UNITED STATES
DEPARTMENT OF THE INTERIOR

# Earthquake Hazard and Prediction in Northwest Mexico and California/Mexico Border

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# SEMI-ANNUAL TECHNICAL AND FINAL REPORT:

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U.S. Geological Survey
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## I. Northern Baja California Seismic Array

Plans for installation of the Northern Baja California telemetering seismic array were again set back. Winter rains made most of Northern Baja California impassable for several months. San Pedro Martir is still not open. (We anticipate that road repairs won't be completed until July.) The UHF radios have still not been delivered. They are now one year late; Monitron promises delivery shortly. There is evidently some problem with the 100 kHz bandwidth we require.

Since array installation is now delayed to the summer, we, with CICESE, plan to expand the temporary array, using both portable drum and digital recorders. Two new sites along the San Miguel Fault (which are not part of the original eight stations) and two sites in the Salton Trough will be installed early this summer, barring any major seismic activity which would need the instruments.

## II. Studies of Historical Seismicity

Over the contract period, a substantial effort has been made to redefine the locations of all past (instrumentally located) earthquakes in Baja California of magnitude $\geq 6.0$. This work is an extension of that found in the Master's Thesis of Alena Leeds (1979), who relocated eleven selected earthquakes in Baja with magnitude $\geq 5.0$. Her principal finding was that several events previously associated with the Agua Blanca Fault must have occurred considerably more to the north, probably on the San Miguel Fault.

The basic approach in these studies has been to carefully re-examine the S-P times of aftershocks at those stations of the Cal Tech network which were closest to Baja California at the times of the events--principally Barrett, La Jolla, Palomar, Riverside, Pasadena and occasionally Mt. Wilson. These S-P times were analyzed relative to one another, and were compared to similar readings from the 1976 Mesa de Andrade and 1975 Pino Solo events, which are well located. Also considered were the similarities or dissimilarities of different earthquakes as recorded at a given site, and/or the character of any one signal vis-a-vis the geological path it is supposed to have followed. Included in the analysis were recordings at Tucson Observatory obtained from the Environmental Data Service at Boulder, Colorado.

The epicenters originally determined by Cal Tech for all Northern Baja earthquakes of magnitude ≥ 6.0 (since 1927) are plotted in Figure 1. There are 12 earthquakes in all, of which the largest is magnitude 7.1. The results of the deliberations described above are shown in Figure 2. It shows that six of the 12 original locations can be substantiated by the available S-P data, albeit in some cases only in a rough areal sense. An example is the 1956 event, of which it might better be said that the data does not contradict this location. For the remaining six events, sufficient evidence exists to warrant moving the epicenters, from a minimum of ten to a maximum of 75 kilometers. Table I gives coordinates and some commentary on each of the events. Note that relative S-P times indicate the 1954 earthquakes and the two events on February 9, 1956 were all in essentially the same place, near the locale of faulting described by Shor and Roberts (1958) following the 1956 series of events. Similar analysis suggests that the February 14 and February 15 events in 1956 were not in identical locations as previously thought.

The principal result is that three of the relocated events now fall most plausibly on the San Miguel Fault. Two of these (October 24, 1954, and November 12, 1954) were previously placed near the Agua Blanca Fault (Figure 1), and the third (February 24, 1935) had been misplaced roughly 75 km to the east.

Relocation of these large earthquakes onto the San Miguel Fault (and away from the Agua Blanca Fault) is compatible with the results of all recent microseismicity studies (Figure 3), as well as additional work by Leeds on events of magnitude $\geq 5.0$, which show high levels of seismicity around the San Miguel system but virtually no activity in the vicinity of the Agua Blanca.

## III. The Mexicali Earthquake of 15 Oct 1979

Within 6 hours of the main event, three IGPP portable stations were installed south of the border, along the Imperial Fault, to insure good epicentral control for aftershocks occurring there. Portable drum and digital recorders were also installed by CICESE that night. Recording continued for approximately one month. CICESE is handling most of the data processing, concentrating first on those events which occurred in Mexico. Data from temporary s tations set up north of the border is being spooled at IGPP and will by analyzed cooperatively.

