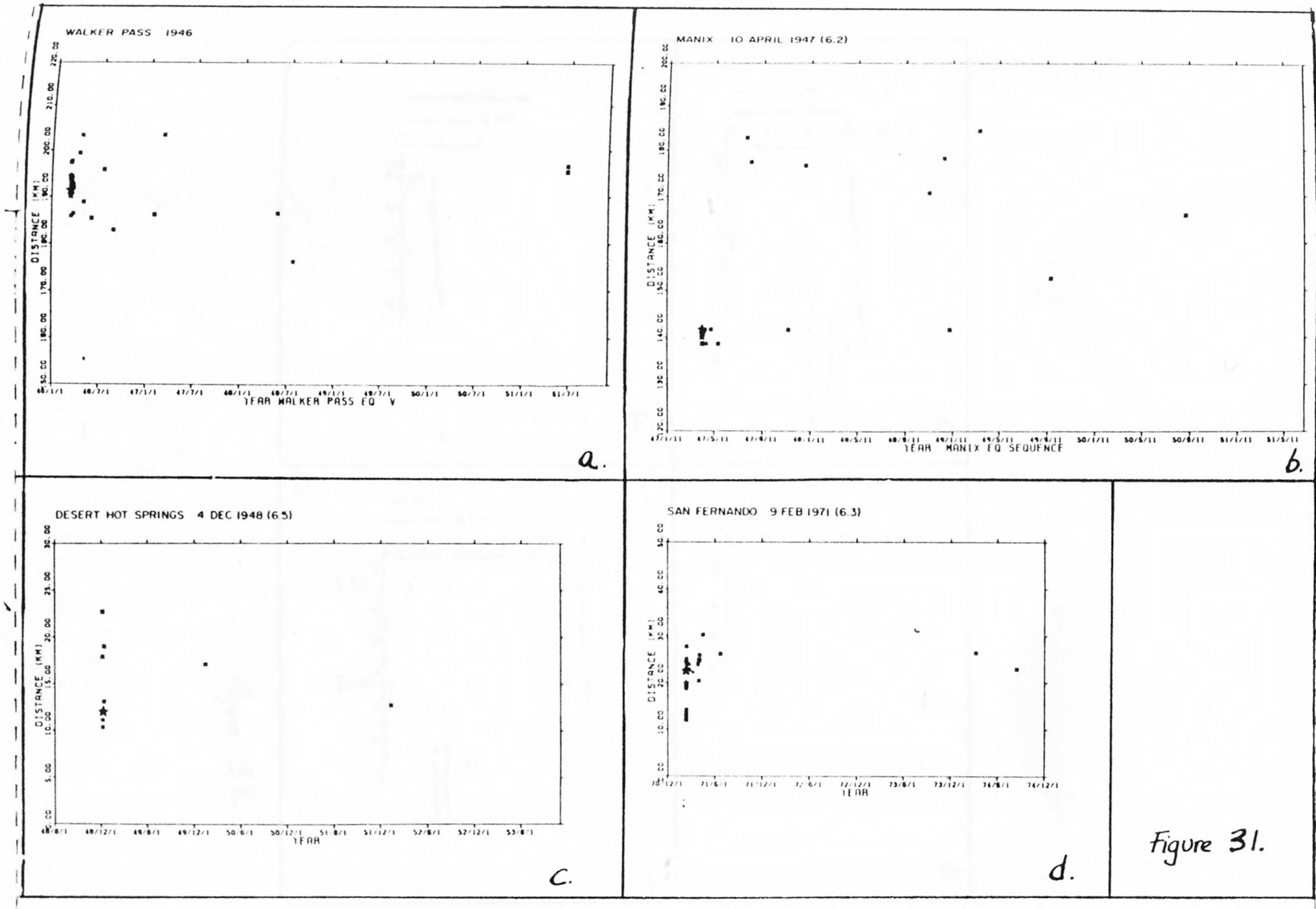

WALKER PASS 1946
DISTANCE (KM)
YEAR WALKER PASS EQ V
a.
MANIX 10 APRIL 1947 (6.2)
DISTANCE (KM)
YEAR MANIX EQ SEQUENCE
b.
DESERT HOT SPRINGS 4 DEC 1948 (6.5)
DISTANCE (KM)
YEAR
c.
SAN FERNANDO 9 FEB 1971 (6.3)
DISTANCE (KM)
YEAR
d.
ZETA RESEARCH, CONCORD, CALIFORNIA
CHART NO. ZF-00 T

Figure 31.

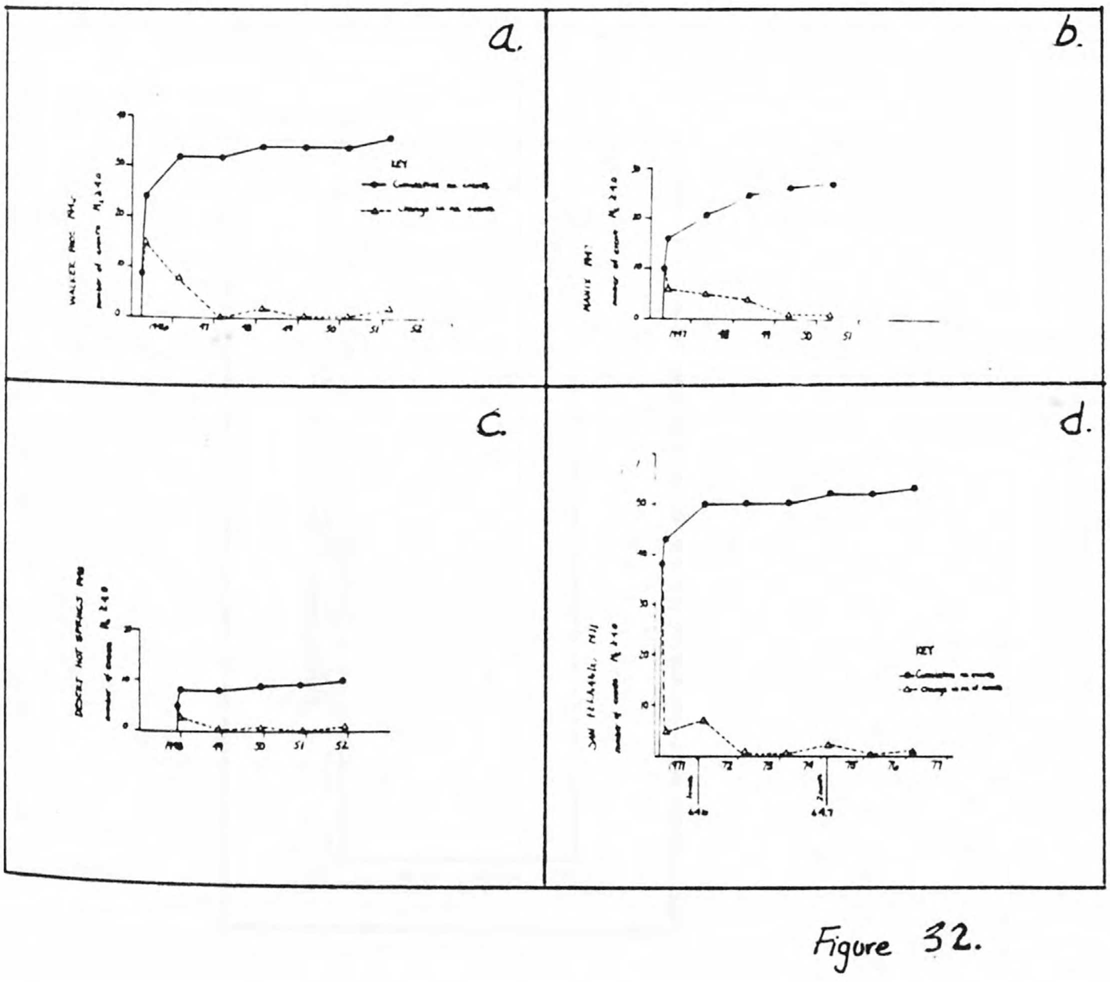


Figure 32.

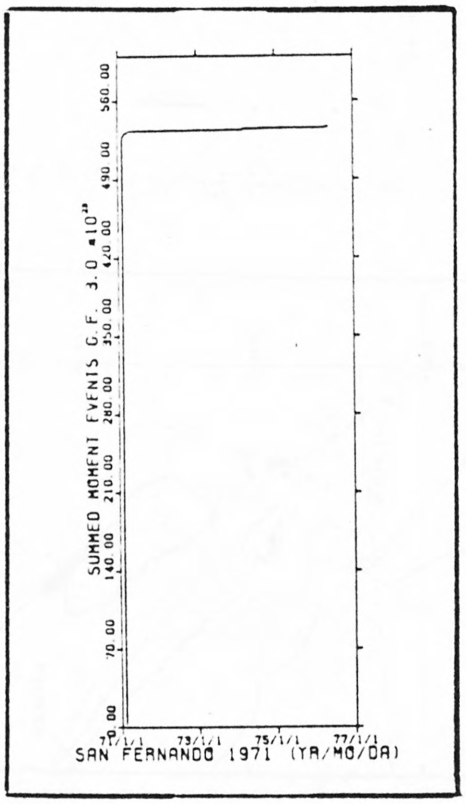

SUMMED MOMENT EVENTS G.F. 3.0 *10^23
0.00
70.00
140.00
210.00
280.00
350.00
420.00
490.00
560.00
71/1/1
73/1/1
75/1/1
77/1/1
SAN FERNANDO 1971 (YR/MO/DA)

Figure 33.

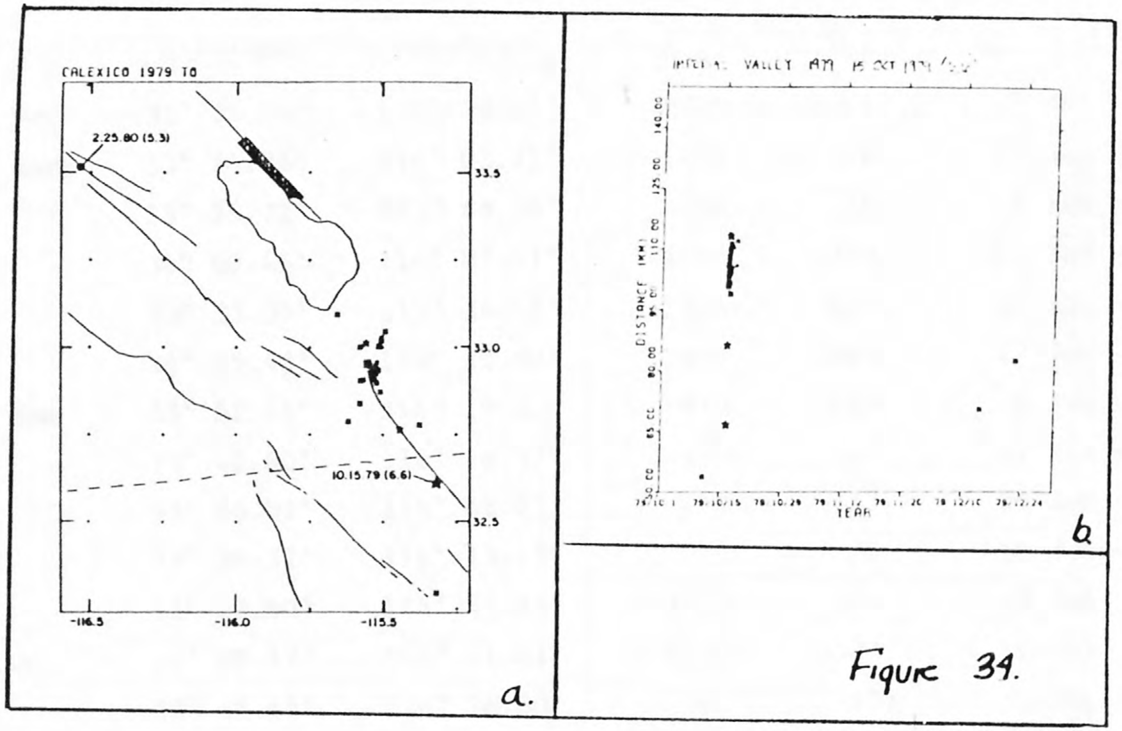

CALEXICO 1979 T0
2.25.80 (5.3)
10.15.79 (6.6)
33.5
33.0
32.5
-116.5
-116.0
-115.5
a.
DISTANCE (KM)
b.

Figure 34.

TABLE 1

MICRO-EARTHQUAKE SURVEY, COACHELLA VALLEY, CALIFORNIA

		Mobile Array Station Name	Latitude	Longitude	Elevation Feet	Elevation Meters	Dates of Operation 1979
1.	PAC	Painted Canyon	33° 38.23'	115° 59.34'	1120	341	5 Jan - 30 Jul
2.	TRR	Travertine Rock	33° 24.26'	116° 03.72'	-20	-6	16 Jan - 9 Jul
3.	BAT	Bat Cave	33° 25.77'	115" 48.78'	50	15	8 Feb - 15 Jun
4.	MON	Monument	34° 00.45'	116° 07.01'	4440	1353	27 Jan - 17 Jun
5.	RED	Red Canyon	33° 33.35'	115° 38.52'	1360	415	10 Jan - 11 Jun
6.	JOB	Joshua Tree	34° 05.48'	116° 18.80'	3500	1067	17 Jan - 7 Aug
7.	THP	Thousand Palms	33° 51.21'	116° 19.62'	810	247	5 Jan - 25 Sep
8.	LAQ	La Quinta	33° 40.60'	116° 18.97'	120	37	11 Jan - 1 Aug
9.	BRD	Berdoo	33° 46.01'	116° 08.23'	450	137	19 Jun - 25 Sep
10.	FSH	Fish Trap	33° 34.32'	116° 13.25'	20	6	15 Jun - 30 Jul
11.	CAB	Cabazon	33° 53.50'	116° 45.24'	1720	524	12 Jul - 1 Aug
12.	TAY	Tayles Ranch	34° 09.17'	116° 41.41'	8440	2573	10 Jul - 25 Sep
13.	BRY	Bryce	33° 45.65'	116° 28.80'	760	232	1 Aug - 25 Sep
14.	LPZ	Lopez	33° 39.93'	116° 17.44'	80	24	1 Aug - 5 Sep
15.	MRN	Morongo	34° 01.64'	116° 30.73'	1940	591	1 Aug - 25 Sep
16.	DUN	Dunkel	33° 53.31'	116° 45.04'	1940	591	1 Aug - 25 Sep
17.	WTR	Whitewater	33° 59.42'	116° 39.31'	2320	707	7 Aug - 25 Sep
18.	BAN	Banning	33° 58.47'	116° 54.73'	3560	1085	5 Sep - 25 Sep

TABLE 2

EVENT CATALOGUE 1 JAN 1979 THRU 30 JUN 1979

YEAR	MO	DA	HRMN	SEC	LATITUDE	LONGITUDE	DEPTH	MAG	NSTA	Q
1979	1	1	1711	36.25	33 30.77	-116 31.52	6.28	1.90	29	C
1979	1	1	1712	4.68	33 30.50	-116 31.04	15.79	3.30	64	B
1979	1	1	1744	56.02	33 30.97	-116 31.34	5.07	0.00	33	B
1979	1	1	2357	6.77	33 31.13	-116 31.43	7.54	0.00	24	C
1979	1	3	326	54.27	33 53.62	-116 15.50	5.53	0.00	15	C
1979	1	3	2159	56.80	33 16.73	-116 15.18	2.42	0.00	13	B
1979	1	4	653	6.38	33 41.59	-116 41.62	5.87	0.00	15	C
1979	1	4	1128	46.90	33 54.31	-116 44.86	10.66	0.00	15	B
1979	1	4	2305	1.27	33 43.08	-116 42.87	5.66	0.00	13	C
1979	1	5	156	19.67	33 27.65	-116 33.70	6.21	0.00	12	C
1979	1	6	933	5.35	33 31.00	-116 30.54	16.32	0.00	14	A
1979	1	10	712	7.74	33 28.64	-116 35.51	6.03	2.10	16	C
1979	1	11	2059	41.72	33 40.18	-116 41.85	5.00	2.30	20	C
1979	1	12	715	12.05	33 39.84	-116 43.19	5.62	2.00	21	C
1979	1	12	1147	15.04	33 30.58	-116 29.82	5.00	3.20	35	C
1979	1	14	240	9.50	33 55.06	-116 42.07	13.87	0.00	19	A
1979	1	16	503	4.44	33 29.44	-116 26.52	15.39	0.00	13	B
1979	1	16	1156	28.95	33 29.96	-116 27.71	7.82	0.00	12	B
1979	1	18	319	10.28	33 58.36	-116 34.49	9.33	2.60	34	A
1979	1	19	233	2.75	33 51.68	-115 54.11	5.70	0.00	10	C
1979	1	20	1228	41.59	33 29.05	-116 29.39	14.22	0.00	18	B

YEAR	MO	DA	HRMN	SEC	LATITUDE		LONGITUDE		DEPTH	MAG	NSTA	Q
1979	1	21	347	0.58	33	29.12	-116	30.26	13.28	0.00	16	A
1979	1	22	634	35.23	33	54.78	-116	41.67	13.62	0.00	13	A
1979	1	23	1830	16.91	33	39.87	-116	44.06	14.39	0.00	19	A
1979	1	27	2218	14.19	33	29.04	-116	25.19	5.11	0.00	10	C
1979	1	30	348	57.42	33	58.56	-116	41.54	12.19	0.00	18	B
1979	1	30	2027	33.46	33	27.66	-116	35.11	5.71	2.30	29	C
1979	1	31	1800	1.36	33	38.01	-116	43.01	13.52	0.00	11	C
1979	1	31	1825	5.33	33	37.66	-116	42.94	4.95	2.00	25	C
1979	2	1	218	49.72	33	28.35	-116	27.69	5.00	2.50	27	C
1979	2	1	1135	2.38	33	57.86	-116	36.44	8.45	2.40	26	A
1979	2	2	406	59.53	33	27.84	-116	30.52	5.76	0.00	14	C
1979	2	2	624	16.21	33	30.51	-116	35.45	5.87	0.00	21	C
1979	2	2	1558	44.18	33	58.93	-116	27.72	5.57	1.90	26	C
1979	2	3	1447	10.75	33	45.90	-116	8.27	5.00	1.80	29	C
1979	2	4	453	22.16	33	28.28	-116	36.04	5.65	1.90	26	C
1979	2	4	610	6.60	33	30.46	-116	30.92	5.04	0.00	12	C
1979	2	4	850	14.53	33	52.87	-116	6.99	4.46	0.00	9	C
1979	2	4	2117	11.05	33	30.35	-116	31.18	14.73	0.00	18	A
1979	2	5	1715	8.21	33	40.10	-116	42.43	2.43	0.00	15	B
1979	2	5	1943	14.79	33	19.77	-116	11.95	8.53	0.00	12	C
1979	2	6	1227	25.65	33	18.68	-116	18.10	5.00	2.90	52	C
1979	2	7	156	37.27	33	57.72	-116	41.32	5.62	0.00	12	C
1979	2	7	1832	52.42	33	56.04	-116	1.59	1.87	0.00	13	A
1979	2	7	1845	42.51	33	56.09	-116	1.91	2.51	1.90	21	A
1979	2	8	10	38.05	33	56.07	-116	1.59	2.57	0.00	11	B
1979	2	8	931	21.97	33	40.98	-116	43.73	5.04	0.00	22	B

YEAR	MO	DA	HRMN	SEC	LATITUDE	LONGITUDE	DEPTH	MAG	NSTA	Q
1979	2	8	1958	39.07	33 30.52	-116 30.02	15.77	0.00	19	B
1979	2	8	2103		TR.PAC S-P 4.32		ML	1.3		
1979	2	9	106		TR.PAC S-P 4.41		ML	1.1		
1979	2	9	214		TR.PAC S-P 3.65		ML	1.1		
1979	2	9	241	3.66	33 40.44	-116 44.19	5.04	2.60	60	B
1979	2	9	258	17.12	33 22.30	-116 22.87	3.70	0.00	28	A
1979	2	9	547	6.89	33 56.23	-116 2.35	5.16	0.00	9	A
1979	2	9	749	55.56	33 55.91	-116 2.31	3.50	0.00	23	A
1979	2	9	750	18.96	33 56.03	-116 2.07	1.96	1.90	23	A
1979	2	9	820		TR.PAC S-P 4.00		ML	1.1		
1979	2	9	1248	47.96	33 56.05	-116 2.22	3.42	1.90	34	A
1979	2	9	1415	14.43	33 56.27	-116 2.50	5.03	0.00	14	B
1979	2	9	1415	34.74	33 56.18	-116 2.42	5.12	0.00	8	A
1979	2	9	1815	0.19	33 56.23	-116 1.91	3.68	0.00	13	A
1979	2	9	2059		TR.PAC S-P 4.41		ML	1.5		
1979	2	9	2224	1.43	33 56.15	-116 2.23	4.03	0.00	14	A
1979	2	9	2225		TR.PAC S-P 4.36		ML	1.1		
1979	2	11	1010	10.85	33 21.96	-116 19.33	11.30	0.00	22	B
1979	2	11	1957	3.36	33 22.29	-116 22.53	11.34	2.60	55	B
1979	2	11	2236	27.54	33 25.47	-116 22.25	13.07	0.00	17	A
1979	2	12	448	42.34	33 27.47	-116 26.05	3.89	4.20	105	B
1979	2	12	450	6.21	33 27.62	-116 25.58	5.88	0.00	18	B
1979	2	12	455	16.10	33 27.47	-116 25.92	4.17	3.20	73	B
1979	2	12	515	23.84	33 27.32	-116 26.01	3.95	3.00	64	B
1979	2	12	1228	48.28	33 59.45	-116 7.40	5.52	1.60	45	B
1979	2	12	1232	47.29	33 59.71	-116 7.29	10.80	0.00	31	A

YEAR	MO	DA	HRMN	SEC	LATITUDE		LONGITUDE		DEPTH	MAG	NSTA	Q
1979	2	13	646	59.76	33	27.89	-116	24.06	7.87	0.00	13	B
1979	2	13	1433	0.80	33	28.27	-116	25.15	1.64	1.60	6	C
1979	2	13	1916	12.99	33	29.46	-116	31.12	12.50	0.00	22	B
1979	2	13	2102	13.79	33	28.24	-116	26.51	5.01	0.00	16	B
1979	2	13	2352	49.91	33	27.85	-116	25.04	6.96	0.00	13	B
1979	2	14	712	20.56	33	56.03	-116	1.98	2.00	1.90	34	A
1979	2	14	831	51.92	33	55.81	-116	2.50	4.38	0.00	13	C
1979	2	14	1854	26.95	33	56.06	-116	1.90	2.13	2.10	32	A
1979	2	14	1856	5.15	33	56.21	-116	2.02	1.94	0.00	16	A
1979	2	14	1857	11.90	33	56.25	-116	1.89	2.51	2.00	20	A
1979	2	15	737	20.77	33	56.18	-116	1.97	1.97	0.00	18	A
1979	2	15	740	8.30	33	55.95	-116	2.52	6.48	0.00	32	B
1979	2	15	759	56.88	33	55.98	-116	2.01	2.01	1.70	30	A
1979	2	15	801	51.08	33	27.33	-116	25.83	4.32	2.80	49	A
1979	2	15	901	25.90	33	56.52	-116	1.55	5.64	1.60	20	C
1979	2	15	951		TR.PAC S-P 4.57				ML 2.2			
1979	2	15	1136	4.11	33	55.90	-116	2.30	1.36	0.00	26	A
1979	2	15	1305	9.52	33	56.21	-116	1.90	3.42	0.00	31	A
1979	2	16	258	48.61	33	56.32	-116	1.99	3.79	0.00	10	A
1979	2	16	1011	7.61	33	56.04	-116	2.59	6.03	1.4		T
1979	2	16	306	17.88	33	56.14	-116	1.97	2.70	1.90	28	A
1979	2	16	528	15.77	33	56.22	-116	1.66	6.05	0.00	15	C
1979	2	16	715	15.58	33	56.25	-116	2.09	3.64	0.00	25	A
1979	2	16	907	33.63	33	56.28	-116	2.02	2.65	0.00	19	A
1979	2	16	908	1.08	33	56.34	-116	1.98	3.33	0.00	21	A
1979	2	16	1012	44.12	33	56.17	-116	1.92	2.27	0.00	18	A

YEAR	MO	DA	HRMN	SEC	LATITUDE		LONGITUDE		DEPTH	MAG	NSTA	Q
1979	2	16	1338	9.71	33	56.28	-116	2.00	3.30	1.70	23	A
1979	2	16	1339	1.49	33	56.22	-116	2.12	3.72	1.70	26	A
1979	2	16	1505	46.39	33	56.05	-116	2.22	3.43	2.70	53	A
1979	2	16	1511	19.87	33	56.25	-116	2.00	3.40	0.00	12	A
1979	2	16	1608	5.35	33	27.20	-116	25.64	4.69	0.00	21	B
1979	2	16	1947	20.35	33	56.23	-116	2.16	3.65	1.80	29	A
1979	2	16	1953	9.58	33	56.28	-116	2.09	3.30	0.00	13	A
1979	2	16	2011		TR.PAC S-P 4.59				ML 1.8			
1979	2	16	2108	32.11	33	56.03	-116	1.96	3.50	2.40	27	A
1979	2	16	2108	22.12	33	56.08	-116	2.00	1.72	0.00	18	A
1979	2	16	2109	46.60	33	53.92	-116	2.10	4.13	0.00	11	C
1979	2	17	319	31.34	33	56.24	-116	1.96	3.40	0.00	20	A
1979	2	17	613	3.44	33	56.37	-116	1.97	2.76	1.70	13	A
1979	2	17	809	38.99	33	55.62	-116	2.30	5.75	0.00	13	C
1979	2	17	819	36.03	33	56.09	-116	2.11	1.55	1.80	20	A
1979	2	17	819	47.41	33	56.34	-116	1.91	4.53	0.00	10	B
1979	2	17	934	56.71	33	19.29	-116	20.52	10.02	0.00	35	A
1979	2	17	1002	38.24	33	17.01	-116	15.51	2.84	0.00	32	A
1979	2	17	1307	35.41	33	56.21	-116	1.96	3.40	0.00	21	A
1979	2	17	1755	36.20	33	56.68	-116	43.93	6.10	2.50	50	B
1979	2	17	2324	8.86	33	56.33	-116	2.09	2.40	0.00	18	A
1979	2	17	2324	47.80	33	56.47	-116	2.07	2.32	0.00	10	A
1979	2	18	747	3.66	33	56.20	-116	1.80	2.61	1.90	23	A
1979	2	18	835	52.99	33	56.13	-116	1.88	2.32	0.00	22	A
1979	2	18	1931	49.46	33	56.19	-116	2.41	6.89	1.80	30	C
1979	2	18	1931	43.51	33	56.06	-116	1.99	1.89	0.00	14	A

YEAR	MO	DA	HRMN	SEC	LATITUDE	LONGITUDE	DEPTH	MAG	NSTA	Q
1979	2	19	259		TR.PAC S-P 4.35		ML	1.5		
1979	2	19	453	36.57	33 18.76	-116 20.53	11.51	0.00	13	B
1979	2	19	1727	9.58	33 56.15	-116 2.10	2.57	1.80	18	A
1979	2	20	241	6.97	33 43.50	-116 0.66	9.86	1.4		
1979	2	20	704	21.88	33 55.97	-116 2.68	7.50	1.5		
1979	2	20	710	59.86	33 57.99	-116 4.21	10.96	1.5		
1979	2	20	752		TR.PAC S-P 4.59		ML	1.2		
1979	2	20	755	33.26	33 56.26	-116 1.94	3.28	0.00	22	A
1979	2	20	927	9.39	33 56.00	-116 2.04	3.47	1.90	34	B
1979	2	20	932	50.82	33 56.38	-116 2.06	2.37	1.50	21	A
1979	2	20	1003	3.41	33 56.30	-116 2.03	3.42	2.00	15	A
1979	2	20	1114		TR.PAC S-P 4.34		ML	1.7		
1979	2	20	1124	0.93	33 56.17	-116 1.88	3.35	0.00	14	A
1979	2	20	1256	11.46	33 56.20	-116 1.98	3.85	0.00	12	A
1979	2	21	642	26.64	33 56.22	-116 1.84	3.99	0.00	13	B
1979	2	22	634	33.96	33 25.28	-116 26.43	5.85	2.00	41	C
1979	2	22	904	38.57	33 40.87	-116 1.77	2.22	0.00	15	A
1979	2	22	906		TR.PAC S-P 1.38		ML	1.9		
1979	2	25	1029	57.00	33 56.11	-116 1.99	2.59	0.00	13	A
1979	2	25	1102	32.88	33 56.24	-116 2.02	3.67	0.00	8	A
1979	2	26	22	31.05	33 28.91	-116 31.13	14.10	0.00	37	A
1979	2	27	2028	44.38	33 39.15	-116 44.48	5.45	2.40	46	B
1979	2	27	2032	13.67	33 39.55	-116 44.45	15.50	0.00	15	A
1979	2	28	1639	50.31	33 55.88	-116 1.90	1.58	1.70	24	A
1979	2	28	2329	8.82	33 33.92	-115 54.15	5.78	0.9		
1979	3	2	42	23.44	33 29.96	-116 24.56	12.74	0.00	27	A

YEAR	MO	DA	HRMN	SEC	LATITUDE	LONGITUDE	DEPTH	MAG	NSTA	Q
1979	3	4	819	33.51	33 41.42	-116 44.70	16.17	0.00	14	A
1979	3	5	916	52.31	33 27.83	-116 25.45	12.31	0.00	39	A
1979	3	5	2200	26.98	33 56.67	-116 41.37	9.86	0.00	13	B
1979	3	6	611	50.76	33 28.48	-116 34.95	6.54	0.00	19	C
1979	3	8	203	21.27	33 55.41	-116 44.70	14.63	0.00	18	A
1979	3	8	1740	27.42	33 52.57	-116 34.07	5.00	0.00	15	B
1979	3	9	1008	25.74	33 25.26	-116 22.43	5.71	1.90	44	C
1979	3	9	1738	34.03	33 24.36	-116 3.82	5.00	1.7		
1979	3	10	317	10.70	33 11.21	-115 57.54	5.00	2.2		
1979	3	11	905	0.67	33 59.37	-116 15.14	1.39	1.80	21	A
1979	3	11	2009	8.89	33 59.45	-116 15.20	1.48	2.00	31	A
1979	3	12	251	9.25	33 39.94	-116 42.77	5.00	1.40	32	B
1979	3	12	1418	18.62	33 30.67	-116 28.34	6.36	0.00	30	B
1979	3	12	1418	30.32	33 30.64	-116 28.62	12.62	0.00	13	C
1979	3	12	1540	12.14	33 27.38	-116 24.89	4.83	0.00	10	B
1979	3	15	715		TR.PAC S-P 1.27		ML	1.2		
1979	3	15	718		TR.PAC S-P 1.12		ML	1.4		
1979	3	15	1915	34.99	33 00.17	-115 55.04	1.36	1.4		
1979	3	16	437	13.31	33 38.84	-116 43.24	5.36	0.00	13	C
1979	3	16	437	22.02	33 39.52	-116 42.41	5.00	0.00	9	C
1979	3	16	527	40.85	33 28.39	-116 28.29	11.88	0.00	18	B
1979	3	16	831	26.42	33 59.70	-116 15.27	2.75	2.20	19	A
1979	3	16	1545	8.90	33 53.94	-116 0.20	6.23	1.90	29	C
1979	3	16	1835	41.17	33 59.70	-116 14.89	1.32	0.00	23	A
1979	3	16	1938	26.33	33 53.69	-116 0.28	5.63	0.00	16	C
1979	3	17	359		TR.PAC S-P 4.07		ML	1.6		

YEAR	MO	DA	HRMN	SEC	LATITUDE	LONGITUDE	DEPTH	MAG	NSTA	Q
1979	3	17	1035	59.89	33 53.66	-116 0.07	5.65	0.00	28	C
1979	3	17	1331		TR.PAC S-P	4.04	ML	1.4		
1979	3	18	617	9.74	33 53.68	-116 0.38	4.99	2.20	50	B
1979	3	18	704		TR.PAC S-P	4.24	ML	1.4		
1979	3	18	713	20.65	33 53.24	-116 0.67	5.53	0.00	8	C
1979	3	18	1347	59.68	33 37.83	-116 44.54	5.00	2.20	50	B
1979	3	19	627	38.05	33 53.29	-116 0.13	5.00	2.00	36	B
1979	3	19	1042	37.11	33 40.78	-116 43.24	15.80	0.00	16	A
1979	3	23	404		TR.PAC S-P	1.88	ML	1.2		
1979	3	23	1116	28.51	33 19.25	-116 24.21	11.34	1.60	23	A
1979	3	23	2336	9.39	33 36.12	-116 38.52	5.93	0.00	30	B
1979	3	23	2337	23.13	33 35.74	-116 38.40	5.04	0.00	28	C
1979	3	24	50	53.71	33 36.38	-116 37.73	14.47	0.00	18	A
1979	3	24	251	15.35	33 35.80	-116 38.49	5.58	0.00	28	C
1979	3	24	624	27.35	33 35.83	-116 37.90	13.58	0.00	21	A
1979	3	24	1754	30.66	33 18.34	-116 14.12	4.59	0.00	11	B
1979	3	25	652		TR.PAC S-P	3.79	ML	1.5		
1979	3	26	2359		TR.PAC S-P	3.21	ML	1.4		
1979	3	27	1100		TR.PAC S-P	2.76	ML	2.1		
1979	3	29	59	40.84	33 39.49	-116 42.45	16.59	0.00	14	B
1979	3	29	217	11.61	33 38.72	-116 43.43	6.52	3.00	100	C
1979	3	29	657	35.00	33 26.99	-116 23.98	13.07	1.90	40	B
1979	3	29	1624		TR.PAC S-P	0.44	ML	0.9		
1979	3	29	2346		TR.PAC S-P	0.42	ML	0.0		
1979	3	30	2011	34.41	33 53.71	-116 0.25	5.00	1.90	29	B
1979	3	31	957	7.99	33 28.97	-116 29.11	14.56	0.00	21	B

YEAR	MO	DA	HRMN	SEC	LATITUDE		LONGITUDE		DEPTH	MAG	NSTA	Q
1979	4	7	1635	55.82	33	37.88	-116	42.45	12.64	0.00	23	B
1979	4	7	1636	2.59	33	38.08	-116	42.09	5.62	2.60	54	C
1979	4	7	1642	38.86	33	37.93	-116	42.45	13.03	0.00	18	A
1979	4	8	1858	20.06	33	17.70	-115	42.25	4.93	1.90	15	A
1979	4	8	2336	15.60	33	58.27	-116	41.00	5.96	0.00	24	C
1979	4	10	1043	24.71	33	57.15	-116	16.24	10.02	0.00	28	A
1979	4	12	2326	8.88	33	38.81	-116	43.64	5.55	0.00	10	C
1979	4	15	2250	26.56	33	57.25	-116	18.71	3.69	0.00	12	B
1979	4	17	1345	30.82	33	19.82	-116	13.34	9.72	0.00	19	A
1979	4	21	830	31.39	33	30.56	-116	30.36	5.00	2.20	39	B
1979	4	21	1203	8.33	33	30.54	-116	30.02	5.61	2.20	39	C
1979	4	21	1357	25.91	33	30.67	-116	30.14	5.00	0.00	27	C
1979	4	21	2246	36.45	33	30.25	-116	30.62	15.59	0.00	14	B
1979	4	22	329	36.57	33	58.57	-116	42.93	5.04	2.10	44	B
1979	4	22	1102	25.99	33	24.61	-116	37.67	5.66	2.90	47	C
1979	4	22	1652	17.28	33	25.36	-116	32.96	13.87	3.30	85	B
1979	4	23	459	2.12	33	23.01	-116	22.80	9.18	0.00	17	A
1979	4	23	1140	29.23	33	21.36	-116	21.72	10.44	0.00	34	A
1979	4	23	2221	27.12	33	59.34	-116	26.76	7.14	1.90	29	A
1979	4	23	2356	13.57	33	55.98	-116	43.85	5.96	0.00	13	C
1979	4	24	1605	54.65	33	59.99	-116	26.35	5.41	3.00	94	B
1979	4	25	1649	38.77	33	21.52	-116	13.82	9.26	0.00	33	B
1979	4	27	2106	5.64	33	22.84	-116	23.38	11.66	0.00	13	A
1979	4	29	938	49.56	33	15.23	-116	6.21	5.00	2.50	39	C
1979	4	29	1526	10.76	33	53.15	-116	33.50	6.28	0.00	39	B
1979	4	29	1635	38.14	33	58.14	-116	41.63	5.07	0.00	18	C

