NASA GRANT NO. NSG-5224

FINAL REPORT

January 1978-December 1979

EARTHQUAKE RESEARCH: PREMONITORY MODELS AND THE PHYSICS OF CRUSTAL DISTORTION

(NASA-CR-169467) EARTHQUAKE RESEARCH: PREMONITORY MODELS AND THE PHYSICS OF CRUSTAL DISTORTION Final Report, Jan. 1978 - Dec. 1979 (California Inst. of Tech.) 17 p HC A02/MF A01 CSCL 08K G3/46

N83-11641

Unclas 01029

James H. Whitcomb*

Principal Investigator

Seismological Laboratory
California Institute of Technology
Pasadena, California 91125

*Now at: Cooperative Institute for Research in Environmental Sciences, University of Colorado, Boulder, Colorado 80309

This grant is to provide support for gathering and analysis of seismic, gravity and electrical resistivity data that are believed to be most relevant to development of earthquake premonitory models of the crust. These methods have been chosen to best complement the crustal distortion information measured by the NASA extraterrestrial geodetic techniques, in particular, the ARIES project. Simultaneous measurement of these geophysical parameters with the NASA extraterrestrial geodetic technique is considered essential to development of a physical model of the crustal processes preceding earthquakes.

Seismic Investigations

Preparing data bases in an easily accessible format to researchers is important in an area with a high seismic hazard such as Southern California. Hand-written records of seismic data from the beginning of the Seismological Laboratory comprise the sole data base of seismicity in Southern California since 1928. However, systematic research on this data has been virtually impossible because of the large task of putting the readings into a computer-compatible format. This task, involving the punching of seismic data, has now been done for the most recent, and most voluminous, part of the data base.

A card image computer tape is now available with earthquake epicenter and P- and S-phase data for local earthquakes in Southern California during the 10-year period of 1966 through 1975. The tape is readable on an IBM 370/158 computer using standard FORTRAN READ statements. The tape is currently being used for several research projects including event relocation, velocity, P-delay, and magnitude studies. This research resource is being made available to all scientific investigators.

The Seismological Laboratory was founded by the Carnegie Institute of Washington in 1927 and management was transferred to the California Institute of Technology (Caltech) in 1936. Although some seismographic stations of the

Caltech network were established as early as 1926, routine and systematic epicentral determinations started only in 1932, with 7 stations reporting. By 1966, the beginning of the data tape, the network had expanded to 19 stations. By 1972, 39 stations were being read for earthquake phases. During the period from 1972 through 1975, the last year of the tape, a cooperative program was established with the U. S. Geological Survey and a major expansion of the Southern California network increased the total number of stations to 103.

Currently, the number of stations in Southern California exceeds 150. This exponentially expanding data base has threatened to saturate even routine analysis of local earthquakes and led to the development of more automated methods of recording and analysis. These new methods include the Caltech Earthquake Detection and Recording (CEDAR) system, which has been in operation since January 1, 1977. Automated earthquake analysis systems need a means to extrapolate their results to past data which, until the generation of this magnetic tape, have been inaccessible for computer processing.

The magnetic tape contains approximately 150,000 card images representing more than 200,000 individual readings, more than one-half are from the last 2 years (1974 to 1975) of the 10-year interval, representing an increase in both the number of stations and the sensitivity of detection/location thresholds. The data tape is formatted chronologically by event such that each event begins with a hypocenter description card followed by P- and S-phase cards for that event. Some phase data follows blank hypocenter cards indicating that the phase data was deemed insufficient to attempt a hypocentral location. One year of data is limited to one tape file, and there are as many records within each file as necessary; records are limited to 1000 cards or less. During the 1966 to 1975 10-year span, hypocenters have been computed with different location programs and different assumptions as to velocity models and station delays. Hopefully, these variables have been modified with time toward improved hypocentral locations. But those studies depending on the uniformity and relative precision of hypocenter calculations during the 10-year span will probably require recomputation with uniform location parameters. Indeed, one of the major incentives for making the phase data available to computation is to remove the dependence of such studies on the particular method and assumptions of hypocentral computation which changes over a long time span (Whitcomb, 1978).