Data anlaysis includes:

(1) Location of larger aftershocks occurring soon after the main event. On hgih gain instruments, arrivals from large events are obscured by smaller previous activity. The digital recorders, set initially at low gain, will provide accurate arrival times for early aftershocks both south and north of the border.

(2) S waves recorded on horizontal seismometers will provide better depth control than possible with only P waves.

(3) Digital recording will allow waveform analysis for use in both focal mechanism and structure studies.

## IV. Laguna Salada Earthquake Swarm

During late 1975 and the first half of 1976, an earthquake swarm with several events of $M_L \sim 5$ occurred in the Laguna Salada region of Northern Baja California. Laguna Salada lies between the Sierra de los Cucapah on the east and the Sierra de Juarez on the west. Kelm (1972) suggests that, based on aeromagnetic and gravity data, the region is a graben. The region would be similar, then, to the Salton Trough, from which it is separated by the Sierras de los Cucapahs and del Mayor. The lengthy earthquake swarm suggests that the region is still active. This activity may have seismic hazard implications north of the border, especially along the Elsinore Fault. The seismicity and tectonics of the Laguna Salada region, therefore, warrant closer study.

Cal Tech locations of the 1975 - 1976 swarm events (Figure 4 contains all events located by Cal Tech in the region during 1976) show considerable scatter. Since this may be either actual scatter of an artifact of the array lying well to the north of the epicentral region, we have relocated many of the swarm events using CIT data and additional readings from Rio Hardy (RHM in Figure 4) which is only 20 km east of the epicentral region. The relocations of 110 events are shown in Figure 5. The scatter is reduced somewhat, and the center is moved northward. These differences may be an artifact of Figure 5 containing a subset of the data of Figure 4. Only events with readings at RHM were relocated. The epicentral region has a northerly elongation, similar to the pattern of earthquake swarms from the Imperial Valley (Johnson, 1979). The locations do not show the connection with the Sierra Juarez fault system to the south. The relocation of the 1934 ($M_L$ = 6.5) event (discussed above) does suggest that the Cucapah Fault, the southern extension of the Elsinore system, may be the northern transform fault boundary of the Laguna Salada "spreading system."

Source mechanisms of the larger swarm events are being examined. Figure 6 shows first motions recorded at Cal Tech stations of two events 14 January 1976, $M_L$ = 4.1 and 17 January 1976, $M_L$ = 4.6. A map projection is used. The pattern of the 14 January event clearly suggests strike slip faulting, with a strike of about 300°. This is parallel to the regional transform faults rather than to the trend of the swarm events. The 17 January event has a somewhat different pattern, suggestive of normal faulting. The dip of such a normal fault is unknown, and any calculation would require accurate knowledge of the structure in the vicinity of the epicenter.

The two patterns in Figure 6 differ at only a few stations. The differences could be due, in part, to uncertainties in reading first motions from short period recordings of relatively small events. For an independent check of the focal mechanisms, then, we are examining surface waves radiation from the two events. SInce the events are small, we are limited to only a few long period stations. A complete radiation pattern analysis may not be possible. We hope that at least one station will be at a favorable azimuth to allow us to determine gross differences in mechanisms. Preliminary analyses are not encouraging.

Other avenues of research in this region include:

(1) Relocation of other events for which Mexican data is available. This may allow us to identify the transform faults which connect this region to the Gulf of California in the south. The events located by Cal Tech using Southern California data are widely scattered. Whether or not this scatter is real remains to be determined. This may also help identify the borders of the Laguna Salada region and determine how much spreading or crustal thinning has taken place there.

(2) Examination of historical seismicity, to estimate the quantity of historic seismic slip relative to the main plate boundary (Imperial and Cerro Prieto Faults south of the border), and to see if activity in the Laguna Salada region is temporally related to activity elsewhere.

## V. Continuation of Research

Work sponsored under Contract 14-08-0001-18216 will be continued during 1980/1981 under USGS Contract 14-08-0001-19163. We hope to have the array installed this summer. Sites are picked and bases are being poured where proper transmission is assured. But delivery of the second UHF radio is required before several transmission paths can be tested and before the entire system can be installed, fully tested, and made operational.

