United States
Department of the Interior
Geological Survey

THE SOUTHERN CALIFORNIA NETWORK BULLETIN

JULY — DECEMBER, 1986

Open–File report 87-488

by

Douglas D. Given[1]

L. Katherine Hutton[2]

and

Lucile M. Jones[1]

[1] U. S. Geological Survey
525 So. Wilson Avenue
Pasadena, Ca., 91106

[2] Seismological Lab
California Institute of Technology
Pasadena, Ca., 91125

Table of Contents

I. Introduction 1

II. Network Configuration 1

Installation of New VCO's 1

Correction to Station LLA 1

New Station Code Convention 2

Network History Data Base 2

III. Network Operations 3

Meaning of Catalog Location Qualities 3

Earthquake Magnitude Estimation Procedures for Local Events 4

Local Magnitude (M_L) 4

Develocorder Duration Magnitudes (M_D) 8

Digital Coda Amplitude Magnitudes (M_{CA}) 8

Helicorder Magnitudes (M_H) 9

Effect on the Catalog 9

Completeness of the Southern California Catalog 10

Level of Completeness 11

Old Data Translation 11

Timing 12

Finalization 13

Magnitude Continuity 13

Off-line Processing Flow 14

CUSP System Components 14

State Driven Data Flow 15

Access to CUSP Data 18

IV. Synopsis of Seismicity 19

North Palm Springs Earthquake – July 8, 1986 19

Oceanside Earthquake – July 13, 1986 20

Imperial Valley 21

San Diego 21

San Bernardino 21

Santa Barbara 22

References 23

Figures 28

List of Tables

Table 1. Stations with J502 VCO's Installed ... 1

Table 2. New Names of Santa Barbara Stations ... 2

Table 3. Meanings of Location Qualities ... 4

Table 4. Wood-Anderson Station Corrections ... 6

Table 5. Catalog Status by Month ... 10

Table 6. Magnitude Levels of Completeness for the Southern California Catalog ... 11

Table 7. Caltech Data Systems, 1977 – 1986 ... 12

Table 8. Untimed Data Gaps for Southern California ... 12

Table 9. Unfinalized Data since 1977 ... 13

Table 10. Earthquakes Greater than or Equal to Magnitude 3.0 ... 24

INTRODUCTION

This report is the fourth in a series of semi-annual Southern California Network Bulletins. The purpose of this series is to keep interested parties, particularly those using seismic data, up to date on the state of the seismographic network. Topics include, but are not restricted to, network instrumentation and telemetry, data processing techniques and condition and availability of data. Each Bulletin also includes a brief synopsis of seismicity for a six month period.

The Southern California Network is run jointly by Caltech and the U. S. Geological Survey. It currently includes about 235 remote seismometer sites (including sites operated by other agencies) that are telemetered to the central processing site on the Caltech campus in Pasadena. These signals are continuously monitered by computers that detect and record an average of 17,000 earthquakes each year. These data are used to compile the Southern California Catalog of Earthquakes; a list beginning in 1932 that currently contains more than 145,000 events.

NETWORK CONFIGURATION

No major changes were made in Network telemetry or processing during this reporting period. No new sites were added and no significant changes to site instrumentation were made.

Installation of New VCO's Installation of the new J502 voltage controlled oscillators (VCO) is continuing. Two units were installed during the reporting period and seven have been installed in the first half of 1987. The stations that now have J502 VCO's and the dates of installation are listed in Table 1. The new VCO's produce a better signal to noise ratio than older units. Installation is proceeding slowly because the change of VCO requires recalibration of the station.

■ Table 1. Stations with J502 VCO's Installed

ADL	24	April	1986
CFT	24	February	1987
ELM	23	April	1986
INS	4	March	1987
MAR	6	April	1987
MIR	8	April	1987
RYS	9	April	1987
SBK	20	January	1987
SDW	3	July	1986
SMO	27	October	1986
THC	19	February	1987

Correction to Station LLA The name for the seismic station at Llano, previously LLA, has been changed to LLN to avoid a conflict with an existing station. Furthermore, the minutes of the latitude and longitude of the location of the station were in error in previous Bulletins and other distributed station lists. The actual location of the site is: 34° 29.13′, -117° 50.73′. The elevation of 1018 m is correct.

New Station Code Convention A convention for designation of station codes has been developed for all California seismic stations. This scheme grew out of a need to insure that each station code was unique and a desire to include region and component information in the code. As a result, data from Northern and Southern California produced by different groups may be merged without fear of duplicating station codes. The new station codes consist of five alphanumeric characters that have positional significance. The first three characters are a station name abreviation, the fourth character is a network identifier and the fifth character is a component identifier. For example the full station code for the vertical component at Pasadena would be PASCV, where PAS is the station name, C stands for "Caltech" and V represents the high gain vertical component.

Network and component information (as well as other station data) has always been available in CUSP format phase data as separate "attributes" and has not been tacked onto the station name. In converting Network data to other formats for non-CUSP consumption this new convention can be easily accomodated.

The Southern California Network has nine stations in the Santa Barbara area that previously had four letter station names; each beginning with the prefix "SB". In order to conform to the above scheme these names have been shortened to three letters by dropping the "B". A list of these stations appears in the Table 2.

■ **Table 2. New Names of Santa Barbara Stations**

Old Name		New Name	Full Code	Full Name
SBAI	⟶	SAI	SAICV	Anacapa Island
SBCC	⟶	SCC	SCCCV	Colson Canyon
SBCD	⟶	SCD	SCDCV	Casitas Dam
SBLC	⟶	SLC	SLCCV	La Cumbre Peak
SBLG	⟶	SLG	SLGCV	Laguna Peak
SBLP	⟶	SLP	SLPCV	Lompoc
SBSC	⟶	SSC	SSCCV	Santa Cruz Island
SBSM	⟶	SSM	SSMCV	San Miguel Island
SBSN	⟶	SSN	SSNCV	San Nicolas Island

Network History Data Base The southern California Network has changed a great deal in its 55 year history. Many stations have been installed and some have been removed, site components have been updated, gains have been changed and network telemetry has evolved. Many of these factors are important to researchers who work with the data produced by the Network.

The last Bulletin (Given *et al.*, 1986) included the calibration information necessary to compute actual ground motion at all the Network sites *at that time*. However, these and other data are not necessarily valid for all times in the past. Station locations, gains, polarities and other attributes of interest to those who use Network data may change. Therefore, it is desirable to be able to get a "snapshot" of the network configuration at any point in its history. Toward this end, information about Network station configuration and telemetry has been collected and entered into a commercially available data base management program (dBase III) on a personal computer. This data base includes such station information as: location, installation date, polarity changes, VCO and discriminator type, discriminator output voltage, attenuation and other attributes. Each item is tied to a date so that the state of each site at any given time can be determined to the extent that the information is known.

Listings of these data in certain pre-set formats are available to workers who need it by contacting the Pasadena Field Office of the U.S.G.S. The raw data on floppy disk in dBase format and sort routines may also be obtained by sending a blank floppy with your request.

NETWORK OPERATIONS

On-line processing continued using the new on-line system software that was introduced in June of 1986 (Given *et al.*, 1986). Network data processing was severely hindered by three large earthquake sequences that occurred in California in July; North Palm Springs on July 8 (M_L = 5.6), Oceanside on July 15 (M_L = 5.3) and Chalfant Valley on July 21 (M_L = 6.4). The first two of these events will be discussed in more detail in the section on seismicity. The Chalfant Valley earthquake was outside the Network but still caused hundreds of triggers on northern stations that were processed and entered into the catalog. These data are also available to supplement data from the central California and Nevada arrays. This earthquake was discussed by Cockerham and Corbett (1987).

The huge increase in the rate of seismicity associated with the North Palm Springs earthquake caused the on-line detection and recording computers to overload and lose data for the first six hours after the main shock. This was described in the last Bulletin (Given *et al.*, 1986). The large number of events recorded also put a severe strain on the off-line processing, causing delays in catalog production. The backlog of events caused by these sequences was finally dissolved in April of 1987. The data gap for the six hours following the main shock will be recovered from "FM" analog tape backups.

Meaning of Catalog Location Qualities The earthquake locations published in this and past Bulletins and otherwise distributed from the Caltech catalog are assigned a one character quality identifier: A, B, C, D, E, P or blank. This quality letter is an estimate of the reliability of the hypocentral solution of that event. But the meaning of this quality identifier has changed over time with changes in the network and processing proceedures. The original definition of quality was described by Hilemen *et al.* (1973). It was in use until 1975 when it was superseded by qualities based on estimates of horizontal and vertical error calculated by the location programs. HYPO71 (Lee and Lahr, 1975) was used to locate events in 1975 and 1976. From 1977 forward several programs have been used but all were evolutionary forerunners of GROPE, the location program currently used by CUSP (Johnson, 1979).

■ **Table 3. Meanings of Location Qualities**

Quality	1975 - present: Horizontal Error (km)	1975 - present: Vertical Error (km)	1932 - 1974: Epicenter	1932 - 1974: Origin time
A	< 1.0	< 2.0	specially investigated	
B	< 5.0	< 2.5	within 5 km	to nearest second
C	< 5.0	> 2.5	within 15 km	to a few seconds
D	> 5.0	> 2.5	not within 15 km	rough
E	— not used —		terrible (probably outside network)	
P	preliminary		— not used —	
blank	— not used —		meaning unknown	

The preliminary ("P") quality means that the event has been located and a magnitude assigned in a rough way that is subject to revision.

These two schemes are not consistant. A quality "A" or "B" event in the old system might be either quality "A", "B" or "C" in the new system. While it is common for researchers to use only "A" quality solutions when interpreting hypocenters to insure that they are using only the best solutions, Table 3 makes it clear that selection by quality over periods spanning changes will be inhomogeneous.

EARTHQUAKE MAGNITUDE ESTIMATION PROCEDURES FOR LOCAL EVENTS

The continuity of the magnitude scale as applied to earthquakes in southern California is crucially important to studies of seismicity rate and possible changes in seismicity rate. For that reason, it is appropriate to summarize the present procedures and the past procedures to the extent that they are known. Station coverage and completeness of event detection are also important, but are not included in this summary.

Local Magnitude (M_L) The primary source of magnitudes for local earthquakes in southern California is still the Wood-Anderson torsion seismometer. In principle, the instrumentation and measuring-room procedures have not changed at all since the 1930's. In practice however, several different people and computer programs have been involved. The principal players have been Charles Richter, John Nordquist, Violet Taylor, Barbara Reed, Kathy Watts, and Kate Hutton. A serious effort has been made by these people to stick to the instructions given in Chapter 22 of *Elementary Seismology* (Richter, 1958) and the early magnitude papers (e.g. Richter, 1935). Some questions have arisen, however, and it is useful to discuss these.

On page 343 of *Elementary Seismology* Richter states:

> "The maximum trace amplitude on a standard seismogram is then measured in millimeters, and its logarithm taken. To this is added the quantity tabulated as $-\log A_0$ for the corresponding distance. The sum is the value for M . . . In using the data of a station with standard seismographs recording both horizontal components, it is correct to determine magnitude independently from each and to take the mean of the two determinations. This method is preferable to combining the components vectorially, for the maximum motion need not represent the same wave on the two seismograms,

and it even may occur at different times. Rough rules like this are necessary for routine work in assigning magnitudes to hundreds of earthquakes.

A correction is applied to each station, or still better for each instrument. It is determined by examining statistically the magnitude determinations for a large number of shocks and finding the systematic deviation of the magnitude determined for any one instrument from that found from the mean result of all instruments. This procedure attaches to each instrument a correction similar to the 'personal equation' of an individual observer. It is probably related cheifly to the local conditions of ground and installation ... Magnitudes are easily assigned to the nearest half unit and can ordinarily be given to the tenth with an uncertainty not much exceeding one tenth."

It is apparent that there have been some changes, but nothing that would affect individual station magnitudes by more than about one tenth of a magnitude unit and, since the average changes little, should not affect the mean or median values in a systematic way. Note that GLAN and GLAE, which are simulated Wood-Anderson instruments, were installed wrong in 1977. That explains the wide difference between the early and late station correction for these components.

A slightly different version of the measuring instructions appear in "Earthquake Measuring Room Procedure, January 1, 1955" and a similar document dated January 1, 1959. They stated, "Amplitudes (A_{mm}) are in millimeters deflection to one side of the trace (half the whole range of the wave). Amplitudes on the film records are as seen on the projector ground glass."

The difference between "half peak-to-peak on the largest single swing" and "half the whole range" will be small in most cases; less than the equivalent of 0.1 magnitude units. It would be systematic, however, with the "half the whole range" method yielding the larger magnitudes.

Instructions passed verbally from Barbara Reed to Kate Hutton and Kathy Watts (oral tradition) indicate that half the peak-to-peak amplitude on the largest single swing in the S wave should be read for local magnitude. Magnitude should be computed for each component, using the nomogram version of the A_0 correction, and averaged. However, a certain amount of judgement entered into the use of stations known to have problems at the time or to be generally unreliable. Often a "typical" magnitude value was selected from the list, in a procedure more akin to a subjective median rather than a statistical mean.

Table 4 shows the station corrections listed by Richter (1958), those used in 1977, those now used, and those determined by Hutton and Boore (1987, in press) to be appropriate to Richter's A_0 curve:

■ Table 4. Wood-Anderson Station Corrections

	Richter		in use '77		present		H & B	
BARN	–0.2		0.0		0.0		–0.20	
CWCN, E			0.0,	0.0	0.0,	0.0	+0.09,	+0.06
GLAN, E			+0.2,	+0.2	–0.2,	–0.2	–0.21,	–0.36
HAIN, E	0.0,	0.0						
ISAN, E			+0.2,	+0.2	+0.2,	+0.2	+0.26,	+0.22
PASN, E	+0.2,	+0.2	+0.2,	+0.2	+0.1,	+0.1	+0.05,	+0.09
PLMN, E					0.0,	0.0	–0.11,	–0.10
RVRN, E	+0.2,	+0.2	+0.2,	+0.2	+0.1,	+0.1	+0.17,	+0.06
SBCN, E	–0.2,	–0.2	–0.2,	–0.2	–0.1,	–0.1	–0.22,	–0.21
TINN, E	–0.2,	–0.2	–0.2,	–0.2	–0.2,	–0.2	–0.29,	–0.30
WDYE		–0.1						
Average	-0.025				-0.012		-0.059	

For large shocks, only Wood-Anderson readings were used, making the result a true M_L. However, station corrections were also available for the short-period vertical Benioff and Benioff-like instruments. For the smaller events, it is not clear to what extent these were included. These instruments are discussed below.

Between 1966 and about 1977, phase data and amplitudes were keypunched. Hypocenters and magnitudes were included in the card decks, but apparently not recomputed, because amplitudes were only included if phase times were available.

The current procedure (dating from at least 1977 and possibly earlier) for reading amplitudes is to take half the peak-to-peak distance on the largest single swing of the S wave. On underexposed photographic torsion records where the trace cannot be followed continuously, the largest distance between peaks at about the same time is taken. There is some tendency to underestimate amplitude in doing this, because the largest peaks may be missed or off the paper. The analyst usually shows restraint in using marginal readings, but sometimes there are no other readings available.

In current routine production, amplitudes are typed into the CUSP data base and the magnitudes computed using a program which interpolates values from Table 22-1 of Richter (1958). A magnitude is computed for each component, and the median is chosen as the event magnitude. We enter all readings made by the analyst, even those listed at 0.1 mm. M_L's are only used in the catalog, however, if there are more than two readings of 0.5 mm or greater. Ideally, readings from more than one site are also required for the inclusion of M_L in the catalog, but this rule may not have been rigorously followed.

Some questions have been raised about how accurately amplitudes were measured in the early years. From 1932 to 1943, the majority of earthquake magnitudes were only reported to the nearest half unit. With that lower standard, analysts may not have been as careful about selecting the largest S wave peak or may not have made the measurements at all.

