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Project REDEAM: Models for Historical Horizontal Deformation

Richard A. Snay
Michael W. Cline
Edward L. Timmerman

Rockville, MD
September 1987

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Project REDEAM: Models for Historical Horizontal Deformation in Tectonically Active Regions of the United States

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ABSTRACT. Models for historical horizontal crustal deformation have been derived for a total of 19 tectonically active regions, 16 of which combine to cover all of California, with one model each representing parts of Nevada, Alaska, and Hawaii. Model parameters were estimated from geodetic data (direction, azimuth, and distance observations). These data span the 1850-1980 interval; however, over 90 percent postdate 1930. The models were developed in support of the redefinition of the North American horizontal reference system. In particular, the models were used to update all appropriate geodetic observations to the values that would be obtained if the observations were remeasured on December 31, 1983. These updated observations were then used to estimate, for this date, the positional coordinates (latitude and longitude) of the geodetic marks that comprise the horizontal reference network.

The models address both the secular and episodic components of motion. For secular motion, each modeled region is partitioned into a mosaic of districts that are individually allowed to translate, rotate, and deform homogeneously as a linear function of time. Episodic movement corresponds to displacements associated with large earthquakes ($M \geq 6$), and is modeled in accordance with elastic dislocation theory. The preponderance of triangulation data for the 1930-80 interval well define the time-averaged pattern for secular shear-strain rates. Much of the pre-1970 distance data, however, are contaminated by systematic errors on the order of several parts in 10^6. As such, an insufficient time span of accurate distances exists to well constrain the scale dependent aspects of the secular deformation which are characterized by strain rates of a few parts in 10^7 per year. Also the rotational component of the secular deformation is hidden within the 0.1-microradian-per-year noise level obtained with existing azimuth data. Episodic motion is well resolved for those earthquakes with $M > 7$; earthquakes with $6<M<7$ are modeled with only mixed success because the corresponding ground movements are near the threshold of pre-1970 geodetic sensitivity.

1. INTRODUCTION

The title REDEAM (REgional Deformation of the EArth Models) identifies the project to model horizontal deformation for various tectonically active regions in the United States. Individual models were developed for 19 mutually disjoint geographic regions. Sixteen of these regions cover, in combination, the State of California (fig. 1.1). The three other regions are located in Nevada (fig. 1.1), Alaska (fig. 1.2), and Hawaii (fig. 1.3).

The REDEAM models were generated in support of the North American Datum (NAD) project, an international project to redefine the geodetic reference system used by map makers, engineers, land surveyors, and others for horizontal positioning in North America.

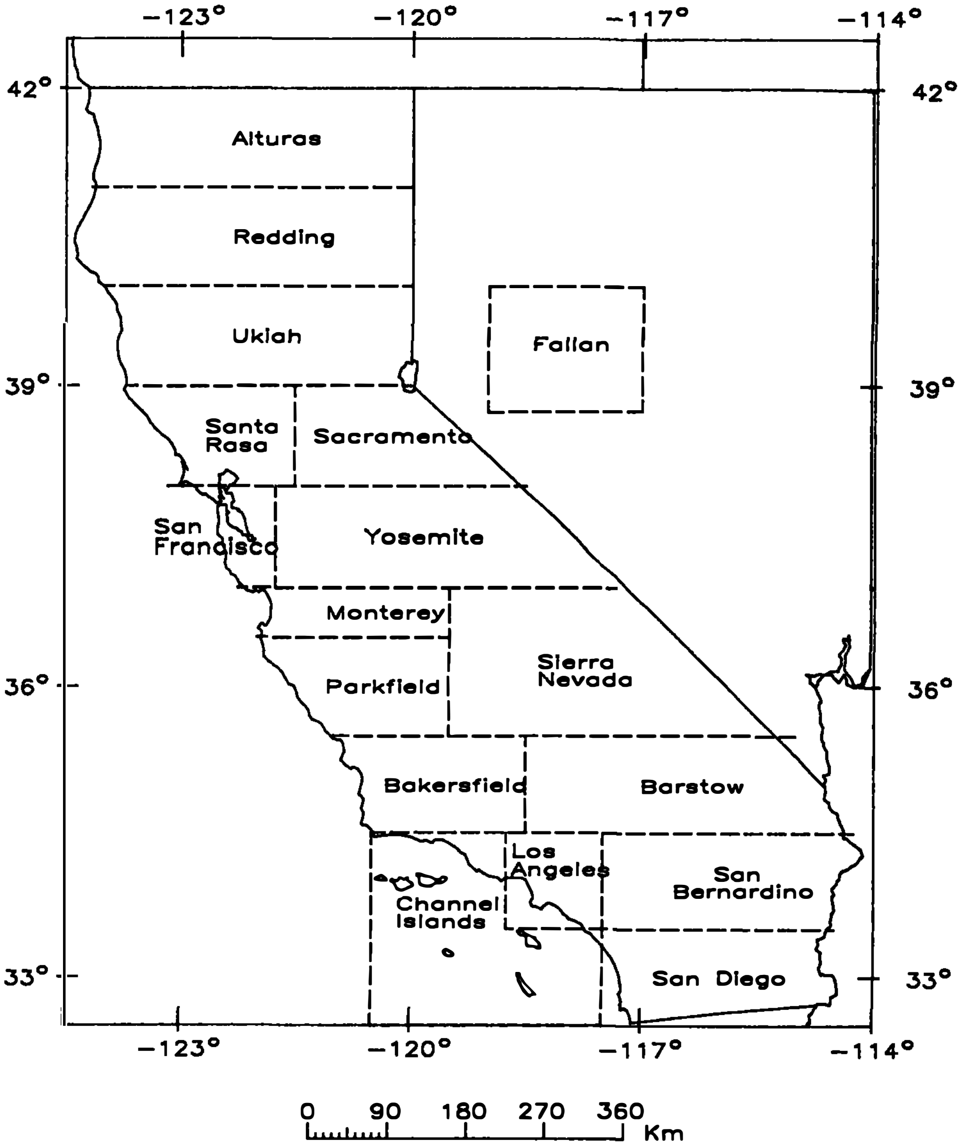


Figure 1.1.--A model for historical crustal deformation was developed for each of 19 regions. Seventeen of these regions are pictured above. Other regions are located in Alaska and Hawaii.

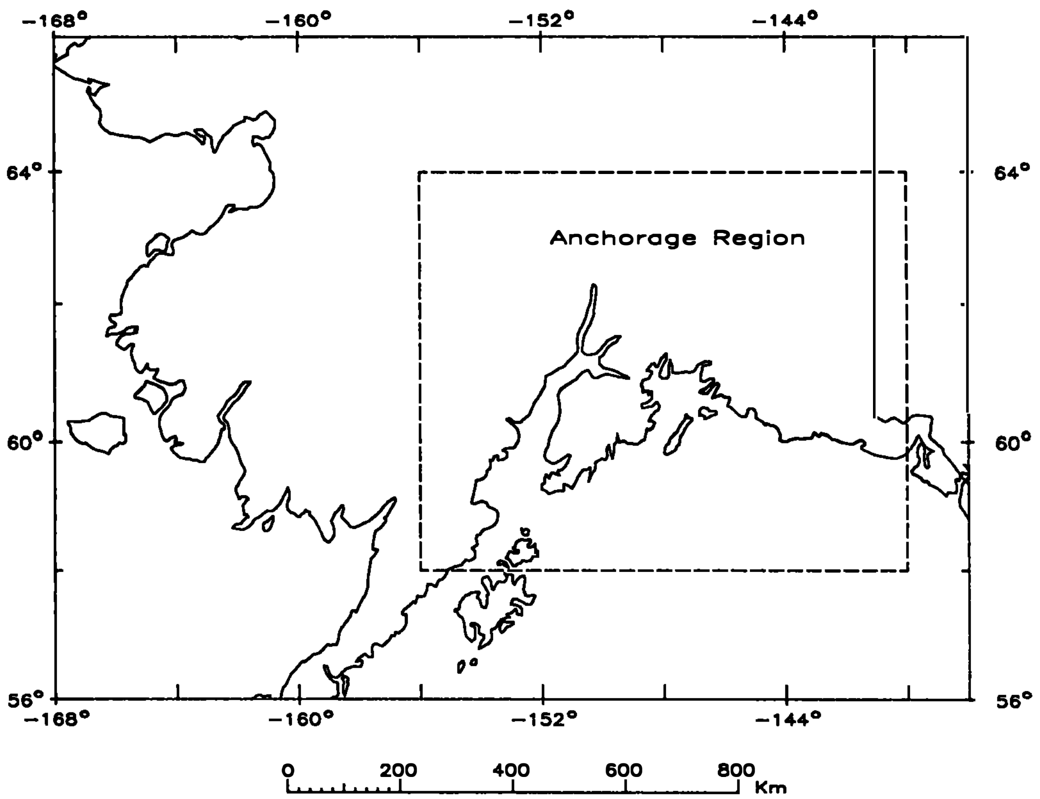


Figure 1.2.--The crustal deformation model for Alaska's Anchorage region characterizes horizontal displacements associated with the 1964 Prince William's Sound earthquake.

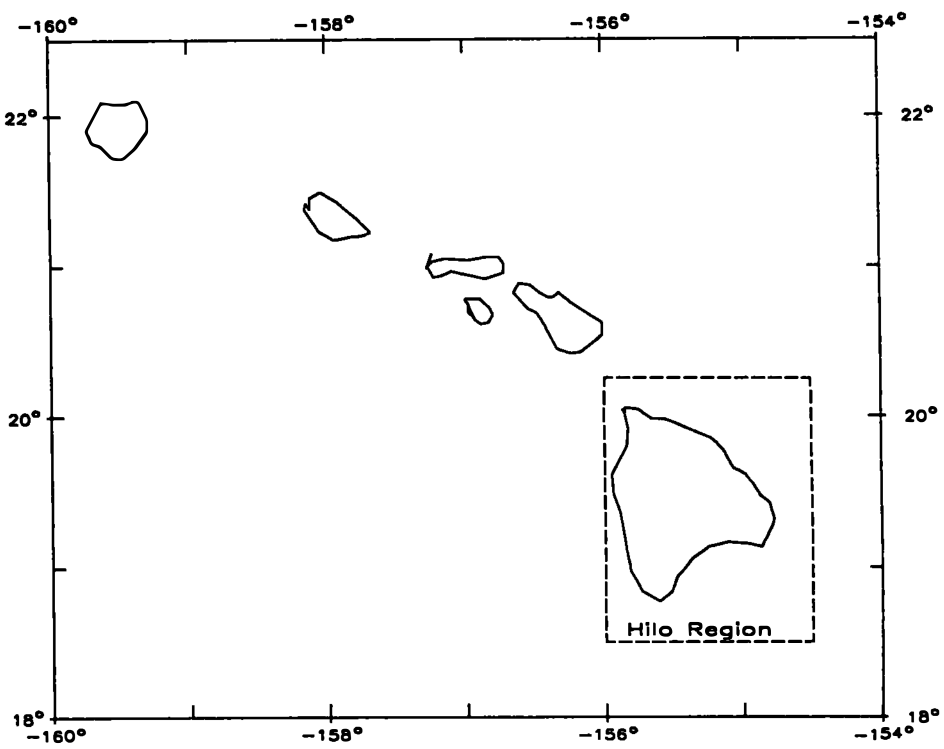


Figure 1.3.--The crustal deformation model for Hawaii's Hilo region addresses horizontal motion associated with volcanic and seismic activity, especially the 1975 Kalpana earthquake (M=7.1).

For the NAD project, all appropriate geodetic observations were entered into a simultaneous solution to estimate positional coordinates (latitude and longitude) for the several hundred thousand monumented stations that comprise the North American horizontal reference network. Prior to entry into the solution, these geodetic data were reduced, using REDEAM models, to a common date (December 31, 1983) to account for temporal variations of the positional coordinates. That is, for each geodetic observation, the REDEAM models served to estimate the value that would be obtained if the observation were remeasured on December 31, 1983. The newly derived NAD positional coordinates thus correspond in time to this date.

Since 1807 the National Geodetic Survey (NGS) and its predecessor agencies have determined latitudes and longitudes of more than 200,000 monumented stations covering the United States at spacings from 0.01 to 100 km. These monuments or marks are 'positioned' through a network of geodetic observations that include directions, taped and electronically measured distances, and astronomically determined azimuths. Currently, geodetic observations for positioning are also obtained by techniques that employ artificial satellites and extragalactic radio sources such as quasars. Today a 10-km length can be measured to a precision of a few millimeters, and a transcontinental distance to within a few centimeters. As instrument accuracies continue to improve, the need to improve the geodetic reference system becomes greater. Anticipating this need, NGS and other national geodetic agencies representing the North American countries and Denmark initiated a joint project to recompute the positions of all marks in North America and Greenland. Such a recomputation was last accomplished for the United States in 1927. The recent effort was characterized by greater rigor as advances in computer technology permitted both the use of more sophisticated mathematical techniques and of more up-to-date scientific theories of the Earth and its environment.

Contributing to the rigor of the new computations, the REDEAM models describe the time variability of station coordinates attributed to horizontal crustal motion. According to plate tectonic theory, the latitudes and longitudes of monumented stations continually change. The rates of these motions have been estimated from geologic and seismic data by using models that assume that the Earth's surface consists of several rigid plates each rotating at a constant rate about a specific pole (Minster and Jordan 1978). Although these models are acceptable on a global scale for motions averaged over millions of years, significant regional deviations develop when the motions are considered over a time period of decades. In particular, friction between adjacent plates retards relative plate motion and causes a gradual bending of the Earth's crust over a zone hundreds of kilometers in width. This regional bending is occasionally interrupted by the sudden displacements associated with earthquakes as elastic crustal elements rebound from their distorted states. The REDEAM models address both this slow regional bending and the rapid coseismic displacements.

The purpose of this report is to document the development and implementation of the REDEAM models. Chapter 2 describes the geodetic data used to estimate model parameters. Chapter 3 describes the mathematical model, and Chapter 4, the relevant software. Chapter 5 specifies the algorithm used for applying the models to update existing geodetic observations. Chapter 6 contains an evaluation of the models, and Chapter 7 summarizes the report. So as not to interrupt the flow of the presentation, this report also contains six appendices: Appendix A describes the application of dislocation theory to the characterization of earthquake displacements, appendix B shows the spatial and temporal distributions of the geodetic data, appendix C tabulates values for model parameters, appendix D tabulates secular rotation rates and strain rates derived from model parameters, appendix E describes the model for Alaska's Anchorage region (fig. 1.2), and appendix F describes the model for Hawaii's Hilo region (fig. 1.3). Appendices E and F are included because the Anchorage and Hilo models differ in form from each other and from the other 17 regional models.

2. GEODETIC DATA

Parameters for REDEAM models were estimated from geodetic data (directions, distances, and azimuths) contained in the archives maintained by NGS. This data base incorporates contributions from various Federal, state, and local organizations. The archives include numerous geodetic measurements in California which were performed explicitly to measure crustal motion. These crustal motion measurements include those performed by NGS and its predecessor agencies following most of the major earthquakes in the United States, including the San Francisco earthquake of 1906. These agencies have also repeatedly surveyed several geographic areas to monitor aseismic strain rate (fig. 2.1) and secular fault slip (fig. 2.2). The archived crustal motion measurements also include the regularly repeated line length determinations performed by the California Department of Water Resources (1968) from 1959 to 1969 and the California Division of Mines and Geology from 1969 to 1979 (Bennett 1980) and the U.S. Geological

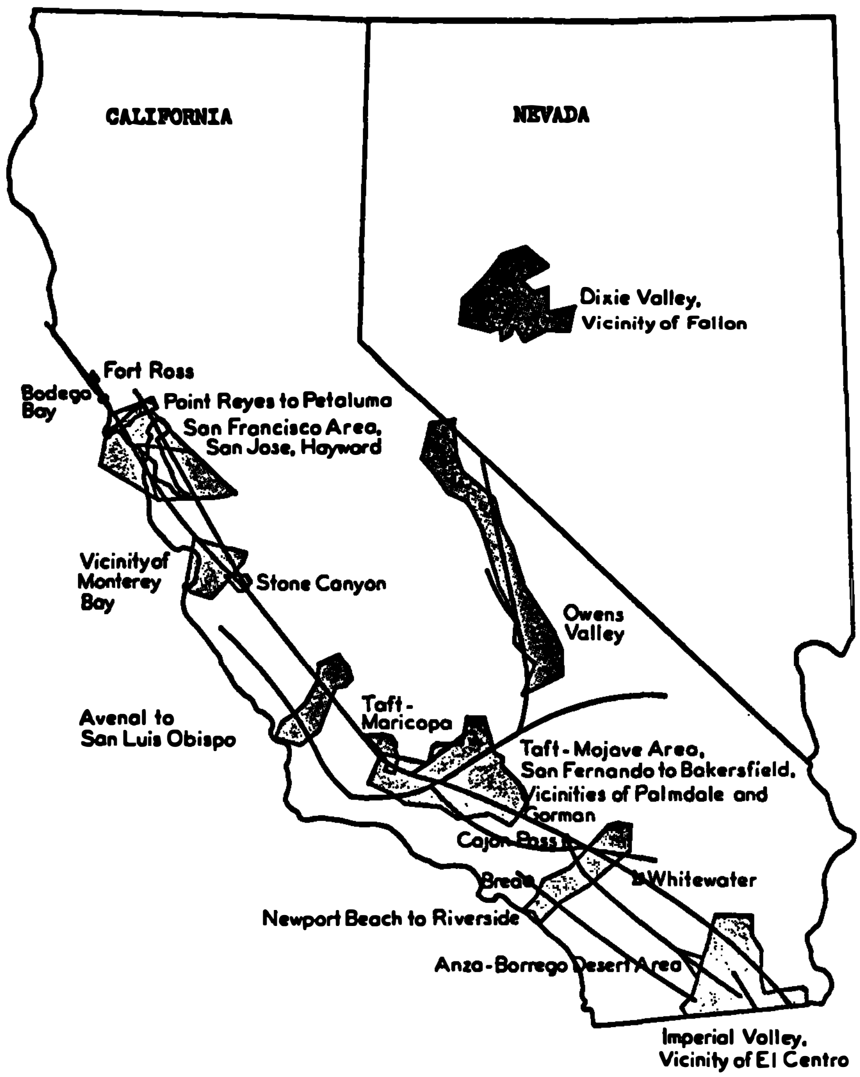


Figure 2.1-- Meade (1971) published this figure identifying several areas that were being monitored before and during the 1960s using direction or triangulation observations. In the early 1970s, the more precise electronic-distance-measuring technique became sufficiently operational for monitoring deformation over large areas.

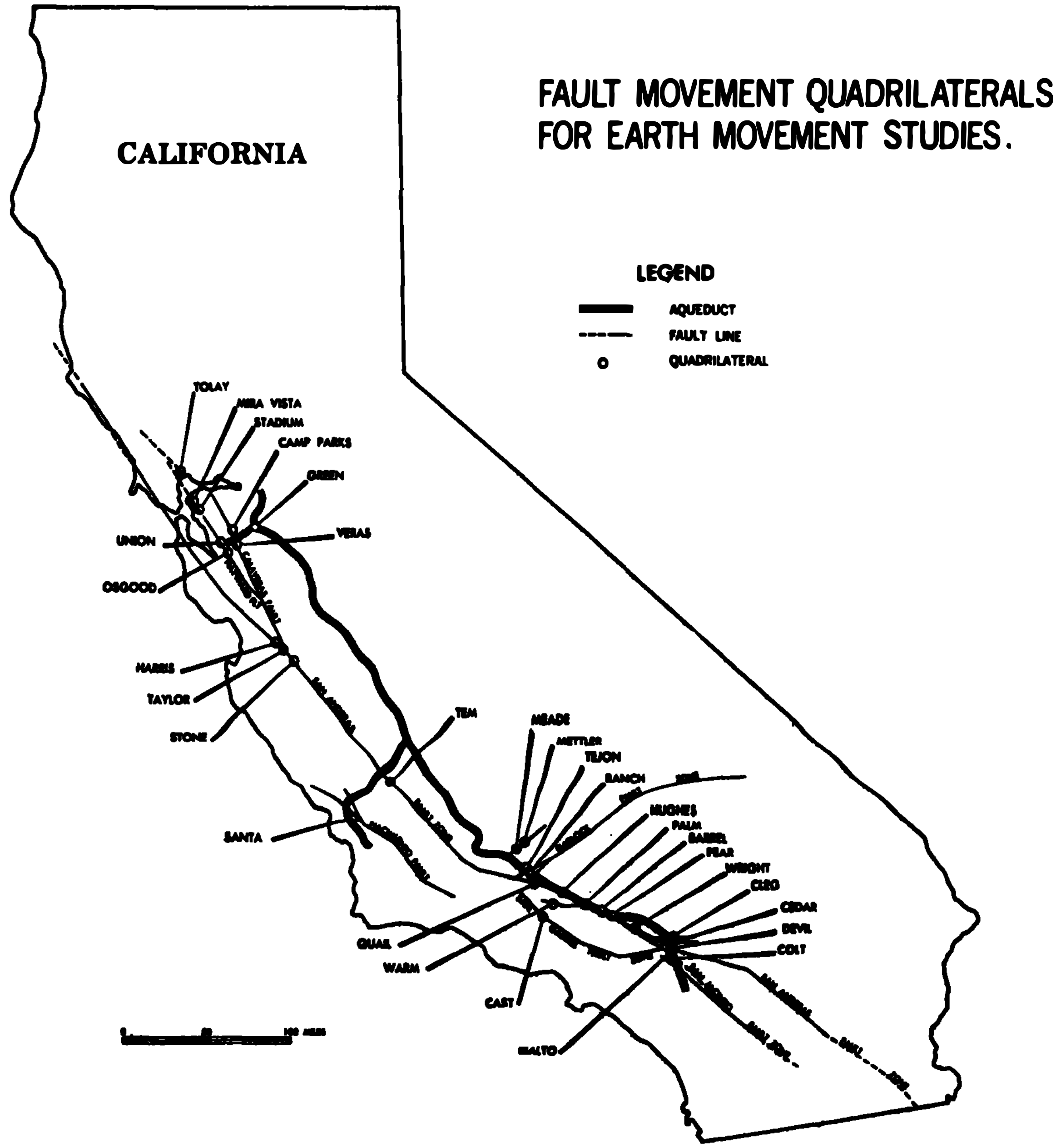


Figure. 2.2.--In the 1960s and 1970s, Federal agencies repeatedly surveyed 30 small geodetic networks to determine fault-slip rates in the vicinity of the California aqueduct. Most of these networks contained six to eight stations located within a kilometer of each other and with half of the stations to either side of the straddled fault (from Meade 1971).

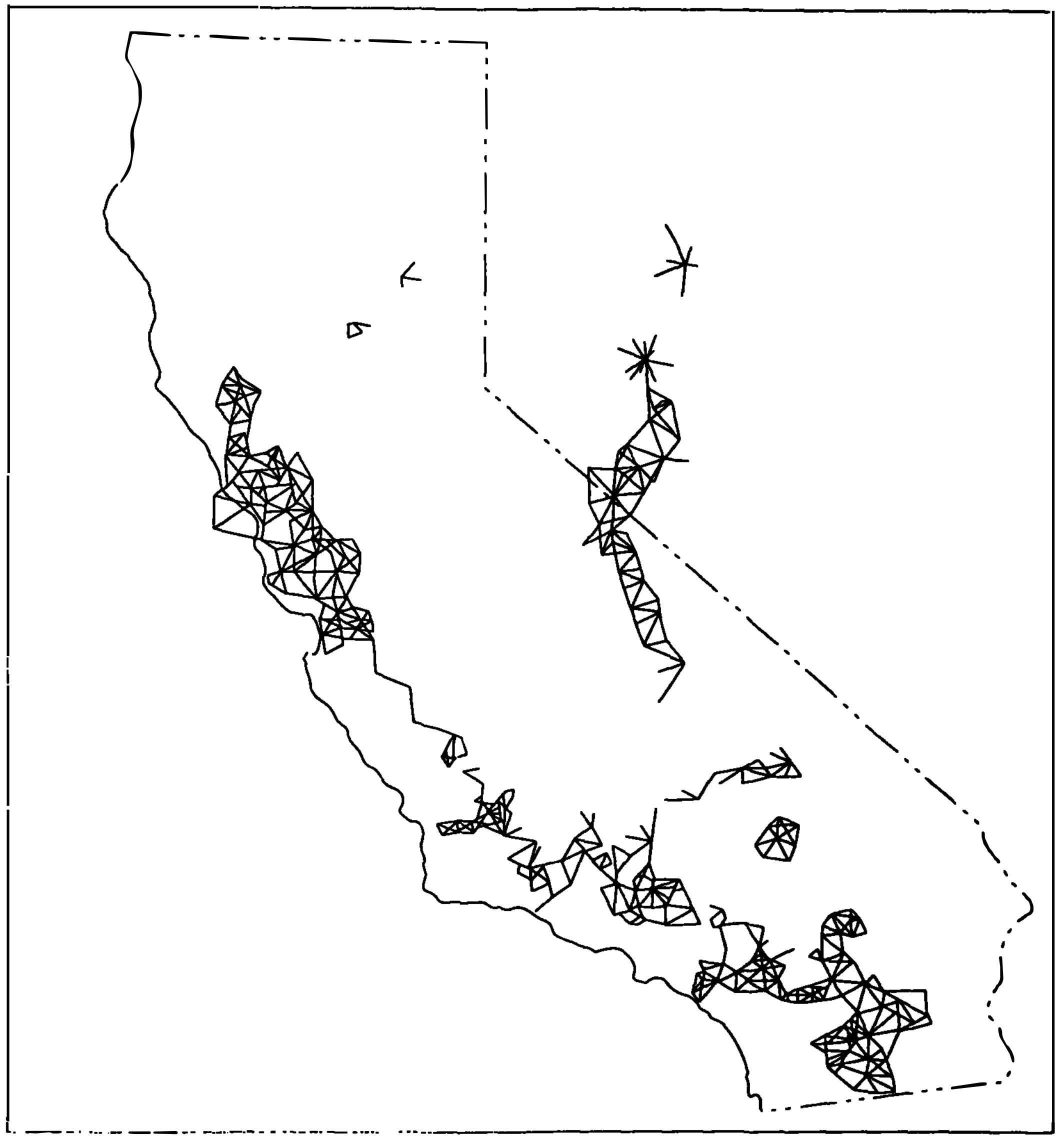


Figure 2.3.--Since the early 1970s, federal and state agencies have monitored crustal deformation using electronic-distance-measuring instrumentation. The figure identifies frequently measured lines located in California and Nevada.

Survey (USGS) from 1970 to the present (Savage 1983). (See fig. 2.3.) It is important to note, however, that most of the geodetic data used for project REDEAM were observed not to measure crustal motion but simply to position horizontal reference marks that comprise the geodetic reference network. The crustal motion information contained in this majority of the data results largely from past demands for additional reference marks whereby previously established marks were resurveyed to position the newer marks.

California's first geodetic data date back to the time of statehood, 1850. Most nineteenth century surveys, however, are concentrated along the coast as they were performed to aid navigation. California's interior network remained sparse until the introduction of Bilby towers around 1930. Because these 20- to 40-m tall observation platforms are transportable and can be erected or dismantled in less than a day, they provided an economical means for seeing over trees, buildings, and other obstacles. Consequently, the 1930s represent the original epoch of data for much of California. With the exception of the San Diego region, only pre-1980 data were included in the modeling effort. This cutoff date reflects the status of NGS's automated data base in early 1982--the time when the data were organized for project REDEAM. The San Diego data set was updated subsequent to 1982 to model coseismic deformation associated with the Imperial Valley earthquake (M=6.6) of 1979.

Direction observations represent the bulk of the archived data. Direction observations are organized into 'bundles'. Each bundle corresponds to a set of measurements made during a single observing session (usually spanning a few hours) from a particular instrumented station-mark to several targeted station-marks that are located within a few tens of kilometers. The standard error of a single direction observation ranges from 0.6 arc-seconds for first-order surveys to 1.2 arc-seconds for third-order surveys, that is, from 3 to 6 microradians.

Distance observations include both those that were taped and those that were obtained with electro-optical distance measuring (EDM) instrumentation. There are relatively few taped distance observations exceeding 1 km in length because the taping process is labor intensive and requires level, unobstructed terrain. The number and length of distance measurements increased drastically around 1960 with the advent of EDM equipment. Consequently, the set of distance observations included for REDEAM essentially spans only about two decades. The standard error of a distance observation is expressed by the empirical formula

$$\sigma = (a^2 + b^2 L^2)^{1/2} \qquad (2.1)$$

where $\underline{a}$ and $\underline{b}$ are specified parameters and L is line length. For first-order surveys performed by NGS, $\underline{a} = 0.015$ m and $\underline{b} = 10^{-6}$ (Gergen 1975). For USGS distance measurements, $\underline{a} \approx 0.003$ m and $\underline{b} = 0.2 \times 10^{-6}$ (Savage and Prescott 1973). The USGS achieves the better precision by flying aircraft along observed lines-of-sight to obtain profiles of temperature and humidity needed to correct for refraction. For routine geodetic work, only endpoint (and sometimes midpoint) readings of temperature and humidity are recorded.

Astronomic azimuth observations also contributed to the REDEAM solutions. NGS's archives contain approximately 400 such observations for California, with each observation having a standard error of 7 microradians or greater. Azimuth observations, however, are distributed poorly through time with approximately 80 percent observed after 1960.

Appendix B contains a number of illustrations, two for each region, presenting the spatial and temporal distributions of the data. They reveal:

- The regional data sets overlap. In particular, the model for each region was derived from not only data within the region but also extending to a distance of 16 km beyond the region's geographic span. This data overlap was engineered to provide a measure of spatial continuity among the various models.

- A significant increase in the number of direction observations occurred around 1930 with the introduction of Bilby towers.

- A significant increase in the number of distance observations occurred around 1960 with the introduction of EDM instrumentation and again around 1970 with the start of USGS's monitoring program.

- Only three regions (Channel Islands, Los Angeles, and Bakersfield) include data that predate the San Franciso earthquake of 1906. For some regions (San Diego, San Bernadino, and Barstow) the pre-1906 data had not been automated when the corresponding models were derived. For the other 10 California regions, the pre-1906 data were intentionally excluded to avoid modeling the coseismic movement associated with the San Francisco earthquake.

- Only the San Diego region includes post-1980 data.

3. MATHEMATICAL MODEL

The mathematical formulation of the REDEAM models includes parameters for both the secular and episodic components of motion.

Secular motion is represented by dividing the region to be modeled into a mosaic of districts. The words, region and district, convey specific meanings in this report. The geographic area pertaining to a specific model is called a region. A district is one of several specifically designated areas associated with a region. Each district is allowed to translate, rotate, and undergo spatially homogeneous deformation at a constant rate with respect to time. By approximating the known geologic faults with district boundaries, the relative motion between districts represents the relative movement across these faults. This is not to say that all district boundaries correspond to faults. Some districts have been introduced simply to increase the spatial resolution of the secular motion. Figure 3.1 identifies the 10 districts that comprise the San Diego region. Similar maps for the other regions are located in appendix B.

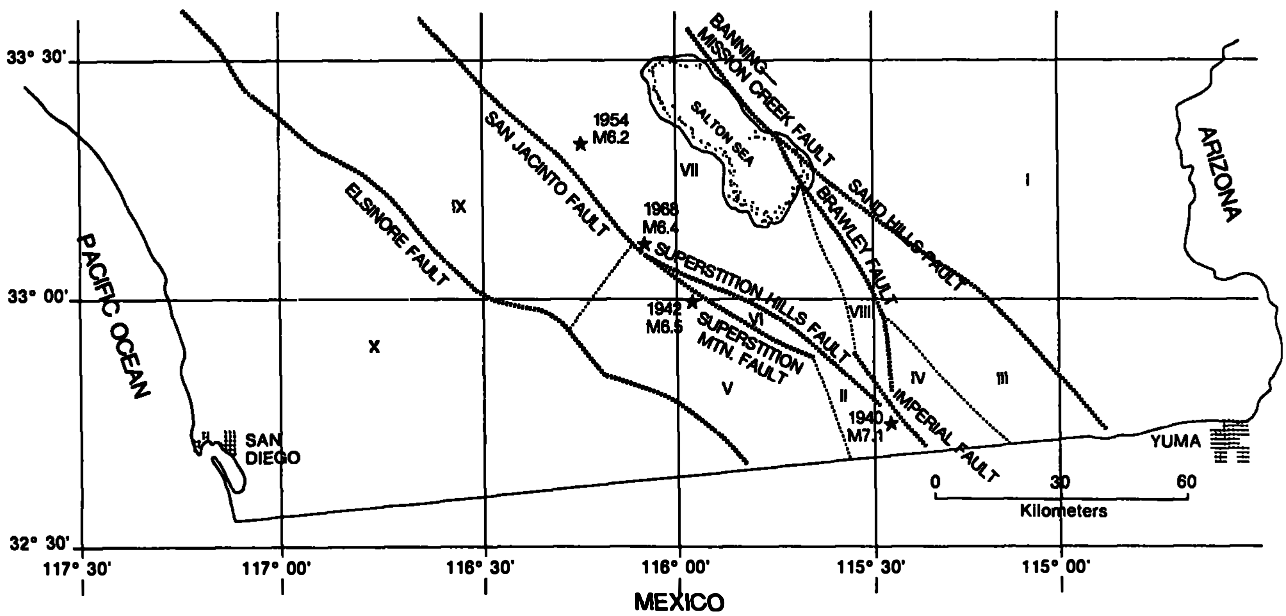


Figure 3.1.--A mosaic of 10 districts is used to model the secular motion of the San Diego region. Each Roman numeral identifies a district that can individually translate, rotate, and undergo homogeneous deformation at a constant rate with respect to time. District boundaries usually approximate geologic faults (hatched lines) so that relative motion between the districts corresponds to secular slip. The dashed lines denote district boundaries that do not correspond to faults. Dislocation theory is used to model the episodic motion associated with major earthquakes. The stars locate four modeled earthquakes identified by year of occurrence and magnitude.

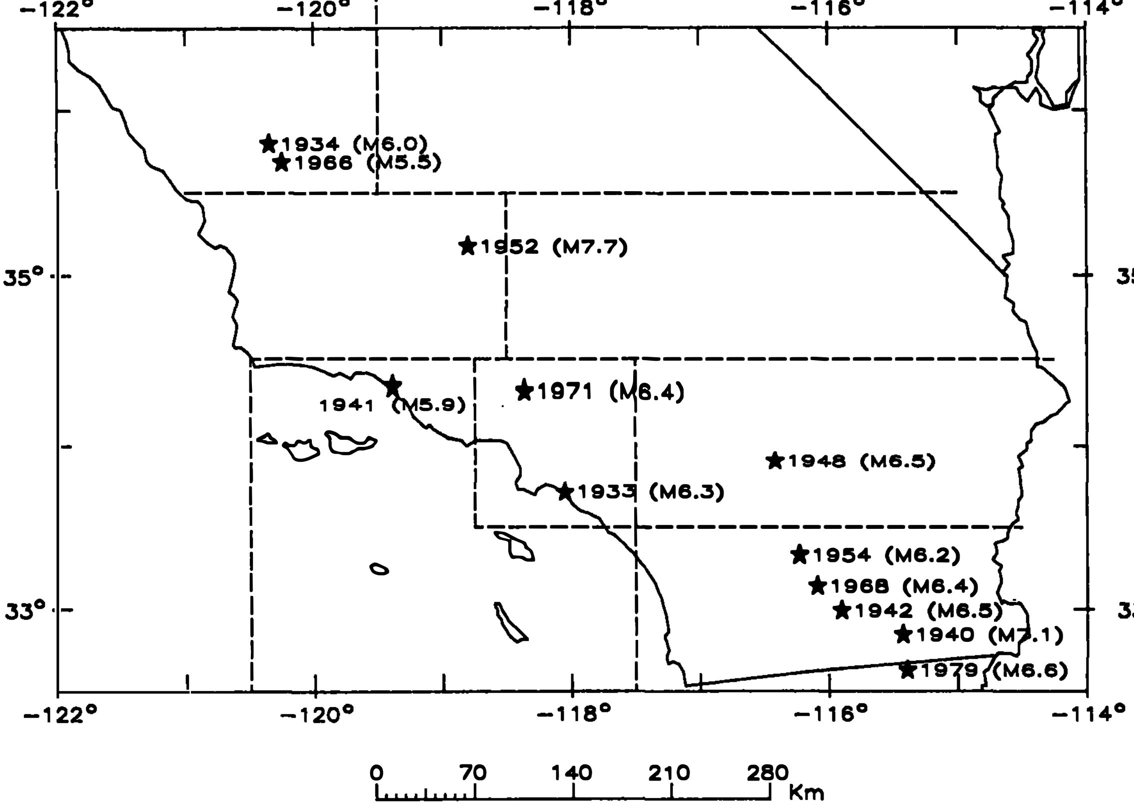


Figure 3.2.--Modeled earthquakes in California identified by year of occurrence and magnitude.