In the meantime, we will continue our examination of Northern Baja California historical seismicity, relocating events down to $M_L = 5.0$ and concentrating on special sequences such as the 1975-1976 Mexicali earthquake. Our aim is to first better understand the regional tectonics, especially their relation with Southern California.

## REFERENCES

Leeds, A. L. (1979). Relocation of $M \geq 5.0$ Northern Baja California earthquakes using S-P times. Master's Thesis, University of California, San Diego.

Shor, George G., Jr., and Ellis Roberts. (1958). San Miguel, Baja California Norte, earthquakes of February, 1956: A field report. Bull. Seism. Soc. Am., 48, 101-116.

TABLE I

NORTHERN BAJA CALIFORNIA EARTHQUAKES

MAGNITUDE ≥ 6.0

(SINCE 1927)

| DATE | MAG | ORIGINAL SEISMOLOGICAL LAB LOCATION | REVISED (5/1/80) LOCATION | REMARKS |
|---|---|---|---|---|
| 30 Dec 1934 | 6.5 | 32° 15' N<br>115° 30' W | (unchanged) | Location confirmed by aftershock S-P times at LJC and comparison with 1976 Mesa de Andrade earthquake, plus 31 Dec 1934 event on PAS N-S torsion seismograph. |
| 31 Dec 1934 | 7.1 | 32° 00' N<br>114° 45' W | (unchanged) | General location corroborated by visible scarp, aftershock signal character at LJC and TUO (rel. to 30 Dec 1934 event), and comparison with 1976 Mesa de Andrade event in essentially same place (on PAS N-S torsion). |
| 24 Feb 1935 | 6.0 | 31° 59' N<br>115° 12' W | 31° 57' N<br>116° 00' W | Moved ∿75 km W, based on S-P times at LJC, RVR, PAS and MWC. LPZ recording at TUO resembles Pino Solo event ( ∿20 km SE). |
| 7 Dec 1940 | 6.0 | 31° 40' N<br>115° 5' W | (unchanged) | Confirmed by S-P times (main shock) at LJC and RVR, plus relative $P_n$ arrival times (given by ISS) at LJC and TUO. Signal character on LPZ at TUO suggests epicenter somewhat closer to TUO than 1954 events. |
| 24 Oct 1954 | 6.0 | 31° 30' N<br>116° 00' W | 31° 40' N<br>115° 50' W | Moved ∿25 km NE, based on S-P times at BAR, PLM and RVR. Confirmed by I.S.S. location. |

| DATE | MAG | ORIGINAL SEISMOLOGICAL LAB LOCATION | REVISED (5/1/80) LOCATION | REMARKS |
|---|---|---|---|---|
| 12 Nov 1954 | 6.3 | 31° 30' N<br>116° 00' W | 31° 40' N<br>115° 50' W | Moved ~25 km NE, based on S-P times at BAR, PLM and RVR. Character of signal at TUO very similar to that from 24 Oct event. |
| 9 Feb 1956 | 6.8 | 31° 45' N<br>115° 55' W | 31° 40' N<br>115° 50' W | Moved ~10 km SE, based on S-P times at BAR, PLM and PAS, plus location of observed scarp (Shor and Roberts). |
| 9 Feb 1956 | 6.1 | 31° 45' N<br>115° 55' W | 31° 40' N<br>115° 50' W | Occurred less than one hour after above, therefore inferred to be in the same place. Impossible to actually separate from continuum of aftershocks following main event (above). |
| 14 Feb 1956 | 6.3 | 31° 30' N<br>115° 30' W | 31° 35' N<br>115° 35' W | Moved ~10 km NW, based on S-P times at BAR and PLM. (Significantly different from those from event on following day.) |
| 15 Feb 1956 | 6.4 | 31° 30' N<br>115° 30' W | (unchanged) | Confirmed by S-P times at BAR, PLM and RVR. |
| 13 Dec 1956 | 6.0 | 31° 00' N<br>115° 00' W | (unchanged) | General locale substantiated by S-P times at BAR, PLM, and RVR, but longitudinal control quite poor. Signal character shows event definitely not in Gulf. Could be as much as 20 km. S of given coordinates. |
| 7 Aug 1966 | 6.3 | 31° 48' N<br>114° 30' W | (unchanged) | Complicated signals support path across upper Delta. S-P times at BAR, PLM and RVR are tenuous and varied but some are consistent with original location. S-P times at RVR and PAS longer than for 31 Oct 1934 event. |

Station Abbreviations: BAR = Barrett Dam, LJC = La Jolla, MWC = Mt. Wilson, PAS = Pasadena, PLM = Palomar, RVR = Riverside, TUO = Tucson Observatory.