YEAR	MO	DA	HRMN	SEC	LATITUDE		LONGITUDE		DEPTH	MAG	NSTA	Q
1979	5	1	548	55.92	33	58.75	-116	24.07	8.10	0.00	18	A
1979	5	3	731	33.61	33	15.18	-116	17.23	4.32	0.00	12	C
1979	5	3	1333	40.09	33	18.32	-116	19.29	4.16	0.00	20	A
1979	5	4	329	58.55	33	46.50	-115	57.19	0.33	0.00	16	B
1979	5	4	444	27.14	33	47.09	-115	57.36	0.66	2.30	26	A
1979	5	4	445	43.00	33	47.23	-115	57.44	1.58	2.50	35	A
1979	5	4	517	54.08	33	47.31	-115	57.62	2.55	0.00	10	A
1979	5	4	524	10.19	33	47.20	-115	57.38	1.17	2.10	31	A
1979	5	4	1418	6.60	33	47.17	-115	57.21	1.92	2.20	47	B
1979	5	4	1426	59.06	33	47.44	-115	57.38	1.36	0.00	16	A
1979	5	5	148	1.09	33	56.98	-116	42.97	17.03	0.00	18	A
1979	5	5	1047	32.10	33	45.41	-116	2.72	5.00	0.00	12	C
1979	5	5	1622	22.95	33	47.07	-115	57.21	1.80	2.80	43	B
1979	5	5	1623	10.87	33	47.55	-115	57.28	1.78	2.30	29	A
1979	5	5	1628	0.29	33	47.30	-115	57.42	2.20	2.30	33	A
1979	5	5	1629	19.91	33	47.11	-115	57.48	1.51	2.20	25	A
1979	5	5	1753	1.54	33	47.41	-115	57.51	1.99	2.00	16	B
1979	5	6	438	5.31	33	47.26	-115	57.25	1.80	2.50	33	A
1979	5	8	2348	17.09	33	21.61	-116	21.83	10.01	0.00	16	B
1979	5	12	130	29.70	33	33.38	-115	53.46	5.08	2.10	27	A
1979	5	15	31	16.38	33	57.58	-115	45.55	8.56	0.00	13	A
1979	5	16	329	50.84	33	26.37	-116	35.43	5.99	0.00	11	C
1979	5	16	426	1.00	33	22.55	-116	21.98	2.80	3.20	84	B
1979	5	16	1629	5.92	33	51.82	-116	30.55	9.56	2.50	88	A
1979	5	19	1901	4.63	33	45.60	-116	2.31	5.53	0.00	20	C
1979	5	20	1522	32.09	33	45.54	-116	2.31	5.52	0.00	18	C

YEAR	MO	DA	HRMN	SEC	LATITUDE	LONGITUDE	DEPTH	MAG	NSTA	Q
1979	5	22	2027	48.50	33 22.75	-116 21.71	3.44	0.00	18	A
1979	5	23	1227	22.14	33 30.60	-116 28.07	6.31	0.00	23	A
1979	5	24	850	37.43	33 56.03	-116 4.86	1.59	1.80	26	A
1979	5	24	948	9.38	33 31.01	-116 26.49	5.00	0.00	9	C
1979	5	24	1214	41.27	33 29.95	-116 27.76	7.65	2.70	43	A
1979	5	24	1617	52.05	33 55.84	-116 4.86	0.69	0.00	26	A
1979	5	24	1700	58.65	33 53.35	-116 35.35	5.13	0.00	15	B
1979	5	25	112	53.40	33 55.83	-116 4.76	1.88	0.00	17	A
1979	5	25	353	26.38	33 27.94	-116 24.90	7.58	0.00	17	A
1979	5	25	852	21.04	33 55.90	-116 19.41	2.80	0.00	22	A
1979	5	25	853	40.77	33 55.50	-116 19.61	2.17	2.10	39	A
1979	5	25	1209	17.85	33 55.52	-116 19.56	2.34	1.90	33	A
1979	5	25	1309	13.52	33 30.66	-116 26.23	7.02	0.00	10	C
1979	5	26	717	4.73	33 30.32	-116 26.60	9.91	0.00	17	A
1979	5	26	1655	48.02	33 22.30	-116 22.36	10.85	0.00	26	A
1979	5	26	2307	28.32	33 58.48	-116 38.59	5.04	0.00	21	C
1979	5	27	1800	42.21	33 57.30	-116 39.57	7.48	0.00	23	A
1979	5	27	2318	33.48	33 15.80	-116 15.77	5.95	0.00	15	B
1979	5	30	444	12.07	33 30.10	-116 27.65	5.00	0.00	15	C
1979	5	30	1028	11.01	33 38.40	-116 39.29	5.00	1.4		
1979	5	30	2347	5.91	33 46.38	-116 39.29	24.54	1.1		
1979	5	31	207	31.89	TR.THP	S-P 1.87	ML	---		
1979	5	31	337	52.25	TR.MON	S-P 2.34	ML	1.2		
1979	5	31	337	50.74	TR.THP	S-P 1.77	ML	1.0		
1979	5	31	343	6.87	33 47.73	-116 33.03	9.68	1.4		
1979	5	31	826	4.61	33 38.40	-116 46.59	35.40	1.4		

YEAR	MO	DA	HRMN	SEC	LATITUDE	LONGITUDE	DEPTH	MAG	NSTA	Q
1979	5	31	1006	19.18	33 31.47	-116 31.42	16.28	0.00	23	B
1979	5	31	1208	59.12	TR.MON S-P	2.41	ML	1.3		
1979	5	31	1424	3.34	33 46.94	-116 34.74	9.16	1.2		
1979	5	31	1534	36.67	33 18.49	-116 11.96	2.15	0.00	10	A
1979	5	31	2034	20.33	TR.MON S-P	3.07	ML	---		
1979	5	31	2034	18.29	TR.THP S-P	3.05	ML	0.9		
1979	5	31	2034	19.00	TR.INS S-P	2.38	ML	1.4		
1979	6	1	458	9.51	TR.MON S-P	3.76	ML	1.5		
1979	6	1	529	57.91	33 18.95	-116 35.00	5.00	0.8		
1979	6	1	530	23.11	TR.THP S-P	2.60	ML	0.5		
1979	6	1	536	57.13	33 27.13	-116 35.00	17.90	1.1		
1979	6	1	537	40.05	D.CTW S-P	2.10.*	ML	1.2		
1979	6	1	558	27.64	33 32.25	-116 27.80	5.00	1.4		
1979	6	1	701	36.85	33 44.20	-116 3.82	5.00	---		
1979	6	1	1149	28.75	33 43.83	-116 35.00	5.00	1.1		
1979	6	1	1557	20.04	TR.THP S-P	1.82	ML	1.3		
1979	6	1	1617	13.57	33 30.26	-116 26.19	9.79	0.00	9	B
1979	6	1	1948	05.32	D.CTW S-P	2.0.*	ML	1.0		
1979	6	1	1951	45.67	33 29.62	-116 27.06	5.00	2.60	35	C
1979	6	2	40	27.61	33 46.37	-115 57.67	4.30	1.92	16	C
1979	6	2	253	59.09	TR.THP S-P	1.69	ML	1.3		
1979	6	2	522	19.26	TR.THP S-P	5.48	ML	1.4		
1979	6	2	545	4.02	33 27.34	-116 18.06	5.00	1.1		
1979	6	2	701	2.68	33 47.66	-116 27.80	5.00	0.9		
1979	6	2	721	3.94	TR.MON S-P	2.71	ML	1.3		
1979	6	2	721	2.00	TR.THP S-P	2.47	ML	1.5		

YEAR	MO	DA	HRMN	SEC	LATITUDE	LONGITUDE	DEPTH	MAG	NSTA	Q
1979	6	2	1541	20.09	TR.THP S-P	1.89	ML	1.5		
1979	6	2	1910	26.91	33 29.39	-116 23.71	13.14	0.00	18	A
1979	6	2	2302	14.78	34 6.45	-116 37.48	5.00	1.4		
1979	6	3	254	0.78	TR.MON S-P	2.78	ML	1.1		
1979	6	3	322	20.48	33 18.67	-116 14.02	4.79	0.00	14	A
1979	6	3	357	12.09	34 6.45	-116 3.02	5.00	1.6		
1979	6	3	501	26.14	34 6.45	-116 5.03	5.00	1.3		
1979	6	3	518	7.64	33 52.90	-116 36.19	8.89	1.6		
1979	6	3	519	12.66	TR.MON S-P	4.97	ML	1.5		
1979	6	3	518	10.32	TR.THP S-P	4.2	ML	1.5		
1979	6	3	522	46.78	33 38.47	-116 3.02	5.00	1.7		
1979	6	3	529	36.83	33 55.12	-116 40.73	15.40	0.9		
1979	6	3	1743	31.01	TR.MON S-P	4.27	ML	1.1		
1979	6	3	2225	22.27	33 29.01	-116 34.33	5.74	0.00	11	C
1979	6	4	912	15.23	33 56.24	-116 3.08	9.71	1.0		
1979	6	4	1136	28.85	TR.MON S-P	2.48	ML	1.4		
1979	6	4	1136	27.85	TR.THP S-P	1.96	ML	1.0		
1979	6	4	1252	56.00	TR.MON S-P	3.30	ML	1.5		
1979	6	4	1330	22.72	TR.THP S-P	2.47	ML	0.8		
1979	6	4	1540	15.72	33 38.09	-116 44.15	4.89	0.00	25	B
1979	6	4	1714	43.71	34 18.64	-116 15.43	5.00	1.6		
1979	6	4	1754	59.83	34 2.85	-116 1.74	9.52	1.0		
1979	6	4	2208	41.03	34 9.34	-116 13.59	0.45	1.8		
1979	6	5	40	42.46	33 56.24	-116 11.76	5.00	1.4		
1979	6	5	154	33.49	34 9.34	-115 57.85	1.86	1.5		
1979	6	5	219	19.68	34 8.25	-116 20.15	5.00	1.6		

YEAR	MO	DA	HRMN	SEC	LATITUDE	LONGITUDE	DEPTH	MAG	NSTA	Q
1979	6	5	822	24.06	TR.PAC S-P 4.50		ML	1.4		
1979	6	5	928	13.51	34 9.34	-116 2.71	5.00	1.6		
1979	6	5	951	32.79	34 9.34	-116 20.07	5.00	1.7		
1979	6	6	529	22.92	33 28.05	-116 25.97	10.78	2.50	98	B
1979	6	6	948	16.64	33 52.02	-116 15.75	5.00	1.6		
1979	6	6	955	1.49	34 3.47	-116 25.47	5.74	1.7		
1979	6	7	643	17.81	34 2.67	-116 23.55	5.12	1.4		
1979	6	7	1810	6.80	33 31.16	-116 26.35	9.03	0.00	10	B
1979	6	7	2153	44.73	33 55.10	-116 39.94	4.73	0.00	23	A
1979	6	8	849	14.09	33 27.28	-116 34.14	12.15	0.00	15	A
1979	6	9	235	1.57	33 51.79	-116 30.42	10.82	0.00	24	A
1979	6	9	629	16.61	33 56.24	-116 13.38	11.26	1.0		
1979	6	9	640	40.02	33 28.63	-116 35.58	6.02	0.00	27	C
1979	6	9	720	16.92	34 8.03	-115 55.13	5.00	1.0		
1979	6	9	1156	7.26	33 54.92	-116 19.72	8.10	1.1		
1979	6	9	1200	6.35	33 54.87	-116 17.52	7.58	1.0		
1979	6	9	1200	42.51	33 55.39	-116 19.08	5.70	1.1		
1979	6	10	1146	10.40	33 55.89	-116 19.03	5.21	1.5		
1979	6	10	1147	30.70	33 55.76	-116 19.64	2.70	1.80	35	B
1979	6	10	1557	7.05	33 59.09	-116 22.16	5.00	2.0		
1979	6	12	1123	16.46	33 30.39	-116 31.34	11.68	0.00	18	B
1979	6	13	1829	3.04	TR.TRR S-P 3.07		ML	1.0		
1979	6	14	140	24.87	TR.TRR S-P 3.85		ML	1.8		
1979	6	14	240	19.71	33 22.24	-116 23.68	11.35	2.00	21	A
1979	6	14	252	27.15	33 30.03	-116 27.65	8.80	0.00	17	A
1979	6	14	834	14.52	TR.TRR S-P 4.37		ML	1.1		

YEAR	MO	DA	HRMN	SEC	LATITUDE	LONGITUDE	DEPTH	MAG	NSTA	Q
1979	6	14	1040	14.53	TR.TRR S-P 2.57		ML	1.0		
1979	6	14	1519	49.16	33 23.76	-116 25.69	10.20	0.00	30	B
1979	6	14	1658	5.65	TR.TRR S-P 3.00		ML	1.5		
1979	6	14	1741	12.48	TR.TRR S-P 4.32		ML	1.3		
1979	6	15	8	14.15	33 30.28	-116 26.91	5.04	0.00	28	A
1979	6	15	11	6.42	33 28.13	-116 26.08	7.78	1.6		
1979	6	15	1106	24.78	33 41.25	-115 54.89	5.78	1.6		
1979	6	15	1842	4.06	TR.THP S-P 2.35		ML	1.7		
1979	6	16	505	54.62	TR.THP S-P 2.09		ML	1.9		
1979	6	16	1651	58.37	TR.TRR S-P 3.38		ML	0.9		
1979	6	16	1746	1.91	33 58.17	-116 22.22	5.00	1.8		
1979	6	17	119	33.93	33 23.80	-116 17.37	5.06	1.90	37	B
1979	6	17	1245	21.89	33 57.34	-116 38.63	11.62	0.00	18	B
1979	6	17	1621	13.66	33 16.22	-116 26.97	0.83	0.00	19	C
1979	6	17	1916	23.50	TR.TRR S-P 2.11		ML	1.0		
1979	6	17	1921	32.00	TR.TRR S-P 3.72		ML	---		
1979	6	17	2216	52.62	TR.TRR S-P 3.62		ML	0.8		
1979	6	18	2322	42.41	TR.TRR S-P 3.76		ML	1.2		
1979	6	19	954	6.74	33 55.17	-116 43.58	14.94	0.00	29	A
1979	6	19	1216	15.45	33 59.80	-116 44.94	19.03	0.00	27	A
1979	6	19	1532	51.65	TR.THP S-P 5.0		ML	1.5		
1979	6	19	1547	44.76	TR.THP S-P 1.76		ML	0.9		
1979	6	19	1635	32.76	TR.THP S-P 2.97		ML	1.1		
1979	6	22	1945	36.12	33 28.52	-116 23.43	10.60	0.00	10	A
1979	6	24	655	56.57	33 29.10	-116 28.41	13.19	0.00	28	B
1979	6	25	1039	17.04	33 30.25	-116 28.12	11.33	0.00	21	A

YEAR	MO	DA	HRMN	SEC	LATITUDE	LONGITUDE	DEPTH	MAG	NSTA	Q
1979	6	26	1436	0.97	33 17.08	-115 43.51	4.16	2.10	30	B
1979	6	26	1513	33.10	33 16.65	-115 42.94	4.60	2.10	24	A
1979	6	26	1526	27.79	33 16.78	-115 42.78	5.00	1.70	20	C
1979	6	27	1659	31.09	33 30.44	-116 26.68	9.80	0.00	11	B
1979	6	27	2034	53.74	33 16.96	-115 43.24	4.00	2.70	35	A
1979	6	27	2044	27.88	33 16.57	-115 42.49	2.46	0.00	12	C
1979	6	28	635	58.03	33 19.19	-115 43.30	5.33	2.20	60	B
1979	6	28	1435	28.90	33 17.40	-116 13.69	5.00	0.00	13	C
1979	6	29	1710	19.23	33 45.74	-116 3.94	5.00	2.20	32	C
1979	6	30	857	34.03	33 59.76	-116 26.63	8.65	0.00	29	A

TR.--- INDICATES TRAILER DATA INSUFFICIENT FOR FULL LOCATION

D.--- INDICATES DEVELOCORDER DATA INSUFFICIENT FOR FULL LOCATION

Table 3

EVENT CATALOGUE 24 OCT 79 THRU 31 OCT 79

YEAR	MO	DA	HRMN	SEC	LATITUDE	LONGITUDE	DEPTH	MAG	NSTA	Q
1979	10	24	41	53.44	33 45.53	-115 33.40	5.00	0.00	8	E
1979	10	24	200	30.05	33 3.30	-115 29.29	3.87	0.00	32	B
1979	10	24	316	32.26	34.19.61	-116 26.18	0.88	0.00	17	A
1979	10	24	804	53.43	33 10.03	-115 38.44	5.34	0.00	35	B
1979	10	24	1111	1.38	33 1.44	-115 33.26	6.04	0.00	16	C
1979	10	24	1158	49.21	33 7.88	-115 36.04	10.27	0.00	23	A
1979	10	24	1332	49.59	34 11.63	-116 25.81	1.69	0.00	101	A
1979	10	24	1523	26.85	33 36.73	-115 57.24	5.45	0.00	52	A
1979	10	24	1755	5.31	33 1.64	-115 33.83	5.71	0.00	19	C
1979	10	24	1757	38.46	34 11.72	-116 25.49	2.34	0.00	17	A
1979	10	24	1810	7.09	34 11.73	-116 25.61	2.46	0.00	24	A
1979	10	24	1932	4.03	33 2.07	-115 34.34	10.15	0.00	10	B
1979	10	24	1945	11.77	34 11.96	-116 25.59	3.75	0.00	5	E
1979	10	24	2022	8.83	34 12.15	-116 25.73	3.76	0.00	6	A
1979	10	24	2123	20.32	34 12.07	-116 25.63	3.05	0.00	6	A
1979	10	25	26	19.31	34 12.15	-116 25.79	3.79	0.00	6	E
1979	10	25	137	17.45	33 45.53	-115 55.74	0.51	1.09	8	SA
1979	10	25	317	6.97	34 12.16	-116 25.92	3.47	0.00	10	B
1979	10	25	449	31.57	33 28.32	-116 29.63	5.00	1.84	10	SA
1979	10	25	616	27.38	34 12.46	-116 26.12	5.16	0.00	9	C
1979	10	25	917	16.25	33 45.76	-115 57.17	2.74	0.96	5	SD

YEAR	MO	DA	HRMN	SEC	LATITUDE		LONGITUDE		DEPTH	MAG	NSTA	Q
1979	10	25	928	16.17	33	1.37	-115	34.18	8.45	0.00	18	B
1979	10	25	1047	24.94	33	33.12	-116	13.32	2.84	1.30	4	SD
1979	10	25	1121	2.39	33	3.61	-115	53.26	5.01	0.00	9	E
1979	10	25	1135	23.15	33	2.22	-115	53.50	4.04	0.00	6	E
1979	10	25	1136	11.68	33	24.36	-116	3.89	5.00	1.93	8	SB
1979	10	25	1226	13.63	34	12.07	-116	25.68	3.05	0.00	16	A
1979	10	25	1609	14.02	33	9.64	-115	38.55	4.92	0.00	17	B
1979	10	25	1609	8.91	33	21.58	-116	57.71	12.24	0.00	14	C
1979	10	25	1611	8.52	33	10.29	-115	39.42	5.08	0.00	14	B
1979	10	25	1837	36.04	33	14.85	-115	39.78	4.05	0.00	16	B
1979	10	25	1850	10.88	33	56.24	-116	11.76	5.00	1.80	9	SD
1979	10	25	1854	4.90	33	4.67	-115	21.61	5.73	0.00	27	C
1979	10	25	2120	22.07	33	2.09	-115	34.50	8.48	0.00	15	A
1979	10	26	355	19.44	34	13.50	-116	26.55	4.88	0.00	5	E
1979	10	26	330	15.56	33	44.89	-116	0.83	5.00	1.32	8	SA
1979	10	26	359	44.90	34	12.12	-116	25.80	3.49	0.00	11	A
1979	10	26	632	12.19	33	56.29	-116	18.21	5.13	0.00	40	SA
1979	10	26	739	49.14	33	56.09	-116	18.27	1.23	0.00	104	B
1979	10	26	930	49.01	33	0.49	-115	31.98	5.00	0.00	11	C
1979	10	26	1129	1.96	33	57.35	-116	56.87	17.06	2.45	54	SA
1979	10	26	1547	9.68	34	12.16	-116	25.81	3.77	0.00	6	A
1979	10	26	1625	51.83	33	56.79	-116	18.18	4.66	0.00	8	E
1979	10	26	1933	36.29	33	7.74	-115	24.11	4.97	0.00	33	B
1979	10	26	1958	38.19	33	40.11	-116	13.32	5.00	1.83	9	SD
1979	10	26	2013	32.10	34	19.54	-116	56.25	5.02	0.00	10	E
1979	10	26	2129	55.83	33	53.29	-115	31.09	0.76	0.00	30	A

YEAR	MO	DA	HRMN	SEC	LATITUDE	LONGITUDE	DEPTH	MAG	NSTA	Q
1979	10	26	2133	20.63	34 20.10	-116 55.43	0.01	0.00	22	A
1979	10	26	2205	7.43	33 55.93	-116 44.10	12.91	0.00	21	A
1979	10	26	2349	42.97	33 2.25	-115 33.08	9.90	0.00	19	B
1979	10	27	034	20.47	33 39.84	-116 0.42	9.15	1.36	11	SA
1979	10	27	110	21.50	33 44.36	-115 59.49	5.79	1.22	9	SA
1979	10	27	657	14.82	34 11.76	-116 9.85	4.90	0.00	17	A
1979	10	27	851	5.90	34 1.14	-116 2.97	3.19	0.00	11	A
1979	10	27	852	37.03	34 1.30	-116 3.09	2.74	0.00	13	A
1979	10	27	857	40.99	33 15.07	-115 40.23	4.59	0.00	50	C
1979	10	27	857	32.87	33 18.16	-115 39.97	5.00	0.00	3	E
1979	10	27	935	37.42	33 44.69	-116 0.86	0.14	0.00	21	A
1979	10	27	937	16.61	33 44.52	-116 0.77	4.38	1.17	10	SA
1979	10	27	957	44.28	33 44.93	-116 0.58	0.99	0.00	27	A
1979	10	27	1021	25.30	33 44.94	-116 0.79	5.00	0.00	27	SA
1979	10	27	1029	19.68	33 14.10	-115 38.73	4.77	0.00	13	B
1979	10	27	1030	37.77	33 1.15	-115 34.24	11.62	0.00	28	B
1979	10	27	1050	17.82	33 44.07	-116 0.83	4.97	0.00	8	E
1979	10	27	1101	36.63	33 44.99	-116 0.35	5.35	0.00	32	SA
1979	10	27	1102	20.92	33 44.79	-116 0.51	3.49	0.00	28	A
1979	10	27	1141	29.51	33 44.82	-115 59.95	4.85	0.00	25	B
1979	10	27	1142	14.16	33 44.63	-116 0.99	1.54	0.00	8	E
1979	10	27	1152	26.78	33 44.77	-116 0.14	4.20	0.00	45	A
1979	10	27	1153	44.90	33 44.48	-116 1.02	0.86	1.57	14	SA
1979	10	27	1214	36.88	33 44.23	-116 0.33	4.33	1.27	11	SA
1979	10	27	1234	18.78	33 44.57	-116 0.60	4.55	0.00	7	C
1979	10	27	1347	13.62	33 44.82	-115 59.49	7.69	1.36	10	SA

YEAR	MO	DA	HRMN	SEC	LATITUDE		LONGITUDE		DEPTH	MAG	NSTA	Q
1979	10	27	1411	22.28	33	43.02	-116	1.82	5.28	1.44	10	SA
1979	10	27	1415	38.07	33	26.94	-116	38.02	6.09	0.00	23	C
1979	10	27	1416	0.16	33	30.94	-116	18.32	3.75	0.00	7	E
1979	10	27	1422	46.68	33	44.23	-116	0.34	9.77	2.42	71	SA
1979	10	27	1423	29.70	33	44.18	-116	0.36	5.29	0.00	11	E
1979	10	27	1608	21.95	33	44.85	-116	0.53	1.46	0.00	30	A
1979	10	27	1822	20.23	33	0.94	-115	33.61	9.03	0.00	33	B
1979	10	27	1825	36.67	33	45.86	-116	16.47	5.00	0.00	22	D
1979	10	27	1836	41.40	33	29.61	-116	27.74	15.26	0.00	6	A
1979	10	27	2045	25.45	33	56.67	-116	55.91	5.75	0.00	31	B
1979	10	27	2112	6.58	33	2.48	-115	34.29	13.23	0.00	35	B
1979	10	27	2228	3.02	33	44.94	-116	0.26	3.63	0.00	28	A
1979	10	27	2351	52.23	33	57.54	-116	25.27	15.76	2.45	47	SA
1979	10	28	130	50.31	33	2.73	-115	50.91	4.48	0.00	11	B
1979	10	28	200	14.93	32	25.36	-115	16.31	3.49	2.94	12	SB
1979	10	28	226	55.42	33	44.69	-116	0.22	4.01	0.00	60	A
1979	10	28	301	9.45	33	51.14	-116	47.87	18.02	1.77	29	SA
1979	10	28	340	46.89	33	18.89	-116	13.32	0.42	1.72	10	SB
1979	10	28	456	8.47	33	16.20	-115	38.84	3.58	0.00	24	SA
1979	10	28	925	39.08	33	28.36	-116	48.16	11.70	2.42	65	SA
1979	10	28	930	14.99	34	19.94	-116	26.76	1.06	0.00	24	A
1979	10	28	931	55.39	33	27.93	-116	29.06	8.18	0.00	22	B
1979	10	28	953	24.49	33	43.97	-116	1.01	7.32	1.45	14	SA
1979	10	28	1258	20.39	33	44.15	-116	0.66	6.53	1.56	6	SA
1979	10	28	1516	58.27	33	58.84	-116	39.85	12.57	2.52	73	SA
1979	10	28	1607	31.05	33	43.93	-116	1.08	3.95	1.30	11	SA

YEAR	MO	DA	HRMN	SEC	LATITUDE	LONGITUDE	DEPTH	MAG	NSTA	Q
1979	10	28	1848	17.86	34 14.80	-116 46.48	4.52	0.00	24	A
1979	10	29	254	45.16	33 1.07	-115 33.83	8.98	0.00	17	B
1979	10	29	344	42.48	34 20.55	-116 26.86	0.53	0.00	14	A
1979	10	29	418	2.72	33 38.01	-116 44.69	16.25	0.00	24	B
1979	10	29	542	10.82	33 10.61	-115 37.09	4.98	0.00	56	B
1979	10	29	803	56.66	33 12.00	-115 37.81	1.22	0.00	7	D
1979	10	29	1151	55.06	33 56.87	-116 50.32	4.38	0.00	11	D
1979	10	29	1555	22.74	33 1.29	-115 34.06	9.77	0.00	31	B
1979	10	29	1826	4.51	33 15.69	-115 21.82	4.38	0.00	10	E
1979	10	29	2231	1.83	34 19.71	-116 55.93	3.79	0.00	6	D
1979	10	30	53	35.69	34 44.29	-116 26.35	0.56	0.00	30	B
1979	10	30	432	56.42	33 22.06	-116 48.46	5.00	0.00	80	B
1979	10	30	442	28.14	33 1.28	-115 34.50	9.49	0.00	27	B
1979	10	30	1517	17.50	34 20.74	-116 51.44	4.38	0.00	9	B
1979	10	30	1538	21.49	33 10.89	-116 7.17	5.00	0.00	11	C
1979	10	30	1539	21.98	34 20.90	-116 51.31	3.59	0.00	7	B
1979	10	30	1846	2.70	34 18.90	-116 26.14	3.54	0.00	9	A
1979	10	30	2052	8.52	33 53.44	-115 32.80	0.03	0.00	19	A
1979	10	30	2134	46.47	34 18.80	-116 59.35	5.08	0.00	6	E
1979	10	30	2155	31.41	33 54.53	-116 15.21	5.10	0.00	22	A
1979	10	30	2230	57.56	33 56.15	-116 17.97	1.50	0.00	8	A
1979	10	31	731	35.75	34 0.54	-116 23.59	6.41	0.00	21	A
1979	10	31	1559	39.03	33 1.92	-115 29.15	4.83	0.00	8	B
1979	10	31	1736	21.50	33 54.52	-116 15.06	5.01	0.00	11	A
1979	10	31	2211	4.16	33 0.62	-116 4.71	1.63	0.00	16	B
1979	10	31	2300	40.46	33 1.63	-115 43.10	7.59	0.00	10	A

YEAR	MO	DA	HRMN	SEC	LATITUDE	LONGITUDE	DEPTH	MAG	NSTA	Q
1979	10	31	2308	8.63	33 53.08	-115 31.46	0.18	0.00	38	B

QUAL S INDICATES INCLUSION OF MEQ800 DATA IN LOCATION

Table 4

MICRO-EARTHQUAKE SURVEY PALMDALE, CALIFORNIA

	Mobile Array Station Name	Latitude	Longitude	Elevation(m)	Dates of Operation
MTE	Mount Emma	34 29.05	118 05.66	1109	5Feb-Present
VAL	Valyermo	34 26.26	117 51.61	1213	11Feb-Present
HAR	Harold's Bcn	34 31.29	118 08.81	1207	14March-Present
MUN	Munz Ranch	34 44.69	118 22.18	860	20June-8July
BEE	Bee Canyon	34 34.20	118 27.13	604	26June-23July
		34 34.62	118 27.13	604	26June-23July
FMT	Fairmont Bts	34 44.88	118 23.91	831	8July-Present
FOX	Foxfield	34 44.70	113 14.44	714	14Aug-Present

Table 5

EVENTS SELECTED FOR FIRST MOTION STUDIES

EVENT NO.	DATE	TIME (HR|MIN)	MAGNITUDE	LATITUDE (LOCAL)	LONGITUDE	DEPTH
1	761103*	17|41	2.6	34 31.11	117 46.40	10.1
2	761107*	14|21	2.6	34 40.20	118 33.10	7.5
3	761213*	08|26	2.2	34 28.56	118 00.60	8.2
4	770101*	01|00	2.8	34 27.49	117 57.69	8.7
5	770214	09|16	2.0	34 28.98	117 51.94	5.0
6	770227	14|48	2.2	34 28.61	117 57.46	10.0
7	770305	14|43	2.1	34 27.66	117 57.50	8.0
8	770307*	11|04	3.0	34 27.68	117 58.18	9.1
9	770323	05|15	2.5	34 27.95	117 57.56	8.0
10	770906*	05|08	2.6	34 27.95	117 57.93	8.7
11	780619*	07|41	3.0	34 37.07	117 45.02	7.6
12	780712	13|23	2.5	34 26.09	117 49.88	8.0
13	790121	16|11	3.1	34 39.86	117 43.62	7.0
14	790217	12|36	2.0	34 27.86	118 04.28	12.0
15	790828	08|57	3.6	34 25.17	117 44.78	7.0
16	790829	14|20	2.5	34 25.32	117 44.19	9.0
17	790830	02|08	2.0	34 25.21	117 44.35	9.0
18	790903	00|06	2.0	34 25.24	117 44.49	8.0
19	791024	07|42	2.0	34 25.13	117 44.71	8.0
20	800427	16|39	2.4	34 28.40	117 56.97	8.0
21	801013	13|39	2.7	34 22 .55	117 40.27	10.0

*Pechmann, 1980

Table 6.

	yr	mo	da	hrmn	sec	latitude	longitude	depth	M_L	M_{KJ}*	km. to MS
Long Beach											
mainshock	1933	3	11	154	7.80	33 37.00	-117 58.00	0.00	6.3	6.4	
aftershock	1933	10	2	910	17.60	33 47.00	-118 8.00	0.00	5.4		30.5
aftershock	1941	11	14	841	36.30	33 47.00	-118 15.00	0.00	5.4		32.0
Cerro Prieto, Baja											
mainshock	1934	12	30	1352	0.00	32 15.00	-115 30.00		6.5		
aftershock	1934	12	31	1845	0.00	32 00.00	-114 45.00		7.1		86.5
relocation	1934	12	31	1845	0.00	32 6.00	-114 54.00				69.5
aftershock	1936	4	29	0850	0.00	31 40.00	-115 5.00		5.0		72.0
Terwilliger Valley											
mainshock	1937	3	25	1649	1.83	33 24.51	-116 15.69	10.00	6.0		
aftershock	1942	5	23	1547	29.00	32 59.00	-115 59.00	0.00	5.0		54.0
Imperial Valley											
mainshock	1940	5	19	436	40.90	32 44.00	-115 30.00		6.7	6.5	
aftershock	1942	5	23	1547	29.00	32 59.00	-115 59.00		5.0		53.0
aftershock	1942	10	22	150	38.00	33 14.00	-115 43.00		5.5		71.5

	yr	mo	da	hrmn	sec	latitude	longitude	depth	M_L	M_{KJ}	km. to MS
Carrizo Mountain											
mainshock	1942	10	21	1622	13.00	32 58.00	-116 0.00		6.5		
aftershock	1945	8	15	1756	24.00	33 13.00	-116 8.00	0.00	5.7		30.5
aftershock	1946	1	8	1854	18.00	33 0.00	-115 50.00	0.00	5.4		16.0
Walker Pass											
mainshock	1946	3	15	1349	35.90	35 43.51	-118 3.28	22.00	6.3		
Manix											
mainshock	1947	4	10	1558	6.00	34 59.00	-116 33.00		6.2		
Desert Hot Springs											
mainshock	1948	12	4	2343	17.00	33 56.00	-116 23.00		6.5	6.5	
Kern County											
mainshock	1952	7	21	1152	14.00	35 0.00	-119 1.00	0.00	7.7	7.2	
aftershock	1952	8	22	2241	24.00	35 20.00	-118 55.00	0.00	5.8		32.5
aftershock	1954	1	12	2333	49.00	35 0.00	-119 1.00	0.00	5.9		0.0
aftershock	1954	1	27	1419	48.00	35 9.00	-118 38.00	0.00	5.0		39.0
aftershock	1954	5	23	2352	43.00	34 59.00	-118 59.00	0.00	5.1		4.0
aftershock	1961	11	15	538	55.49	34 56.47	-118 59.20	10.70	5.0		7.5

	yr	mo	da	hrmn	sec	latitude	longitude	depth	M_L	M_{KJ}	km. to MS
Rabbit Peak											
mainshock	1954	3	19	954	29.00	33 17.00	-116 11.00	0.00	6.2		
aftershock	1957	4	25	2224	12.00	33 11.00	-115 51.00	0.00	5.1		33.0
aftershock	1957	5	26	1559	33.64	33 13.88	-116 0.27	15.10	5.0		17.5
San Miguel, Baja											
mainshock	1956	2	9	1432	38.00	31 45.00	-115 55.00		6.8	6.8	
aftershock	1956	2	9	1524	26.00	31 45.00	-115 55.00		6.1		0.0
aftershock	1956	2	14	1445	34.00	31 30.00	-115 30.00		6.3		52.0
aftershock	1956	2	14	1833	34.00	31 30.00	-115 30.00		6.4		52.0
aftershock	1956	12	13	1315	37.00	31 0.00	-115 0.00		6.0		124.0
Borrego Mountain											
mainshock	1968	4	9	228	59.06	33 11.40	-116 7.72	11.10	6.4	6.8	
aftershock	1969	4	28	2320	42.87	33 20.60	-116 20.78	20.00	5.8		26.5
aftershock	1971	9	30	2246	11.30	33 2.01	-115 49.24	8.00	5.1		33.5
San Fernando											
mainshock	1971	2	9	1400	41.83	34 24.67	-118 24.04	8.40	6.4	6.3	
Imperial Valley											
mainshock	1979	10	15	2316	53.44	32 36.82	-115 19.09	12.28	6.6	6.6	
aftershock	1980	2	25	1047	37.69	33 30.85	-116 32.33	10.07	5.3		

	yr	mo	da	hrmn	sec	latitude	longitude	depth	M_L	M_{KJ}	km. to MS
Mammoth Lakes											
mainshock	1980	5	25	1633	44.80	37 36.47	-118 49.27	3.72	6.5		
Cerro Prieto, Baja											
mainshock	1980	6	9	328	19.37	32 11.12	-115 4.55	5.00	6.1		

* Magnitude calculation by Kanamori and Jennings (1978).