The closest major fault to the NASA long-baseline geodetic site Mount Otay, which is used by the laser-ranging SAFE and VLBI ARIES projects, is the Elsinore fault. The seismicity of this fault bears directly on the formation of tectonic models for distortion in this region, and not surprisingly on the seismic hazard in the San Diego area. A relatively small $M_L = 4.8$ earthquake and its aftershock series on the southern portion of the Elsinore Fault Zone in eastern San Diego County, California, provided a rare opportunity to study this area which has been subjected to variable tectonic interpretations in the past. Within 12 to 26 hours after the main shock, a network of four portable seismograph stations was established around the main event near Aqua Caliente Springs to supplement the stations of the Southern California Seismographic Network. Four days after the main shock, seven additional portable seismograph stations were installed. In addition to the main event, 45 subsequent events were studied, ranging in magnitude from about 1.0 to 3.7. Of these, 36 could be termed aftershocks by their close proximity to the main event, whose proper location was determined by analysis of the aftershock series. Of the two branches of the Elsinore Fault in this region, the south branch is associated with the earthquake series. Focal mechanisms are consistent with right-lateral strike-slip along the south branch, with northeast dip at latitude 32°51'N. These conclusions are supported by hypocentral locations. Thrust activity on the two fault branches may be developing a horst between them, accounting for elevation and tilt changes observed near Aqua Caliente (Allison et al., 1978).

A great deal of potential information about an earthquake is contained within the coda or the energy after the body phases recorded at a seismic station. Many questions relating properties of the coda to the size of the earthquake and to the properties of the medium of the crust in the vicinity of the earthquake have been unanswered until recently. Research on these questions has produced a relationship between the seismic moment, M_0, of shallow local earthquakes, coda amplitudes, and the total duration of the signal, t, in seconds, measured from the earthquake origin time. The theory assumes that the end of the coda is composed of backscattering surface waves due to lateral heterogeneity in the shallow crust. Using the linear relationship between the logarithm of M_0 and the local Richter magnitude M_L, we obtained a relationship between M_L and t, of the form: $M_L = a_0 + a_1 \log t + a_2 t^{1/3} + f(t)$, where a_0, a_1, a_2 are constants depending on an attenuation parameter (effective Q) and geometric spreading; and $f(t)$ is a function of the scattering process. This relationship is different from the empirical one generally used $M_L = a_0 + a_1 \log \tau + a_2 (\log \tau)^2 + a_3 \Delta$, where τ is the duration measured from the first P arrival time and Δ is epicentral distance in kilometers. In the theoretical relationship, the dependence on epicentral distance is implicit in t. The theoretical relationship is used to calculate a coda magnitude M_c that is compared to M_L for Southern California earthquakes which occurred during the period from 1972 to 1975. This comparison is made independently at six stations of the CIT network. At all stations, a good linear fit ($M_L = C_0 + C_1 M_c$) is obtained. The standard errors range from 0.2 to 0.3 and the correlation coefficients from 0.80 to 0.90. Once station gain is accounted for, station correlation terms are less than 0.17 magnitude unit when comparing M_L and M_c. M_c calculation is not limited to a duration measurement but can utilize the entire earthquake coda in order to increase by many times the statistical confidence in an estimate of an earthquake's magnitude. Temporal variations in the parameter Q may be fundamentally related to models of the process of preparation for earthquakes (Suteau and Whitcomb, 1979).

All researchers in tectonophysics that are trying to measure geophysical parameters of crustal distortion have a need to be informed in a timely manner of the level of seismicity in their particular area of interest. In Southern California, the sole source of this information is the Seismological Laboratory. While the seismicity reports out of this institution have been more rapid than any other similar agency, there is usually a delay measured in years from the time of the earthquake to the time of the report detailing its occurrence. In the interest of improving the timing of the seismicity reports, preliminary monthly seismicity reports have been instituted beginning in 1978 that have a delay that is now measured in months instead of years. This service continues at the present time. Ultimately, the goal is to publish reports for a month's seismicity no later than one week from the end of the report period (Whitcomb et al., 1978).