Other Abbreviations: I.S.S. = International Seismological Summary

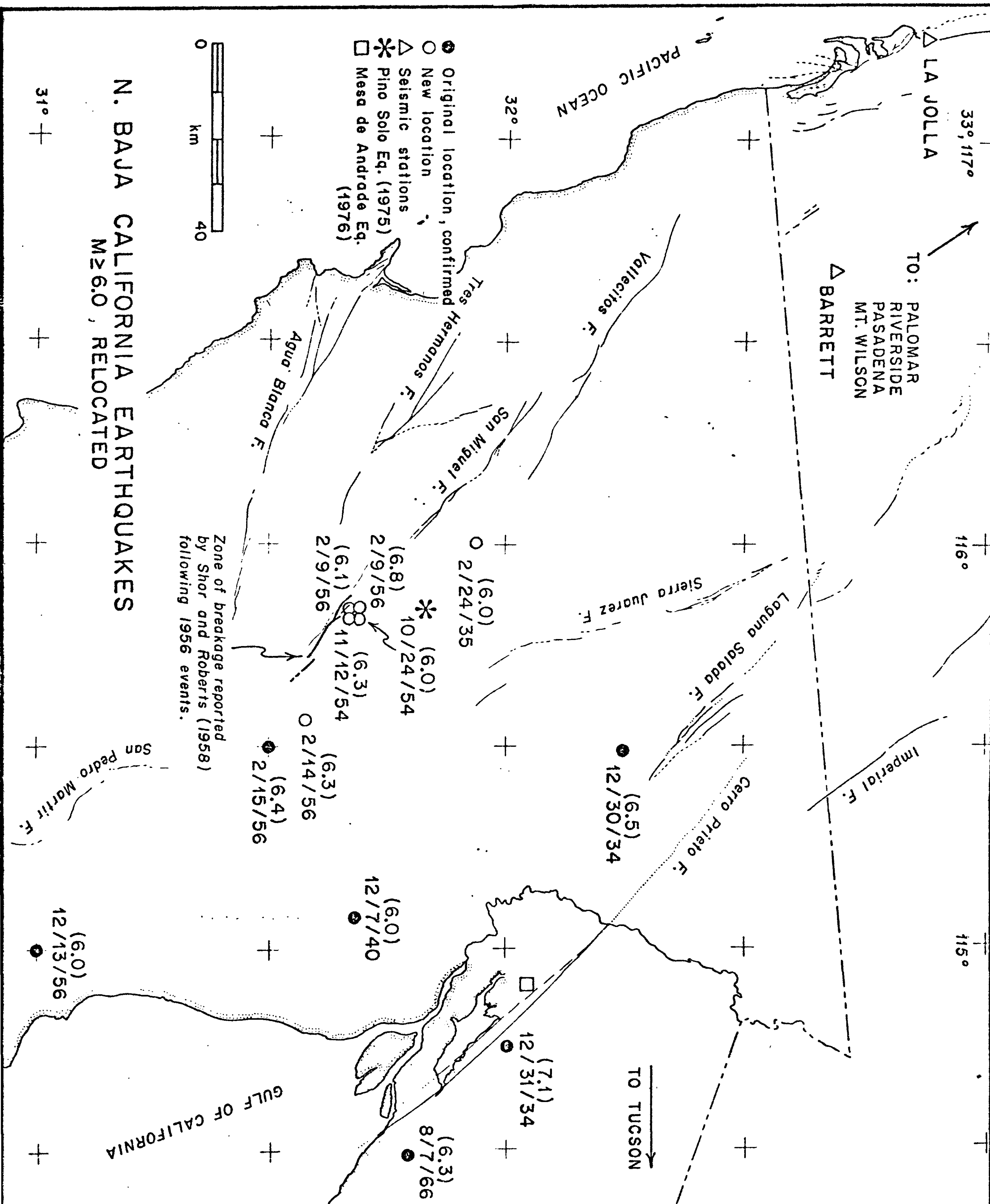


Figure 1. Epicenters originally detemrined by the Cal Tech Seismological Laboratory for all Northern Baja California earthquakes of magnitude ≥ 6.0 (since 1927).