Modeled episodic motion corresponds to displacements associated with large earthquakes. For the episodic motion the Earth is considered to be an isotropic, homogeneous, elastic halfspace whose bounding plane represents the Earth's surface; that is, the Earth is represented as the set of points (x,y,z) with $z \leq 0$. Rectangular planes of finite dimensions are embedded in the halfspace to represent seismically active faults. The motions associated with an earthquake correspond to the displacements that the elastic halfspace undergoes in response to slip along the rectangular surfaces. This motion is given by the equations of dislocation theory (appendix A). The displacements are a function of the location, size, and orientation of the rectangles, as well as the amount and sense of the slip. Figure 3.2 identifies the earthquakes modeled for the 16 California regions.

More specifically, the mathematical model expresses the geodetic latitude $\phi_M(t)$ (positive north) and longitude $\lambda_M(t)$ (positive west) of a station M in district i at time t by the equation

$$\begin{bmatrix} \phi_M(t) \\ \lambda_M(t) \end{bmatrix} = \begin{bmatrix} \phi_M(t_o) \\ \lambda_M(t_o) \end{bmatrix} + \begin{bmatrix} a_{\phi *}(i) & a_{\phi\phi}(i) & a_{\phi\lambda}(i) \\ a_{\lambda *}(i) & a_{\lambda\phi}(i) & a_{\lambda\lambda}(i) \end{bmatrix} \begin{bmatrix} 1 \\ \phi_M(t_o) - \bar{\phi} \\ \lambda_M(t_o) - \bar{\lambda} \end{bmatrix} (t - t_o)$$

$$+ \sum_k r(t,t_k) \begin{bmatrix} A_k & B_k \\ C_k & D_k \end{bmatrix} \begin{bmatrix} s_k \\ d_k \end{bmatrix} \qquad (3.1)$$

Here t_o is a fixed time of reference. The preceding equation states that a station's coordinate values at time t equal its coordinate values at time t_o plus a secular term, plus an episodic term.

In using eq. (3.1), we presume that secular motion is linear in time. In the secular term the variables $(\overline{\phi},\overline{\lambda})$ represent reference coordinates that are selected prior to adjusting the model to the geodetic data. The variables $a_{\phi *}(i)$, $a_{\phi\phi}(i)$, $a_{\phi\lambda}(i)$, $a_{\lambda *}(i)$, $a_{\lambda\phi}(i)$, $a_{\lambda\lambda}(i)$ are parameters to be estimated for district i. Equation (3.1) implies that the secular motion interior to each district is essentially homogeneous strain plus rotation at a constant rate with respect to time. (See appendix D.)

The expression that involves the summation sign in eq. (3.1) corresponds to the episodic motion and gives the change of the station's latitude $\Delta_k\phi$ and longitude $\Delta_k\lambda$ caused by strike slip s_k and dip slip d_k at time t_k on the k-th rectangle for each value of k. That is,

$$\begin{bmatrix}\Delta_k\phi\\ \Delta_k\lambda\end{bmatrix} = r(t,t_k)\begin{bmatrix}A_k & B_k\\ C_k & D_k\end{bmatrix}\begin{bmatrix}s_k\\ d_k\end{bmatrix} \tag{3.2}$$

The episodic time dependence is embedded in the step function $r(t,t_k)$ defined by the conditions:

$$\text{for} \quad t_k < t_o \qquad r(t,t_k) = \begin{cases}-1 & \text{if } t < t_k\\ 0 & \text{if } t > t_k\end{cases}$$

$$\text{for} \quad t_k > t_o \qquad r(t,t_k) = \begin{cases}0 & \text{if } t < t_k\\ 1 & \text{if } t > t_k\end{cases} \tag{3.3}$$

Equation (3.3) prescribes that the slip on the k-th rectangle occurs instantaneously at time t_k. In eqs. (3.1) and (3.2) the quantities A_k, B_k, C_k, and D_k represent mathematical expressions involving the coordinates of station M as well as the location, orientation, and size of the k-th rectangle. Formulas for calculating these quantities are developed in the following paragraphs.

The fault center of the k-th rectangle is defined as the midpoint of the line segment that is the projected image of the rectangle onto the Earth's surface. (See appendix A.) Relative to no displacement at the fault center, let $U_{1k}(\phi,\lambda)$ denote the displacement due to slip on the k-th rectangle in the direction parallel to this rectangle's strike as realized at the point of the Earth's surface with coordinates (ϕ,λ). Then by dislocation theory, functions $F_{1k}(\phi,\lambda)$ and $G_{1k}(\phi,\lambda)$ exist such that

$$U_{1k}(\phi,\lambda) = F_{1k}(\phi,\lambda)s_k + G_{1k}(\phi,\lambda)d_k . \tag{3.4}$$

Similarly, functions $F_{2k}(\phi,\lambda)$ and $G_{2k}(\phi,\lambda)$ exist such that

$$U_{2k}(\phi,\lambda) = F_{2k}(\phi,\lambda)s_k + G_{2k}(\phi,\lambda)d_k \tag{3.5}$$

where $U_{2k}(\phi,\lambda)$ represents the displacement perpendicular to the strike at (ϕ,λ). The functions $F_{jk}(\phi,\lambda)$ and $G_{jk}(\phi,\lambda)$ for $j = 1,2$ are given in appendix A. In addition to being functions of position, these functions depend on the k-th rectangle's size, location, orientation (strike and dip angle), and on Poisson's ratio which characterizes crustal elasticity. For this study, Poisson's ratio is set equal to 0.24.

A differential approximation gives the displacements $\Delta_k\phi$ and $\Delta_k\lambda$ on the curved surface of the Earth relative to the assumption that the position $(\bar{\phi},\bar{\lambda})$ does not move. That is,

$$\begin{bmatrix} \Delta_k\phi \\ \Delta_k\lambda \end{bmatrix} = r(t,t_k) \left\{ [T_k][H_k(\phi,\lambda)] \begin{bmatrix} s_k \\ d_k \end{bmatrix} - [T_k][H_k(\bar{\phi},\bar{\lambda})] \begin{bmatrix} s_k \\ d_k \end{bmatrix} \right\} \tag{3.6}$$

where

$$[H_k(\phi,\lambda)] = \begin{bmatrix} F_{1k}(\phi,\lambda) & G_{1k}(\phi,\lambda) \\ F_{2k}(\phi,\lambda) & G_{2k}(\phi,\lambda) \end{bmatrix} \tag{3.7}$$

and

$$[T_k] = \begin{bmatrix} R^{-1} & 0 \\ 0 & (R\cos\phi_k)^{-1} \end{bmatrix} \begin{bmatrix} \cos\alpha_k & -\sin\alpha_k \\ -\sin\alpha_k & -\cos\alpha_k \end{bmatrix} . \tag{3.8}$$

Here R = the Earth's radius;

ϕ_k = the latitude of k-th fault center;

α_k = the strike of the k-th rectangle measured clockwise from north. The matrix $[T_k]$ transforms displacements from a locally defined reference system, referred to the k-th fault plane, to the globally defined ellipsoidal reference system.

Eqs. (3.2) and (3.6) imply that

$$\begin{bmatrix} A_k & B_k \\ C_k & D_k \end{bmatrix} = [T_k]\,[H_k(\phi,\lambda) - H_k(\bar{\phi},\bar{\lambda})] . \tag{3.9}$$

With eq. (3.1) observations are entered into a least-squares process to estimate the unknown coordinates $(\phi_M(t_o),\lambda_M(t_o))$ for all M, the unknown parameters $a_{\phi *}(i)$, $a_{\phi\phi}(i),\ldots,a_{\lambda\lambda}(i)$ for all values of i, and the slips s_k and d_k for all values of k. In the least-squares process an observation β_t at time t (a direction, a distance, or an azimuth) is first corrected for known systematic errors such as refraction and it is then projected onto an ellipsoidal reference surface so that the 'reduced' observation β_t' is expressible solely as a function h of mark coordinates. That is,

$$\beta_t' = h[\phi_P(t),\ \lambda_P(t),\ \phi_Q(t),\ \lambda_Q(t)] \tag{3.10}$$

where P and Q denote marks associated with the observation. Substituting into this equation from eq. (3.1), β_t' becomes a function of the coordinates $(\phi_P(t_o),\lambda_P(t_o))$ and $(\phi_Q(t_o),\lambda_Q(t_o))$, the parameters $a_{\phi *}(i)$, $a_{\phi\phi}(i),\ldots,a_{\lambda\lambda}(i)$ for all i corresponding to the district(s) containing P and Q, and also a function of the slips s_k and d_k for all values of k. These expressions constitute the so-called 'observation equations' of the least squares process. The observations are weighted in the solution equal to the squared inverse of their respective standard errors.

4. PARAMETER ESTIMATION

Once the boundary of a particular region had been identified, we assembled all available geodetic data in that region into a single computer file called a TRAVDECK. Model parameters were estimated from these data via the least squares process. Here we briefly describe the software employed to obtain these estimates. The estimates themselves are tabulated in appendix C.

In addition to observational records, a TRAVDECK contains a positional record for each geodetic mark in the region. This positional record contains, among other information, preliminary estimates of the mark's latitude and longitude and adopted values for its orthometric height and geoid height. These positional quantities are needed for reducing observations to corresponding values on a mathematical reference ellipsoid. Preliminary latitude and longitude estimates are also needed because of the nonlinear relationship (eq. 3.10) between the observables and the estimated quantities.

The processing software, entitled MOTION III, was fashioned after the computer program TRAV10 which NGS employed during the late 1970s and early 1980s. TRAV10 performed a static network adjustment of a collection of horizontal data; that is, TRAV10 only estimated horizontal coordinates. For developing MOTION III, we modified the TRAV10 code to include the capability of estimating secular motion coefficients and earthquake-related slip vectors in addition to positional coordinates. MOTION III consists of six separate routines: QUIKR, REDUCE, REORD, BNDRY, CRUNCH, and POMOT.

QUIKR assigns a unique identification number to each geodetic mark and modifies the TRAVDECK so that updated positional records and updated observational records contain the numbers assigned to the mark(s) associated with those records. Subsequent routines use these identification numbers for internal computer reference.

REDUCE computes and applies "corrections" required to project observations onto the reference ellipsoid. The corresponding formulas are given by Schwarz (1978).

REORD determines an ordering of the geodetic marks to minimize computer-storage requirements of the array containing the least-squares normal-equations matrix when it is formed and manipulated in the subsequent routine CRUNCH. CRUNCH uses the same profile storage scheme as TRAV10 (Schwarz 1978). In particular, REORD employs the "banker's" algorithm (Snay 1976) to obtain a near optimal ordering of the marks.

BNDRY assigns each geodetic mark to its proper district. Recall that each region is partitioned into a mosaic of districts and, within a particular district, secular horizontal velocity is constrained to be a linear function of latitude and longitude per eq. (3.1). Also recall that district boundaries often, but not always, correspond to geologic faults. District boundaries were selected with the help of published geodetic diagrams for California (NOAA 1971) which show the relative locations of geodetic marks and geologic faults. The 1:250,000 series of the Geologic Map of California (Olaf P. Jenkins edition available from the California Division of Mines and Geology, San Francisco) was also frequently consulted. The boundary of a particular district is defined by specifying the coordinates for the vertices of a simple closed polygon, that is, a polygonal loop that does not intersect itself. Such a loop bounds two disjoint areas on the Earth's surface. In BNDRY the district corresponding to a particular polygon is the bounded area that does not contain the North Pole. In BNDRY, every mark is assigned to one and only one district. Appendix C tabulates vertices defining the districts for the various regions. See also appendix B for maps of the various regions that illustrate the spatial extent of the districts.

CRUNCH performs the least squares adjustment for estimating user-designated model parameters. (See chapter 3.) In particular, CRUNCH computes the coefficients of the observation equations, forms and solves the normal equations, and then computes residuals. The observation-equation coefficients are computed by an application of the chain rule. That is, if β_t' is a reduced observation, say a distance, observed at time t, and if α is a parameter to be estimated, say a secular motion coefficient, then from eq. (3.10) the coefficient $(\partial\beta_t')/(\partial\alpha)$ may be computed by the equation:

$$\frac{\partial\beta_t'}{\partial\alpha} = \left(\frac{\partial h}{\partial\phi_P(t)}\right)\left(\frac{\partial\phi_P(t)}{\partial\alpha}\right) + \left(\frac{\partial h}{\partial\lambda_P(t)}\right)\left(\frac{\partial\lambda_P(t)}{\partial\alpha}\right) + \left(\frac{\partial h}{\partial\phi_Q(t)}\right)\left(\frac{\partial\phi_Q(t)}{\partial\alpha}\right) + \left(\frac{\partial h}{\partial\lambda_Q(t)}\right)\left(\frac{\partial\lambda_Q(t)}{\partial\alpha}\right) \tag{4.1}$$

The partials $\frac{\partial h}{\partial\phi_P(t)}, \frac{\partial h}{\partial\lambda_P(t)}, \frac{\partial h}{\partial\phi_Q(t)}, \frac{\partial h}{\partial\lambda_Q(t)}$ in eq. (4.1) are exactly the coefficients that would be computed for a static horizontal network adjustment, and the appropriate formulas are given by Schwarz (1978). The other four partials on the right-hand-side of eq. (4.1), namely those involving partial derivatives with respect to α, may be computed by differentiating eq. (3.1) with respect to α. To compute these latter four partials, the following information must be provided initially to CRUNCH: (1) the time of reference t_o, (2) the coordinates $(\bar{\phi},\bar{\lambda})$ for the origin of reference, and (3) the dates of the earthquakes together with the various parameter values defining location, size, and orientation for the corresponding dislocation surfaces. (See appendix A.)

POMOT prints the parameter estimates obtained in CRUNCH with the associated correlation matrix for the crustal motion parameters. POMOT will also compute certain derived quantities if requested; namely, (1) station positions at specified times, (2) displacements attributed to earthquakes at specified locations, and (3) secular strain-rate parameters for specified districts. In addition POMOT prints residuals and normalized residuals for the observations.

5. MODEL IMPLEMENTATION

The derived crustal motion models were used to "update" all archived horizontal data in the United States to the common date December 31, 1983. Thus an observation measured in 1940, for example, was updated to approximate the value that would be expected if it were remeasured on December 31, 1983. These updated observations were then entered into a static horizontal network adjustment to determine latitudes and longitudes for the North American Datum of 1983 (NAD 83) geodetic reference system. This chapter describes the algorithm used for computing the crustal motion "corrections" for updating observations.

Crustal motion corrections were applied to all observations that involve two stations, namely, direction, azimuth, and distance observations. Crustal motion corrections were not applied to observations involving only a single station, namely, Doppler positioning observations, because the data used to generate the models are insensitive to 'absolute' motion. The effect of not correcting the Doppler observations should be insignificant because all archived Doppler observations were performed after 1970 and because the horizontal components of these observations have meter-level uncertainties.

To correct an observation between two stations P and Q measured at time t_1 to its corresponding value at time t_2, approximate horizontal coordinates for P and Q at the preselected reference time t_o = January 1, 1950 are needed. Because we are interested only in changes to observations from one time to another, the selection of t_o was rather arbitrary (1950 corresponds to the approximate weighted midpoint in the observation dates), and the station coordinates at time t_o did not need to be extremely accurate. For our purpose, the NAD 27 coordinates of P and Q constitute sufficiently accurate estimates for $\phi_P(t_o)$, $\lambda_P(t_o)$, $\phi_Q(t_o)$, and $\lambda_Q(t_o)$.

Step 1: Determine the regions R_P and R_Q that contain stations P and Q, respectively. Recall that crustal motion models were formulated for 19 mutually disjoint regions. Points in the United States that are not contained in any of these 19 regions are assigned to a twentieth, complementary region where the crustal motion model for region 20 is defined as the null model, that is, no motion.

Step 2: Let T denote the type of observation to be corrected. Use the model for R_P to compute $\phi_P(t_1)$, $\lambda_P(t_1)$, $\phi_Q(t_1)$, and $\lambda_Q(t_1)$ according to eq. (3.1), and let $b(t_1,R_P)$ denote the hypothetical observation of type T that would be measured at time t_1 between P and Q given these coordinates. Similarly use the model for R_P to compute $\phi_P(t_2)$, $\lambda_P(t_2)$, $\phi_Q(t_2)$, and $\lambda_Q(t_2)$ according to eq. (3.1), and let $b(t_2,R_P)$ denote the hypothetical observation of type T that would be measured at time t_2 between P and Q given these coordinates.

Step 3: Use the model for R_Q to compute, as in step 2, the hypothetical observations $b(t_1,R_Q)$ and $b(t_2,R_Q)$ of type T between P and Q at times t_1 and t_2, respectively.

Step 4: If b denotes the value of the actual observation measured at time t_1, then

$$b' = b + 1/2\,[b(t_2,R_P) - b(t_1,R_P)] + 1/2\,[b(t_2,R_Q) - b(t_1,R_Q)] \quad (5.1)$$

is the corrected observation corresponding to time t_2.

Note that the correction in eq. (5.1) represents the average of two estimates for the crustal motion between times t_1 and t_2: one estimate from the model for region R_P and the other from the model for region R_Q. This averaging process minimizes possible discrepancies between different models for observations that cross regional boundaries. Recall that regional boundaries are artifacts which, unlike most district boundaries, do not correspond to geologic faults.

Note also that the algorithm does not require that observation b be projected onto the reference ellipsoid to compute b', even though $b(t_1,R_P)$, $b(t_2,R_P)$, $b(t_1,R_Q)$, and $b(t_2,R_Q)$ may correspond to hypothetical observations on the reference ellipsoid. Moreover, any other data correction, for example, refraction, can be applied either before or after the crustal motion correction, provided the value of the correction does not strongly depend on the date of observation or on the horizontal coordinate changes at the level of expected crustal motion.

Finally note that REDEAM models should not be used to compute positions that predate the 1906 San Francisco earthquake (April 18) for marks in California which are north of the 35.5° parallel of latitude.

6. MODEL EVALUATION

Evaluation of the REDEAM models constitutes an ongoing process. Five papers, in addition to this one, have already appeared in print, and other studies are anticipated. Four of these five publications discuss specific models and compare these models both with results derived by independent investigators and with current geophysical theories. In particular, these publications discuss the model for the San Diego region (Snay et al. 1983), the model for the Los Angeles region (Cline et al. 1984), the models for the San Francisco, Santa Rosa, and Ukiah regions (Cline et al. 1985), and the model for the Fallon, Nevada, region (Snay et al. 1985). The fifth publication (Snay et al. 1986) presents an overall evaluation of the 16 regional models spanning California. The fifth paper also discusses ideas for improving the models. This chapter recaps some of the material appearing in these five publications.

Figure 6.1 portrays the derived shear strain pattern for California. (See appendix D for a discussion of strain.) Because we have chosen to model the 16 California regions independently, artificial discontinuities in secular velocity occur across regional boundaries. These discontinuities have an rms value of ~5 mm/yr even after individual models are adjusted to be mutually compatible. We partitioned California into 16 regions to limit the size of the individual data sets. Even with 16 regions the data sets were often too large for a person to become adequately familiar with

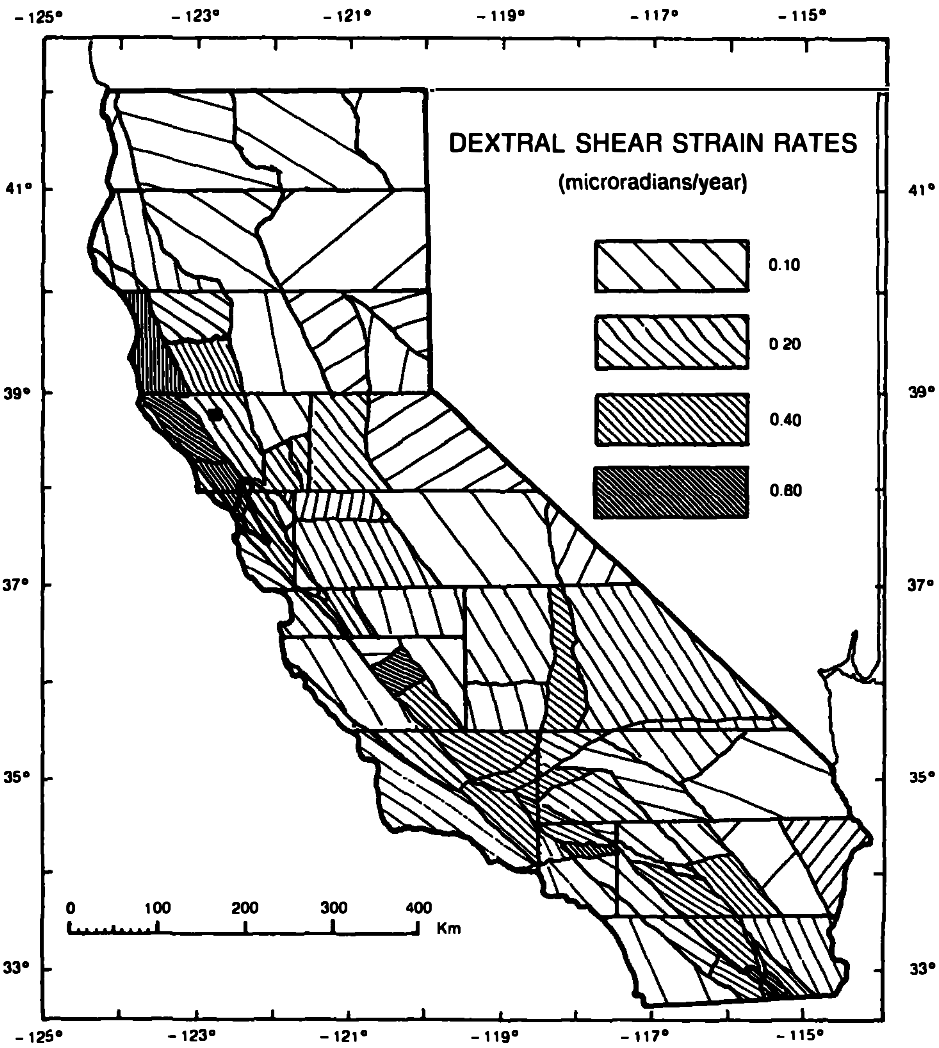


Figure 6.1.--Secular shear strain pattern for California as derived from historical geodetic data. The line patterns designate the directions and magnitudes (engineering units) of maximum dextral (right-lateral) shear strain rates for the mosaic of districts. Shearing between the North American and Pacific plates dominates the regional stress field producing an overall northwest-southeast trend for the direction of maximum dextral shear strain. The secular motion is assumed to be linear in time and excludes the movements associated directly with earthquakes of magnitude six and greater.

all the data contained in a region. Also, we limited the sizes of the data sets because model development was largely a trial-and-error procedure: (1) the data sets had to be screened for blunders, (2) district boundaries had to be resolved, and (3) appropriate earthquake fault parameters had to be determined. It was not uncommon for us to perform as many as 10 adjustments of a region's data to various models in search of the best representation for regional crustal movement. Moreover, each such adjustment strained computer resources to the extent that frequently the computer could only execute the adjustment over the weekend. Now, having modeled the 16 regions, we feel sufficiently familiar with the data, the techniques, and the geophysics to undertake a simultaneous adjustment of all California data to a single model. We need only develop the appropriate software and allocate the necessary resources.

Figure 6.1 presents only the shear components of the secular deformation pattern. Data limitations render our estimates of the other components (rotation and dilatation) questionable.

The rotation estimates depend on the astronomic azimuth data. The geodetic archives contain less than 400 such azimuth observations for California, with each observation having a standard deviation of 7 microradians or greater. Moreover, the azimuth observations are distributed poorly through time, with approximately 80 percent observed since 1960. Consequently, rotation uncertainties (1σ) for districts are about 0.1 microradians per year (appendix D). Said differently, for every 100 km separating two stations, an uncertainty of 1 cm/yr exists in the transverse component of the secular velocity between these stations. These velocity uncertainties are similiar in magnitude to the expected secular velocities between stations on opposite sides of the state (Minster and Jordan 1978). The near-future availability of space-based data, providing 3-dimensional coordinate differences between stations to centimeter-level precision over lines exceeding 100 km in length, will enhance our estimates of regional rotation.

The dilatation component of the deformation depends on the collection of distance observations. Prior to the initial deployment of electro-optical distance measuring equipment in 1959, distances were laboriously taped. Consequently, the set of distance observations essentially spans only the last two decades. Moreover, unmodeled systematic errors, having magnitudes on the order of several parts in 10^6, are thought to contaminate much of the distance data [see table 2 in Snay et al. (1983) and table 4 in Cline et al. (1984)]. Considering the short time base, such errors could easily bias our estimated dilatation rates at the level of a few parts in 10^7 per year--a level that approximates in magnitude the dilatation rates that have been accurately measured with EDM by the U.S. Geological Survey (USGS) for selected areas of California (Savage 1983). These USGS EDM data are more precise than most of the other archived distance measurements because the USGS flew aircraft over the observed lines-of-sight to obtain temperature and humidity profiles to better correct for refraction. For routine geodetic work, only endpoint meteorological readings are recorded. The highly precise USGS EDM data measured before 1979 were included in the REDEAM modeling project. These data profoundly helped to subdue biases in our dilatation rate estimates, yet their effect was understandably limited to the areas that these data cover. The USGS monitoring program continues through time to the present and has expanded gradually to cover a greater area. Our planned second generation model will benefit from the inclusion of the USGS data measured since 1979.

Also, to better address the problem of systematic errors in the distance data, a future generation model will probably include several scale parameters. These parameters would be introduced on the premise that a large part of the systematic error manifests itself as scale factors, each such factor being common to a group of distances observed with the same instrument. Such an error could be caused, for example, by instrumental miscalibration. These scale parameters would be estimated simultaneously with other model parameters via the least squares process.

The secular shear strain pattern (fig. 6.1) is well determined for California because of the preponderance of triangulation data. The earliest data are from the 1850s, but most pre-1900 data are concentrated along the coast where they primarily supported navigational charting. For most California areas, then, the first geodetic data were

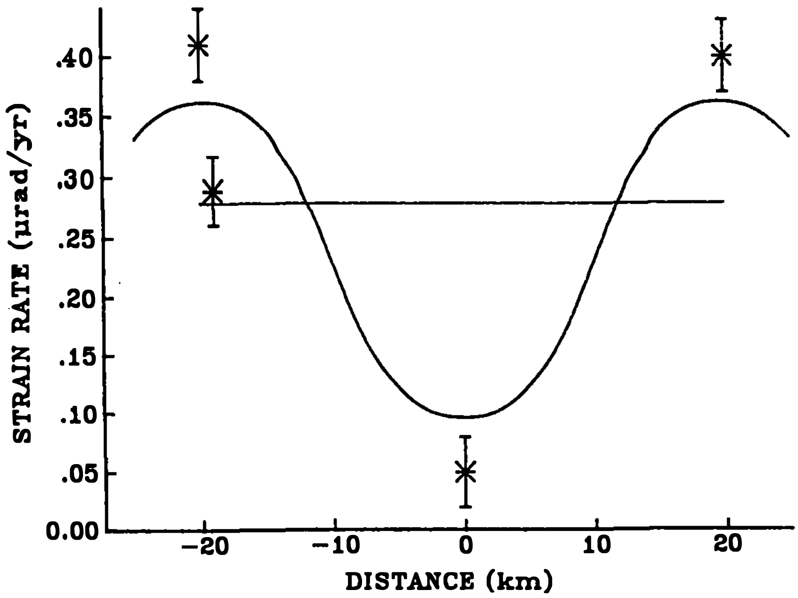


Figure 6.2.--The San Bernardino regional model contains a district corresponding in area to the 40-km wide strip of land between the San Andreas and San Jacinto fault zones. The above graph represents a cross section of this strip with the San Andreas fault zone located at +20 km and the San Jacinto at -20 km. The REDEAM model presumes that the secular shear-strain rate is homogeneous across the strip. The horizontal line represents the REDEAM rate. Asterisks (with 1 σ error bars) represent four localized strain-rate estimates that reveal significant spatial variation across the strip. The curve corresponds to a hypothetical representation of this variation as proposed by King and Savage (1983).

observed in the 1930s, corresponding in time to the introduction of the Bilby tower. Consequently, the shear strain-rate estimates correspond essentially to a 50-year time interval, 1930-80. These estimates also represent spatial averages over several tens of kilometers; that is, the models presume that secular strain is spatially homogeneous within each district. A localized study of USGS EDM data in southern California (King and Savage 1983) demonstrates the need for a model allowing greater spatial resolution (fig. 6.2).

Table C.3 presents parameters for modeled earthquakes in California and Nevada. In addition the parameters for some of these earthquakes have been discussed by Snay et al. (1983 and 1985) and Cline et al. (1984). The locations, dimensions, and orientations of the various rectangles that represent the fault planes were specified after reviewing the geologic and seismic literature. We scanned this literature for hypocenters, aftershock zones, focal mechanisms, and surface ruptures. The uncertainties (1σ) associated with the estimated components of the coseismic slip vectors imply decimeter-level resolution. We believe these uncertainties, however, are overly optimistic because the locations, dimensions, and orientations of the dislocation planes were introduced into the solution as if they were perfectly known. Also, the derived uncertainties are optimistic because of the ambiguities that exist in discriminating between coseismic and secular fault slip. Consequently, we contend that the existing geodetic data in general suffice only to resolve those coseismic slips exceeding a meter in magnitude. A meter of slip essentially requires an event with $M \geq 7$ (Bonilla and Buchanan 1970), such as the 1940 Imperial Valley earthquake ($M = 7.1$) or the 1952 Kern County earthquake ($M = 7.7$). Only a few seismic events with $6 \leq M \leq 7$ have their coseismic slips well determined by existing horizontal data.

It may be unfair to attribute this poor resolution of coseismic slip completely to data limitations. Some of the problem, more than likely, rests with our employed mathematical representation of earthquake movement. Our technique assumes that coseismic slip is constant over a rectangle whose dimensions are typically on the order of tens of kilometers. Current theory for earthquake mechanics, however, favors the existence of significant spatial variations in slip over the rupture surface. The newer theory promotes the concepts of "asperities" and "barriers" that strongly influence the distribution of coseismic slip (Aki 1984). Both terms refer to strong patches on the fault that are resistive to breaking. Considerable study is yet needed to identify and classify these fault features and then develop analytic expressions that will more realistically represent the episodic motion.

7. SUMMARY

Crustal motion models were produced for 19 total regions, 16 of which combine to cover all of California, with one model each for parts of Nevada, Hawaii, and Alaska. We view this accomplishment not as an end but as the beginning of a new approach to the description of crustal motion--an approach that integrates both large volumes of data as well as various types of data. In producing these first models, we have gained such an increased understanding of the data and of the geophysics that work on the second generation model is already in the planning stage. Table 7.1 summarizes the contemplated improvements to the original regional models. Some of these improvements will be incorporated into the second generation model; others will come only with later generations. The requirement for model improvement is also driven by the continual accession of new and often more accurate data. One of our goals is to synthesize the space-based data into the modeling process as techniques like the Global Positioning System, mobile Very Long Baseline Interferometry, and Satellite Laser Ranging become more operational. Other geophysical data types might also be synthesized into the modeling process. Our original models indirectly used processed seismic data to define certain coseismic fault parameters. These models also indirectly used geologic information to delineate district boundaries. Future models could possibly benefit from additional data types, such as measurements of fault creep, gravity, in situ stress, or heat flow. The synthesis of these various data types will necessarily lead to the development of physically more realistic models.

Table 7.1.--Proposed improvements to original crustal motion models

Improvement	Purpose
Adjust California to a single model	To remove artificial discontinuities along regional boundaries and to "push back" boundary effects.
Incorporate space-based data	To constrain the accumulation of systematic errors over distance and to better resolve regional rotation.
Introduce scale parameters	To remove systematic scale biases suspected among many groups of distance observations.
Incorporate more recent USGS EDM data	To better resolve secular dilatation rates.
Replace current expressions for secular motion with individual station velocity parameters	To provide better spatial resolution of the secular motion.
Refine earthquake models	To represent episodic motion more realistically.

APPENDIX A.--DISLOCATION EQUATIONS

From the analysis of the surface displacements associated with the 1906 San Francisco earthquake, Hayford and Baldin (1908) found: (1) that points on opposite sides of the disrupted San Andreas fault moved in opposite directions, (2) that displacements were less the greater the distance from the fault, and (3) that the directions of the displacements correlated well with fault orientation. These discoveries helped establish the then controversial theory that fault slip causes the vibrations in the ground that we know as earthquakes. The association between fault slip and earthquakes extends even further. Numerous studies, for example, Chinnery (1961), Savage and Hastie (1966), Hastie and Savage (1970), Stein and Thatcher (1981), and Snay et al. (1982), have since demonstrated that coseismic crustal deformation relates quantitatively to fault slip. Steketee (1958a,b) constructed the mathematical foundation for this relationship by translating relevant concepts from the theory that deals with dislocations or offsets in the lattice structure of crystals. Even the name, dislocation theory, has been carried from crystallography to the realm of geophysics. There is a basic difference, however. Whereas crystallography deals with dislocations in a discrete structure, geophysics is concerned with dislocations in a continuum.

A dislocation surface in a continuous 3-dimensional body is, briefly, a surface of discontinuity in displacement. It may be understood conceptually by visualizing its formation in the following process:

a) make a cut inside the body to form an arbitrary new surface S;
b) apply relative displacement of slip-type to the two faces of the cut;
c) rejoin the faces in their new positions.

In this way the body regains its stress continuity, but undergoes deformation to accommodate the displacement discontinuity across S.

In geophysical applications the body encompassing the dislocation surface is customarily a homogeneous, isotropic, elastic halfspace whose free surface represents the Earth's surface. For the special case of uniform slip over a rectangular dislocation surface whose upper edge parallels the free surface (fig. A.1), closed analytical formulas for computing the associated displacement field have been published by several authors. In particular, see Okada (1985) for an overview of existing literature. REDEAM software incorporates the formulas published by Dunbar (1977).

The equations assume a right-hand coordinate system (fig. A.1) with the 1-axis and 2-axis defining a horizontal plane and the 3-axis corresponding to the vertical dimension. The 1-axis parallels the strike of the rectangle, the 2-axis is positive in the direction of dip, and the 3-axis is positive into the halfspace. The origin of the coordinate system corresponds to a specific point on the line where the plane of the rectangle intersects the free surface. If the rectangle is projected orthogonal to its strike onto this line, then the origin corresponds to the midpoint of the projected rectangle. If $X(x_1,x_2,x_3)$ denotes an arbitrary point in the halfspace, the equations yield the displacements $U_1(X)$ and $U_2(X)$ which parallel the 1-axis and the 2-axis, respectively, as a function of

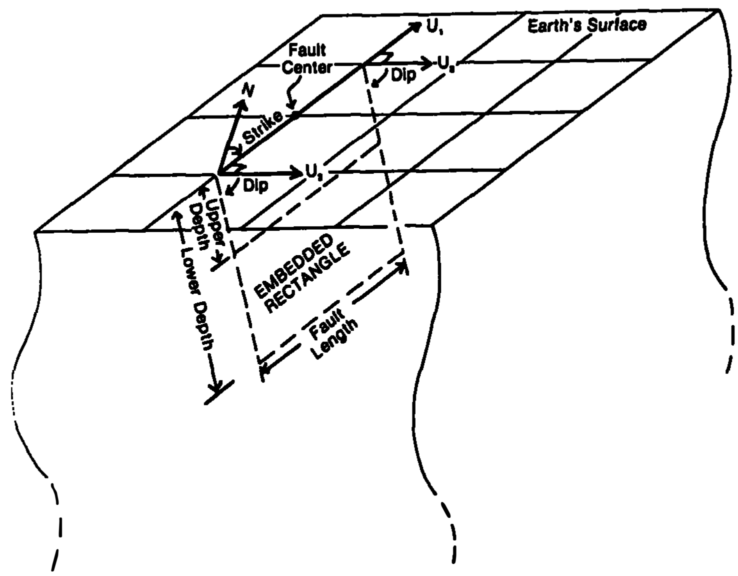


Figure A.1.--Given a rectangle embedded in an isotropic homogeneous elastic halfspace, dislocation theory describes how each point of the halfspace moves in response to relative slip between opposing rectangular faces. It is assumed that the upper and lower edges of the rectangle are parallel to the Earth's surface and that the slip is pure translation in the plane of the rectangle, in particular, no rotation. The figure identifies a set of parameters sufficient to specify the size, location, and orientation of the rectangle. The motion depends on these parameters, the Poisson ratio of the crust, and the slip vector. A constant slip vector over the rectangle is required by the mathematical formulation employed in this report. Spatial variation of fault slip is introduced by approximating the fault with multiple disjoint rectangles. The axes U_1 and U_2 define a local reference system for horizontal motion. The U_1 axis is positive along the fault strike. The U_2 axis is oriented 90° clockwise from U_1 and is positive in the direction of the dip.

s	strike slip
d	dip slip
Θ	fault dip
D_U	upper fault depth (measured along dip)
D_L	lower fault depth (measured along dip)
H	fault half-length
ν	Poisson's ratio.