Hutton *et al.* (1979) looked briefly at this problem in connection with the apparent abrupt change in seismicity rate in 1952. They pulled a few random records out of the archives and reread the amplitudes. No excessive or systematic difference was found. In any case, a rate change would be expected in January 1944 rather than (or in addition to) 1952, if this were a serious problem.

Haukson and Gross (unpublished data), however, believe there is a systematic problem with amplitudes read for the Long Beach sequence in 1933.

An interesting comment emerged from a memorandum by Richter found in a file in the Measuring Room, which was apparently a response to a threatened funding cut:

> "Since 1953, especial effort has been made to provide complete statistics for shocks of magnitude 3 and over in southern California. Excluding occasional numerous aftershock sequences, these amount to about 300 annually. Shocks of magnitude 4 and over in adjacent areas (Nevada, Lower California) are included in the measuring room routine as completely as possible; they are listed, by only rough locations are attempted ... Statistics before 1952 vary in quality, partly because of intervals of defective recording, partly because of administrative efforts to reduce costs by economizing on contents of the bulletins."

It is interesting that the rate of occurrence of earthquakes in a particular magnitude range is higher prior to 1953 than afterwards, rather than the reverse, which one would expect from the above statement. If not tectonically significant, that trend would have to be due to a gross change in magnitude procedure, enough to produce systematic magnitude offsets on the order of 0.2. Such a problem has not yet been found.

For a certain number of the largest events, amplitudes are also measured on the so-called "100x torsions" co-located with the Wood-Anderson insturments at four of the sites. These are optical instruments recording on 35 mm photographic film, but are not true Wood-Anderson instruments. Theoretically, the instrument response is the same, except that the static magnification is 100 rather than 2800. In reality, this is apparently not the case. Comparison of readings for the same events recorded on both instruments, where both are available, suggest that the gain is really about 200, if the Wood-Anderson gain is assumed to be the canonical 2800. Hutton and Boore (1987, in press) have obtained a similar number from an inversion for station corrections and the distance correction function. The current practice is to include 100x data with an empirical "station" (instrument) correction. This would apply to events since about 1980. It is not known how, if at all, 100x readings were included in magnitude estimates earlier than that.

McEvilly (personal communication) has commented that at least some Wood-Andersons in operation in northern California appear to have gains of about 2100, rather than 2800. This information emerges from laboratory tilt tests on the instruments to determine the static magnification. Johnson and Hutton tried this on the operational Wood-Andersons at Pasadena with inconclusive results. In the vault, in the dark, it seems nearly impossible to get free period measurements with two significant figures. The free period appears squared in the formula for static magnification.

In any case, the gain of the Wood-Anderson is irrelevant to the magnitude scale as long as all other forms of magnitude used are calibrated against M_L empirically. The problem could only conceivably appear in those rare large events where strong motion accelerograph readings, for example, were used to help compute the magnitude.

Perhaps a more serious problem is the matter of the distance correction, which appears to produce magnitudes somewhat less than the proper value at close stations and significantly higher than the proper value at large distances (Hutton and Boore, 1987, in press). At distances beyond about 300 km, magnitude estimates too large by up to 0.4 can occur. Since large events appear on scale only at large distances, there is a magnitude dependent bias in the M_L values. Hopefully, this difficulty does not affect the continuity of the catalog, because the same distance correction has been applied throughout. However, the effect is large enough to be quite obvious to the analysts who do the routine work. It is not known if Charles Richter or Violet Taylor was aware of this problem and, if so, if it affected the selection of stations to be included in magnitude estimates.

Develocorder Duration Magnitudes - (M_D) From about 1972 through 1977 and perhaps later, the main source of magnitudes for events too small to record on the Wood-Anderson instruments was duration magnitude (M_D) measured on the develocorders. Different analysts had their own approaches to accuracy for duration measurements; to 0.1 second accuracy in one case. Also, the overall result tended to differ systematically from analyst to analyst. It appears that the calibration used did not take into account station corrections of any sort.

Digital Coda Amplitude Magnitudes - (M_{CA}) With the demise of the develocorders, a method was sought to calculate magnitudes for the smaller events automatically on the triggered digital systems (CEDAR and CUSP) which replaced them.

A detailed description of the method used can be found in Johnson (1979). In short, coda amplitude is represented by an exponential function which is fit to two second averages of rectified amplitude in the time window after the S wave, where the signal is no longer clipped but has not yet subsided to the background noise level. In practice, the decay constant of the exponential curve is held fixed at a typical value, and only the amplitude scaling factor is fit to the data. This scaling factor, which is a function of instrumental gain, is then calibrated using events having M_L from Wood-Anderson readings.

Periodic recalibration is necessary because, in the long term, station gains do not remain constant. In routine processing this is done quarterly. Shorter time periods typically yield too few events with good M_L's for a meaningful calibration. Also, shorter time periods would probably be biased significantly by individual sequences. A magnitude estimate from an individual trace has a large error bar, typically 0.6 or larger depending on how many two second averages are available.

For M_L's smaller than about 3.8 (and larger than about 2.0, which is the about the smallest reliable M_L), M_L and M_{CA} show a tight, linear relationship (Figure 1). The scatter seems to be roughly 0.2, which is only slightly larger than the best possible uncertainty in the M_L itself. It may be that an M_{CA} averaged over the 25 or more stations typically recording a small earthquake may be more reliable than an M_L averaged over half a dozen Wood-Andersons, even though the latter is the standard.

However, the M_{CA} scale saturates at slightly above 4.0; we never see M_{CA} larger than 4.3. This may be due to the small number of recordings of codas that are available for the larger events. The lack of large event codas is a result of the lower frequency of occurrence of such events and the tendency of the computer triggering and recording programs to cut off well before the amplitude returns to the background noise level. Fortunately, we have good M_L's for virtually all events above 3.8 and the M_{CA}'s are not needed.

M_{CA} also runs into problems with multiple events. The fitting algorithm recognizes when an increase in amplitude occurs in what is supposed to be a coda and uses no data after that point. Also, the analyst has the option of chopping off the seismogram to avoid confusing the magnitude program. This is sometimes done for non-seismic noise as well as for aftershocks. If not enough data remain to compute a coda fit, magnitude has to be computed by other means; generally by visual comparison of the event with other (single) events in the same or similar location. Sometimes a small foreshock will adopt the magnitude of the main shock. In those cases, the M_{CA} is deleted and the magnitude is estimated visually.

For events less than about 0.8, M_{CA} does not appear to work well at all. This is because the averaging interval of two seconds is of the same order as the length of the coda. These events remain at 0.0 magnitude in the catalalog.

Helicorder Magnitudes - (M_H) For preliminary work, and for events which have no other magnitude, we often use the helicorder short-period vertical (mainly Benioff and Benioff-like instruments with a period of about one second). Amplitudes are read and used as if they were Wood-Anderson readings, with the same A_0 table. An empirical station correction is applied, which was once (long ago) computed for events which did have good M_L's. One problem with taking these number too seriously is that these instruments seem to require more maintenance than the Wood-Andersons and seem (due to telemetry?) not to come back with quite the same gain most of the time. The corrections are old, and since they do not affect the final catalog much, are rarely redone.

Another problem seems to be related to the systematic error in the A_0 distance correction discussed above. On-scale readings for the verticals tend to be at larger distances than on the Wood-Andersons, so magnitudes are often overestimated by a few tenths.

The first "public" magnitude for most minor felt earthquakes is M_H. Currently, this is superceded in a few days by an M_{CA}, which is typically a few tenths different and generally lower. This change can be quite confusing to the press. In some older time periods when the processing of the digital data is incomplete the M_H remains in the catalog.

Effect on the Catalog In current routine processing, a preliminary M_{CA} using a generic calibration is calculated immediately after each event is timed. If timing is more than about a week behind, an even more preliminary "pinked" location and magnitude may appear in the catalog (so called because data used to be put onto bright pink index cards which were merged with the Measuring Room card file). The magnitudes for these come almost exclusively from the helicorders (M_H).

Before the Monthly Listing is printed, a few quick checks are made. M_H or a preliminary M_L is inserted for events larger than 3.8. Any possible cases of large M_{CA}'s applied to foreshocks are checked, and the M_{CA} eliminated if necessary. Any events that were felt by people and, therefore, located on the spot for the press are checked against the catalog and any missing magnitudes added (generally M_H). The result is a usable, if preliminary, catalog.

At some later date, after all of the (mail-in) outside stations have been read for a given three-month period, all Wood-Anderson amplitudes are typed into the data base. M_L's are calculated and the M_{CA} calibration done for the quarter. Final M_{CA}'s are then computed. M_L supercedes M_{CA} in the catalog, if it is present, and M_{CA} in turn supercedes M_H. In the final catalog, the only M_H's left should be events completely missed by CUSP, which occasionally happens, or significant events which for one reason or another (like immediate aftershocks) have no M_{CA}. At this point, all the data is checked and marked off as final.

The status of each month of catalog data since the advent of digital recording is shown in Table 5.

■ Table 5. Catalog Status by Month

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1977	P	P	P	P	P	P	P	P	P	P	P	P
1978	F	F	F	F	F	F	F	F	F	F	F	F
1979	P	P	P	P	P	P	P	P	P	P	P	P
1980	P	P	P	P	Pnk	Pnk	Pnk	Pnk	Pnk	Pnk	Pnk	Pnk
1981	Pnk	Pnk	Pnk	Pnk	Pnk	Pnk	Pnk	Pnk	Pnk	Pnk	Pnk	Pnk
1982	Pnk	Pnk	Pnk	Pnk	Pnk	Pnk	Pnk	Pnk	Pnk	Pnk	Pnk	Pnk
1983	Pnk	Pnk	Pnk	Pnk	Pnk	Pnk	Pnk	Pnk	Pnk	F	F	F
1984	F	F	F	F	F	F	F	F	F	F	F	F
1985	F	F	F	F	F	F	F	F	F	P	P	Pnk
1986	F	F	F	F	F	F	P	P	P	P	P	P
1987	P	P	P	P	P							

F = final, Pnk = "pinked", P = preliminary

A large section of the 1981 through 1983 period has actually been timed, and digital seismograms are available, but the "pink" version is still used for any purposes requiring good magnitudes for large earthquakes or completeness for large earthquakes, because of missing events and missing magnitudes. The data await a human with enough time to do the final editing.

Because M_L's, and M_{CA}'s which are directly calibrated against M_L, were used for the "final" catalog produced over the past few years, that part is theoretically compatible with the pre-1974 period. (1975 and 1976 are not really final, although they are develocorder rather than digitally recorded data.) The intervening period depends heavily on M_H, which is not as reliable. The user should be wary.

COMPLETENESS OF THE SOUTHERN CALIFORNIA CATALOG

The southern California seismic network is one of the longest running networks in continuous operation in the world. This provides a unique opportunity to study long term patterns in seismicity and seismicity rates. In any such studies, however, the magnitude levels of completeness of the catalog and the continuity of the techniques for magnitude estimation are crucial. The current catalog is not uniform to the point that long term seismicity rates can be reliably studied.

For a number of reasons, the Caltech catalog of southern California earthquakes has several data gaps and widely varying magnitude levels of completeness. For instance, the coincidence of the installation of a new computer processing system with the Coalinga earthquake sequence in 1983 produced a five month period of untimed data. Because of a long term lack of man power, magnitude calibrations have not been calculated for several years of old data. Since 1975 only two years, 1978 and 1984, have been finalized (i.e. all of the necessary processing has been completed). New computer systems with increased processing capabilities have been installed and no new software modifications are planned so we are reasonably confident that the present system can handle the data input and that new data gaps will not be created. However, the residual problems restrict the research use of the data from southern California because phase data and seismograms are not available for times of data gaps and magnitude calibrations are incomplete for most years. In the following discussion we review the level of completeness of the catalog and the data processing that is needed to make all recorded data available for research.

Level of Completeness The discussion of magnitude estimation procedures in the last section described, in detail, the methods used for estimating magnitudes over the years at Caltech. The resulting levels of completeness of the Caltech catalog are summarized in Table 6.

▪ Table 6. Magnitude Levels of Completeness for the Southern California Catalog

$M \geq 4.0$	The whole catalog is complete at this level (since 1932). All magnitudes are M_L so the procedures used to determine them are nominally the same for the whole time period.
$3.0 \leq M \leq 4.0$	The whole catalog is complete at this level with the exception of 1933 (Long Beach earthquake sequence) and 1952 (Kern County earthquake sequence). From 1977 to 1983 some of the magnitudes are M_H since the finalization procedures (including entering Wood-Anderson amplitudes) have not been completed. The calibration of M_H to M_L is rough and not necessarily extremely accurate.
$2.5 \leq M \leq 3.0$	The catalog is complete at this level since 1975. During times when some of the computer-recorded data are still untimed (the data gaps in Table 8), the locations are calculated form 10-20 hand-timed phases and are not as accurate as the computer timed locations. Many of the magnitudes greater than or equal to 3.0 from 1977 to 1983 are M_H.
$1.5 \leq M \leq 2.5$	The catalog is complete at this level for the central parts of the network for times since 1977 when computer recorded data has been timed (see Table 9). In most cases, the M_{CA} magnitudes have not yet been calibrated against M_L (see Table 9).

Old Data Translation Four different processing systems and data formats have been used since 1977 when digital recording began. Because the old recording systems no longer exist on a Caltech computer, the goal is to translate all data into CUSP form so that the present system can be used to finalize the data (i.e., check the quality of the picks, add Wood-Anderson and helicorder amplitudes, and calibrate and calculate final magnitudes). The different data systems with their times of operation are listed in Table 7.

■ **Table 7. Caltech Data Systems 1977 - 1986**

Dates	System	Notes
01/1977 – 04/1980	CEDAR	No untimed events. Tapes are degenerating and will soon be unreadable. Mostly unfinalized.
05/1980 – 02/1981	UNIX	System collapsed under Mammoth. All events need to be timed.
03/1981 – 06/1983	Q-tape	Similar to CUSP and already translated. Five months untimed.
07/1983 – present	CUSP	Standard system. Ten quarters finalized.

The programs to translate CEDAR data and UNIX data have been written. The CEDAR data conversion should be started within a year, before the seismogram archive tapes become too degenerate and a substantial proportion of the data are lost.

Timing In the old system, after an event was triggerred and recorded on the on-line computers, it was written onto a FLING tape and transferred to the off-line computer for processing. If the off-line computer was not operational or if earthquakes were being recorded faster than they could be processed, the FLING tapes were stored for later processing. Processing of FLING data tapes includes demultiplexing, timing and locating the earthquake. This requires some computational resources and an average of eight minutes per event for an analyst to time. This is the most crucial step in the data recovery because, for events that have not been timed, phase arrival times, first motions and seismograms are not available. These data gaps are listed in Table 8.

■ **Table 8. Untimed Data Gaps for Southern California**

Time period	No. of events	Hours	Man-years
12/3/85 – 12/16/85	500	70	0.04
2/10/83 – 7/11/83	5000	666	0.36
1981 – 83 (a few large events)	60	8	—
5/80 – 2/81	7500	1000	0.53

The latest gap is being processed now after each day's current events. Generally, more than half of the analyst's time is devoted to the backlog. At the present rate, we expect to eliminate the 1985 backlog by the fall of 1987.

The 1985 gap was created when off-line processing was discontinued for four months to install a new computer. It was originally three months long but has been reduced to only 13 days. The 1980 and 1983 backlogs were created when new processing software systems were installed one week before the Mammoth earthquakes of May 25, 1980 and two weeks before the Coalinga sequence of May 2, 1983. The occurrance of these gaps has lead to the theory that large earthquakes are caused by on-line system software changes but are not affected by hardware. During the Q-tape period (1981 – 1983), some very long triggers and triggers that were recorded across two tapes (started on one and ended on the other) could not be loaded by that system. These tapes have been saved.

Finalization After an event is timed and located, the quality of the location is checked by an analyst by examining the completeness of timing (all near stations, some S waves, no huge residuals, etc.), the decoding of the time code, and the location (reasonable RMS, fixed depth if necessary, etc.). This is done in the QED editor in CUSP. At the same time, amplitudes from the helicorders and photographic (Wood-Anderson) seismographs are added.