A P P E N D I C E S

INVESTIGATIONS OF SEISMIC QUIESCENCE AND MICROEARTHQUAKES ALONG THE SOUTHERN SAN ANDREAS FAULT: COACHELLA VALLEY, CALIFORNIA

Barbara J. Leitner
Eugene Humphreys
Karen C. McNally
Hiroo Kanamori (all at Seismological Laboratory, California Institute of Technology, Pasadena, California 91125)

Since Feb 1979, a 100 km section of the southern San Andreas fault between the Salton Sea and Desert Hot Springs has been the focus of an intensive microearthquake field study using a mobile array of 8 seismographic trailers. This section of the fault had been relatively quiet from 1932 until 1977, when activity clearly increased in the southeastern portion of the Coachella Valley. Unfortunately our knowledge of the seismic history of the region was not sufficient to determine what fraction of this activity represented a change in the nature of the seismicity as opposed to a change in seismic detection. We have found a relative increase in the rate of microearthquake activity (0.23 ± 0.59 earthquakes/day, 7 to 20 Feb 1979 and 0.56 ± 0.88 21 Feb to 9 Apr 1979) compared withthe results of Brune and Allen (0 earthquakes/day) (1967). The relatively small number of events in this area tend to be associated with E-W lineations to the northeast of the San Andreas, such as the Blue Cut and Porcupine Wash trends, rather than with the main trace of the San Andreas, however. We conclude that the relative quiescence of the San Andreas in this region since 1932 is maintained at microearthquake detection levels ($M_L \gtrsim 1.4$). In addition, we observe essentially no activity along the southwest side of the San Andreas between the Salton Sea and Palm Springs. These observations further document the existence of a seismicity "gap" in this area.

1. AGU Fall Meeting

2. MC N707386

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SEISMICITY OF THE BORREGO MOUNTAIN REGION 1960-1968

CORBETT, E. J., AND McNALLY, K. C., Seismological Laboratory, 252-21, California Institute of Technology, Pasadena, California 91125

Body of Abstract

Seismic events occurring in the eight years preceding the 1968 Borrego Mountain earthquake (M_L 6.4) have been relocated using: 1) recent events located by the Caltech-USGS SCARLET network as master events; and 2) well-located aftershocks of the 1968 main event (Hamilton, 1972) to determine station delays. Comparison of results indicate that method (2) locates events generally within 1-2 km of their true epicenters; while method (1) introduces a systematic shift in the epicenter of 3-5 km to the SW, similar to the mislocation observed in the catalog. The relocations also reduce the scatter of locations by resolving confusion between Pg and Pn that occurred in the original routine locations, and because of improved knowledge of southern California velocity structure.

The relocated epicenters indicate the following seismicity pattern. From 1960 through 1965 there was almost no activity along the Coyote Creek fault trend. Most of the activity occurred in swarms that were located about 15 km from the fault. Two of these, in autumn 1961 and autumn 1962 were located SW of the mainshock epicenter. The third, in August 1963 was located NE of the main shock. Then, late in 1965 and 1966 there was diffuse activity along the Coyoto Creek fault, including two magnitude 4 events. Finally, there was a single event (M_L 3.4) in the epicentral region in Feb. 1967, 14 months preceding the foreshock and mainshock of 9 April 1968. The spatial seismicity pattern during these eight years apparently premiered the 1968 aftershock pattern.

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STATISTICAL ANALYSIS OF EARTHQUAKE CLUSTERING ($M_L \geq 3.5$) AND MODERATE EARTHQUAKES ($M_L \geq 6$) IN THE SALTON TROUGH (CALIFORNIA), 1932-1979.

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Ten clusters of earthquakes have been found which may be associated with the 4 moderate ($M_L \geq 6$) earthquakes occurring in the Salton Trough since 1932. The following clusters were identified with statistical analyses based on the generalized Poisson model:

1932-1940: 4 clusters (1932, 1936 (2), and 1938) within 35 km of the Imperial Valley earthquake (M_L = 6.5), 1940)
1940-1942: 1 cluster (1940) within 15 km of the Borrego Valley earthquake (M_L = 6.4, 1942)
1945-1968: 4 clusters (1963, (2) and 1965 (2)); 1 (1965) within 15 km and 3 (1963, 1965) at 50 km SE of the Borrego Mtn. earthquake (M_L = 6.8, 1968)
1969-1979: 1 cluster (1975) within 30 km of the Mexicali earthquake (M_L = 6.6, 1979)

Earthquakes within the entire geological province and its boundaries (> 15,000 km^2) were analyzed, within a minimum magnitude threshold of M_L 3.5 to insure uniformity from 1932-1979. The clustering criterion determined for this region and magnitude threshold is a time separation $\leq$ 7 days between consecutive events. Clusters containing more events by 1-2 STD. DEV. from the mean number of events per cluster are considered distinct from the "background" clustering activity. (Sequences associated with $M \geq 5.0$ earthquakes are excluded to avoid statistical bias due to aftershocks). As in all other regions analyzed to date, a spatial correlation of these "large clusters" with subsequent moderate earthquakes occurring within 2-8 years is suggested.

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AFTERSHOCK SEQUENCES AND MINOR SEISMICITY IN SOUTHERN CALIFORNIA AND MEXICO: RELATIONSHIP TO THE MEXICALI EARTHQUAKE (M_L = 6.6, M_S = 6.8) OF 15 OCTOBER 1979

McNALLY, K. C., RICHTER, C. F., LEITNER, B. J., AND KANAMORI, H., Seismological Laboratory, 252-21, California Institute of Technology, Pasadena, California 91125

Body of Abstract

The development of the Mexicali 1979 (M_L = 6.6) earthquake sequence in time, space and magnitude is compared with other notable sequences in southern California and Mexico: Long Beach 1933 (6.4)*, Imperial Valley 1940 (6.5), Desert Hot Springs 1948 (6.5), Kern County 1952 (7.2), San Miguel fault 1954 (6.3) and 1956 (6.8), Borrego Mtn. 1968 (6.8) and San Fernando 1971 (6.3). Following the suggestion of Richter (1958), the late aftershock activity may concentrate toward the ends of the rupture zone. In all cases studied except San Fernando and Desert Hot Springs, a "large ($M_L \geq 5$) late aftershock" occurs between 7 months - 4 years of the main event at either or both ends of the zone.

Although such a "large late aftershock" has not occurred by this writing (1/80) for the Mexicali earthquake, aftershock activity immediately following the mainshock has been high at the ends of the active zone, indicating the redistribution of stress during the main event. Further evidence of the effect of the mainshock at large distance is the "sympathetic slip" observed by Sieh (1980) along the locked section of the San Andreas in the Mecca Hills near the northern end of the active zone. This indication of stress redistribution caused us to investigate associated minor seismicity along the San Andreas using a portable field array. Earthquake activity was observed near these surface cracks within 4 km NE of the mapped trace of the San Andreas fault.

*all magnitudes are M_L as revised (Kanamori and Jennings, 1979)

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Large, late Aftershocks as seen from the Temporal and Spatial Characteristics of Aftershock Sequences following large, $M_L \geq 6.0$ events in southern California, and Implications for expected future activity

by

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(Draft of manuscript to be submitted to Bull. Seism. Soc. Amer.)

In major earthquake sequences, Richter (1958) has suggested that relatively large, late-occurring aftershocks are not uncommon. When aftershocks have apparently subsided, what appears to be an unusually large event occurs unexpectedly. Such an event often has its own aftershock series. We have evaluated time, space and magnitude relationships of mainshock-aftershock patterns for twelve large, ($M_L \geq$ 6.0) earthquakes which have occurred in Southern California since 1932 in order to establish a firm empirical basis for this evaluation. We then consider the discernible patterns and regularities, in the study of an ongoing mainshock-aftershock sequence in Southern California, that of the 15 October 1979 (M_L = 6.6) Imperial Valley earthquake.

We also examine the observation made by Richter (1958) that late aftershock activity may concentrate toward the ends of the rupture zone. High activity near the end of an aftershock area can be explained by a concentration of stress at the ends of a main break (Scholz, 1968).

Several examples of earthquakes followed by large, late occurring aftershocks were suggested by Richter (1958). These include the Santa Barbara earthquake of 29 June 1925 (Rossi-Forel intensity IX, according to Townley and Allen, 1939) which was followed by a large, late aftershock (intensity VII to VIII), which occurred one year later to the day and was called the "anniversary shock". The Long Beach earthquake (1933, M_L = 6.3), was followed by two large aftershocks to the north at Signal Hill (M_L = 5.4) and Torrance (M_L = 5.4), occurring at intervals of 7 and 108 months, and 30 and 33 km away, respectively. In the large Kern Co. series in 1952, (M_L = 7.7, 6.4, 6.1, 6.1) there were no shocks of M_L - 5.0 from August 22, 1952 to Jan 12, 1954 at which time an earthquake of M_L = 5.9 occurred almost precisely at the epicenter of the main earthquake of 21 July 1952. A similar aftershock pattern was observed for the Hawkes Bay, New Zealand earthquake of 2 Feb. 1931 (M_L = 7.9), which was followed by the Wairoa earthquake of 15 Sept. 1932 (M_L = 6.8), some distance away (Richter, 1958).

Qualitatively, the process we are attempting to characterize using data from the large $M_L \geq 6.0$ earthquakes of the Southern California catalogue has been described by Benioff (1951). Richter (1958) summarizes the description by Benioff as follows:

> "The chief process of a major earthquake can run its course in about two minutes or less, yet there is adjustment of strain involving blocks whose linear dimensions are on the order of 100 km. or more. Even if these blocks were perfectly coherent internally, their elastic recovery could hardly be completed in so short a time. Recovery is in reality further delayed by the lack of perfect elasticity. The process of recovery continuing after the main event will produce creep. In this way, further strain accumulates along the original fracture until it overcomes the resistance of the temporary blocking which brought about the close of the first event, thus leading to further fracture."

"The process is repeated in general on a smaller scale at each recurrence until there is sufficient residual strain to break through the remaining resistance. Further motion depends on the continuing tectonic forces which caused the original strain. With time these may again raise the strain to the point of breaking through resistance. On the small scale this may account for the sudden large apparent aftershocks which occur after the general activity has subsided."

Aspects of the process described in this way by Benioff have been examined by a number of recent theoretical works on aftershock occurrence, e.g., Knopoff (1971); Das and Aki (1977); and Das and Scholz (1980). Knopoff (1971) suggests a model in which aftershocks are the consequence of the superposition of a tectonic driving stress and a second force, either pre-stress along the fault or the residual stress left by the occurrence of earlier shocks. In this model aftershocks can occur at some time delay after the mainshock and most would tend to be near the edge of the original rupture zone. Das and Aki (1977) model a fault plane with barriers which considers the presence or absence of aftershocks as a function of the strength of a barrier to the tectonic stress. Concepts of fracture mechanics are utilized by Das and Scholz (1980) in a theory of time-dependent rupture which is used to explain multiple events, post seismic rupture growth and aftershocks among other phenomena. Future evaluations of these and related works will be enhanced by consideration of the results obtained in our study.

All earthquake sequences associated with events of $M_L \geq 6.0$ which are listed in the Caltech southern California catalogue and which occur in California are considered in this observational study (See Fig. 1). These include the Long Beach 1933, Terwilliger Valley 1937, Imperial Valley 1940, Carrizo Mountain 1942, Walker Pass 1946, Manix 1947, Desert Hot Springs 1948, Kern County 1952, Rabbit Peak 1954, Borrego 1968, San Fernando 1971 and Mexicali 1979 earthquake sequences. Our results indicate that large, late aftershocks have occurred in 64 percent, or 7 out of 11, of the sequences associated with $M_L \geq 6.0$ earthquakes since 1932 and prior to 15 October 1979. The magnitudes of all large, late aftershocks appear to be M_L - 5.0, although we have examined Omori-type decay curves for all events in order to verify that sequences which apparently lack large, late aftershocks are not actually disturbed by late events of $M_L \leq 5.0$.

As tabulated by Table 1, the average separation in time between the mainshock and the large, late aftershock is 38 months, with a range of 7 months to 108 months. Both of these extreme values were observed for the Long Beach 1933 sequence. The mean distance separating a mainshock and its large, late aftershock is 34 km. The average difference in magnitude between the mainshock and its large late aftershock is 1.5 units of magnitude. The large magnitudes of the Kern Co. sequence cause this value to be high; if the Kern Co. values are removed, the average difference in magnitude is 1.2. This agrees well with the average difference in magnitude between a mainshock and its largest aftershock found by Båth and Benioff (1952).

Thus, it appears that the phenomenon of large, late aftershocks is significant in southern California and must be considered in the development of models of aftershock occurrence. Other $M_L \geq 6.0$ events which have occurred in the surrounding regions of Mexico, Nevada and central California are also reviewed. However only limited data are available from the Caltech catalogue for these events, making it difficult to obtain truly comparable results.

Southern California Data

Events with large, late aftershocks

We have considered every event with $M_L - 6.0$ in the southern California region defined by Hileman et al., (1973) which has occurred from 1932 to date in establishing an empirical base with which the occurrence of other large, late aftershocks can be compared (see Figure 1). Major features of aftershock activity observed for these sequences are discussed in the following paragraphs. A catalogue of specific mainshock and aftershock data is contained in Table 1. Aftershock areas in each case are based on seismicity maps from the Caltech southern California catalogue for the years immediately following the mainshock, and are considered to be those regions about each mainshock which experienced an increase in activity in response to the main event. For each of the mainshock-aftershock series studied, a number of representations of the aftershock data were examined including: 1) seismicity maps of the mainshock-aftershock areas (see Figures 2a-g, 6a-d, 10, 11, 12, 13a); 2) time-distance plots of earthquakes along the rupture zone (see Figures 3a-g, 7a-d, 13b); 3) changes in the seismic moment of the aftershock area as a function of time (see Figures 4a-f, 9a, 13c); and 4) cumulative plots of the numbers of events occurring in the aftershock area for up to 10 years following the main event (see Figures 5a-g and 8a-d).

Long Beach, 1933

Two large, late occurring aftershocks are a part of the Long Beach earthquake sequence. This destructive shock on 10 March 1933 (M_L = 6.3, M_{KJ} = 6.3; where used, M_{KJ} indicates a Kanamori and Jennings, 1978, magnitude calculation) was followed immediately by aftershocks along the Inglewood fault zone. The Long Beach sequence is illustrated in Figure 2a, which indicates the relative postions of the mainshock and the two aftershocks. The mainshock was followed by two events to the north, which we suggest as large, late aftershocks. The first of these, at Signal Hill (M_L = 5.4), occurred 7 months later at a distance of 30km from the mainshock. A second large, late aftershock (M_L = 5.4) occurred near Torrance 33 km away, 108 months after the mainshock. The temporal and spatial relationships of the mainshock and the two large, late aftershocks are illustrated by the time vs. distance plot of Figure 3a. Moment plotted as a function of time for the Long Beach series illustrates that significant changes in the moment can be observed in association with each of these aftershocks (see Figure 4a). We have also compared the numbers of aftershocks in each of our sequences to expected rates of aftershock activity as described by Omori (1900), the graph of which is a hyperbolic decay curve. In the Long Beach series, a smooth decay curve is disturbed by an increase in the number of events associated with the large, late aftershock (see Fig. 5a). In these figures, both the importance in size of the two large, late aftershocks and their separation in time relative to immediate aftershocks of the Long Beach 1933 event are made apparent.

Terwilliger Valley, Imperial Valley, Carrizo Mountain 1937, 1940, 1942

The mainshock and aftershock distributions of the Imperial Valley, 1940, Terwilliger Valley 1937, and Carrizo Mountain 1942 earthquakes are complex due to the close spatial and temporal relationship of these events. Therefore, difficulties are encountered in separating these sequences in time and space. Seismicity plots of each of these series are shown in figures 2b, c, d.

One potential, large, late aftershock to the Terwilliger Valley earthquake (25 March 1937, $M_L = 6.0$,) occurs 62 months later and 53km to the southeast along the San Jacinto fault zone (see Figs. 2b and 3b). However, this event ($M_L = 5.0$, 23 May 1942) occurs almost at the epicenter of and only 5 months prior to the Carrizo Mountain 1942 mainshock. The total moment of the aftershock area of the 1937 event is increased by this event as shown by Figure 4b. It is difficult, if not impossible, to identify this event as an aftershock or a foreshock to either of these series. Given that no information requires otherwise, we consider it reasonable to suggest this event is an aftershock to the

Terwilliger Valley mainshock.

The most destructive event in the aftershock sequence of the 19 May 1940 Imperial Valley occurred at Brawley, one and one-half hours after the mainshock. Despite problems with their spatial and temporal proximity to the 1937 and 1942 events along the San Jacinto fault, two earthquakes could be suggested as large, late aftershocks of the Imperial Valley 1940 mainshock (see Fig. 2c). The earliest of these occurs 23 May 1942, but as discussed above this earthquake could better be considered an aftershock of the 1937 Terwilliger Valley event. The most likely large, late aftershock is located in the Salton Sea (22 Oct 1942, M_L = 5.5), 71 km northwest of the Imperial Valley mainshock (see Figure 3b). This suggestion is made on the basis of the currently recognized seismic connection between the Imperial and the San Andreas faults. However, the choice of this event in 1942 as a large late aftershock to the Imperial Valley 1940 mainshock is ambiguous due to the temporal coincidence between this aftershock and the Carrizo Mountain mainshock, i.e., 1 day apart (see Figure 3c). The effect of the 22 October event on the cumulative moment released by the Imperial Valley 1940 earthquake and subsequent aftershocks is also obscured by this temporal coincidence (see Figure 4c).

The 21 October 1942 (M_L = 6.5) Carrizo Mountain sequence shares the above mentioned difficulties in distinguishing separate features. This event, the latest of the three earthquakes in the region at that time, appears to have two large, late occurring aftershocks (see Figures 2d and 3d). An aftershock occurs to the north of the mainshock at a distance of 30 km within 3 years. A second aftershock occurs 16km to the east of the mainshock in 3 years and 3 months (see Fig. 2d). These two earthquakes sharply increase the total moment in the aftershock area as illustrated by Figure 4d. A large shock in the Salton Sea occurs one day after the 1942 mainshock, however, as discussed in the previous paragraph, this event is being considered as a large, late aftershock of the Imperial Valley 1940 event.

Normal patterns of the decay of aftershock activity which could be indicated by the numbers of events following each of the 1937, 1940 and 1942 mainshocks (see Figures 5b-d) are also indistinguishable because of the close spatial and temporal occurrence of these earthquakes.

Kern County 1952

The largest sequence studied is the Kern County 1952 series. In this series, (see Table 1 for complete details), the first event M_L = 7.7 occurs at the southern end of the main rupture zone. It is followed shortly by two events also of M_L - 6.0 at the northern end of the zone (see Fig. 2e and Table 1). The aftershock responsible for most of the damage at the city of Bakersfield occurred 7 weeks after the first Kern Co. event. This "Bakersfield shock" on 22 Aug 1952 has a M_L = 5.8. Three aftershocks of $M_L \geq 5.0$ occur late, from 1954 through 1961. The largest, late aftershock which is located more than 8 km from the mainshock occurs on 27 Jan 1954 (M_L = 5.0) 40 km northeast of the first shock (see Figure 3e). This aftershock occurs midway between the endpoints of the rupture area, in a region which is not the site of other major activity. Following this aftershock, activity is observed to "shut off" in this area while the northern and southern ends of the rupture zone remain active (see Figure 3e), as if the large, late aftershock had relieved stress along this part of the fault.

Also in Jan 1954, an event of M_L = 5.9 occurs at the site of the M_L = 7.2 mainshock. This event does not occur away from the mainshock, however, both it and the mainshock occur at the south end of the original aftershock area. The effect these two events in Jan 1954 have on the total seismic moment of the Kern Co series is shown in Fig. 3b. In this plot of moment released per month during 10 years after the mainshock, the largest addition to the original energy released during July and August 1952, is the increase of Jan. 1954 (see Fig. 4e).

Rabbit Peak 1954

The Rabbit Peak (19 Mar 1954, M_L = 6.2) sequence occurs along the San Jacinto fault in the same general region as the Terwilliger Valley 1937, and Carrizo Mountain 1942 events, but is sufficiently isolated in time for two, large, late aftershocks to be clearly identified (see Fig. 2f). Both occur in 1957. The first late, large aftershock occurs 33 km away along an extension of one segment of the San Jacinto from the mainshock (25 Apr 1957, M_L = 5.1). This event is followed a month later by a second aftershock (26 May 1957, M_L = 5.0), located midway along the same extension of the San Jacinto fault between the mainshock and the first, large, late aftershock (see Figures 2f and 3f). The disturbance these two events cause to the decay of aftershock activity is seen by the sharp increase in the number of aftershocks in 1957, shown in Figure 5f.

Borrego Mountain 1968

The large, late aftershock pattern is strongly developed in the Borrego Mountain 1968 earthquake series (See Fig. 2g). Extensive investigation of the relationships betwween the mainshock and the larger of two late aftershocks has been made by Thatcher and Hamilton (1973). Following the mainshock, an aftershock occurred 26 km to the northwest at Coyote Mountain, after an interval of 12 months (28 Apr 1969, M_L = 5.8). This has been identified as an abrupt northwesterly extension of the Borrego Mountain 1968 aftershock zone by Thatcher and Hamilton (1973). The Coyote Mountain event was located in an area where aftershock activity of the 1968 event was low (Thatcher and Hamilton, 1973). These authors consider that microearthquake recordings of Coyote Mountain aftershocks indicate that this large, late event resulted primarily from sudden growth of the zone involved in the Borrego Mountain shock. Two and one-half years later, a second break (30 Sept 1971, M_L = 5.1), occurred 34 km to the southeast, 41 months after the mainshock. A time-distance plot of this series clearly indicates the separation in time and distance of these breaks to the northwest and southeast, away from the mainshock (see Fig. 3g). The relationship of these two aftershocks to the space-time and moment-time history of the Borrego Mountain sequence is illustrated by Figures 3g and 4f. The later aftershock of 1971, most perturbs the decay of aftershock activity as shown in Figure 5g.

Sequences without large, late aftershocks

Large, late aftershocks are not associated with all of the earthquakes of $M_L \geq 6.0$ which have occurred since 1932 in the southern California region. In this section we describe the mainshock-aftershock patterns of these events and describe, where possible, why large, late aftershocks are not observed. Additional data for these events can be found in Table 1.

Walker Pass 1946

On 15 March 1946 a shock of $M_L = 6.3$ occurred along the Sierra Nevada fault, north of its intersection with the Garlock fault (see Fig. 6a). Five aftershocks of $M_L \geq 5.0$ followed within 4 days, after which no further aftershocks with $M_L \geq 5.0$ occur. A time-distance plot of this sequence (see Fig. 7a). indicates that aftershock activity continues through 1951 in this region, with an event in 1948 occurring some distance away from the mainshock. However, the largest of these late aftershocks is $M_L = 4.6$, and as observed in Fig. 8a, a normal decay curve for aftershock activity is not significantly disturbed by these events.

Manix 1947

No large, late occurring aftershocks are observed in the seismicity patterns of the 10 April 1947, Manix event (M_L = 6.2, See Fig. 6b). Three aftershocks of $M_L \geq 5.0$ occur, all within 24 hours of the mainshock. Of these immediate aftershocks, none are located more than 5 km from the mainshock (see Figure 7b). As is shown by Figure 8b, the number of aftershocks to the Manix event decays by 1951 without being perturbed by late occurring events.

Desert Hot Springs 1948

The Desert Hot Springs earthquake (4 Dec 1948, M_L = 6.5) and its aftershock series do not contain a large late aftershock of the type we have been studying (see Fig. 6c, 7c and 8c). Overall, the sequence is smaller than the others examined, and no aftershocks with magnitudes greater than 5.0 are observed. Neither do any earthquakes of M_L - 5.0 disturb the graph of normal aftershock decay (see Fig. 8c). Richter et al., (1958) report that in contrast to what is shown in Figure 7c for events of $M_L \leq 4.0$, when considered at all magnitude levels, aftershock activity appears to concentrate toward the ends of the aftershock area.

San Fernando 1971

No large, late aftershock appears as part of the San Fernando earthquake activity (9 Feb 1971, M_L = 6.4, see Figs. 6d, 7d, 8d, and 9a). In the five years following the mainshock, only one aftershock of M_L = 5.0 occurs at any distance from the mainshock. This event, at a distance of 10km, occurs only 40 minutes after the mainshock (9 Feb 1971, $M_L = 5.2$). Three other aftershocks of $M_L \geq 5.0$ occur within 10 minutes of the mainshock, but, unfortunately, the exact positions of these events are questionable as they are given D quality locations and placed at the mainshock epicenter (Hileman, et.al., 1973). Analysis of the source spectrum of the San Fernando mainshock by Das and Aki (1977) indicates that this event has barriers which were not broken in the mainshock. However, there is no indication of a large, late aftershock in this sequence to date, as indicated by the plot of cumulative energy release in the mainshock-aftershock area (see Fig. 9a).

Extension to regions bordering southern California

Seismic activity of areas bordering the southern California region is seen in some cases to have similar characteristics of late occurring aftershocks. Differences in the aftershock patterns between these sequences and those in southern California proper, suggest that important variations occur according to tectonic setting. This is particularly noticeable in the spatial relationships of the Nevada sequences in the Basin and Range province. Unfortunately, the relatively poorer location qualities of events in these border areas make direct comparisons to the California results discussed above difficult.

Nevada 1932 and 1934

Earthquakes in west central Nevada in 1932 and 1934 appear to exhibit the temporal characteristics of a mainshock with large, late aftershocks. Spatial relationships, however, are somewhat different from those observed for southern California. The first event of this sequence, at Cedar Mountain, 20 Dec 1932 (M_L = 7.3) was located in one of the valleys of the Great Basin. Its meizoseismal area and the mapped extent of fissuring extended south along the valley about 50 miles. This shock was followed by later aftershocks, occurring to the west, including a shock of M_L = 6.1 on 25 June 1933, and two shocks in the Excelsior Mountain area on 30 Jan 1934 of M_L = 5.5 and M_L = 6.5 respectively, which are located some 50 miles southwest of the 1932 rupture zone. This pattern of late aftershock occurrence on different, but regionally associated fault systems, happens again during the 1954 Nevada sequence.

Nevada 1954

The Nevada earthquakes of 1954 exhibit several important characteristics of a sequence with large, late aftershocks, in that there are both time and distance separations between the first and later shocks (see Fig. 10 and Table 1). Two lineaments are suggested by the four events (M_L = 6.6, 6.8, 7.1, 6.8) of July, August and December 1954, one on either side of the Stillwater Range. As observed in 1932 and 1934, apparently the tectonic nature of faulting in the Basin and Range province results in a different spatial relationship between a large, late aftershock and the mainshock than is observed in southern California. These Nevada examples indicate that characteristics of large, late aftershocks are present, although differences in the behavior of the aftershock activity are noted.

Owens Valley 1941

The 1941 earthquakes in the Owens Valley near Rock Creek illustrate the difficulties encountered in studying distant sequences. These events are located just within the northern limits of the southern California box established by Hileman et al. (1972). The mainshock at Rock Creek, M_L = 6.0 and three other shocks of $M_L \geq 5.0$ occurred within 5 hours on 14 Sept 1941. Possibly this event and later shocks are an example of a sequence containing a large, late aftershock, because earthquakes of $M_L \geq 5.0$ occur about 100km to the southeast in 1945 and 1949. Limited data on the aftershock distributions and problems with location accuracy (the events in 1945 and 1949 are only located with C qualities, or known to within 15 km) suggest that these events are not strong supporting evidence, however, the similarity to other late aftershocks is recognizable.

Mexico: Cerro Prieto, 1934

The Caltech southern California catalogue lists four events in the region of the Cerro Prieto and Laguna Salada faults of northern Baja California between 1934 and 1936. See Figure 11 and Table 1. The first two of these earthquakes are clearly related in time, occurring on Dec. 30 and 31, 1934, even though the first and northern event (M_L = 6.5) is located by both Caltech and Leeds (1979) on the Laguna Salada fault, and the second, southern event (M_L = 7.1) is located on the Cerro Prieto fault. The third event (24 Feb 1935, M_L = 6.0), which is placed in the same general area as the two earlier events by Caltech, has recently been relocated by Leeds (1979), to a position 90 km due west on the San Miguel fault, thereby removing it from consideration as a late aftershock of the 1934 shocks. On 29 April 1936, a fourth event of M_L = 5.0 occurred, which could potentially be a large, late aftershock to either of the 1934 events. The location is assigned a D quality by the Caltech catalogue, indicative of a rough location with errors of 15 km or more. Given the uncertainty of its location, this event can only be identified as a potential distant, large, late aftershock, although its occurrence exhibits the temporal and spatial characteristics we have observed in southern California.

Mexico: San Miguel fault 1956

The Baja California earthquake sequences in 1954 and 1956 also show close temporal and spatial relationships, and again, relocations made by Leeds (1979) are critical in recognizing characteristics of the aftershock pattern. Locations of the six events of $M_L \geq 6.0$ associated with the San Miguel fault are shown in Fig. 12 . Specific data is tabulated in Table 1. The first shocks in this group occurred in October and November of 1954. Original locations, given by the Caltech catalogue, placed these events of $M_L = 6.0$ and $M_L = 5.0$ on the Agua Blanca fault. This position is 15 km south of the 1956 events on the San Miguel fault. Locations of the 1954 events have since been revised by Leeds (1979) to new positions in the epicentral region of the 9 Feb 1956 earthquakes ($M_L = 6.8$ and $M_L = 6.1$). These shocks are followed within one week by two events of $M_L = 6.3$ and 6.4, located 40 km to the southeast, on trend with the San Miguel fault. Ten months after the February 1956 event, a late aftershock occurred one-half degree of latitude away to the south. Despite location inaccuracies at this distance from the Caltech network (the event of 13 Dec 1956, $M_L = 6.0$, is a D quality location), we consider this event to be a part of the 1956 sequence to its north, and identify it as a late aftershock. Thus, the locations of the 1956 mainshock and its immediate and late aftershocks imply progressive faulting from northwest to southeast as noted by Shor and Roberts (1958).

Results, applications and discussion

These examples indicate that late, large aftershocks are observed for a significant number of mainshock-aftershock sequences in southern California. It is important, then, to consider the empirical regularities and patterns established in our seismicity studies as a factual basis for the development of theoretical models of earthquake occurrence. In addition, these regularities and patterns should be considered in the evaluation of ongoing earthquake sequences, particularly in southern California where their significance has just been shown.

Application to ongoing sequences

Comparison of these characteristics of large late occurring aftershocks to the 15 October 1979, ML = 6.6, earthquake along the international border near Mexicali has been a major goal of this study. All aftershocks through the end of 1979 with ML ≥ 4.0 from the CIT catalogue are plotted in Fig. 13a. In addition, an event which occurred on the San Jacinto fault on 25 Feb 1980 is shown. We have attempted to determine whether this event is the large late aftershock which might be expected in this series. When comparisons are made to the characteristics observed for other large late aftershocks, the 25 Feb 1980 event, also known as the Turkey Track or Hemet event, is rejected and not believed to be the expected large late aftershock. This rejection is based on: a) timing, the event occurs too early in comparison to the other examples, b) distance, the Hemet event at some 120 km distance is much further away than others observed in southern California, although a large, late afteshock occurred nearly 124 km away from the 1956 mainshock in northern Mexico. and c) the occurrence of this aftershock on the San Jacinto rather than on the Imperial or the San Andreas faults.

Even without the occurrence of the expected large, late aftershock at this point (August 1980), aftershock activity immediately following the Mexicali mainshock has been high at the ends of the aftershock zone, indicative of stress redistribution during the main event (Johnson and Hutton, 1980).

Further evidence of the effect of the mainshock at large distances is the "sympathetic slip" observed by Kerry Sieh (1980) along the locked section of the San Andreas fault near the northern ends of the active zone (shown in Fig. 14). This indication of stress redistribution caused us to investigate micro-earthquake activity in this portion of the San Andreas. A separate publication describes the results of this special study in detail.

For a one week period following the mainshock, we occupied 5 temporary sites on both sides of the San Andreas in an area where we had a baseline of micro-earthquake data for the 7 months immediately preceding the October mainshock. Sites are noted as stations ORF, PAC, TRR, FSH, BRD in Fig. 14. During the October micro-earthquake study, activity was high but at a rate not unusual for this area. Specifically, on the 3rd and 4th days of our occupation of these sites, a cluster of activity occurred along an east-west lineation known as Porcupine Wash. This cluster contained about 85 events. Clusters are quite common along the east-west lineations in this area and had been observed during our earlier study.

Other activity during the time of this special study also appeared similar to that observed during our earlier micro-earthquake work. Small numbers of events occurred along the San Jacinto and the Mission Creek faults and at the edges of the San Jacinto mountains. The events ranged in magnitude from $1.0 \leq M_L \leq 2.5$. Two events observed do appear related to the observed slip of Sieh's work. These events near Sieh's observed slip, occur within 4 km of the mapped surface trace of the San Andreas , making them among the closest to the fault of any events observed during our entire micro-earthquake work in this area.

In southern California, two additional events of $M_L \geq 6.0$ provide ongoing experiments to test the regional significance of large, late occurring aftershocks although these recent events near Mammoth Lakes (25 May 1980, $M_L = 6.5$) and in the Cerro Prieto region (9 June 1980, $M_L = 6.1$) occur near the border of the study region. Our review of the nature of earlier sequences in both locations, indicates that large, late aftershocks occurred in each region in the past and can be expected in the current series.

Conclusions

The high quality and large quantity of data contained in the southern California catalogue (Hileman et. al., 1973 and subsequent editions) demonstrate that in at least one seismically active area for which an extensive 50 year data set is available, 7 out of 11 aftershock sequences or 64 percent of those for earthquakes of $M_L \geq 6.0$ contained large, late occurring events of $M_L \geq 5.0$. Thus in southern California, the occurrence of large, late aftershocks is considered significant throughout the region. It follows that such shocks can be identified as particularly likely in those local areas which have previously exhibited such patterns e.g., the Imperial Valley, the southern San Jacinto fault, and northern Mexico. For this reason, three areas in southern California merit special consideration at this time with regard to expected aftershocks. These include the aftershock regions of the 15 October 1979 (M_L = 6.6) earthquake, the Mammoth Lakes earthquake aftershock area (25 May 1980, M_L = 6.5), and the region of the 9 June 1980 (M_L = 6.1) earthquake in northern Baja along the Cerro Prieto fault.

Analyses such as ours provide a firm empirical basis against which the models suggested in theoretical works on aftershock occurrence can be tested. In this light, further study of the rupture patterns of these three events should be undertaken in a specific effort to predict the approximate location and size of the expected aftershocks.