The equations are of the form

$$U_i(X) = F_i(X)\ s + G_i(X)\ d \tag{A.1}$$

where
$$F_i(X) = \int_{D_U}^{D_L} \int_{-H}^{H} f_i(X,\xi)\ d\xi \tag{A.2}$$

for $\xi(\xi_1, \xi_2, \xi_3)$ denoting points on the rectangle.

Consequently,

$$\begin{aligned} F_i(X) &= f_i(X,\xi)\big|_{\xi = \xi(+H,\ D_L \cos\Theta,\ D_L \sin\Theta)} \\ &- f_i(X,\xi)\big|_{\xi = \xi(-H,\ D_L \cos\Theta,\ D_L \sin\Theta)} \\ &- f_i(X,\xi)\big|_{\xi = \xi(+H,\ D_U \cos\Theta,\ D_U \sin\Theta)} \\ &+ f_i(X,\xi)\big|_{\xi = \xi(-H,\ D_U \cos\Theta,\ D_U \sin\Theta)} \end{aligned} \tag{A.3}$$

Similarly
$$G_i(X) = \int_{D_U}^{D_L} \int_{-H}^{H} g_i(X,\xi)\ d\xi \tag{A.4}$$

To express the equations $f_i(X,\xi)$ and $g_i(X,\xi)$, it is convenient to introduce the notation: (Mansinha and Smylie 1971):

$$\xi_0 = (\xi_2^2 + \xi_3^2)^{1/2}$$

$$r_2 = x_2 \sin\theta - x_3 \cos\theta \qquad q_2 = x_2 \sin\theta + x_3 \cos\theta$$

$$r_3 = x_2 \cos\theta + x_3 \sin\theta \qquad q_3 = -x_2 \cos\theta + x_3 \sin\theta$$

$$\begin{aligned} R^2 &= (x_1-\xi_1)^2 + (x_2-\xi_2)^2 + (x_3-\xi_3)^2 \\ &= (x_1-\xi_1)^2 + r_2^2 + (r_3-\xi_0)^2 \end{aligned}$$

$$Q^2 = (x_1-\xi_1)^2 + (x_2-\xi_2)^2 + (x_3+\xi_3)^2$$

$$= (x_1-\xi_1)^2 + q_2^2 + (q_3+\xi_0)^2$$

$$k^2 = (x_1-\xi_1)^2 + q_2^2$$

$$h^2 = q_2^2 + (q_3+\xi_0)^2$$

$$\xi_2 = \xi_0\cos\theta \qquad \xi_3 = \xi_0\sin\theta$$

Thus the expressions involving strike slip are

$$f_1(X,\xi) = \frac{1}{8\pi(1-\nu)}\Bigg[2(1-\nu)\tan^{-1}\left\{\frac{(x_1-\xi_1)(r_3-\xi_0)}{r_2R}\right\} + \frac{r_2(x_1-\xi_1)}{R(R+r_3-\xi_0)}$$

$$- 2(1-\nu)\tan^{-1}\left\{\frac{(x_1-\xi_1)(q_3+\xi_0)}{q_2Q}\right\} - (x_1-\xi_1)\Bigg[\frac{(3-4\nu)x_2\sin\theta + x_3\cos\theta}{Q(Q+q_3+\xi_0)}$$

$$- 2q_2x_3\sin\theta\left\{\frac{1}{Q^3} - q_3\frac{(2Q+q_3+\xi_0)}{Q^3(Q+q_3+\xi_0)^2}\right\}\Bigg]$$

$$- 4(1-\nu)(1-2\nu)\tan\theta\Bigg\{2\tan\theta - \tan^{-1}\left[\frac{(k-q_2\cos\theta)(Q-k) + k(q_3+\xi_0)\sin\theta}{(x_1-\xi_1)(q_3+\xi_0)\cos\theta}\right]$$

$$+ \frac{x_1-\xi_1}{Q+x_3+\xi_3}\Bigg\}\Bigg]$$

As $\theta \to \pi/2$, $-\tan\theta\,\{\ \} \to + \dfrac{x_2(x_1-\xi_1)}{2(Q+x_3+\xi_3)^2}$

$$f_2(X,\xi) = \frac{1}{8\pi(1-\nu)}\left[\begin{aligned}
&-(1-2\nu)\sin\theta\,\ln(R+r_3-\xi_0) + \frac{r_2\cos\theta}{R} + \frac{r_2^2\sin\theta}{R(R+r_3-\xi_0)} \\
&-(1-2\nu)\sin\theta\,\ln(Q+q_3+\xi_0) + \frac{((3-4\nu)x_2\sin\theta + x_3\cos\theta)\cos\theta - 2x_3\sin^2\theta}{Q} \\
&-\sin\theta\cdot\frac{[q_2((3-4\nu)x_2\sin\theta + x_3\cos\theta) + 2x_3(q_2\cos\theta - q_3\sin\theta)]}{Q(Q+q_3+\xi_0)} \\
&+2q_2x_3\sin\theta\left\{\frac{[x_2-\xi_2+q_3\cos\theta]}{Q^3} - q_2q_3\sin\theta\cdot\frac{(2Q+q_3+\xi_0)}{Q^3(Q+q_3+\xi_0)^2}\right\} \\
&+4(1-\nu)(1-2\nu)\tan\theta\left\{\tan\theta\cdot[\ln(Q+x_3+\xi_3) - \sin\theta\,\ln(Q+q_3+\xi_0)]\right. \\
&\left.-\frac{x_2-\xi_2}{Q+x_3+\xi_3}\right\}
\end{aligned}\right].$$

$$\text{As } \theta \to \pi/2,\ \tan\theta\,\{\ \} \to \frac{1}{2}\left\{\frac{x_3+\xi_3}{Q+x_3+\xi_3} + \ln(Q+x_3+\xi_3) + \frac{x_2^2}{(Q+x_3+\xi_3)^2}\right\}.$$

and the expressions involving dip slip are

$$g_1(X,\xi) = \frac{1}{8\pi(1-\nu)}\left[\begin{aligned}
&\frac{r_2}{R} + \frac{(3-4\nu)x_2\sin\theta + x_3\cos\theta}{Q} - \frac{2q_2x_3\xi_3}{Q^3} - \frac{4(1-\nu)q_2x_3\sin\theta}{Q(Q+q_3+\xi_0)} \\
&+4(1-\nu)(1-2\nu)\left\{\tan\theta\cdot[\sin\theta\,\ln(Q+x_3+\xi_3) - \ln(Q+q_3+\xi_0)]\right. \\
&\left.-\frac{(x_2-\xi_2)\sin\theta}{Q+x_3+\xi_3}\right\}
\end{aligned}\right]$$

$$\text{As } \theta \to \pi/2,\ \{\ \} \to 0$$

$$
g_2(X,\xi) = \frac{1}{8\pi(1-\nu)} \left[- (1-2\nu)\sin\theta \ln(R+x_1-\xi_1) + 2(1-\nu)\cos\theta \cdot \tan^{-1}\left\{ \frac{(x_1-\xi_1)(r_3-\xi_0)}{r_2 R} \right\} \right.
$$

$$
+ \frac{r_2(x_2-\xi_2)}{R(R+x_1-\xi_1)} + (1-2\nu)\sin\theta \ln(Q+x_1-\xi_1) - 2(1-\nu)\cos\theta \cdot \tan^{-1}\left\{ \frac{(x_1-\xi_1)(q_3+\xi_0)}{q_2 Q} \right\}
$$

$$
+ \frac{(3-4\nu)r_2(x_2-\xi_2) + 2\xi_3 x_3 \sin\theta + 4(1-\nu)x_3[r_3 + \xi(\sin^2\theta - \cos^2\theta)]}{Q(Q+x_1-\xi_1)}
$$

$$
+ \frac{4(1-\nu)x_3(x_1-\xi_1)\sin^2\theta}{Q(Q+q_3+\xi_0)} - 2q_2 x_3 \xi_3 (x_2-\xi_2)\frac{(2Q+x_1-\xi_1)}{Q^3(Q+x_1-\xi_1)^2}
$$

$$
+ 4(1-\nu)(1-2\nu)\sin\theta \left\{ 2\tan\theta \cdot \tan^{-1}\left[\frac{(k-q_2\cos\theta)(Q-k) + k(q_3+\xi_0)\sin\theta}{(x_1-\xi_1)(q_3+\xi_0)\cos\theta} \right] \right.
$$

$$
\left. \left. + \frac{x_1-\xi_1}{Q+x_3+\xi_3} \right\} \right] .
$$

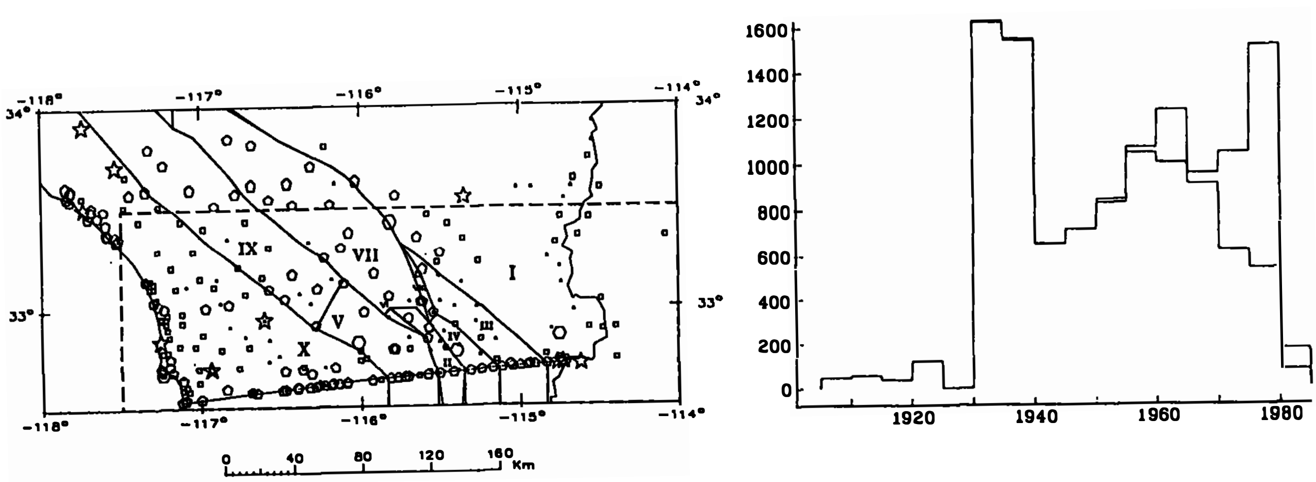
As $\theta \to \pi/2$, $\cdot\{\ \} \to 0$.

APPENDIX B.--DATA DISTRIBUTIONS

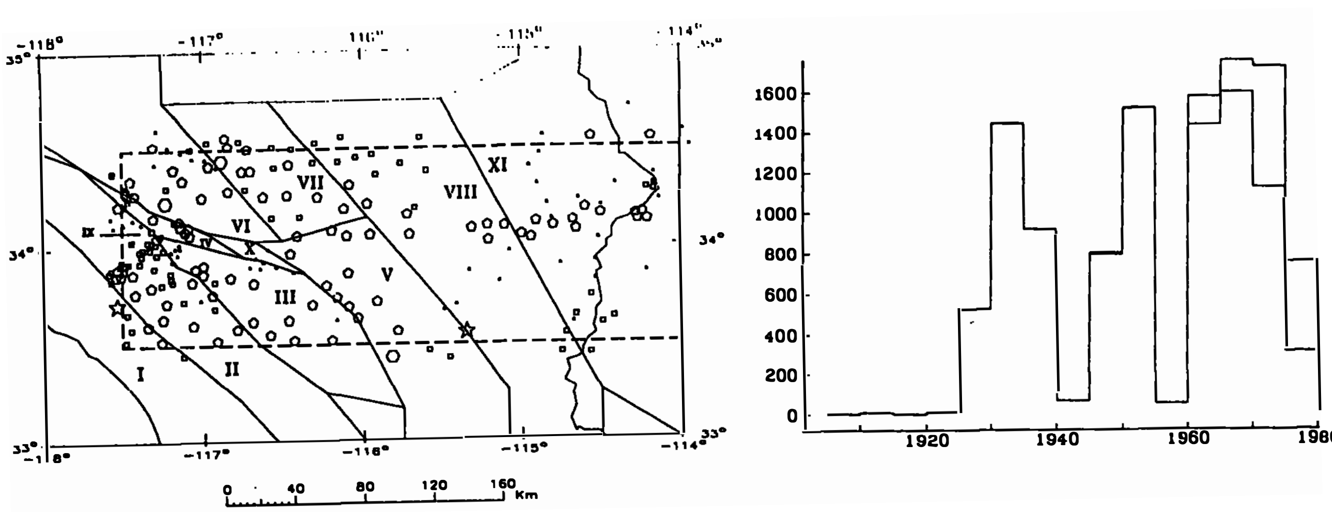
This appendix contains various maps and histograms, a pair for each of the 16 REDEAM regions of California. Together, a region's map and histogram depict the spatial and temporal distributions of the geodetic data used in developing the corresponding model.

On the maps, regional boundaries are plotted as dashed lines and district boundaries as solid lines. Roman numerals identify the various districts. Map symbols (triangles, squares, pentagons, hexagons, and stars) locate geodetic marks and specify the time interval between the earliest and latest observations at these marks.

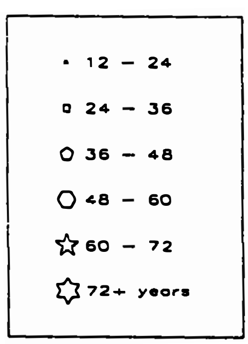
In the histograms the numbers of direction and distance observations for various 5-year intervals are plotted as a function of time. The lower column height represents the number of direction observations, and the height difference between the lower and upper columns represents the number of distance observations.