Two types of magnitude are calculated. Wood-Anderson M_L is calculated from amplitudes of paper records using Richter's formulation. This is the standard magnitude and provides continuity with the 55 year historic catalog. Because the M_L calculation requires paper records, it is usually only available for events with $M_L \geq 2.5$. M_{CA} (coda amplitude) is calculated automatically by CUSP for most events by fitting an envelope to the amplitude decay of the trace. It is calibrated against M_L every quarter to correct for changes in station gain. Thus a pseudo-M_L is calculated for all earthquakes that is nominally consistent with the magnitudes that have been used in southern California for 60 years.

Because of the magnitude calibration procedure, the earthquake catalog is finalized by quarter after the M_{CA} calibration. This final stage has been reached for only 15 quarters in the last 10 years. About ten minutes of analyst time is needed for finalization of each event. The times involved are listed in Table 9.

▪ Table 9. Unfinalized Data Since 1977

Date	Timed	Quality checked	Amps Added	Final	Rearchive	No. of events	Hours
1977	yes	no	no	no	yes	5,000	833
1978	yes	yes	yes	yes	yes	6,000	50
1979	yes	no	no	no	yes	10,000	1,667
1/80 – 4/80	yes	no	no	no	yes	1,500	250
5/80 – 2/81	no	no	no	no	yes	7,000	2,100
3/81 – 2/83	yes	no	no	no	—	15,000	2,500
3/83 – 6/83	no	no	no	no	—	5,000	1,500
7/83 – 9/83	yes	yes	yes	no	—	2,000	100
10/83 – 1/85	yes	yes	yes	yes	—	done	—
10/85 – 12/85	partial	no	no	no	—	2,000	100
1/86 – 6/86	yes	yes	yes	yes	—	done	—
7/86 – present		in production					

This is a total of 9,000 hours of work or about 4.5 man-years of analyst time.

Magnitude Continuity As discussed in the previous section, we are not sure how magnitude estimation procedures used in the past may have differed from those used now. Thus for any study of seismicity rates in southern California, it would be highly desirable to have the phase and amplitude data for the whole catalog entered into a common data base so that magnitudes could be calculated for the whole time period using the same procedures. Having the phase data from the early part of the catalog in a computer file is obviously desirable for relocation and other studies. Arrival times are already on tape for 1960 to 1976. Entering the amplitudes for that period is estimated to take 2,000 hours. It would also take approximately 2,000 hours to enter the phase data and amplitudes for 1932 to 1959. Thus a total of 13,000 hours or about 7 man-years of work would put the whole catalog into a finalized, consistent form.

CUSP OFF-LINE PROCESSING FLOW

As a sequel to the last Network Bulletin's (Given *et al.*, 1986) description of the on-line seismic data recording and processing system currently used at Caltech, we here present a brief description of the portion of the CUSP (Caltech USGS Seismic Processing) system that performs all of the off-line data processing: demultiplexing, phase picking, location, magnitude determination and archiving. Because CUSP is complicated and there is little documentation, the system remains a mystery to many people, including some who use it every day. In the first part of this section, we will describe the program modules that a user might come into contact with, and show how they fit into the overall system. In the second part, we will follow some events through the processing stream. In the third, we outline how a user might gain access to CUSP data. This is not intended to be a self-contained instruction manual; at the moment that does not exist. Users will probably still have to locate a CUSP "guru" if they intend to become seriously immersed. CUSP has a great deal of jargon but, for the most part, this jargon is descriptive and is helpful in understanding the different parts of CUSP.

As an aid to understanding, different entities in this discription are represented in different type styles. Directory names are always enclosed in square brackets and capitalized (e.g. [CUSP.SRC]) and process states are simply presented in upper case (e.g. FREEZE). File names and file type suffixes are shown as follows: `FILENAME.TYP`, `.GRM`. Programs are represented thus: `PROGRAM`.

Cusp System Components The CUSP system consists of a of number modules which operate on CUSP data bases and other CUSP files. Active CUSP data is kept in several different data base files. These files have the file type suffix of `.KIN`, `.MEM` or `.GRM`, depending on their data type and format. The database manipulation subroutines that are used in the program modules are also fairly accessible and easy to use, so that data of any type may be kept in a CUSP data base.

CUSP is currently tied firmly to the Digital Equipment Corporation's RMS (Record Management System) that is available on the RSX and VMS operating systems. At Caltech, all the off-line seismic network processing is done using CUSP on a VAX 750 under the VMS operating system. Prior to September 1985, similar software ran on a PDP 11/70 under RSX-11M+. All CUSP code is written in FORTRAN.

CUSP data files are protected against corruption by unauthorized or careless users by VMS system level protections and priveleges. CUSP users involved in routine data processing are all members of the CUSP group and have many group priveleges, which allows them to work interchangibly with all the data and yet still leave their identity stamped onto the events they work with. At login time, each user runs a .COM procedure which defines the long list of symbols and logical names needed to operate CUSP.

CUSP system files exist in a series of directory trees with standardized names. The [CUSP] main directory tree, has subdirectories like [CUSP.SRC], [CUSP.LIB], etc. They contain the programs and various command procedures which make up the CUSP system. There is also a network specific directory tree, in our case [CIT]. A few of the subdirectories (e.g. [CIT.BASE]) contain various station or magnitude calibration information, often in ASCII form, or local command proceedures. Most [CIT] subdirectories (e.g. [CIT.87JAN]) are processing directories and contain seismic data. Each data directory contains two data bases; a CUSP.KIN file, which keeps track of the processing path and current state of each trigger and a CAT.KIN file, which is a preliminary hypocentral catalog of the earthquakes in the directory. The researcher will most commonly use data from the CAT.KIN.

As each event enters the system it is assigned a unique number called the CUSPID. Events in the CAT.KIN are keyed on the CUSPID number and also on origin time (T_0). The CUSPID is a more reliable event identifier because the origin time of an event can change when it is relocated or as time code errors are corrected. Hypocentral location, magnitude, number of phases picked, solution error, quarry identity (if applicable) and comments also reside in the CAT.KIN.

Another commonly used data base file is the .MEM file. One .MEM file exists for each event in the CAT.KIN of a given subdirectory. For example, if the CAT.KIN contains an event with CUSPID 700719, then a file called X700719.MEM should also be present. This file will reside either on disk, if the event is currently being processed, or on a FREEZE tape if phase picking is complete. It contains all the phase pick information for the event, pointers to the digital seismograms in the associated .GRM file, and a pointer to the ARKIVE tape (see below) if the event has been archived, plus much more. The contents of the .MEM file may be seen in ASCII form by running **EXPORT** and examining the resulting output file (**X700719.DCK**). This data base may be accessed directly by writing programs which use the **EVT** subroutines.

If an event is in an active state of processing, its .GRM file (for example: X700719.GRM) will also be present. A .GRM file is not a data base file but a sequential file that contains nothing but the digital seismograms for the given event strung end to end. Pointers contained in the X700719.MEM are necessary to interpret it.

Because the .MEM is the summary and map to an event, CUSP modules, like **QED**, read the whole .MEM file into a dynamic memory region. Access to the phase data from the event is, therefore, fast enough to do phase picking with interactive graphics (although the .GRM file must still be read from disk as needed). In this scheme consecutive CUSP modules may map to the .MEM structure in memory, read and modify data and never do a disk operation until all tasks are complete. At that time the modified .MEM structure is saved to a disk file.

State Driven Data Flow CUSP is a state run processing system. That is, events in an active processing subdirectory are scheduled for certain processes ("states"), at various priority levels that determine the order in which processes are run ("ranks"). For example, when an event has been processed to the point where it is ready to be timed interactively it is in a GREEN state. No other process further down the schedule list may operate on that event until its phases have been interactively timed (the GREEN process). The scheduling and current state of each event in a subdirectory is kept track of in the CUSP.KIN data base.

CUSP processes are run either in interactive or batch mode. When run, they then operate on all events in a directory which are in the state that corresponds to that process but have no CUSP.KIN entries at a lower rank. If, for example, event 700719 is scheduled for ARKIVE 100, GREEN 100, and CLEAN 1000, then the event must be archived and timed (GREEN) before it can be cleaned up and deleted from the subdirectory (CLEAN). Event 700719 is "in the GREEN state" and "the ARKIVE state". Because GREEN and ARKIVE have the same rank they may be run in any order but the CLEAN process will skip over this event until both GREEN and ARKIVE have completed because they have a lower rank.

The scheduling and status of events in the CUSP.KIN is maintained by the individual CUSP modules. For example, when an event is timed (using QED) the GREEN entry in the CUSP.KIN is deleted and an entry for the next process is added. What this next process will be depends on the result of the current process (exit status). In this example if the event turns out to be a local earthquake it is scheduled for LOCAL 100; a teleseism would be scheduled for WORLD 100. When archiving is done, the ARKIVE entry disappears; no new one is added. Each event is thus shepherded through the intertwined chains of processing steps and, unless it is purposely or accidently deleted, it never gets lost.

Each of the different processes that are run on the seismic events represents one or more FORTRAN programs, referred to as CUSP modules. Examples include demultiplexing an event from the on-line system, timing it, archiving it, computing a coda magnitude on it, etc. Most CUSP modules belong to what is called the Q scenario. A "Q module" works on a single events which is already resident in a dynamic memory region. Setting up the memory region and loading the proper .MEM file into it is either performed by calling CUSP utility routines in command or batch files, or by using the interactive timing program QED, which is actually a suite of Q modules. Most commands used in QED actually call individual Q modules which operate on the .MEM file image.

If the same process (e.g. magnitude calibration) must be performs successively on most or all event in a particular CAT.KIN, the "Z scenario" is used. In both the Z and the Q cases, the user's code is written as a subroutine which is called by ZMAIN or QMAIN, which perform any necessary operation on the data.

The following description is intended to trace an individual event through the processing chain:

Once trigger processing is finished for an event on the on-line system, the .EVT file (header information plus multiplexed seismograms) is available to be copied over the Ethernet from the on-line PDP 11/34 to the off-line VAX 750. A batch procedure (HARVEST), which is running continually on the VAX, looks for new files every 10 minutes. The only time that HARVEST does not run is when the seismicity is so high and the on-line system so severely loaded, that the Ethernet transfer cannot gain sufficient computer resources on the on-line system to run.

.EVT files are copied every day to a tape from both the primary and the backup on-line system (FLING). If the Ethernet transfer and processing is keeping up with the recording, the data are redundent and the tapes are simply recycled after processing is finished and checked. If not, data are buffered on the FLING tapes until the events can be loaded from the tapes onto the VAX for processing (DEFLING).

At Caltech, the active processing directories are [CIT.N34] and [CIT.S34] (named for the two on-line systems, which are on the north and south sides of the room) for current activity, and [CIT.HOT], [CIT.COLD], and [CIT.MOLD] for our various backlogs.

All events passing out of HARVEST or DEFLING in one of these directories are scheduled for demultiplexing (DEMULT). DEMULT produces a .MEM file and a .GRM file, containing demultiplexed seismograms, for each trigger. Decoders are run on the WWVB and IRIG time traces. If it is available, the WWVB decode is used for the event time. If it is not, then IRIG is used. If neither is available, which happens for 1 to 2% of events, the on-line system real-time clock is used. DEMULT is also set up to run on a continuous basis, but seldom does because of disk space limitations on the VAX.

In addition to the next steps in the processing chain, every event coming out of DEMULT (or later generated by CLONE) is immediately scheduled for ARKIVE (and for CLEAN at a rank higher that any other CUSP process). Since the archive tape contains only raw seismograms, the ARKIVE step may happen at any time during processing after DEMULT.

Following DEMULT, a certain amount of automatic preprocessing is available. Under the guise of a batch procedure called GNOME, several Q modules, including an automatic P-picking pass followed by a hypocentral location and coda-amplitude magnitude determination, are run. This produces a preliminary catalog, with about 80% of the hypocenters being reasonably reliable. However, the P-picker is easily confused by multiple events in the same trigger and by telemetry noise , so GNOME works less well when the seismicity is high. In addition, DEMULT is often run just before the event is to be timed by an analyst, therefore, the GNOME step is skipped.

The output state of GNOME is GREEN; named for the green screen of the Tektronix 4014 terminal, where the seismograms are displayed. An analyst may look at an event in any state, provided that the .MEM and .GRM files are present, but there is seldom reason do do so unless the event is in the GNOME or GREEN state. The first job of the analyst is to determine if a trigger is actually seismic and, if it is, to distinguish local events from regional events and teleseisms, each of which has a different output state from GREEN. If it is a local event, as many P and S picks as possible are made, and the event interactively located. The events presented on the screen are compared with a hardcopy listing from the on-line system to make sure that no events have been lost. If more than one event is present in a trigger, copies (called "clones") of the .MEM and .GRM files are made for each new event with new CUSPID numbers. Teleseisms and regional events may also be timed, but are not located.

Local events then pass to the LOCAL state where they are scheduled for a series of Q modules similar to those under GNOME. The catalog is updated at this point.

For local events, a Versatek output called a TROUT (*tr*ace-*out*put) listing is made at this stage. It is similar to a HYPO71 listing and contains time, hypocentral location, picks, residuals, etc., but with seismogram traces included as well. Traces for all stations that have picks and all stations where the coda-amplitude magnitude (M_{CA}) computation was successful are included (see Johnson 1979, Hutton and Johnson 1987). The TROUT listings are filed by date, and are often the first place a user goes to look at a particular event.

When an event emerges from LOCAL, it is scheduled for CLEAN. If ARKIVE has been run, saving a copy of the .GRM file, CLEAN deletes the .GRM file, which occupies a large amount of disk space, and transfers the .MEM files and catalog entry in the CAT.KIN to a holding directory called [CIT.CARB].

In [CIT.CARB] an interpolation is done to determine the correct time of events that had no sucessfully decoded WWVB or IRIG time code. From there, the events are distributed to the individual monthly directories.

At some later time, phases from our few stations that are not telemeted are typed into the data base (using QED). Amplitudes read from the photographically recorded Wood-Andersons are also entered. Every three months, we calibrate the constants used in the coda-amplitude magnitude determination against the events with Wood-Anderson readings (Hutton and Johnson 1987) and all the M_{CA}'s for that quarter are recomputed. After a final check for mistakes and for missing events, the three monthly directories for the quarter are declared "final" and FREEZE tapes are made. The FREEZE tapes contain images of the .MEM files and are then the primary source of data. If a worker is only interested in retrieving phase data the FREEZE tape is sufficient. If seismograms are desired the .MEM files on the FREEZE tapes are necessary to decode the .GRM file that are saved on the ARKIVE tapes. Multiple copies of FREEZE tapes are kept at Caltech in Pasadena and USGS Western Region Headquarters in Menlo Park. After the FREEZE tapes have been made, the .MEM files are deleted from the disk, leaving only the CAT.KIN (and the CUSP.KIN which at this point contains no entries). The CAT.KIN remains on disk indefinitely.

CAT.BIN files, which are binary catalogs, are made for each monthly directory and then concatenated into yearly .BIN files in the catalog directories [CIT.CAT] and [CIT.PNK] (which handle the backlogs differently).

Access to Cusp Data There are several levels at which the user may access data from the CUSP data bases. In most cases this can be done with software that is already written. However, a basic CUSP tree structure and certain modules must be present if a user wished to use CUSP data in their "native" form. No special tree structure is needed to use data that have been converted to non-CUSP formats.

The briefest form of the Network data is, of course, the earthquake catalog. This is a concatenation of binary data extracted from the many monthly directories. Programs exist to sort and reformat these data. ASCII card image versions of the catalog also exist, on disk and on the catalog tape, which is fairly widely distributed.