Gravity Investigations

The Southern California gravity monitoring project, begun in May 1974, is intended to coordinate gravity measurements with the long-baseline three-dimensional geodetic measurements of the AIRES (Astronomical Radio Interferometric Earth Surveying) project which uses radio interferometry with extra-galactic radio sources. Gravity data from 28 stations, shown on Figure 1, are monitored on an approximately one- to two-month basis. Appendix I shows the gravity data from the first five years of observation of the networks.

ORIGINAL PAGE IS
OF POOR QUALITY

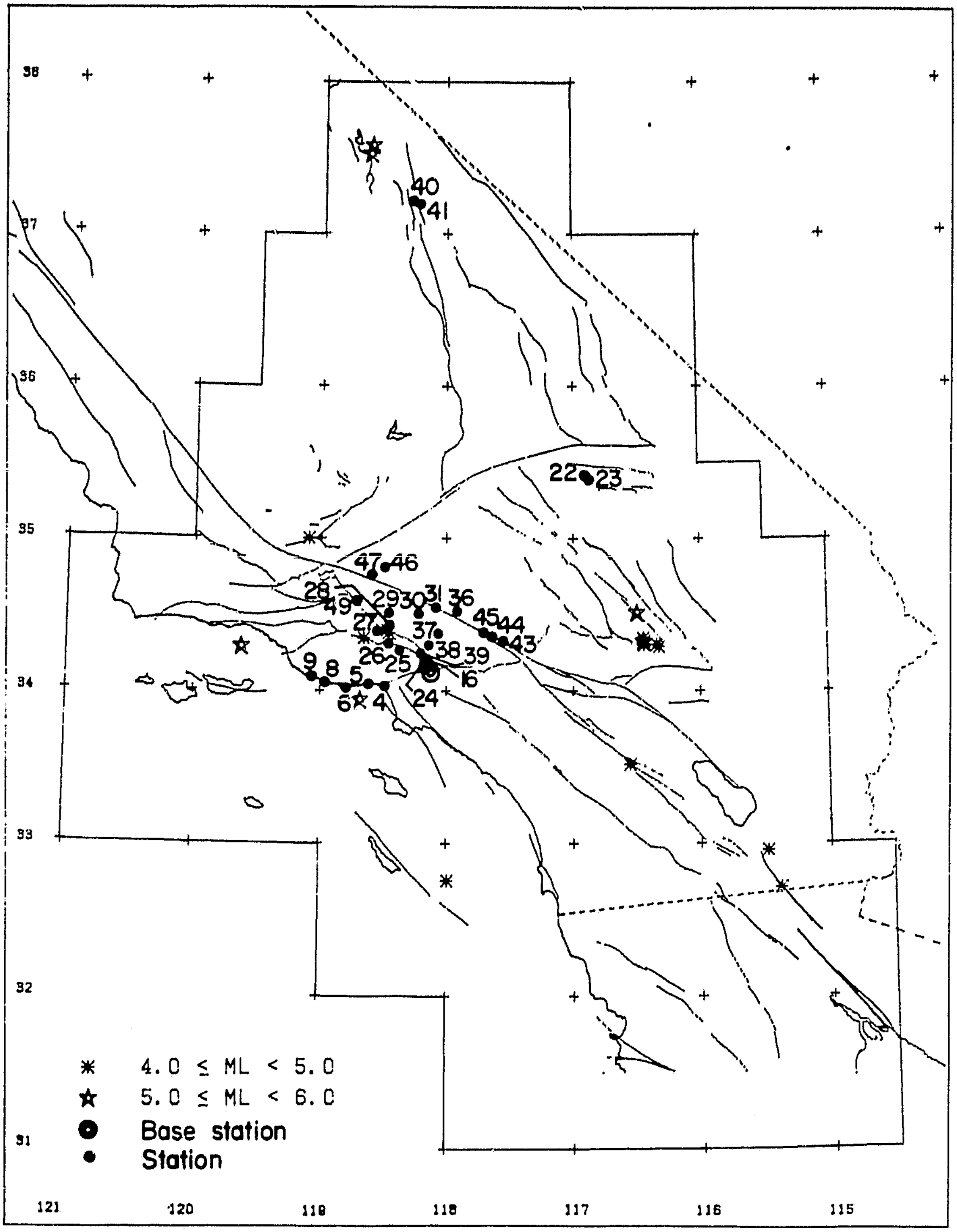


Figure 1. Gravity stations of the Southern California Gravity Network.