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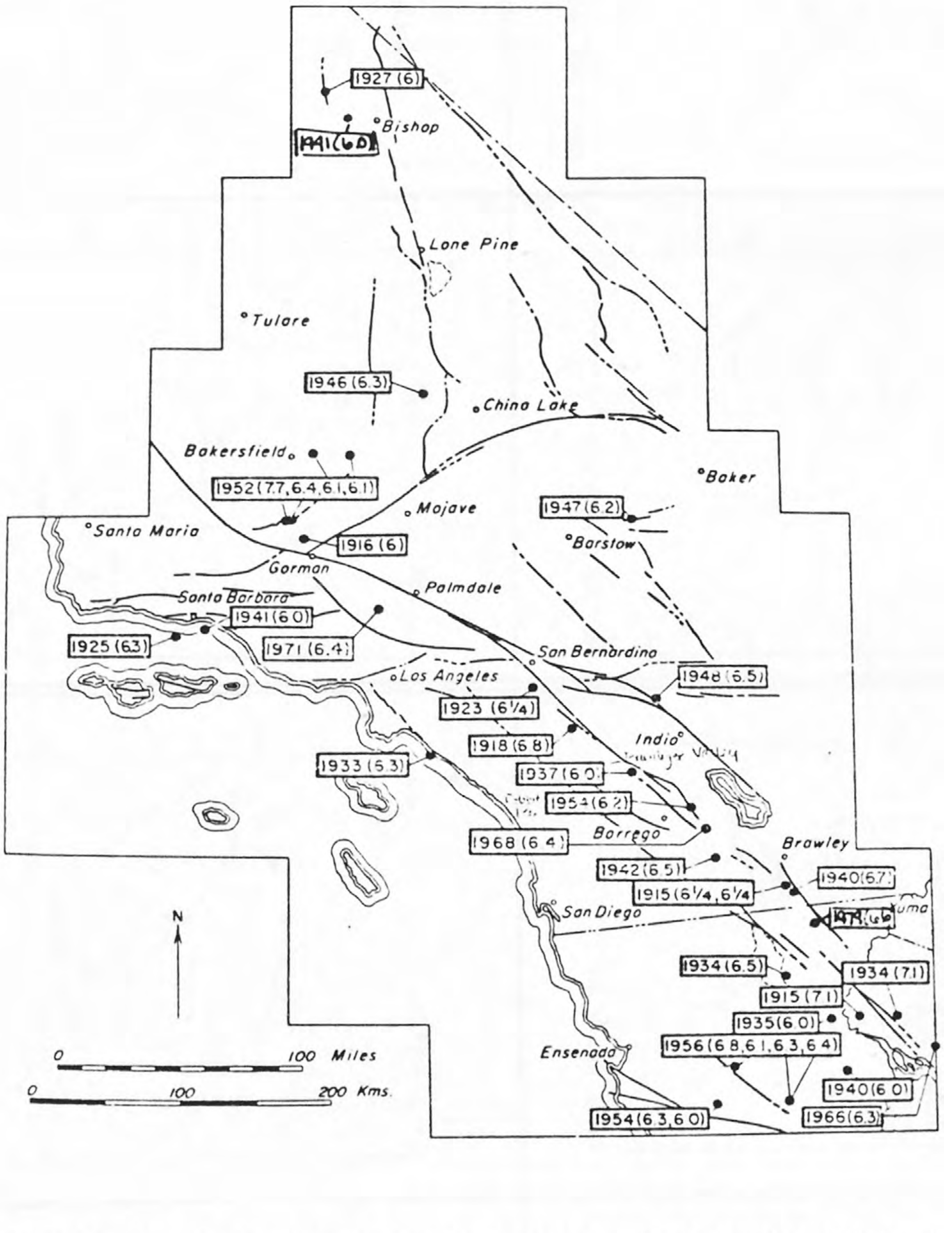


Figure 1. Earthquakes of magnitude 6.0 and greater in the southern California region, 1912-1972, modified from Allen et al. (1965).

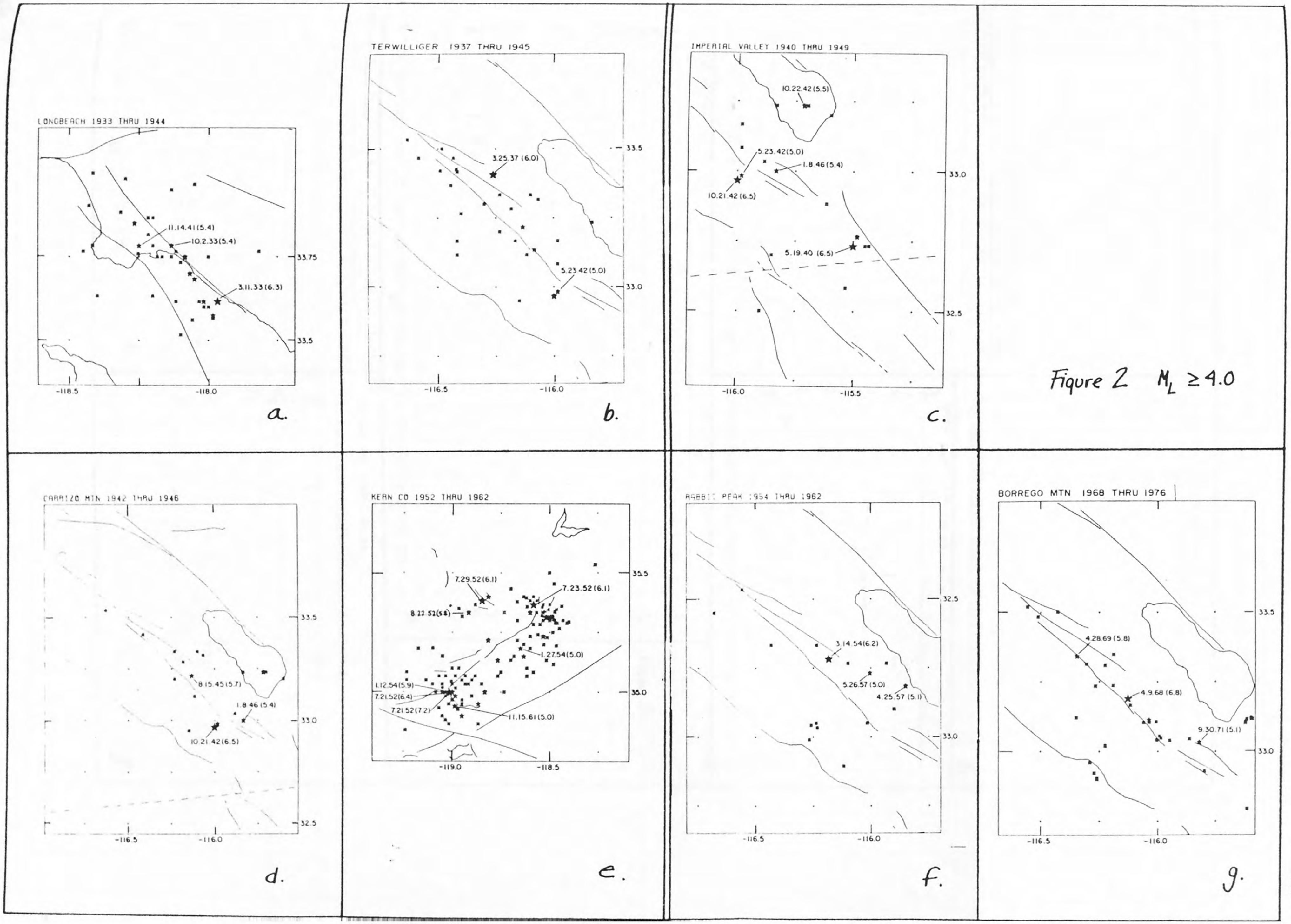


Figure 2 $M_L \geq 4.0$

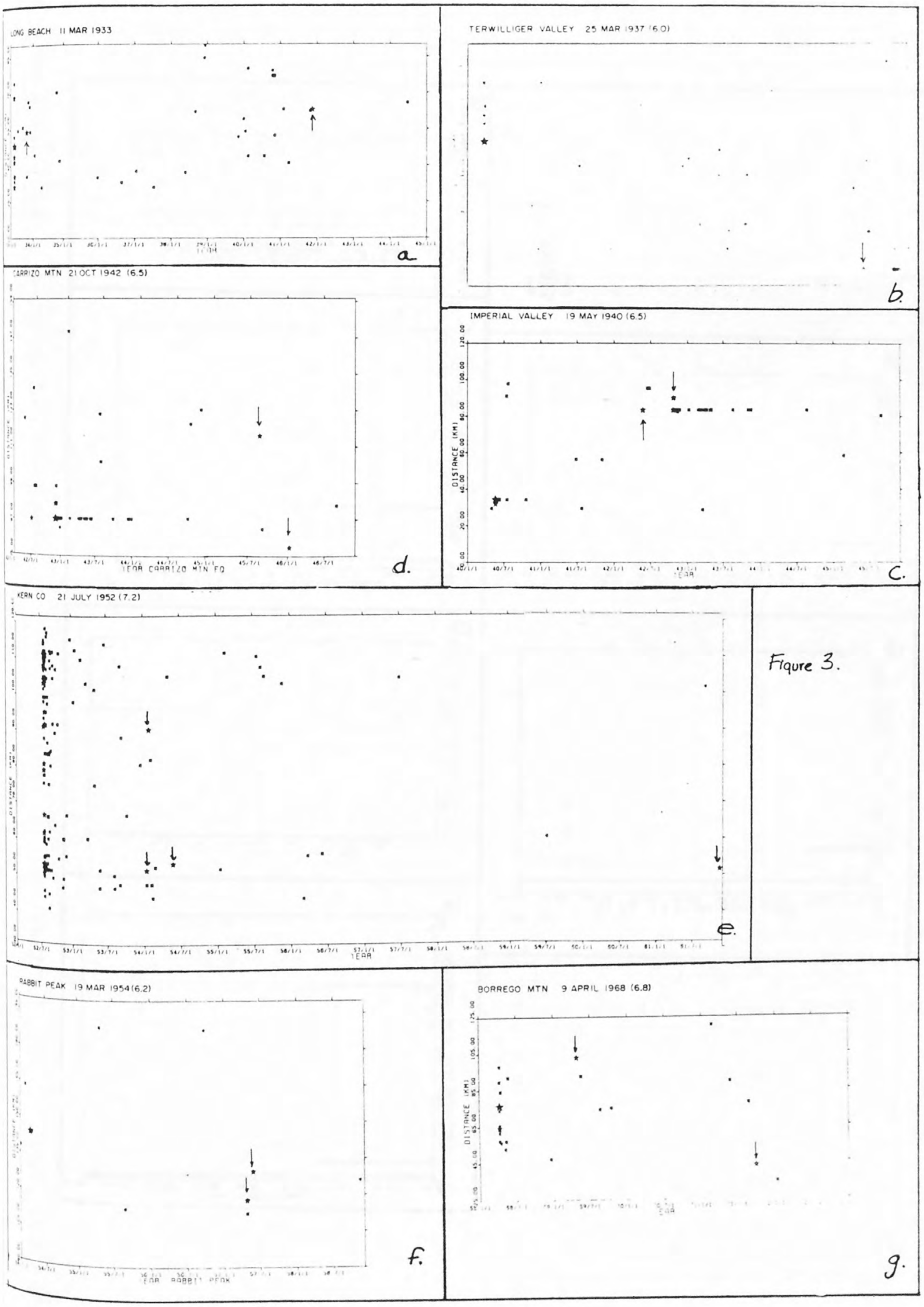

LONG BEACH 11 MAR 1933
a
TERWILLIGER VALLEY 25 MAR 1937 (6.0)
b
CARRIZO MTN 21 OCT 1942 (6.5)
YEAR CARRIZO MTN EQ
d
IMPERIAL VALLEY 19 MAY 1940 (6.5)
DISTANCE (KM)
YEAR
c
KERN CO 21 JULY 1952 (7.2)
YEAR
e
RABBIT PEAK 19 MAR 1954 (6.2)
YEAR RABBIT PEAK
f
BORREGO MTN 9 APRIL 1968 (6.8)
DISTANCE (KM)
g

Figure 3.

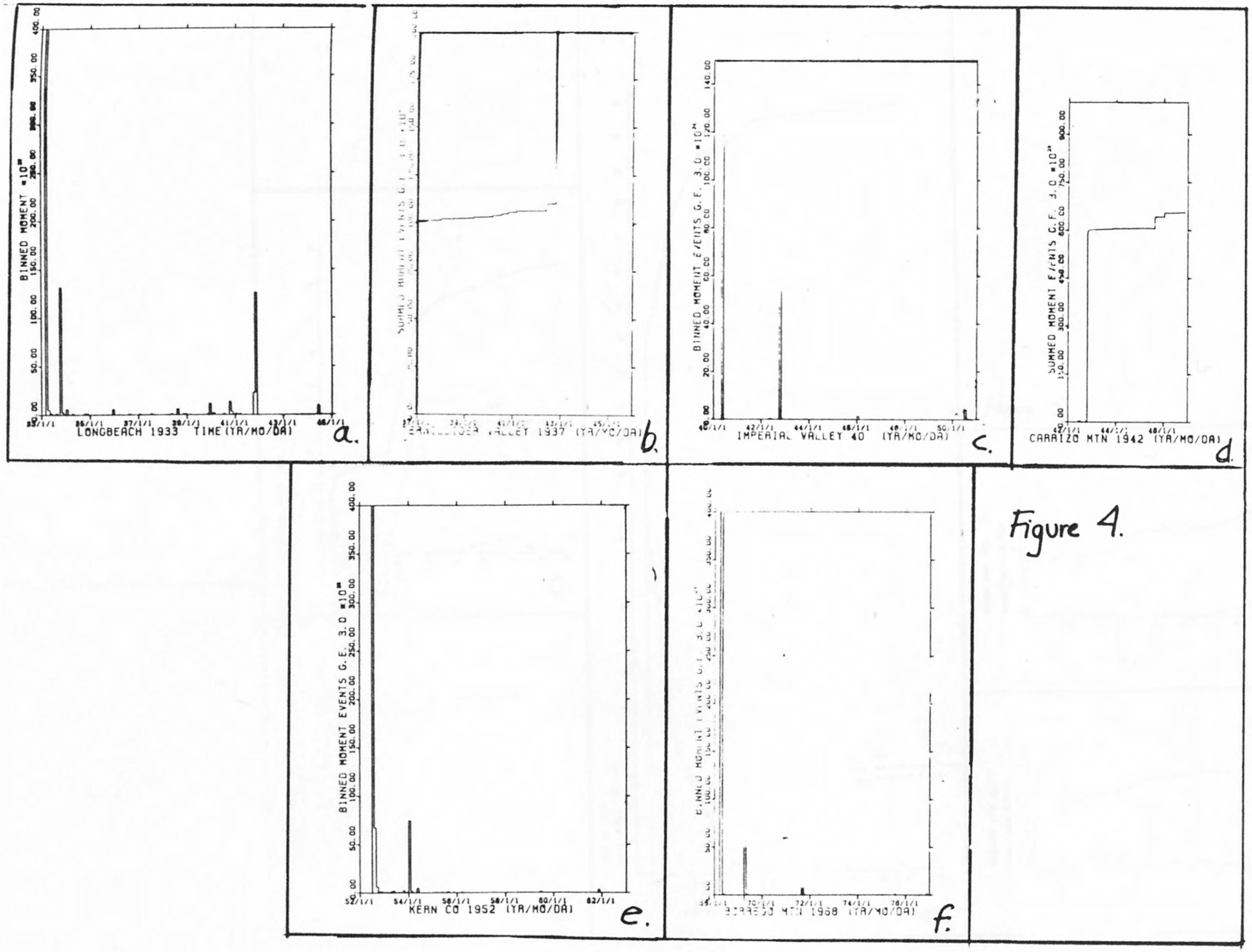

BINNED MOMENT
LONGBEACH 1933 TIME (YR/MO/DA)
a.
(YR/MO/DA)
b.
BINNED MOMENT EVENTS G.E. 3.0
IMPERIAL VALLEY 40 (YR/MO/DA)
c.
SUMMED MOMENT EVENTS G.E. 3.0
CARRIZO MTN 1942 (YR/MO/DA)
d.
BINNED MOMENT EVENTS G.E. 3.0
KERN CO 1952 (YR/MO/DA)
e.
MTN 1968 (YR/MO/DA)
f.

Figure 4.

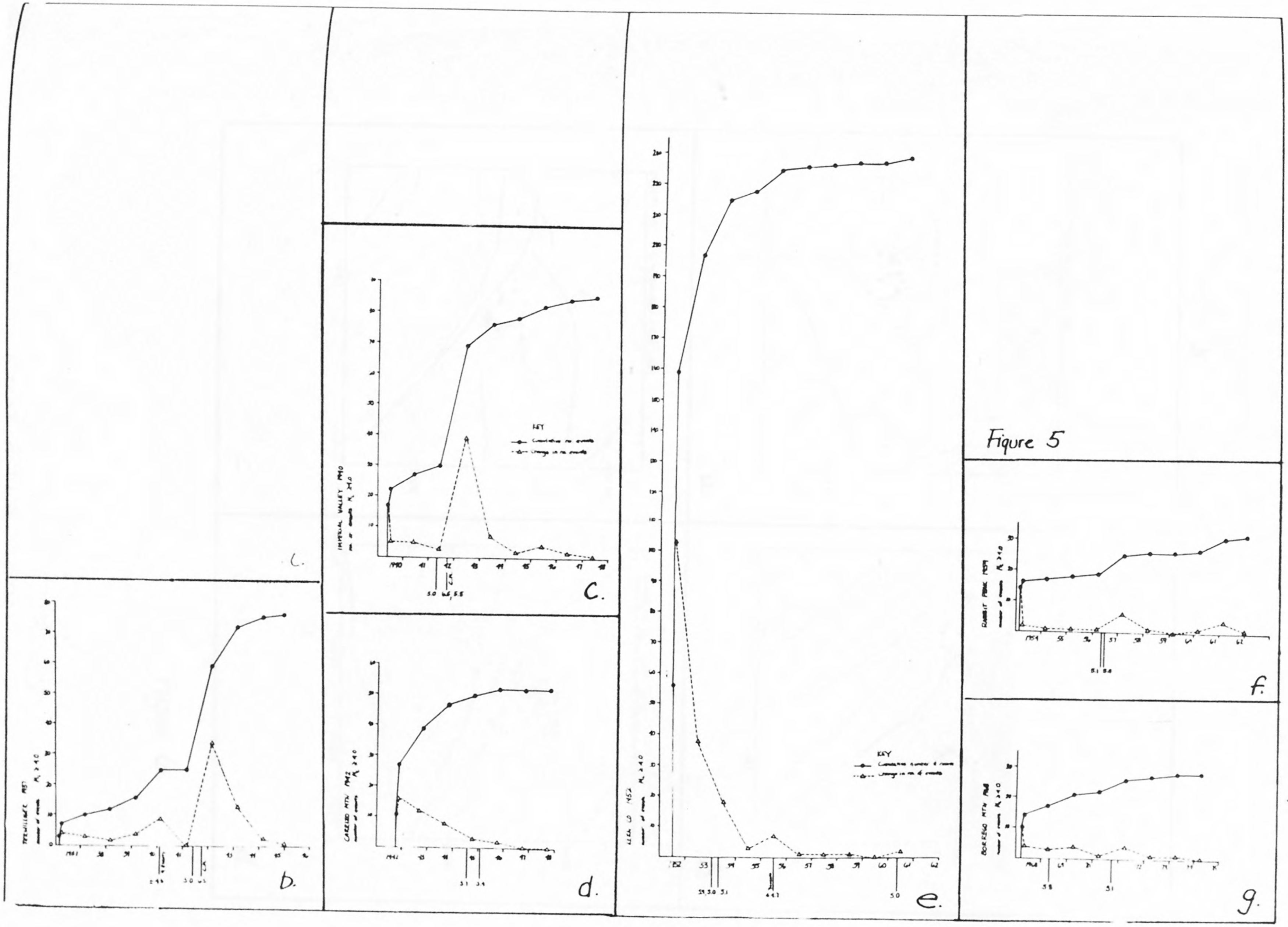


Figure 5

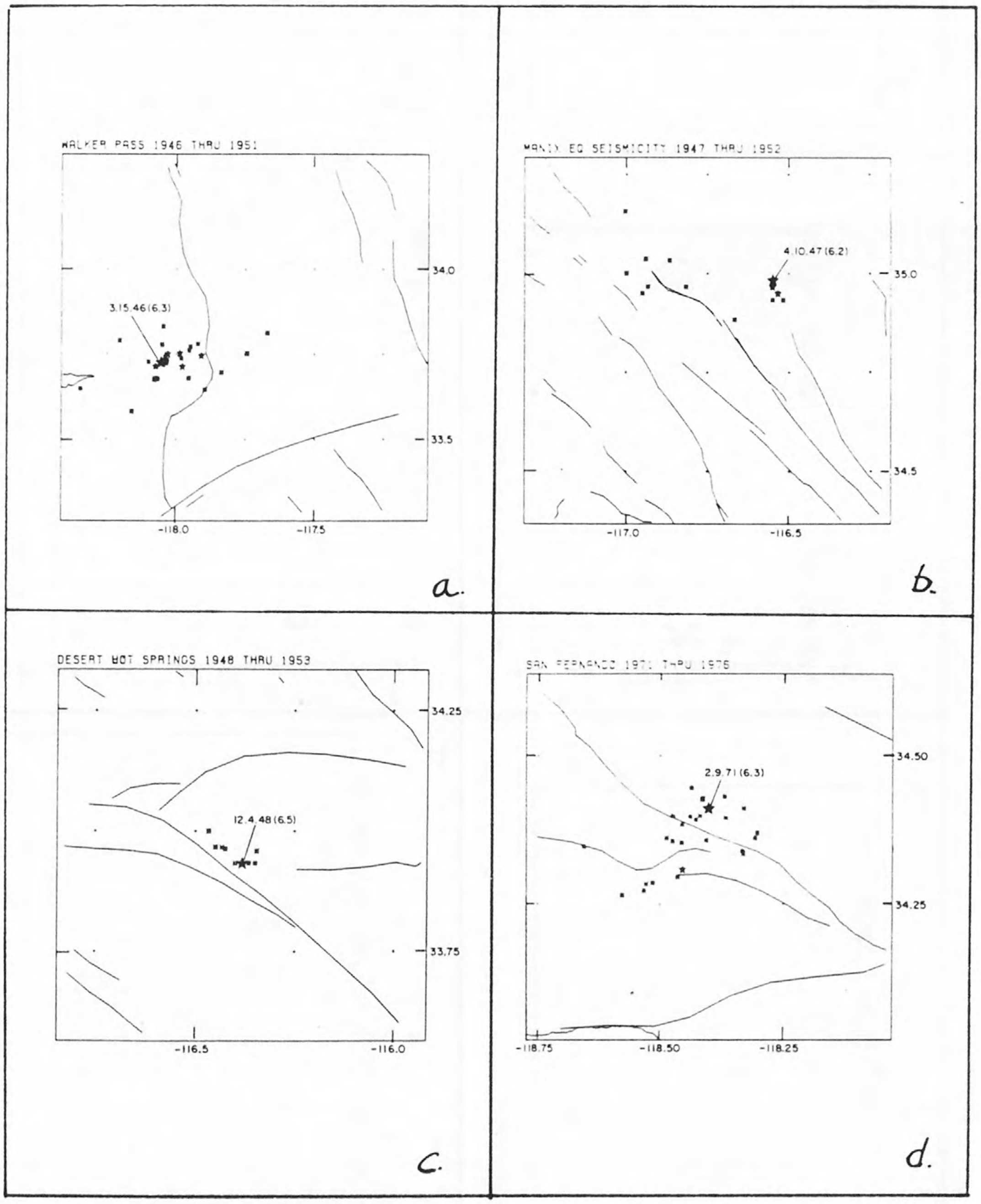
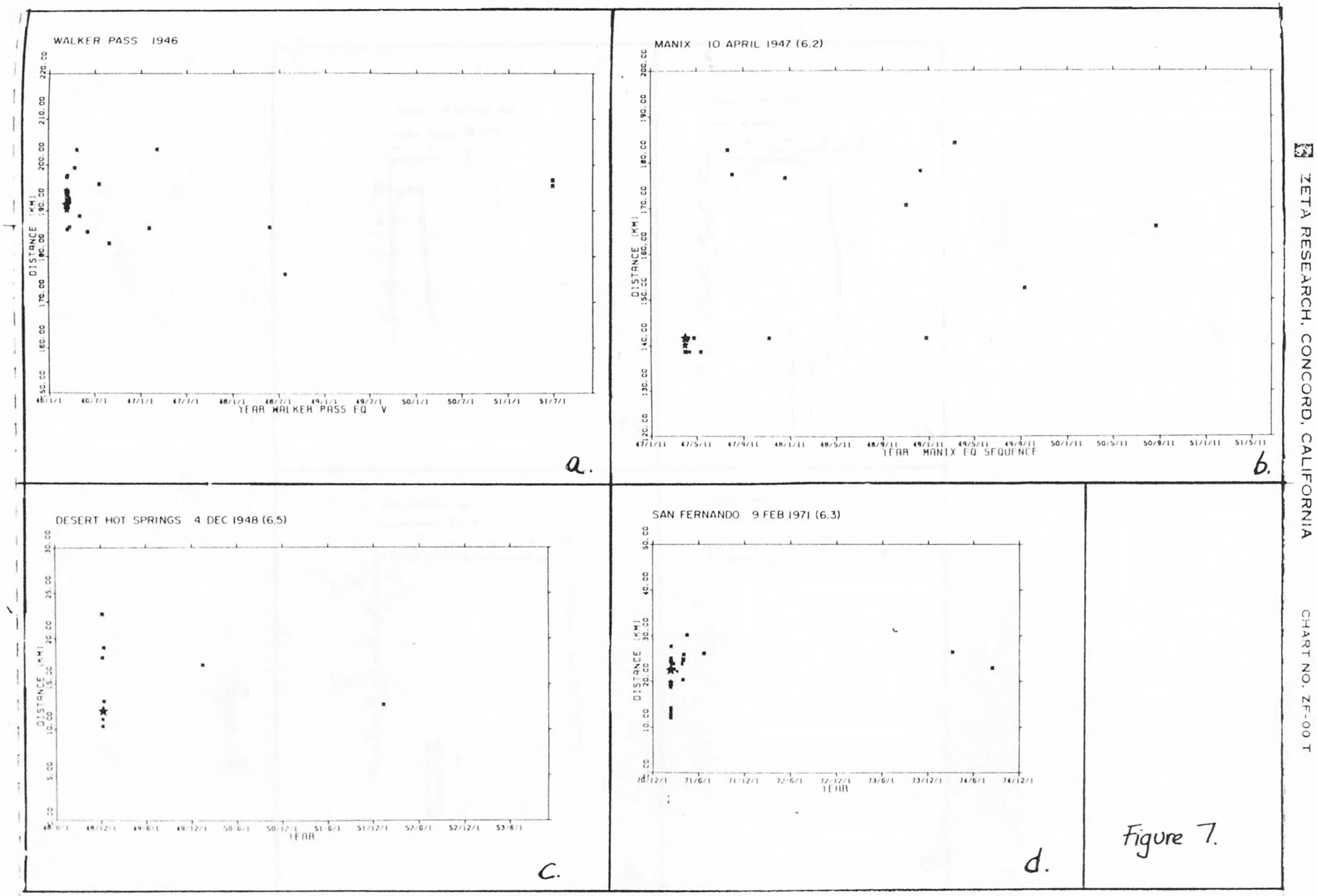

WALKER PASS 1946 THRU 1951
3.15.46 (6.3)
34.0
33.5
-118.0
-117.5
a.
MANIX EQ SEISMICITY 1947 THRU 1952
4.10.47 (6.2)
35.0
34.5
-117.0
-116.5
b.
DESERT HOT SPRINGS 1948 THRU 1953
12.4.48 (6.5)
34.25
33.75
-116.5
-116.0
c.
SAN FERNANDO 1971 THRU 1976
2.9.71 (6.3)
34.50
34.25
-118.75
-118.50
-118.25
d.

Figure 6.



WALKER PASS 1946
DISTANCE (KM)
YEAR WALKER PASS EQ V
a.
MANIX 10 APRIL 1947 (6.2)
DISTANCE (KM)
YEAR MANIX EQ SEQUENCE
b.
DESERT HOT SPRINGS 4 DEC 1948 (6.5)
DISTANCE (KM)
YEAR
c.
SAN FERNANDO 9 FEB 1971 (6.3)
DISTANCE (KM)
YEAR
d.
ZETA RESEARCH, CONCORD, CALIFORNIA
CHART NO. ZF-00 T

Figure 7.

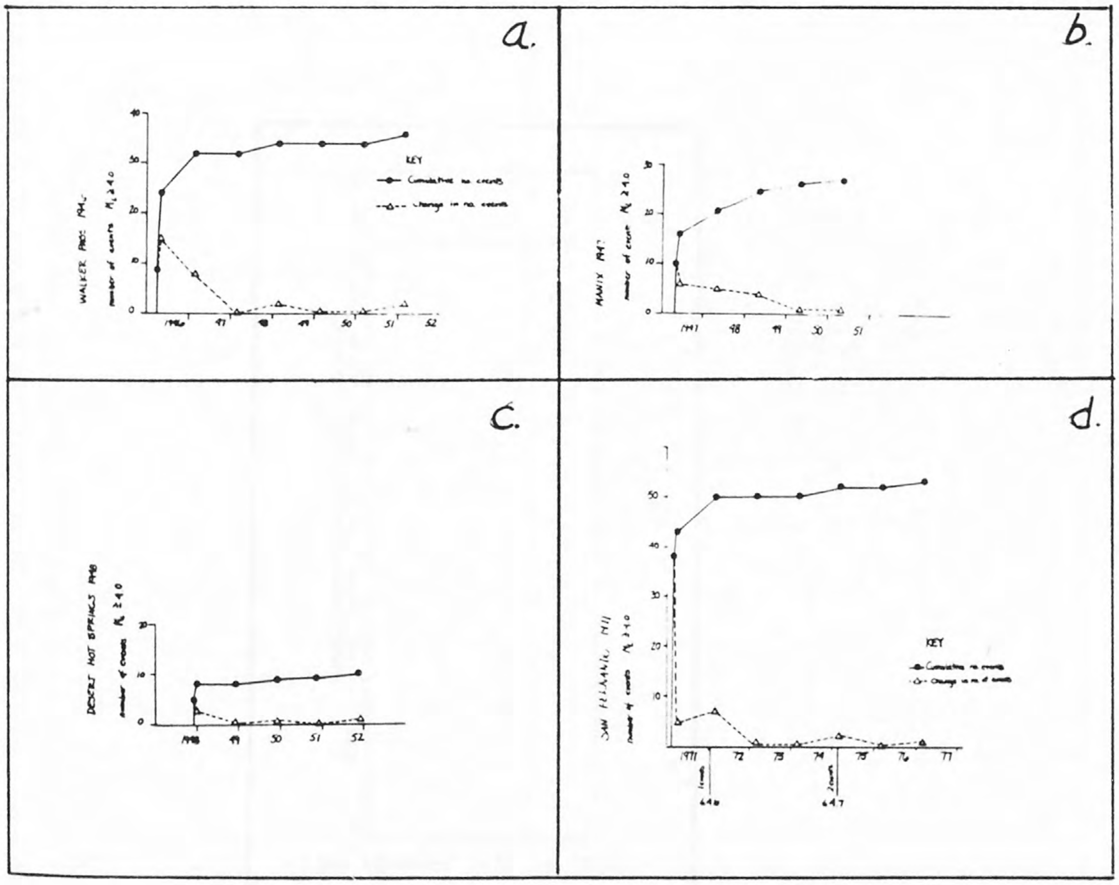


Figure 8.

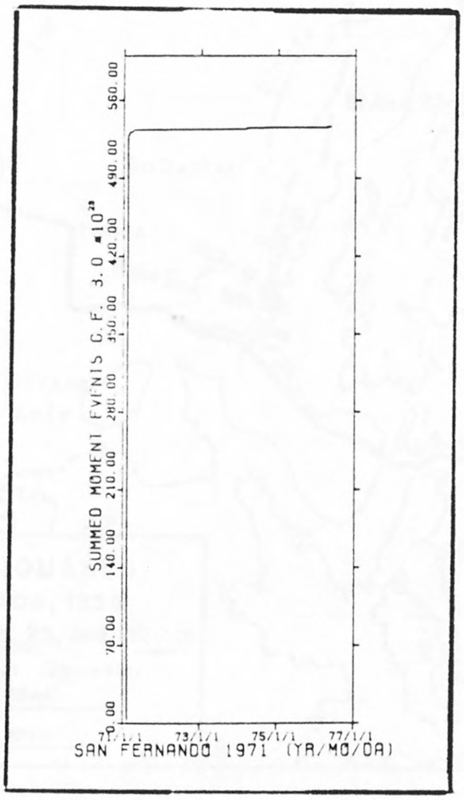

SUMMED MOMENT EVENTS C.F. 3.0 *10^23
0.00
70.00
140.00
210.00
280.00
350.00
420.00
490.00
560.00
71/1/1
73/1/1
75/1/1
77/1/1
SAN FERNANDO 1971 (YR/MO/DA)

Figure 9.

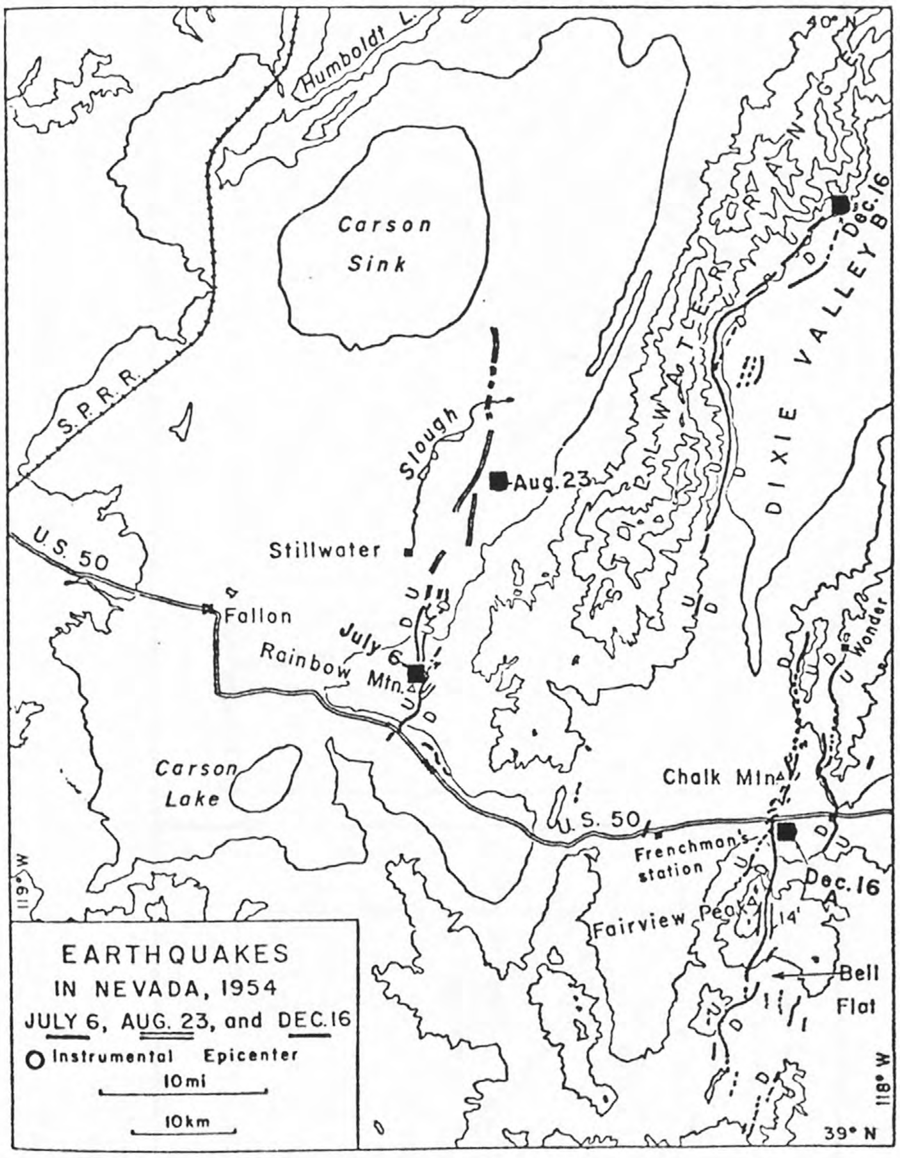

Humboldt L.
Carson
Sink
S.P.R.R.
Slough
Aug. 23
Stillwater
U.S. 50
Fallon
July 6
Rainbow Mtn.
Carson
Lake
Chalk Mtn.
U.S. 50
Frenchman's
station
Dec. 16
Fairview Peak
14'
Bell
Flat
Wonder
DIXIE VALLEY
STILLWATER RANGE
Dec. 16
40° N
39° N
118° W
119° W
EARTHQUAKES
IN NEVADA, 1954
JULY 6, AUG. 23, and DEC. 16
Instrumental Epicenter
10 mi
10 km

Figure 10.