The next level of available data is the phase data. For a user with access to a CUSP directory structure, the most complete form is the .MEM files themselves. For recently processed data, the .MEM files may still be resident on disk and can be copied to the user's directory. If they are not resident, they can be recovered from the FREEZE tapes, of which there is one for every month. Software exists (WINNOW) to do some simple selection from the data on a FREEZE tape. For small amounts of data, EXPORT can be used to produce ASCII versions of .MEM data base files. Another program, RDFRZ allows users to produce ASCII versions of .MEM files. Recently, an effort has been made to supply yearly ASCII phase tapes in HYPO71 format. In the future we plan to put all the .MEM files on-line on laser disk.

Digital seismograms may be accessed from the ARKIVE tapes. About two such tapes are written every week, and the events are in the order in which they were processed rather than the order in which they happened. All pointers necessary for their access are found in the .MEM files for the events in question. At the moment, we have no plans to distribute seismogram data in any form other than CUSP readable tapes.

SYNOPSIS OF SEISMICITY

The seven month seismic quiescence that had reigned in southern California since November of 1985 was dramatically ended in July 1986 by the occurrance of major sequences in North Palm Springs on July 8 (M_L = 5.6) and off the coast at Oceanside on July 15 (M_L = 5.3). An even bigger sequence began on July 21 (M_L = 6.4) in Chalfant Valley north of Bishop. Although this sequence was north of the Southern California Network, it was recorded by Network stations and contributed substantially to the data processing load. In addition, the overall rate of activity in southern California, exclusive of these sequences, returned to a normal (higher) rate, underscoring the end of the seven month quiet period.

The occurrence of these three large earthquakes in California within a two week period caused much speculation (especially among the media) that they might be related. However, based on the average rate of events of this size in the state such a random temporal clustering might be expected to occur, on average, every 41 years.

A total of 14,143 earthquakes and 606 blasts were recorded, located and archived by the Network in the second half of 1986 (Figure 2). 675 of these earthquakes were greater than or equal to M_L 3.0 (Figure 3), including 94 aftershocks of the North Palm Springs earthquake, 89 aftershocks of the Oceanside earthquake and 405 quakes located north of 36° 30′; mostly associated with the Chalfant Valley earthquake. The remaining 87 events greater than of equal to M_L 3.0 were scattered throughout the region (Figure 3). Table 10 lists the significant earthquakes (M_L $\geq$ 3.0) in southern California from July to December 1986. To keep the table a reasonable size, only events of M_L $\geq$ 4.0 are listed for the areas within 20 km of the North Palm Springs and Oceanside earthquakes. Some of the larger Chalfant Valley earthquakes are also included but the list is not complete.

As in previous Bulletins, southern California has been divided into eleven sub-regions (Figure 4). This practice, like that of considering only earthquakes in southern California, is arbitrary, but useful in discussing characteristics of seismicity in a manageable context. Plots summarizing the activity of each sub-region over the past four years are given in Figures 5a and 5b. In this section we will first discuss the major sequences at North Palm Springs and Oceanside. This will be followed by discussions of those sub-regions that have been of seismic interest during this reporting period.

North Palm Springs Earthquake – July 8, 1986 This earthquake occurred at 9:20 UTC on July 8, 1986. It was widely felt in southern California and caused approximately $3 million in damage. The epicenter was located between the Banning and Mission Creek strands of the San Andreas fault zone in San Gorgonio Pass (sometimes mistakenly called Banning Pass). The official Caltech location is: 33° 59.9′, -116° 36.4′, at 11.48 km depth. A preliminary magnitude of 5.9 was released by the Caltech Seismological Lab and has been published and widely circulated, however, the final M_L has been revised to 5.6. There were only five aftershocks greater than or equal to M_L 4.0, the largest (M_L = 4.6) occurring eleven days after the main shock. The details of this sequence as described by Jones *et al.* (1986) will be summarized here.

Prior to this event the area had been quiet at the M_L 5.0 and larger level since 1948. In that year a M_L 6.5 earthquake occurred in the vicinity of Desert Hot Springs. This event seemed to signal the culmination of a period of higher than normal activity that included the 1944 Kitching Peak Sequence (M_L = 5.3) and the 1947 Morongo Valley sequence (M_L = 5.5)(Figure 6).

The preferred plane of the focal mechanism solution of the main shock indicates pure right lateral strike-slip motion on a plane that strikes N60°W and dips at 45° to the northeast (Figure 3). This strike is consistent with the strike of the San Andreas strands in the region but the shallow dip was unsuspected. It is also surprising that there was no component of dip-slip during the main shock on the such a shallowly dipping structure. Dip-slip motion was evident in the focal mechanism solutions of some of the aftershocks.

This same plane is well delineated by the distribution of aftershocks in cross-section (Figure 8). The aftershocks strongly suggest the existance of a large, coherent structure that is at least 15 km long in map view and extends from a depth of 4 km down to about 15 km. Extrapolation of this structure up dip indicates that it is most likely expressed at the surface as the Banning fault.

Jones *et al.* (1986) have noted that the planar structure indicated by the aftershocks is straight and contiuous along strike to the northwest while the surface traces of the San Andreas system change to a more east-west orientation. This suggests that a major, thoughgoing structure may exist at depth in the area of San Gorgonia Pass and that it is not reflected in the surface geology. If this is true, the possibility of a great earthquake rupturing through San Gorgonio Pass is greater than previously supposed.

Oceanside Earthquake – July 13, 1986 The main shock of this sequence occurred about 55 km off the southern California coast, southwest of the town of Oceanside and 70 km northwest of San Diego (Figure 9). The origin time was July 13, 1986 at 13:47 UTC. The catalog location is: 32° 58.2′ , -117° 52.2′ with the depth fixed at 6 km. The final M_L is 5.3. Because they were offshore, in an area of sparse station coverage, locations for events in the sequence were less well resolved than most catalog locations and focal depths were fixed. The sequence appears to be associated with the northern end of the San Diego Trough–Bahia Soledad fault zone: a northwest trending, bathymetrically defined fault zone that parallels the coastline and extends southward past the latitude of Ensenada. The focal mechanism indicates either right-lateral strike slip displacement on a nearly vertical plane striking N10°E or left-lateral strike slip motion on a plane stiking N83°W, dipping about 60° to the north (Figure 3). Neither of these planes is consistent with the northwest trend of known offshore structures.

Only one other moderate earthquake has occurred in the area off the coast of San Diego during the 55 year history of network coverage; a M_L 5.9 quake located near the southeast tip of San Clemente Island on December 26, 1951 (Richter, 1958). This event caused no damage.

Some perculiar aspects of the seismicity in this region are evident in the time/distance plot shown in Figure 10. Several of the larger events ($M_L \geq 4.0$) have few or no aftershocks. This is in stark contrast to the aftershock sequence of the Oceanside earthquake that was unusually intense and protracted. Figure 10 also emphasizes that the Oceanside mainshock (the largest circle) is located at the extreme west of the aftershock distribution, suggesting unilateral rupture propagation. A solitary M_L 4.3 event occurred on February 22, 1983; about 12 km to the northwest of the future epicenter of the Oceanside earthquake. Later, on September 7, 1984, the area was activated by a sequence (M_L = 4.3) that continued for about 14 months. This activity seems to have subsided about seven months before the Oceanside mainshock, coinciding with a seven month quiescence that occurred throughout southern California.

An appearent relationship between earthquakes in the epicentral area of the Oceanside earthquake and events in the San Diego area will be discussed below.

Imperial Valley – Region 1 An intense swarm of earthquakes began on September 6, 1986 south of the U.S–Mexico border (Figure 5a, Figure 11). The swarm was located at the southern end of the Imperial fault were it steps right to the Cerro Prieto fault near the Cerro Prieto volcano. The swarm included more than 200 events, eleven of which were greater than or equal to M_L 3.0. The largest was M_L 3.6.

Because the swarm occurred outside the Network the locations of these events are almost all of "C" quality and, therefore, have horizontal error estimates of up to 5 km. All depths were fixed at 6.0 km. Also, focal mechanisms could not be well constrained. However, even with these large error bars the distribution of the swarm suggests the existance of a sub-perpendicular structure connecting the Imperial and Cerro Prieto faults.

San Diego – Region 4 Even if the Oceanside earthquake sequence is not considered the rate of seismic activity in this sub-region was about 400% higher than normal (Figure 12a). This high level was due to seismicity in San Diego Bay and in an area offshore, about 25 km to the southwest (Figure 9). The current episode of seismic activity in the San Diego area began last year, on June 18, 1985, with a swarm of earthquakes (M_L 3.9, 4.0 and 3.8) right under downtown San Diego (Norris *et al.*, 1986). Such activity had occurred only once before when a smaller swarm (M_L 3.7, 3.6) shook the area in 1964. Higher than normal seismic activity continued this year with a M_L 3.0 event on July 13, 1986 (about two hours before the Oceanside earthquake) and a M_L 4.1 quake on October 29, 1986. The focal mechanism for this M_L 4.1 quake has one plane that strikes N40°W and dips steeply to the northeast (Figure 3). This orientation is consistent with the Rose Canyon fault; the major on-shore fault in the San Diego area.

There appears to be a temporal correlation between earthquakes near San Diego and activity in the area of the Oceanside sequence, 70 km away (Heaton, 1987). The San Diego swarm of June 18, 1985 occurred only thirty-eight hours after a M_L 3.9 quake in the epicentral area of the future Oceanside event. On July 13, 1986 a M_L 3.0 event occurred in the San Diego area about two hours before the Oceanside mainshock. Twenty-five days later, on August 8, 1986, a swarm of quakes (M_L 3.0, 3.4, 3.1, 3.1 and 3.6) began about 25 km southwest of San Diego in an area that had previously been quiet. On October 29, 1986 another strongly felt quake (M_L = 4.1) rocked San Diego.

San Bernardino – Region 7 The large increase of activity in this sub-region is, of course, a result of the North Palm Springs earthquake sequence that was discussed above. However, Figure 12b illustrates that the rate of seismicity in this sub-region increased by about 30% over the prevous year exclusive of an area with a radius of 15 km around the North Palm Springs mainshock. (The rate change is more appearent in the plot if you look down the time-number curve with your eye just above the plane of the paper.) The idea that this earthquake affected other structures in the area is supported by two different lines of evidence. First, a small cluster of earthquakes occurred four days after and 12 km northeast of the main shock. These events appear to have occurred on the Morongo Valley fault; a fault that is nearly perpendicular to the Banning fault (Figure 7). Because of its proximity to the mainshock this group of events was not include in 30% increase sited above. Second, evidence of slip was observed on the southern San Andreas fault from 43 to 86 km away from the mainshock (Williams *et al.*, 1986). Also Fagerson *et al.* (1986) report that three creep events were recorded by a creep meter on the San

Andreas fault 86 km from the main shock. These creep events were not coseismic but occurred 33 hours after the quake (1.4 mm), five and a half days after the quake (2.0 mm) and 14 days after the event (amount of slip uncertain).

It is possible that all these fault movements, including the North Palm Springs sequence, were caused by some regional stress event but this explanation seems somewhat less likely because neither the creep events nor the regional increase in seismicity preceded the North Palm Springs mainshock.

Santa Barbara – Region 11 The small increase in activity in the Santa Barbara region in Figure 5b was caused by a M_L 4.0 earthquake near Solvang on November 6, 1986. The focal mechanism for this event indicates oblique thrust movement on a northwest striking plane (Figure 3).

REFERENCES

Cockerham, Robert S. and Edward J. Corbett, 1987, The July 1986 Chalfant Valley, California, Earthquake Sequence: Preliminary Results: BSSA, v. 77, no. 1, p. 280-289.

Fagerson, Sally H., John N. Louie, Clarence R. Allen and Kerry E. Sieh, 1986, Measurements of Triggered Slip on the Southern San Andreas Fault Associated with the North Palm Springs Earthquake (abs.): EOS, v. 67, no. 44, p. 1090.

Given, D. D., R. Norris, L. M. Jones, L. K. Hutton, C. E. Johnson, S. Hartzell, 1986, The Southern California Network Bulletin, January through June, 1986: U.S. Geological Survey Open File Report 86-598, 28 p.

Heaton, Thomas H., 1987, Anomalous Seismicity in the San Diego Coastal Region, *in* Physical and Observational Basis for Intermediate-term Earthquake Prediction: U.S.G.S. Open-file Report, [in preparation].

Hileman, James A., Clarence R. Allen and John M. Nordquist, 1973, Seismicity of the Southern California Region, 1 January 1932 to 31 December 1972: Contribution No. 2385, Division of Geological and Planetary Sciences, Seismological Laboratory, California Institure of Technology, Pasadena, Ca., 487 p.

Hutton, L. K. and D. M. Boore, 1987, The M_L Scale in Southern California: [submitted to BSSA].

Hutton, L. K., C. E. Johnson, 1987, Routine Coda Decay Measurements from the Southern California Network: Seism. Res. Letters, v. 58, p. 28.

Hutton, L. K., J. B. Minster and C. E. Johnson, 1979, Seismicity Trends in Southern California (abs.): EOS, v. 60, p. 883.

Johnson, C. E., 1979, I. CEDAR - An Approach to the Computer Automation of Short-period Local Seismic Networks: Ph.D. dissertation, California Institute of Technology, 332 p.

Jones, Lucile M., L. Katherine Hutton, Douglas D. Given and Clarence R. Allen, 1986, The North Palm Springs, California, Earthquake Sequence of July 1986: BSSA, v. 76, no. 6, p. 1830-1837.

Lee, W. H. K. and J. C. Lahr, 1975, HYPO71 (revised): A Computer Program for Determinating Hypocenter, Magnitude, and First Motion Pattern of Local Earthquakes: U.S.G.S., Open-file Report 75-311, 113 p.

Richter, C. F., 1935, An Instrumental Earthquake Magnitude Scale: BSSA, v. 25, p. 1-31.

Richter, C. F., 1958, Elementary Seismology: W. H. Freeman and Co., San Francisco, 768 p.

Williams, Patrick, Sally Fagerson and Kerry Sieh, 1987, Triggerd Slip of the San Andreas Fault after the July 8, 1986 North Palm Springs Earthquake (abs.): EOS, v. 67, no. 44, p. 1090.

■ Table 10. Significant Southern California Earthquakes

All event of $M_L \geq 3.0$. Only events of $M_L \geq 4.0$ are listed for the North Palm Springs, Oceanside and Chalfant Valley sequences.)