Different symbols correspond to different meters used in the survey. The double line represents plus and minus two standard errors of the mean of a five-point weighted moving average. Several lines of evidence indicate that the four standard error interval is a good estimate of the actual gravity value which can be used to test the significance of a change in gravity.

Electrical Resistivity Investigations by Means of Magnetotellurics (MT)

Magnetotelluric (MT) determinations of crusted electrical resistivity is one of the most promising techniques for determining the depth dependence of crustal distortion. It, therefore, has a direct bearing on the formulation of distortion models. Early in the grant period, substantial modifications were made to the MT hardware which was developed under earlier grants. These included redesign of the electric field pre-amplifiers and major changes to the data-logger logic to enable the 9-track tapes to be processed more efficiently. Software was implemented on the departments NOVA and ECLIPSE computers which enabled high-speed plotting of both raw and digitally filtered data. Only two sites were occupied during the first six months of 1978. This was partially due to problems in the electric field preamplifiers which were not fully resolved until July. In addition, the China Flats and Lytle Creek sites were inaccessible for the first six months of 1978 due to heavy rainfall washing out the access roads. Good data was obtained from the three MT sites during the months of July, August, September and November of 1978. Processing has been performed on this data to obtain maximum and minimum apparent resistivity curves in the frequency range 0.001 - 30 Hz. Significant changes in high frequency apparent resistivity estimates have been observed at all three sites. These have been interpreted in terms of reduced near surface resistivities due to heavy rainfall.

A study of the effects of magnetic source field polarization was performed on data collected from the three sites. It was discovered that highly polarized source fields can cause a slight upward bias in the diagonal elements of the impedance tensor. Software has been developed to remove the biasing effect of noise on the resistivity estimates. The technique utilizes a singular valued decomposition of the matrix of Fourier coefficients of the electric and magnetic fields. This technique considerably improves the repeatability of the resulting resistivity estimates.

We have developed a technique which can be used to estimate magnetotelluric impedance from selectively polarized source fields. The technique involves digital filtering of time-series data, followed by estimates of the amplitudes and phases of single cycles, utilizing a simple "maximum/minimum" approach. This yields impedance estimates that are at least as consistent as estimates obtained using the more usual Fast Fourier Transform/bandwidth averaging technique. When the source fields are subdivided into intervals on the basis of polarization direction, the diagonal elements of the impedance tensor determined in each interval show an upward bias. We interpret this as due to instability in the solutions for the impedances which occurs when the source fields are highly polarized. In addition, one of the tensor elements shows a consistent upward trend when the source field is polarized close to the east-west direction. Since we observe this at three separate sites, we suggest that it may be due to either a noise source which is polarized in the east-west direction, or to a lack of uniformity in the horizontal source fields which are polarized in this same direction (Lienert, 1979).

Radon Investigations

It is difficult to find other long-term geophysical measurements that are believed to be relevant to the process of preparation of earthquakes with long-term stability comparable to that of NASA's long-baseline geodetic techniques such as AIRES. One such technique is the monitoring of radon emanating from the crust. This grant has been used to support the initial effort to develop an automated radon monitoring system for installation near ARIES sites. The first such site is near the ARIES JPL site in Pasadena. Up to this time data have been gathered from 20 months of near real-time (3 samples per day) radon monitoring at this hard-rock site in the Transverse Ranges of Southern California. An annual cycle is evident in the data which is attributed to thermo-elastic strains in the vicinity of the borehole site. Between 1 April 1977 and 31 October 1978 there were 11 earthquakes with magnitude ≥ 2.0 within 25 km of the monitoring site. Three of these events appeared to be preceded by precursory signals, four were preceded by "possible" precursory signals, and four were not preceded by any apparent precursors. Before the 4.6 M Malibu earthquake of 1 January 1979, a possible precursory signal sequence of 40-50 days duration was observed (Shapiro et al., 1978).