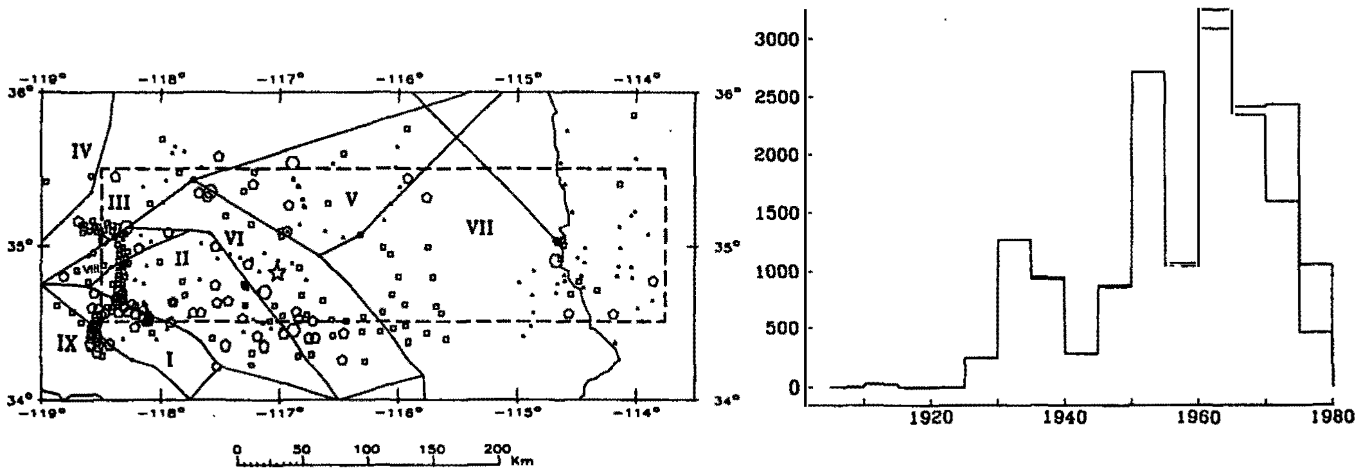


Region 1. San Diego

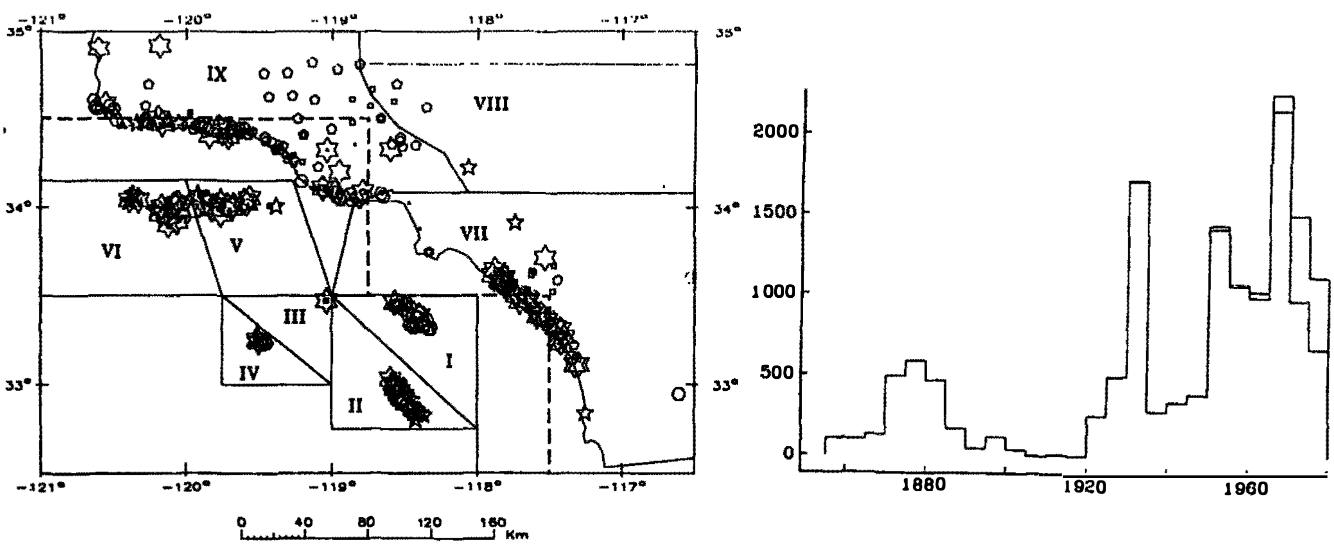


Region 2. San Bernardino

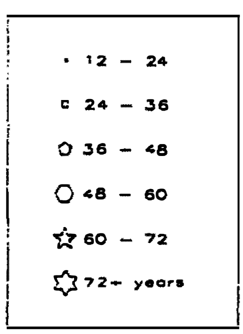


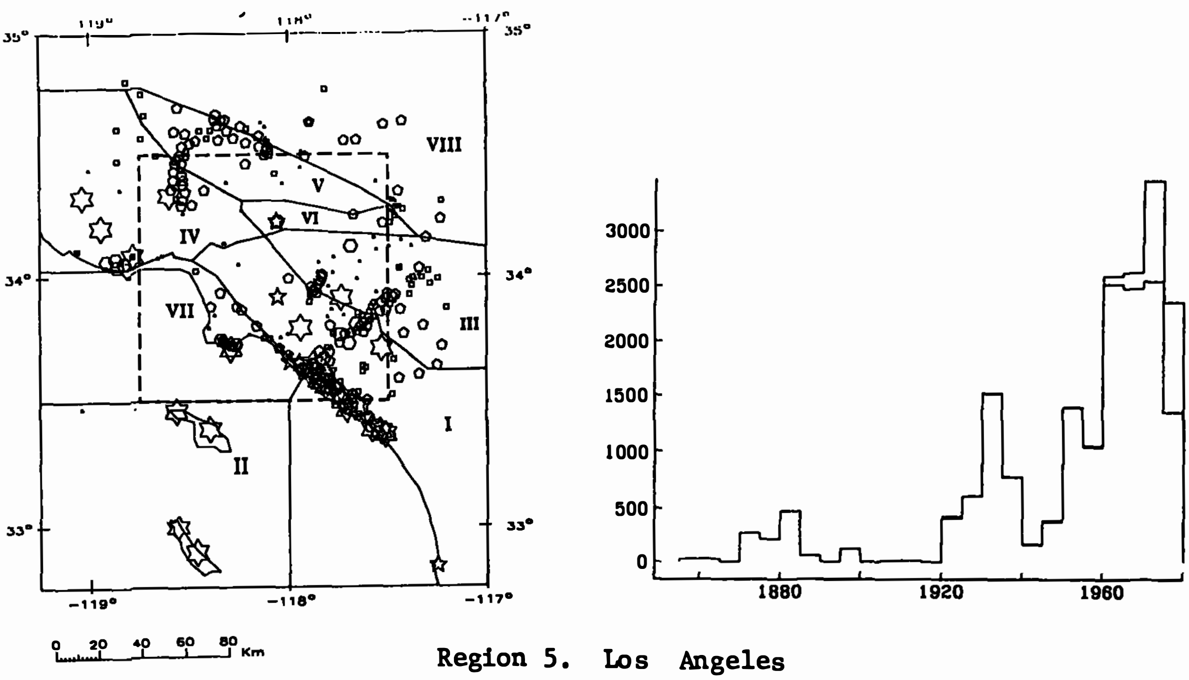


Region 3. Barstow

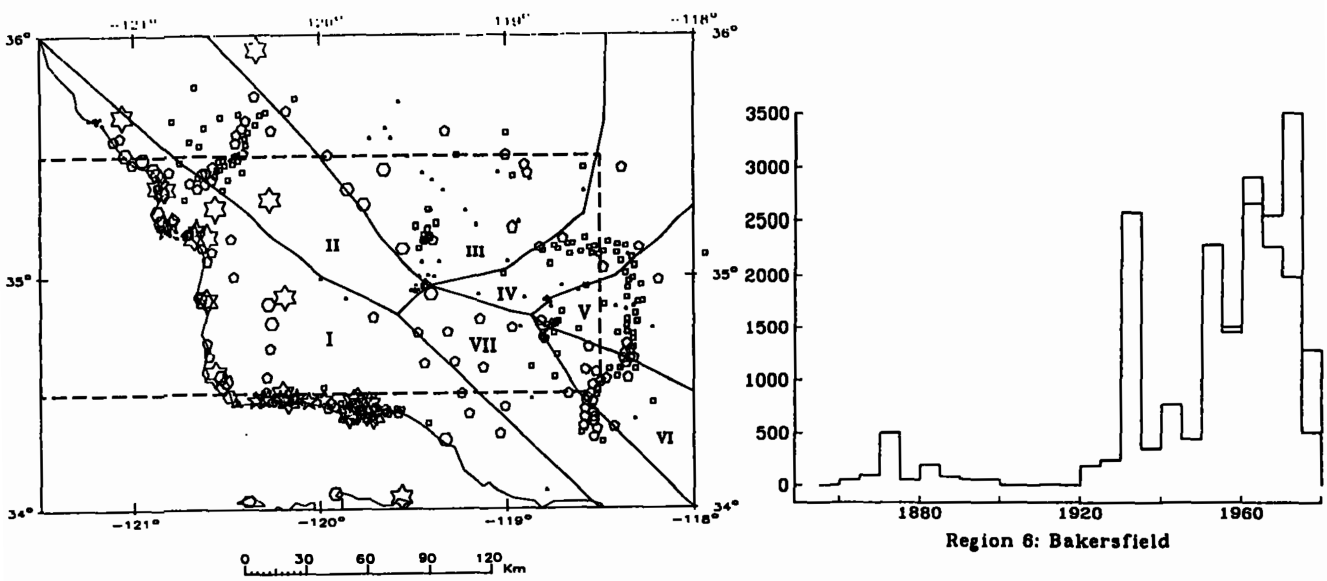


Region 4. Channel Islands

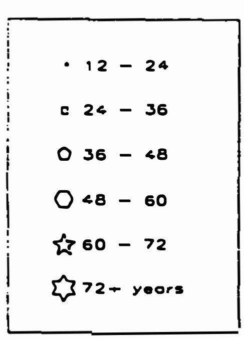


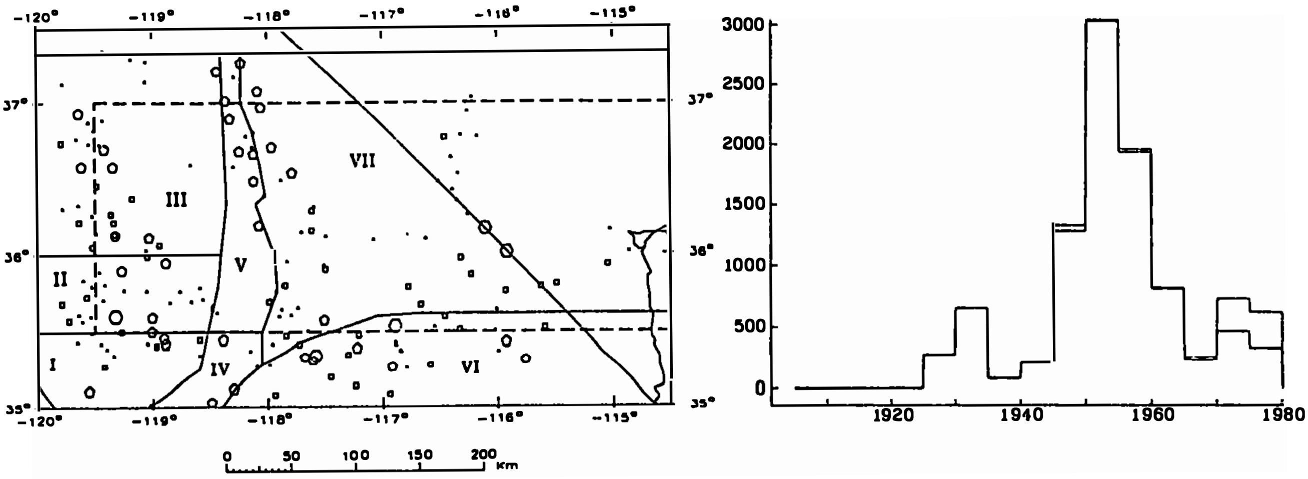


Region 5. Los Angeles

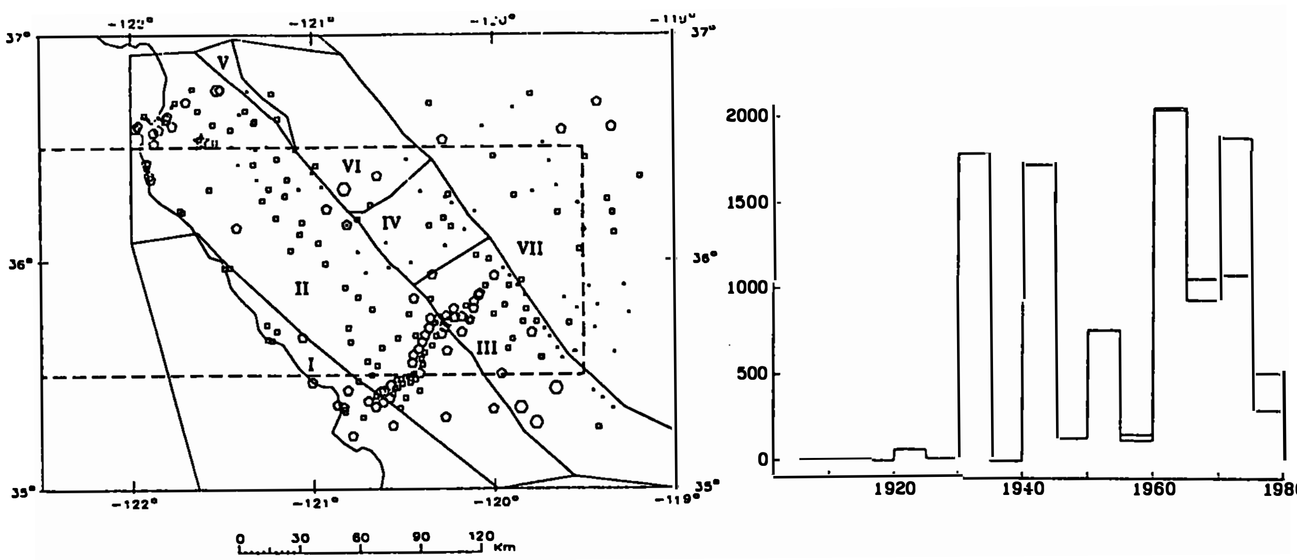


Region 6. Bakersfield

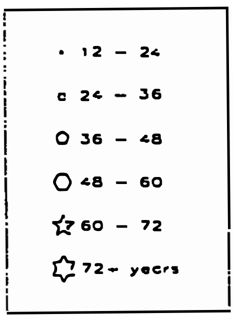


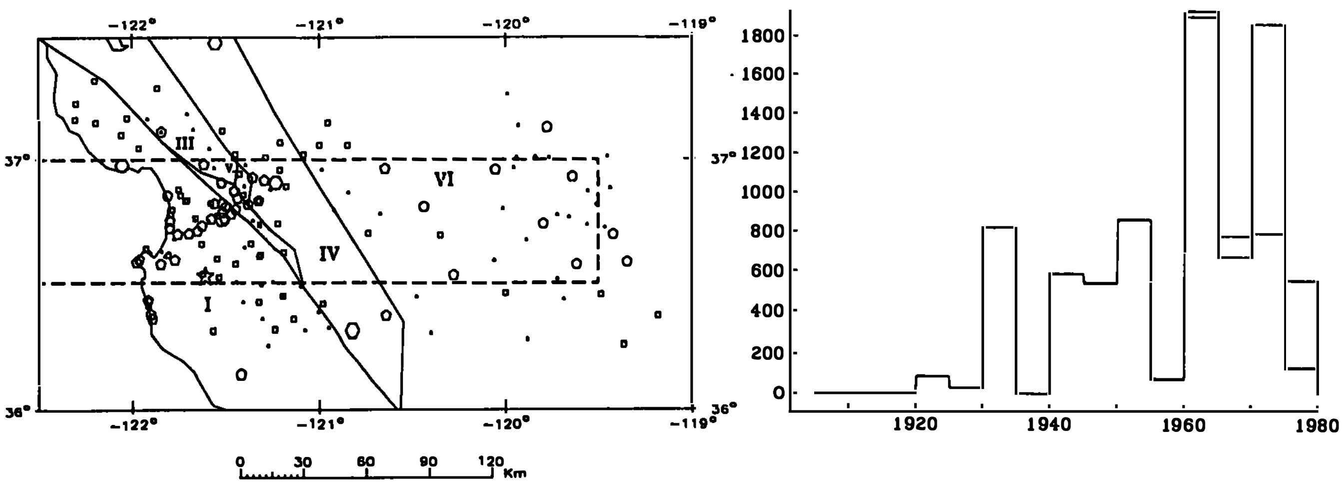


Region 7. Sierra Nevada

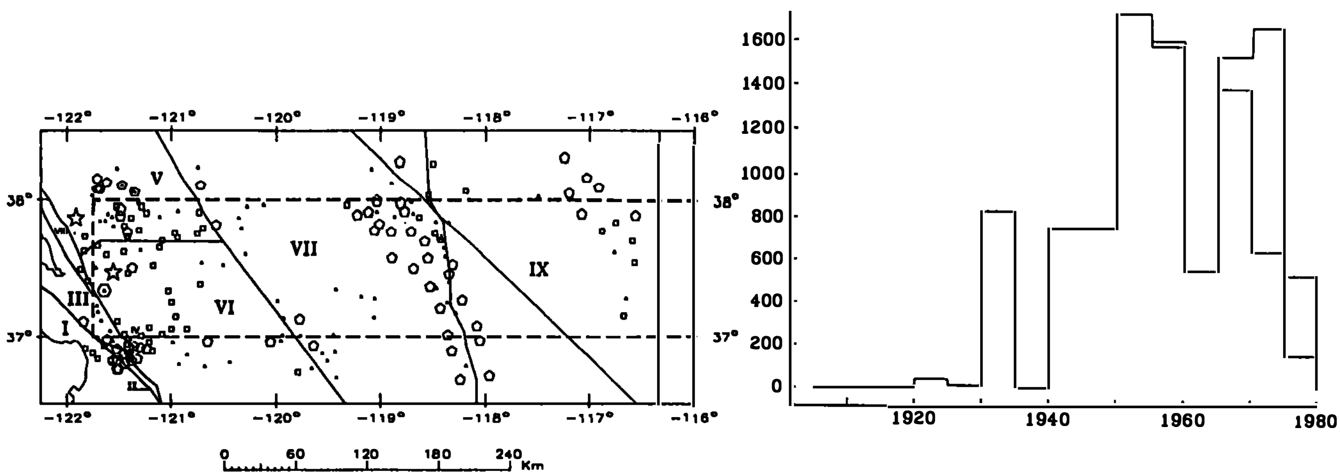


Region 8. Parkfield

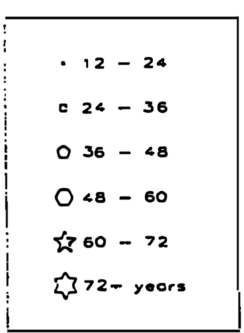


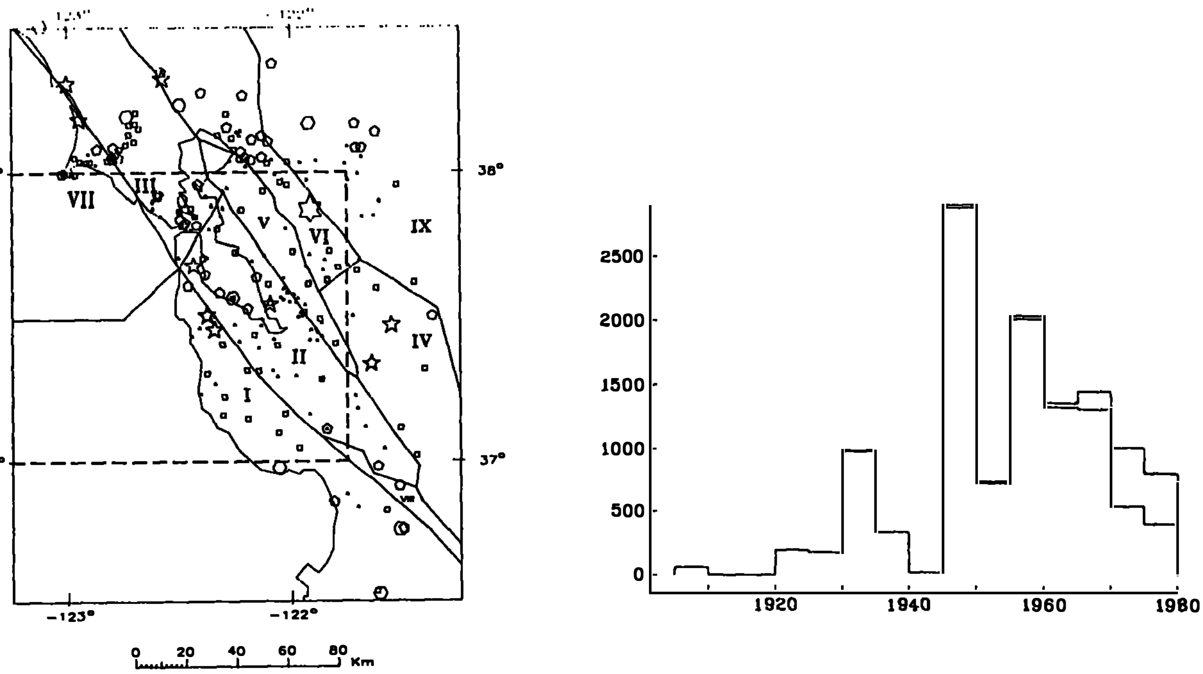


Region 9. Monterey

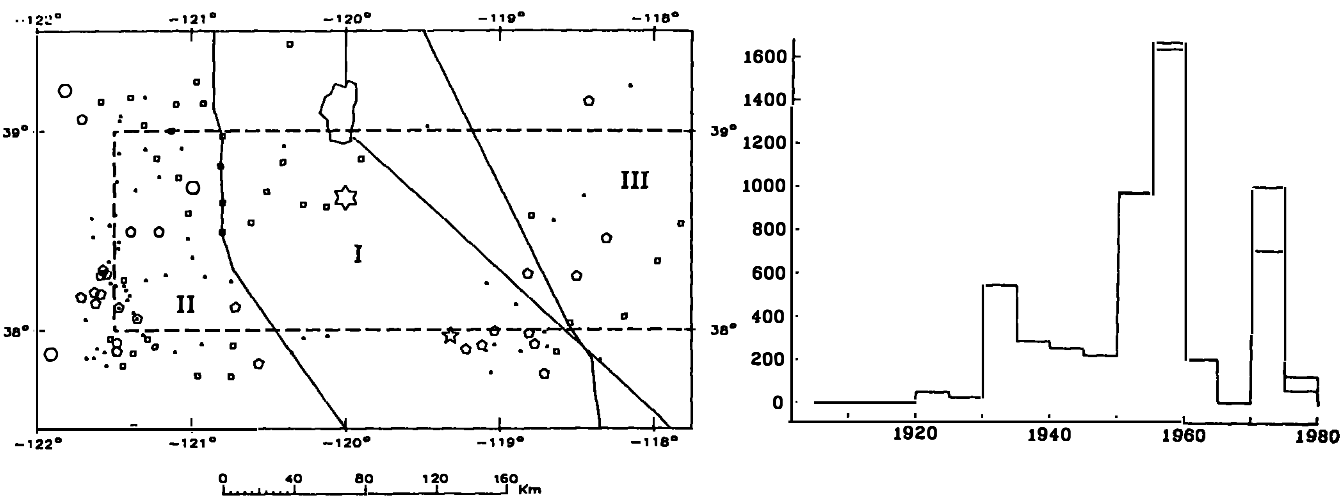


Region 10. Yosemite

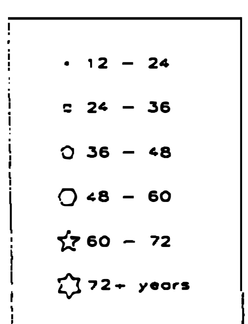


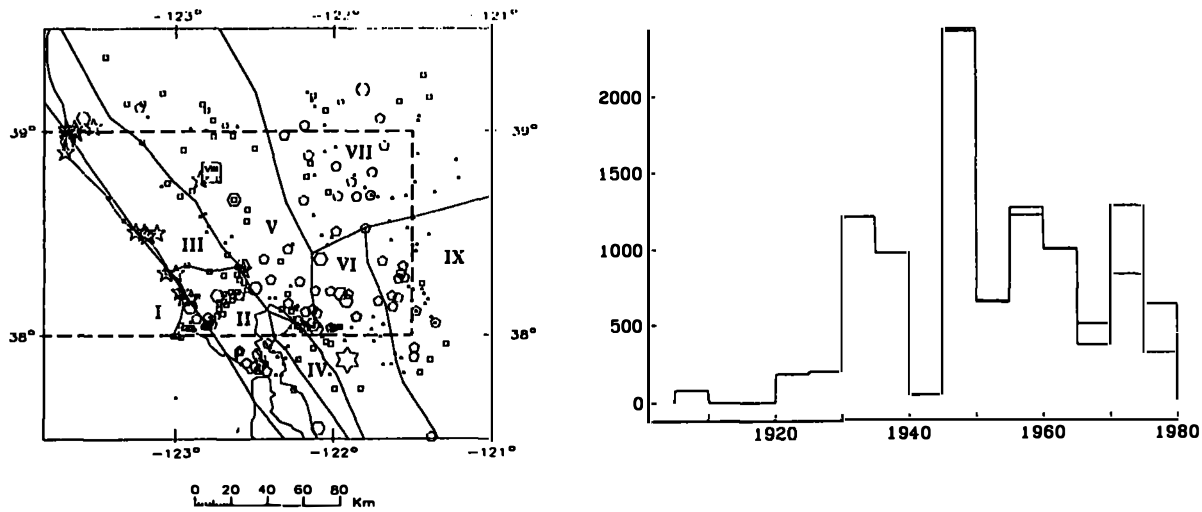


Region 11. San Francisco

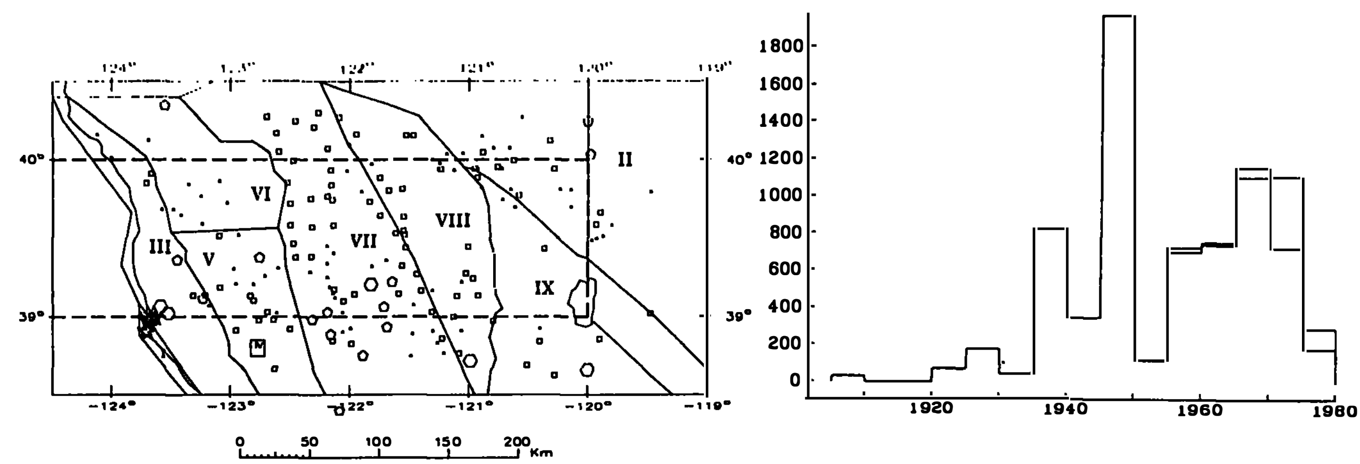


Region 12. Sacramento

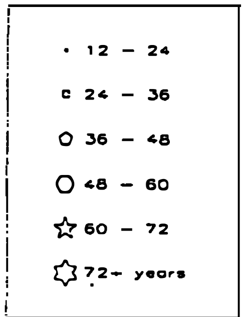


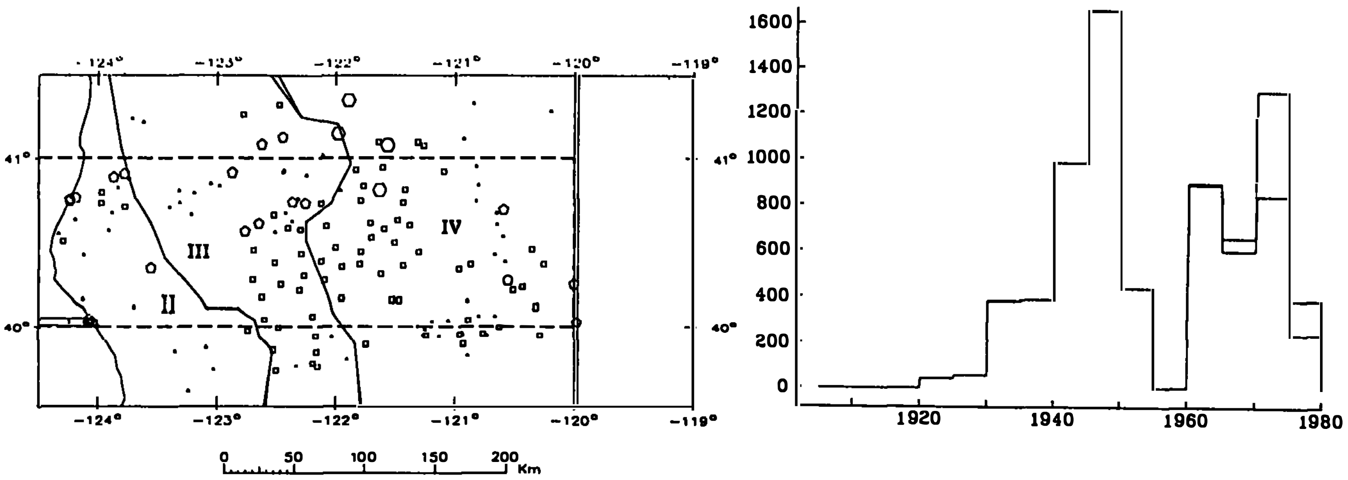


Region 13. Santa Rosa

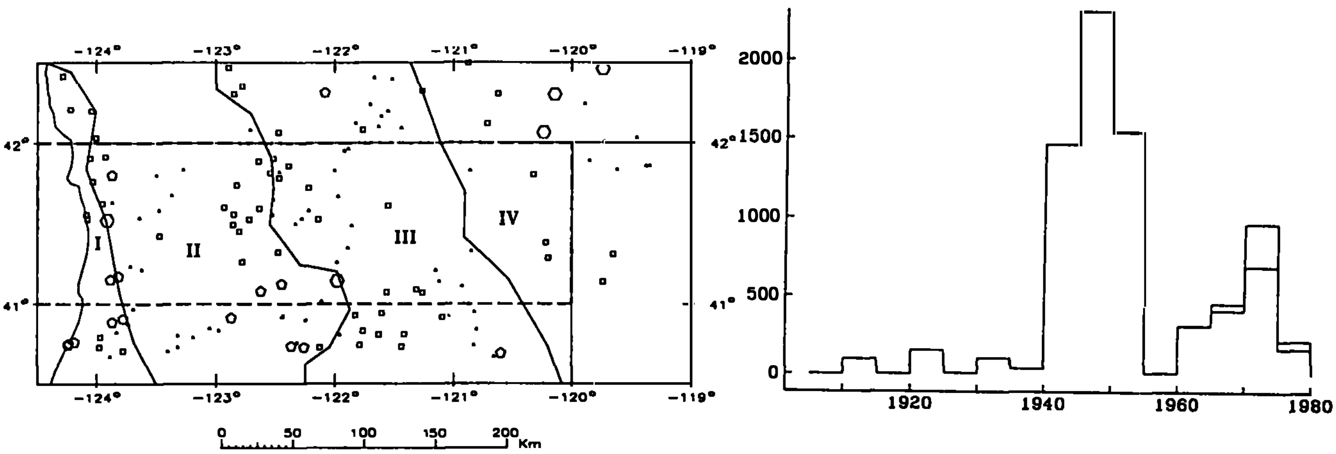


Region 14. Ukiah

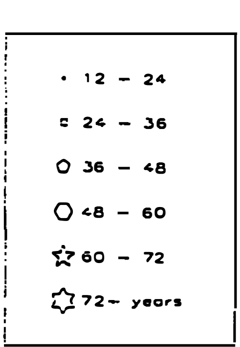




Region 15. Redding



Region 16. Alturas



APPENDIX C.--PARAMETER VALUES

This appendix contains four tables that document the parameter values for REDEAM regions in California and Nevada. For the regions in Alaska and Hawaii certain parameter values are found in other appendices because the representation of episodic motion differs for these latter two States. In particular, parameters for the Anchorage, Alaska, region are documented in appendix E while parameters pertaining to episodic motion for the Hilo, Hawaii, region are documented in appendix F. Secular motion parameters for the Hilo region are, however, documented in this appendix.

The tabulated parameters enable one to compute $(\phi_M(t), \lambda_M(t))$ for a point M at time t according to eq. (3.1) if the coordinates $(\phi_M(t_o), \lambda_M(t_o))$ are given where t_o = January 1, 1950. Recall that for our application of the REDEAM models (chapter 5), we compute only corrections to observations, and thus the choice of t_o could be and was rather arbitrary. Moreover for our application, the NAD 27 positions provide sufficiently accurate values for coordinates at time t_o.

Table C.1 contains the values for the reference coordinates (latitude and longitude) of the various regions. These parameters are referred to as $\bar{\phi}$ and $\bar{\lambda}$ in eq. (3.1). Table C.2 contains the values for the estimated secular motion parameters, and table C.3 contains values for episodic motion parameters. Finally, table C.4 contains the vertices that define the boundaries for the various regions and their districts. These vertices are represented as coordinate pairs (latitude and longitude). A simple closed polygon is formed by connecting consecutive vertices with edges and by similarly connecting the first and last vertices. For operational purposes, a geodetic mark is considered to be located in a region or district if it is located inside the corresponding polygonal loop. (A simple closed polygon bounds two disjoint areas on the Earth's surface. A point is said to be _inside_ this polygon if it is located in the bounded area that does not contain the North Pole.)

Table C.1.--Reference coordinates

Region	Latitude (deg-min-sec)	Longitude (deg-min-sec)
San Diego (CA)	33 16 44.384	115 30 01.121
San Bernardino (CA)	34 11 45.849	115 40 15.762
Barstow (CA)	35 04 15.283	116 19 21.480
Channel Islands (CA)	34 19 32.41086	119 02 17.689
Los Angeles (CA)	34 13 25.51664	118 03 38.66333
Bakersfield (CA)	34 45 14.69362	119 28 27.34339
Sierra Nevada (CA)	37 00 38.382	118 21 37.546
Parkfield (CA)	35 25 49.913	119 26 55.226
Monterey (CA)	36 46 39.990	121 28 13.088
Yosemite (CA)	37 09 25.683	116 40 03.267
San Francisco (CA)	37 28 38.609	121 33 17.529
Sacramento (CA)	38 26 50.125	121 23 48.071
Santa Rosa (CA)	38 40 10.00120	122 37 56.60606
Ukiah (CA)	39 12 21.300	121 49 10.350
Redding (CA)	40 45 05.030	124 13 51.856
Alturas (CA)	41 31 42.127	122 08 22.245
Fallon (NV)	39 34 59.23375	118 14 04.07787
Anchorage (AK)	NA	NA
Hilo (HI)	19 43 10.832	155 05 57.572

Table C.2.--Parameter values for secular motion

District	$a_{\phi *}$ 10^{-8} rad/yr	$a_{\phi\phi}$ 10^{-6}/yr	$a_{\phi\lambda}$ 10^{-6}/yr	$a_{\lambda *}$ 10^{-8}rad/yr	$a_{\lambda\phi}$ 10^{-6}/yr	$a_{\lambda\lambda}$ 10^{-6}/yr
SAN DIEGO REGION, CALIFORNIA						
I	0.0000*	-0.1120 (0.027)	0.1020 (0.105)	0.0000*	-0.0066 (0.149)	0.0412 (0.022)
II	0.1870 (0.036)	-0.2330 (0.039)	-0.0170 (0.112)	-0.2530 (0.047)	-0.5060 (0.153)	0.6260 (0.063)
III	-0.0514 (0.016)	-0.2430 (0.049)	0.1240 (0.110)	-0.0518 (0.018)	-0.1690 (0.157)	0.2120 (0.054)
IV	-0.6250 (0.069)	-1.0200 (0.093)	0.5210 (0.120)	0.4280 (0.084)	0.4670 (0.183)	0.0183 (0.093)
V	0.2770 (0.035)	-0.1630 (0.028)	-0.0079 (0.107)	0.0141 (0.043)	-0.2480 (0.149)	0.1420 (0.034)
VI	0.3200 (0.061)	0.0000*	0.0000*	0.2550 (0.086)	0.0000*	0.0000*
VII	0.1560 (0.027)	-0.2310 (0.039)	0.0590 (0.107)	0.0368 (0.028)	-0.1700 (0.152)	0.1200 (0.031)
VIII	0.0675 (0.041)	-0.2000 (0.071)	0.0000*	0.0160 (0.025)	-0.1970 (0.156)	0.0000*
IX	0.3210 (0.072)	-0.1550 (0.037)	-0.0192 (0.108)	0.2390 (0.060)	-0.0759 (0.151)	0.0148 (0.030)
X	0.3270 (0.042)	-0.1430 (0.025)	-0.0223 (0.104)	0.5000 (0.053)	0.0778 (0.146)	-0.0991 (0.022)
SAN BERNARDINO REGION, CALIFORNIA						
I	0.4960 (0.243)	0.0693 (0.114)	0.0000*	0.0592 (0.115)	-0.2140 (0.118)	0.0000*
II	-0.0008 (0.077)	-0.1690 (0.024)	0.0865 (0.056)	0.1080 (0.084)	-0.1480 (0.081)	-0.0057 (0.023)
III	-0.0060 (0.079)	-0.1810 (0.041)	0.0682 (0.057)	-0.1360 (0.080)	-0.2380 (0.090)	0.0702 (0.028)
IV	-0.2250 (0.176)	-0.1590 (0.100)	0.1470 (0.076)	-0.2820 (0.198)	-0.3170 (0.132)	0.1170 (0.066)
V	-0.1470 (0.039)	-0.2040 (0.034)	0.1630 (0.064)	-0.1570 (0.046)	-0.1950 (0.090)	0.1170 (0.033)
VI	-0.1990 (0.090)	-0.1340 (0.043)	0.1350 (0.061)	-0.1610 (0.103)	-0.2240 (0.097)	-0.0365 (0.038)
VII	-0.0914 (0.041)	-0.0950 (0.034)	0.0857 (0.060)	-0.0283 (0.049)	-0.1340 (0.093)	0.0280 (0.040)
VIII	0.0000*	-0.0282 (0.046)	-0.0356 (0.068)	0.0000*	0.0535 (0.095)	-0.0606 (0.053)
IX	0.1210 (0.170)	-0.7050 (0.300)	0.0000*	-0.0092 (0.082)	-0.7370 (0.310)	0.0000*
X	0.1930 (0.102)	0.0000*	0.0000*	0.0750 (0.059)	0.0000*	0.0000*
XI	-0.0130 (0.059)	0.0446 (0.057)	-0.0579 (0.070)	-0.0296 (0.071)	0.1290 (0.102)	-0.1240 (0.054)
BARSTOW REGION, CALIFORNIA						
I	-0.1780 (0.092)	-0.1890 (0.029)	0.0723 (0.103)	-0.5300 (0.101)	-0.3870 (0.153)	0.1220 (0.019)
II	-0.1570 (0.067)	-0.1610 (0.022)	0.0724 (0.103)	-0.1050 (0.073)	-0.1850 (0.151)	0.0442 (0.016)
III	0.0790 (0.080)	-0.1980 (0.047)	0.0070 (0.102)	0.0547 (0.121)	-0.1800 (0.156)	0.0073 (0.035)
IV	-1.2300 (0.800)	1.3400 (0.455)	0.0810 (0.196)	2.7200 (1.380)	-3.2000 (0.386)	-0.2120 (0.345)
V	0.0000*	-0.1630 (0.054)	0.0416 (0.104)	0.0000*	-0.0164 (0.155)	-0.0472 (0.039)
VI	0.0888 (0.061)	-0.0523 (0.028)	-0.0247 (0.103)	0.0192 (0.070)	-0.1000 (0.151)	0.0100 (0.039)
VII	-0.0431 (0.035)	-0.2020 (0.062)	-0.0057 (0.113)	-0.0301 (0.047)	-0.0229 (0.163)	-0.1750 (0.070)
VIII	0.1480 (0.095)	-0.2100 (0.047)	-0.0158 (0.104)	-0.2910 (0.108)	-0.1750 (0.157)	0.1020 (0.028)
IX	-0.7770 (0.232)	-0.4070 (0.047)	0.1580 (0.115)	0.4780 (0.239)	0.0131 (0.168)	-0.0240 (0.047)
CHANNEL ISLANDS REGION, CALIFORNIA						
I	0.4610 (0.656)	0.1240 (0.411)	0.1510 (0.178)	0.2060 (0.588)	-0.1810 (0.268)	0.3910 (0.402)
II	-0.1180 (2.290)	-0.2220 (0.993)	0.3280 (0.130)	-0.5150 (0.861)	-0.3330 (0.175)	0.1830 (0.995)
III	0.1950 (0.107)	0.0000*	0.0000*	0.1280 (0.160)	0.0000*	0.0000*
IV	0.1780 (0.795)	-0.1590 (0.400)	-0.1790 (0.206)	0.6960 (0.607)	0.5930 (0.274)	0.4740 (0.409)
V	-0.2710 (0.106)	-0.2370 (0.143)	0.1600 (0.083)	0.0791 (0.156)	-0.0339 (0.173)	-0.1440 (0.118)
VI	0.4910 (0.264)	0.1640 (0.259)	-0.1010 (0.102)	-0.5990 (0.435)	-1.1400 (0.203)	-0.1420 (0.224)
VII	-0.1820 (0.102)	-0.1880 (0.123)	-0.1810 (0.085)	0.0718 (0.133)	0.2740 (0.123)	-0.1070 (0.121)
VIII	0.1920 (0.193)	-0.3800 (0.212)	0.0584 (0.138)	0.3490 (0.254)	-0.2440 (0.238)	0.2100 (0.211)
IX	0.0000*	-0.1590 (0.026)	-0.0006 (0.042)	0.0000*	0.0789 (0.065)	-0.0742 (0.025)

*Parameter constrained to this value.

Table C.2.--Continued

LOS ANGELES REGION, CALIFORNIA						
I	0.0974 (0.029)	-0.0722 (0.023)	0.0995 (0.048)	-0.0507 (0.025)	-0.1310 (0.068)	0.0492 (0.022)
II	0.0611 (1.070)	0.0843 (0.616)	0.2140 (0.341)	0.0468 (0.363)	0.0356 (0.191)	0.3060 (0.375)
III	0.0328 (0.030)	-0.0884 (0.034)	0.0448 (0.048)	-0.0480 (0.026)	-0.1470 (0.076)	0.0474 (0.021)
IV	-0.0387 (0.041)	-0.3060 (0.034)	0.0757 (0.052)	0.1020 (0.039)	0.0887 (0.079)	-0.1330 (0.027)
V	-0.0206 (0.035)	-0.1620 (0.033)	0.0236 (0.049)	0.0576 (0.030)	-0.2610 (0.079)	0.0751 (0.019)
VI	0.0000*	-0.5400 (0.117)	0.0185 (0.056)	0.0000*	0.0148 (0.182)	0.0408 (0.032)
VII	-0.0722 (0.133)	-0.2160 (0.141)	0.1020 (0.089)	0.0103 (0.192)	-0.0300 (0.215)	-0.1030 (0.120)
VIII	-0.1020 (0.042)	-0.0297 (0.044)	-0.0294 (0.051)	-0.0713 (0.042)	-0.0435 (0.090)	-0.0036 (0.029)
BAKERSFIELD REGION, CALIFORNIA						
I	0.0535 (0.013)	-0.1190 (0.032)	0.1640 (0.041)	-0.0241 (0.015)	-0.3240 (0.065)	0.0492 (0.026)
II	-0.0374 (0.019)	-0.1750 (0.039)	0.2380 (0.044)	0.0286 (0.024)	-0.3840 (0.073)	0.0601 (0.029)
III	0.0263 (0.022)	-0.3030 (0.031)	0.1640 (0.046)	0.0375 (0.025)	-0.4310 (0.069)	0.0016 (0.027)
IV	0.0130 (0.028)	-0.2630 (0.035)	0.1840 (0.050)	0.0411 (0.030)	-0.5070 (0.079)	0.0097 (0.025)
V	-0.0900 (0.029)	-0.3830 (0.032)	0.1060 (0.048)	0.0123 (0.034)	-0.2800 (0.077)	0.0682 (0.021)
VI	-0.1160 (0.037)	-0.2150 (0.035)	0.0794 (0.052)	0.0707 (0.043)	-0.3600 (0.074)	0.1110 (0.031)
VII	0.0000*	-0.2810 (0.027)	0.1780 (0.047)	0.0000*	-0.2990 (0.073)	0.0465 (0.026)
SIERRA NEVADA REGION, CALIFORNIA						
I	-0.7580 (0.648)	-0.4350 (0.239)	0.0754 (0.099)	-1.6901 (0.541)	-0.8380 (0.222)	-0.0856 (0.085)
II	0.1160 (0.189)	-0.0933 (0.080)	0.1420 (0.086)	0.2660 (0.220)	-0.1180 (0.141)	-0.0483 (0.058)
III	0.0479 (0.087)	-0.0927 (0.055)	0.1700 (0.082)	-0.0198 (0.071)	-0.2010 (0.127)	-0.0013 (0.044)
IV	-0.0506 (0.579)	-0.1830 (0.209)	-0.4040 (0.179)	-0.4310 (0.419)	-0.3590 (0.175)	0.2220 (0.227)
V	0.0000*	-0.1830 (0.047)	0.0822 (0.100)	0.0000*	-0.2150 (0.120)	0.1410 (0.089)
VI	0.1590 (0.243)	-0.1160 (0.076)	0.0980 (0.076)	0.2890 (0.290)	-0.0358 (0.131)	-0.0284 (0.027)
VII	0.0563 (0.033)	-0.1920 (0.042)	0.1280 (0.075)	0.1120 (0.045)	-0.1040 (0.118)	-0.0297 (0.026)
PARKFIELD REGION, CALIFORNIA						
I	0.2190 (0.122)	-0.1550 (0.077)	0.1130 (0.112)	0.1320 (0.139)	-0.0402 (0.167)	-0.0495 (0.064)
II	0.1450 (0.053)	-0.1100 (0.028)	0.1470 (0.100)	0.0590 (0.062)	-0.1620 (0.150)	-0.0162 (0.029)
III	0.0000*	-0.2500 (0.037)	0.2500 (0.105)	0.0000*	-0.4210 (0.154)	0.0796 (0.043)
IV	0.5840 (0.137)	-0.4260 (0.088)	-0.0174 (0.111)	0.0814 (0.190)	-0.5590 (0.191)	0.0607 (0.071)
V	-1.2500 (0.228)	0.6380 (0.170)	0.0000*	-0.4990 (0.319)	0.0000*	0.0000*
VI	-0.0581 (0.096)	0.0119 (0.074)	0.0041 (0.123)	-0.3930 (0.138)	-0.1210 (0.183)	0.0061 (0.101)
VII	0.0444 (0.072)	-0.1980 (0.061)	0.1460 (0.111)	-0.0505 (0.065)	-0.1940 (0.163)	-0.1320 (0.080)
MONTEREY REGION, CALIFORNIA						
I	0.0000*	-0.1820 (0.021)	0.2070 (0.089)	0.0000*	-0.2900 (0.136)	-0.0315 (0.021)
II	-0.0901 (0.005)	-0.4410 (0.043)	0.5890 (0.098)	-0.1480 (0.006)	-0.4110 (0.145)	0.2820 (0.053)
III	-0.1320 (0.021)	-0.2540 (0.076)	0.3630 (0.101)	-0.2760 (0.034)	-0.2150 (0.173)	0.1810 (0.054)
IV	-0.3210 (0.015)	-0.2020 (0.031)	0.3030 (0.093)	-0.2770 (0.016)	-0.3280 (0.137)	0.0560 (0.036)
V	-0.2050 (0.042)	-0.8390 (0.097)	0.2380 (0.252)	-0.5690 (0.052)	0.2470 (0.180)	-1.8100 (0.292)
VI	-0.4260 (0.066)	-0.0814 (0.073)	0.2300 (0.097)	-0.3120 (0.092)	-0.2470 (0.154)	-0.0269 (0.069)
YOSEMITE REGION, CALIFORNIA						
I	1.2300 (1.050)	-0.0761 (0.119)	0.0015 (0.143)	-0.1300 (0.880)	0.0546 (0.249)	0.0062 (0.089)
II	-1.1900 (1.512)	-0.3570 (0.048)	0.2540 (0.100)	-5.0800 (0.579)	-0.1160 (0.153)	0.5640 (0.061)
III	0.9080 (0.606)	-0.1970 (0.091)	0.0151 (0.106)	-1.6600 (0.501)	-0.1460 (0.173)	0.1490 (0.051)
IV	-3.7000 (1.900)	-0.9360 (0.086)	0.5040 (0.204)	-0.4020 (0.214)	0.0227 (0.144)	0.0000*

*Parameter constrained to this value.

Table C.2.--Continued

V	-1.2700 (0.403)	0.0295 (0.064)	0.2330 (0.089)	0.0006 (0.425)	-0.1120 (0.145)	-0.0601 (0.049)
VI	-0.4120 (0.257)	-0.1830 (0.024)	0.1480 (0.085)	-0.2730 (0.243)	-0.0866 (0.135)	-0.0251 (0.024)
VII	0.1700 (0.200)	-0.0432 (0.027)	0.0401 (0.091)	-0.4530 (0.199)	-0.0468 (0.140)	0.0001 (0.036)
VIII	0.9120 (0.791)	0.0000*	0.0000*	-0.5190 (0.238)	0.0000*	0.0000*
IX	0.0000*	-0.0874 (0.036)	0.1020 (0.108)	0.0000*	-0.0882 (0.144)	-0.1560 (0.062)
SAN FRANCISCO REGION, CALIFORNIA						
I	0.2880 (0.055)	-0.1730 (0.041)	-0.0564 (0.064)	0.0595 (0.055)	-0.0283 (0.104)	0.0036 (0.035)
II	0.0565 (0.033)	-0.2370 (0.029)	0.0832 (0.064)	-0.0166 (0.034)	-0.0376 (0.097)	0.0760 (0.035)
III	0.1290 (0.061)	-0.4920 (0.047)	0.1680 (0.068)	-0.1720 (0.073)	0.0103 (0.112)	0.1220 (0.044)
IV	0.0000*	-0.1110 (0.053)	-0.0762 (0.079)	0.0000*	0.0992 (0.104)	-0.1200 (0.049)
V	-0.0386 (0.039)	-0.1710 (0.048)	0.0864 (0.085)	-0.0706 (0.039)	-0.0173 (0.107)	0.0832 (0.073)
VI	-0.0479 (0.027)	-0.0913 (0.039)	0.0027 (0.067)	-0.0524 (0.025)	-0.0906 (0.103)	0.1360 (0.044)
VII	-0.2120 (0.122)	-0.1080 (0.084)	0.1500 (0.079)	-0.6130 (0.182)	-0.1520 (0.126)	0.3960 (0.086)
VIII	0.3490 (0.029)	0.0000*	0.0000*	0.0701 (0.096)	0.0000*	0.0000*
IX	-0.0833 (0.044)	-0.1520 (0.097)	0.0797 (0.106)	-0.0918 (0.049)	0.2470 (0.159)	-0.2740 (0.112)
SACRAMENTO REGION, CALIFORNIA						
I	-0.0925 (0.069)	0.0016 (0.062)	0.4600 (0.408)	-0.2940 (0.105)	-0.7980 (0.663)	-0.0791 (0.076)
II	0.0000*	-0.0534 (0.077)	0.5010 (0.403)	0.0000*	-0.7640 (0.657)	0.1600 (0.089)
III	0.7190 (0.374)	-0.0468 (0.036)	0.6280 (0.416)	-0.2120 (0.385)	-0.8650 (0.667)	-0.0382 (0.050)
SANTA ROSA REGION, CALIFORNIA						
I	-0.0368 (0.062)	-0.3330 (0.051)	0.3050 (0.097)	-0.0774 (0.081)	-0.4110 (0.151)	0.2540 (0.061)
II	-0.0828 (0.022)	-0.3490 (0.032)	0.3830 (0.090)	0.0422 (0.031)	-0.3430 (0.143)	0.1140 (0.039)
III	0.0436 (0.432)	-0.3140 (0.049)	0.2300 (0.099)	-0.1640 (0.057)	-0.5880 (0.157)	0.3410 (0.079)
IV	0.0697 (0.127)	-0.2520 (0.100)	0.4010 (0.120)	-0.0135 (0.148)	-0.1980 (0.178)	-0.2830 (0.128)
V	0.0000*	-0.2070 (0.027)	0.2950 (0.090)	0.0000*	-0.3690 (0.145)	-0.0115 (0.032)
VI	-0.0930 (0.071)	-0.2670 (0.062)	0.2310 (0.097)	0.1380 (0.082)	-0.2590 (0.155)	0.0044 (0.064)
VII	0.0036 (0.078)	-0.1720 (0.065)	0.2810 (0.103)	0.1040 (0.100)	-0.4090 (0.159)	-0.1050 (0.068)
VIII	0.5240 (0.076)	-2.8900 (0.280)	0.2290 (0.358)	0.8120 (0.092)	1.3600 (0.348)	-4.2000 (0.415)
IX	0.0083 (0.134)	-0.2680 (0.074)	0.2760 (0.121)	0.1520 (0.186)	-0.2850 (0.162)	-0.0337 (0.121)
UKIAH REGION, CALIFORNIA						
I	-2.5200 (1.820)	-0.2210 (0.441)	1.2000 (0.597)	-3.5400 (1.430)	-1.2600 (0.971)	0.9320 (0.448)
II	-0.0137 (0.194)	0.0161 (0.116)	0.0825 (0.095)	-0.0244 (0.293)	-0.2530 (0.199)	-0.0309 (0.093)
III	-1.3700 (0.441)	-0.4720 (0.219)	0.7740 (0.186)	1.3100 (0.664)	-0.1450 (0.275)	-0.4980 (0.256)
IV	-1.9800 (0.140)	-2.9000*	0.2300*	8.2000 (0.134)	1.3600*	-4.2000*
V	-0.1400 (0.102)	-0.2610 (0.041)	0.2870 (0.091)	-0.1600 (0.116)	-0.1780 (0.151)	0.0587 (0.048)
VI	-0.1160 (0.313)	0.1190 (0.186)	0.1970 (0.147)	-0.6280 (0.467)	-0.4540 (0.251)	0.3100 (0.190)
VII	0.0000*	0.0128 (0.052)	0.1470 (0.081)	0.0000*	-0.1630 (0.132)	0.0399 (0.057)
VIII	-0.0701 (0.046)	0.0853 (0.063)	0.1000 (0.088)	0.0182 (0.058)	-0.2230 (0.134)	-0.0034 (0.076)
IX	0.1160 (0.255)	0.0729 (0.105)	0.1850 (0.128)	0.0367 (0.307)	-0.2340 (0.169)	0.0485 (0.140)
REDDING REGION, CALIFORNIA						
I	0.2890 (3.100)	-0.4650 (0.382)	0.5970 (0.249)	0.0000*	0.5010 (0.413)	-0.0284 (0.387)
II	0.0000*	0.2420 (0.145)	-0.0806 (0.237)	0.0000*	0.2740 (0.393)	0.3330 (0.157)
III	-0.1070 (0.092)	0.2120 (0.118)	-0.1360 (0.234)	-0.1230 (0.143)	0.1970 (0.402)	0.2750 (0.117)
IV	0.0388 (0.199)	0.2050 (0.119)	-0.0944 (0.236)	-0.4900 (0.261)	0.1550 (0.404)	0.1770 (0.116)

*Parameter constrained to this value.

Table C.2.--Continued

ALTURAS REGION, CALIFORNIA						
I	-0.0631 (0.412)	0.0567 (0.051)	0.0135 (0.105)	0.0519 (0.513)	0.0182 (0.062)	0.0272 (0.132)
II	-0.0231 (0.033)	0.0312 (0.040)	-0.0321 (0.043)	0.0116 (0.045)	-0.0199 (0.061)	0.0265 (0.057)
III	0.0000*	-0.0567 (0.035)	0.0026 (0.039)	0.0000*	-0.0238 (0.055)	-0.0221 (0.060)
IV	0.0427 (0.240)	-0.0229 (0.072)	0.0086 (0.068)	-0.0568 (0.323)	0.0124 (0.108)	-0.0397 (0.087)
FALLON REGION, NEVADA						
I	0.0000*	-0.2010 (0.115)	0.1030 (0.210)	0.0000*	-0.0995 (0.325)	-0.0987 (0.113)
HILO REGION, HAWAII						
I	0.1840 (0.089)	0.6650 (0.204)	0.3540 (1.880)	0.2320 (0.103)	0.6160 (2.090)	0.8960 (0.167)
II	-2.0900 (0.599)	0.0000*	0.0000*	-0.3950 (1.330)	0.0000*	0.0000*
III	-0.0928 (0.375)	0.0000*	0.0000*	0.0941 (1.260)	0.0000*	0.0000*
IV	-0.7820 (0.375)	0.1630 (0.630)	1.9700 (1.890)	-1.3200 (0.501)	-1.6500 (2.240)	0.4380 (0.300)
V	0.0000*	0.2760 (0.165)	0.1940 (1.870)	0.0000*	-0.2560 (2.080)	0.1650 (0.177)

*Parameter constrained to this value.