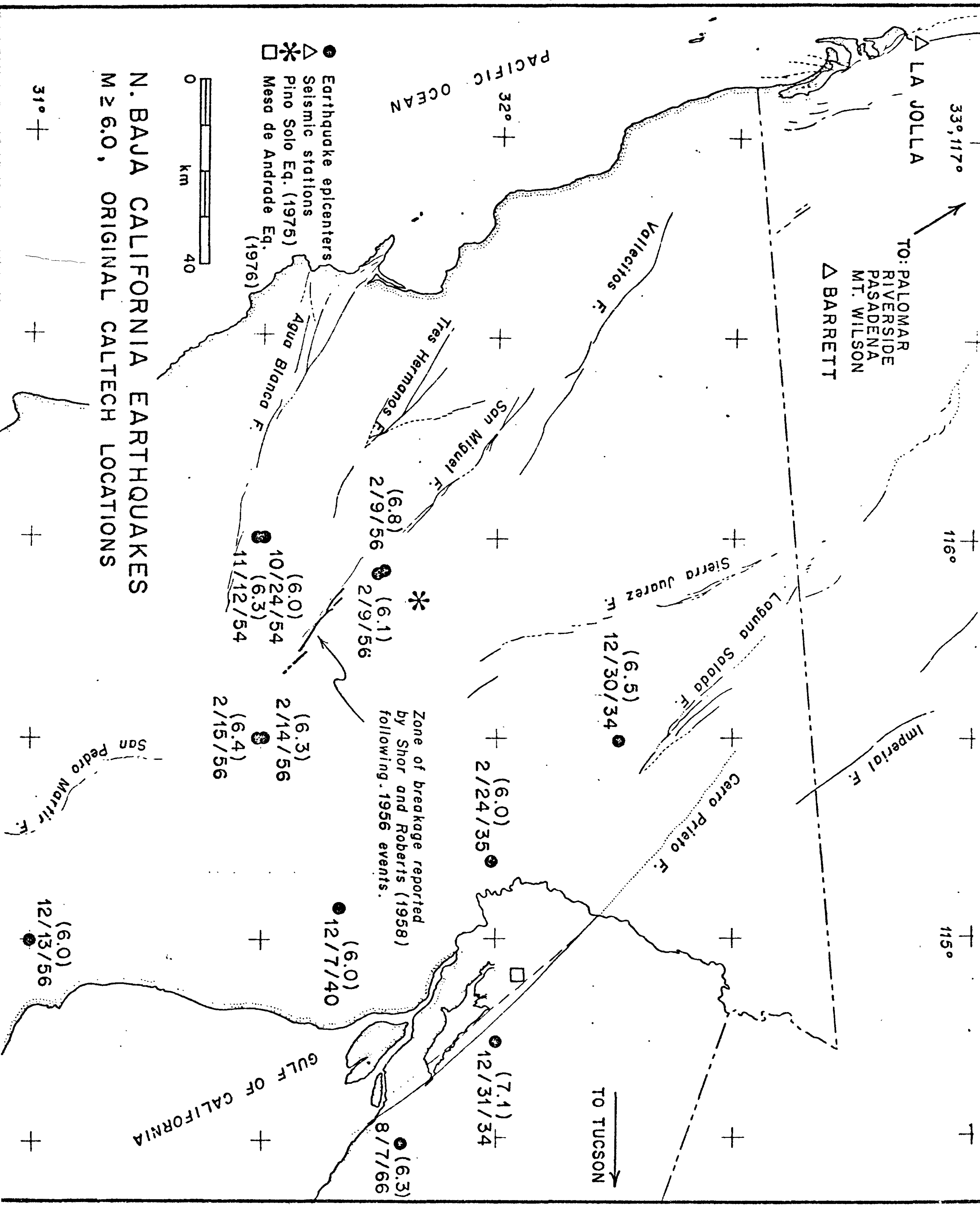


Figure 2. Epicenters of all Northern Baja California earthquakes of magnitude ≥ 6.0 (since 1927) determined by analysis of S-P times and other signal characteristics at stations in Southern California and Arizona.