Other Work

During the grant period, contributions were made to educational and scientific publications including 1) a popularized article on earthquake prediction (Whitcomb, 1978), 2) an invited paper in a National Academy of Sciences study on the impact of technology on geophysics (Whitcomb, 1979), 3) a contribution to NASA Technical Paper 1464, and 4) a study of real time data management/analysis system for operational earthquake prediction (Lohman et al., 1979).

Publications

Whitcomb, J. H. Earthquake prediction...how close to reality? *In Focus, California Museum of Science and Industry*, 1, 6-10, 1978.

Whitcomb, J. H., P- and S-phase data from local earthquakes in Southern California for 1966-1975, *Seismol. Soc. Am. Bull.*, 68, No. 2, 523-525, 1978.

Whitcomb, J. H., G. R. Allen, et al., Southern California Array for Research on Local Earthquakes and Teleseisms (SCARLET) Caltech-USGS Monthly Preliminary Epicenters for January 1977 to March 1978, Seismological Laboratory, California Institute of Technology, Pasadena, 1978.

Allison, M. L., J. H. Whitcomb, C. E. Cheatum, and R. B. McEuen, Elsinore fault seismicity: The September 13, 1973, Aqua Caliente Springs, California, earthquake series, *Seismol. Soc. Am. Bull.*, 68, No. 2, 429-440, 1978.

Shapiro, M. H., J. D. Melvin, N. A. Copping, T. A. Tombrello, and J. H. Whitcomb, Automated Radon-Thoron monitoring for earthquake prediction research, *Proceedings of the Natural Radiation Environment III Conference*, 1978.

Whitcomb, J. H., Impact of technology on tectonophysics, in *Impact of Technology on Geophysics*, National Academy of Sciences National Research Council, 70-80, 1979.

Suteau, A. M., and J. H. Whitcomb, A local earthquake coda magnitude and its relation to duration, moment M_0, and local Richter magnitude M_L, *Seismol. Soc. Am. Bull.*, 69, 353-368, 1979.

Contribution to *Application of Space Technology to Crustal Dynamics and Earthquake Research*, NASA Technical Paper 1464, August, 1979.

Lohman, G. M., A. J. Ferrari, J. H. Whitcomb, and W. Porche, *An Assessment Study for an Operational Earthquake Prediction System*, Jet Propulsion Laboratory Technical Report, August, 1979.

Lienert, B. R., The effect of source field polarization on estimates of the magnetotelluric impedance tensor, submitted to *Phys. Earth Planet. Int., 1979.*

Abstracts

Ferrari, A. J., G. M. Lohman, J. H. Whitcomb, W. D. Porche, An assessment study for an operational earthquake prediction system for Southern California, *EOS, Trans. Am. Geophys. U.*, *60*, 889, 1979.

Shapiro, M. H., J. D. Melvin, T. A. Tombrello, and J. H. Whitcomb, Southern California Radon Anomaly, *EOS, Trans. Am. Geophys. U.*, *60*, 883, 1979.

Whitcomb, J. H., Recent Temporal gravity changes in Southern California, *EOS, Trans. Am. Geophys. U.*, *60*, 810,1979.

Lienert, B. R., J. H. Whitcomb, and R. J. Phillips, Magnetotelluric measurements close to the San Andreas and Garlock faults, *EOS, Trans. Am. Geophys. U.*, *60*, 243, 1979.

Whitcomb, J. H., Temporal gravity changes over a five-year period in Southern California, *EOS, Trans. Am Geophys. U.*, *50*, 315, 1979.

Shapiro, M. H. J. D. Melvin, T. A. Tombrello, J. H. Whitcomb, Data from the Caltech automated Radon-Thoron monitors, *EOS, Trans. Am. Geophys. U.*, *59*, 1196, 1978.