YEAR	MO	DY	HRMN	SEC	LAT	LON	Z	Q	M	TYP	RMS	NPH	CUSPID
1986	JUL	2	811	3.16	33.9896	-117.2290	-6.00	C	3.1	M_{CA}	0.14	46	127155
1986	JUL	5	324	22.97	35.0802	-119.0912	-18.11	A	3.1	M_{CA}	0.23	39	700799
1986	JUL	5	1411	59.85	35.6980	-117.6450	-7.50	A	3.1	M_{CA}	0.14	42	700811
1986	JUL	6	1634	37.48	32.4941	-115.2387	-6.00	C	3.1	M_{CA}	0.35	24	700842
1986	JUL	7	913	22.69	34.1491	-117.7447	-5.46	A	3.0	M_{CA}	0.17	67	700871
1986	JUL	8	40	31.55	35.8509	-121.1074	-6.00	C	3.6	M_{CA}	0.66	24	700904
1986	JUL	8	920	44.52	33.9985	-116.6064	-11.69	A	5.6	M_L	0.31	162	700917
1986	JUL	8	924	12.82	34.0314	-116.6566	-6.00	C	4.4	M_H	0.14	13	700919
1986	JUL	8	1022	40.62	33.9667	-116.6167	-6.00	C	4.4	M_H	0.28	2	127946
1986	JUL	8	1555	26.16	33.9667	-116.6167	-6.00	C	4.0	M_H	0.69	2	127968
1986	JUL	9	12	32.11	33.9871	-116.5692	-6.00	C	4.4	M_H	0.24	8	127924
1986	JUL	13	1125	34.99	32.6466	-117.1383	-10.00	C	3.0	M_{CA}	0.41	41	127297
1986	JUL	13	1347	8.20	32.9707	-117.8698	-6.00	C	5.3	M_L	0.54	122	127298
1986	JUL	13	1401	33.01	32.9896	-117.8493	-12.00	C	4.6	M_H	0.28	43	127300
1986	JUL	14	32	46.21	32.9704	-117.8027	-10.00	C	4.0	M_{CA}	0.40	65	601649
1986	JUL	15	317	40.38	34.0046	-116.8988	-11.37	A	3.1	M_{CA}	0.15	26	601835
1986	JUL	16	708	57.62	31.9549	-115.6151	-6.00	D	3.1	M_{CA}	0.46	23	601982
1986	JUL	17	2035	15.02	33.9888	-116.6493	-6.22	A	4.0	M_{CA}	0.19	112	702983
1986	JUL	17	2154	45.16	33.9911	-116.6486	-7.38	A	4.4	M_L	0.25	145	702997
1986	JUL	18	1700	36.85	36.0926	-117.8490	-1.50	A	3.7	M_{CA}	0.17	45	602301
1986	JUL	18	1702	50.60	36.0981	-117.8490	-2.87	A	3.4	M_{CA}	0.16	34	602302
1986	JUL	18	1855	43.04	36.0901	-117.8546	-2.14	A	3.1	M_{CA}	0.15	40	602331
1986	JUL	19	224	43.91	36.3136	-120.3641	-13.63	C	3.1	M_{CA}	0.17	19	703230
1986	JUL	19	827	52.79	35.9150	-117.7156	-6.00	C	3.0	M_{CA}	0.47	43	703273
1986	JUL	19	1321	0.55	36.0912	-117.8470	-2.59	A	3.2	M_{CA}	0.15	43	602456
1986	JUL	19	1918	19.08	36.0896	-117.8514	-2.27	A	3.3	M_{CA}	0.17	46	602489
1986	JUL	20	1429	46.27	37.5830	-118.4497	-6.00	C	5.9	M_L	0.15	24	602580
1986	JUL	20	1838	51.87	37.6417	-118.3733	-6.00	C	4.8	M_H	0.32	20	602637
1986	JUL	21	312	9.60	37.7224	-118.3578	-6.00	D	4.3	M_H	0.41	49	602704
1986	JUL	21	1115	22.02	37.5799	-118.4682	-6.00	C	4.6	M_H	0.23	37	602753
1986	JUL	21	1442	26.72	37.5425	-118.4440	-6.00	C	5.9	M_L	0.19	45	602779
1986	JUL	21	1445	21.04	37.5833	-118.4167	-6.00	C	4.6	M_H	0.36	2	127724
1986	JUL	21	1451	8.77	37.5988	-118.3198	-6.00	C	5.4	M_L	0.28	22	602780
1986	JUL	21	1453	58.12	37.5833	-118.5833	-6.00	C	4.9	M_L	0.00	1	127728
1986	JUL	21	1454	39.16	37.5833	-118.4167	-6.00	C	4.5	M_H	0.00	1	127729

■ Table 10. Significant Southern California Earthquakes (continued)

YEAR	MO	DY	HRMN	SEC	LAT	LON	Z	Q	M	TYP	RMS	NPH	CUSPID
1986	JUL	21	1457	50.15	37.6071	-118.6656	-6.00	C	4.7	M_H	0.73	12	602781
1986	JUL	21	1458	58.16	37.5833	-118.4167	-6.00	C	4.0	M_H	0.00	1	127731
1986	JUL	21	1511	30.77	37.5973	-118.4857	-6.00	D	4.7	M_H	0.35	16	602783
1986	JUL	21	1519	35.65	37.5858	-118.4566	-6.00	D	4.5	M_H	0.32	17	602784
1986	JUL	21	1705	32.28	37.6548	-118.3978	-6.00	D	4.6	M_H	0.37	35	602802
1986	JUL	21	2207	18.73	37.6476	-118.5024	-6.00	C	5.4	M_L	0.23	17	127368
1986	JUL	21	2209	22.11	37.6131	-118.5686	-6.00	D	4.7	M_H	0.11	4	602845
1986	JUL	22	25	19.00	36.0767	-117.8626	-2.64	A	3.3	M_{CA}	0.16	37	703797
1986	JUL	22	621	52.95	37.4455	-118.3809	-6.00	C	4.1	M_H	0.33	42	602941
1986	JUL	22	1224	50.35	37.5343	-118.4813	-6.00	C	4.6	M_L	0.26	41	603004
1986	JUL	22	1226	15.46	37.5833	-118.4167	-6.00	C	4.0	M_H	0.00	1	127824
1986	JUL	22	1333	58.92	37.6266	-118.3856	-6.00	D	5.0	M_L	0.26	39	127371
1986	JUL	22	1348	59.00	37.6205	-118.3984	-6.00	D	5.2	M_H	0.28	50	603020
1986	JUL	22	1829	44.31	37.5182	-118.3994	-6.00	C	4.4	M_H	0.19	23	603062
1986	JUL	22	2016	57.93	37.7847	-118.3182	-6.00	D	4.4	M_H	0.41	22	603080
1986	JUL	22	2022	24.69	37.7714	-118.3767	-6.00	D	4.2	M_H	0.49	16	603081
1986	JUL	25	544	3.68	34.4241	-118.4069	-10.68	A	3.0	M_{CA}	0.27	72	704430
1986	JUL	28	1300	12.91	36.1690	-120.2038	-6.00	C	3.0	M_{CA}	0.32	21	704830
1986	JUL	29	817	41.61	32.9333	-117.8408	-10.00	C	4.3	M_H	0.43	83	603888
1986	JUL	29	817	41.84	32.9448	-117.8307	-10.00	C	4.1	M_{CA}	0.30	47	704924
1986	JUL	29	957	57.39	37.6121	-118.4741	-6.00	C	4.6	M_L	0.23	38	603895
1986	JUL	30	641	53.03	37.5894	-118.4618	-6.00	C	4.8	M_L	0.16	38	603969
1986	JUL	31	722	40.46	37.4731	-118.3722	-6.00	C	5.9	M_L	0.22	47	604071
1986	JUL	31	728	3.83	37.5333	-118.4167	-6.00	C	4.4	M_H	0.28	3	127743
1986	AUG	8	2051	47.07	32.5455	-117.3382	-6.00	C	3.0	M_{CA}	0.23	25	605035
1986	AUG	9	52	29.27	32.5002	-117.3985	-6.00	D	3.4	M_{CA}	0.28	45	605052
1986	AUG	11	19	41.92	32.5365	-117.3462	-6.00	C	3.1	M_{CA}	0.22	33	605235
1986	AUG	11	26	41.00	32.5532	-117.3317	-6.00	C	3.1	M_{CA}	0.26	31	605237
1986	AUG	15	1915	6.21	34.6200	-113.1500	0.00	A	3.0	M_{CA}	0.28	8	707080
1986	AUG	16	2119	17.85	33.5720	-118.9545	-10.18	B	3.0	M_{CA}	0.26	39	605751
1986	AUG	21	657	15.43	31.7040	-116.0003	-6.00	D	3.2	M_{CA}	0.35	15	707550
1986	AUG	21	1742	37.67	34.6200	-113.1500	0.00	A	3.1	M_{CA}	0.73	8	707577
1986	AUG	24	1248	9.22	32.9795	-115.8795	-12.81	A	3.2	M_{CA}	0.17	32	606270
1986	AUG	27	1828	29.46	34.6200	-113.1500	0.00	A	3.1	M_{CA}	0.22	2	708082
1986	AUG	28	1014	16.29	32.4908	-117.4199	-6.00	C	3.6	M_{CA}	0.33	52	606558

YEAR	MO	DY	HRMN	SEC	LAT	LON	Z	Q	M	TYP	RMS	NPH	CUSPID
1986	AUG	28	1632	14.66	33.9170	-116.2712	-7.09	A	3.2	M_{CA}	0.19	64	606583
1986	AUG	29	644	42.97	35.8870	-120.4512	-10.78	A	3.6	M_{CA}	0.20	42	606615
1986	AUG	30	2058	23.23	34.2125	-119.5256	-11.38	C	3.0	M_{CA}	0.20	28	606699
1986	SEP	1	1943	3.90	35.8011	-120.3753	-8.63	C	3.0	M_{CA}	0.19	17	708385
1986	SEP	6	2005	15.48	32.4305	-115.1234	-6.00	C	3.0	M_{CA}	0.38	21	607067
1986	SEP	7	103	31.10	32.3964	-115.1644	-6.00	C	3.3	M_{CA}	0.38	24	607077
1986	SEP	7	109	19.25	32.4349	-115.1162	-6.00	C	3.2	M_{CA}	0.29	15	607078
1986	SEP	7	111	1.84	32.4190	-115.1287	-6.00	C	3.6	M_{CA}	0.48	21	607079
1986	SEP	7	113	5.46	32.3634	-115.0557	-6.00	D	3.3	M_H	0.40	6	128366
1986	SEP	7	235	6.39	32.4316	-115.1207	-6.00	C	3.1	M_{CA}	0.47	22	607087
1986	SEP	7	417	37.89	32.4228	-115.1416	-6.00	C	3.1	M_{CA}	0.47	17	607109
1986	SEP	7	432	35.38	32.4429	-115.1291	-6.00	C	3.4	M_{CA}	0.45	20	607112
1986	SEP	7	550	26.02	32.3834	-115.1604	-6.00	C	3.5	M_{CA}	0.53	36	708773
1986	SEP	7	640	10.41	32.4293	-115.1239	-6.00	C	3.4	M_{CA}	0.48	19	607133
1986	SEP	7	1314	1.99	32.3805	-115.1185	-6.00	C	3.3	M_{CA}	0.46	17	607170
1986	SEP	9	842	29.38	31.6071	-115.8873	-6.00	D	3.0	M_{CA}	0.46	15	607286
1986	SEP	12	2338	10.42	36.2864	-120.4499	-6.00	C	3.3	M_{CA}	0.33	19	607508
1986	SEP	18	759	47.93	37.6189	-118.4302	-6.00	C	4.2	M_H	0.23	17	607801
1986	SEP	19	626	33.98	36.3117	-120.3237	-6.00	C	3.1	M_{CA}	0.21	20	709602
1986	SEP	23	1927	50.59	35.9446	-122.2198	-6.00	D	3.5	M_{CA}	0.24	16	709708
1986	SEP	24	1046	30.13	34.5405	-119.0359	-18.00	B	3.4	M_{CA}	0.35	68	608080
1986	SEP	30	2229	59.29	37.3209	-116.1987	0.00	D	5.4	M_H	0.24	141	710086
1986	OCT	7	440	23.86	32.4391	-115.3705	-6.00	C	3.5	M_{CA}	0.49	24	710413
1986	OCT	1	2012	18.56	32.9861	-117.8440	-6.00	C	4.0	M_H	0.34	46	710131
1986	OCT	9	537	26.07	37.3686	-118.4123	-9.39	C	4.3	M_H	0.19	29	710545
1986	OCT	15	228	47.79	33.9536	-116.5723	-8.73	A	4.7	M_H	0.28	80	710934
1986	OCT	15	819	17.88	34.9858	-119.2070	-1.44	A	3.2	M_{CA}	0.21	60	710955
1986	OCT	17	28	45.42	31.6679	-116.2217	-6.00	D	3.4	M_{CA}	0.41	37	711116
1986	OCT	17	1856	16.61	34.3698	-116.3846	-7.33	C	3.5	M_{CA}	0.24	59	711160
1986	OCT	19	1809	56.58	36.0985	-117.8454	-3.91	A	3.2	M_{CA}	0.10	31	711270
1986	OCT	22	807	12.31	35.0614	-119.0868	-16.01	A	3.0	M_{CA}	0.25	39	711483
1986	OCT	25	1640	28.49	36.0955	-117.8476	-4.13	A	3.1	M_{CA}	0.08	29	711731
1986	OCT	26	517	56.23	35.5750	-117.2290	-6.00	D	3.0	M_H	5.50	6	129080
1986	OCT	29	238	15.33	32.6146	-117.1521	-14.59	A	4.1	M_{CA}	0.31	95	711952
1986	OCT	29	815	34.52	34.7341	-120.1445	-0.01	A	3.1	M_{CA}	0.16	26	711966

▪ Table 10. Significant Southern California Earthquakes (continued)

YEAR	MO	DY	HRMN	SEC	LAT	LON	Z	Q	M	TYP	RMS	NPH	CUSPID
1986	OCT	31	1427	5.19	35.5784	-117.1791	-5.88	C	3.8	M_{CA}	0.23	59	712099
1986	NOV	3	2104	1.44	33.8745	-116.8591	-10.62	B	3.1	M_{CA}	0.13	44	712271
1986	NOV	6	919	58.29	34.7356	-120.1470	-0.01	A	4.0	M_{CA}	0.24	35	129146
1986	NOV	6	2302	50.52	34.3660	-116.3835	-2.23	A	3.1	M_{CA}	0.15	47	712486
1986	NOV	12	2207	16.40	36.1559	-120.0750	-6.00	C	3.2	M_{CA}	0.34	19	712887
1986	NOV	21	213	50.45	32.4861	-119.5266	-6.00	D	3.3	M_{CA}	0.40	41	713398
1986	NOV	22	1836	57.39	36.1162	-119.9737	-6.00	C	3.1	M_{CA}	0.24	31	713464
1986	NOV	22	2231	27.39	36.0985	-119.9868	-6.00	C	3.0	M_{CA}	0.32	30	713470
1986	NOV	23	208	55.94	34.0959	-120.8482	-6.00	C	3.2	M_{CA}	0.27	28	713477
1986	NOV	24	431	48.61	36.1211	-119.9481	-6.00	C	3.4	M_{CA}	0.34	21	129280
1986	NOV	24	1815	25.16	34.3688	-116.3840	-2.70	A	3.0	M_{CA}	0.12	48	713553
1986	DEC	2	1315	15.34	31.7456	-116.2222	-6.00	D	3.0	M_{CA}	0.27	24	713917
1986	DEC	2	2309	1.18	36.1429	-120.0430	-6.00	C	3.1	M_{CA}	0.30	22	713958
1986	DEC	7	1233	9.25	35.3251	-120.9827	-7.76	C	3.3	M_{CA}	0.38	22	714269
1986	DEC	8	1248	44.55	31.6192	-115.9997	-6.00	D	3.0	M_{CA}	0.37	13	714327
1986	DEC	18	1704	37.16	35.9233	-118.3552	-6.00	C	3.0	M_{CA}	0.11	27	612251
1986	DEC	18	1730	17.65	35.9181	-118.3550	-6.00	C	3.0	M_{CA}	0.19	43	612255
1986	DEC	25	1735	22.86	32.9840	-116.2866	-7.86	B	3.4	M_{CA}	0.20	52	715002
1986	DEC	26	1707	24.87	32.8406	-118.2100	-6.00	D	3.0	M_{CA}	0.59	38	715040
1986	DEC	27	1913	3.95	33.5059	-116.5509	-11.89	A	3.2	M_{CA}	0.19	49	715113
1986	DEC	29	821	3.91	34.5381	-118.9118	-18.22	A	3.2	M_{CA}	0.26	73	715179
1986	DEC	29	1605	13.99	33.0199	-115.7693	-4.39	A	3.4	M_{CA}	0.15	32	129393