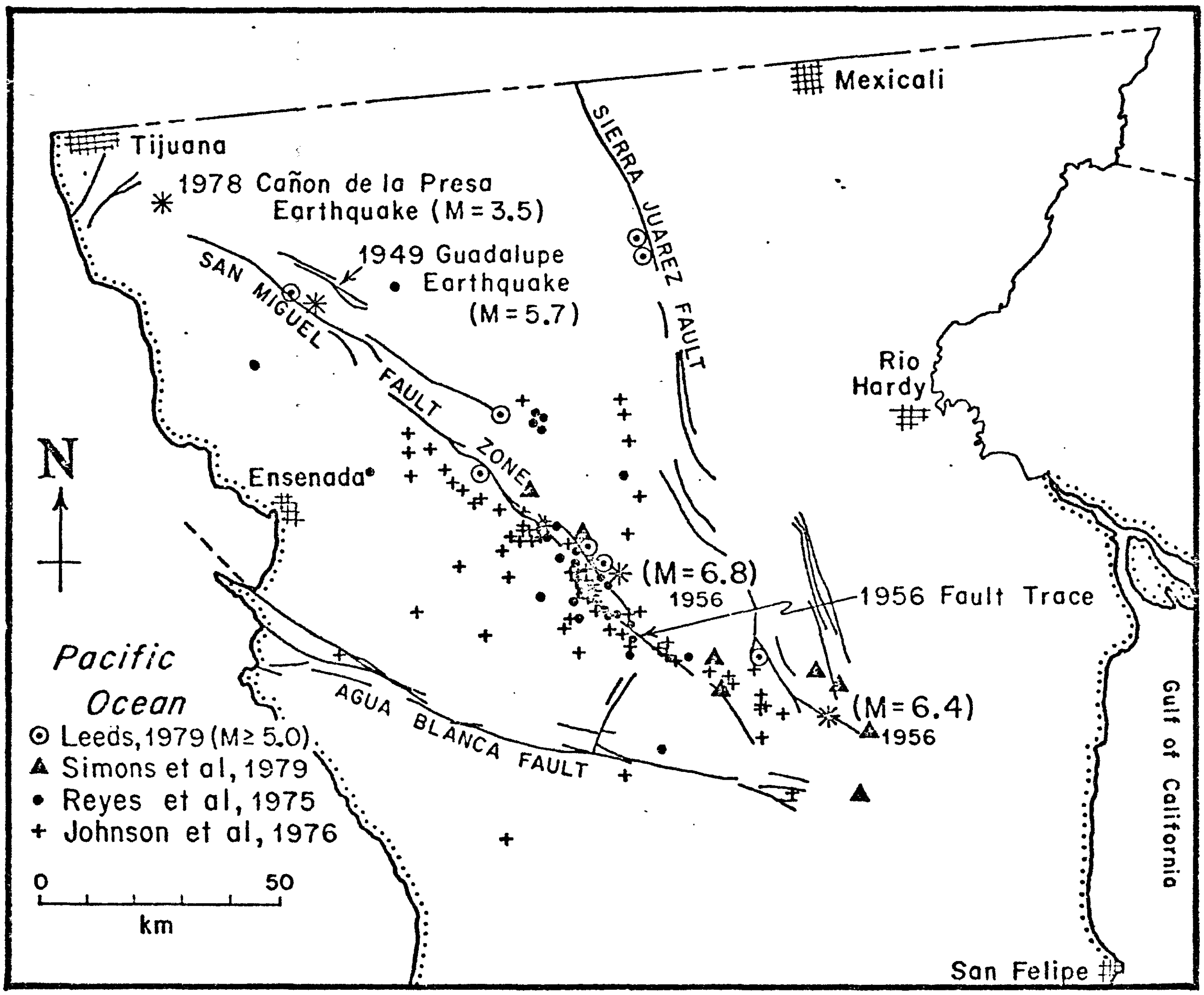


Figure 3. Summary of recent microseismicity studies of the San Miguel Fault zone. Also shown are epicenters of those events $M_L \simeq 5$ which have been relocated.