Table C.3.--Parameters for modeled earthquakes in California and Nevada

Earthquake Year/Day (Magnitude)	Fault Center Latitude (N)	Fault Center Longitude (W)	Fault Orientation Strike	Fault Orientation Dip	Fault Size Depth Range, km	Fault Size Length, km	Slip (standard error) Strike, m	Slip (standard error) Dip, m
SAN DIEGO REGION								
1940/138(M7.1)	32° 34' 31"	115 14' 44"	N 37° W	75°NE	0-10	22	-2.62(.31)	0.03(.47)
1940/138(M7.1)	32° 41' 00"	115 20' 30"	N 37° W	75°NE	0-10	8	-4.33(.16)	2.58(.16)
1940/138(M7.1)	32° 44' 38"	115 23' 35"	N 37° W	75°NE	0-10	8	-1.34(.12)	-0.99(.20)
1940/138(M7.1)	32° 50' 31"	115 28' 59"	N 37° W	75°NE	0-10	20	-1.03(.06)	0.20(.09)
1940/138(M7.1)	32° 55' 15"	115 29' 12"	N 03° W	90°	0-10	12	-0.01(.08)	0.28(.10) (east up)
1942/294(M6.5)	32° 59' 23"	115 54' 00"	N 50° W	90°	0-10	30	-0.11(.07)	0.23(.12) (east up)
1954/078(M6.2)	33° 19' 30"	116 13' 30"	N 46° W	90°	0-10	30	-0.26(.09)	0.48(.21) (west up)
1968/100(M6.2)	33° 08' 06"	116 05' 10"	N 40° W	83°NE	1-10	30	-0.70(.14)	0.39(.16)
1979/288(M6.6)	32° 46' 49"	115 25' 21"	N 37° W	90°	0-10	40	-0 65(.03)	0.45(.07) (west up)
SAN BERNARDINO REGION								
1948/338(M6.5)	33° 54' 00"	116 25' 00"	N 50° W	70°NE	5-25	18	0.09(46)	0.09(.48)
BARSTOW REGION								
1952/203(M7.7)	Three rectangles. See Bakersfield region for parameters.							
1971/040(M6.4)	Four rectangles. See Los Angeles region for parameters.							
CHANNEL ISLANDS REGION								
1933/070(M6.3)	One rectangle. See Los Angeles region for parameters.							
1941/181(M5.9)	34° 20' 53"	119 23' 22"	N 70°W	80°N	0-10	18	-0.18(.02)	-0.13(.09)
1971/040(M6.4)	Four rectangles. See Los Angeles region for parameters.							
LOS ANGELES REGION								
1933/070(M6.3)	33° 43' 01"	118 02' 57"	N 47°W	90°	5-15	38	-0.09(.17)	0.04(.15) (east up)
1971/040(M6.4)	34° 16' 54"	118 22' 40"	N 70°W	35°N	1-12	12	-0.43(.07)	-2.23(.17)
1971/040(M6.4)	34° 19' 10"	118 21' 40"	N 70°W	52°N	8.7-20	12	1.76(.37)	-2.69(.57)
1971/040(M6.4)	34° 15' 52"	118 29' 22"	N 70°W	35°N	3-24	6	-0.29(.08)	-0.86(.10)
1971/040(M6.4)	34° 20' 30"	118 25' 15"	N 20°E	90°	1.7-6.9	10	1.86(.27)	0.00(fixed)
BAKERSFIELD REGION								
1952/203(M7.7)	35° 00' 53"	119 02' 27"	N 73°E	75°S	5-27	25	-0.07(.23)	-3.40(.29)
1952/203(M7.7)	35° 10' 33"	118 47' 51"	N 58°E	35°S	6-26	25	1.36(.07)	-1.20(.12)
1952/203(M7.7)	35° 17' 41"	118 35' 53"	N 43°E	20°S	6-26	25	0.19(.04)	-0.39(.06)
1971/040(M6.4)	Four rectangles. See Los Angeles region for parameters							
SIERRA NEVADA REGION								
1952/203(M7.7)	Three rectangles. See Bakersfield region for parameters.							
PARKFIELD REGION								
1934/158(M6.0)	35° 48' 00"	120 20' 58"	N 43°W	90°	0-10	20	-0.01(.04)	0.15(.06) (west up)
1966/179(M5.5)	35° 47' 25"	120 20' 25"	N 43°W	90°	5-20	32	-0.15(.07)	0.41(.08) (west up)
1966/179(M5.5)	35° 41' 23"	120 14' 37"	N 43°W	90°	0-5	4	-0.03(.01)	0.02(.03) (west up)
1966/179(M5.5)	35° 48' 12"	120 21' 19"	N 43°W	90°	0-5	28	-0.21(.01)	0.25(.03) (west up)
FALLON REGION								
1954/350(M7.1)	39° 13' 16"	118 07' 55"	N 13°E	63°E	0-5	36	-4.11(.08)	2.99(.09)
1954/350(M7.1)	39° 23' 38"	118 05' 02"	N 07°W	70°W	0-5	24	-1.44(.08)	0.27(.12)
1954/350(M6.9)	39° 38' 00"	118 11' 00"	N 08°E	60°E	0-6	38	-0.91(.22)	2.26(.29)
1954/350(M7.1)	39° 18' 25"	118 08' 53"	N 16°W	54°E	3.5-41	51.5	-0.40(.10)	1.29(.15)
1954/187(M6.6)	39° 28' 08"	118 27' 54"	N 12°E	63°E	0-10	40	0.68(.43)	-1.10(1.25)
1954/235(M6.8)	39° 28' 08"	118' 27' 54"	N 12°E	63°E	0-10	40	-1.48(.43)	3.15(1.21)

Comments: Depth measured along dip of rectangle.
Positive strike slip denotes left-lateral slip.
Positive dip slip denotes normal slip.

Table C.4.--District boundaries

San Diego region

```
REGION BOUNDARY
  32 30   114  0
  32 30   117 30
  33 30   117 30
  33 30   114  0

DISTRICTS *****

 DISTRICT  1

  DISTRICT BOUNDARY
    32 42 30.00  114 50  0.00
    33  0  0.00  115 14  0.00
    33 20  0.00  115 45  0.00
    33 25 30.00  115 49  0.00
    33 37 30.00  116  2  0.00
    33 42  0.00  116 10 15.00
    33 50  0.00  116 30  0.00
    34 10  0.00  117  6  0.00
    40  0  0.00  121  0  0.00
    40  0  0.00   90  0  0.00
    20  0  0.00   90  0  0.00
    20  0  0.00  114 50  0.00

 DISTRICT  2

  DISTRICT BOUNDARY
    32 41  0.00  115 21  0.00
    32  0  0.00  115 25  0.00
    32 40  0.00  115 31  0.00
    32 47  0.00  115 34  0.00
    32 50 40.00  115 35  0.00
    33  0  0.00  115 49  0.00
    33  0  0.00  115 39  0.00
    32 55 30.00  115 34  0.00

 DISTRICT  3

  DISTRICT BOUNDARY
    32 41 29.00  115  8  0.00
    32 55  0.00  115 25  0.00
    32 58  0.00  115 31 30.00
    33 10  0.00  115 37  0.00
    33 20  0.00  115 45  0.00
    33  0  0.00  115 14  0.00
    32 42 30.00  114 50  0.00
    20  0  0.00  114 50  0.00
    20  0  0.00  115  8  0.00

 DISTRICT  4

  DISTRICT BOUNDARY
    32 41  0.00  115 21  0.00
    32 55 30.00  115 34  0.00
    32 58  0.00  115 31 30.00
    32 55  0.00  115 25  0.00
    32 41 29.00  115  8  0.00
    20  0  0.00  115  8  0.00
    20  0  0.00  115 21  0.00

 DISTRICT  5

  DISTRICT BOUNDARY
    32 38 30.00  115 50  0.00
    32 47  0.00  116  0  0.00
    32 54  0.00  116 17  5.00
    33  9  0.00  116  6 30.00
    32 58  0.00  115 51  0.00
    32 57  0.00  115 49 24.00
    32 50 40.00  115 35  0.00
    32 47  0.00  115 34  0.00
    32 40  0.00  115 31  0.00
    20  0  0.00  115 21  0.00
    20  0  0.00  115 50  0.00

 DISTRICT  6

  DISTRICT BOUNDARY
    32 50 40.00  115 34 40.00
    32 57  0.00  115 49 24.00
    32 58  0.00  115 51  0.00
    33  0  0.00  115 49  0.00

 DISTRICT  7

  DISTRICT BOUNDARY
    33  0  0.00  115 49  0.00
    32 58  0.00  115 51  0.00
    33  9  0.00  116  6 30.00
    33 15  0.00  116 14  0.00
    33 30  0.00  116 38  0.00
    33 51 30.00  117  2  0.00
    33 54 30.00  117  9 30.00
    34 10  0.00  117  9 30.00
    33 50  0.00  116 30  0.00
    33 42  0.00  116 10 15.00
    33 37 30.00  116  2  0.00
    33 25 30.00  115 49  0.00
    33 20  0.00  115 45  0.00
    33 10 16.00  115 40  0.00
    33  1  0.00  115 36  0.00
    32 55 30.00  115 34  0.00
    33  0  0.00  115 39  0.00

 DISTRICT  8

  DISTRICT BOUNDARY
    32 55 30.00  115 34  0.00
    33  1  0.00  115 36  0.00
    33 10 16.00  115 40  0.00
    33 20  0.00  115 45  0.00
    33 10  0.00  115 37  0.00
    32 58  0.00  115 31 30.00

 DISTRICT  9

  DISTRICT BOUNDARY
    32 54  0.00  116 17  5.00
    33  6  0.00  116 34 40.00
    33 13  0.00  116 46 15.00
    33 19  0.00  116 55  0.00
    33 37  0.00  117 20 30.00
    34  0  0.00  117 45  0.00
    35  0  0.00  118 30  0.00
    33 54 30.00  117  9 30.00
    33 51 30.00  117  2  0.00
    33 30  0.00  116 38  0.00
    33 15  0.00  116 14  0.00
    33  9  0.00  116  6 30.00

 DISTRICT 10

  DISTRICT BOUNDARY
    20  0  0.00  115 50  0.00
    32 38 30.00  115 50  0.00
    32 47  0.00  116  0  0.00
    32 54  0.00  116 17  5.00
    33  6  0.00  116 34 40.00
    33 13  0.00  116 46 15.00
    33 19  0.00  116 55  0.00
    33 37  0.00  117 20 30.00
    34  0  0.00  117 45  0.00
    35  0  0.00  118 30  0.00
    35  0  0.00  120  0  0.00
    20  0  0.00  120  0  0.00
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San Bernardino region

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REGION BOUNDARY
  33 30   114  0
  33 30   117 30
  34 30   117 30
  34 30   114  0

DISTRICTS *****

 DISTRICT  1

  DISTRICT BOUNDARY
    33 13  0.00  116 46 15.00
    33 19  0.00  116 55  0.00
    33 37  0.00  117 20 30.00
    34  0  0.00  117 45  0.00
    34 45  0.00  118 45  0.00
    32 40  0.00  118 30  0.00
    32 40  0.00  116 10  0.00

 DISTRICT  2

  DISTRICT BOUNDARY
    33 13  0.00  116 46 15.00
    33 19  0.00  116 55  0.00
    33 37  0.00  117 20 30.00
    34  0  0.00  117 45  0.00
    34 45  0.00  118 45  0.00
    34 25  0.00  117 45  0.00
    34 13  0.00  117 29 10.00
    34  6 15.59  117 19 36.00
    34  6 17.00  117 19 51.00
    34  4 41.00  117 19 51.00
    34  4 41.00  117 18 14.00
    34  4 37.00  117 18  8.00
    33 54 30.00  117  9 30.00
    33 51 30.00  117  2  0.00
    33 30  0.00  116 38  0.00
    33 15  0.00  116 14  0.00
    32 45  0.00  115 45  0.00
    32 40  0.00  116 10  0.00

 DISTRICT  3

  DISTRICT BOUNDARY
    33 15  0.00  116 14  0.00
    33 30  0.00  116 38  0.00
    33 51 30.00  117  2  0.00
    33 54 30.00  117  9 30.00
    34  4 37.00  117 18  8.00
    33 57  0.00  116 44  0.00
    33 56  0.00  116 37  0.00
    33 52 30.00  116 25 30.00
    33 52  0.00  116 21 50.00
    33 38 10.00  116  2  0.00
    33 38  3.00  116  2  0.00
    33 10  0.00  115 45  0.00

 DISTRICT  4

  DISTRICT BOUNDARY
    33 57  0.00  116 44  0.00
    34  4 37.00  117 18  8.00
    34  4 32.00  117 18  2.00
    34  6  4.00  117 18  2.00
    34  6  4.63  117 19 34.00
    34  6 15.59  117 19 36.00
    34 13  0.00  117 29 10.00
    34 25  0.00  117 45  0.00
    34 16 25.00  117 27  9.00
    34 16  0.00  117 25 24.00
    34 12  2.00  117 19 56.00
    34 11 56.00  117 19 44.00
    34  4 30.00  116 58  6.00

 DISTRICT  5

  DISTRICT BOUNDARY
    33 38 10.00  116  2  0.00
    33 52  0.00  116 21 50.00
    33 52 10.00  116 21 30.00
    34  1 54.00  116 40  9.00
    34  2  0.00  116 30  0.00
    34  9  0.00  115 58  0.00
    33 33 40.00  115 21  0.00
    33 15  0.00  115  5  0.00
    32 30  0.00  115  5  0.00
    32 30  0.00  115 45  0.00
    33 10  0.00  115 45  0.00
    33 38  3.00  116  2  0.00
```

(continued)

Table C.4.--Continued

San Bernardino region

DISTRICT 6

DISTRICT BOUNDARY

34	2	0.00	116	30	0.00
34	1	54.00	116	40	9.00
34	4	50.00	116	58	6.00
34	11	56.00	117	19	44.00
34	12	2.00	117	19	56.00
34	16	0.00	117	25	24.00
34	16	25.00	117	27	9.00
34	25	0.00	117	45	0.00
35	0	0.00	118	45	0.00
35	0	0.00	117	15	0.00
34	45	0.00	117	15	0.00

DISTRICT 7

DISTRICT BOUNDARY

34	2	0.00	116	30	0.00
34	45	0.00	117	15	0.00
34	45	0.00	116	35	0.00
34	31	0.00	116	21	0.00
34	18	0.00	116	7	0.00
34	9	0.00	115	58	0.00

DISTRICT 8

DISTRICT BOUNDARY

34	45	0.00	115	30	0.00
33	15	0.00	114	30	0.00
32	30	0.00	114	30	0.00
32	30	0.00	115	5	0.00
33	15	0.00	115	5	0.00
33	33	40.00	115	21	0.00
34	9	0.00	115	58	0.00
34	18	0.00	116	7	0.00
34	31	0.00	116	21	0.00
34	45	0.00	116	35	0.00

DISTRICT 9

DISTRICT BOUNDARY

34	4	33.00	117	18	8.00
34	4	41.00	117	18	14.00
34	4	41.00	117	19	51.00
34	6	17.00	117	19	51.00
34	6	15.59	117	19	36.00
34	6	4.63	117	19	34.00
34	6	4.00	117	18	2.00
34	4	32.00	117	18	2.00

DISTRICT 10

DISTRICT BOUNDARY

33	52	0.00	116	21	50.00
33	52	30.00	116	25	30.00
33	56	0.00	116	37	0.00
33	57	0.00	116	44	0.00
34	4	30.00	116	58	6.00
34	11	56.00	117	19	44.00
34	4	50.00	116	58	6.00
34	1	54.00	116	40	9.00
33	52	10.00	116	21	30.00

DISTRICT 11

DISTRICT BOUNDARY

34	45	0.00	115	30	0.00
33	15	0.00	114	30	0.00
32	0	0.00	112	0	0.00
36	0	0.00	112	0	0.00

Barstow region

REGION BOUNDARY

34	30	114	0
34	30	118	30
35	30	118	30
35	30	114	0

DISTRICTS *****

DISTRICT 1

DISTRICT BOUNDARY

34	0	0.00	117	45	0.00
34	13	26.00	118	3	38.00
34	16	9.00	118	14	17.00
34	21	10.00	118	25	43.00
34	26	10.00	118	32	31.00
34	28	44.00	118	33	57.00
34	45	0.00	119	0	0.00
34	45	3.00	118	44	32.00
34	44	0.00	118	36	0.00
34	40	34.00	118	27	17.50
34	40	32.89	118	26	57.00
34	34	52.00	118	11	12.40
34	34	44.00	118	10	54.80
34	32	0.00	118	4	16.00
34	31	59.00	118	4	3.00
34	29	29.00	117	55	5.20
34	25	0.00	117	45	0.00
34	22	4.00	117	39	36.00
34	22	2.50	117	39	26.00
34	13	0.00	117	29	10.00

DISTRICT 2

DISTRICT BOUNDARY

34	13	0.00	117	29	10.00
34	22	2.50	117	39	26.00
34	22	4.00	117	39	36.00
34	25	0.00	117	45	0.00
34	29	29.00	117	55	5.20
34	31	59.00	118	4	3.00
34	32	0.00	118	4	16.00
34	34	44.00	118	10	54.00
34	34	52.00	118	11	12.40
34	40	32.89	118	26	57.00
34	40	34.00	118	27	17.50
34	44	0.00	118	36	0.00
34	51	30.00	118	25	0.00
34	59	0.00	118	7	0.00
35	6	0.00	117	45	0.00
35	5	0.00	117	34	45.00
34	42	0.00	117	12	0.00
34	30	0.00	117	0	0.00
34	0	0.00	116	30	0.00

DISTRICT 3

DISTRICT BOUNDARY

34	45	0.00	119	0	0.00
34	56	45.00	119	50	0.00
35	1	39.00	118	59	45.00
35	21	0.00	118	35	11.00
35	47	13.00	118	25	36.00
36	6	38.00	118	23	25.00
36	8	0.00	115	0	0.00
35	25	27.00	117	43	39.00
35	7	14.80	118	17	0.00
35	3	25.00	118	23	31.00

DISTRICT 4

DISTRICT BOUNDARY

34	56	45.00	119	50	0.00
35	1	39.00	118	59	45.00
35	21	0.00	118	35	11.00
35	47	13.00	118	25	36.00
36	6	38.00	118	23	25.00

DISTRICT 5

DISTRICT BOUNDARY

35	25	27.00	117	43	39.00
36	6	0.00	115	0	0.00
35	4	14.00	116	19	21.00
34	56	7.00	116	39	57.00

DISTRICT 6

DISTRICT BOUNDARY

34	0	0.00	116	30	0.00
34	30	0.00	117	0	0.00
34	42	0.00	117	12	0.00
35	5	0.00	117	34	45.00
35	6	0.00	117	45	0.00
35	7	14.80	118	17	0.00
35	25	27.00	117	43	39.00
34	56	7.00	116	39	57.00
34	45	0.00	116	25	0.00
34	9	0.00	115	47	10.00

DISTRICT 7

DISTRICT BOUNDARY

36	6	0.00	115	0	0.00
36	6	0.00	112	40	0.00
33	0	0.00	112	40	0.00
33	0	0.00	114	30	0.00
33	30	0.00	115	45	0.00
34	9	0.00	115	47	10.00
34	45	0.00	116	25	0.00
34	56	7.00	116	39	57.00
35	4	14.00	116	19	21.00

DISTRICT 8

DISTRICT BOUNDARY

34	45	0.00	119	0	0.00
34	45	3.00	118	44	32.00
34	44	0.00	118	36	0.00
34	51	30.00	118	25	0.00
34	59	0.00	118	7	0.00
35	6	0.00	117	45	0.00
35	7	14.80	118	17	0.00
35	3	25.00	118	23	31.00

DISTRICT 9

DISTRICT BOUNDARY

34	0	0.00	117	45	0.00
34	13	26.00	118	3	38.00
34	16	9.00	118	14	17.00
34	21	10.00	118	25	43.00
34	26	10.00	118	32	31.00
34	28	44.00	118	33	57.00
34	45	0.00	119	0	0.00
34	0	0.00	119	0	0.00

Table C.4.--Continued

Channel Islands region

```
REGION BOUNDARY
  32 30    117 30
  32 30    121  0
  34 30    121  0
  34 30    118 45
  33 30    118 45
  33 30    117 30

DISTRICTS *****

 DISTRICT  1

  DISTRICT BOUNDARY
   33 30  0.00  118  0  0.00
   32 45  0 00  118  0  0.00
   33 30  0.00  119  0  0.00

 DISTRICT  2

  DISTRICT BOUNDARY
   33 30  0.00  119  0  0.00
   32 45  0.00  118  0  0.00
   32 45  0.00  119  0  0.00

 DISTRICT  3

  DISTRICT BOUNDARY
   33 30  0.00  119  0  0.00
   33  0  0.00  119  0  0.00
   33 30  0.00  119 45  0.00

 DISTRICT  4

  DISTRICT BOUNDARY
   33 30  0.00  119 45  0.00
   33  0  0.00  119  0  0.00
   33  0  0.00  119 45  0.00

 DISTRICT  5

  DISTRICT BOUNDARY
   33 30  0.00  119  0  0.00
   34  9  0.00  119 16  0.00
   34  9  0.00  120  0  0.00
   33 55  0.00  119 55  0.00
   33 30  0.00  119 45  0.00

 DISTRICT  6

  DISTRICT BOUNDARY
   33 30  0.00  119 45  0.00
   33 55  0.00  119 55  0.00
   34  9  0.00  120  0  0.00
   34  9  0.00  121  0  0.00
   33 30  0.00  121  0  0 00

 DISTRICT  7

  DISTRICT BOUNDARY
   34  1 52.00  118 50 39.89
   34  2 26.50  118 46 31.16
   34  6  0.00  118 35  0.00
   34  4 57.52  118 34 25.24
   34  4 57.52  118  3 38.69
   34  4 57.52  116  0  0.00
   32  0  0.00  116  0  0.00
   32  0  0.00  118  0  0.00
   33 30  0.00  118  0  0.00
   33 30  0.00  119  0  0.00

 DISTRICT  8

  DISTRICT BOUNDARY
   34  4 57.52  116  0  0.00
   34 48 15.00  116  0  0.00
   34 48 15.00  118 48 52.60
   34 46 38.19  118 48 52.60
   34 37 46.00  118 44  6.50
   34 28 17.87  118 34  9.00
   34 27  0.59  118 32 27.69
   34 18 31.90  118 13 59.39
   34  4 57.52  118  3 38.69

 DISTRICT  9

  DISTRICT BOUNDARY
   34 48 15.00  118 48 52.60
   34 46 38.19  118 48 52.60
   34 37 46.00  118 44  6.50
   34 28 17.87  118 34  9.00
   34 27  0.59  118 32 27.69
   34 18 31.90  118 13 59.39
   34  4 57.52  118  3 38.69
   34  4 57.52  118 34 25.24
   34  6  0.00  118 35  0.00
   34  2 26.50  118 46 31.16
   34  1 52.00  118 50 39.89
   33 30  0.00  119  0  0.00
   34  9  0.00  119 16  0.00
   34  9  0.00  120  0  0.00
   34  9  0.00  121  0  0.00
   35  5  0.00  121  0  0.00
   35  5  0.00  118 48 52.60
```

Los Angeles region

```
REGION BOUNDARY
  33 30    117 30
  33 30    118 45
  34 30    118 45
  34 30    117 30

DISTRICTS *****

 DISTRICT  1

  DISTRICT BOUNDARY
   33 37 13.58  117 17 46.42
   33 37 13.58  116  0  0.00
   32 30  0.00  116  0  0.00
   32 30  0.00  118  0  0 00
   33 30  0.00  118  0  0.00
   33 36 26.00  117 55  6.58
   33 36 44.18  117 55  6.58
   33 47 19.57  118  8 16.46
   33 51 38.85  118 13 55.00
   33 56 16.84  118 18 12.00
   34  0 15.91  118 21 44.50
   34  4  2.25  118 29  9.61
   34  8 13.09  118 23 31.00
   34  7  7.40  118 19 29.67
   34  8 28.21  118 15 37.33
   34  9 48.85  118  7  7.87
   33 56 26.53  117 53 25.85
   33 56  6.28  117 51 39.37
   33 50 41.89  117 36 36.19
   33 50 29.60  117 33 12.00
   33 46 22.50  117 31 59.00

 DISTRICT  2

  DISTRICT BOUNDARY
   32 30  0.00  118  0  0.00
   33 30  0.00  118  0  0.00
   33 30  0.00  119 15  0 00
   34  1 52.00  119 15  0.00
   34 15  0.00  119 15  0.00
   34 15  0.00  119 30  0.00
   32 30  0.00  119 30  0.00

 DISTRICT  3

  DISTRICT BOUNDARY
   33 37 13.58  116  0  0.00
   34  0  0.00  116  0  0.00
   34  9 21 67  117 20 45.66
   34 11 29.90  118  0 59.46
   34  9 48.85  118  7  7.87
   33 56 26.53  117 53 25.85
   33 56  6.28  117 51 39.37
   33 50 41.89  117 36 36.19
   33 50 29.60  117 33 12.00
   33 46 22.50  117 31 59.00
   33 37 13.58  117 17 46.42

 DISTRICT  4

  DISTRICT BOUNDARY
   34  9 48.85  118  7  7.87
   34 16  8.39  118 14 17.08
   34 18 31.90  118 13 59.39
   34 27  0.59  118 32 27.69
   34 28 17.87  118 34  9.00
   34 37 46.00  118 44  6.50
   34 46 38.19  118 48 52.60
   34 46 38.19  119 15  0.00
   34 15  0.00  119 15  0.00
   34  1 52.00  119 15  0.00
   34  1 52.00  118 50 39.69
   34  2 26.50  118 46 31.16
   34  6  0.00  118 35  0.00
   34  4 57.52  118 34 25.24
   34  4  2.25  118 29  9.61
   34  8 13.09  118 23 31.00
   34  7  7.40  118 19 29.67
   34  8 28.21  118 15 37.33
   34 18 31.90  118 13 59.39
   34 18 31.90  118  0 59.46
   34 14 53.00  117 40 27.24
   34 17 12.70  117 29  9.79
```

(continued)

Table C.4.--Continued

Los Angeles region	Bakersfield region

Los Angeles region

DISTRICT 5

DISTRICT BOUNDARY

34	22	2.52	117	39	26.10
34	22	4.29	117	39	36.10
34	31	59.05	118	4	3.16
34	32	0.69	118	4	16.25
34	32	51.07	118	6	28.03
34	34	44.78	118	10	54.85
34	34	52.39	118	11	12.46
34	37	53.80	118	21	11.17
34	39	14.83	118	22	20.87
34	46	38.21	118	44	32.54
34	46	38.19	118	48	52.60
34	37	46.00	118	44	6.50
34	28	17.87	118	34	9.00
34	27	0.59	118	32	27.69

DISTRICT 6

DISTRICT BOUNDARY

34	18	31.90	118	13	59.39
34	18	31.90	118	0	59.46
34	14	53.00	117	40	27.24
34	17	12.70	117	29	9.79
34	15	53.75	117	27	51.10
34	15	10.59	117	27	48.59
34	9	21.67	117	20	45.66
34	11	29.90	118	0	59.46
34	9	48.85	118	7	7.87
34	16	8.39	118	14	17.08

DISTRICT 7

DISTRICT BOUNDARY

33	30	0.00	118	0	0.00
33	36	26.00	117	55	6.58
33	36	44.18	117	55	6.58
33	47	19.57	118	8	16.46
33	51	38.85	118	13	55.00
33	56	16.84	118	18	12.00
34	0	15.91	118	21	44.50
34	4	2.25	118	29	9.61
34	4	57.52	118	34	25.24
34	6	0.00	118	35	0.00
34	2	26.50	118	46	31.16
34	1	52.00	118	50	39.89
34	1	52.00	119	15	0.00
33	30	0.00	119	15	0.00

DISTRICT 8

DISTRICT BOUNDARY

34	0	0.00	116	0	0.00
34	9	21.67	117	20	45.66
34	15	10.59	117	27	48.59
34	15	53.75	117	27	51.10
34	17	12.70	117	29	9.79
34	22	2.52	117	39	26.10
34	22	4.29	117	39	36.10
34	31	59.05	118	4	3.16
34	32	0.69	118	4	16.25
34	32	51.07	118	6	28.03
34	34	44.78	118	10	54.85
34	34	52.39	118	11	12.46
34	37	53.80	118	21	11.17
34	39	14.83	118	22	20.87
34	46	38.21	118	44	32.54
34	46	38.19	118	48	52.60
34	46	38.19	119	15	0.00
35	0	0.00	119	15	0.00
35	0	0.00	116	0	0.00

Bakersfield region

REGION BOUNDARY

34	30	118	30
34	30	121	30
35	30	121	30
35	30	118	30

DISTRICTS •••••

DISTRICT 1

DISTRICT BOUNDARY

36	0	0.00	121	30	0.00
33	30	0.00	121	30	0.00
33	30	0.00	118	30	0.00
34	0	0.00	118	30	0.00
34	50	0.00	119	35	0.00
35	0	0.00	119	59	0.00
35	22	9.00	120	33	35.00
35	24	6.20	120	37	6.90
35	24	20.39	120	37	14.50
35	28	30.00	120	44	50.00

DISTRICT 2

DISTRICT BOUNDARY

36	0	0.00	121	30	0.00
35	28	30.00	120	44	30.00
35	24	20.39	120	37	14.50
35	24	6.20	120	37	6.90
35	22	9.00	120	33	35.00
35	0	0.00	119	59	0.00
34	50	0.00	119	35	0.00
34	57	32.00	119	25	0.00
35	3	13.00	119	33	15.00
35	30	31.00	120	0	23.69
35	39	0.00	120	10	9.00
36	0	0.00	120	36	0.00

DISTRICT 3

DISTRICT BOUNDARY

36	0	0.00	120	36	0.00
35	39	0.00	120	10	9.00
35	30	31.00	120	0	23.69
35	3	13.00	119	33	15.00
34	57	32.00	119	25	0.00
35	1	41.39	119	0	8.75
35	2	41.00	118	57	44.00
35	2	50.00	118	57	25.69
35	7	26.00	118	49	17.80
35	15	0.00	118	35	11.50
35	38	29.60	118	28	33.00
36	0	0.00	118	28	0.00

DISTRICT 4

DISTRICT BOUNDARY

36	0	0.00	118	28	0.00
35	38	29.60	118	28	33.00
35	15	0.00	118	35	11.50
35	7	26.00	118	49	17.80
35	2	50.00	118	57	25.69
35	2	41.00	118	57	44.00
35	1	41.39	119	0	8.75
34	57	32.00	119	25	0.00
34	50	33.00	118	58	51.00
34	49	30.00	118	52	0.00
34	53	0.00	118	46	6.00
34	53	5.70	118	45	58.70
34	53	46.00	118	45	56.70
34	57	21.00	118	34	20.60
35	0	0.00	118	25	5.00
35	16	51.60	118	0	0.00
36	0	0.00	118	0	0.00

DISTRICT 5

DISTRICT BOUNDARY

35	16	51.60	118	0	0.00
35	0	0.00	118	25	5.00
34	57	21.00	118	34	20.60
34	53	46.00	118	45	56.70
34	53	5.70	118	45	58.70
34	53	0.00	118	46	6.00
34	49	30.00	118	52	0.00
34	46	13.30	118	45	47.00
34	46	11.90	118	45	30.19
34	40	34.00	118	27	17.50
34	40	32.89	118	26	57.00
34	38	16.00	118	20	35.50
34	30	0.00	118	0	0.00
34	0	0.00	117	0	0.00
35	0	0.00	117	0	0.00

DISTRICT 6

DISTRICT BOUNDARY

34	30	0.00	118	0	0.00
34	38	16.00	118	20	35.50
34	40	32.89	118	26	57.00
34	40	34.00	118	27	17.50
34	46	11.90	118	45	30.19
34	46	13.30	118	45	47.00
34	49	30.00	118	52	0.00
34	30	0.00	118	37	0.00
34	0	0.00	118	0	0.00

DISTRICT 7

DISTRICT BOUNDARY

34	50	0.00	119	35	0.00
34	57	32.00	119	25	0.00
34	50	33.00	118	58	51.00
34	49	30.00	118	52	0.00
34	30	0.00	118	37	0.00
34	0	0.00	118	0	0.00
34	0	0.00	118	30	0.00

Table C.4.--Continued

Sierra Nevada region

```
REGION BOUNDARY
  35 30    115  0
  35 30    119 30
  37  0    119 30
  37  0    115  0

DISTRICTS *****

 DISTRICT  1

  DISTRICT BOUNDARY
    35 10  0.00  120  0  0.00
    34 30  0.00  119 25  0.00
    35  1 41.39  119  0  8.75
    35  2 41 00  118 57 44 00
    35  2 50.00  118 57 25.69
    35  7 26.00  118 49 17.80
    35 15  0.00  118 35 11.50
    35 30  0.00  118 31  0.00
    35 30  0.00  120  0  0.00

 DISTRICT  2

  DISTRICT BOUNDARY
    35 30  0.00  118 31  0.00
    35 47 13.30  118 25 37.00
    36  0  0.00  118 24  0.00
    36  0  0.00  120  0  0.00
    35 30  0.00  120  0  0.00

 DISTRICT  3

  DISTRICT BOUNDARY
    36  0  0.00  118 24  0.00
    36 20  0.00  118 21  0.00
    37 20  0.00  118 24  0.00
    37 30  0.00  118 24  0.00
    37 30  0.00  120  0  0.00
    36  0  0.00  120  0  0.00

 DISTRICT  4

  DISTRICT BOUNDARY
    34 30  0.00  119 25  0.00
    35  1 41.39  119  0  8.75
    35  2 41.00  118 57 44.00
    35  2 50.00  118 57 25.69
    35  7 26.00  118 49 17.80
    35 15  0.00  118 35 11.50
    35 30  0.00  118 31  0.00
    35 30  0.00  118  3  0.00
    35 17  0.00  118  3  0.00
    35  7  0.00  118 17 36.00
    34 30  0.00  118 50  0.00

 DISTRICT  5

  DISTRICT BOUNDARY
    35 30  0.00  118  3  0.00
    35 45 43.00  117 55  0.00
    35 59 13.00  117 56  0.00
    36 20  0.00  118  6  0.00
    36 23 26.50  118  1  0.00
    36 35 28.00  118  3 45.00
    36 48 24.00  118  7 30.00
    37  0  0.00  118 13 30.00
    37 20  0.00  118 13 30.00
    37 20  0.00  118 24  0.00
    36 20  0.00  118 21  0.00
    36  0  0.00  118 24  0.00
    35 47 13.30  118 25 37.00
    35 30  0.00  118 31  0.00

 DISTRICT  6

  DISTRICT BOUNDARY
    34 30  0.00  118 50  0.00
    35  7  0.00  118 17 36.00
    35 17  0.00  118  3  0.00
    35 26  0.00  117 44  0.00
    35 33 13.00  117 14  7.60
    35 36  0.00  117  3  0.00
    35 37  0.00  116 41  0.00
    35 37  0.00  113 50  0.00
    34 30  0.00  113 50  0.00

 DISTRICT  7

  DISTRICT BOUNDARY
    37 20  0.00  118 13 30.00
    37  0  0.00  118 13 30.00
    36 48 24.00  118  7.30.00
    36 35 28.00  118  3 45.00
    36 23 26.50  118  1  0.00
    36 20  0.00  118  6  0.00
    35 59 13.00  117 56  0.00
    35 45 43.00  117 55  0.00
    35 30  0.00  118  3  0.00
    35 17  0.00  118  3  0.00
    35 26  0.00  117 44  0.00
    35 33 13.00  117 14  7.60
    35 36  0.00  117  3  0.00
    35 37  0.00  116 41  0.00
    35 37  0.00  113 50  0.00
    35 37  0.00  113 30  0.00
    38  0  0.00  113 30  0.00
    38  0  0.00  114  3  0.00
```

Parkfield region

```
REGION BOUNDARY
  35 30    119 30
  35 30    122  0
  36 30    122  0
  36 30    119 30

DISTRICTS *****

 DISTRICT  1

  DISTRICT BOUNDARY
    35  0  0.00  121 38  0.00
    34 50  0.00  120 36  0.00
    35  0  0.00  119 59  0.00
    35 22  9.00  120 33 35.00
    35 24  6.20  120 37  6.90
    35 24 20.39  120 37 14.50
    35 28 30.00  120 44 50.00
    35 40 35.00  121  3  5.00
    36  0 44.00  121 30  5.00
    36  7 32.00  121 38  0.00
    36  5  0.00  122  0  0.00

 DISTRICT  2

  DISTRICT BOUNDARY
    36  7 32.00  121 36  0.00
    36  0 44.00  121 30  5.00
    35 40 35.00  121  3  5.00
    35 28 30.00  120 44 50.00
    35 24 20.39  120 37 14.50
    35 24  6.20  120 37  6.90
    35 22  9.00  120 33 35.00
    35  0  0.00  119 59  0.00
    35  3 13.00  119 33 15.00
    35 15  0.00  119 50  0.00
    35 21 10.00  119 55  0.00
    35 29 50.00  120  3 30.00
    35 35 30.00  120  7 30.00
    35 38  0.00  120 10 50.00
    35 41 18.00  120 14 30.00
    35 41 29.00  120 14 43.00
    35 43  0.00  120 15 55.00
    35 44 50.00  120 17 50.00
    35 49 52.00  120 22  0.00
    35 53 30.00  120 26 30.00
    35 57 50.00  120 31 50.00
    35 59  0.00  120 34  0.00
    36  3 50.00  120 39  0.00
    36 11  0.00  120 45  6.00
    36 13  4.00  120 48 10.00
    36 24  0.00  121  0  0.00

    36 28 50.00  121  5  0.00
    36 37  0.00  121 12  0.00
    36 38  3.00  121 14  0.00

    36 38 11.00  121 14 13.00
    36 45  6.00  121 23  7.00
    36 55 51.00  121 38 35.10
    36 55  0.00  122  0  0.00
    36  5  0.00  122  0  0.00

 DISTRICT  3

  DISTRICT BOUNDARY
    35  3 13.00  119 33 15.00
    35 15  0.00  119 50  0.00
    35 21 10.00  119 55  0.00
    35 29 50.00  120  3 30.00
    35 35 30.00  120  7 30.00
    35 38  0.00  120 10 50.00
    35 41 18.00  120 14 30.00
    35 41 29.00  120 14 43.00
    35 43  0.00  120 15 55.00
    35 44 50.00  120 17 50.00
    35 49 52.00  120 22  0.00
    35 53 30.00  120 26 30.00
    35 57  0.00  120 20  0.00
    36  5 59.00  120  1  7.00
    35 51  0.00  119 49  0.00
    35 35 12.00  119 35  9.00
    35 21 19.00  119 16 17.00
    35 15  0.00  119  0  0.00
    35  0  0.00  119  0  0.00
```