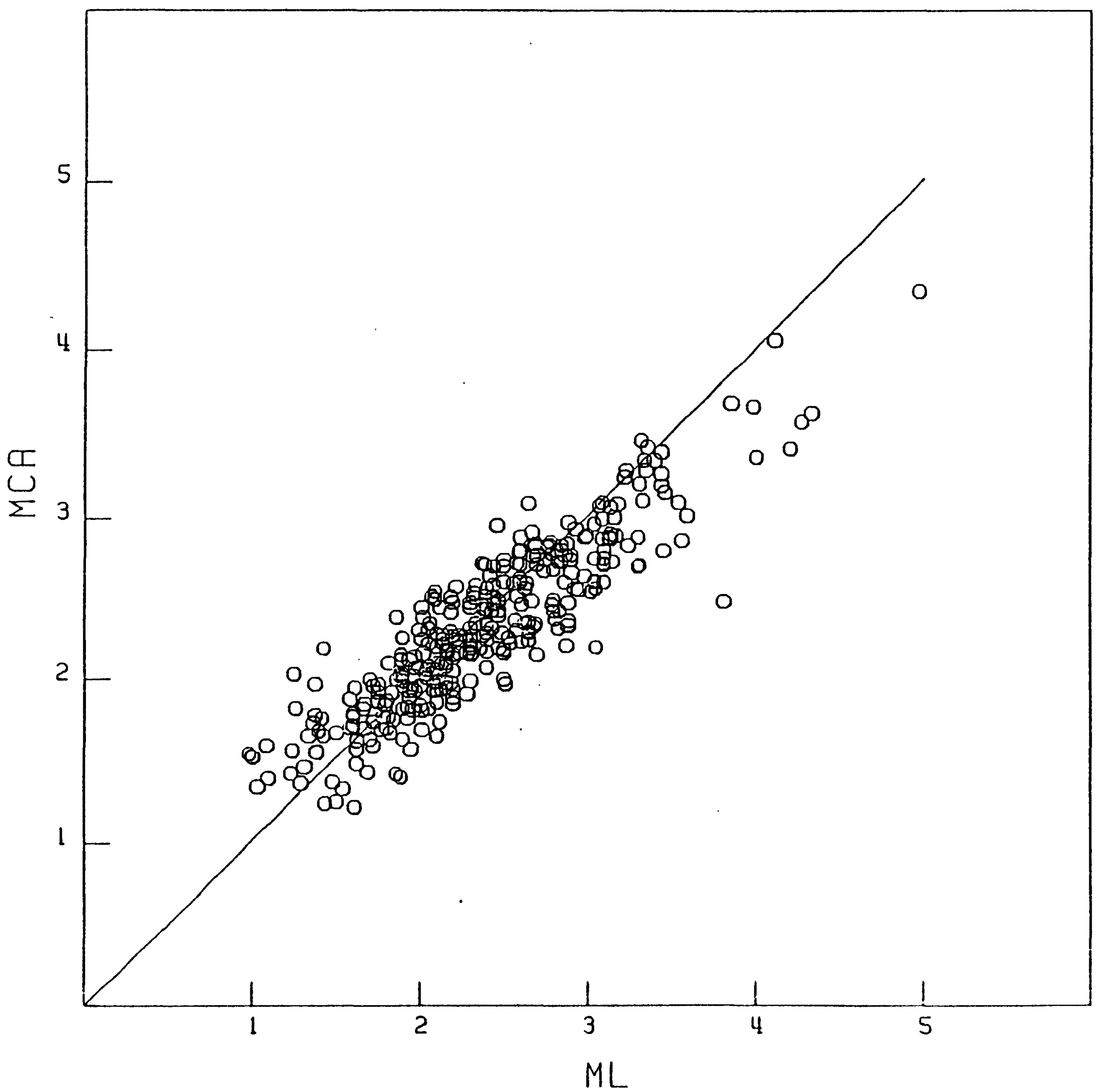

Figure 1. Wood-Anderson magnitude (M_L) versus coda amplitude (M_{CA}) for southern California earthquakes recorded between January and March 1986. The straight line is $M_L = M_{CA}$.

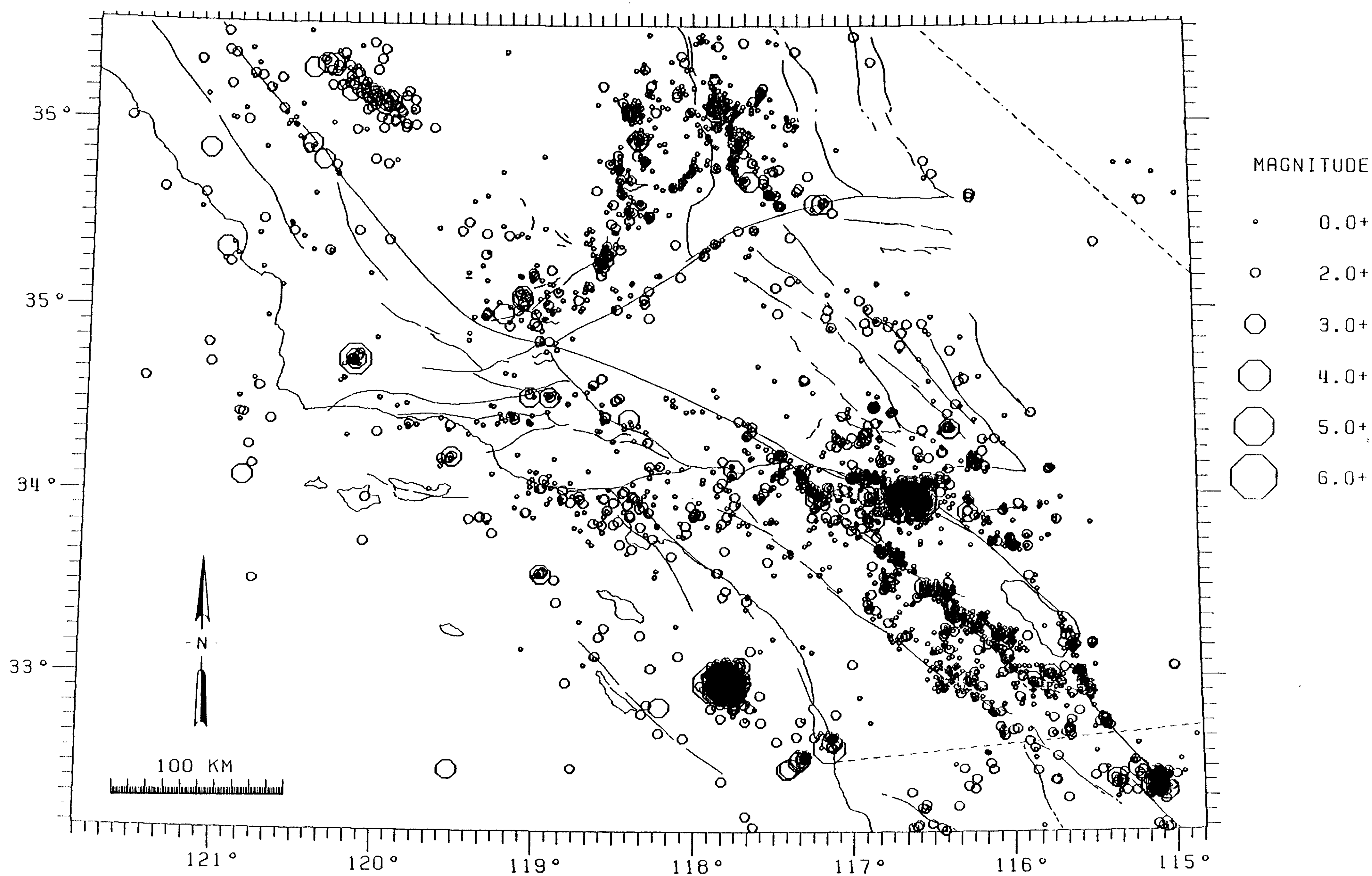

Figure 2. Map of all located earthquakes in southern California for the period of July to December 1986.

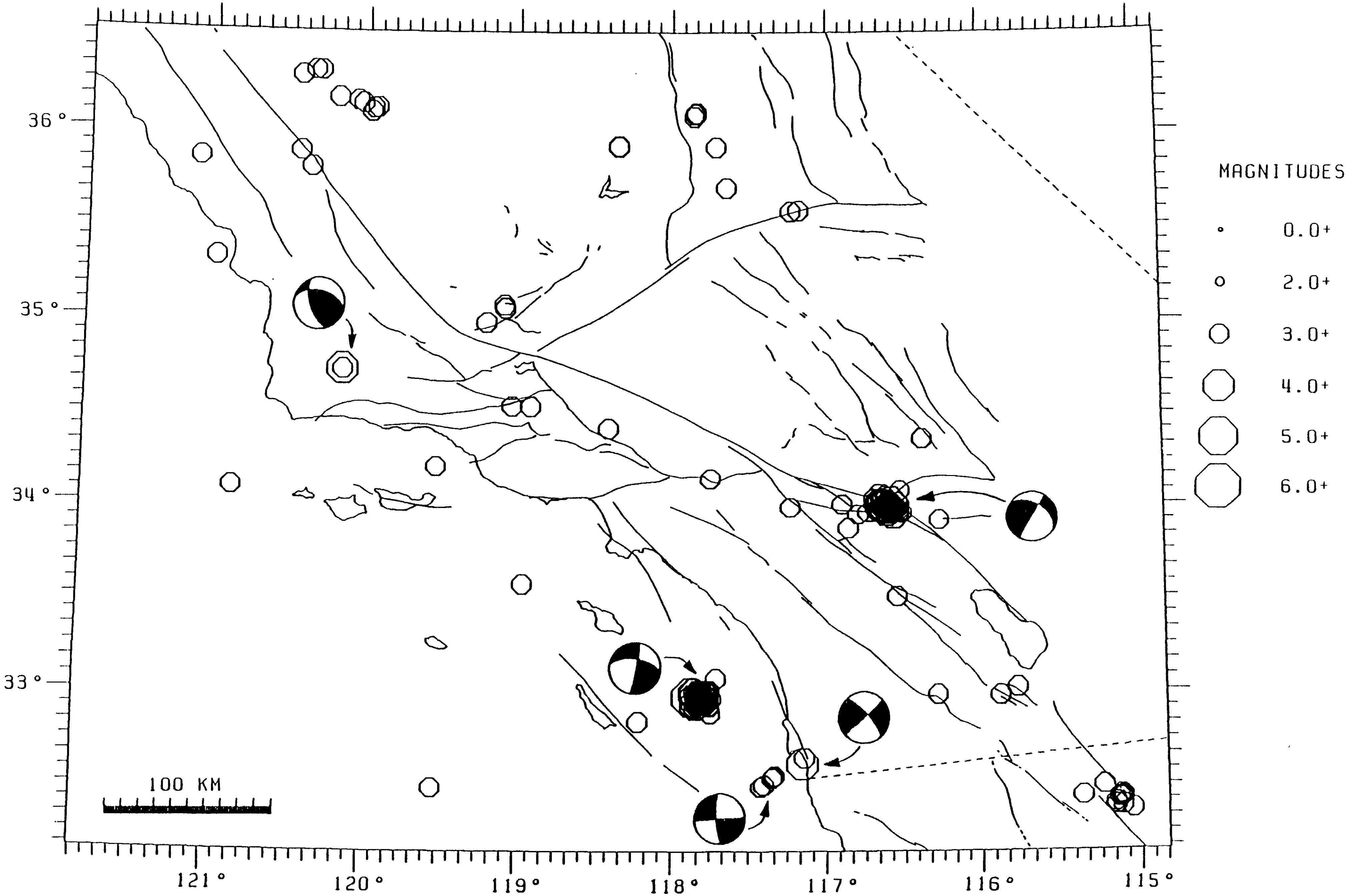

Figure 3. Map of all southern California earthquakes with $M_L \geq 3.0$ for the period of July to December 1986. Focal mechanisms for selected events, as discussed in the text, are shown as lower hemisphere projections.

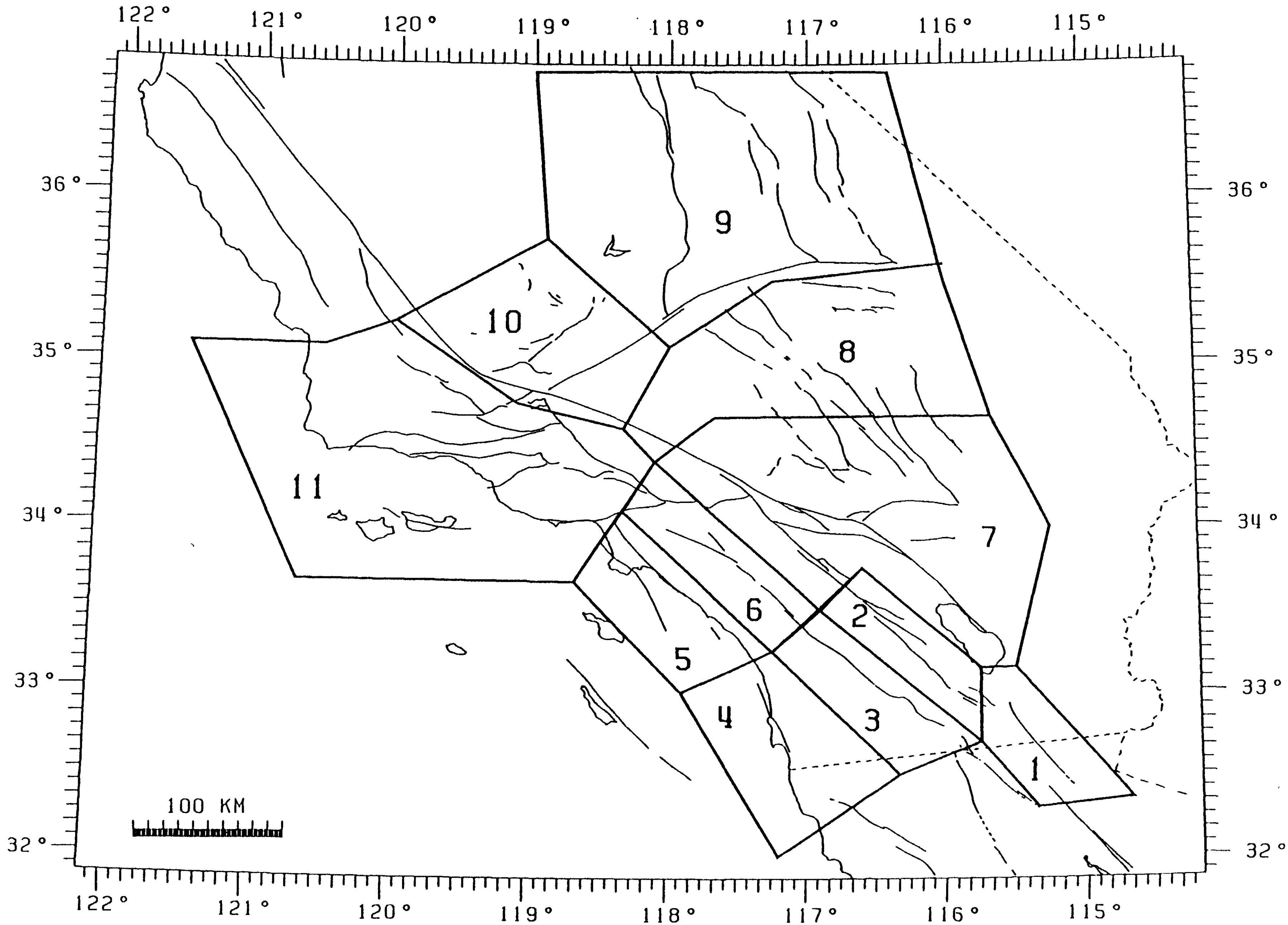

Figure 4. Map of sub-regions used in Figures 5a and 5b. The geographic name of each sub-region, as used in the text, can be found in the headings of Figures 5a and 5b.