LAGUNA SALADA CALTEC LOCATIONS

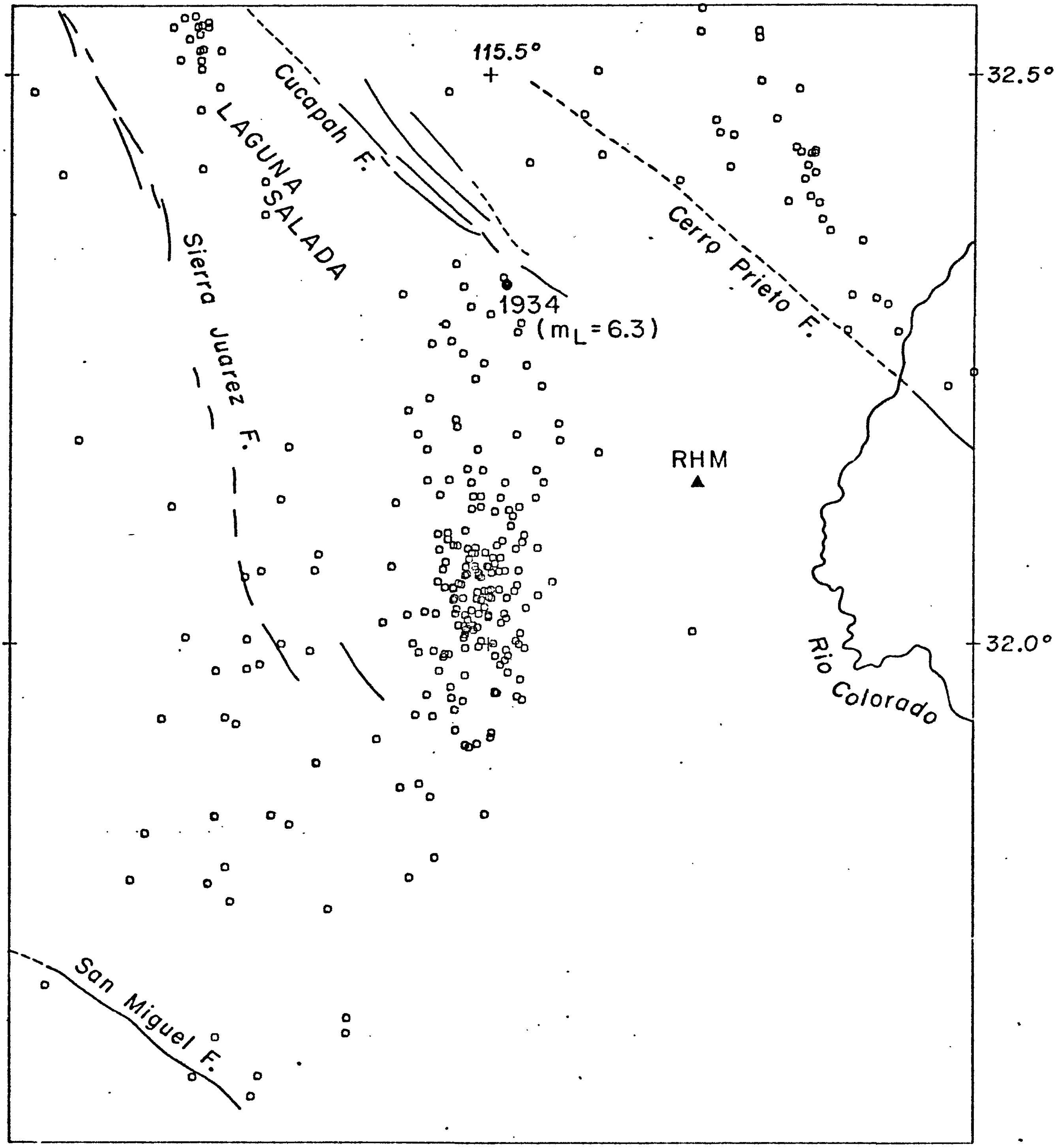


Figure 4