(continued)

Parkfield region

DISTRICT 4

DISTRICT BOUNDARY

35	53	30.00	120	26	30.00
35	57	50.00	120	31	50.00
35	59	0.00	120	34	0.00
36	3	50.00	120	39	0.00
36	11	0.00	120	45	6.00
36	13	4.00	120	48	10.00
36	12	49.00	120	42	57.00
36	16	55.00	120	34	8.00
36	26	44.00	120	20	11.00
36	11	52.00	120	8	0.00
36	5	59.00	120	1	7.00
35	57	0.00	120	20	0.00

DISTRICT 5

DISTRICT BOUNDARY

36	28	50.00	121	5	0.00
36	37	0.00	121	12	0.00
36	38	3.00	121	14	0.00
36	38	11.00	121	14	13.00
36	45	6.00	121	23	7.00
36	55	51.00	121	38	35.10
36	59	0.00	121	26	0.00
36	49	5.00	121	22	45.00
36	43	0.00	121	16	0.00
36	38	0.00	121	8	0.00

DISTRICT 6

DISTRICT BOUNDARY

36	13	4.00	120	48	10.00
36	24	0.00	121	0	0.00
36	28	50.00	121	5	0.00
36	38	0.00	121	8	0.00
36	43	0.00	121	16	0.00
36	49	5.00	121	22	45.00
36	59	0.00	121	26	0.00
36	55	0.00	120	50	0.00
36	33	4.00	120	29	17.00
36	26	44.00	120	20	11.00
36	16	55.00	120	34	8.00
36	12	49.00	120	42	57.00

DISTRICT 7

DISTRICT BOUNDARY

35	0	0.00	119	0	0.00
35	15	0.00	119	0	0.00
35	21	19.00	119	16	17.00
35	35	12.00	119	35	9.00
35	51	0.00	119	49	0.00
36	5	59.00	120	1	7.00
36	11	52.00	120	8	0.00
36	26	44.00	120	20	11.00
36	33	4.00	120	29	17.00
36	55	0.00	120	50	0.00
37	11	0.00	121	14	0.00
37	32	0.00	121	21	0.00
37	32	0.00	119	0	0.00
37	11	0.00	119	0	0.00
36	55	0.00	119	0	0.00

Monterey region

REGION BOUNDARY

36	30	119	30
36	30	123	0
37	0	123	0
37	0	119	30

DISTRICTS *****

DISTRICT 1

DISTRICT BOUNDARY

36	24	0.00	121	0	0.00
36	28	50.00	121	5	0.00
36	37	0.00	121	12	0.00
36	38	3.00	121	14	0.00
36	38	11.00	121	14	13.00
36	45	6.00	121	23	7.00
36	45	10.00	121	23	17.00
36	46	24.00	121	25	29.00
36	46	35.00	121	25	40.00
36	49	55.00	121	30	0.00
36	55	51.00	121	38	35.10
37	4	0.00	121	50	0.00
37	19	12.00	122	8	45.00
37	30	0.00	122	29	45.00
37	30	0.00	122	30	0.00
35	59	0.00	122	30	0.00
35	59	0.00	120	34	0.00
36	3	50.00	120	39	0.00
36	10	0.00	120	46	0.00

DISTRICT 2

DISTRICT BOUNDARY

36	28	50.00	121	5	0.00
36	38	0.00	121	8	0.00
36	43	0.00	121	16	0.00
36	49	0.00	121	23	0.00
36	51	0.00	121	25	0.00
36	54	0.00	121	27	0.00
36	57	0.00	121	38	0.00
37	4	0.00	121	50	0.00
36	55	51.00	121	38	35.10
36	49	55.00	121	30	0.00
36	46	35.00	121	25	40.00
36	46	24.00	121	25	29.00
36	45	10.00	121	23	17.00
36	45	6.00	121	23	7.00
36	38	11.00	121	14	13.00
36	38	3.00	121	14	0.00
36	37	0.00	121	12	0.00

DISTRICT 3

DISTRICT BOUNDARY

36	54	0.00	121	27	0.00
36	59	0.00	121	26	0.00
37	5	0.00	121	32	0.00
37	30	0.00	121	54	43.00
37	30	0.00	122	29	45.00
37	19	12.00	122	8	45.00
37	4	0.00	121	50	0.00
36	57	0.00	121	38	0.00

DISTRICT 4

DISTRICT BOUNDARY

36	59	0.00	121	26	0.00
37	5	0.00	121	32	0.00
37	30	0.00	121	54	43.00
37	30	0.00	121	27	0.00
37	11	0.00	121	14	0.00
36	47	40.00	120	55	18.00
36	20	41.00	120	33	0.00
35	59	0.00	120	34	0.00
36	3	50.00	120	39	0.00
36	10	0.00	120	46	0.00
36	24	0.00	121	0	0.00
36	28	50.00	121	5	0.00
36	38	0.00	121	8	0.00
36	43	0.00	121	16	0.00
36	49	5.00	121	22	45.00
36	55	33.00	121	21	22.00

DISTRICT 5

DISTRICT BOUNDARY

36	43	0.00	121	16	0.00
36	49	0.00	121	23	0.00
36	51	0.00	121	25	0.00
36	54	0.00	121	27	0.00
36	59	0.00	121	26	0.00
36	55	33.00	121	21	22.00
36	49	5.00	121	22	45.00

DISTRICT 6

DISTRICT BOUNDARY

37	30	0.00	121	27	0.00
37	11	0.00	121	14	0.00
36	47	40.00	120	55	18.00
36	20	41.00	120	33	0.00
35	59	0.00	120	34	0.00
35	59	0.00	118	30	0.00
37	30	0.00	118	30	0.00

Table C.4.--Continued

Yosemite region

```
REGION BOUNDARY
  37  0   117  0
  37  0   121 45
  38  0   121 45
  38  0   117  0

DISTRICTS *****

 DISTRICT  1

  DISTRICT BOUNDARY
    36 30  0.00  121  0  0.00
    36 28 50.00  121  5  0.00
    36 37  0.00  121 12  0.00
    36 38  3 00  121 14  0.00
    36 38 11.00  121 14 13.00
    36 45  6.00  121 23  7.00
    36 45 10.00  121 23 17.00
    36 46 24.00  121 25 29.00
    36 46 35.00  121 25 40.00
    36 49 55.00  121 30  0.00
    36 55 51.00  121 38 35.10
    37  4  0.00  121 50  0.00
    37 19 12 00  122  8 45.00
    37 30  0.00  122 29 45.00
    37 30  0 00  122 30  0.00
    35 59  0.00  122 30  0.00
    35 59  0.00  120 34  0.00
    36  3 50.00  120 39  0.00
    36 10  0.00  120 46  0.00

 DISTRICT  2

  DISTRICT BOUNDARY
    36 28 50.00  121  5  0.00
    36 38  0.00  121  8  0.00
    36 43  0.00  121 16  0.00
    36 49  0.00  121 23  0.00
    36 51  0.00  121 25  0.00
    36 54  0.00  121 27  0.00
    36 57  0.00  121 38  0.00
    37  4  0.00  121 50  0.00
    36 55 51.00  121 38 35.10
    36 49 55.00  121 30  0.00
    36 46 35.00  121 25 40.00
    36 46 24.00  121 25 29.00
    36 45 10.00  121 23 17.00
    36 45  6.00  121 23  7.00
    36 38 11.00  121 14 13.00
    36 38  3.00  121 14  0.00
    36 37  0.00  121 12  0.00

 DISTRICT  3

  DISTRICT BOUNDARY
    36 54  0.00  121 27  0.00
    36 59  0.00  121 26  0.00
    37  0  0.00  121 28 45.00
    37 17 34.00  121 42 25.69
    37 18 51.39  121 45 16.09
    37 31 21.90  121 56 33.00
    37 31 31.69  121 56 43.00
    37 35 59.00  122  0 36.00
    37 36  4.00  122  0 41.00
    38 35  0.00  122 40  0.00
    37 30  0.00  122 40  0.00
    37 30  0.00  122 29 45.00
    37 19 12.00  122  8 45.00
    37  4  0.00  121 50  0 00
    36 57  0.00  121 38  0.00

 DISTRICT  4

  DISTRICT BOUNDARY
    36 43  0.00  121 16  0.00
    36 49  0.00  121 23  0.00
    36 51  0.00  121 25  0.00
    36 54  0.00  121 27  0.00
    36 50  0.00  121 26  0.00
    36 55 33.00  121 21 22 00
    36 49  5.00  121 22 45.00

 DISTRICT  5

  DISTRICT BOUNDARY
    38 35  0.00  122 40  0.00
    37 51 26.00  122  3  0.00
    37 49  4.00  122  0  0.00
    37 41  7.00  121 55 45.00
    37 35 36.00  121 52 30.00
    37 39  0.00  121 46 55.00
    37 42 25.00  121 41 20.00
    37 42  0.00  120 30  0.00
    38  6  0.00  120 50  0.00
    38 35  0.00  121 13  0.00

 DISTRICT  6

  DISTRICT BOUNDARY
    37 35 36.00  121 52 30.00
    37 34 52.00  121 51 59.00
    37 34 44.00  121 51 52.00
    37 27  0.00  121 48 45.00
    37 17 34.00  121 42 25.69
    37  0  0.00  121 28 45.00
    36 59  0.00  121 26  0.00
    36 55 33.00  121 22  0.00
    36 49  5.00  121 22 45.00
    36 43  0.00  121 16  0.00
    36 38  0.00  121  8  0.00
    36 28 50.00  121  5  0.00
    36 30  0.00  121  0  0.00
    36 10  0.00  120 46  0.00
    36 10  0.00  119 10  0.00
    36 30  0.00  119 20  0.00
    37 42  0.00  120 30  0.00
    37 42 25.00  121 41 20.00
    37 39  0.00  121 46 55.00

 DISTRICT  7

  DISTRICT BOUNDARY
    38 35  0.00  121 13  0.00
    38  6  0.00  120 50  0.00
    37 42  0.00  120 30  0.00
    36 30  0.00  119 20  0.00
    36 30  0.00  118  5  0.00
    36 41  0.00  118  5  0.00
    36 56  0.00  118 11  0.00
    37  2  0.00  118 12  0.00
    37 14  0.00  118 20  0.00
    37 23  0.00  118 20  0.00
    37 32  0.00  118 21  0.00
    37 42  0.00  118 23  0.00
    37 51  0.00  118 24  0.00
    38  0  0.00  118 32  0.00
    38 35  0.00  118 35  0.00
    38 45  0.00  118 35  0 00
    38 45  0.00  121 13  0.00

 DISTRICT  8

  DISTRICT BOUNDARY
    37 17 34.00  121 42 25.69
    37 27  0.00  121 48 45.00
    37 34 44.00  121 51 52.00
    37 34 52.00  121 51 59.00
    37 35 36.00  121 52 30.00
    37 41  7.00  121 55 45.00
    37 49  4.00  122  0  0.00
    37 51 26.00  122  3  0.00
    38 35  0.00  122 40  0.00
    37 36  4.00  122  0 41.00
    37 35 59.00  122  0 36.00
    37 31 31.69  121 56 43.00
    37 31 21.90  121 56 33.00
    37 18 51.39  121 45 16.09

 DISTRICT  9

  DISTRICT BOUNDARY
    39  0  0.00  118 35  0.00
    38  0  0.00  118 32  0.00
    37 51  0.00  118 24  0.00
    37 42  0.00  118 23  0.00
    37 32  0.00  118 21  0.00
    37 23  0.00  118 20  0.00
    37 14  0.00  118 20  0.00
    37  2  0.00  118 12  0.00
    36 56  0.00  118 11  0.00
    36 41  0.00  118  5  0.00
    36 30  0.00  118  5  0.00
    36 30  0.00  116 20  0.00
    39  0  0.00  116 20  0.00
```

San Francisco region

```
REGION BOUNDARY
  37  0   121 45
  37  0   123 30
  38  0   123 30
  38  0   121 45

DISTRICTS *****

 DISTRICT  1

  DISTRICT BOUNDARY
    36 24  0.00  121  0  0.00
    36 45 10.00  121 23 17.00
    36 49 55.00  121 30  0.00
    36 55 51 00  121 38 35.10
    37  5  8.00  121 51 58.00
    37  9 30.00  121 58 25.00
    37 18 15.00  122  9  0.00
    37 40 47.39  122 30  0.00
    37 30  0.00  122 45  0.00
    37 30  0.00  123 15  0.00
    36 24  0.00  123 15  0.00

 DISTRICT  2

  DISTRICT BOUNDARY
    37  5  8.00  121 51 58.00
    37  9 30.00  121 58 25.00
    37 18 15.00  122  9  0.00
    37 40 47.39  122 30  0.00
    37 48 24.00  122 24  5.00
    37 56  2.00  122 18  9.90
    37 52 16.00  122 14 58.80
    37 36  4.00  122  0 41.00
    37 35 59.00  122  0 36.00
    37 31 31.69  121 56 43.00
    37 31 21.90  121 56 33.00
    37 18 51.39  121 45 16.09
    37 17 34.00  121 42 25.69
    37  5  0.00  121 32  0.00
    36 59  0.00  121 26  0.00
    36 54  0.00  121 27  0.00
    36 57  0.00  121 38  0.00
    37  2  0.00  121 41  0.00

 DISTRICT  3

  DISTRICT BOUNDARY
    37 40 47.39  122 30  0.00
    37 48 24.00  122 24  5.00
    37 56  2.00  122 18  9.90
    37 56  7.00  122 18 17.00
    37 58 52.00  122 22 14.00
    38  6 55.00  122 24 25.00
    38 13 43.00  122 31 18.00
    38 19 46.00  122 35 40.00
    38 20 35.00  122 35 40.00
    38 26 12.00  122 42 23.00
    38 35 35.00  122 49 50.00
    38 35 35.00  123 15  0.00
    38 30 41.00  123 14 55.00
    38 19  0.00  123  2 21.00
    38 10 54.00  122 55 25.00
    38  3  8.00  122 48 11.00
    38  2 41.39  122 47 50.80
    38  2 40.50  122 47 50.39
    37 55 52.00  122 41 39.00

 DISTRICT  4

  DISTRICT BOUNDARY
    36 24  0.00  121  0  0.00
    36 43  0 00  121 16  0.00
    36 49  0.00  121 23  0.00
    36 51  0.00  121 25  0.00
    36 54  0.00  121 27  0.00
    36 59  0.00  121 26  0.00
    37  5  0.00  121 32  0.00
    37 17 34.00  121 42 25.69
    37 20  0.00  121 42 25.69
    37 34 44.00  121 51 52.00
    37 34 52.00  121 51 59.00
    37 35 36.00  121 52 30.00
    37 39  0.00  121 46 55.00
    37 42 25.00  121 41 20.00
    37 32  0.00  121 21  0 00
    37 11  0.00  121 14  0.00
    36 55  0.00  121  0  0.00
    38 10  0.00  120 45  0.00
    38 45  0.00  120  0  0.00
    38 45  0.00  119  0  0.00
    37 50  0.00  119  0  0.00
```

(continued)

Table C.4.--Continued

San Francisco region

DISTRICT 5

DISTRICT BOUNDARY

37	17	34.00	121	42	25.69
37	18	51.39	121	45	16.09
37	31	21.90	121	56	33.00
37	31	31.69	121	56	43.00
37	35	59.00	122	0	36.00
37	36	4.00	122	0	41.00
37	52	16.00	122	14	58.80
37	56	2.00	122	18	9.90
37	56	7.00	122	18	17.00
37	58	52.00	122	22	14.00
38	6	55.00	122	24	25.00
38	3	23.00	122	13	32.00
38	0	46.00	122	10	31.00
37	55	2.00	122	4	24.00
37	53	12.00	122	3	45.00
37	48	51.00	121	58	54.00
37	41	7.00	121	55	45.00
37	35	36.00	121	52	30.00
37	34	52.00	121	51	59.00
37	34	44.00	121	51	52.00
37	20	0.00	121	42	25.69

DISTRICT 6

DISTRICT BOUNDARY

39	4	0.00	123	25	0.00
38	35	35.00	122	49	50.00
38	26	12.00	122	42	23.00
38	20	35.00	122	35	40.00
38	19	46.00	122	35	40.00
38	13	43.00	122	31	18.00
38	6	55.00	122	24	25.00
38	3	23.00	122	13	32.00
38	0	46.00	122	10	31.00
37	55	2.00	122	4	24.00
37	53	12.00	122	3	45.00
37	48	51.00	121	58	54.00
37	41	7.00	121	55	45.00
37	35	36.00	121	52	30.00
37	39	0.00	121	46	55.00
37	42	25.00	121	41	20.00
37	43	2.00	121	41	27.00
38	0	0.00	121	59	4.29
38	6	55.00	122	7	0.00
38	14	26.00	122	8	27.00
38	24	17.00	122	8	7.00
38	35	35.00	122	16	0.00
39	11	29.00	122	29	49.00
39	12	0.00	120	0	0.00
39	30	0.00	120	0	0.00
39	30	0.00	123	25	0.00

DISTRICT 7

DISTRICT BOUNDARY

38	35	35.00	123	15	0.00
38	30	41.00	123	14	55.00
38	19	0.00	123	2	21.00
38	10	54.00	122	55	25.00
38	3	8.00	122	48	11.00
38	2	41.39	122	47	50.80
38	2	40.50	122	47	50.39
37	55	52.00	122	41	39.00
37	40	47.39	122	30	0.00
37	30	0.00	122	45	0.00
37	30	0.00	123	15	0.00

DISTRICT 8

DISTRICT BOUNDARY

37	5	8.00	121	51	58.00
37	2	0.00	121	41	0.00
36	57	0.00	121	38	0.00
36	54	0.00	121	27	0.00
36	51	0.00	121	25	0.00
36	49	0.00	121	23	0.00
36	43	0.00	121	16	0.00
36	24	0.00	121	0	0.00
36	45	10.00	121	23	17.00
36	49	55.00	121	30	0.00
36	55	51.00	121	38	35.10

DISTRICT 9

DISTRICT BOUNDARY

37	42	25.00	121	41	20.00
37	43	2.00	121	41	27.00
38	0	0.00	121	59	4.29
38	6	55.00	122	7	0.00
38	14	26.00	122	8	27.00
38	24	17.00	122	8	7.00
38	35	35.00	122	16	0.00
38	45	0.00	122	16	0.00
38	45	0.00	120	55	0.00
38	35	35.00	120	55	0.00
36	55	0.00	121	0	0.00
37	11	0.00	121	14	0.00
37	32	0.00	121	21	0.00

Sacramento region

REGION BOUNDARY

38	0	118	30
38	0	121	30
39	0	121	30
39	0	118	30

DISTRICTS *****

DISTRICT 1

DISTRICT BOUNDARY

37	30	0.00	120	0	0.00
37	23	0.00	118	20	0.00
37	32	0.00	118	21	0.00
37	42	0.00	118	23	0.00
37	51	0.00	118	24	0.00
38	0	0.00	118	32	0.00
39	30	0.00	119	30	0.00
40	0	0.00	119	30	0.00
40	0	0.00	120	51	15.00
39	6	38.00	120	51	15.00
38	58	25.00	120	47	50.00
38	49	30.00	120	48	30.00
38	38	25.00	120	47	45.00
38	29	25.00	120	48	10.00
38	18	0.00	120	43	30.00
37	53	0.00	120	21	15.00

DISTRICT 2

DISTRICT BOUNDARY

37	0	0.00	123	0	0.00
37	0	0.00	120	0	0.00
37	30	0.00	120	0	0.00
37	53	0.00	120	21	15.00
38	18	0.00	120	43	30.00
38	29	25.00	120	48	10.00
38	38	25.00	120	47	45.00
38	49	30.00	120	48	30.00
38	58	25.00	120	47	50.00
39	6	38.00	120	51	15.00
40	0	0.00	120	51	15.00
40	0	0.00	123	0	0.00

DISTRICT 3

DISTRICT BOUNDARY

37	23	0.00	118	20	0.00
37	23	0.00	117	0	0.00
40	0	0.00	117	0	0.00
40	0	0.00	119	30	0.00
39	30	0.00	119	30	0.00
38	0	0.00	118	32	0.00
37	51	0.00	118	24	0.00
37	42	0.00	118	23	0.00
37	32	0.00	118	21	0.00

Table C.4.--Continued

Santa Rosa region

REGION BOUNDARY

38	0	121	30
38	0	124	0
39	0	124	0
39	0	121	30

DISTRICTS •••••

DISTRICT 1

DISTRICT BOUNDARY

37	30	0.00	122	18	21.00
37	40	47.39	122	30	0.00
37	55	52.00	122	41	39.00
38	2	40.39	122	47	50.39
38	2	41.30	122	47	50.80
38	3	8.00	122	48	11.00
38	10	54.00	122	55	25.00
38	19	0.00	123	2	21.00
38	30	41.00	123	14	55.00
38	59	15.30	123	40	59.00
39	0	34.00	123	41	0.00
39	30	0.00	124	10	0.00
37	30	0.00	124	10	0.00

DISTRICT 2

DISTRICT BOUNDARY

37	30	0.00	122	18	21.00
37	40	47.39	122	30	0.00
37	55	52.00	122	41	39.00
38	2	40.39	122	47	50.39
38	2	41.30	122	47	50.80
38	3	8.00	122	48	11.00
38	10	54.00	122	55	25.00
38	19	0.00	123	2	21.00
38	20	48.00	122	55	47.60
38	18	52.70	122	47	21.00
38	20	35.00	122	35	40.00
38	19	46.00	122	35	40.00
38	13	43.00	122	31	18.00
38	6	55.00	122	24	25.00
37	58	52.00	122	22	14.00
37	56	7.00	122	18	17.00
37	56	2.00	122	18	10.00
37	50	1.00	122	12	55.00
37	30	0.00	121	54	0.00

DISTRICT 3

DISTRICT BOUNDARY

38	19	0.00	123	2	21.00
38	30	41.00	123	14	55.00
38	59	15.30	123	40	59.00
39	0	34.00	123	41	0.00
39	30	0.00	124	10	0.00
39	32	0.00	123	45	0.00
39	4	0.00	123	25	0.00
38	56	55.00	123	13	0.00
38	45	21.00	123	0	44.00
38	39	29.00	122	52	15.00
38	35	35.00	122	49	50.00
38	26	12.00	122	42	23.00
38	20	35.00	122	35	40.00
38	18	52.70	122	47	21.00
38	20	48.00	122	55	47.60

DISTRICT 4

DISTRICT BOUNDARY

37	30	0.00	121	54	0.00
37	50	1.00	122	12	55.00
37	56	2.00	122	18	10.00
37	56	7.00	122	18	17.00
37	58	52.00	122	22	14.00
38	6	55.00	122	24	25.00
38	3	23.00	122	13	32.00
38	0	46.00	122	10	31.00
37	55	2.00	122	4	24.00
37	53	12.00	122	3	45.00
37	48	51.00	121	58	54.00
37	42	25.00	121	55	30.00
37	30	0.00	121	48	4.00

DISTRICT 5

DISTRICT BOUNDARY

38	3	23.00	122	13	32.00
38	6	55.00	122	24	25.00
38	13	43.00	122	31	18.00
38	19	46.00	122	35	40.00
38	20	35.00	122	35	40.00
38	26	12.00	122	42	23.00
38	35	35.00	122	49	50.00
38	45	0.00	122	50	0.00
38	45	0.00	122	43	0.00
38	51	0.00	122	43	0.00
38	51	0.00	122	50	0.00
38	45	0.00	122	50	0.00
38	35	35.00	122	49	50.00
38	39	29.00	122	52	15.00
38	45	21.00	123	0	44.00
38	56	55.00	123	13	0.00
39	4	0.00	123	25	0.00
39	32	0.00	123	45	0.00
39	32	0.00	122	45	0.00
39	11	29.00	122	29	49.00
38	39	16.00	122	17	59.00
38	24	17.00	122	8	7.00
38	14	26.00	122	8	27.00
38	6	55.00	122	7	0.00
38	2	26.00	122	7	5.00

DISTRICT 6

DISTRICT BOUNDARY

37	30	0.00	121	48	4.00
37	42	25.00	121	55	30.00
37	48	51.00	121	58	54.00
37	53	12.00	122	3	45.00
37	55	2.00	122	4	24.00
38	0	46.00	122	10	31.00
38	3	23.00	122	13	32.00
38	2	26.00	122	7	5.00
38	6	55.00	122	7	.0.00
38	14	26.00	122	8	27.00
38	24	17.00	122	8	7.00
38	31	55.00	121	48	3.00
38	21	31.00	121	47	7.00
38	9	9.00	121	40	6.00
37	52	36.00	121	36	0.00
37	46	0.00	121	33	11.00
37	32	0.00	121	21	0.00
37	30	0.00	121	20	0.00

DISTRICT 7

DISTRICT BOUNDARY

38	24	17.00	122	8	7.00
38	39	16.00	122	17	59.00
39	11	29.00	122	29	49.00
39	32	0.00	122	45	0.00
39	30	0.00	121	0	0.00
39	30	0.00	120	0	0.00
38	41	0.00	120	0	0.00
38	41	0.00	121	0	0.00
38	37	5.00	121	17	46.00
38	34	50.00	121	29	35.00
38	31	55.00	121	48	3.00

DISTRICT 8

DISTRICT BOUNDARY

38	51	0.00	122	50	0.00
38	45	0.00	122	50	0.00
38	45	0.00	122	43	0.00
38	51	0.00	122	43	0.00

DISTRICT 9

DISTRICT BOUNDARY

38	41	0.00	121	0	0.00
38	37	5.00	121	17	46.00
38	34	50.00	121	29	35.00
38	31	55.00	121	48	3.00
38	21	31.00	121	47	7.00
38	9	9.00	121	40	6.00
37	52	36.00	121	36	0.00
37	46	0.00	121	33	11.00
37	32	0.00	121	21	0.00
37	30	0.00	121	20	0.00
37	30	0.00	119	50	0.00
38	50	0.00	119	50	0.00

Ukiah region

REGION BOUNDARY

39	0	120	0
39	0	124	30
40	0	124	30
40	0	120	0

DISTRICTS •••••

DISTRICT 1

DISTRICT BOUNDARY

38	19	0.00	123	2	21.00
38	30	41.00	123	14	55.00
38	57	0.00	123	40	0.00
38	57	0.00	123	37	0.00
39	1	0.00	123	37	0.00
39	1	0.00	123	42	0.00
39	5	0.00	123	46	0.00
38	53	0.00	123	46	0.00
38	19	0.00	123	10	0.00

DISTRICT 2

DISTRICT BOUNDARY

40	30	0.00	122	15	0.00
40	16	0.00	121	25	0.00
40	0	0.00	121	5	50.00
39	57	0.00	121	2	30.00
39	56	15.00	120	57	35.00
39	52	30.00	120	49	50.00
39	49	35.00	120	45	0.00
39	44	50.00	120	36	5.00
39	38	50.00	120	27	30.00
39	34	30.00	120	21	20.00
39	30	50.00	120	16	20.00
39	23	30.00	120	4	50.00
39	22	15.00	120	0	0.00
39	1	17.00	119	28	0.00
38	40	0.00	119	0	0.00
40	30	0.00	119	0	0.00
40	50	0.00	121	57	0.00

DISTRICT 3

DISTRICT BOUNDARY

38	19	0.00	123	2	21.00
38	30	41.00	123	14	55.00
38	57	0.00	123	40	0.00
38	57	0.00	123	37	0.00
39	1	0.00	123	37	0.00
39	1	0.00	123	42	0.00
39	5	0.00	123	46	0.00
39	20	0.00	123	55	0.00
39	40	0.00	123	50	0.00
40	15	0.00	124	25	0.00
40	23	39.00	124	30	0.00
40	23	39.00	124	22	30.00
40	1	8.00	123	42	45.00
39	54	20.00	123	38	0.00
39	49	30.00	123	37	15.00
39	41	23.00	123	32	20.00
39	32	20.00	123	30	0.00
39	25	30.00	123	22	0.00
39	21	50.00	123	22	40.00
39	10	35.00	123	13	30.00
39	8	16.00	123	12	0.00
39	4	10.00	123	9	0.00
39	0	20.00	123	6	50.00
38	56	10.00	123	3	40.00
38	50	10.00	123	0	50.00
38	45	21.00	123	0	44.00
38	39	29.00	122	52	15.00
38	35	35.00	122	49	50.00
38	26	12.00	122	42	23.00
38	20	35.00	122	35	40.00
38	18	52.70	122	47	21.00
38	20	48.00	122	55	47.60

DISTRICT 4

DISTRICT BOUNDARY

38	45	0.00	122	50	0.00
38	45	0.00	122	43	0.00
38	51	0.00	122	43	0.00
38	51	0.00	122	50	0.00

(continued)

Table C.4.--Continued

Ukiah region	Redding region

DISTRICT 5

DISTRICT BOUNDARY

38	20	35.00	122	35	40.00
38	26	12.00	122	42	23.00
38	35	35.00	122	49	50.00
38	45	0.00	122	50	0.00
38	45	0.00	122	43	0.00
38	51	0.00	122	43	0.00
38	51	0.00	122	50	0.00
38	45	0.00	122	50	0.00
38	35	35.00	122	49	50.00
38	39	29.00	122	52	15.00
38	45	21.00	123	0	44.00
38	50	10.00	123	0	50.00
38	56	10.00	123	3	40.00
39	0	20.00	123	6	50.00
39	4	10.00	123	9	0.00
39	8	16.00	123	12	0.00
39	10	35.00	123	13	30.00
39	21	50.00	123	22	40.00
39	25	30.00	123	22	0.00
39	32	20.00	123	30	0.00
39	33	10.00	123	3	15.00
39	34	0.00	122	36	30.00
39	27	20.00	122	32	45.00
39	20	20.00	122	32	30.00
39	11	29.00	122	29	49.00
38	39	16.00	122	17	59.00
38	24	17.00	122	8	7.00
38	19	0.00	122	8	10.00

DISTRICT 6

DISTRICT BOUNDARY

40	23	39.00	124	22	30.00
40	1	8.00	123	42	45.00
39	54	20.00	123	38	0.00
39	49	30.00	123	37	15.00
39	41	23.00	123	32	20.00
39	32	20.00	123	30	0.00
39	33	10.00	123	3	15.00
39	34	0.00	122	36	30.00
39	51	0.00	122	32	0.00
39	55	38.00	122	38	20.00
40	2	47.00	122	40	43.50
40	6	44.00	122	49	0.00
40	6	44.00	123	5	0.00
40	15	37.00	123	16	0.00
40	23	40.00	123	26	5.00

DISTRICT 7

DISTRICT BOUNDARY

38	19	0.00	122	8	10.00
38	24	17.00	122	8	7.00
38	39	10.00	122	17	59.00
39	11	29.00	122	29	49.00
39	20	20.00	122	32	30.00
39	27	20.00	122	32	45.00
39	34	0.00	122	36	30.00
39	51	0.00	122	32	0.00
39	55	38.00	122	38	20.00
40	2	47.00	122	40	43.50
40	6	44.00	122	49	0.00
40	6	44.00	123	5	0.00
40	15	37.00	123	16	0.00
40	23	40.00	123	26	5.00
40	40	0.00	122	39	0.00
40	30	0.00	122	15	0.00
40	5	30.00	122	1	0.00
40	0	0.00	121	55	20.00
39	22	0.00	121	27	20.00
39	0	0.00	121	15	0.00
38	30	0.00	120	56	40.00
38	19	0.00	120	45	0.00
37	50	0.00	120	45	0.00
37	50	0.00	122	8	10.00

DISTRICT 8

DISTRICT BOUNDARY

38	19	0.00	120	45	0.00
38	30	0.00	120	56	40.00
39	0	0.00	121	15	0.00
39	22	0.00	121	27	20.00
40	0	0.00	121	55	20.00
40	5	30.00	122	1	0.00
40	30	0.00	122	15	0.00
40	16	0.00	121	25	0.00
40	0	0.00	121	5	50.00
39	57	0.00	121	2	30.00
39	49	20.00	120	53	20.00
39	42	30.00	120	50	25.00
39	29	20.00	120	49	15.00
39	25	20.00	120	47	40.00
39	8	30.00	120	46	25.00
39	3	10.00	120	43	10.00
39	1	0.00	120	46	50.00
38	58	25.00	120	47	20.00
38	52	10.00	120	49	40.00
38	44	0.00	120	46	25.00
38	39	30.00	120	48	40.00
38	30	0.00	120	50	20.00

DISTRICT 9

DISTRICT BOUNDARY

38	19	0.00	120	45	0.00
38	30	0.00	120	50	20.00
38	39	30.00	120	48	40.00
38	44	0.00	120	46	25.00
38	52	10.00	120	49	40.00
38	58	25.00	120	47	20.00
39	1	0.00	120	46	50.00
39	3	10.00	120	43	10.00
39	8	30.00	120	46	25.00
39	25	20.00	120	47	40.00
39	29	20.00	120	49	15.00
39	42	30.00	120	50	25.00
39	49	20.00	120	53	20.00
39	57	0.00	121	2	30.00
39	56	15.00	120	57	35.00
39	52	30.00	120	49	50.00
39	49	35.00	120	45	0.00
39	44	50.00	120	36	5.00
39	38	50.00	120	27	30.00
39	34	30.00	120	21	20.00
39	30	50.00	120	16	20.00
39	23	30.00	120	4	50.00
39	22	15.00	120	0	0.00
39	1	17.00	119	28	0.00
38	40	0.00	119	0	0.00
38	19	0.00	119	0	0.00

REGION BOUNDARY

40	0	120	0
40	0	124	30
41	0	124	30
41	0	120	0

DISTRICTS •••••

DISTRICT 1

DISTRICT BOUNDARY

40	3	30.00	125	0	0.00
40	3	30.00	124	2	0.00
40	1	50.00	124	2	0.00
40	0	0.00	124	4	0.00
40	1	50.00	125	0	0.00

DISTRICT 2

DISTRICT BOUNDARY

40	3	30.00	125	0	0.00
40	3	30.00	124	2	0.00
40	1	50.00	124	2	0.00
40	0	0.00	124	4	0.00
40	1	50.00	125	0	0.00
39	20	0.00	124	30	0.00
39	20	0.00	122	38	20.00
39	51	0.00	122	32	0.00
39	55	38.00	122	38	20.00
40	2	47.00	122	40	43.50
40	6	44.00	122	49	0.00
40	6	44.00	123	5	0.00
40	15	37.00	123	16	0.00
40	23	40.00	123	26	5.00
40	32	17.80	123	30	50.00
40	36	52.00	123	33	36.00
40	45	33.00	123	41	0.00
40	52	30.00	123	43	55.00
41	4	14.00	123	48	14.00
41	11	11.00	123	49	58.00
41	31	28.00	123	55	0.00
41	30	0.00	124	30	0.00

DISTRICT 3

DISTRICT BOUNDARY

41	31	28.00	123	55	0.00
41	11	11.00	123	49	58.00
41	4	14.00	123	48	14.00
40	52	30.00	123	43	55.00
40	45	33.00	123	41	0.00
40	36	52.00	123	33	36.00
40	32	17.80	123	30	50.00
40	23	40.00	123	26	5.00
40	15	37.00	123	16	0.00
40	6	44.00	123	5	0.00
40	6	44.00	122	49	0.00
40	2	47.00	122	40	43.50
39	55	38.00	122	38	20.00
39	51	0.00	122	32	0.00
39	10	0.00	122	38	20.00
39	10	0.00	121	45	0.00
39	53	0.00	121	50	0.00
40	5	30.00	122	1	0.00
40	30	0.00	122	15	0.00
40	37	0.00	122	15	0.00
40	43	35.00	122	2	28.00
40	57	47.00	121	52	10.00
41	12	8.00	121	58	45.00
41	14	40.00	122	17	26.00
41	30	0.00	122	33	0.00

DISTRICT 4

DISTRICT BOUNDARY

39	20	0.00	121	45	0.00
39	53	0.00	121	50	0.00
40	5	30.00	122	1	0.00
40	30	0.00	122	15	0.00
40	37	0.00	122	15	0.00
40	43	35.00	122	2	28.00
40	57	47.00	121	52	10.00
41	12	8.00	121	58	45.00
41	14	40.00	122	17	26.00
41	35	0.00	122	33	0.00
41	35	0.00	119	40	0.00
39	20	0.00	119	40	0.00