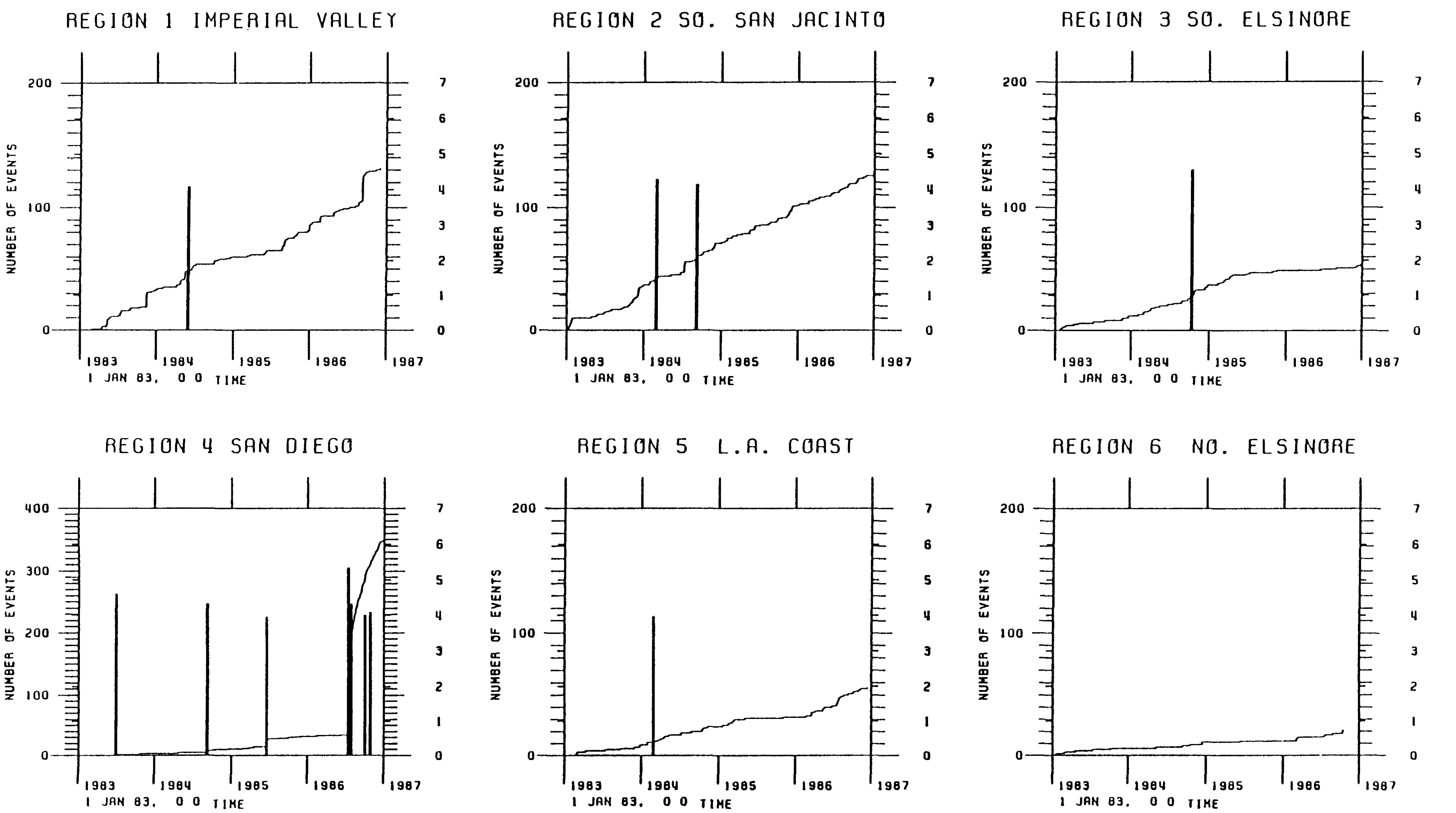

Figure 5a. Cumulative number of events ($M_L \geq 2.5$) in sub-regions 1 through 6 over the four year period ending December 1986. The boundaries of the sub-regions are shown in Figure 4. Vertical bars represent time and magnitude (scale on right) of large events ($M_L \geq 4.0$). Note that the vertical scales of the plots may not be the same.

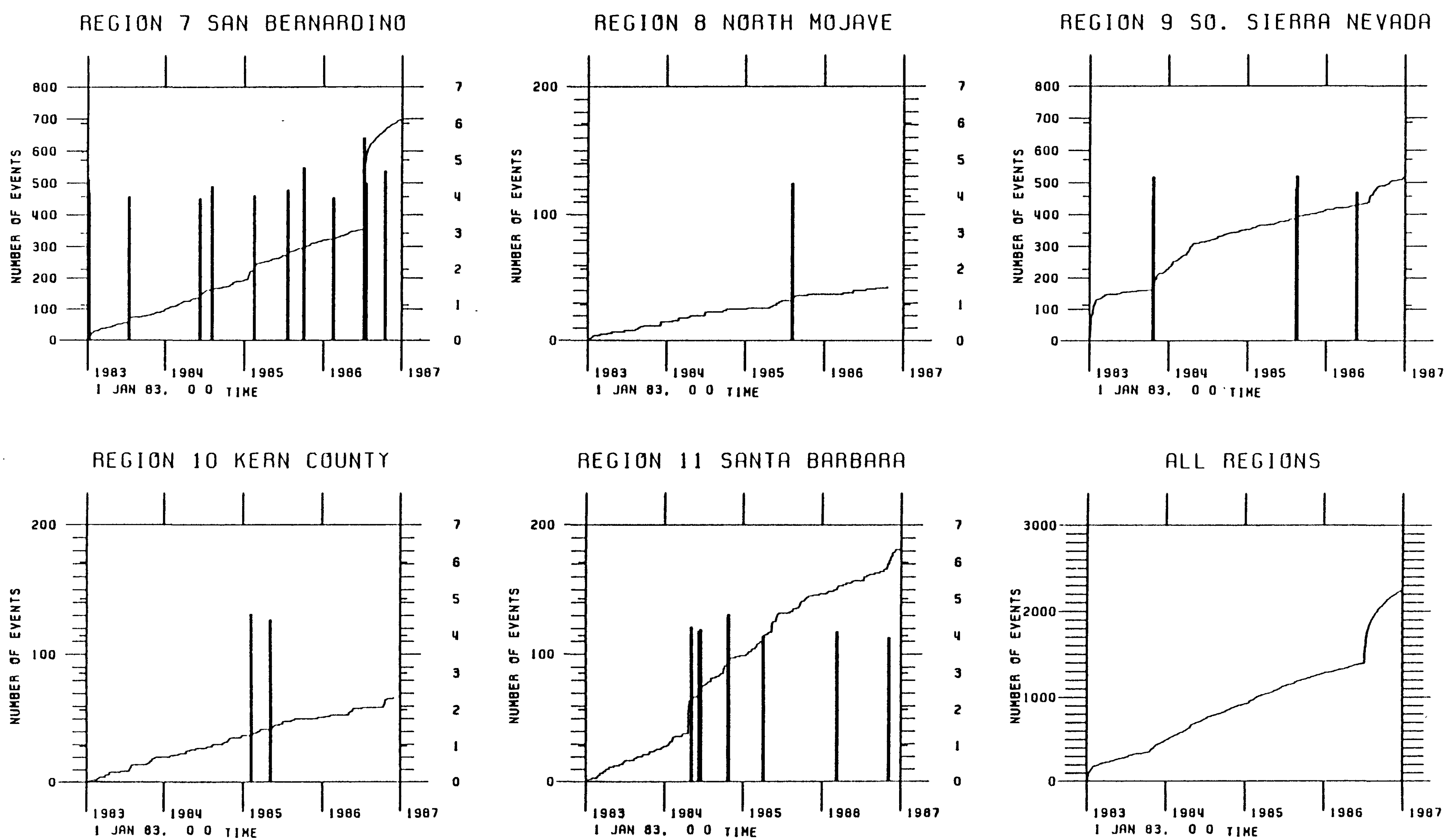

Figure 5b. Cumulative number of events ($M_L \geq 2.5$) in sub-regions 7 through 11 and for all sub-regions over the four year period ending December 1986. The boundaries of the sub-regions are shown in Figure 4. Vertical bars represent time and magnitude (scale on right) of large events ($M_L \geq 4.0$). Note that the vertical scales of the plots may not be the same.

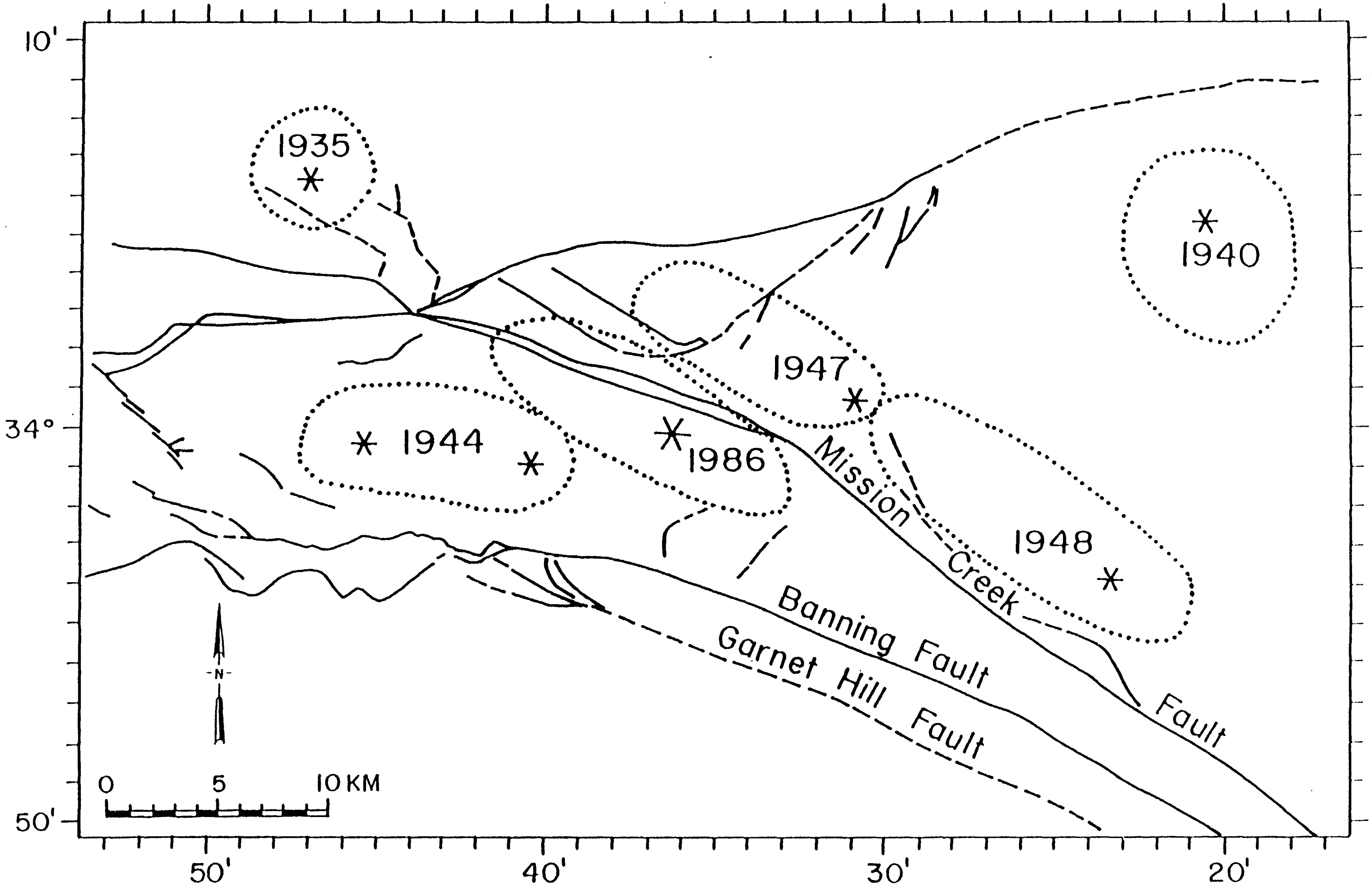

Figure 6. Significant earthquake sequences in the San Gorgonio Pass region. Stars represent mainshocks, dotted areas represent extent of associated aftershock zones.

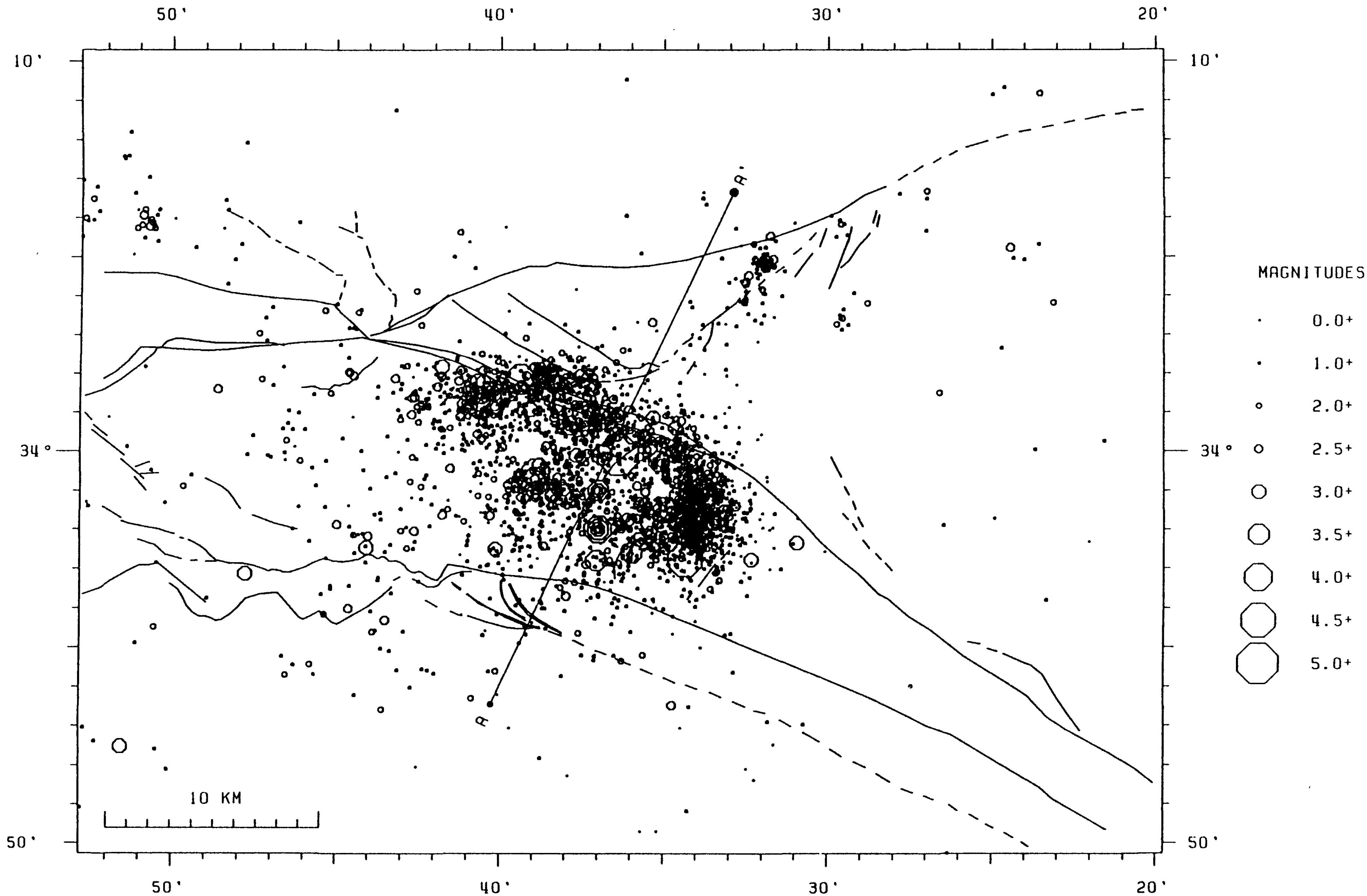

Figure 7. Map of the San Gorgonio Pass area, July to December, 1986. Area was dominated by the North Palm Springs earthquake sequence of July 1986 (M_L = 5.6). Faults are labled on Figure 6. Section line A–A′ refers to cross-section in Figure 8.