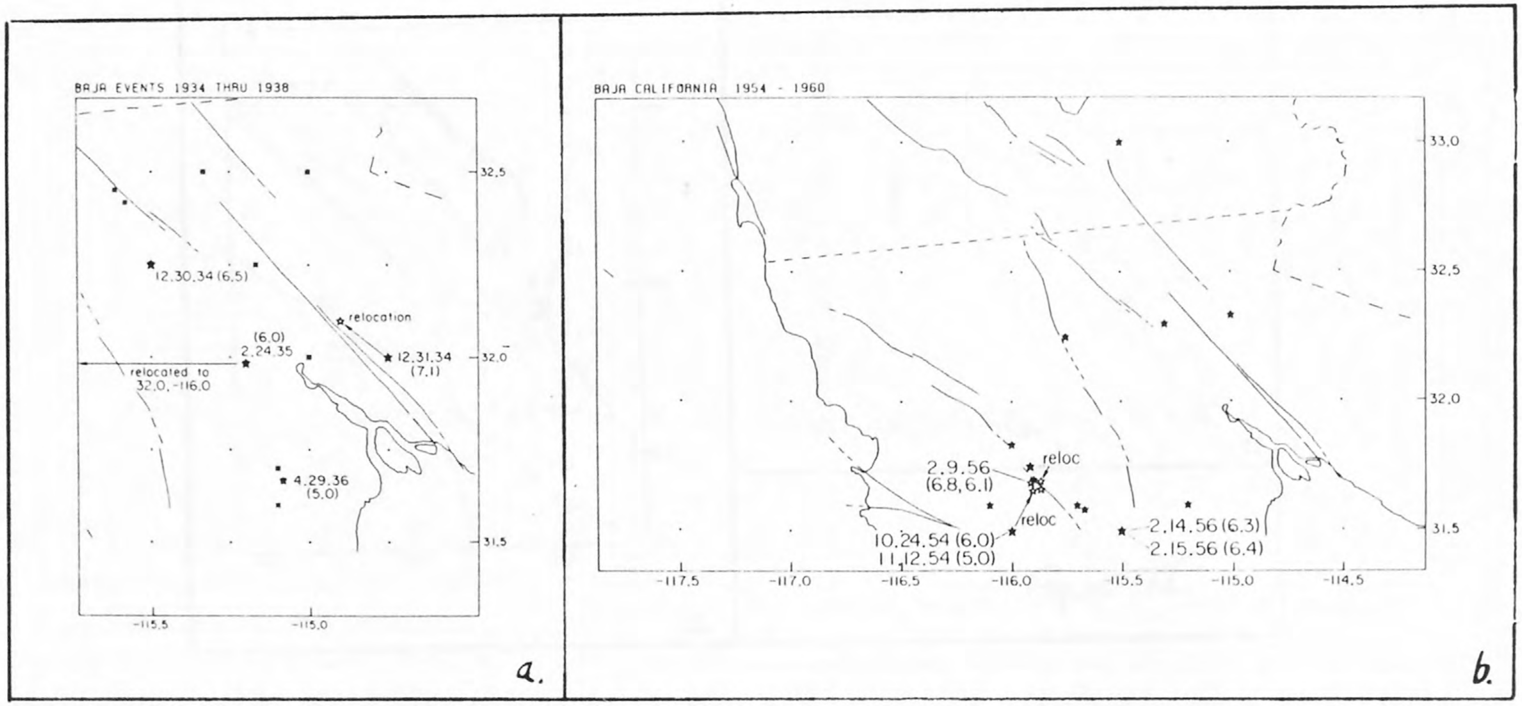

BAJA EVENTS 1934 THRU 1938
12.30.34 (6.5)
relocation
(6.0)
2.24.35
12.31.34
(7.1)
relocated to
32.0, -116.0
4.29.36
(5.0)
32.5
32.0
31.5
-115.5
-115.0
a.
BAJA CALIFORNIA 1954 - 1960
2.9.56
(6.8, 6.1)
reloc
reloc
10.24.54 (6.0)
11.12.54 (5.0)
2.14.56 (6.3)
2.15.56 (6.4)
33.0
32.5
32.0
31.5
-117.5
-117.0
-116.5
-116.0
-115.5
-115.0
-114.5
b.

Figure 11.

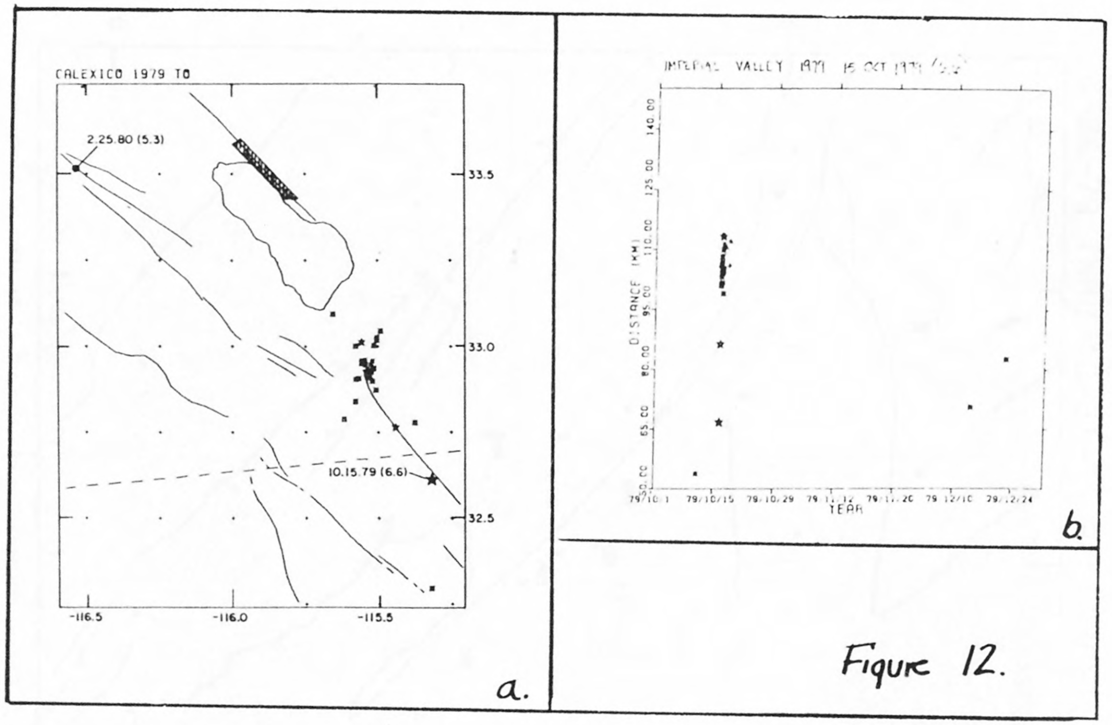

CALEXICO 1979 TO
2.25.80 (5.3)
10.15.79 (6.6)
33.5
33.0
32.5
-116.5
-116.0
-115.5
a.
DISTANCE (KM)
YEAR
b.

Figure 12.

10-24-79 THRU 10-31-79 ALL EVENTS MEQ800 AND CIT

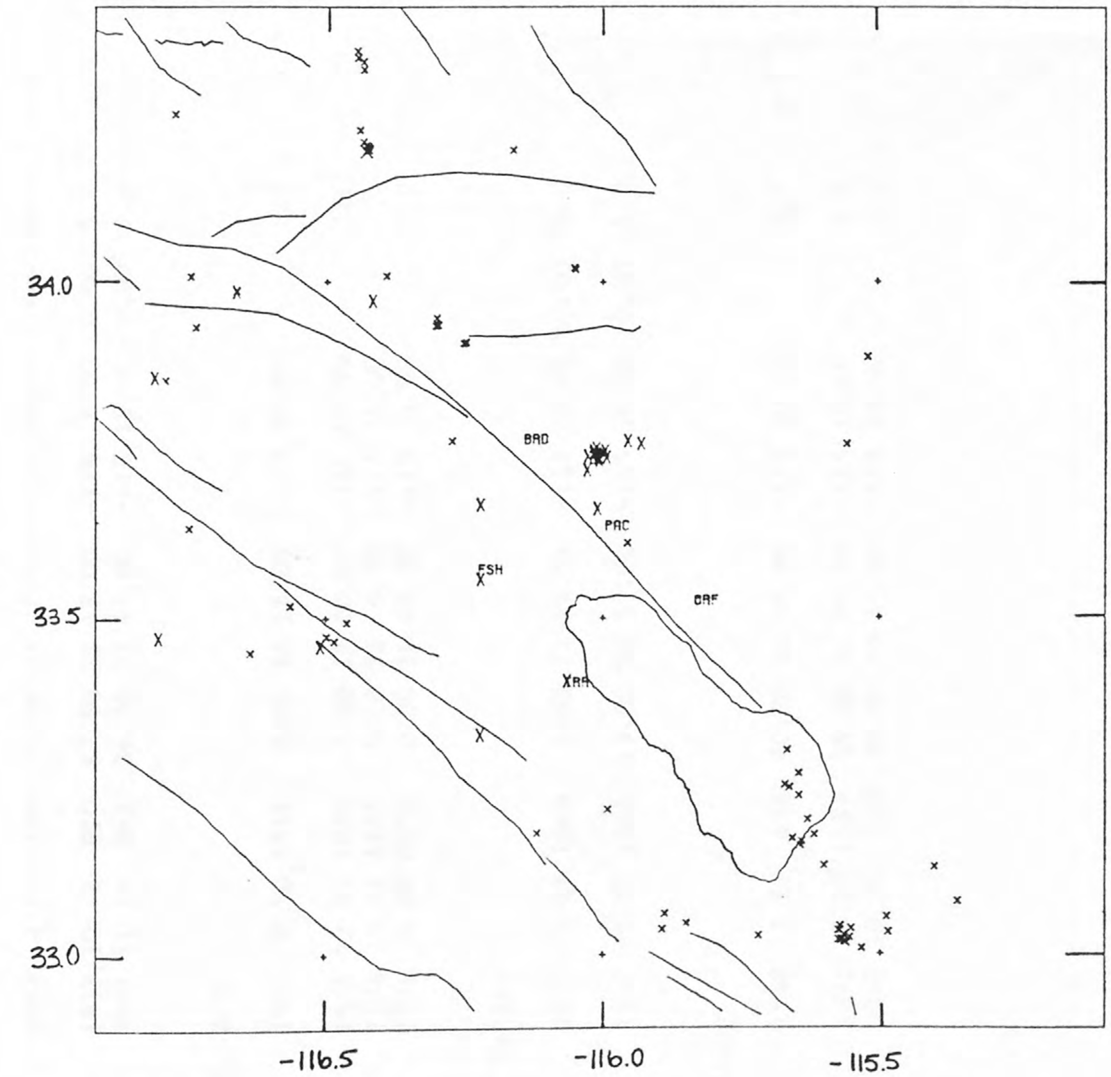


Figure 13.

TABLE 1.

	yr	mo	da	hrmn	sec	latitude	longitude	depth	M_L	M_{KJ}	km. to MS
Long Beach											
mainshock	1933	3	11	154	7.80	33 37.00	-117 58.00	0.00	6.3	6.4	
aftershock	1933	10	2	910	17.60	33 47.00	-118 8.00	0.00	5.4		30.5
aftershock	1941	11	14	841	36.30	33 47.00	-118 15.00	0.00	5.4		32.0
Cerro Prieto, Baja											
mainshock	1934	12	30	1352	0.00	32 15.00	-115 30.00		6.5		
aftershock	1934	12	31	1845	0.00	32 00.00	-114 45.00		7.1		86.5
relocation	1934	12	31	1845	0.00	32 6.00	-114 54.00				69.5
aftershock	1936	4	29	0850	0.00	31 40.00	-115 5.00		5.0		72.0
Terwilliger Valley											
mainshock	1937	3	25	1649	1.83	33 24.51	-116 15.69	10.00	6.0		
aftershock	1942	5	23	1547	29.00	32 59.00	-115 59.00	0.00	5.0		54.0
Imperial Valley											
mainshock	1940	5	19	436	40.90	32 44.00	-115 30.00		6.7	6.5	
aftershock	1942	5	23	1547	29.00	32 59.00	-115 59.00		5.0		53.0
aftershock	1942	10	22	150	38.00	33 14.00	-115 43.00		5.5		71.5

	yr	mo	da	hrmn	sec	latitude		longitude		depth	M_L	M_{KJ}	km. to MS
Carrizo Mountain													
mainshock	1942	10	21	1622	13.00	32	58.00	-116	0.00		6.5		
aftershock	1945	8	15	1756	24.00	33	13.00	-116	8.00	0.00	5.7		30.5
aftershock	1946	1	8	1854	18.00	33	0.00	-115	50.00	0.00	5.4		16.0
Walker Pass													
mainshock	1946	3	15	1349	35.90	35	43.51	-118	3.28	22.00	6.3		
Manix													
mainshock	1947	4	10	1558	6.00	34	59.00	-116	33.00		6.2		
Desert Hot Springs													
mainshock	1948	12	4	2343	17.00	33	56.00	-116	23.00		6.5	6.5	
Kern County													
mainshock	1952	7	21	1152	14.00	35	0.00	-119	1.00	0.00	7.7	7.2	
aftershock	1952	8	22	2241	24.00	35	20.00	-118	55.00	0.00	5.8		32.5
aftershock	1954	1	12	2333	49.00	35	0.00	-119	1.00	0.00	5.9		0.0
aftershock	1954	1	27	1419	48.00	35	9.00	-118	38.00	0.00	5.0		39.0
aftershock	1954	5	23	2352	43.00	34	59.00	-118	59.00	0.00	5.1		4.0
aftershock	1961	11	15	538	55.49	34	56.47	-118	59.20	10.70	5.0		7.5

	yr	mo	da	hrmn	sec	latitude	longitude	depth	M_L	M_{KJ}	km. to MS
Rabbit Peak											
mainshock	1954	3	19	954	29.00	33 17.00	-116 11.00	0.00	6.2		
aftershock	1957	4	25	2224	12.00	33 11.00	-115 51.00	0.00	5.1		33.0
aftershock	1957	5	26	1559	33.64	33 13.88	-116 0.27	15.10	5.0		17.5
San Miguel, Baja											
mainshock	1956	2	9	1432	38.00	31 45.00	-115 55.00		6.8	6.8	
aftershock	1956	2	9	1524	26.00	31 45.00	-115 55.00		6.1		0.0
aftershock	1956	2	14	1445	34.00	31 30.00	-115 30.00		6.3		52.0
aftershock	1956	2	14	1833	34.00	31 30.00	-115 30.00		6.4		52.0
aftershock	1956	12	13	1315	37.00	31 0.00	-115 0.00		6.0		124.0
Borrego Mountain											
mainshock	1968	4	9	228	59.06	33 11.40	-116 7.72	11.10	6.4	6.8	
aftershock	1969	4	28	2320	42.87	33 20.60	-116 20.78	20.00	5.8		26.5
aftershock	1971	9	30	2246	11.30	33 2.01	-115 49.24	8.00	5.1		33.5
San Fernando											
mainshock	1971	2	9	1400	41.83	34 24.67	-118 24.04	8.40	6.4	6.3	
Imperial Valley											
mainshock	1979	10	15	2316	53.44	32 36.82	-115 19.09	12.28	6.6	6.6	
aftershock	1980	2	25	1047	37.69	33 30.85	-116 32.33	10.07	5.3		120.0

Page 3

	yr	mo	da	hrmn	sec	latitude	longitude	depth	M_L	M_{KJ}	km. to MS
Mammoth Lakes											
mainshock	1980	5	25	1633	44.80	37 36.47	-118 49.27	3.72	6.5		
Cerro Prieto, Baja											
mainshock	1980	6	9	328	19.37	32 11.12	-115 4.55	5.00	6.1		

February 1980 Special Report to U.S.G.S.

Recent Seismicity Changes Along the San Andreas Fault near Palmdale, California

by

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and

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We are fortunate in having a well established baseline for the microearthquake activity from 1976-1978 (prior to the strain change), from operation of the seismographic trailer array in the Palmdale area. During this time an anomalous swarm of earthquakes occurred along the San Andreas with concentration at Juniper Hills, approximately 30 km SE of Palmdale (McNally et al, 1978; Drowley & McNally, 1980). The swarm was characterized by a change in earthquake fault mechanisms with time at the same location (Figure 1); all mechanisms were, however, consistent with the principal deviatoric strains measured by Lisowski and Savage (1979) (Figure 2a). Pechmann (1979) studied earthquakes which occurred in the central Transverse Ranges between 1974 and 1978 and also found faulting mechanisms which were consistent with N-S contraction (Figures 2b, 3, 4, 5). He calculated that the change associated with these earthquakes is smaller by 2 orders of magnitude than the strain measured by Savage, which suggests that this seismicity has reflected the larger strain field without significantly altering it.

If this is the case, the recent strain changes may be accompanied by changes in the dominant faulting mechanism. For instance, the decrease in north-south compression and increase in east-west extension observed geodetically near Palmdale may favor strike-slip faulting on northwest-striking planes (right-lateral) or northeast-striking planes (left-lateral) rather than thrusting on east-striking planes as observed previously. Figure 14 shows a focal mechanism for one of the larger events in the Palmdale area since the strain anomalies began, an M_L = 3.6 shock on 8/28/79 located ∿ 2 km NW of station BLU (Figure 11). Although this mechanism appears to be consistent with focal mechanisms for the central Transverse Ranges observed during 1974-8 (Figures 2b, 3, 4, 5) it is significantly different from mechanisms observed near the same area by Hadley (personal communication) in 1967 and 1969. (Figures 15 and 16). It is important to study a large number of earthquakes before attempting to draw any conclusions, however, since focal mechanisms can only be considered to represent the the regional stress field in a statistical sense.

A striking feature of the Juniper Hills swarm was a concurrent dispersion of activity which slowly "spread out" from the central swarm area between 1977 and 1978 to 30 km NW and SE along the San Andreas fault. This suggests a stress redistribution from the small (∿ 3km) swarm "knot" or an apparent migration velocity of ∿ 15km/yr over a distance of at least 60 km. Since 1979, the seismicity has suddenly ceased along the San Andreas at the NW and SE endpoints of the migration path. This marked quiescence corresponds in time with the strain reversal observed by Savage. A low level of seismicity continues in the middle of the quiet zone at the initial swarm location, however, throughout 1979. The seismicity patterns along the San Andreas fault are illustrated in the following figures. A detailed map of the fault zone, the seismographic trailer stations, and the microearthquake swarm at Juniper Hills is shown in Figure 6. The distribution of microearthquake activity with time and distance (along line AB, Figure 6) is shown in Figure 7. The swarm intensity is seen to diminish with time, in parallel with the spreading out of activity along the fault. These data were collected by the seismographic trailer array. The area of the 1976-1978 microearthquake study is shown as a dotted box in the context of the regional seismicity in Figure 8. In this case, however, only the earthquakes recorded by the permanent network ("SCARLET") are shown. The yearly development of the swarm activity (near JNH) is shown in Figures 8-11. (Note that 6 seismograph stations were added to the network in this area throughout 1976 and the listings of the earthquakes in that year are probably incomplete relative to subsequent years. In fact, the microearthquake trailer study in 1976 showed substantial activity near Lake Hughes (Figure 12) which was not detected by ("SCARLET").

It is extremely interesting that the swarm was accompanied by scattered activity along the entire San Andreas fault zone, from the Tejon Pass fault to Cajon Pass, in 1976, 1977, and 1978 (Figures 8-10). In 1979, however, activity has completely ceased to the NW and SE of the swarm area (Figure 11). (The seismically quiet areas of 1979 are enclosed by solid lines in Figure 11). This marked quiescence corresponds in time with the strain reversal observed by Savage. The distribution of seismic activity with time and distance along the San Andreas is shown in Figure 13 for the box (solid outline) indicated in Figure 8. The time of the strain reversal (Fig. 13) and the location of the Palmdalc Geodolite network (Fig. 8) are also shown.

It is not clear whether the quiescence indicates a return to a period of generally low activity such as Brune and Allen found in 1965, or whether the fault is undergoing seismicity changes precursory to a large earthquake in the near future. No similar seismic quiescence is observed NW of the Garlock/San Andreas intersection, or along the San Jacinto through Cajon Pass. The Tehachapi and Los Padres Geodolite networks, which are also showing anomolous strain changes, include part of the former area. Thus, the strain anomaly apparently covers a much larger area than the seismicity anomaly.

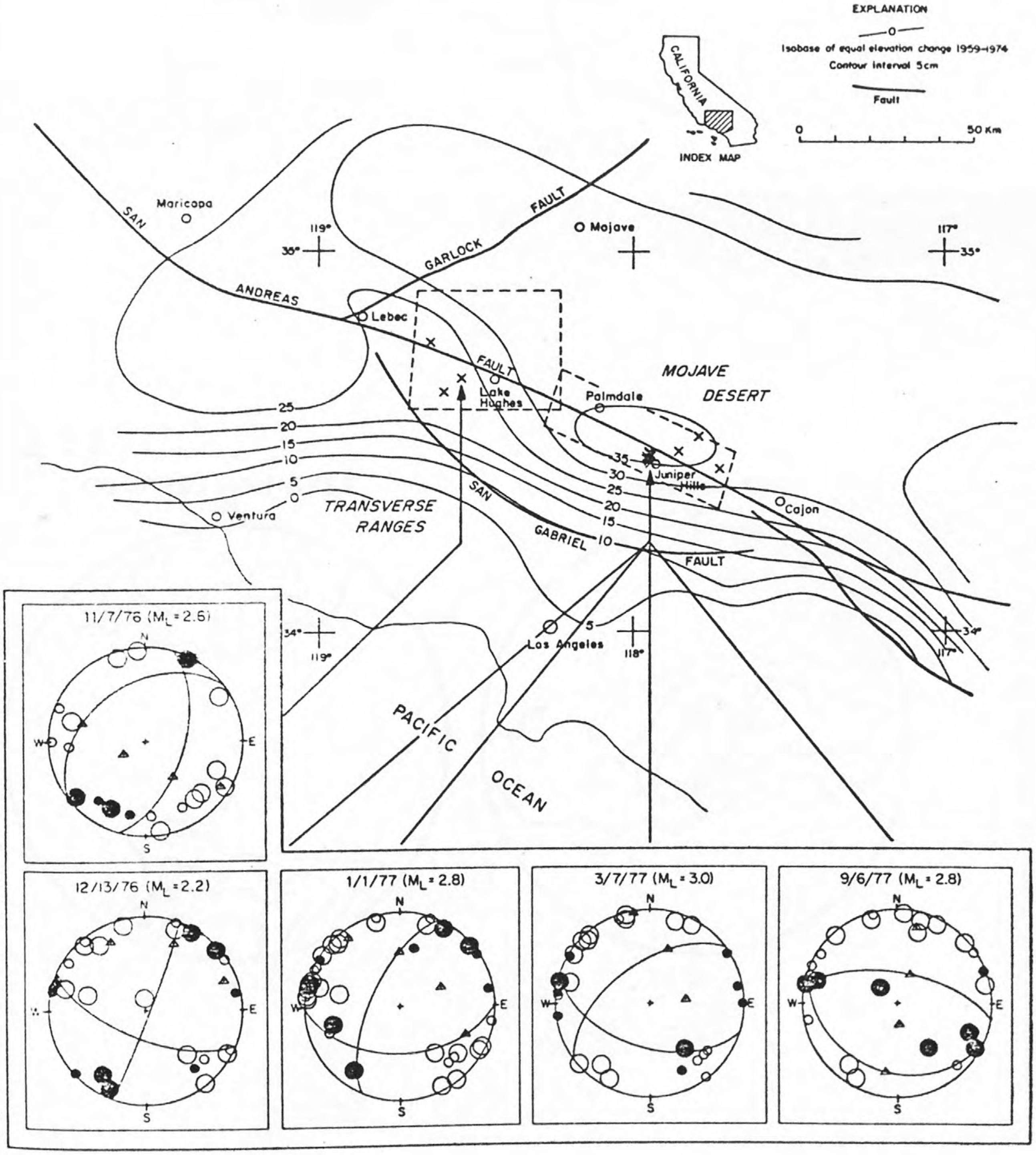

EXPLANATION
Isobase of equal elevation change 1959-1974
Contour interval 5cm
Fault
0
50 Km
CALIFORNIA
INDEX MAP
SAN ANDREAS FAULT
GARLOCK FAULT
SAN GABRIEL FAULT
Maricopa
Mojave
Lebec
Lake Hughes
Palmdale
Juniper Hills
Cajon
Ventura
Los Angeles
MOJAVE DESERT
TRANSVERSE RANGES
PACIFIC OCEAN
119°
118°
117°
35°
34°
11/7/76 (M_L = 2.6)
12/13/76 (M_L = 2.2)
1/1/77 (M_L = 2.8)
3/7/77 (M_L = 3.0)
9/6/77 (M_L = 2.8)

Fig. 1

Fig 2a.

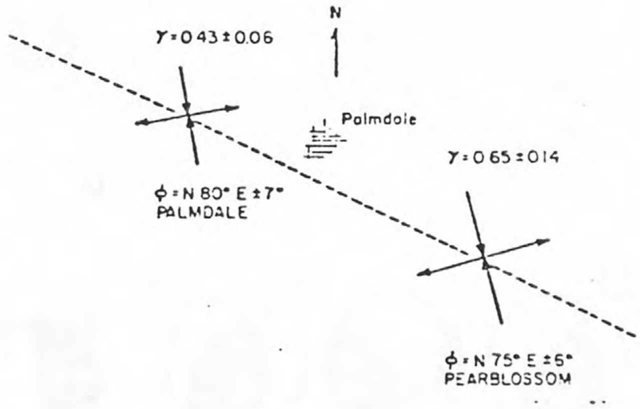
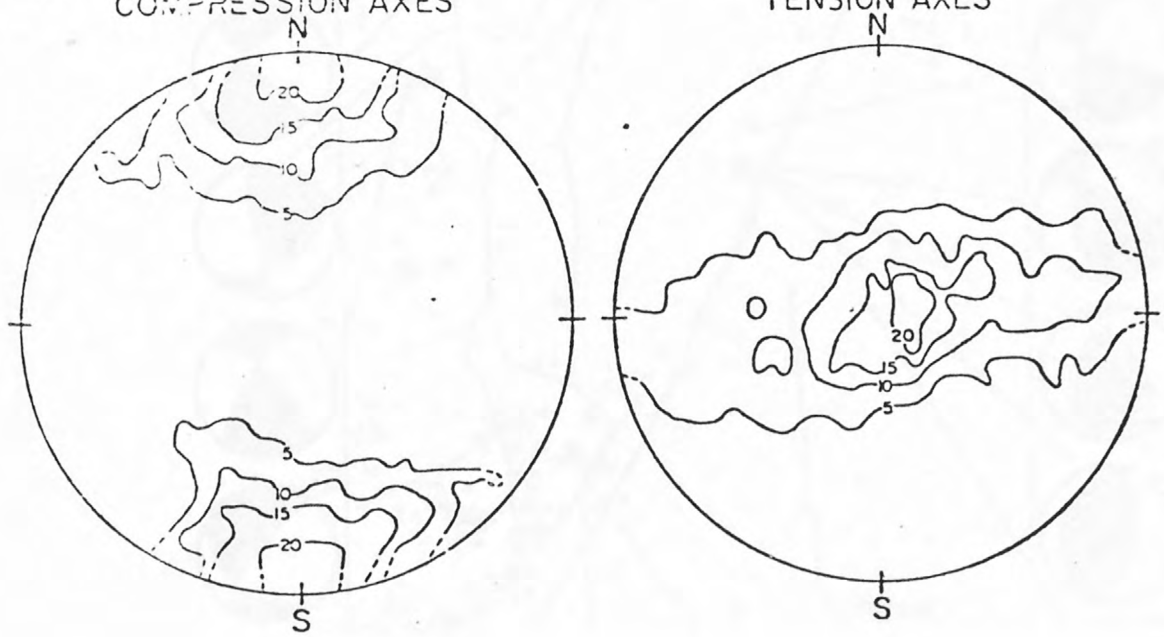


Fig 2b.

COMPRESSION AXES

TENSION AXES



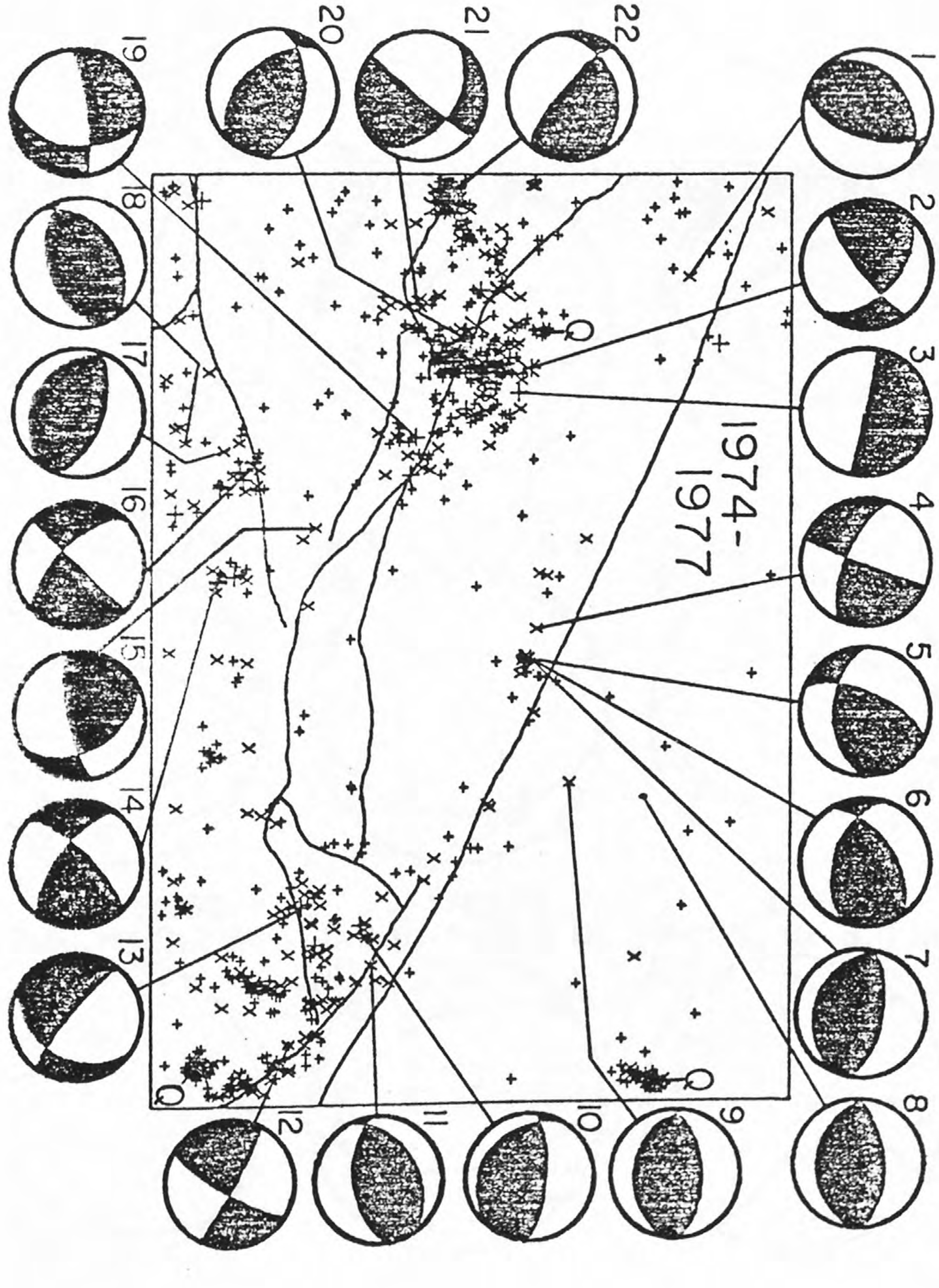


Fig. 3

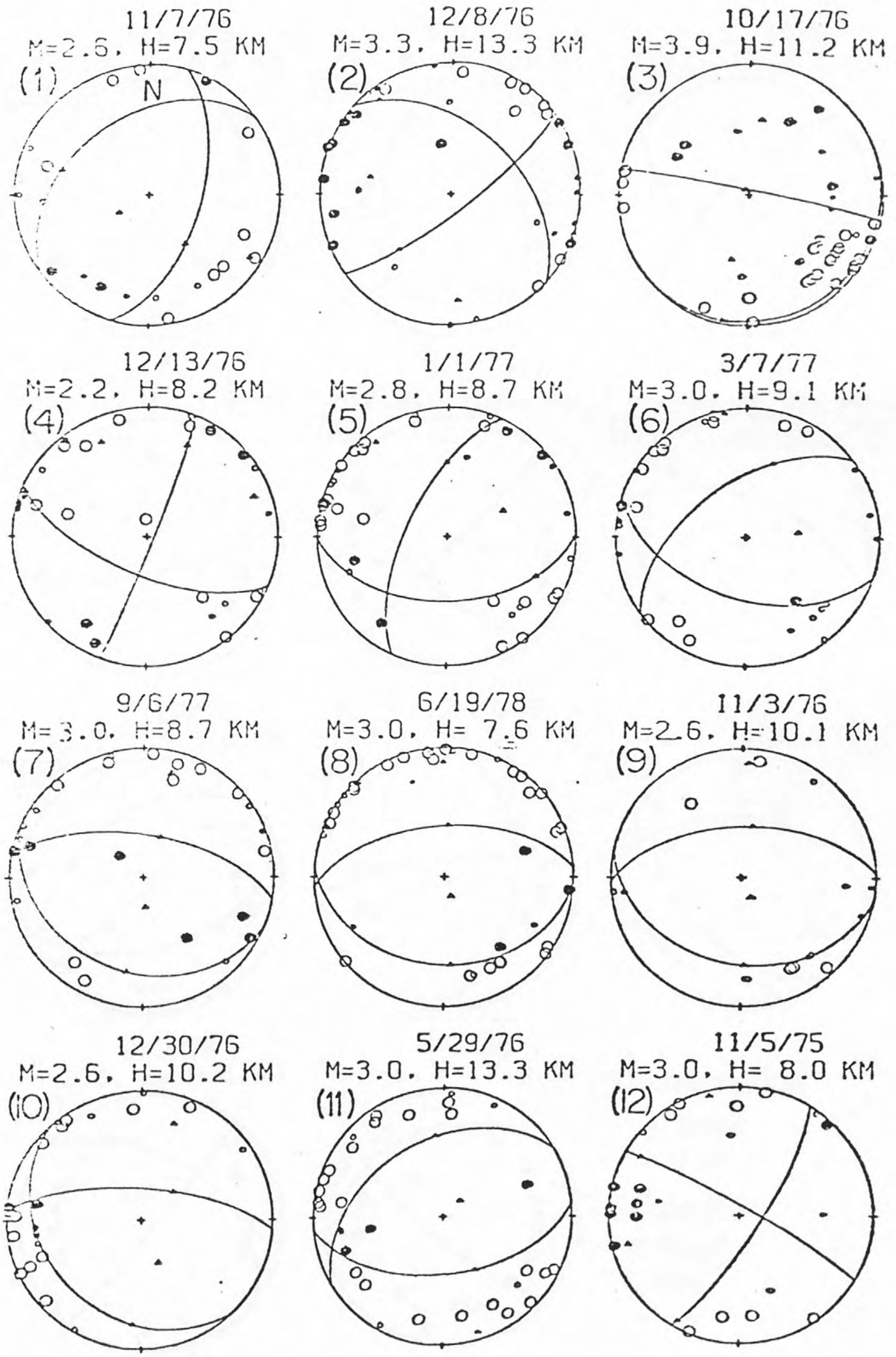

11/7/76
M=2.6, H=7.5 KM
(1)
N
12/8/76
M=3.3, H=13.3 KM
(2)
10/17/76
M=3.9, H=11.2 KM
(3)
12/13/76
M=2.2, H=8.2 KM
(4)
1/1/77
M=2.8, H=8.7 KM
(5)
3/7/77
M=3.0, H=9.1 KM
(6)
9/6/77
M=3.0, H=8.7 KM
(7)
6/19/78
M=3.0, H= 7.6 KM
(8)
11/3/76
M=2.6, H=10.1 KM
(9)
12/30/76
M=2.6, H=10.2 KM
(10)
5/29/76
M=3.0, H=13.3 KM
(11)
11/5/75
M=3.0, H= 8.0 KM
(12)

Fig 4.