Table C.4.--Continued

Alturas region, CA

```
REGION BOUNDARY
  41  0    120  0
  41  0    124 30
  42  0    124 30
  42  0    120  0

DISTRICTS *****

 DISTRICT  1

  DISTRICT BOUNDARY
    40 30  0.00  123 30  0.00
    40 45 33.00  123 41  0.00
    40 52 30.00  123 43 55.00
    41  4 14 00  123 48 14.00
    41 11 11.00  123 49 58.00
    41 31 28.00  123 55  0.00
    41 42 11.00  124  1  0.00
    41 50 37.00  124  5 12.00
    42 11 52.00  124  0 24.00
    42 26 30.00  124 13  0.00
    42 30  0.00  124 25  0.00
    42 30  0.00  125  0  0.00
    40 30  0.00  125  0  0.00

 DISTRICT  2

  DISTRICT BOUNDARY
    40 30  0.00  123 30  0.00
    40 45 33.00  123 41  0.00
    40 52 30.00  123 43 55.00
    41  4 14.00  123 48 14.00
    41 11 11.00  123 49 58.00
    41 31 28.00  123 55  0.00
    41 42 11.00  124  1  0.00
    41 50 37.00  124  5 12.00
    42 11 52.00  124  0 24.00
    42 26 30.00  124 13  0.00
    42 30  0.00  124 25  0.00
    42 30  0.00  125  0  0.00
    42 45  0.00  125  0  0.00
    42 45  0.00  123  0  0.00
    42 20 20.00  123  0  0.00
    42 10 53.00  122 42 30.00
    41 54 19.00  122 32  0.00
    41 42 51.00  122 31  0.00
    41 30  0.00  122 33  0.00
    41 14 40.00  122 17 26.00
    41 12  8.00  121 58 45.00
    40 57 47.00  121 52 10.00
    40 43 35.00  122  2 28.00
    40 37  0.00  122 15  0.00

    40 30  0.00  122 15  0.00

 DISTRICT  3

  DISTRICT BOUNDARY
    40 30  0.00  122 15  0.00
    40 37  0.00  122 15  0.00
    40 43 35.00  122  2 28.00
    40 57 47.00  121 52 10.00
    41 12  8.00  121 58 45.00
    41 14 40.00  122 17 26.00
    41 30  0.00  122 33  0.00
    41 42 51.00  122 31  0.00
    41 54 19.00  122 32  0.00
    42 10 53.00  122 42 30.00
    42 20 20.00  123  0  0.00
    42 45  0.00  123  0  0.00
    42 45  0.00  121 30  0.00
    42 19 35.00  121 16  3.00
    42  0 24.00  121  6 51.00
    41 41 39.00  120 54  7.00
    41 24 51.00  120 54 42.00
    41  9 25.00  120 32  4.00
    40 43 49.00  120 11 49.00
    40 30  0.00  120  5  0.00

 DISTRICT  4

  DISTRICT BOUNDARY
    42 45  0.00  121 30  0.00
    42 19 35.00  121 16  3.00
    42  0 24.00  121  6  5.09
    41 41 39.00  120 54  7.00
    41 24 51.00  120 54 42.00
    41  9 25.00  120 32  4.00
    40 43 49.00  120 11 49.00
    40 30  0.00  120  5  0.00
    40 30  0.00  119  0  0.00
    42 45  0.00  119  0  0.00
```

Fallon region, NV

```
REGION BOUNDARY
  38 45    119  0
  40  0    119  0
  40  0    117  0
  38 45    117  0

DISTRICTS *****

 DISTRICT  1

  OISTRICT BOUNDARY
    37 45  0.00  120  0  0.00
    41  0  0.00  120  0  0.00
    41  0  0.00  115 20  0.00
    37 45  0.00  115 20  0.00
```

Hilo region, HI

```
REGION BOUNDARY
  18 45    154 45
  18 45    156 15
  20 17    156 15
  20 17    154 45

DISTRICTS *****

 DISTRICT  1

  DISTRICT BOUNDARY
    19  0  0.00  155 15  0.00
    19 12 50.17  155 22  7.00
    19 15  0.00  155 22 30.00
    19 16 11.07  155 22 35.00
    19 18 25.00  155 23  0.00
    19 21 20.00  155 16 45.09
    19 22 30.00  155 12 29.49
    19 27  0.00  154 56 50.00
    19 27  0.00  154 56  0.00
    19 25 45.00  154 54  0.00
    19 15  0.00  154 45  0.00
    19 15  0.00  154  0  0.00
    19 38 45.00  154 56  0.00
    19 36  0.00  155  3 30.00
    19 31 15.00  155 18  6.00
    19 29 30.00  155 23 15.00
    19 22  6.00  155 25 30.00
    19 14 27.00  155 27 10.00
    19  8 52.00  155 28  0.00

 DISTRICT  2

  DISTRICT BOUNDARY
    19 21 13.59  155 16 45.30
    19 21 13.75  155 16 45.30
    19 21 13.75  155 16 45.07
    19 21 13.59  155 16 45.07

 DISTRICT  3

  DISTRICT BOUNDARY
    19 22 28.10  155 12 29.50
    19 22 28.30  155 12 29.50
    19 22 28.30  155 12 29.40
    19 22 28.10  155 12 29.40

 DISTRICT  4

  DISTRICT BOUNDARY
    19  0  0.00  155 15  0.00
    19 12 50.17  155 22  7.00
    19 15  0.00  155 22 30.00
    19 16 11.07  155 22 35.00
    19 18 25.00  155 23  0.00
    19 21 20.00  155 16 45 09
    19 22 30.00  155 12 29.49
    19 27  0.00  154 56 50.00
    19 27  0.00  154 56  0.00
    19 25 45.00  154 54  0.00
    19 15  0.00  154 45  0.00
    19  0  0.00  154 45  0.00

 DISTRICT  5

  DISTRICT BOUNDARY
    19 38 45.00  154 56  0.00
    19 36  0.00  155  3 30.00
    19 31 15.00  155 18  6.00
    19 29 30.00  155 23 15.00
    19 22  6.00  155 25 30.00
    19 14 27.00  155 27 10.00
    19  8 52.00  155 28  0.00
    19  0  0.00  155 15  0.00
    18  0  0.00  155 15  0.00
    18  0  0.00  156 30  0.00
    21  0  0.00  156 30  0.00
    21  0  0.00  154  0  0.00
```

APPENDIX D.--SECULAR STRAIN RATES

For a point P that is interior to the i-th district, let ω denote the rotation rate at P in the clockwise direction and let $\dot{\varepsilon}_{EE}$, $\dot{\varepsilon}_{NN}$, and $\dot{\varepsilon}_{EN}$ denote the components of the two-dimensional, second rank, strain rate tensor at P referred to a coordinate system whose positive coordinate axes are oriented in the east (E) and north (N) directions. Then using a spherical approximation of the Earth, the values of these parameters may be obtained from model parameters by the following relations:

$$\dot{\omega} = 0.5(a_{\phi\lambda}(i) \sec\tilde{\phi} - a_{\lambda\phi}(i) \cos\tilde{\phi}) \qquad (D.1)$$
$$\dot{\varepsilon}_{EE} = a_{\lambda\lambda}(i) \qquad (D.2)$$
$$\dot{\varepsilon}_{NN} = a_{\phi\phi}(i) \qquad (D.3)$$
$$\dot{\varepsilon}_{EN} = -0.5(a_{\phi\lambda}(i) \sec\tilde{\phi} + a_{\lambda\phi}(i) \cos\tilde{\phi}) \qquad (D.4)$$

where positive strain corresponds to extension. In (D.1) and (D.4), $\tilde{\phi}$ represents the latitude at P. A single set of values for $\dot{\omega}$, $\dot{\varepsilon}_{EE}$, $\dot{\varepsilon}_{NN}$, and $\dot{\varepsilon}_{EN}$ that is representative of the deformation throughout the i-th district is obtained by substituting an average value for the latitude in (D.1) and (D.4).

Auxiliary strain-rate parameters, derivable from the above tensor components, include

$$\dot{\Delta} = \dot{\varepsilon}_{EE} + \dot{\varepsilon}_{NN} \qquad (D.5)$$
$$\dot{\gamma}_1 = \dot{\varepsilon}_{EE} - \dot{\varepsilon}_{NN} \qquad (D.6)$$
$$\dot{\gamma}_2 = 2\dot{\varepsilon}_{EN} \quad . \qquad (D.7)$$

The parameter $\dot{\Delta}$, called the dilatation rate, measures the areal expansion rate of a district. The quantities $\dot{\gamma}_1$ and $\dot{\gamma}_2$ denote (right-lateral) shear-strain rates in specific directions. Shear strain for a given direction measures the change in magnitude of a right angle, the angle being considered in the clockwise sense, whose initial side coincides with this direction. The formula

$$\dot{\gamma}_\alpha = -(\dot{\gamma}_1 \sin 2\alpha + \dot{\gamma}_2 \cos 2\alpha) \qquad (D.8)$$

gives the shear strain rate for the direction α as measured clockwise from north. Consequently, $\dot{\gamma}_1$ corresponds to the shear strain rate for the northwest or southeast direction, $\dot{\gamma}_2$ the rate for the east or west direction. The direction of maximum shear strain rate, denoted ψ and measured clockwise from north, is given by the relation

$$\tan 2\psi = \dot{\gamma}_1/\dot{\gamma}_2 \ . \qquad (D.9)$$

The quantity

$$\dot{\gamma} = (\dot{\gamma}_1^{\,2} + \dot{\gamma}_2^{\,2})^{1/2} \qquad (D.10)$$

represents the magnitude of shear strain rate for the direction ψ. The auxiliary parameters $\dot{\Delta}$, $\dot{\gamma}$, and ψ present the same information as that contained in the strain rate tensor. Numerical estimates for these quantities are thus tabulated in table D.1 along with estimates for the rotation rate ω. Numbers in parentheses denote formal standard errors.

Table D.1.--Secular strain-rate estimates

District	Rotation rate $\dot{\omega}$, μrad/yr	Dilatation rate $\dot{\Delta}$, μ strain/yr	Max. shear rate $\dot{\gamma}$, μrad/yr	Direction of max. dextral shear, deg.
SAN DIEGO REGION				
I	0.064 (0.124)	-0.070 (0.036)	0.196 (0.035)	N 26 W (5)
II	0.201 (0.128)	0.393 (0.083)	0.966 (0.070)	N 59 W (2)
III	0.145 (0.127)	-0.031 (0.083)	0.455 (0.067)	N 45 W (5)
IV	0.117 (0.134)	-0.997 (0.151)	1.450 (0.113)	N 23 W (3)
V	0.099 (0.125)	-0.021 (0.045)	0.374 (0.042)	N 63 W (3)
VI*				
VII	0.106 (0.125)	-0.111 (0.045)	0.357 (0.053)	N 51 W (4)
VIII*				
IX	0.020 (0.126)	-0.140 (0.043)	0.190 (0.047)	N 59 W (8)
X	-0.046 (0.122)	-0.242 (0.038)	0.059 (0.027)	N 24 W (14)
SAN BERNARDINO REGION				
I*				
II	0.114 (0.066)	-0.174 (0.035)	0.164 (0.031)	N 48 W (5)
III	0.146 (0.069)	-0.111 (0.044)	0.276 (0.051)	N 57 W (5)
IV	0.220 (0.086)	-0.042 (0.122)	0.289 (0.113)	N 53 W (11)
V	0.179 (0.072)	-0.087 (0.044)	0.324 (0.051)	N 42 W (5)
VI	0.174 (0.072)	-0.171 (0.063)	0.100 (0.051)	N 51 W (16)
VII	0.107 (0.071)	-0.089 (0.056)	0.123 (0.050)	N 47 W (12)
VIII	-0.044 (0.075)	-0.089 (0.081)	0.033 (0.057)	N 44 E (51)
IX*				
X*				
XI	-0.088 (0.081)	-0.079 (0.102)	0.172 (0.045)	N 39 E (8)
BARSTOW REGION				
I	0.203 (0.125)	-0.067 (0.036)	0.386 (0.031)	N 63 W (3)
II	0.120 (0.124)	-0.117 (0.029)	0.215 (0.027)	N 54 W (4)
III	0.078 (0.124)	-0.191 (0.071)	0.248 (0.046)	N 62 W (5)
IV	1.360 (0.222)	1.130 (0.601)	2.960 (0.380)	N 74 E (5)
V	0.032 (0.123)	-0.210 (0.074)	0.122 (0.060)	N 36 W (15)
VI	0.026 (0.123)	0.423 (0.054)	0.128 (0.044)	N 75 W (8)
VII	0.006 (0.134)	-0.378 (0.124)	0.037 (0.044)	N 67 W (34)
VIII	0.062 (0.126)	-0.108 (0.059)	0.351 (0.050)	N 59 W (4)
IX	0.091 (0.137)	-0.431 (0.070)	0.434 (0.060)	N 31 W (4)
CHANNEL ISLANDS REGION				
I	0.167 (0.211)	0.514 (0.816)	0.269 (0.114)	N 41 W (12)
II	0.336 (0.146)	-0.039 (1.990)	0.423 (0.075)	N 37 W (5)
III*				
IV	-0.353 (0.225)	0.315 (0.797)	0.690 (0.136)	N 33 W (7)
V	0.111 (0.109)	-0.380 (0.240)	0.191 (0.105)	N 15 W (18)
VI	0.410 (0.130)	0.022 (0.463)	1.110 (0.141)	N 82 E (4)
VII	-0.223 (0.101)	-0.295 (0.241)	0.082 (0.039)	N 43 W (13)
VIII	0.136 (0.118)	-0.171 (0.346)	0.604 (0.244)	N 51 W (13)
IX	-0.033 (0.051)	-0.233 (0.043)	0.107 (0.026)	N 26 W (7)

* District contains an insufficient number of geodetic stations to compute parameters.

Table D.1.--Continued

LOS ANGELES REGION				
I	0.114 (0.057)	-0.023 (0.040)	0.122 (0.019)	N 42 W (5)
II	0.115 (0.219)	0.390 (0.915)	0.363 (0.592)	N 19 W (18)
III	0.088 (0.058)	-0.041 (0.045)	0.152 (0.034)	N 58 W (7)
IV	0.009 (0.062)	-0.439 (0.051)	0.239 (0.037)	N 23 W (4)
V	0.122 (0.060)	-0.087 (0.041)	0.303 (0.033)	N 64 W (4)
VI	0.005 (0.089)	-0.499 (0.122)	0.582 (0.121)	N 43 W (8)
VII	0.074 (0.111)	-0.319 (0.186)	0.151 (0.172)	N 24 W (39)
VIII	0.000 (0.064)	-0.033 (0.053)	0.076 (0.053)	N 80 W (19)
BAKERSFIELD REGION				
I	0.233 (0.050)	-0.070 (0.050)	0.181 (0.027)	N 56 W (5)
II	0.302 (0.054)	-0.115 (0.057)	0.236 (0.038)	N 48 W (5)
III	0.277 (0.054)	-0.301 (0.047)	0.341 (0.034)	N 58 W (3)
IV	0.320 (0.060)	-0.254 (0.047)	0.334 (0.038)	N 63 W (3)
V	0.180 (0.058)	-0.314 (0.041)	0.462 (0.035)	N 51 W (2)
VI	0.196 (0.058)	-0.105 (0.053)	0.382 (0.038)	N 61 W (3)
VII	0.231 (0.056)	-0.235 (0.036)	0.329 (0.038)	N 48 W (3)
SIERRA NEVADA REGION				
I	0.382 (0.121)	-0.520 (0.283)	0.672 (0.216)	N 74 W (8)
II	0.136 (0.104)	-0.142 (0.117)	0.095 (0.069)	N 14 W (23)
III	0.187 (0.099)	-0.094 (0.081)	0.105 (0.057)	N 30 W (15)
IV	-0.109 (0.138)	0.039 (0.397)	0.890 (0.262)	N 76 W (6)
V	0.137 (0.100)	-0.042 (0.109)	0.332 (0.094)	N 51 W (8)
VI	0.076 (0.092)	-0.144 (0.086)	0.129 (0.072)	N 21 W (18)
VII	0.122 (0.092)	-0.222 (0.057)	0.180 (0.039)	N 32 W (6)
PARKFIELD REGION				
I	0.086 (0.132)	-0.204 (0.116)	0.150 (0.086)	N 22 W (14)
II	0.156 (0.122)	-0.126 (0.052)	0.106 (0.025)	N 31 W (7)
III	0.325 (0.125)	-0.170 (0.068)	0.331 (0.044)	N 48 W (4)
IV	0.217 (0.131)	-0.365 (0.122)	0.681 (0.114)	N 67 W (5)
V*				
VI	0.052 (0.135)	0.018 (0.133)	0.094 (0.130)	N 88 E (36)
VII	0.168 (0.131)	-0.330 (0.123)	0.069 (0.071)	N 36 W (25)
MONTEREY REGION				
I	0.246 (0.109)	-0.213 (0.032)	0.153 (0.026)	N 40 W (6)
II	0.532 (0.114)	-0.159 (0.067)	0.829 (0.070)	N 30 W (3)
III	0.312 (0.120)	-0.073 (0.098)	0.518 (0.101)	N 29 W (6)
IV	0.321 (0.111)	-0.146 (0.044)	0.283 (0.054)	N 33 W (5)
V	0.050 (0.198)	-2.650 (0.287)	1.090 (0.300)	N 31 E (9)
VI	0.242 (0.120)	-0.108 (0.129)	0.104 (0.053)	N 16 W (16)
YOSEMITE REGION				
I	-0.021 (0.160)	-0.070 (0.136)	0.094 (0.169)	N 31 W (60)
II	0.206 (0.116)	0.207 (0.081)	0.948 (0.074)	N 38 W (3)
III	0.068 (0.122)	-0.048 (0.106)	0.359 (0.095)	N 53 W (10)
IV*				
V	0.191 (0.108)	-0.031 (0.094)	0.222 (0.069)	N 12 E (9)
VI	0.128 (0.106)	-0.208 (0.033)	0.197 (0.039)	N 27 W (5)
VII	0.044 (0.110)	-0.043 (0.046)	0.045 (0.044)	N 37 W (29)
VIII*				
IX	0.099 (0.120)	-0.244 (0.080)	0.090 (0.066)	N 25 E (23)

* District contains an insufficient number of geodetic stations to compute parameters.

Table D.1.--Continued

SAN FRANCISCO REGION				
I	-0.024 (0.077)	-0.170 (0.055)	0.200 (0.047)	N 59 W (9)
II	0.067 (0.075)	-0.160 (0.048)	0.321 (0.044)	N 38 W (4)
III	0.102 (0.084)	-0.371 (0.078)	0.652 (0.047)	N 35 W (2)
IV	-0.087 (0.084)	-0.231 (0.067)	0.020 (0.081)	N 76 E (100)
V	0.061 (0.084)	-0.088 (0.089)	0.271 (0.088)	N 35 W (10)
VI	0.038 (0.078)	0.045 (0.064)	0.238 (0.055)	N 53 W (7)
VII	0.155 (0.092)	0.288 (0.155)	0.509 (0.071)	N 41 W (4)
VIII*				
IX	-0.048 (0.110)	-0.426 (0.141)	0.321 (0.141)	N 11 E (14)
SACRAMENTO REGION				
I	0.606 (0.519)	-0.077 (0.128)	0.089 (0.054)	N 58 E (16)
II	0.619 (0.513)	0.107 (0.159)	0.218 (0.050)	N 40 W (8)
III	0.740 (0.526)	-0.085 (0.051)	0.125 (0.062)	N 02 W (16)
SANTA ROSA REGION				
I	0.356 (0.116)	-0.079 (0.094)	0.591 (0.063)	N 42 W (4)
II	0.379 (0.112)	-0.234 (0.063)	0.514 (0.034)	N 32 W (2)
III	0.377 (0.116)	0.027 (0.106)	0.676 (0.085)	N 52 W (4)
IV	0.334 (0.126)	-0.535 (0.185)	0.360 (0.150)	N 03 E (11)
V	0.333 (0.113)	-0.218 (0.046)	0.215 (0.036)	N 33 W (5)
VI	0.249 (0.118)	-0.262 (0.097)	0.287 (0.079)	N 35 W (7)
VII	0.340 (0.124)	-0.277 (0.115)	0.078 (0.068)	N 29 W (23)
VIII	-0.385 (0.306)	7.090 (0.407)	1.890 (0.440)	N 22 E (9)
IX	0.288 (0.126)	-0.301 (0.163)	0.268 (0.118)	N 30 W (14)
UKIAH REGION				
I	1.260 (0.758)	0.711 (0.881)	1.290 (0.118)	N 32 W (3)
II	0.151 (0.126)	-0.015 (0.179)	0.101 (0.103)	N 76 E (36)
III	0.556 (0.186)	-0.969 (0.402)	0.887 (0.270)	N 01 E (9)
IV	-0.385 (0.306)	7.090 (0.407)	1.890 (0.440)	N 22 E (9)
V	0.254 (0.112)	-0.202 (0.056)	0.396 (0.076)	N 27 W (5)
VI	0.303 (0.187)	0.429 (0.363)	0.214 (0.093)	N 58 W (13)
VII	0.158 (0.102)	0.053 (0.103)	0.068 (0.034)	N 12 W (15)
VIII	0.151 (0.104)	0.082 (0.123)	0.099 (0.065)	N 58 E (19)
IX	0.210 (0.133)	0.121 (0.202)	0.063 (0.137)	N 11 E (66)
REDDING REGION				
I	0.204 (0.313)	-0.494 (0.760)	1.250 (0.134)	N 10 W (3)
II	-0.157 (0.302)	0.575 (0.288)	0.136 (0.092)	N 24 W (20)
III	-0.164 (0.306)	0.487 (0.230)	0.070 (0.045)	N 58 W (18)
IV	-0.121 (0.308)	0.382 (0.230)	0.029 (0.049)	N 52 E (51)
ALTURAS REGION				
I	0.002 (0.073)	0.084 (0.135)	0.043 (0.140)	N 21 E (104)
II	-0.014 (0.039)	0.058 (0.078)	0.058 (0.068)	N 88 E (30)
III	0.011 (0.039)	-0.079 (0.079)	0.038 (0.059)	N 56 W (40)
IV	0.001 (0.077)	-0.063 (0.135)	0.027 (0.074)	N 20 E (96)
FALLON REGION (NEVADA)				
I	0.105 (0.270)	-0.300 (0.221)	0.117 (0.054)	N 31 W (14)
HILO REGION (HAWAII)				
I	-0.10 (1.97)	1.56 (0.29)	0.98 (0.23)	N 07 W (7)
II*				
III*				
IV	1.82 (2.01)	0.60 (0.71)	0.61 (0.84)	N 13 W (34)
V	0.22 (2.00)	0.44 (0.31)	0.12 (0.15)	N 36 E (36)

* District contains an insufficient number of geodetic stations to compute parameters.

APPENDIX E.--ANCHORAGE REGION

The crustal motion model for Alaska's Anchorage region differs in form from models for the other 18 REDEAM regions. The Anchorage model was developed to characterize horizontal displacements associated with the 1964 Prince William Sound earthquake (M=8.4). At some locations, these displacements exceed 10 m in magnitude (fig. E.1).

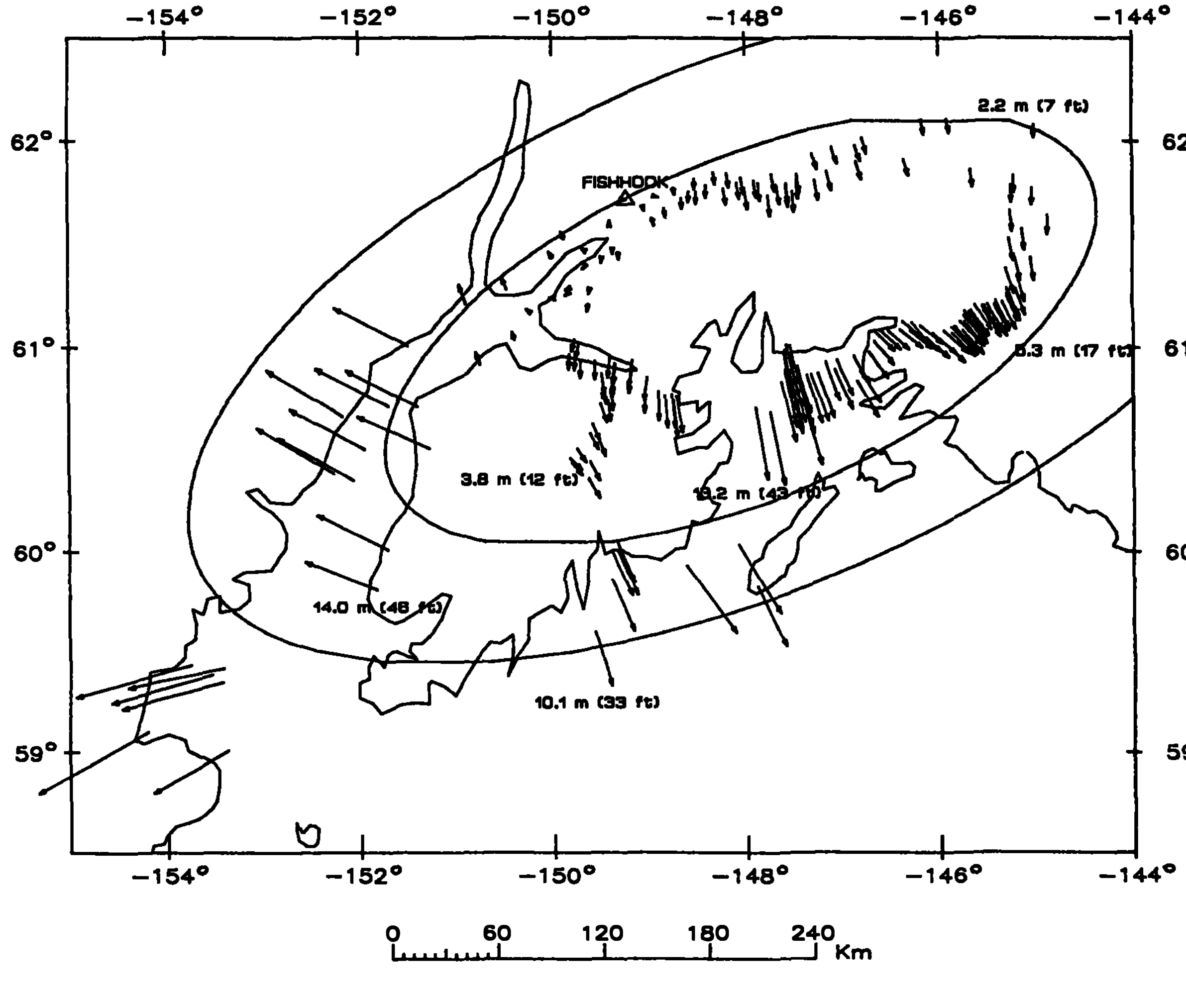

Figure E.1.--Displacement vectors for 1964 Prince William Sound earthquake as derived by differencing pre- and post-earthquake positions. Vectors are relative to the assumption of no motion at station FISHHOOK. Vectors west of the 151°W meridian are highly suspect because of poor network geometry. Displacement magnitudes are given for selected stations. These vectors were used to estimate polynomial coefficients for our model. Ellipses delineate the area where the polynomials are scaled from their full value to zero as described in the text.

The dislocation formulation that was used to model earthquakes in California and Nevada proved relatively unsatisfactory for the Prince William Sound earthquake. Our colleague, Steven Musman, found that the associated coseismic displacements were better represented by second order polynomials in two variables. With the polynomial model, the eastward displacement d_x and the northward displacement d_y at a point is expressed as

$$d_x = a_o + a_1 x + a_2 y + a_3 x^2 + a_4 xy + a_5 y^2$$

$$d_y = b_o + b_1 x + b_2 y + b_3 x^2 + b_4 xy + b_5 y^2 \qquad \text{(E.1)}$$

where x and y denote coordinates of the point east and north of some reference origin, and a_i and b_i (for i = 0,1,2,...,5) are parameters to be estimated from the data. Indeed, when observations (directions, distances, and azimuths) in the vicinity of the earthquake were updated to a common time (see chapter 5) using the best polynomial model, a network adjustment of these updated observations yielded a variance of unit weight that is five times better than the variance of unit weight for a network adjustment of the same observations when updated by our best dislocation model.

Coefficients for the polynomial model were estimated using the positional coordinates and displacements for 198 geodetic stations (table E.1). These displacements were computed by differencing two sets of horizontal positions. The first set was obtained by a free adjustment of pertinent pre-earthquake horizontal data, and the second set by a free adjustment of pertinent postearthquake horizontal data. For a yet to be explained reason, these displacement vectors differ from those published by Parkin (1969) as presented in fig. E.2.

The following FORTRAN routine documents the derived polynomial coeeficients. This routine may be used to calculate modeled displacements for the 1964 Alaska earthquake. The definition of two concentric ellipses (fig. E.1) is embedded within this routine. Inside the inner ellipse modeled displacements are as given by the polynomial expressions. For modeled displacements between the two ellipses, values from the polynomial expressions are multiplied by a function that decreases monotonically from 1 to 0 along any line segment starting at the perimeter of the inner ellipse and ending on the perimeter of the outer ellipse. Outside the outer ellipse, modeled displacements are defined as zero.

Table E.1.--Coseismic displacements for Prince William Sound earthquake

Station	Latitude deg	Latitude min	Longitude deg	Longitude min	Displacement East, m	Displacement North, m
ANCHOR POINT 1908	59	48.8	151	49.7	-13.05	4.94
ANCHOR 1947	60	53.1	147	15.1	2.95	-7.74
AUDRY 1961	60	30.8	151	16.6	-13.23	5.74
AXIS USE 1942	60	27.1	149	36.6	1.78	-3.30
BAHIA 1947	60	55.0	147	27.8	2.42	-8.06
BAKER 1905	59	51.7	149	23.3	3.98	-9.06
BEAR USE 1942	60	52.9	149	29.7	.56	-3.63
BELUGA 1909	61	12.7	150	53.5	-1.27	3.19
BENCH 1941	61	5.3	145	45.3	3.92	-4.26
BERNARD 1941	61	34.3	145	8.4	.42	-3.74
BIRCH HILL 1942	60	55.3	150	45.0	-.86	2.07
BIRCH 1947	60	59.5	147	36.0	1.53	-7.41
BIRD POINT 1912	60	55.6	149	21.7	-.32	-3.30
BLUFF 1905	60	.5	149	20.0	3.61	-7.92
BONE USE 1942	60	22.1	149	37.9	1.94	-3.38
BOU 1944	61	50.8	147	43.5	.58	-2.93
BOULDER 1914	60	46.4	148	50.3	.49	-5.57
BRUIN 1941	61	10.8	145	43.8	3.42	-4.30
BUNCH 1901	61	4.9	146	39.9	3.56	-3.37
BURR 1913	59	25.1	153	25.2	-17.46	-3.53
BUSBY 1942	60	53.8	146	48.9	3.67	-5.51
BUTTE 1908	60	40.4	152	10.6	-13.83	7.85
CAA 1944	61	47.3	147	40.3	.56	-3.37
CALL 1947	60	52.8	147	19.4	3.20	-8.17
CAPE 1912	60	58.1	149	46.0	-.17	-2.46
CASCADE 1944	61	49.8	148	2.6	.55	-2.83
CASTLE 1944	61	49.3	148	31.5	-.05	-1.70
CENTRAL 1912	60	51.9	149	1.4	-.52	-4.25
CHISWELL 1905	59	36.1	149	33.9	2.85	-9.72
CHUGACH 1941	61	13.7	145	24.8	2.62	-4.81
CLEO USE 1942	60	48.1	149	2.6	-.18	-3.94
COOPER USE 1942	60	28.0	149	49.0	2.09	-1.97
COST 1961	60	43.3	151	42.2	-13.35	6.46
CRAG USE 1944	61	40.3	148	50.3	.31	-1.60
CROMBIE 1941	61	4.4	146	12.9	4.23	-3.17
CUB USE 1942	60	51.0	149	29.1	.31	-3.37
DARK 1912	61	2.4	149	46.7	-.50	-1.99
DIVIDE 1941	61	7.8	145	46.4	3.78	-4.17
DIVIDE 1947	60	52.6	147	22.0	2.75	-8.40
DORF 1961	61	15.7	149	49.7	-.59	-.40
DROP 1941	61	10.9	145	39.8	3.26	-4.43
EKLUTNA 1922	61	27.5	149	19.0	.10	-1.20
ELBOW 1941	61	12.5	145	25.7	2.70	-4.58
ELF 1947	60	56.6	147	3.3	2.91	-5.96
ERMI USE 1942	60	49.8	149	28.9	.48	-3.38
ERNESTINE 1941	61	26.0	145	3.1	.63	-3.98
EVANS 1905	60	2.2	148	4.7	7.66	-12.19
EVEN 1947	60	58.7	147	33.1	1.79	-7.45
FAIR 1947	60	52.6	147	27.6	2.66	-8.92
FALL 1941	61	20.5	145	11.2	1.34	-4.29
FALLS USE 1942	60	52.9	149	22.3	-.05	-3.47
FINSKI 1947	60	54.0	147	4.5	3.17	-6.73
FIRE 1944	61	58.9	146	51.4	.90	-2.63

Table E.1.--Coseismic displacements for Prince William Sound earthquake (cont'd)

Station	Latitude		Longitude		Displacement	
	deg	min	deg	min	East, m	North, m
FISHOOK 1944	61	43.0	149	14.0	0.00	0.00
FISHLAKE 1922	61	31.5	149	52.8	-.63	1.13
FLIENT 1947	60	56.1	147	10.3	2.57	-6.54
FLOW 1901	60	57.7	146	52.8	2.99	-4.50
FOOT 1941	61	10.9	145	32.3	3.14	-4.59
FORKS 1941	61	15.4	145	16.1	2.04	-4.49
FOSSIL 1944	61	16.8	149	36.6	-.29	-.81
GILPATRICK USE 1942	60	35.2	149	36.8	1.54	-2.70
GLACIER 1944	61	44.6	147	45.7	.48	-3.80
GLEN EAST BASE 1944	61	49.0	147	28.0	.38	-3.42
GLOBE B I E USE 1961	61	17.0	149	49.4	-.60	-.30
GOOSE GFLAT 1909	61	.6	151	30.0	-13.36	6.36
GRANT 1947	60	54.1	147	33.0	2.28	-8.90
GULL ROCK 2 USE 1942	60	58.2	149	49.8	-.13	-2.38
HARRIET 1908	60	23.5	152	16.1	-14.17	7.94
HELD 1901	61	7.7	146	22.7	3.88	-2.87
HELEN 1961	60	43.2	151	24.3	-13.03	6.27
HICKS 1944	61	48.9	147	54.6	.51	-3.00
HOG BACK 1941	61	2.4	145	58.9	4.46	-3.62
HOPE USE 1942	60	56.3	149	42.8	-.02	-2.66
HORN 1944	62	1.0	146	47.1	.80	-2.57
HUDSON 1941	61	52.1	145	40.3	.42	-3.00
INDIA 1947	60	52.6	147	33.1	2.39	-9.52
INLET 1947	60	56.8	147	32.2	2.05	-7.99
ISLE 1912	61	1.0	149	44.1	-.50	-2.28
JACK 1901	61	1.9	146	40.3	3.62	-3.79
JETTY 1947	61	.9	147	32.9	1.81	-6.42
JOHN USE 1942	60	34.2	149	31.6	1.30	-3.30
JONAH 1947	61	1.1	147	35.0	1.83	-6.92
KALGIN 1944	60	21.5	152	4.0	-13.81	7.43
KAMISHAK 1946	59	20.8	153	26.0	-18.31	-4.74
KENNY 1941	61	46.6	145	2.1	0.00	-3.12
KEY 1941	61	4.3	145	51.7	4.26	-3.90
KING 1944	61	45.6	148	30.5	.06	-2.28
KINIK 1947	60	50.3	147	37.6	2.62	-10.42
KLAWASI 1941	62	4.9	145	.4	-.09	-2.20
KNIFE 1941	61	6.5	146	11.9	4.12	-3.02
KNOB 1928	59	56.0	148	37.1	9.12	-11.97
KNOWLES 1941	61	15.3	145	18.0	2.12	-4.49
LAZY USE 1944	61	37.4	148	57.9	.39	-1.24
LEAN USE 1942	60	30.8	149	44.8	1.65	-2.21
LEILA 1944	61	48.8	147	16.7	.78	-3.53
LINA 1944	61	54.2	146	51.1	1.04	-2.98
LITTLE TONSINA 1941	61	31.6	145	16.8	.90	-3.88
LONG 1944	61	25.9	149	59.8	-.76	.93
LOON 1944	61	47.5	148	24.4	-.02	-2.22
LOWE 1941	61	3.1	146	8.1	4.28	-3.31
MAC 1941 RM 3	61	14.3	149	59.1	-.73	-.01
MAT 1944	61	46.5	148	13.3	.51	-2.92
MC NEIL 1946	59	6.1	154	12.0	-20.02	-11.13
MIDDLE 2 1927	60	3.4	149	20.5	3.25	-7.38
MISERY 3 1944	61	16.6	150	28.2	-.99	2.04