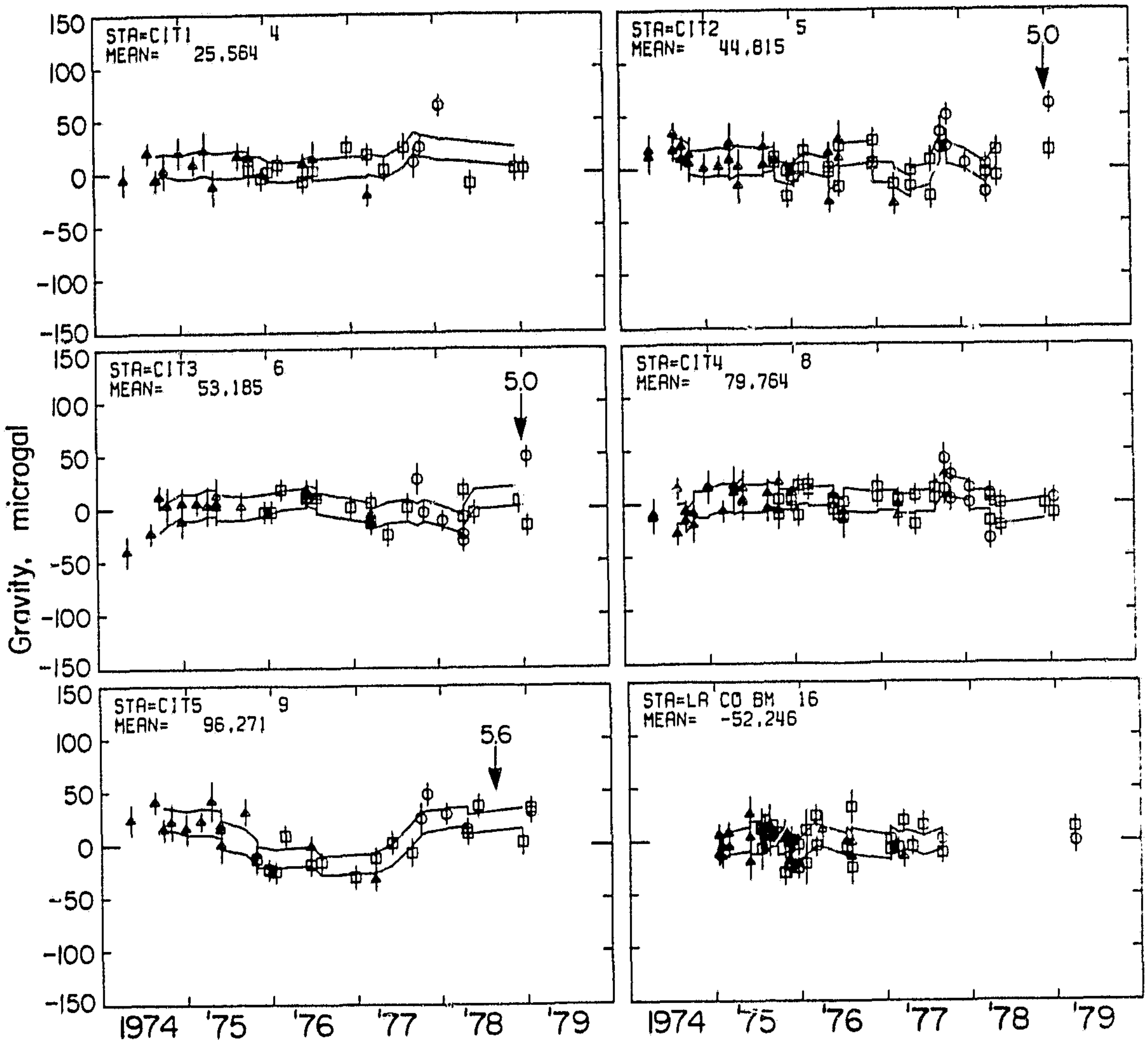
Whitcomb, J. H. and L. K. Hutton, On the magnitude of the August 13, 1978, Santa Barbara, California Earthquake, *EOS, Trans. Am. Geophys. U.*, *59*, 1130, 1978.

Lienert, B. R., J. H. Whitcomb, and R. J. Phillips, The effect of source field polarization characteristics on magnetotelluric impedance tensor estimates, *EOS, Trans. Am. Geophys. U.*, *59*, 1054, 1978.