LAGUNA SALADA MICRO LOCATIONS

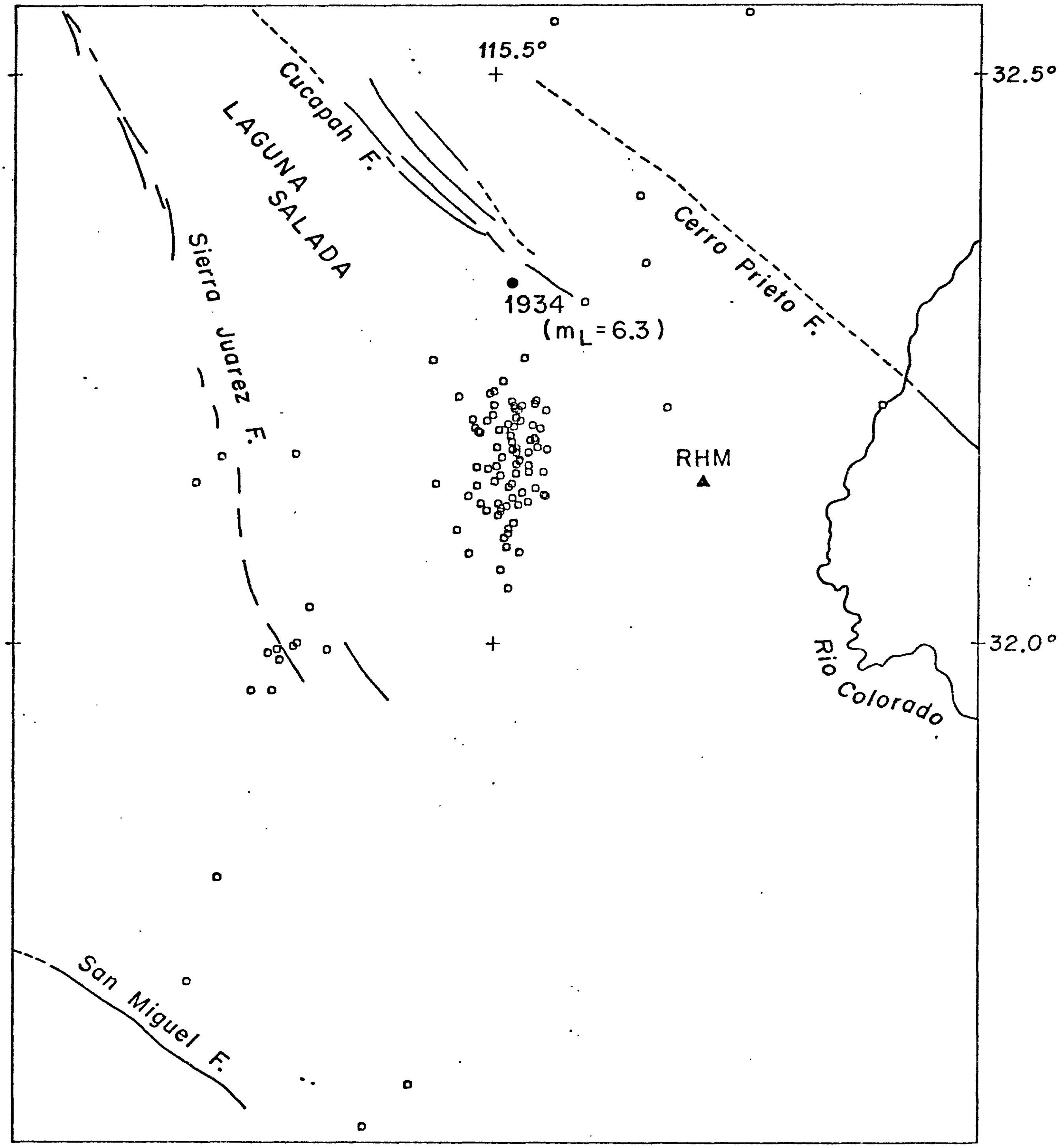


Figure 5