Table E.1.--Coseismic displacements for Prince William Sound earthquake (cont'd)

Station	Latitude deg	Latitude min	Longitude deg	Longitude min	Displacement East, m	Displacement North, m
MOOSE USE 1942	60	45.0	149	25.7	.53	-3.49
MOOSE 1944	61	40.6	149	3.2	.26	-.62
NEL 1944	61	51.4	147	9.3	.90	-3.27
NELSON USE 1942	60	48.3	149	23.8	.39	-3.65
NINILCHIK 19082	60	.6	151	42.8	-13.02	6.13
NORTH KALGIN 1908	60	30.5	151	56.7	-13.82	7.12
NUSKA 1944	61	45.6	147	30.5	.37	-3.76
O BRIEN 1944	61	45.8	148	0.0	.54	-3.32
ODESSEY 1941	61	8.5	145	41.7	3.53	-4.37
OLSEN 1947	60	51.8	147	33.1	2.52	-9.77
PARK 1944	61	45.6	148	34.9	-.12	-1.98
PELLEW 1947	61	5.1	146	36.4	3.73	-3.24
PERRY 1912	60	43.1	147	53.9	2.37	-12.60
PETERS EAST BASE 1922	61	28.2	149	22.5	.04	-.72
PETERS WEST BASE 1922	61	25.7	149	29.3	-.12	-.72
POINT 1912	60	57.1	149	24.6	-.46	-3.17
POSSESSION 1909	61	2.3	150	23.7	-.55	1.29
POWER 1941	61	5.1	146	18.2	4.06	-3.05
PTARMIGAN 1941	61	12.5	145	37.6	3.08	-4.32
PUDD 1944	61	51.2	148	19.7	.36	-2.00
PURIN 1944	61	48.3	148	5.2	.51	-2.84
QUOTE 1947	60	50.9	147	27.0	2.85	-9.43
RACE POINT 1909	61	10.1	150	13.4	-.88	.58
RAM USE 1944	61	43.5	148	39.4	.14	-1.96
RED 1944	61	48.2	147	51.9	.43	-3.21
REEF 1942	60	50.7	146	50.6	3.81	-6.21
RICE 1941	61	22.8	145	18.4	1.52	-4.25
RIGID 1947	60	58.8	147	36.5	1.62	-7.65
RIM 1941	61	12.7	145	29.7	2.86	-4.51
ROCK SPUR 1941	61	9.5	145	44.3	3.55	-4.31
ROSE 1914	61	28.4	149	40.8	-.35	.21
RUSH 1944	61	50.9	148	11.4	.48	-2.40
SALMON 1914	60	47.6	148	54.2	-.04	-4.96
SAW 1901	61	5.4	146	24.5	4.17	-3.05
SCARP 1950	61	38.2	144	52.4	-.16	-3.23
SECOND 1912	60	55.6	149	21.2	-.37	-3.29
SHAKESPEARE 1914	60	45.0	148	45.1	.87	-6.46
SHAW 1946	59	.5	153	22.4	-13.63	-7.70
SHEEP ASTRO AZ MK 1943	61	47.1	147	34.5	.46	-3.60
SHEEP ASTRO 1943	61	48.0	147	34.4	.46	-3.48
SHEPARD 1941	62	6.7	145	54.4	.54	-2.36
SHIP 1944	61	12.5	149	37.6	-.14	-1.15
SIDE 1901	60	58.9	146	43.6	3.50	-4.26
SIGHT 1944	61	50.6	147	27.9	.51	-3.19
SIWASH 1947	60	56.6	147	35.0	1.89	-8.28
SLIDE 1914	60	46.1	148	43.0	1.11	-6.28
SNOW 1941	61	4.9	145	56.6	4.32	-3.64
SPONGE 1941	61	4.4	146	4.1	4.32	-3.37
SQUARE 1941	61	11.3	145	28.5	3.25	-4.71
SQUAW 1944	61	56.4	147	18.2	.84	-2.60

Table E.1.--Coseismic displacements for Prince William Sound earthquake (cont'd)

Station	Latitude deg	Latitude min	Longitude deg	Longitude min	Displacement East, m	Displacement North, m
STAIR 1905	59	49.9	147	53.1	5.20	-10.76
STEP 1913	59	26.1	153	45.7	-20.97	-5.85
STETSON USE 1942	60	26.8	149	47.9	1.96	-2.16
STONE 1941	61	5.0	145	49.3	4.10	-4.06
STOREY 1947	60	44.6	147	24.1	3.47	-11.05
STUART NORTH BASE 1941	61	16.4	145	16.7	1.99	-4.37
STUART 1941	61	16.8	145	12.1	1.74	-4.33
STUCK 1941	61	47.5	145	15.2	.12	-3.20
SUGAR 1941	61	5.0	146	17.0	4.07	-2.92
SUMMIT USE 1942	60	38.2	149	35.3	1.30	-2.89
SUMMIT 1941	61	26.0	145	12.7	1.03	-3.98
TAHNETA 1944	61	58.3	147	6.0	.94	-2.66
TAZ 1944	61	55.0	146	21.7	.96	-2.75
THOMPSON PASS 1941	61	7.7	145	43.8	3.69	-4.27
TIEKEL 1941	61	17.0	145	18.0	1.95	-4.39
TOLSONA 1944	62	6.3	146	10.3	.56	-2.50
TONSINA 1941	61	39.7	145	15.7	.30	-3.63
TRIB USE 1942	60	44.1	149	30.5	1.20	-3.15
TRIPLE 1912	60	53.4	149	11.2	-.48	-3.76
TSINA EAST BASE 1941	61	12.2	145	31.6	2.99	-4.49
TSINA WEST BASE 1941	61	12.1	145	33.0	3.03	-4.46
TSINA 1941	61	13.2	145	20.4	2.41	-4.64
TURN 1905	59	59.7	149	23.1	3.51	-7.51
UNAK 1947	60	53.6	147	31.0	2.44	-8.81
VALDEZ NORTH BASE 1901	61	7.4	146	16.8	3.25	-3.70
VISIT 1947	61	5.0	146	31.7	3.83	-3.12
VISTA 1914	60	46.7	148	45.9	.64	-5.79
WALKER USE 1942	60	51.5	149	23.2	.14	-3.38
WASILLA 1922	61	36.6	149	24.5	.05	.05
WAVER 1947	60	41.9	147	44.9	2.83	-12.92
WEST AUGUSTINE 1913	59	23.1	153	32.5	-18.34	-5.08
WHITNEY 1922	61	23.3	149	40.0	-.31	-.32
WILLOW CRK S BASE 1941	61	50.3	145	13.5	.12	-3.08
WINDY 1912	60	56.2	149	33.8	-.08	-2.93
WISH USE 1944	61	44.2	148	57.0	.97	-.26
WOOD USE 1941	60	56.4	149	10.6	-.79	-4.59
WORTHINGTON NE BASE 1941	61	10.6	145	41.2	3.39	-4.38
WORTHINGTON SW BASE 1941	61	9.8	145	42.4	3.44	-4.35
WORTMAN NE BASE 1941	61	6.4	145	50.0	4.05	-4.03
WORTMAN SW BASE 1941	61	6.0	145	51.9	4.08	-3.94
YEAST 1947	60	53.1	147	35.3	2.18	-9.51
YOUNG 1944	61	46.7	148	44.5	.22	-1.23
ZINC 1947	60	54.1	147	35.6	2.07	-9.16

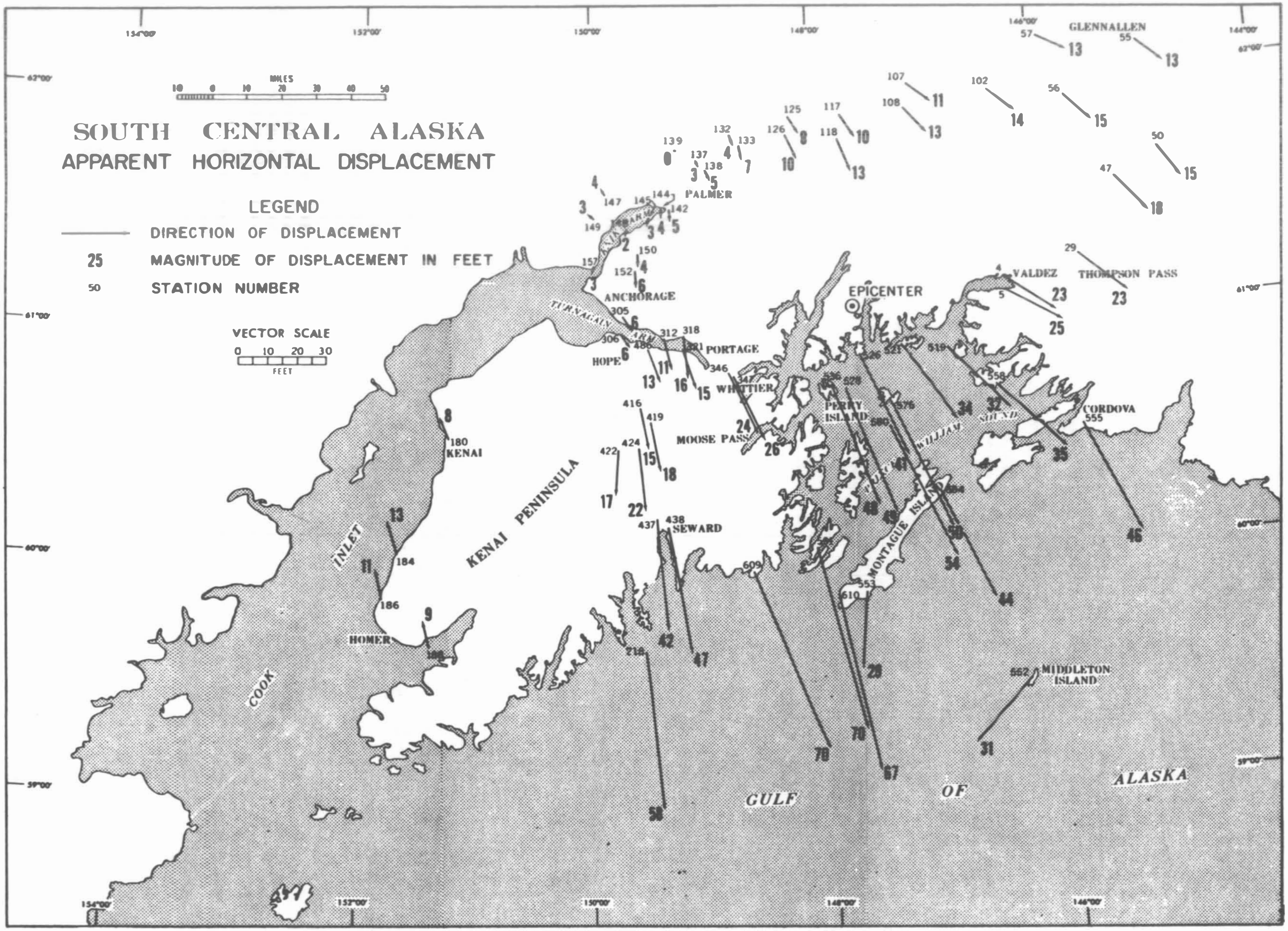

Figure E.2.--Displacement vectors for 1964 Prince William Sound earthquake as published by Parkin (1969).

```
      SUBROUTINE INTER(XLA,XLO,DX,DY)
C
C     This subroutine interpolates to find the displacement at
C     an arbitrary position for the 1964 Alaska earthquake.
C     INPUT:
C       XLA is the (north) latitude of the position in degrees.
C       XLO is the (west) longitude of the position in degrees.
C     OUTPUT:
C       DX is the eastward displacement in meters at the position.
C       DY is the northward displacement in meters at the position.
C     R quantifies the distance of the position from the centroid
C       of the observations.  In the region where R has a value
C       between 1.8 and 2.8, interpolation is somewhat suspect, and
C       all displacements in this region are reduced.  All displacements
C       in the region where R is greater than 2.8 are set to zero.
C
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      DIMENSION CX(5), CY(5)
      PI = 3.14159265D0
      HALFPI = PI/2.D0
      XBAR = 58.5D0
      YBAR = 64.9D0
      XX = 3772.D0
      XY = 1202.D0
      YY = 1240.D0
      DELTA = XX*YY - XY*XY
      DX0 = 0.25D0
      DY0 = -3.60D0
      CX(1) = +.5153D-01
      CY(1) = -.4312D-01
      CX(2) = -.4471D-01
      CY(2) = +.6828D-01
      CX(3) = -.4415D-03
      CY(3) = +.6686D-03
      CX(4) = -.6772D-03
      CY(4) = -.6842D-03
      CX(5) = +.6147D-03
      CY(5) = -.3730D-03
      X = DCOS(60.D0*PI/180.D0)*60.D0*(150.D0 - XLO)
      X = X -XBAR
      Y = 60.D0*(XLA - 60.D0)
      Y = Y - YBAR
      R = X*X*YY -2.D0*X*Y*XY + Y*Y*XX
      R = R/DELTA
      R = DSQRT(R)
      F = X*X - XX
      G = X*Y - XY
      H = Y*Y - YY
      DX = DX0 + CX(1)*X + CX(2)*Y + CX(3)*F + CX(4)*G + CX(5)*H
      DY = DY0 + CY(1)*X + CY(2)*Y + CY(3)*F + CY(4)*G + CY(5)*H
      IF(R.GE.1.8D0 .AND. R.LT.2.8D0)THEN
           FACR = (DSIN((2.8D0 - R)*HALFPI))**2
           DX = FACR*DX
           DY = FACR*DY
      ELSEIF (R.GE.2.8D0) THEN
           DX = 0.D0
           DY = 0.D0
      ENDIF
      RETURN
      END
```

APPENDIX F.--HILO REGION

The Hilo region covers the Island of Hawaii (fig. F.1). This island is often referred to as the "Big Island" to distinguish it from the entire group of islands which is also known as Hawaii. The REDEAM model for the Hilo region differs in form from models for the other 18 regions. The dislocation approach used successfully for modeling earthquakes in California and Nevada proved relatively unsatisfactory for representing horizontal displacements associated with the 1975 Kalpana earthquake (M=7.1). We found that coseismic displacements for this Hawaiian event were better represented by second order polynomials in two variables. These polynomials are equivalent in form to those used to model displacements for the Prince William Sound earthquake of Alaska's Anchorage region (Appendix E). The Hilo model differs from the Anchorage model, however, in that the Hilo region contains sufficient data to enable a rough estimate of secular motion. These data include EDM measurements from a deformation network regularly monitored by the USGS since 1970.

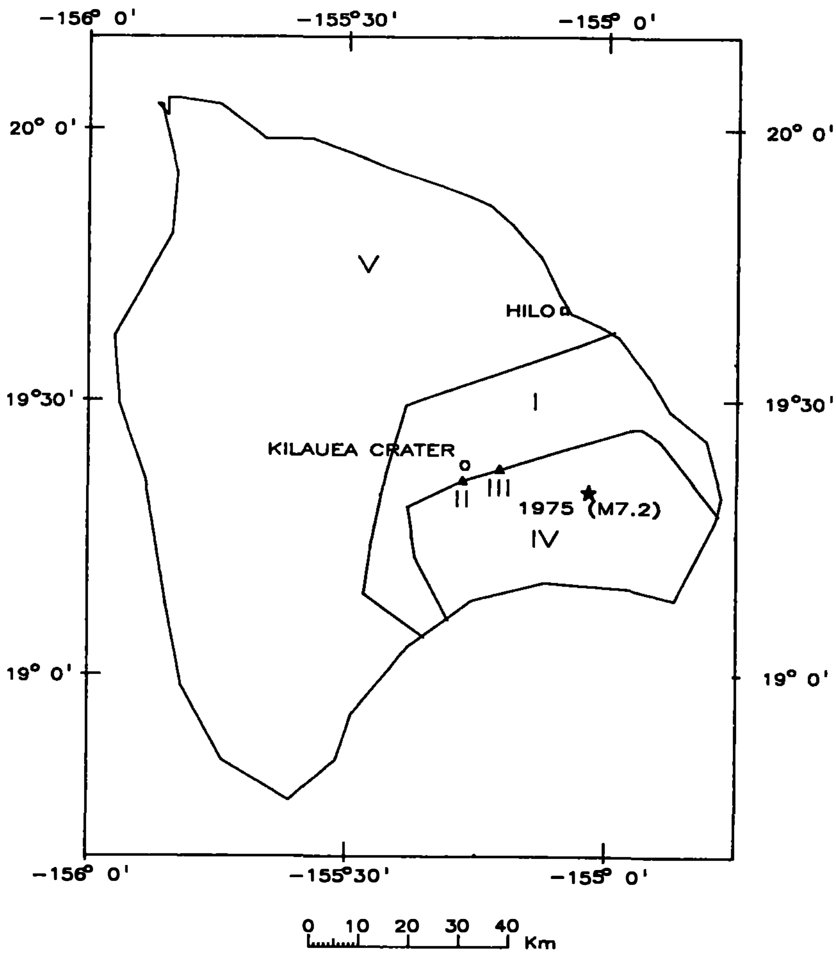

Figure F.1.--The Hilo region covers the Island of Hawaii. Roman numerals identify the various districts in the REDEAM model. The star represents the epicenter of the 1975 Kalpana earthquake.

Hawaii is the southeasternmost island of a 6,000 km long chain of islands and seamounts across the central Pacific Ocean. According to the theory of plate tectonics, these islands and seamounts were formed as a result of the relative northwesterly motion of the Pacific lithospheric plate over a thermal plume in the Earth's mantle (a "hot spot"). The theory contends that lavas of basalt composition emanate from the hot spot, forming volcanic islands or seamounts, which subsequently become inactive as plate motion continues. The northwestern end of this island-seamount chain is about 70 million years old, while the southeastern extremity of the chain, Hawaii's Kilauea volcano, is less than 1 million years in age.

Kilauea, like other volcanoes in the Hawaiian chain, is a "shield" volcano. Shield volcanoes are gently sloping and much broader than they are high. The extruded material from a shield volcano consists almost exclusively of lava flowing out in quiet eruptions from a central vent or from closely related fissures, called rifts, that extend laterally for several kilometers from the central vent. This type of volcano contrasts with the steeper "cone" volcanoes, like Mount Saint Helens, which are characterized by violent, explosive eruptions of cinders and pyroclastic materials which may or may not be accompanied by lava flows. The absence of violent eruptions, however, does not preclude the occurrence of destructive earthquakes near Kilauea as manifested by the 1975 Kalpana event on the south flank of the volcano. An earthquake of similar magnitude is thought to have occurred at Kilauea around 1868 (Wyss et al. 1981). Since 1868, repeated episodes of magma intrusion into the rifts have compressed the south flank--in effect, pushing it away from the rest of the island (fig. F.2). The large 1975 rupture is a result of this 100+ years of stress loading.

Ando (1979) published a detailed study of the mechanism of the Kalpana earthquake, including a dislocation fault model. Ando's disloction parameters, describing the size and orientation of a fault plane and amount and sense of slip on this fault plane, were estimated from a comprehensive set of body wave and surface wave data, the aftershock distribution, tsunami effects, and geodetically derived crustal deformation data. Note that Ando's use of the geodetic data, however, was strictly qualitative—a yardstick to compare the coseismic models suggested by the other data types or to support the hypothesized strain pattern on the south flank of Kilauea. In Ando's model the dislocation surface is thought to represent the boundary between the original ocean floor and the overlying layer of solidified lava.

Table F.1--Dislocation parameters (Ando 1979)

Strike	= N70°E
Dip	= 20° SSE
Fault length	= 40 km
Fault width	= 20-30 km
Upper depth	= 10 km (measured vertically)
Dip slip	= 3.7 - 5.5 m (normal slip)

We used Ando's dislocation parameters (table F.1) as a "first approximation" dislocation plane to model the 1975 earthquake with the geodetic data. The location of this fault plane--the "ramp" in figure F.2--was computed from the seismically determined epicenter of the earthquake. A computer program, called JIGGL, was next used to vary the dislocation model parameters until a best fit to the geodetic data was found.

Given "observed" displacement vectors, JIGGL first computes corresponding horizontal shear strains for a collection of prespecified station groupings (for example, shear

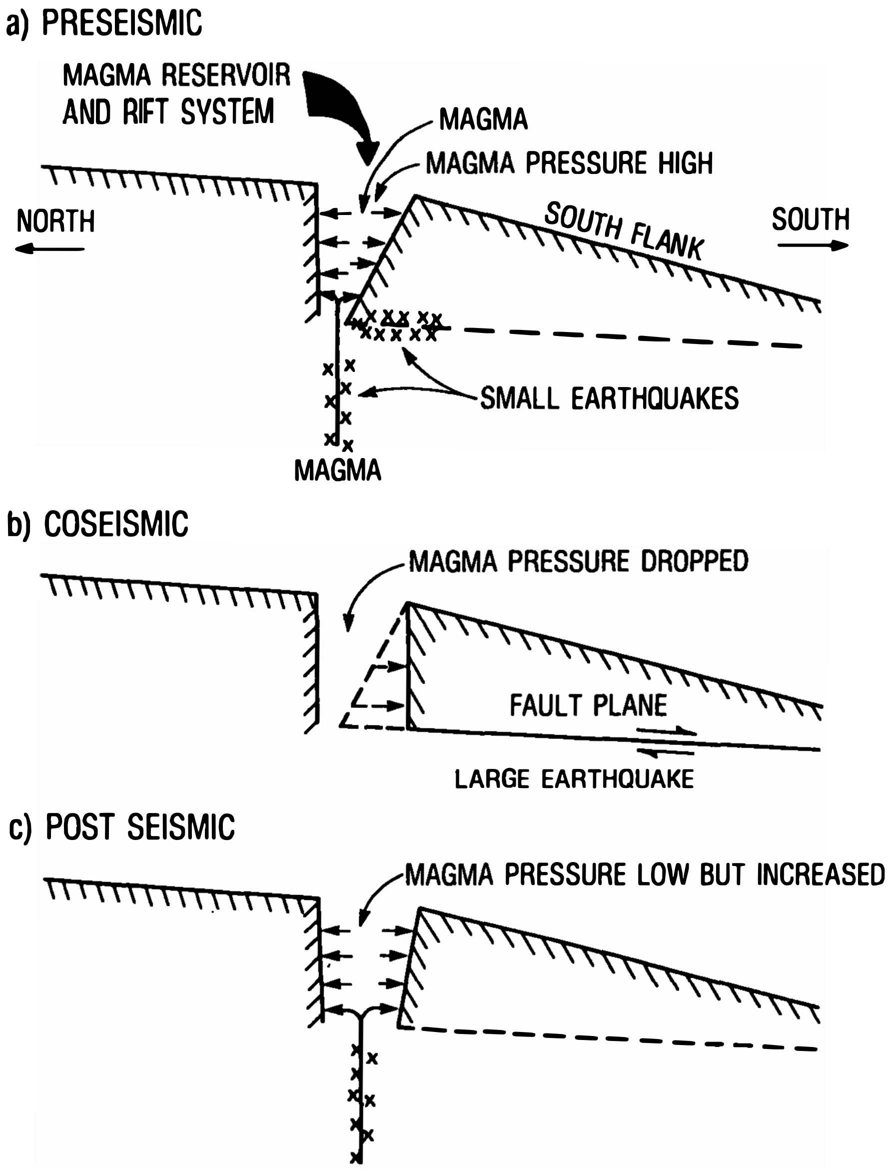

Figure F.2.--A schematic model for strain (a) accumulation, (b) release (earthquake), and (c) reaccumulation in the south flank of Kilauea. The sliding plane corresponds to the 1975 fault plane and is also inferred from background seismicity (from Ando 1979).

strain is computed for selected triangles in the network). Next, the software computes, for these same groupings, theoretical shear strains corresponding to the input dislocation model. The rms difference between the observed and theoretical strains is computed. The software then varies the values of the fault parameters seeking the best rms fit. JIGGL tests each dislocation parameter, one-by-one, to see if changing its current value by plus-or-minus some user-specified increment will decrease the rms. Parameter values are then changed, if necessary, to reflect the best fit. After testing the last parameter, the procedure is iterated until either a convergence criteria is met or a specified number of iterations are performed.

In the case of the Kalpana earthquake the observed displacements were computed at 68 geodetic stations by differencing the adjusted positions resulting from a minimally constrained adjustment of the 1974 USGS EDM data with adjusted positions from such an adjustment of the 1976 USGS EDM data.

The JIGGL results for Ando's dislocation model were poor. The best fitting set of parameters had an rms strain of 70 microradians (about 10 σ). Furthermore, this solution required over 18 meters of normal dip slip on a plane dipping only 2° from the horizontal. These results are geophysically implausible. An additional fault plane, representing the vertical magma chamber on Kilauea (see fig. F.2), was added to Ando's model and the JIGGL process was repeated. This new model produced an even poorer fit to the geodetic displacements--an rms strain of over 112 microradians. Moreover, the resultant fault plane parameters were still unreasonable with more than 10 meters of dip slip on the "ramp" plane and the "magma chamber" plane dipping 8° to the northwest. There are several possible explanations for our inability to model the 1975 Kalpana earthquake with a dislocation model:

(a) anomalous local offsets may be clouding the coseismic displacements;

(b) extensive aseismic motions occurring over the 18-month period between the preseismic and postseismic geodetic surveys may bias the results;

(c) the mathematics of dislocation theory may be inappropriate for modeling the displacements associated with this event.

Evidence in support of items (a) and (b) is discussed later in this appendix. Relating to item (c), Eissler and Kanamori (1987) have proposed that the 1975 Kalpana earthquake was due to a massive landslide and not to elastic dislocation. Concern for item (c) caused us to adopt an alternate modeling approach. In this approach, the coefficients of a second-order polynomial in two variables (latitude and longitude) were estimated from the displacements. In other words, the observed geodetic displacements (table F.2) were fit by a quadratic function of position. The same technique had been introduced by Steven Musman to model the 1964 Prince William Sound, Alaska, earthquake (appendix E). With the exception of the stations noted below the polynomial model fit the Hawaiian data rather well. Indeed for the 21 sites shown in figure F.3, the discrepancy between observed and modeled displacements has an rms value of only 0.33 m whereas observed displacements range between 0.74 m and 6.43 m.

Six stations on the summit of Kilauea volcano experienced anomalous coseismic motion. These stations were treated as distinct points--"before" and "after" the 1975 earthquake. These stations are:

HVO 113 USGS
KEANAKAKOI 1949
OHAIKEA HTS 1949
SAND HILL USGS
UWEKAHUNA HGS 1896
VOLCANO HOUSE FLAG

Similarly, the stations listed below were also treated as before-and-after stations. Station descriptions and written correspondence between the USGS and NGS suggest that mark stability is questionable on the entire south flank of Kilauea. This isn't surprising since the marks are set in young, solidified lava. Many points have been reset owing either to the geological instability, underlying magma instrusion, or nearby lava flows.

Table F.2.--Coseismic displacements for 1975 Kalpana earthquake

Station	Latitude deg min	Longitude deg min	Displacement East, m	Displacement North, m
1 APUA PT BM	19 15.8	155 11.7	3.42	-5.45
2 GOAT 2 USGS	19 20.0	155 13.7	1.41	-2.58
3 HAKUMA 1914	19 20.9	154 58.9	1.38	-1.91
4 HEIHEIAHULU 1914	19 25.6	154 59.6	0.23	-1.22
5 HILINA USGS	19 17.9	155 18.6	1.64	-3.42
6 HOLEI HVO162 USGS	19 19.0	155 08.2	1.42	-3.03
7 HVO 147 USGS	19 24.1	154 55.5	0.71	-0.54
8 IILEWA USGS	19 26.3	154 57.6	0.01	-0.74
9 KAENA POINT USGS 1977	19 17.1	155 07.5	2.73	-3.97
10 KALALUA USGS	19 24.2	155 04.1	0.49	-1.50
11 KAMOAMOA HVO158 USGS	19 19.3	155 03.9	1.65	-2.56
12 KAU USGS	19 17.3	155 19.6	1.57	-3.55
13 KUPAPAU 1914	19 19.9	155 01.2	1.62	-2.48
14 LAEAPUKI 1914	19 18.2	155 05.4	2.04	-3.10
15 MAKAHANU PALI USGS	19 18.2	155 15.5	1.75	-4.40
16 MOANA HAUAE USGS 1978	19 22.5	154 57.2	1.07	-1.12
17 OHALE HGS 1897	19 21.2	155 16.8	1.10	-2.17
18 PANAU 1914	19 19.4	155 06.5	1.46	-2.55
19 PILAU 3 USGS	19 19.3	155 11.4	1.53	-2.41
20 PULAMA 1914	19 21.3	155 02.6	1.15	-1.89
21 PUU HULUHULU HGS 1891	19 22.5	155 12.5	0.90	-1.71

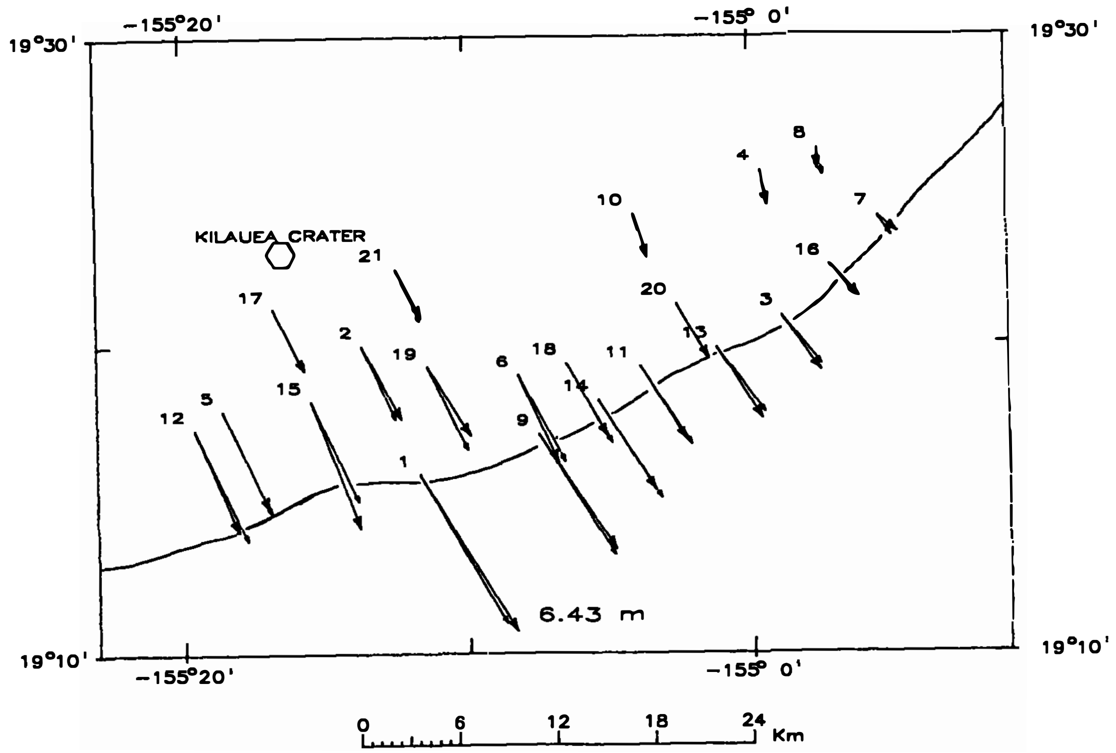

Figure F.3.--Comparison between observed displacements (large arrowheads) and modeled displacements (smaller arrowheads) for the 1975 Kalpana earthquake. Numerals identify stations as keyed in table F.2.

HVO 128 USGS
KAAHA USGS
KALIU HGS 1891
KOAE USGS 1949
NALI USGS
PAPAYA RESET USGS
PUU KAPUKAPU 1914

The MOTION III software (chapter 4) was used to derive a model for the secular movement of the stations in the Hilo region. While the formulation of the model allows for both secular and episodic movement, only the secular parameters were estimated in the Hawaii application of MOTION III. To achieve this, "front end" software was written to correct the geodetic observations for coseismic motion attributed to the 1975 earthquake. Using the results from the empirical coseismic model, corrections were applied to all observations involving stations in the "earthquake zone" (described later in this appendix). The pre-earthquake observations were corrected to be compatible with the post-earthquake observations. This allowed us to model the secular motion as if the earthquake had not occurred.

The Hilo region was divided into five districts (fig. F.1). This districting scheme differs from those used for most other REDEAM models in that district boundaries do not correspond to geologic faults. The rationale for the Hawaii districting scheme follows:

District I -- A buffer between the earthquake zone (District IV) and the rest of the island (District V).

District II -- Station OHALE HGS 1897 (and a no-check spur) only. The reasons for this district are given below.

District III -- Station PUU HULUHULU HGS 1891 (and a no-check spur) only. The reasons for this district are given below.

District IV -- The earthquake zone. District II and III are embedded in, but separate from, this district.

District V -- The rest of the "Big Island."

Note, that there are several fault systems on the flanks of Kilauea. There is, however, insufficient temporal and spatial distribution of geodetic data in these areas to justify the finer districting scheme required to resolve movements associated with these fault systems.

Swanson et al. (1976) published a study of the 20th century triangulation, trilateration, and leveling data in the vicinity of Kilauea. These data (and the preparation of their report) precede the 1975 earthquake. Swanson et al. examined the geodetic data epoch-by-epoch and related observed displacements to the geology and to episodes of forceful magma intrusion. Their report is a landmark study on south flank tectonics and offers a concise picture of secular deformation patterns. In summarizing the geodetic data from 1914 to 1971, Swanson et al. showed that the summit area undergoes uplift between eruptions. In addition, the filling and emptying of the magma reservoir system beneath the summit of Kilauea are generally accompanied by largely reversible ground deformation. Those authors document short term deformation events keyed to specific eruptions or episodes of ground cracking associated with intrustions. A good example of extensive aseismic movement on the south flank is seen by comparing the 1970 and 1974 USGS trilateration data. These data span a time period characterized by the onset of swarms of intrustions and eruptions which culminated in the 1975 earthquake. The picture, then, is that of strain accumulation on the south flank that is nonlinear in time and spatially heterogeneous. Obviously a more sophisticated model than ours (which has the assumption of linear strain accumulation over time and spatial homogeniety within districts) would be required to describe such complex deformation. It is not clear that a single model--rather than several models keyed to specific episodes of eruptions or intrusions--is possible.

Swanson et al. also noted large, atypical displacements at stations OHALE and PUU HULUHULU for the 1949-70 data epoch. In our early adjustments, these two stations had large residuals and we therefore designated them as districts II and III in our final districting scheme. These two "ad hoc" districts are embedded in district IV, which encompasses the earthquake zone.

The following FORTRAN routine documents the derived polynomial coefficients that characterize the coseismic displacements associated with the 1975 Kalpana earthquake. Note that nonzero displacements are obtained only for districts II, III, and IV.

```
      SUBROUTINE HAMOV(XLA,XLO,IDIST,DX,DY)
C
C     This subroutine interpolates to find the displacement at
C     an arbitrary position for the 1975 Hawaii earthquake.
C     INPUT:
C       XLA denotes the (north) latitude of the position in degrees.
C       XLO denotes the (west) longitude of the position in degrees.
C       IDIST is a district identifier.
C     OUTPUT:
C       DX is the eastward displacement in meters at the position.
C       DY is the northward displacement in meters at the position.
C
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      DIMENSION CX(5), CY(5)
      PI = 3.14159265D0
      IF(IDIST.EQ.1 .OR. IDIST.EQ.5) THEN
          DX = 0.0D0
          DY = 0.0D0
      ELSEIF(IDIST.EQ.2 .OR. IDIST.EQ.3 .OR. IDIST.EQ.4) THEN
          XBAR = 7.2154D0
          YBAR = 5.4478D0
          XX = 45.9756D0
          XY = 11.6674D0
          YY = 7.5701D0
          DX0 = 1.397D0
          DY0 = -2.5D0
          CX(1) = .03058D0
          CY(1) = .03280D0
          CX(2) = -.3087D0
          CY(2) = .3881D0
          CX(3) = .003245D0
          CY(3) = .003092D0
          CX(4) = -.02123D0
          CY(4) = .002082D0
          CX(5) = .04132D0
          CY(5) = -.04603D0
          X = DCOS(19.25D0*PI/180.D0)*60.D0*(155.25D0 -XLO)
          X = X - XBAR
```

```
      Y = 60.D0*(XLA - 19.25D0)
      Y = Y - YBAR
      F = X*X - XX
      G = X*Y - XY
      H = Y*Y - YY
      DX = DX0 + CX(1)*X + CX(2)*Y + CX(3)*F + CX(4)*G + CX(5)*H
      DY = DY0 + CY(1)*X + CY(2)*Y + CY(3)*F + CY(4)*G + CY(5)*H
   ELSE
      WRITE(6,10)
10    FORMAT(' IMPROPER DISTRICT IDENTIFIER')
   ENDIF
   RETURN
   END
```

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