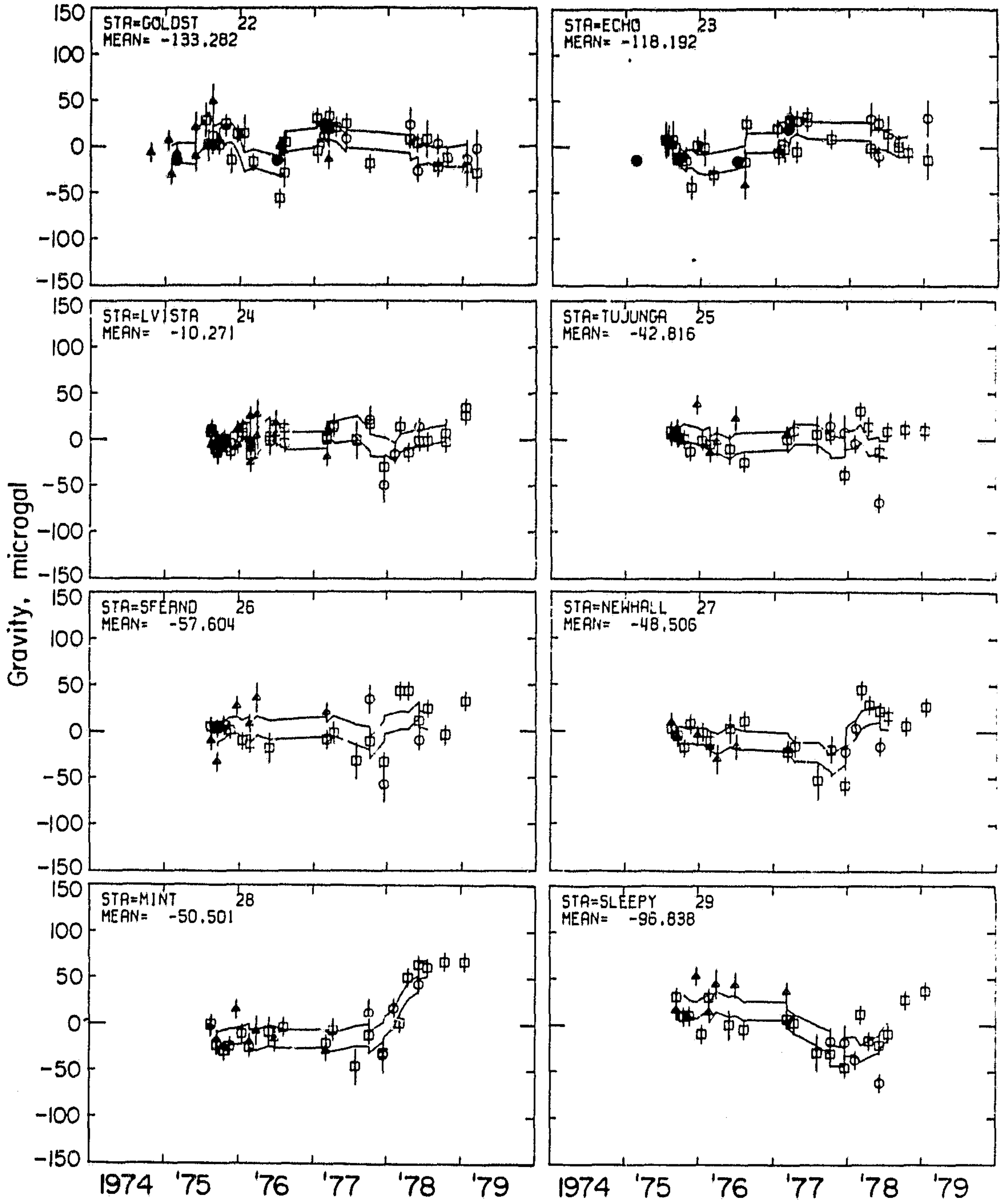
Appendix I.

Gravity data from the first five years of operation of the Southern California Gravity Network. Station locations are shown in Figure 1.