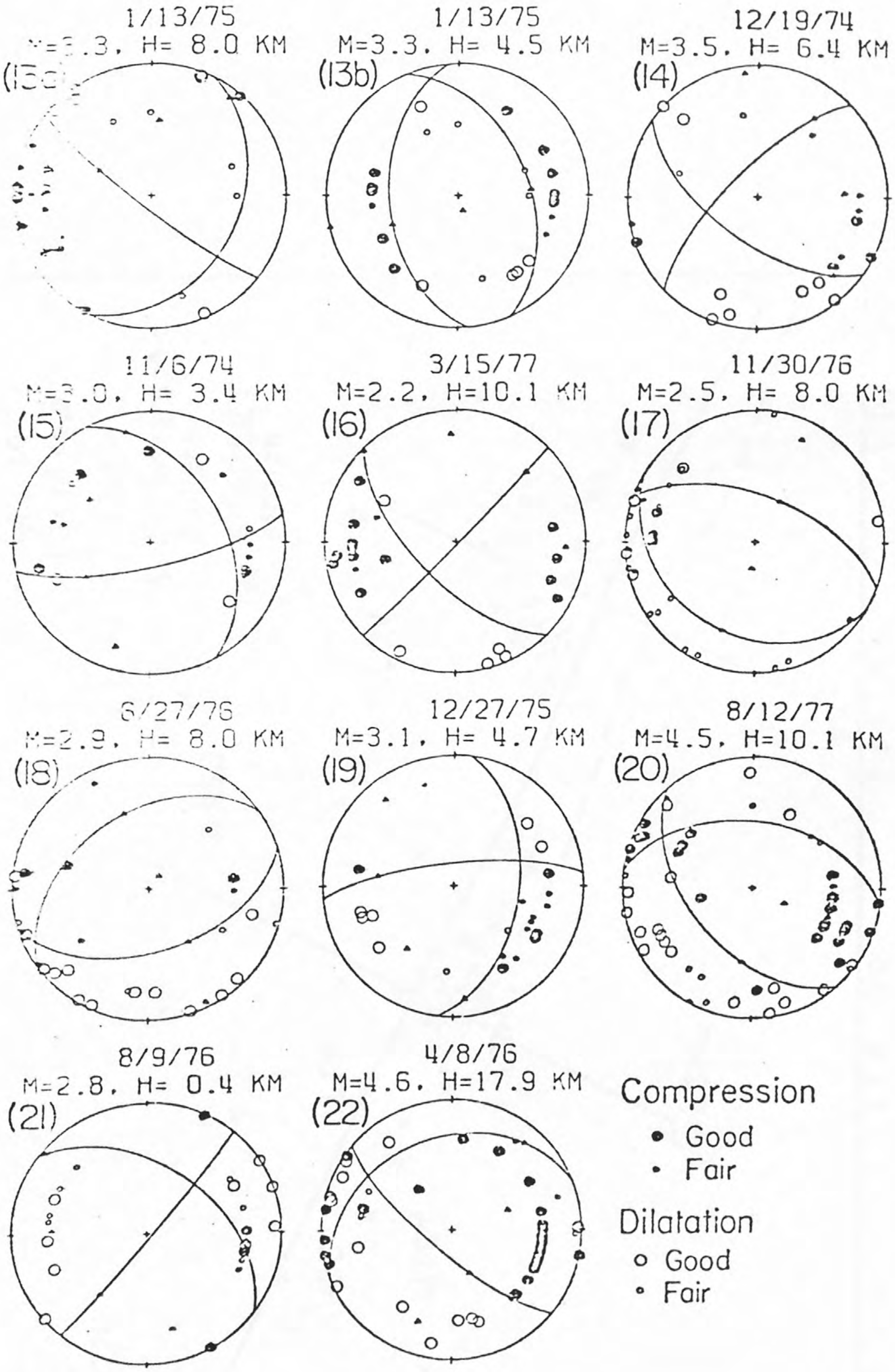

1/13/75
H= 8.0 KM
(13a)
1/13/75
M=3.3, H= 4.5 KM
(13b)
12/19/74
M=3.5, H= 6.4 KM
(14)
11/6/74
H= 3.4 KM
(15)
3/15/77
M=2.2, H=10.1 KM
(16)
11/30/76
M=2.5, H= 8.0 KM
(17)
6/27/76
H= 8.0 KM
(18)
12/27/75
M=3.1, H= 4.7 KM
(19)
8/12/77
M=4.5, H=10.1 KM
(20)
8/9/76
M=2.8, H= 0.4 KM
(21)
4/8/76
M=4.6, H=17.9 KM
(22)
Compression
Good
Fair
Dilatation
Good
Fair

Fig 5.

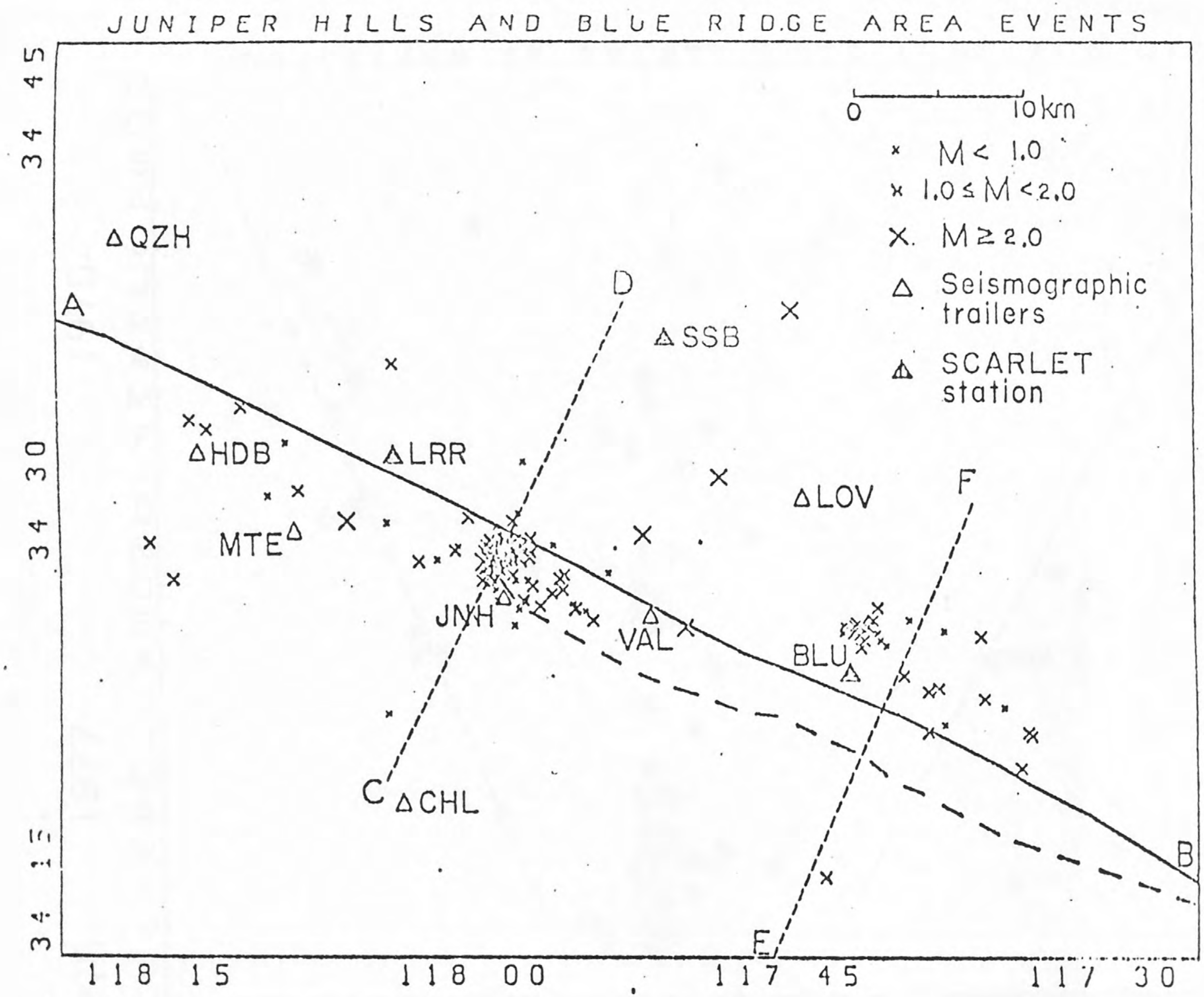

JUNIPER HILLS AND BLUE RIDGE AREA EVENTS
0
10 km
M < 1.0
1.0 ≤ M < 2.0
M ≥ 2.0
Seismographic trailers
SCARLET station
QZH
A
D
SSB
HDB
LRR
LOV
F
MTE
JNH
VAL
BLU
C
CHL
B
E
34 45
34 30
34 15
118 15
118 00
117 45
117 30

FIG 6

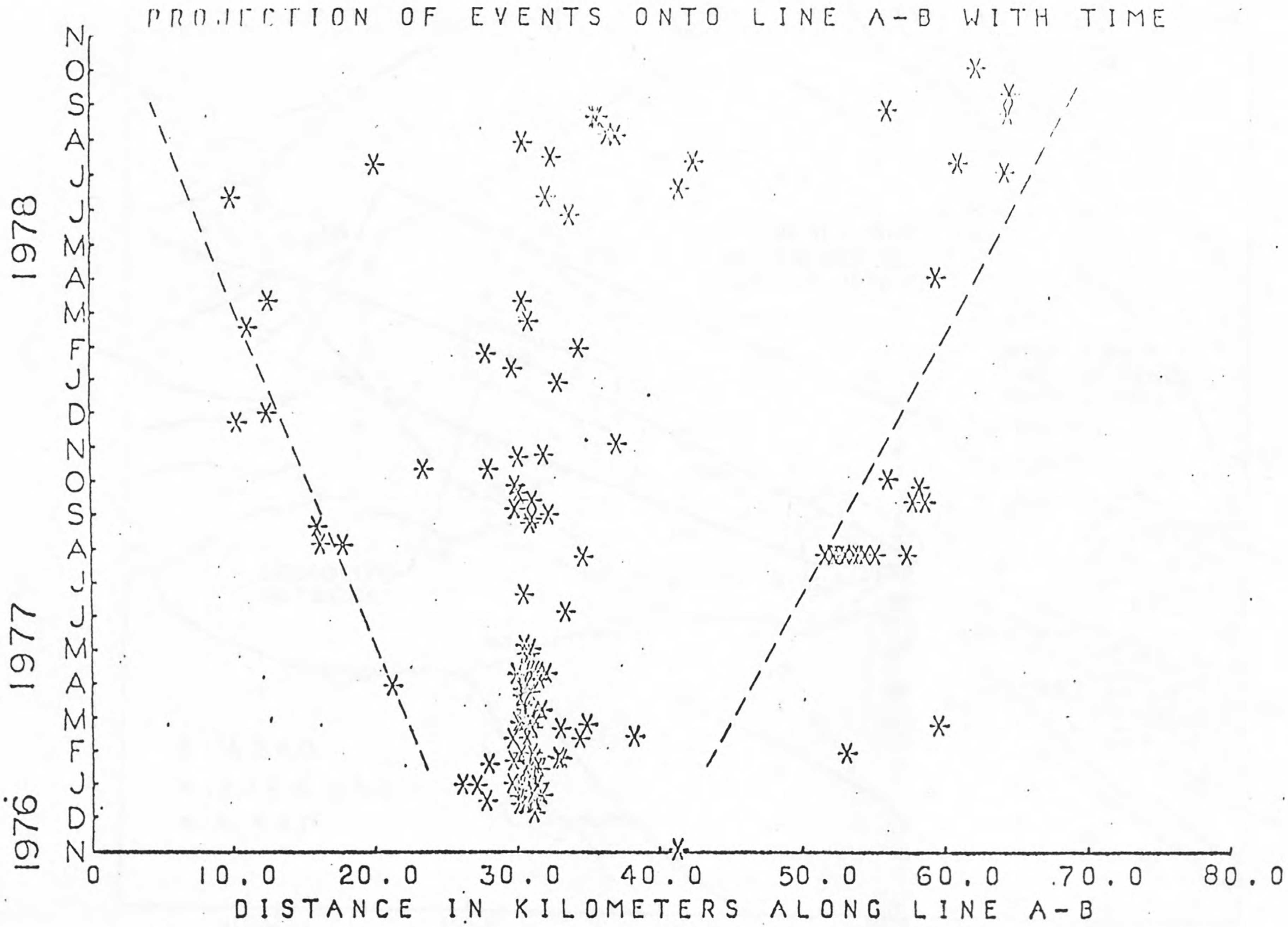

PROJECTION OF EVENTS ONTO LINE A-B WITH TIME
N
O
S
A
J
J
M
A
M
F
J
D
N
O
S
A
J
J
M
A
M
F
J
D
N
1978
1977
1976
0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
DISTANCE IN KILOMETERS ALONG LINE A-B

FIG 7

1976

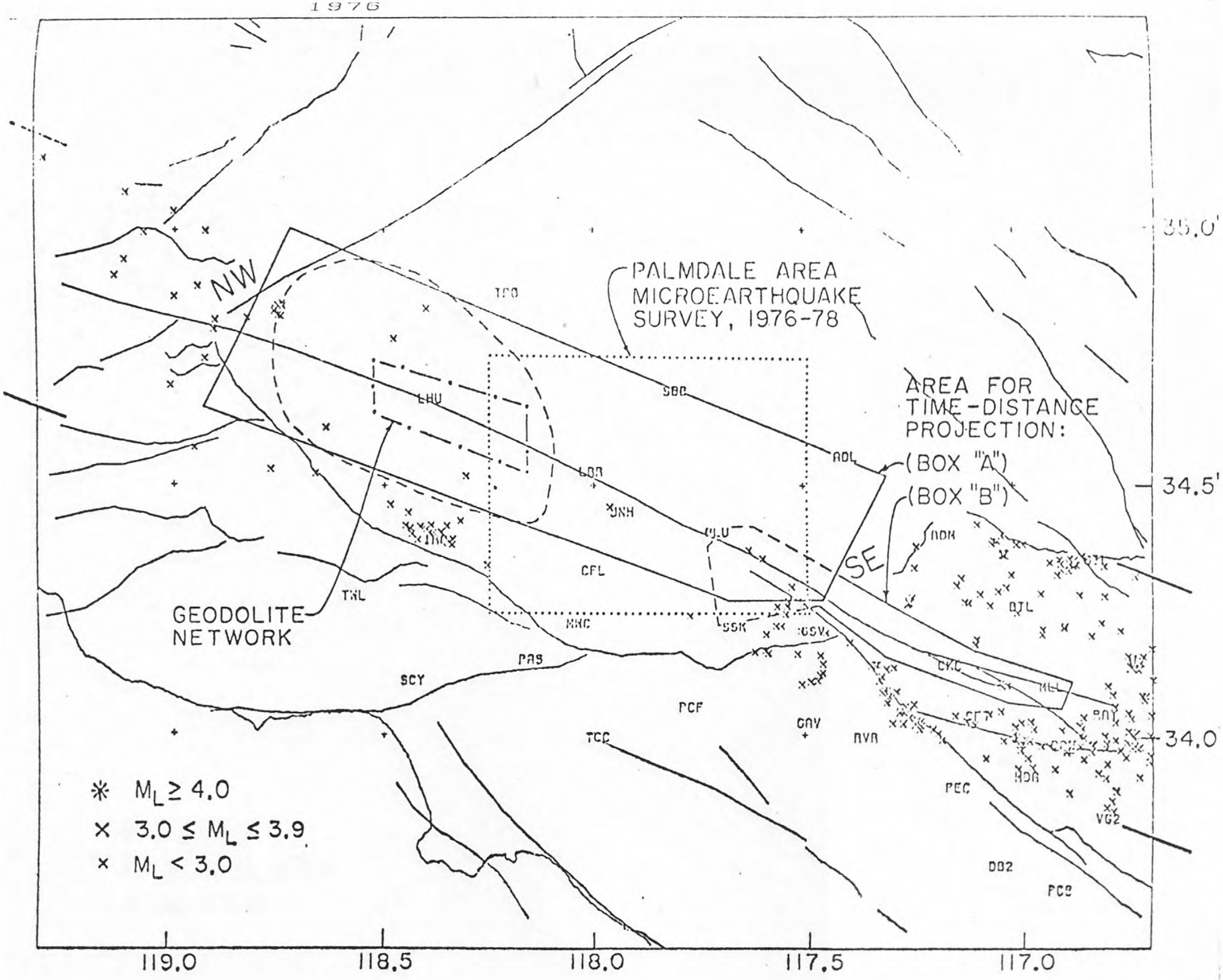
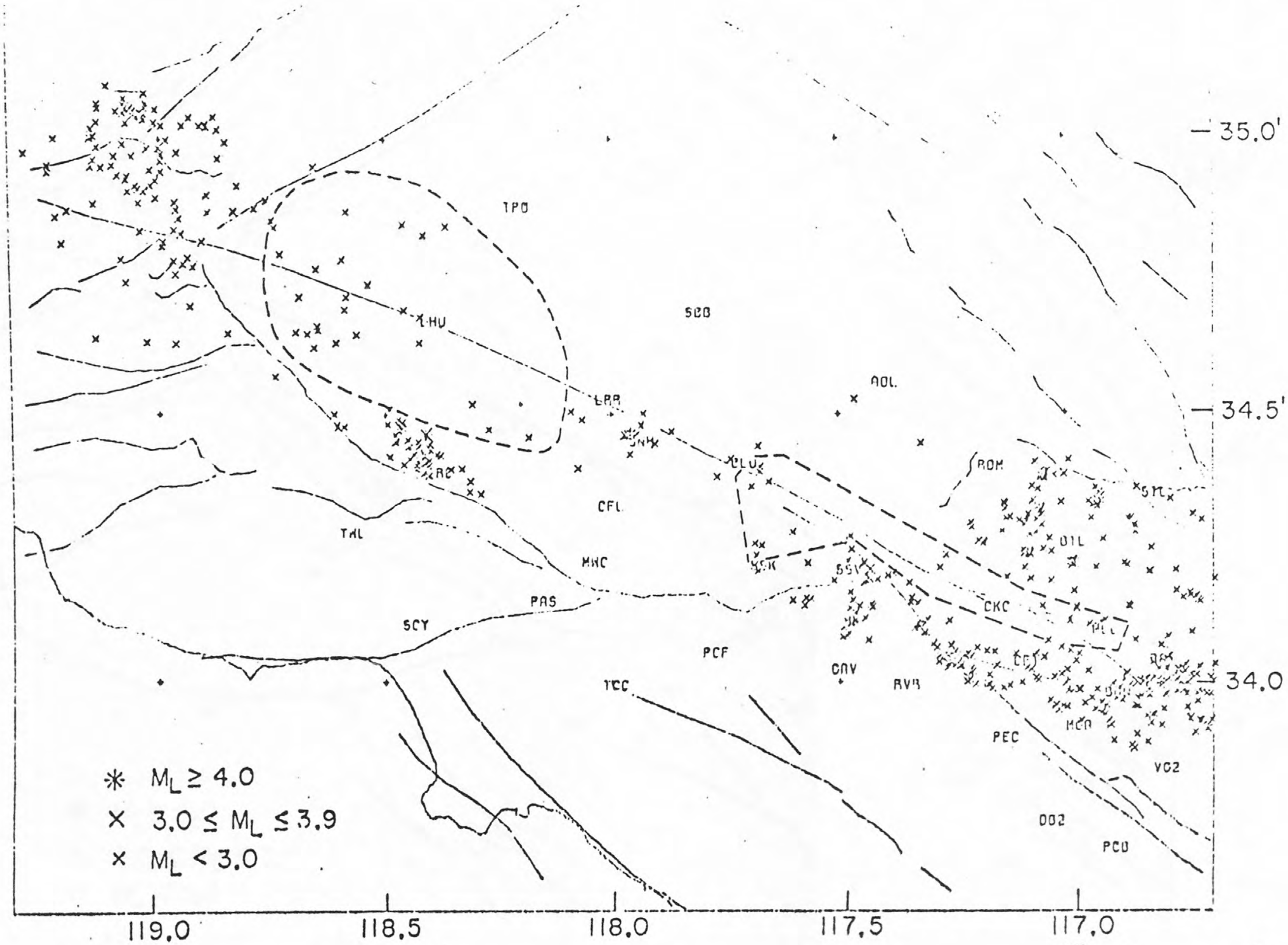

PALMDALE AREA
MICROEARTHQUAKE
SURVEY, 1976-78
AREA FOR
TIME-DISTANCE
PROJECTION:
(BOX "A")
(BOX "B")
NW
SE
GEODOLITE
NETWORK
35.0'
34.5'
34.0
119.0
118.5
118.0
117.5
117.0
$M_L \geq 4.0$
$3.0 \leq M_L \leq 3.9$
$M_L < 3.0$

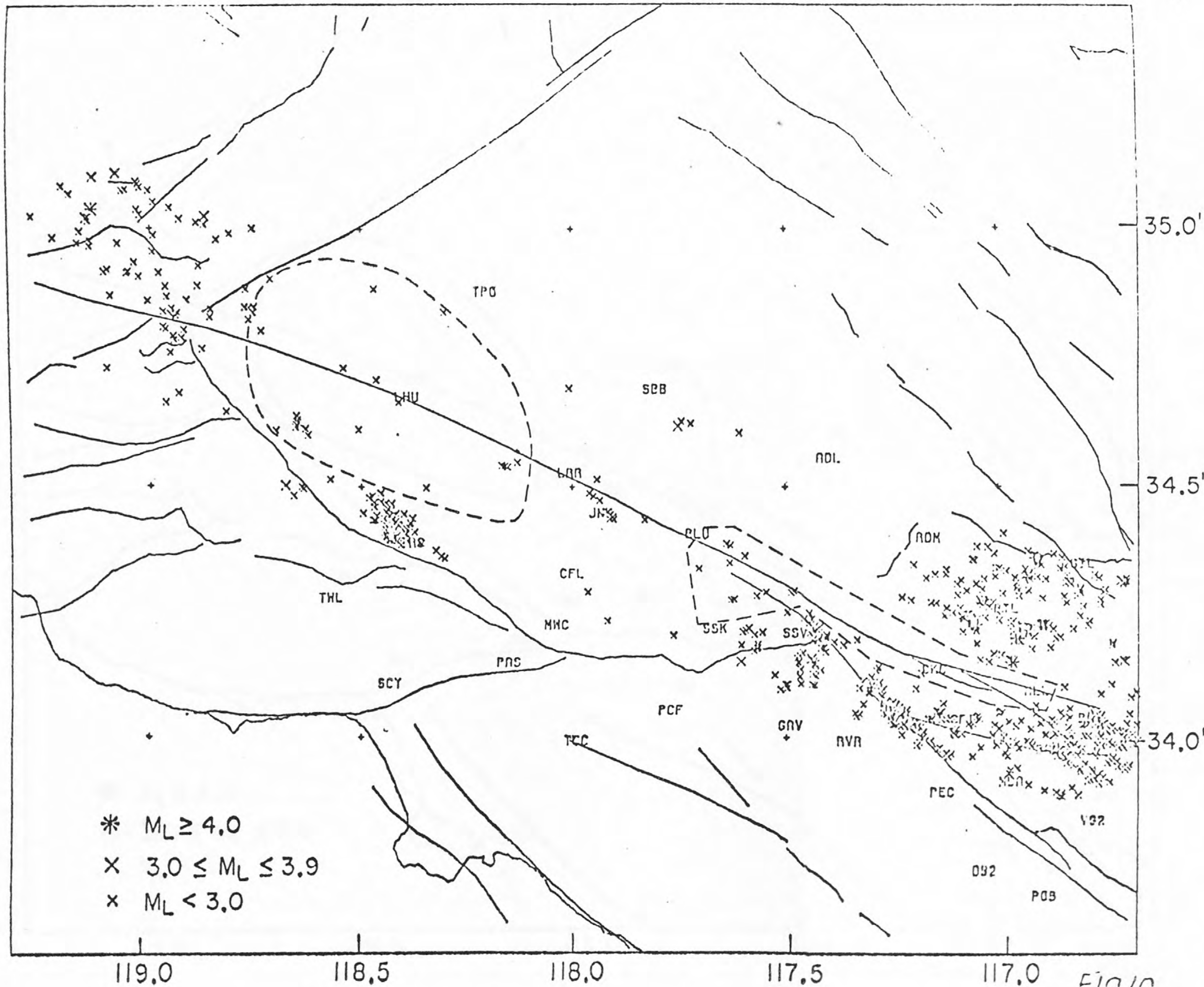
Fig 8



35.0'
34.5'
34.0
119.0
118.5
118.0
117.5
117.0
TPO
SCB
CHU
LRR
ADL
CLU
CFL
TAL
MWC
PAS
SCY
PCF
TCC
CRV
RVR
SSV
ROM
DTL
CKC
PEC
MCR
VGZ
DDZ
PCD
✳ $M_L \geq 4.0$
× $3.0 \leq M_L \leq 3.9$
× $M_L < 3.0$

Fig 9

1978



TPO
SBB
LHU
ADL
LOR
JNS
CLO
ADM
CFL
THL
MHC
SSK
SSV
PAS
SCY
PCF
GAV
RVR
TCC
PEC
VSR
OBZ
POB
35.0'
34.5'
34.0'
119.0
118.5
118.0
117.5
117.0
$M_L \geq 4.0$
$3.0 \leq M_L \leq 3.9$
$M_L < 3.0$

Fig 10

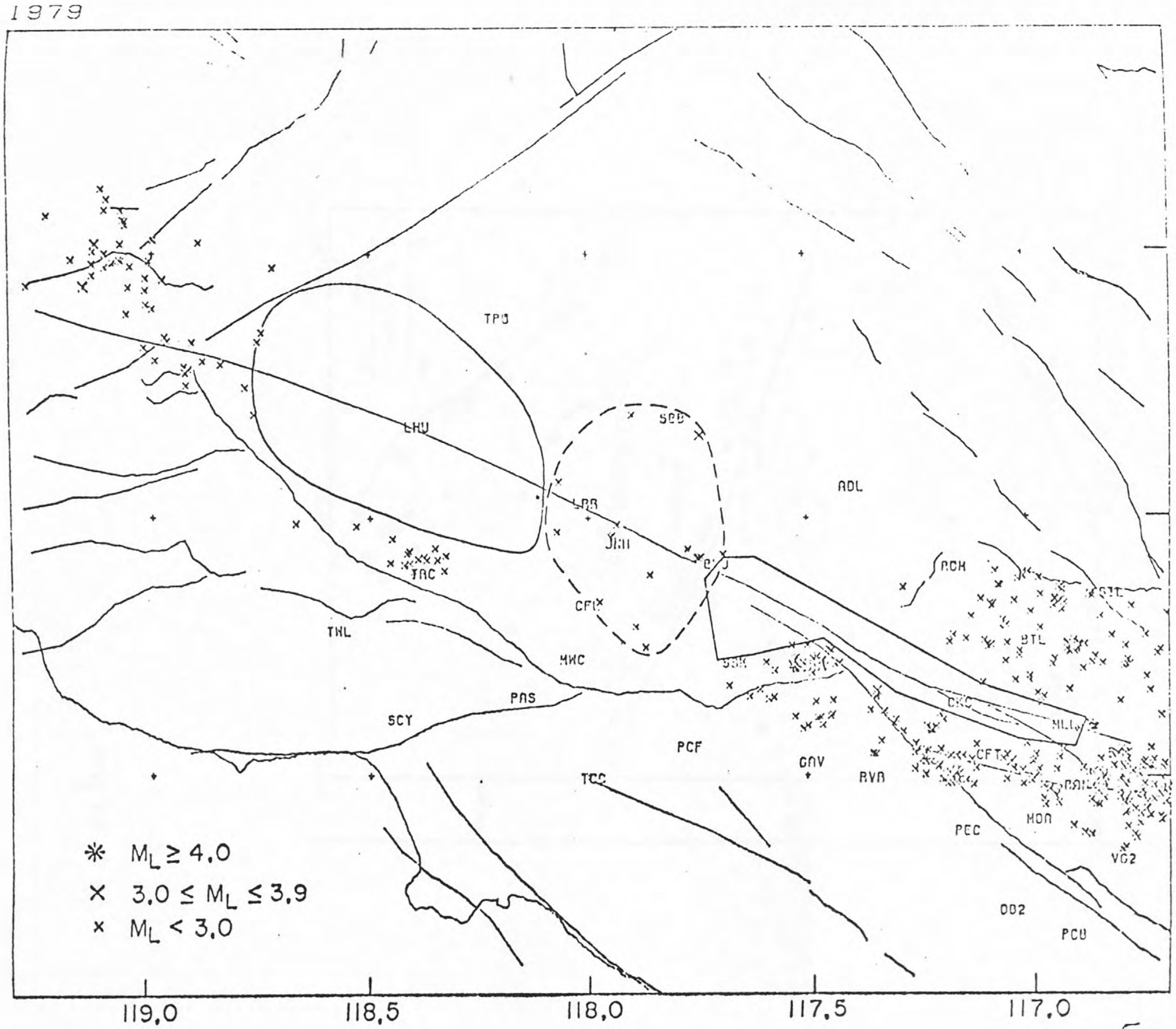

1979
35.0'
34.5'
34.0'
119.0
118.5
118.0
117.5
117.0
TPO
LHU
SCG
ADL
LRR
TRC
CFT
THL
MWC
PAS
SCY
PCF
GAV
RVR
TCC
RCH
BTL
CFT
PEC
MON
VG2
OB2
PCU
* $M_L \geq 4.0$
× $3.0 \leq M_L \leq 3.9$
× $M_L < 3.0$

Fig 11

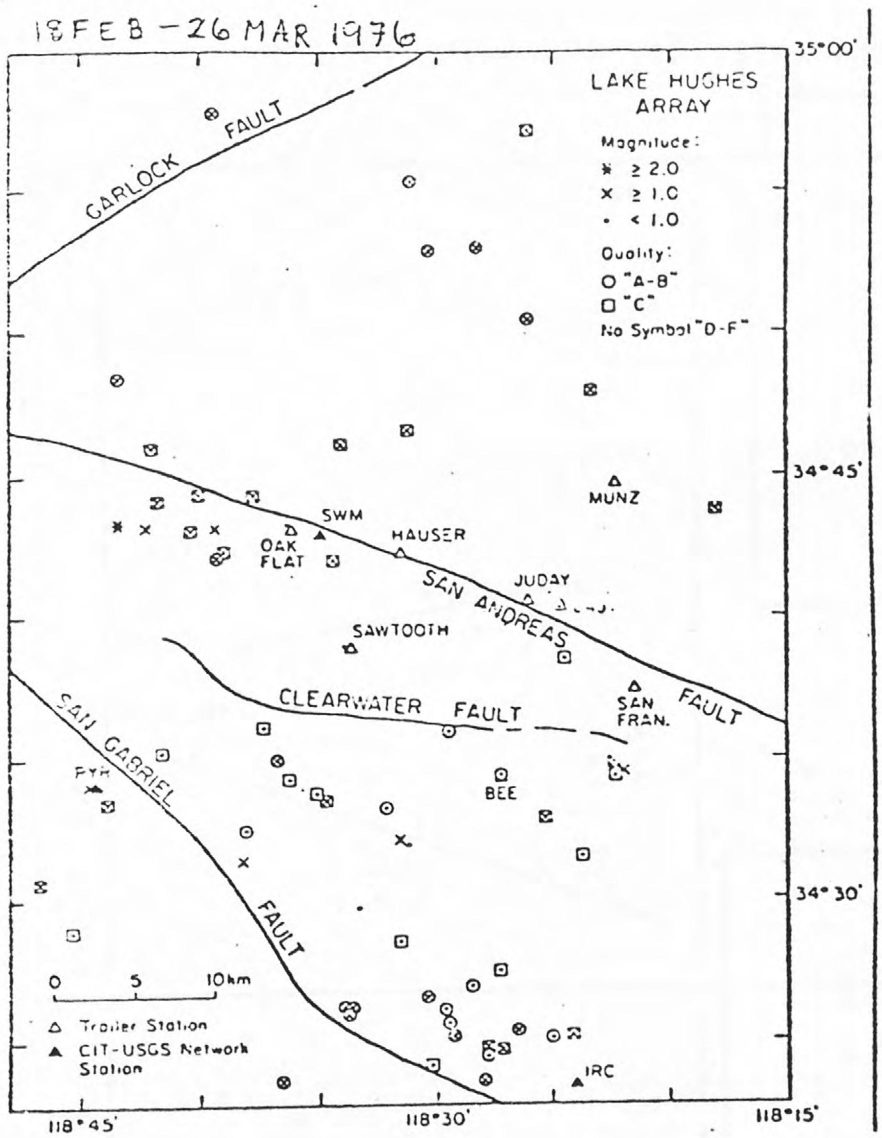

18 FEB - 26 MAR 1976
LAKE HUGHES
ARRAY
Magnitude:
* ≥ 2.0
× ≥ 1.0
· < 1.0
Quality:
O "A-B"
□ "C"
No Symbol "D-F"
GARLOCK FAULT
SAN ANDREAS FAULT
CLEARWATER FAULT
SAN GABRIEL FAULT
SWM
HAUSER
OAK FLAT
JUDAY
SAWTOOTH
MUNZ
SAN FRAN.
BEE
PYR
IRC
0 5 10km
Trailer Station
CIT-USGS Network Station
35°00'
34°45'
34°30'
118°45'
118°30'
118°15'

Fig 12

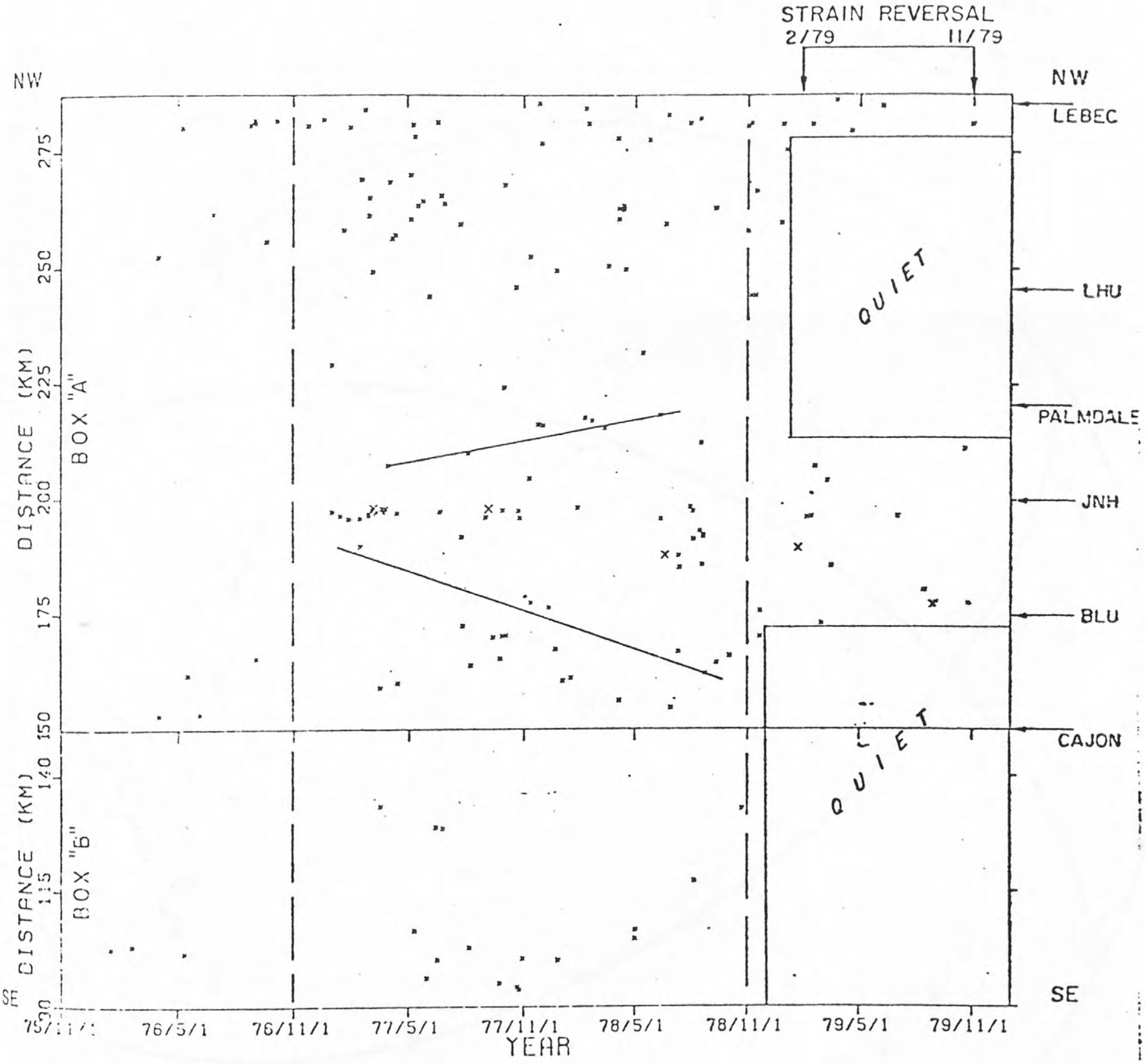

STRAIN REVERSAL
2/79
11/79
NW
NW
LEBEC
LHU
PALMDALE
JNH
BLU
CAJON
SE
SE
QUIET
QUIET
DISTANCE (KM)
BOX "A"
DISTANCE (KM)
BOX "B"
275
250
225
200
175
150
140
115
76/5/1
76/11/1
77/5/1
77/11/1
78/5/1
78/11/1
79/5/1
79/11/1
YEAR