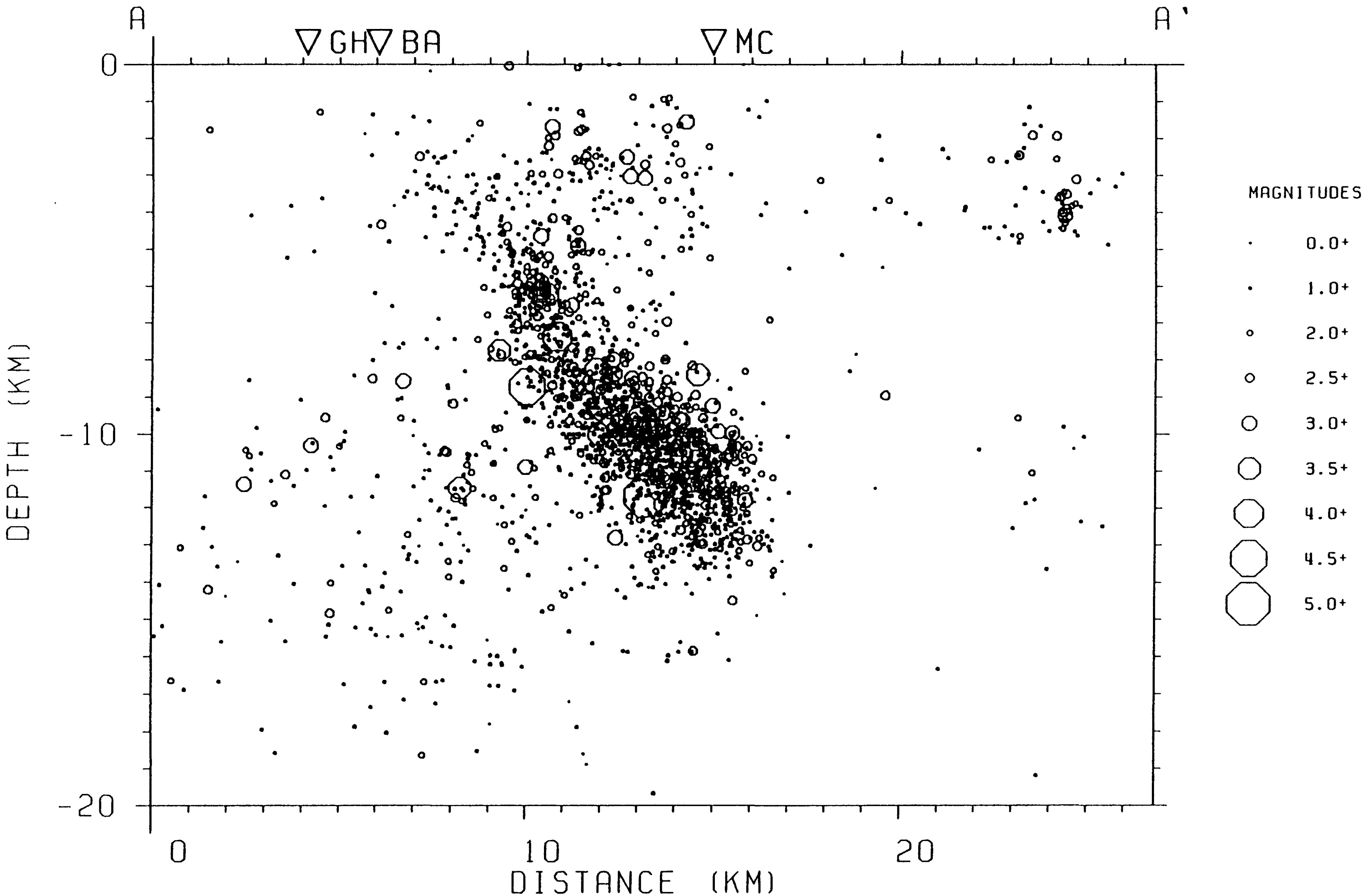

Figure 8. Cross-section of aftershock zone of the North Palm Springs earthquake sequence perpendicular to the San Andreas fault zone. The fault plane dipping about 45° to the northeast is well delineated by aftershocks. GH = Garnet Hill fault, BA = Banning fault and MC = Mission Creek fault. Only "A" quality events are plotted. Section A–A′ is shown on Figure 7.

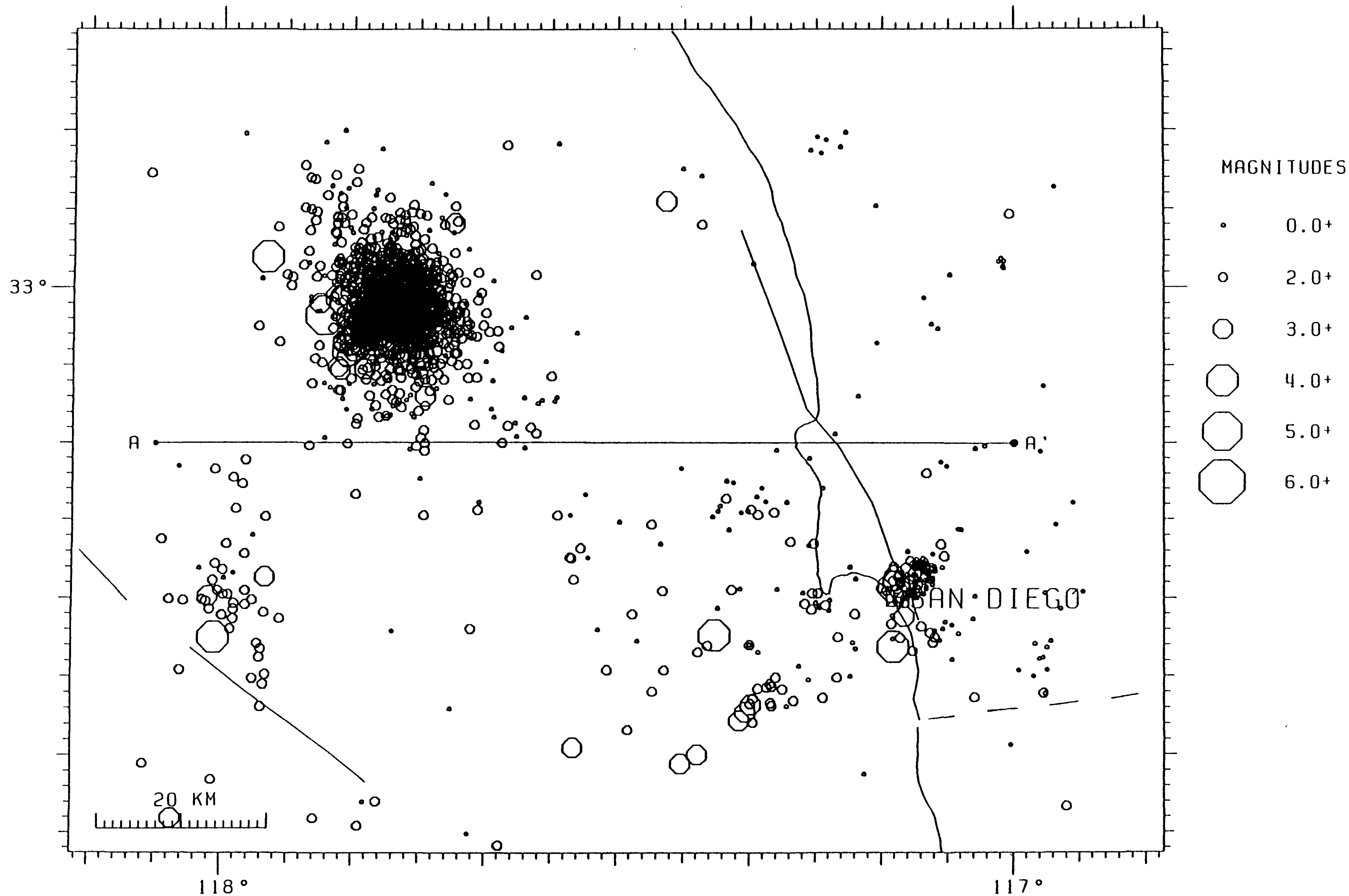

Figure 9. Earthquakes in the off-shore San Diego area from 1981 to present, including the Oceanside earthquake sequence of July 13, 1986 ($M_L = 5.3$). Section line A–A′ refers to the time/distance plot in Figure 10.

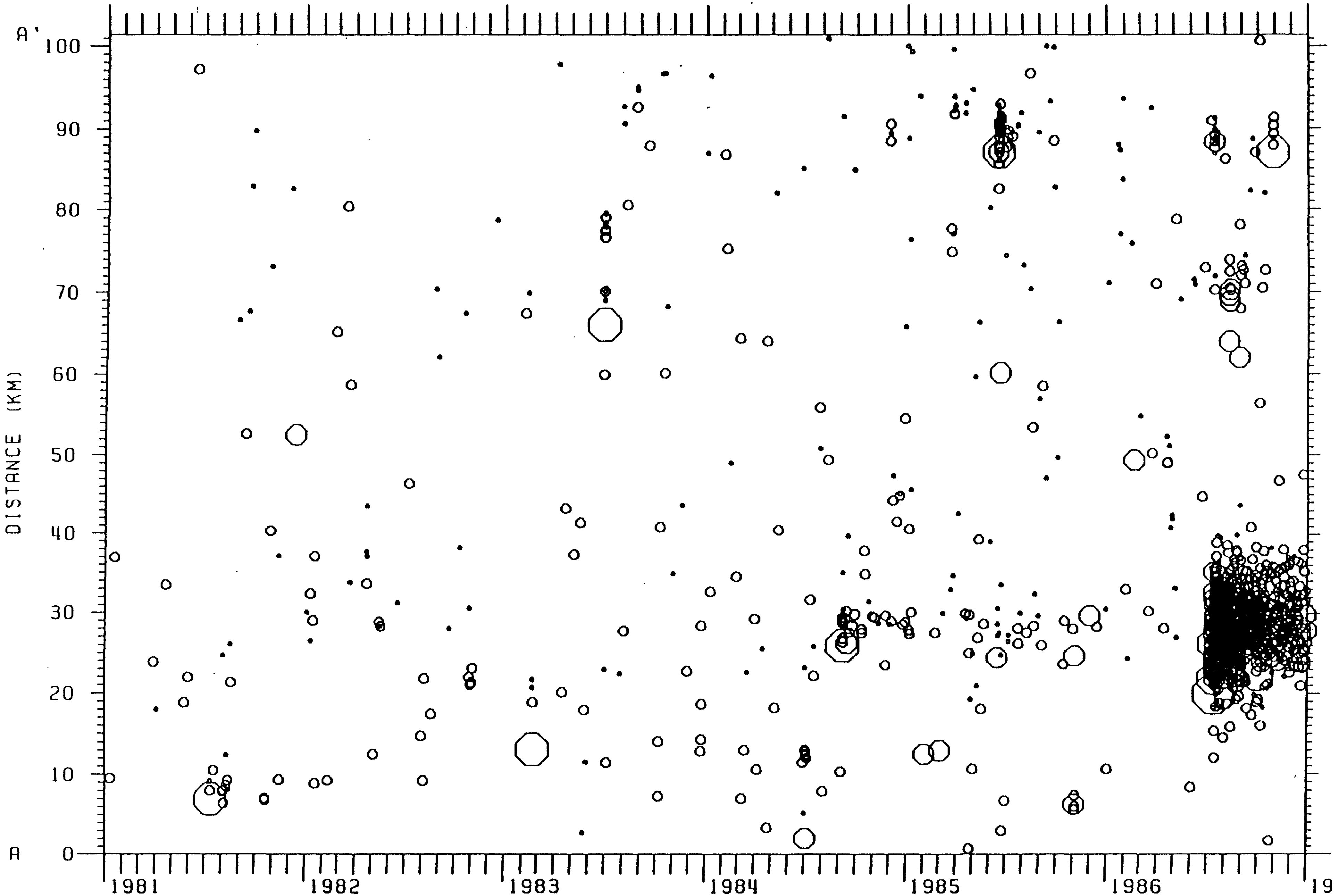

Figure 10. Time/distance plot of earthquakes in the San Diego area since 1981. Distance is measured from east to west along line A–A′ as shown in Figure 9. Each time tick equals one month. Long ticks to the left of year annotations represent the beginning of each year.

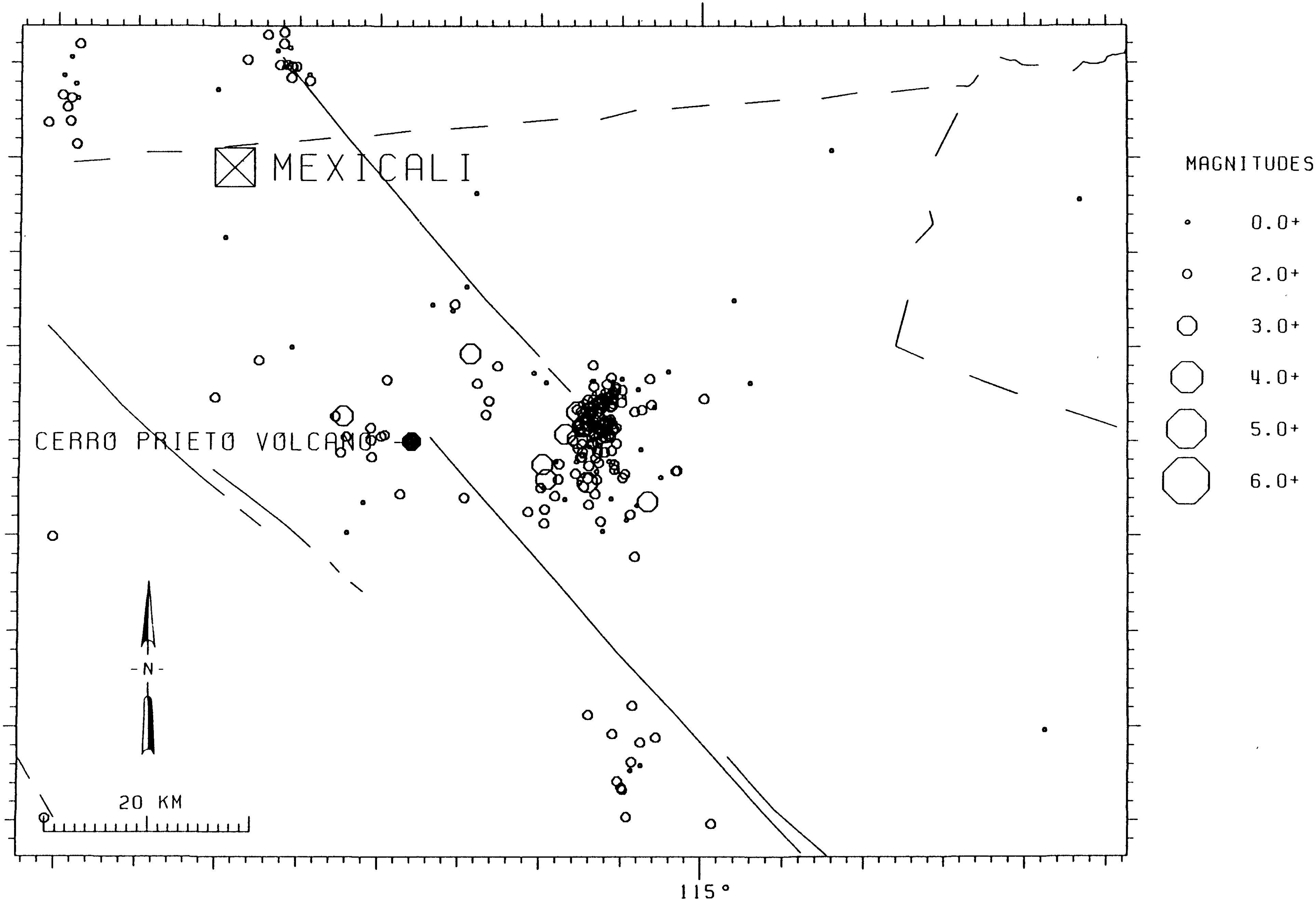

Figure 11. Cerro Prieto earthquake swarm of September 6-7, 1986 (maximum $M_L = 3.6$). The swarm appears to span the step between the Imperial fault to the north and the Cerro Prieto fault to the south.