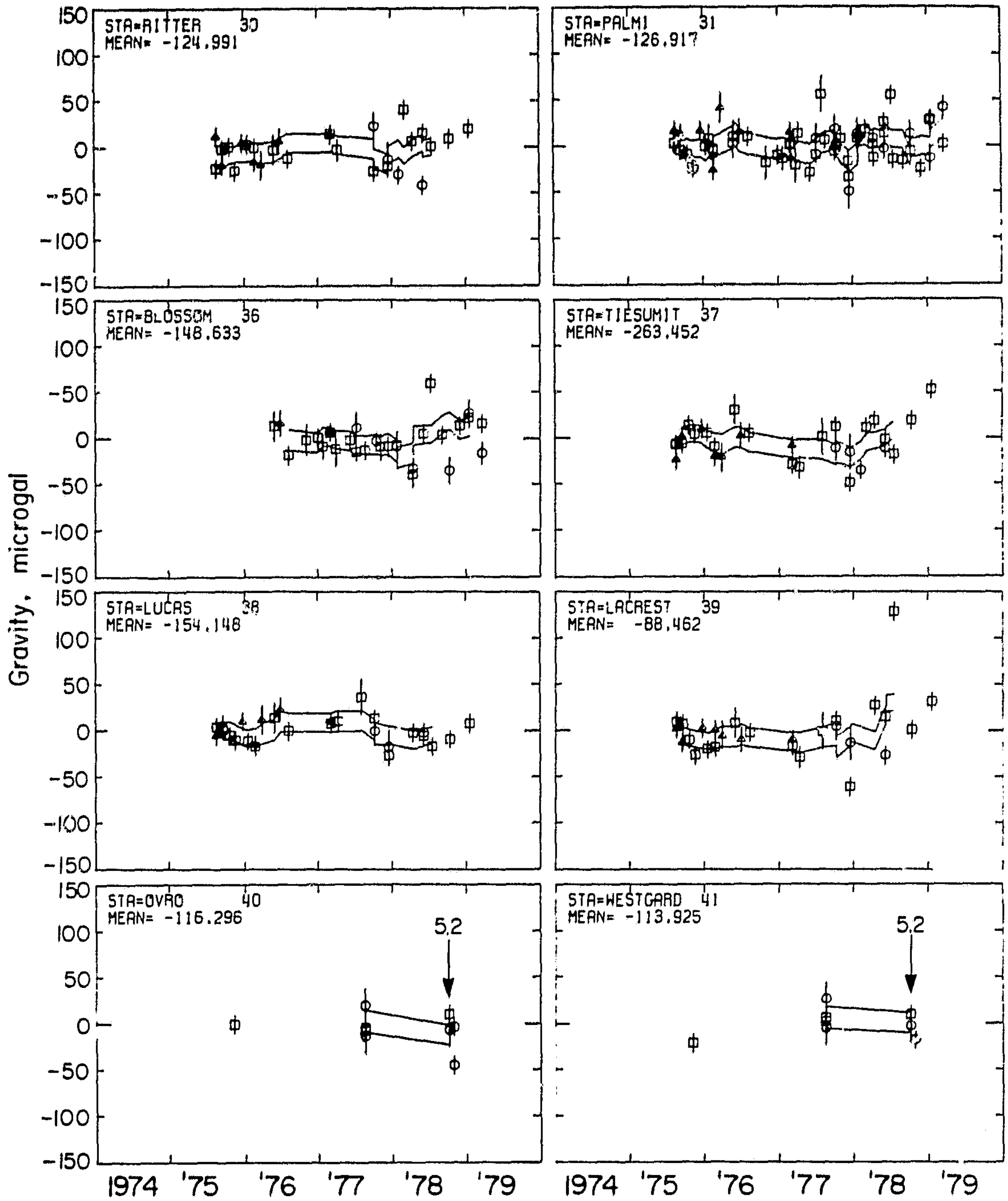
ORIGINAL PAGE IS OF POOR QUALITY



ORIGINAL PAGE IS
OF POOR QUALITY



ORIGINAL PAGE IS
OF POOR QUALITY



ORIGINAL PAGE IS
OF POOR QUALITY