Fig 13

Hadley / Kanamori Crustal Model
Azimuthally - Varying

34° 25.17' N
117° 44.78' W
Depth = 7.2
8/28/79; 8:57 GM
(Wrightwood)
$M_L = 3.6$

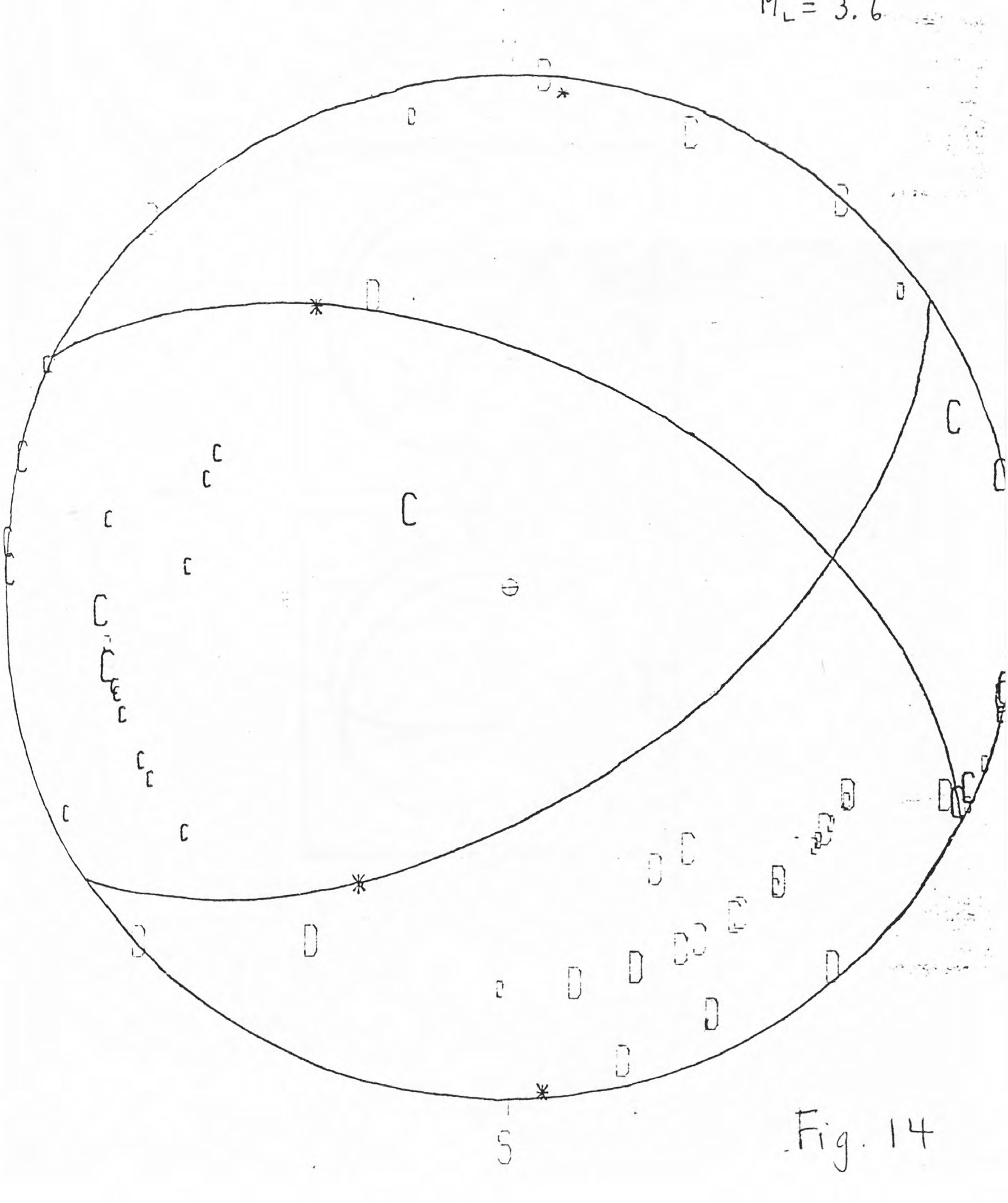


Fig. 14

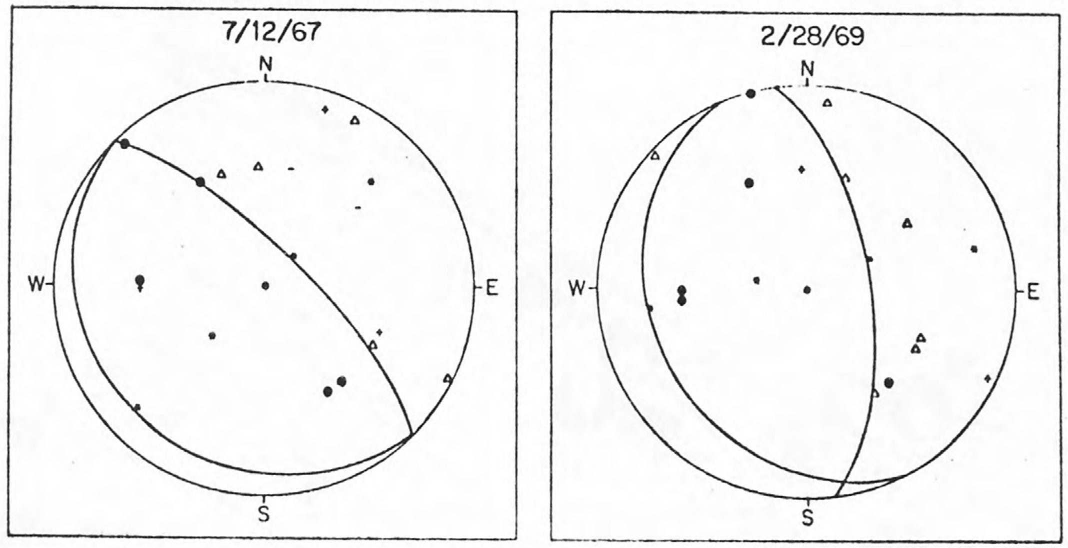
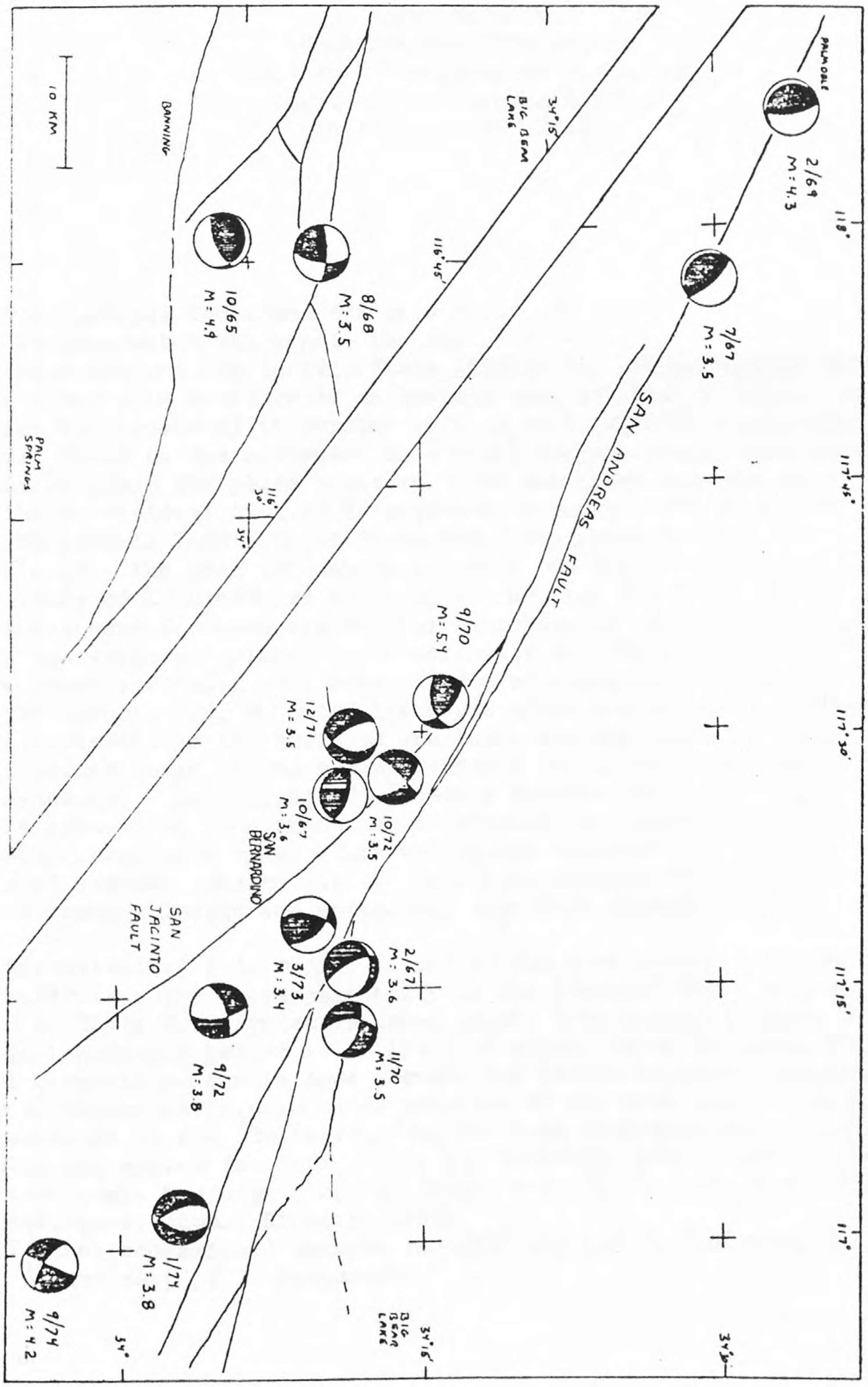


Fig. 15



10 KM
PALMDALE
BANNING
PALM SPRINGS
BIG BEAR LAKE
BIG BEAR LAKE
SAN ANDREAS FAULT
SAN JACINTO FAULT
SAN BERNARDINO
2/69 M: 4.3
7/67 M: 3.5
10/65 M: 4.9
8/68 M: 3.5
9/70 M: 5.4
12/71 M: 3.5
10/72 M: 3.5
10/67 M: 3.6
3/73 M: 3.4
2/67 M: 3.6
11/70 M: 3.5
9/72 M: 3.8
1/74 M: 3.8
9/74 M: 4.2
118°
117°45'
117°30'
117°15'
117°
116°45'
116°30'
34°
34°15'
34°30'

Fig. 16

McNally, K. C., 1980, 1979 Calexico earthquake: seismological data; Reconnaissance Report, Imperial County, California, Earthquake October 15, 1979, E.E.R.I., Berkeley, California, 194 pp.

1979 Calexico Earthquake: Seismological Data

Karen McNally
Seismological Laboratory
California Institute of Technology
Pasadena, California 91125

Contribution No. 3413

The Imperial fault and its seismicity are related to the San Andreas fault system, which represents the tectonic boundary between the North American Plate and the Pacific Plate (Figure 1). Right-lateral movement occurs along this boundary at an average rate of about 6 cm/yr. The Calexico earthquake of 15 October 1979 (M_L=6.6, M_S=6.8) broke along the Imperial fault to the northwest in a right lateral sense, consistent with the motion along the plate boundary. The mainshock and aftershock locations from the Provisional List of Earthquakes, October 1979, Seismological Laboratory, California Institute of Technology, are shown in Figure 2 and listed in Table 1*. The main aftershock activity and fault surface rupture (Figure 2, courtesy of K. Sieh) are confined to the area northwest of the mainshock. Two conspicuous features are the concentration of aftershocks extending beyond the surface rupture to the northwest and the paucity of aftershocks in the immediate epicentral area. Three aftershocks exceeded M_L=5 and occurred about 6 1/2, 7, and 7 1/2 hours after the mainshock. Two of these largest aftershocks lie north of the fault surface rupture. The first aftershock located north of the surface rupture ($M_L \geq 3$) occurred only 1h 45m after the mainshock. Clearly this discrepancy between the fault surface rupture length and the aftershock zone cannot be attributed to a gradual increase in the aftershock area with time. This earthquake sequence may represent a typical source of scatter inherent in the relations between aftershock area, fault surface rupture length and earthquake magnitude commonly used for design purposes.

Historically, this region is one of the most active for moderate earthquakes in California. The known seismicity of the Imperial fault region, $M_L \geq 6.0$, is listed in Table 2. Five earthquakes ($M_L \geq 6$) have occurred since 1906; the average recurrence period is 18 1/4 ± 17 years, based on these observations. Useful comparisons can be made between the recent Calexico earthquake and the Imperial Valley earthquake which occurred in the same area on 19 May 1940. The magnitude of the 1940 earthquake has been redetermined at M_L=6.4, using the same procedures for both events (J. Pechmann, pers. comm.). However, the 1940 earthquake had significantly larger rupture area and fault displacements (K. Sieh, pers. comm.; Richter, 1958).

Further comparisons between the 1940 and 1979 earthquakes are given in Table 3 (courtesy of J. Pechmann).

*These locations are preliminary at the time of writing; the Caltech-U.S. Geological Survey Preliminary Catalog should be consulted after April 1980.

Acknowledgment

This research was supported by U. S. Geological Survey contract number 14-08-0001-18322.

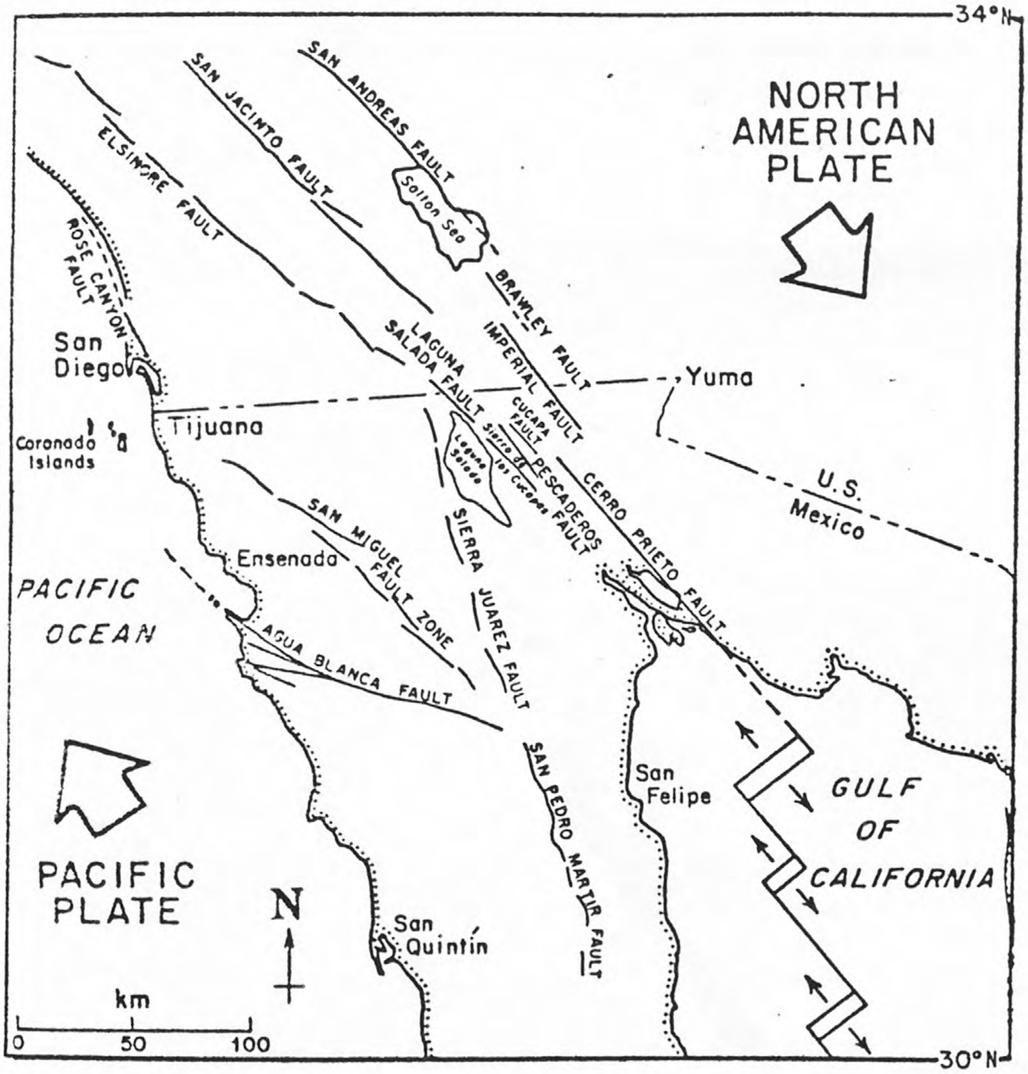


Figure 1. The major faults of southern California and northern Baja California. (After Brune, et al., 1979).

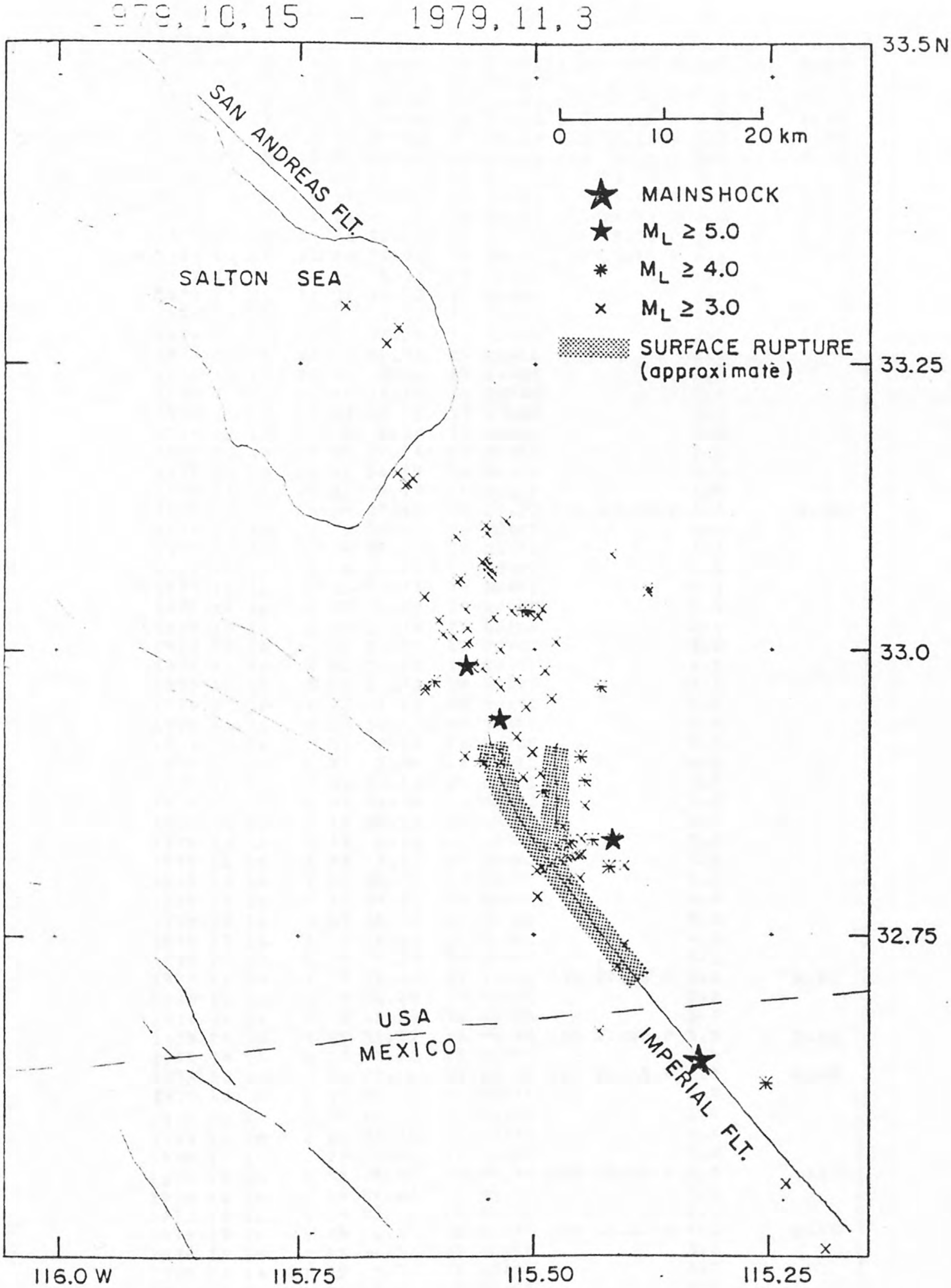


Figure 2. The 15 Oct. 1979 earthquake sequence.

Greater for October 1979

Seismological Laboratory

California Insitute of Technology

OCTOBER 1979

	1979	10	1	4	17	42.55	31	59.41	116	14.67	P	3.2	5.07
	1979	10	1	11	52	0.41	37	42.01	118	39.67	P	3.3	9.30
	1979	10	1	11	52	25.08	37	24.53	118	44.97	P	3.5	5.00
	1979	10	1	12	37	3.90	37	35.00	118	41.36	P	3.3	4.95
	1979	10	3	8	54	27.56	37	30.62	118	55.13	P	3.2	4.99
	1979	10	3	8	58	32.92	37	31.39	119	3.54	P	3.2	5.00
	1979	10	4	13	44	17.80	33	36.68	117	13.34	P	3.3	16.52
	1979	10	5	4	52	37.52	37	28.46	119	19.40	P	3.0	9.31
	1979	10	8	11	26	43.07	32	58.46	116	18.74	P	3.6	5.00
	1979	10	10	19	48	36.65	32	17.73	115	19.23	P	4.1	6.00
*	1979	10	15	23	16	55.09	32	38.37	115	19.68	P	6.6	5.88
	1979	10	15	23	26	1.93	IV	QUAKE *				4.1	
	1979	10	15	23	31	15.73	IV	QUAKE				3.5	
	1979	10	15	23	34	1.83	IV	QUAKE				3.2	
	1979	10	15	23	35	23.35	IV	QUAKE				3.5	
	1979	10	15	23	36	53.13	IV	QUAKE				3.5	
	1979	10	15	23	39	9.28	IV	QUAKE				3.3	
	1979	10	15	23	40	12.53	IV	QUAKE				3.4	
	1979	10	15	23	43	19.03	IV	QUAKE				3.4	
	1979	10	15	23	45	14.38	IV	QUAKE				3.6	
	1979	10	15	23	51	27.33	IV	QUAKE				3.6	
	1979	10	15	23	51	56.29	IV	QUAKE				3.5	
	1979	10	15	23	53	6.78	IV	QUAKE				3.8	
	1979	10	15	23	54	59.41	32	37.22	115	15.33	P	4.2	5.00
	1979	10	16	0	1	50.57	IV	QUAKE				3.5	
	1979	10	16	0	4	52.73	IV	QUAKE				3.1	
	1979	10	16	0	6	22.03	IV	QUAKE				3.6	
	1979	10	16	0	16	59.53	IV	QUAKE				3.3	
	1979	10	16	0	17	32.93	IV	QUAKE				3.4	
	1979	10	16	0	19	11.78	IV	QUAKE				3.1	
	1979	10	16	0	20	21.85	IV	QUAKE				3.5	
	1979	10	16	0	22	15.81	IV	QUAKE				4.1	
	1979	10	16	0	26	11.93	IV	QUAKE				3.1	
	1979	10	16	0	27	3.23	IV	QUAKE				3.4	
	1979	10	16	0	27	54.52	IV	QUAKE				3.8	
	1979	10	16	0	30	2.83	IV	QUAKE				3.5	
	1979	10	16	0	34	1.98	IV	QUAKE				3.2	
	1979	10	16	0	34	39.53	IV	QUAKE				3.0	
	1979	10	16	0	35	46.78	IV	QUAKE				3.2	
	1979	10	16	0	38	36.53	IV	QUAKE				3.5	
	1979	10	16	0	42	8.78	IV	QUAKE				3.1	
	1979	10	16	0	48	3.85	IV	QUAKE				3.2	
	1979	10	16	0	50	26.43	IV	QUAKE				3.8	
	1979	10	16	0	55	35.91	IV	QUAKE				3.4	
	1979	10	16	0	59	52.58	IV	QUAKE				3.6	
	1979	10	16	1	0	14.93	IV	QUAKE				4.7	
	1979	10	16	1	5	7.53	IV	QUAKE				3.1	
	1979	10	16	1	7	12.30	32	49.73	115	28.63	P	3.6	5.00
	1979	10	16	1	8	20.28	IV	QUAKE				3.2	
	1979	10	16	1	9	43.03	IV	QUAKE				3.0	
	1979	10	16	1	11	51.72	32	49.75	115	27.80	P	3.5	5.00
	1979	10	16	1	12	28.73	IV	QUAKE				3.6	
	1979	10	16	1	14	22.96	32	53.11	115	26.83	P	4.3	3.88
	1979	10	16	1	22	52.78	IV	QUAKE				3.0	
	1979	10	16	1	24	13.43	IV	QUAKE				3.3	
	1979	10	16	1	25	33.98	IV	QUAKE				3.4	
	1979	10	16	1	25	53.08	IV	QUAKE				3.8	
	1979	10	16	1	33	48.99	32	49.76	115	27.84	P	3.5	5.00
	1979	10	16	1	34	58.63	IV	QUAKE				3.2	
	1979	10	16	1	35	23.03	IV	QUAKE				3.3	
	1979	10	16	1	39	6.59	32	58.04	115	25.83	P	4.0	5.00
	1979	10	16	1	41	36.33	IV	QUAKE				3.0	
	1979	10	16	1	42	9.78	IV	QUAKE				3.1	
	1979	10	16	1	43	18.18	IV	QUAKE				3.1	
	1979	10	16	1	44	53.53	IV	QUAKE				3.1	
	1979	10	16	1	48	53.53	IV	QUAKE				3.3	
	1979	10	16	1	49	44.53	IV	QUAKE				3.4	
	1979	10	16	1	50	23.18	IV	QUAKE				3.6	
	1979	10	16	1	58	12.08	IV	QUAKE				3.5	
	1979	10	16	2	0	7.98	IV	QUAKE				3.2	

1979	10	16	2	10	19.50	32	48.65	115	24.33	P	3.8	5.00
1979	10	16	2	24	11.03	IV	QUAKE				3.1	
1979	10	16	2	26	14.23	IV	QUAKE				3.0	
1979	10	16	2	29	42.03	IV	QUAKE				3.2	
1979	10	16	2	36	35.77	IV	QUAKE				3.7	
1979	10	16	2	41	5.53	IV	QUAKE				3.2	
1979	10	16	2	42	23.53	IV	QUAKE				3.2	
1979	10	16	2	45	0.37	IV	QUAKE				3.1	
1979	10	16	2	47	36.50	IV	QUAKE				3.3	
1979	10	16	2	49	12.03	IV	QUAKE				3.2	
1979	10	16	2	51	49.03	IV	QUAKE				3.3	
1979	10	16	2	53	1.78	IV	QUAKE				3.1	
1979	10	16	3	1	57.75	32	47.99	115	27.11	P	3.0	5.00
1979	10	16	3	7	43.78	IV	QUAKE				3.4	
1979	10	16	3	9	44.86	32	49.24	115	27.02	P	3.5	5.00
1979	10	16	3	10	39.61	32	50.05	115	26.33	P	4.5	5.00
1979	10	16	3	13	10.42	32	50.08	115	27.05	P	3.5	5.00
1979	10	16	3	14	13.33	IV	QUAKE				3.5	
1979	10	16	3	15	18.53	IV	QUAKE				3.3	
1979	10	16	3	15	50.53	IV	QUAKE				3.5	
1979	10	16	3	16	27.47	32	49.95	115	25.12	P	4.1	5.00
1979	10	16	3	22	6.68	IV	QUAKE				3.1	
1979	10	16	3	27	47.52	IV	QUAKE				3.0	
1979	10	16	3	37	28.03	IV	QUAKE				3.1	
1979	10	16	3	39	34.65	32	59.15	115	34.00	P	4.5	8.29
1979	10	16	3	43	55.28	IV	QUAKE				3.5	
1979	10	16	3	46	14.22	IV	QUAKE				3.7	
1979	10	16	4	3	41.55	IV	QUAKE				3.8	
1979	10	16	4	16	5.18	IV	QUAKE				3.0	
1979	10	16	4	22	20.31	IV	QUAKE				3.4	
1979	10	16	4	25	29.58	IV	QUAKE				3.5	
1979	10	16	4	29	57.90	IV	QUAKE				3.6	
1979	10	16	4	32	33.93	32	51.78	115	26.81	P	3.8	4.96
1979	10	16	4	32	55.38	IV	QUAKE				3.8	
1979	10	16	4	40	11.48	IV	QUAKE				3.1	
1979	10	16	4	44	32.30	IV	QUAKE				3.8	
1979	10	16	4	59	24.18	IV	QUAKE				3.5	
1979	10	16	5	15	12.68	IV	QUAKE				3.3	
1979	10	16	5	16	15.16	32	49.61	115	29.41	P	3.5	5.00
1979	10	16	5	17	11.53	IV	QUAKE				3.4	
1979	10	16	5	18	3.62	32	58.89	115	29.33	P	3.5	5.00
1979	10	16	5	18	41.69	IV	QUAKE				3.5	
1979	10	16	5	23	1.84	32	49.07	115	27.86	P	3.2	5.00
1979	10	16	5	38	2.25	32	53.31	115	30.71	P	3.1	5.00
1979	10	16	5	41	17.74	32	48.55	115	29.54	P	3.0	5.03
1979	10	16	5	49	10.99	32	56.37	115	32.25	P	5.0	4.69
1979	10	16	5	52	52.48	IV	QUAKE				3.8	
1979	10	16	6	4	17.03	IV	QUAKE				3.1	
1979	10	16	6	4	40.98	IV	QUAKE				4.1	
1979	10	16	6	10	38.22	IV	QUAKE				3.5	
1979	10	16	6	12	1.98	IV	QUAKE				4.2	
1979	10	16	6	13	29.93	IV	QUAKE				4.2	
1979	10	16	6	17	33.78	IV	QUAKE				3.2	
1979	10	16	6	19	4.51	IV	QUAKE				3.6	
1979	10	16	6	19	50.41	IV	QUAKE				5.1	
1979	10	16	6	22	46.53	IV	QUAKE				3.6	
1979	10	16	6	25	9.38	IV	QUAKE				3.3	
1979	10	16	6	28	18.08	IV	QUAKE				3.4	
1979	10	16	6	29	32.13	IV	QUAKE				3.6	
1979	10	16	6	34	44.53	IV	QUAKE				3.4	
1979	10	16	6	35	43.03	IV	QUAKE				3.1	
1979	10	16	6	37	43.28	IV	QUAKE				3.0	
1979	10	16	6	38	57.03	IV	QUAKE				3.3	
1979	10	16	6	43	23.43	IV	QUAKE				3.5	
1979	10	16	6	44	8.53	IV	QUAKE				3.6	
1979	10	16	6	47	51.88	IV	QUAKE				3.3	
1979	10	16	6	54	7.33	IV	QUAKE				3.3	
1979	10	16	6	55	24.70	32	49.91	115	27.69	P	4.6	5.29
1979	10	16	6	58	43.25	32	59.14	115	34.39	P	5.8	4.23
1979	10	16	7	2	11.63	IV	QUAKE				3.8	
1979	10	16	7	3	33.78	IV	QUAKE				3.3	
1979	10	16	7	11	37.53	IV	QUAKE				3.2	
1979	10	16	7	13	27.93	IV	QUAKE				3.4	
1979	10	16	7	19	18.28	IV	QUAKE				3.0	
1979	10	16	7	20	20.28	IV	QUAKE				3.2	
1979	10	16	7	23	25.99	32	48.57	115	25.29	P	4.2	5.00
1979	10	16	7	26	17.91	IV	QUAKE				3.9	
1979	10	16	7	28	19.53	IV	QUAKE				3.7	
1979	10	16	7	35	3.19	32	48.78	115	28.89	P	3.5	5.72

1979	10	16	7	35	57.53	IV	QUAKE				3.2	
1979	10	16	7	36	49.46	IV	QUAKE				3.7	
1979	10	16	7	49	50.09	IV	QUAKE				4.0	
1979	10	16	7	58	47.77	IV	QUAKE				3.2	
1979	10	16	7	59		IV	QUAKE				3.4	
1979	10	16	8	1	35.33	IV	QUAKE				3.2	
1979	10	16	8	2	25.48	IV	QUAKE				3.0	
1979	10	16	8	3	6.15	32	39.92	115	25.91	P	3.1	5.00
1979	10	16	8	6	56.58	IV	QUAKE				3.0	
1979	10	16	8	9	43.12	32	57.41	115	28.89	P	3.5	5.00
1979	10	16	8	14	33.96	32	48.90	115	28.32	P	3.0	5.00
1979	10	16	8	37	54.28	32	49.18	115	27.19	P	3.4	5.00
1979	10	16	9	23	21.81	32	55.40	115	31.12	P	3.9	4.62
1979	10	16	9	33	53.30	32	58.02	115	32.16	P	3.6	5.36
1979	10	16	9	36	42.95	32	54.36	115	27.07	P	4.0	3.57
1979	10	16	9	49	22.73	IV	QUAKE				3.0	
1979	10	16	9	57	4.76	32	48.40	115	29.80	P	3.2	5.00
1979	10	16	10	11	54.88	32	58.33	115	32.53	P	3.8	5.00
1979	10	16	10	30	1.91	32	49.21	115	27.37	P	3.6	5.00
1979	10	16	10	34	38.51	32	58.43	115	31.14	P	3.7	5.00
1979	10	16	10	35	46.70	IV	QUAKE				3.7	
1979	10	16	10	37	18.98	IV	QUAKE				3.2	
1979	10	16	10	51	27.82	32	56.28	115	32.72	P	4.0	4.67
1979	10	16	10	53	56.73	IV	QUAKE				3.0	
1979	10	16	10	57	51.68	IV	QUAKE				3.1	
1979	10	16	11	9	43.03	IV	QUAKE				3.3	
1979	10	16	11	11	41.28	IV	QUAKE				3.3	
1979	10	16	11	15	56.96	33	2.76	115	36.99	P	3.5	4.99
1979	10	16	11	19	12.68	33	0.39	115	34.15	P	3.8	5.00
1979	10	16	11	26	48.09	IV	QUAKE				4.0	
1979	10	16	11	46	56.15	32	54.16	115	33.44	P	4.8	5.04
1979	10	16	11	55	22.03	IV	QUAKE				3.2	
1979	10	16	11	56	21.53	IV	QUAKE				3.5	
1979	10	16	12	1	45.69	32	52.54	115	29.47	P	4.0	5.21
1979	10	16	12	6	10.88	IV	QUAKE				3.2	
1979	10	16	12	9	35.98	IV	QUAKE				3.4	
1979	10	16	12	10		IV	QUAKE				3.3	
1979	10	16	12	12	7.38	IV	QUAKE				3.6	
1979	10	16	12	25	47.40	32	59.01	115	33.33	P	3.4	5.00
1979	10	16	12	49	5.66	33	0.69	115	35.16	P	3.3	5.00
1979	10	16	12	54	16.24	32	50.70	115	28.22	P	3.1	5.00
1979	10	16	12	58	0.54	33	4.99	115	25.18	P	3.8	5.00
1979	10	16	13	14	57.48	32	47.89	115	27.87	P	3.0	5.00
1979	10	16	13	30	22.25	IV	QUAKE				3.0	
1979	10	16	13	33	32.95	33	4.00	115	32.98	P	3.2	5.00
1979	10	16	14	8	32.39	33	1.66	115	32.64	P	3.1	5.09
1979	10	16	14	20	7.73	33	0.31	115	34.34	P	3.3	5.00
1979	10	16	15	0	2.39	33	2.04	115	30.76	P	4.0	5.00
1979	10	16	15	5	41.11	33	4.60	115	33.34	P	3.4	4.92
1979	10	16	15	9	5.03	32	55.97	115	30.50	P	3.2	5.38
1979	10	16	15	13	14.90	32	49.98	115	25.23	P	3.1	5.89
1979	10	16	15	16	1.45	33	1.53	115	36.09	P	3.3	5.91
1979	10	16	16	37	16.59	33	0.79	115	35.80	P	3.4	5.09
1979	10	16	17	22	55.40	32	59.99	115	32.19	P	3.7	5.47
1979	10	16	19	7	56.13	33	3.53	115	34.91	P	3.3	5.00
1979	10	16	20	19	49.53	IV	QUAKE				3.0	
1979	10	16	21	48	43.60	33	3.71	115	34.73	P	3.9	5.00
1979	10	16	22	32	22.23	33	5.93	115	35.02	P	3.4	5.00
1979	10	16	22	33	57.30	IV	QUAKE				3.1	
1979	10	16	23	12	36.59	32	4.32	115	31.94	P	3.4	1.78
1979	10	16	23	16	32.20	33	4.46	115	33.26	P	4.9	5.00
1979	10	16	23	21	38.79	IV	QUAKE				3.4	
1979	10	16	23	22	3.86	IV	QUAKE				3.3	
1979	10	16	23	23	52.38	32	49.12	115	27.64	P	3.3	5.00
1979	10	16	23	58	53.50	IV	QUAKE				3.3	
1979	10	17	0	1	0.78	33	0.39	115	28.66	P	3.3	5.00
1979	10	17	0	6	22.10	33	3.80	115	32.75	P	3.3	6.29
1979	10	17	0	14	55.04	33	4.09	115	32.70	P	3.2	6.15
1979	10	17	0	15	17.22	32	47.00	115	29.76	P	3.2	5.71
1979	10	17	0	28	50.03	IV	QUAKE				3.2	
1979	10	17	0	31	14.68	33	6.12	115	33.08	P	3.5	5.02
1979	10	17	1	29	49.72	33	18.00	115	42.14	P	3.2	5.09
1979	10	17	2	13	17.89	33	16.06	115	39.47	P	3.3	5.01
1979	10	17	2	28	18.80	33	4.77	115	33.16	P	3.5	5.91
1979	10	17	2	29	14.23	IV	QUAKE				3.2	
1979	10	17	6	14	2.20	33	4.31	115	33.04	P	3.6	5.62
1979	10	17	7	1	45.87	33	6.76	115	31.84	P	3.0	5.59
1979	10	17	8	27	20.22	33	3.02	115	22.88	P	3.1	5.00
1979	10	17	8	38	51.81	33	3.23	115	22.88	P	3.4	6.04
1979	10	17	9	17	22.75	33	9.28	115	38.76	P	3.4	5.86

1979	10	17	16	0	2.60	32	28.57	115	11.66	P 3.7	5.41
1979	10	17	16	9	5.49	32	31.99	115	14.11	P 3.1	5.40
1979	10	17	16	17	35.42	33	1.13	115	34.26	P 3.3	6.21
1979	10	17	19	3	3.29	33	6.51	115	33.16	P 3.4	4.96
1979	10	17	19	14	37.96	32	58.32	115	36.36	P 4.2	4.69
1979	10	17	20	52	37.18	33	54.61	118	40.59	P 4.2	5.52
1979	10	17	22	45	34.12	33	2.01	115	30.39	P 4.6	5.00
1979	10	17	22	50	31.98	33	2.14	115	29.54	P 3.2	5.02
1979	10	17	22	54	20.49	33	2.02	115	31.47	P 3.4	3.82
1979	10	17	23	27	31.11	33	1.77	115	29.79	P 3.2	4.34
1979	10	17	23	35	26.35	32	24.75	115	11.83	P 3.2	4.93
1979	10	18	0	29	47.93	33	8.71	115	38.10	P 3.3	4.66
1979	10	18	2	14	48.42	33	8.65	115	38.26	P 3.1	4.91
1979	10	18	3	17	16.71	32	54.42	115	34.39	P 3.5	4.76
1979	10	18	4	25	43.14	33	55.89	118	39.83	P 3.3	5.93
1979	10	18	4	40	55.48	33	9.30	115	37.76	P 3.0	4.95
1979	10	18	12	1	9.72	32	58.12	115	36.91	P 3.5	9.25
1979	10	18	13	20	25.86	32	53.48	115	29.61	P 3.2	5.09
1979	10	18	14	56	19.91	31	1.73	115	29.65	P 3.3	4.23
1979	10	18	19	18	57.88	32	57.88	115	36.93	P 3.2	14.53
1979	10	19	10	35	8.79	32	54.06	115	33.22	P 3.2	15.14
1979	10	19	12	22	37.67	34	13.00	117	31.17	P 4.1	4.87
1979	10	19	19	42	36.30	32	24.42	115	13.44	P 3.5	4.99
1979	10	20	5	4	7.70	32	54.68	115	32.25	P 3.3	16.02
1979	10	20	7	25	23.57	32	26.54	115	12.82	P 3.1	5.00
1979	10	20	8	46	42.50	32	3.06	116	20.88	P 3.1	4.91
1979	10	20	11	35	33.10	32	44.45	115	24.35	P 3.0	16.79
1979	10	20	13	36	23.56	33	2.10	115	34.40	P 3.2	11.87
1979	10	21	18	17	58.52	32	54.62	115	30.11	P 3.4	5.05
1979	10	21	20	27	40.59	32	23.01	115	10.39	P 3.1	5.00
1979	10	23	1	13	13.40	32	54.07	115	32.14	P 3.1	14.51
1979	10	23	23	33	13.46	33	16.86	115	38.58	P 3.1	4.28
1979	10	24	6	44	27.15	32	25.09	115	13.22	P 3.2	4.98
1979	10	24	13	32	49.58	34	11.53	116	25.80	P 3.5	1.68
1979	10	31	11	43	46.42	32	43.34	115	24.79	P 3.4	17.36

Magnitude and origin time was computed for those Imperial Valley which have not yet been located by assuming coordinates of 32°50 N' and 115°25' W.

* The mainshock location has been redetermined as: 32°38.62'N 115° 18.72'W h = 9.87 km (Peter German, pers. Comm.) based on a crustal velocity model from Mooney & Healy (pers. Comm.) and all available data from California and Mexico.

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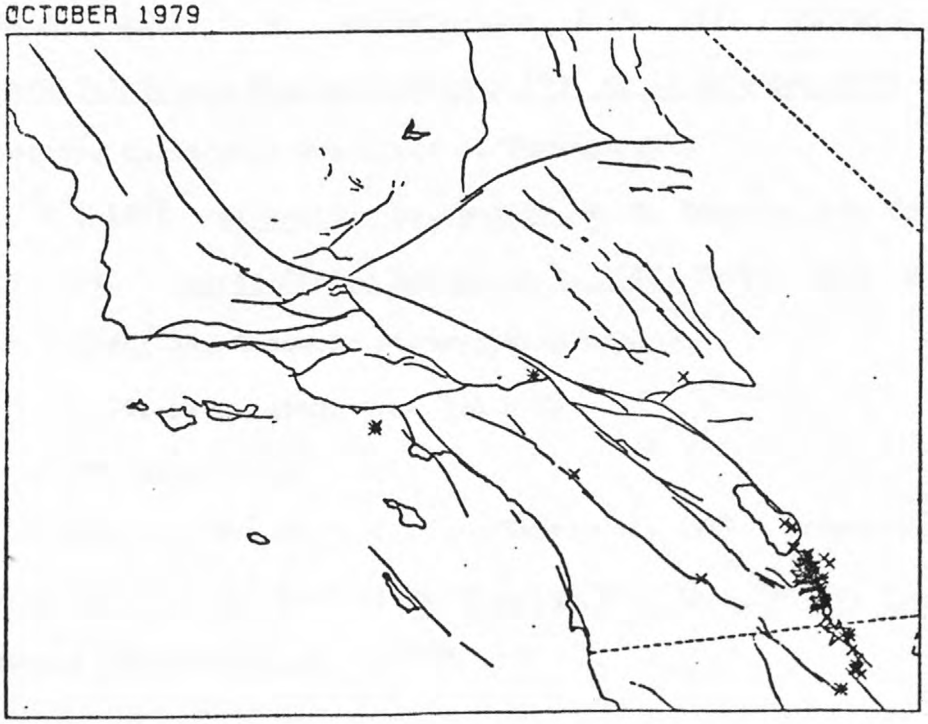

Table 2. Seismicity of the Imperial Fault Region, $M_L \geq 6.0$

	GMT				I max (MM)	Felt area ($x10^3 km^2$)	Source
1852 29 Nov.	20:00	32.5	115.0	M = 6.5	9		1
1906 19 Apr.	00:30	32.5	115.5	M = 6.0	8	100	2
1915 23 Jun.	03:59	32.8	115.5	M = 6.3	8	200	2
1915 23 Jun.	04:56	32.8	115.5	M = 6.3	8	200	2
(1927 1 Jan.	08:16:45	32.5	115.5	M = 5.8	8	130	2)
1940 19 May	04:36:40.9	32.733	115.50	M_L = 6.4	10	155	3,4,5,6
				M_s = 7.1			
1979 15 Oct.	23:16:54.3	32.644	115.312	M_L = 6.6			6,7
				M_s = 6.8			

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Table 3. Imperial Valley Earthquakes, 1940 and 1979 Comparisons

		5/18/40	10/15/79
Based on amplitude of 0.1-1.0-sec waves	Local Magnitude (M_L) (best estimate)	6.4±.2	6.6±.3
	M_L at Pasadena	6.2±.1	6.7±.2
	M_L at Tinemaha	6.4±.1	6.7±.1
20-sec. waves	Surface Wave Magnitude (M_s)	7.1	6.8
very long period waves	Seismic Moment (M_o) ($\mu S \bar{d}$)	5.6×10^{26} dyne-cm	6×10^{25} dyne-cm
	Maximum Accelerations at El Centro	0.22g vertical 0.36g horizontal	0.38g vertical 0.40g horizonta
	Duration of strong shaking (>0.1g) at El Centro	∿20 sec.	∿7 sec.
	Length of Surface Rupture	60 km	30 km
	Max. ∿ Coseismic Surface Displacement	5.8 m	0.5 m
	Avg. ∿ Coseismic Surface Displacement	1.25 m	0.21 m
	Avg. Displacement at Depth	2.3 m	0.4 m
	Rupture Mode	Bilateral	North Unilateral
	Number of Aftershocks $M_L \geq 5.0$	4	3
	Deaths	9	0
	Property Loss (Including damage to buildings, canals, and crops) and crops)	5-6 million $	30 million $

Table 3. Imperial Valley Earthquake Comparisons Data Sources

	5/18/40	10/15/79
Local Magnitude (M_L) (best estimate)	Mean magnitude from 6 torsion records (3 stations, 2 components each) on file at Caltech, and the 2 horizontal El Centro accelerograph records. (Kanamori & Jennings, 1978) ± is one standard deviation.	Mean magnitude from 10 torsion records (5 stations, 2 components each). ± is one standard deviation. Measurements by L. K. Hutton, Caltech.
M_L at Pasadena	Redetermined from original 2800X torsion records on file at Caltech. Error bars reflect variation between the NS and EW components.	Determined by L. K. Hutton from 100X torsion records. Error bars reflect the variation between the NS and EW components.
M_L at Tinemaha	Same as for M_L at Pasadena	Lower limit on magnitude estimated from 2800X torsion records, which are off scale. Error bars reflect variation between NS and EW records.
Surface Wave Magnitude (M_s)	From Richter (1958). Also from unpublished worksheets by B.Gutenberg & C. Richter, referenced in Kanamori and Jennings (1978).	From John Minsch, U.S. Geological Survey, Golden, Colorado. 11/7/79 Preliminary result.
Seismic Moment (M_o)	Estimated by Kanamori and Anderson (1975) from surface displacements and geodetic data, M_o was not determined seismologically for this event.	Determined by Hiroo Kanamori, Caltech, from Pasadena and Berkeley ultra-long period seismograph records.
Maximum Accelerations at El Centro	From Neumann (1942)	From Ron Porcella, U.S.Geological Survey, Menlo Park, Calif.
Duration of strong shaking (>0.1g) at El Centro	Ron Porcella, U. S. Geological Survey, Menlo Park, California. (Rough estimate).	
Length of Surface Rupture Max.∿Coseismic Surface Displacement	Richter (1958)	Kerry Sieh, Caltech
Avg.∿Coseismic Surface Displacement	Determined by Brune and Allen (1967) from Buwalda's unpublished field notes.	Determined from measurements supplied by Kerry Sieh,Caltech

Average Displacement at Depth	Calculated by Byerly and De-Noyer (1958) from geodetic observations.	Calculated from M_o. Assumes $\mu = 3x10^{11}$ cgs, fault depth = 12 km, fault length = 40 km.
Rupture Mode	Follows from the location of the epicenter near the center of the zone of surface rupture. However, displacements were much greater south of the epicenter (Richter, 1956).	Follows from the location of the Caltech-U.S.G.S. epicenter several km south of the beginning of the surface rupture.
Number of Aftershocks $M_L \geq 5.0$	Hileman et al. (1973).	From L. K. Hutton (Caltech) and Carl Johnson (U.S.G.S.).
Deaths	Richter (1958).	L. A. Times
Property Loss	Richter (1958).	Leivas et al., Effect of Imperial Valley Earthquake, California, Geology, in press.

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The Responsibility of Scientists

Karen C. McNally

(Presented to the Conference on
Earthquake Prediction Information,
Los Angeles, 29 Jan 1980)

"In a recent number of *Science*, Dr. H. Landsberg stated quite correctly that in the present state of knowledge reliable earthquake prediction is impossible; and he went on to mention briefly some of the lines of research which have been suggested as prerequisite to any competent prediction."

"To have any useful meaning the prediction of an earthquake must indicate accurately, *within narrow limits*, the region or district where and the time when it will occur—and, unless otherwise specified, it must refer to a shock of important size and strength."

"On the other hand, generalized forecasting of the occurrence of shocks in regions known to be seismically active is entirely possible, but this is not earthquake prediction in the proper sense. The exact, or even approximate, time, place and magnitude can not be stated; only that shocks will occur and that some will be strong, so that proper safeguards should be set up to minimize the risk incurred from them."

"Earthquake prediction has two aspects, one relating to the development of seismologic science and one relating to public welfare. With respect to the latter, unless and until such prediction can be reduced to a very precise procedure, giving place, time and magnitude reliably and almost infallibly, the public announcement of a prediction is likely to be harmful and mischievous, causing unwarranted worry and apprehension among large numbers of the population. On the other hand, even only approximately successful forecasting of earthquake occurrence on a rational basis, or even only empirically, would be an important forward step in seismology, for it would mean the attainment of a better understanding of the action of the forces which produce earthquakes. Such prediction or forecasting should not be made public in the press, however, but simply notified to proper scientific groups who would subject it to test as to its realization and rational method, to determine its value."

"In the very strictest sense we do not know what causes earthquakes. Again in a very strict sense we do not know whether the rock strain is developed suddenly or slowly, but once more the evidence is very strong that in most cases it is of slow growth. However, it is possible that such strain could be of rapid growth due to sudden changes. Such a possibility must be kept in mind."

"Any moderately successful method of prediction for scientific testing will be welcomed by all seismologists, but public prediction in the present state of knowledge is nothing short of a menace. Generalized forecasting, on the other hand, is not a menace but is a duty which informed men of science owe to the population of seismically active lands."

This article by Harry O. Wood and B. Gutenberg, was published in *Science* 6 September 1935.

Things have changed since that time. In 1976, Clarence Allen wrote: "Most of us, as scientists, are not comfortable working in the public eye and under the intense scrutiny of the news media; certainly this is not the deliberative science to which we are accustomed. Nevertheless, if we are to claim that earthquake predictions will have significant social benefits—which I am firmly convinced is the case—and if we are to use this as an argument for taxpayer support of our research, then we must necessarily be willing to interface with the public and with public agencies in ways quite different from those we have been accustomed to in the past. Somehow we must find ways of doing this that are both scientifically honest and fair, and at the same time socially responsible."

My own views are well reflected by this address of Clarence Allen to the Seismological Society of America in 1976. In fact, in preparing this talk, I found that Clarence had made many of the points I planned to discuss. I won't repeat his eloquence, but rather refer you to his article of December, 1976, BSSA.

With this latter perspective The Seismological laboratory at Caltech has expanded their policy of public responsiveness to include an openness about ongoing research for earthquake prediction. This research is difficult—for decades seismologists have studied this problem-, but challenging. With new data and computer technology we are encouraged to new levels of investigation. As scientists, our driving force is to solve the unsolved problems. We prefer to work quietly, among the community of scientists, however. The public, on the other hand, has a justifiable personal interest in the consequences of our research, and we are prodded to recognize our social responsibility. At Caltech we live at the "center of concern for earthquakes" of the vast Los Angeles population. We respond to hundreds of inquiries weekly.

Despite these pressures, the primary responsibility of scientists is to produce excellent science, science that will stand the test of time. It is no favor to the public if we jump to prediction before the fundamentals are well thought out. Thus, a delicate balance must be found between the time needed to respond to public interest, and the time for thoughtful science.

Let me return to the statements of Clarence Allen:
"A valid earthquake prediction should ideally have six attributes:
1. It must specify a time window.
2. It must specify a space window.
3. It must specify a magnitude window.
4. It must give some sort of indication of the author's confidence in the reliability of the prediction.
5. It must give some sort of indication of the chances of the earthquake occurring anyway, as a random event.
6. It must be written and presented in some accessible form so that data on failures are as easily obtained as data on successes."

This is a fairly concrete scenario, and it allows for the planning by society for earthquake prediction response. The subject I would like to discuss today is the "incomplete predictions or forecasts" for which there are no current review channels. We are now in a research stage for earthquake prediction, and may commonly find cases of "partial evidence" which lead us to expect either the place and/or the magnitude, rarely the time, and never the percentage probability of the forecast. This stage of research is necessary toward the ultimate goal of prediction, but also of uncertain, though probably extended, duration. In parallel the increasing awareness of public agencies and the press leads to numerous requests for information on "new developments". If our research is conducted in secrecy the public will wonder what we are trying to hide.

Confronted with this dilemma our tendency as scientists seems to be toward truthful but ambiguous language: "forecast" instead of prediction, "special study area", "earth changes", etc. This is understandable, but the public may feel helpless in knowing how to react. An example is provided by the conversation of 2 neighbors to the very responsible article in this weekend's Los Angeles Times: "I read the article - it was scary..." "Do you think Karen can tell us if there will be an earthquake?" "No, they don't know what's happening..." (with discouragement). Similarly, a group of engineers from Alaska: "What does the special study area mean? What should we do?" A disastrous consequence to a scientifically ambiguous "forecast" occurred in Mexico, in 1978, when odds-makers and a prophet supplied the unambiguous missing link: the date of the earthquake forecast. This non scientific statement received broad credibility due to the supporting evidence regarding place and magnitude by responsible scientists. Approximately 20% of the inhabitants left their homes and family dwellings were sold cheaply. Government officials had to take extraordinary measures to calm the fears augmented by the press coverage. This incident greatly complicated the research efforts of both Mexican and U.S. scientists. This lesson is relevant in that a similar situation could occur in the U.S., and because our research increasingly extends across international boundaries to acquire more data.

The merit of our "incomplete predictions" in the public eye is that - hopefully - the public will become aware of the scientists efforts as we try to solve the problems, and perhaps become educated to receive a trial stage of predictions without panic. Yet we have to admit that a "gap" (if you'll excuse the term) exists, and will exist for some time, until predictions are made.

I propose that a team of scientists be formed at the national level for the purpose of reviewing the "incomplete predictions" that fail to meet the criteria for formal predictions. This team could provide constructive review and recommendations for further studies needed. Furthermore it could overview and integrate the relevant, but diverse, studies from the many independent investigators. And finally, it could help develop guidelines or general criteria for interpreting the information to the public. Specific suggestions for public "self help" appropriate to the "level of concern" could be issued. The composition of this group should be experienced fellow scientists who are independent from funding agencies in order to encourage research review without a fear of jeopardizing research support or scientific reputation, which would defeat the goal of progress in earthquake prediction research. I suggest that this is a second responsibility of scientists, appropriate at this time.

The third and final responsibility I will suggest today is shared by the public, the press, and the scientists. This is the responsibility for a genuine reciprocal interest and mutual respect. There are lengthy discussions of the scientists' responsibility to the public, but less often the converse.

Particularly the public representatives and press should take time to listen to what we are doing and visit our laboratories, not just when the news headlines are burning! This background effort will be more than justified when we need to communicate with and help, each other in time of crisis. The "extra efforts" must be mutual in order to maintain a positive attitude toward social responsibility.

Acknowledgment

This work was supported by U. S. Geological Survey Grants No. 14-08-0001-18371, 14-08-0001-18331, and 14-08-0001-18322. Contribution No. 3424 Division of Geological and Planetary Sciences, California Institute of Technology, Pasadena, California 91125.

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THE STATUS OF EARTHQUAKE HAZARD REDUCTION

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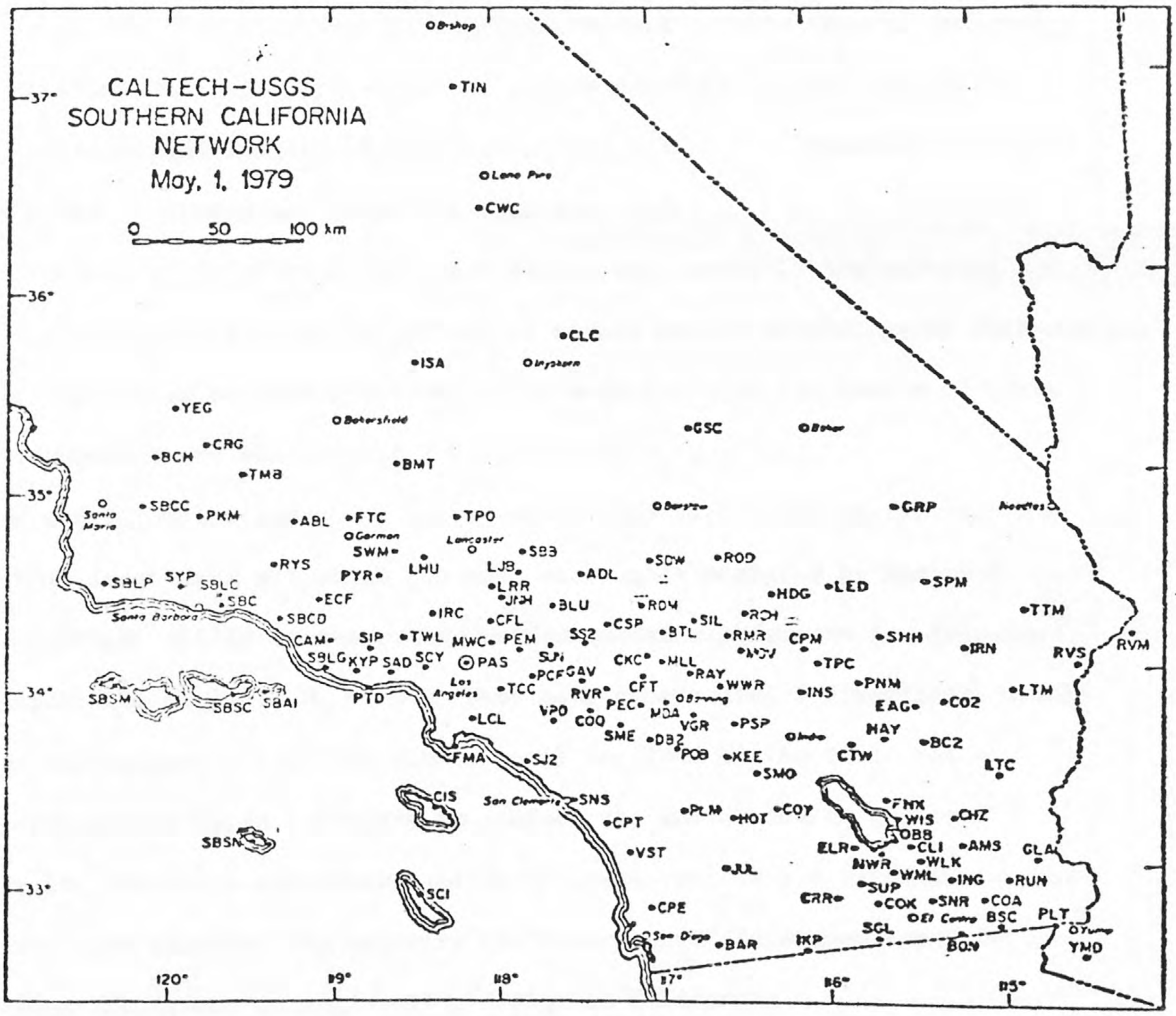
Earthquake research at Caltech spans numerous projects related to earthquake prediction and hazard reduction. Governments are increasingly aware of the potential loss of lives and property due to earthquakes and are directing support to mitigate against these disasters. I will review the framework and necessary components of a successful hazard reduction and earthquake prediction program using the Caltech studies as examples, although similar research is underway at many institutions in the world today. The goal of such a program is both humanitarian and pragmatic: to eliminate the risk to life and to the economy. The fundamental problems are to identify (1) all sources of severe earthquake potential, i.e. active faults, and (2) all structures that would be damaged in strong shaking. In an ideal situation such structures would be rebuilt to withstand future earthquakes. In reality, as was found in China, the cost of rebuilding would be exorbitant - more than a society can afford. This leads to a program for rebuilding the most hazardous structures and (3) for providing warnings, or predictions, of impending earthquakes to reduce hazards from the structures which remain. In addition, warning is needed for other hazards which can result from earthquakes and are not due to man-made structures, such as landslides,tsunami,seiche, soil liquifaction, etc. Clearly, public education programs, ongoing studies for safe structural design, and legislation of standards for future building and site safety are also required. These are the significant components of the earthquake prediction and hazard reduction programs in the U. S. today.

The efforts of both geologists and seismologists are necessary for identifying the sources of severe earthquake potential. Detailed fault mapping, trenching, and dating of offsets can identify areas of potential surface breakage, faults which are active in modern time, lengths of continuous rupture and the degree, or rates, of activity. Estimates of the location, size, and frequency of earthquakes are commonly made on this basis for siting critical facilities. The geologic studies in the western U.S. and northern Mexico are too numerous to mention, and yet we are still faced with substantial ignorance regarding these parameters for major fault systems. In response to the enormity of this task many studies are currently funded for further mapping and trenching of faults in southern California. Sieh (1978) has recently obtained the first information on the recurrence rates of great earthquakes since the sixth century A.D. along the San Andreas fault in Southern California. He finds an average time period of 160 years between great earthquakes ($M \sim 8$) based on dates of disturbed sediment layers in an excavation along the fault. Since the last great earthquke in this area occurred in 1857, this research provides a rough estimate of the immediacy of one potential hazard source. Crook, Allen, Kamb, Payne and Proctor (1979) have recently studied the Sierra Madre fault system in an extensive mapping and trenching program. Their results indicate different levels of activity along several segments of this system with recurrence intervals for the largest events ranging from 3,000 years to greater than 5,000 years. Clearly each fault warrants individual study.

In many cases clever techniques must be developed for assessing the fault activity in modern time due to the erosion of surface features or in accessibility of the fault trace due to water, vegetation, or man-made features. In these cases seismological studies are particularly helpful using a well designed seismograph array. Lineations of intense activity may be found to elucidate the paths of through-going fault weakness. Earthquake fault mechanisms can be determined for interpretation of stress fields and sense of displacement relative to the known geologic structures.

Caltech has maintained a seismograph array in Southern California since the early part of this century. At present, in cooperation with U.S.G.S. and with partial support from the State of California, the array contains approximately 150 stations (Fig. 1). Earthquake maps and catalogs are routinely produced which are available for studies of fault activity. Seismograph coverage at this station density provides detection for $M_L \geq 2.5$ earthquakes over most of Southern California. (Coverage near the Calif./Mexico border has been extremely poor, excepting the recent installation of stations in the Imperial Valley in 1973.) Caltech has turned to computer automation of the array since 1977 in order to cope with the increasing demands for manpower with network expansion. This facility also accelerates the production of the earthquake catalogs. Despite adequate seismograph array coverage, several questions regarding seismic activity and potential hazard remain: Does an absence of seismicity indicate low or high risk along a fault? What is the interpretation of earthquake fault mechanisms which are inconsistent with the geology? What is the meaning of seismicity patterns which don't correlate with any geologic structures active in modern time? What is the relationship between the rate of small earthquakes and the maximum, or biggest earthquake to be expected along a fault? It would directly benefit both California and Mexico to intensify joint seismological and geological research efforts along fault systems crossing the border in order to improve assessments of earthquake potential within the respective countries.

The second major problem area involves the determination of earthquake effects. The four main factors determining the effects of an earthquake are: (1) the earthquake source mechanism, (2) the wave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119°
118°
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CRG
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BMT
GSC
SBCC
PKM
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propagation effects, (3) the local site geology, and, (4) the structural response. In the last decade seismological research has produced deterministic models which simulate the effects of an earthquake source and resulting wave propagation through complex crustal structures. Reliable modeling a ground motion is now possible for periods of one-second and longer. Of particular importance for engineers are the studies of strong ground motion near the source of a major earthquake. The State of California and the U.S.G.S. are currently implementing a program for widespread deployment of strong motion accelerograph instruments. Strong motion accelerograms which are recorded near the source of large earthquakes are scarce, but constitute the fundamental data for joint research by seismologists and earthquake engineers. One significant data set which has been thoroughly analyzed by Heaton & Helmberger (1979) is the strong-motion record set for the San Fernando earthquake of 1971, $M_L = 6.4$. They have constructed 3-dimensional models to investigate the motion due to small sections of the fault and how various wave types interfere to produce the motion due to the total fault. Analysis and understanding of these records are critical in that they have provided the majority of "near-source" data considered for recent decisions on engineering design in California.

A "semi-empirical" approach has been used by Kanamori (1979) to predict the very long period (several seconds or longer) ground motions generated by a great earthquake. He considers that most large earthquake along a fault like the San Andreas are complex multiple events which occur in sequence. Kanamori and Stewart (1978) have shown that the 1976 Guatemala earthquake can be modeled by approximately 10 events with $M_s \simeq 6.5$. Kanamori (1979) has empirically predicted the long period ground motions of the Guatemala earthquake by convolving the ground motion of the Borrego Mountain earthquake of 1968 (M_L = 6.4) with the source time sequence of the Guatemala earthquake.

Another important factor influencing the effects of an earthquake is the near surface site condition. Examples are the site geology (e.g. "rock" or "soft" sites), the soil profile and the depth of the structure foundation. Typically these conditions have been analyzed by engineers, assuming the incidence of a simple vertically polarized SH wave. Seismological methods allow more realistic analyses considering different wave types. Other parameters which are being studied for their influence on strong ground motion are fault roughness and barriers, source effects such as source mechanism, directivity, and stress drop, and attenuation. Previously the main source parameters considered were the size (or magnitude) of the earthquake, the peak acceleration, and the duration. Attenuation effects were estimated by extrapolation of data obtained at large distances; currently new data recorded near the source of earthquakes provides an opportunity for verification of previous attenuation relations through complete seismological modeling.

In parallel, as more accurate descriptions of the strong ground shaking input to structures are available, engineers are refining the models of structural response to shaking. Strong motion recordings at key points within structures provide essential data for these analyses. Scott, at Caltech, has used strong motion records to model the response of earth dams to strong shaking. Recently Jennings has discussed the unprecedented significance of the strong motion records from 13 instruments in the six floor Imperial County Services Building which suffered severe structural damage in the Mexicali earthquake of of 15 October 1979 ($M_L = 6.6$).

As these joint investigations yield new information, better guidelines can be adopted for new building construction. Similarly, the potential hazard of existing structures can be more accurately assessed for informing governmental agencies of the potential loss due to earthquake effects.

The third approach to the problem of seismic hazard is earthquake prediction. At the present time earthquake prediction is in a "research" stage as opposed to a "prediction" stage. In this regard Mexico and California share a great "natural resource": numerous earthquakes for basic research. An understanding of the physical basis of earthquakes is fundamental to future prospects for prediction, and involves basic research on tectonics and earthquake source studies. Kanamori and coworkers are making substantial contributions in this area with the discovery of "slow" earthquakes and "complex" earthquakes. These studies lead to the inescapable conclusion that earthquakes are highly different from one another and that predictions may rely on quite variable precursory phenomena. Models of tectonic processes and plate motions provide a broad framework for categorizing types, sizes, and frequency of earthquakes (Minster and Jordan, 1978; Uyeda and Kanamori, 1979). Another area of research which is critical for earthquake prediction is the partitioning of crustal movements into seismic vs. aseismic slip (Kanamori, 1977) in order to identify zones where seismic rupture can be expected to accommodate plate movements. A further refinement is the study of variable slip rates along contiguous sections of subduction zone boundaries (McNally and Minster, 1979). These studies seek to isolate "seismic gaps" which can be expected to break.

The studies just described form jointly a background from which to pursue prefailure, or precursory, phenomena. From a seismological perspective, long term seismicity patterns appear promising if they can be used as stress indicators. Patterns of earthquake clustering, seismic quiescence, spectral content in waveforms, foreshock behavior, fault mechanisms, microearthquake activity, and earthquake statistics are at the focus of Caltech research on prefailure phenomena (Ishida and Kanamori, 1977, 1979; McNally et al., 1978; McNally, 1978; Drowley and McNally, 1978; Carlson et al., 1979; Ponce et al., 1979; Singh, et al., 1979; Hutton et al., 1979). Despite somewhat encouraging results, substantially more experience and data will be required with moderate and large earthquakes in California, Mexico or worldwide before concrete models can be proposed for prediction purposes. In addition, it is necessary to understand the physical processes leading to failure which produce these anomalies before "true precursory behavior" can be distinguished from background fluctuations.

Scientists working in a future "prediction" stage will require immediate access to a wide variety of geophysical field measurements in an earthquake prone area. This necessitates "real time" monitoring and data analysis capabilities which are only possible with telemetry links to a central computer. The Caltech Seismological Laboratory foresaw this need and initiated the Caltech Remote Observatory Support System (CROSS), which consists of a number of Telemetry Interface Module (TIM) units deployed at field sites of various remote sensing instruments such as strainmeters, radon gas monitors, well-water level monitors, tiltmeters, etc. These remote TIM units store digitized data as collected and are then interrogated on a scheduled basis by the central computer at the Caltech laboratory using direct dial phone line telemetry. This rapid and economical system is currently in use for selected geophysical measurements, but holds potential for widespread development as real time monitoring efforts are expanded.

Conclusions and Recommendations: These efforts constitute the major thrust of the current earthquake hazard reduction program. The successful assessment of earthquake potential and earthquake effects, and earthquake prediction and monitoring require ongoing cooperation between geologists, seismologists, engineers, and governments. It is clear that it is highly desirable and of mutual benefit to both countries that the State of California and Mexico seek new ways to intensify joint research in studies of fault systems crossing the border. Specifically joint geological and seismological research, data exchange and equipment transport should be facilitated for scientists and engineers across the international border. A high priority should be given to joint expansion of seismograph array coverage near the border in California and in northern Mexico due to the presence of hazardous fault zones and densely populated areas. Finally, joint symposia on these topics should be held on a regular basis to promote vigorous and ongoing exchange.

Acknowledgments

This research was supported by U. S. Geological Survey Contract No. 14-08-0001-18371. Contribution Number 3372, Division of Geological and Planetary Sciences, California Institute of Technology, Pasadena, California 91125.

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