STATE OF CALIFORNIA
The Resources Agency
Department of Water Resources

BULLETIN No. 116-6

GEODIMETER FAULT MOVEMENT INVESTIGATIONS IN CALIFORNIA

MAY 1968

RONALD REAGAN
Governor
State of California

WILLIAM R. GIANELLI
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TENHI
TO TEJON
ZONE
Highway 138

FOREWORD

Active faults in the vicinity of the State Water Project have been monitored by the Department since 1959. This bulletin is a technical summary of the fault monitoring activity.

The investigation was initiated because the State Water Project aqueduct unavoidably crosses the San Andreas and other active faults; many of the Project's pumping plants and dams are, by necessity, located near active faults among their ancillary fractures; and, although some of these faults were known to be moving, quantitative measurements needed for engineering purposes were not available.

This type of investigation is authorized in the California Water Code by Sections 225, 227, 6081, 12616 and others. The Department is specifically authorized to take into consideration that a dam or reservoir might be endangered by earth movement and to conduct investigations and surveys concerning the protection and utilization of water resources.

The objective of the fault monitoring program is to develop a more complete understanding of continuing fault movements in California. Results indicate that movement ranges from little in the Carrizo Plains to about one and one-half inches a year a few miles south of Hollister. This rate, if continued, would produce a horizontal offset of about seven feet in 50 years. Changes in fault movement are shown to vary with time and place, and appear to be associated with the occurrence of earthquakes.

This bulletin is the sixth in a series about earthquake and ground movement problems of direct concern to the Department.

William R. Gianelli

William R. Gianelli, Director
Department of Water Resources
State of California
April 15, 1968

ABOUT THE FRONTISPIECE

This aerial view of the San Andreas rift looks southeast to where the California Aqueduct must cross the fault. Here, opposite sides of the fault are estimated to have moved as much as 20 feet past each other during the 1857 Fort Tejon earthquake--the last known displacement in this area.

Although this portion of the fault zone has been relatively quiet during the period of Geodimeter observations, this awesome crack in California's foundation is testimony to its past activity and a persistent warning against complacency.

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STATE OF CALIFORNIA
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CONSULTING BOARD FOR EARTHQUAKE ANALYSIS

California Department of Water Resources is advised and its earthquake programs are guided by its Consulting Board for Earthquake Analysis.

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Acting Chairman, Division of Geological Sciences, California Institute of Technology, Pasadena
Mechanics of faulting; relation of seismicity to geologic structures; tectonics of Southern California and Baja California, Mexico.

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Design of earth and rockfill dams.

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Earthquake-resistant designs and construction of large structures.

DR. BRUCE A. BOLT

Director of the Seismographic Stations and Professor of Seismology, University of California, Berkeley.
Seismic wave theory; structure of the earth; theoretical geophysics.

Mr. Nathan Whitman and Dr. Hugo Benioff were original members of the Board. Mr. Whitman, who died in 1966, was a structural engineer and specialist in design of hydraulic structures with the firm of Whitman, Atkinson and Associates. Dr. Benioff, who died in 1968, was chairman of the Board until the fall of 1965, when he retired. He was a seismologist, specialist in earthquake strain accumulation and instrumentation, and Professor Emeritus of the California Institute of Technology.

ABSTRACT

The California State Water Project, a two billion dollar water conveyance and storage system, crosses known active faults in over a dozen places and it closely parallels the active San Andreas for several hundred miles. Lack of quantitative information concerning the magnitude and extent of fault movement resulted in the initiation of the Department of Water Resources' fault monitoring program in 1959. A Model 2A Geodimeter is used to measure changes in the length of lines 8 to 20 miles long which cross the San Andreas and related faults over the 450-mile length of the Project aqueduct. There are over 2,000 miles of lines in the fault monitoring network.

Movement along the San Andreas fault is a maximum south of Hollister at 4.4 cm/year. This represents nearly 7 feet of movement over a 50-year span. It diminishes southward until nearly unmeasurable in the vicinity of Los Angeles. The coastal side of the San Andreas fault moves generally north relative to the continental side. North of Hollister, the combined annual rate of movement across the San Andreas, Hayward, and Calaveras faults equals that near Hollister on the San Andreas alone. The distribution of creep between these faults varies with time. Recent measurements near San Bernardino have indicated movement not previously evident. Small movements continue in the vicinity of the White Wolf fault but the Garlock fault has remained relatively quiet.

The rate of fault movement often changes prior to small earthquakes which occur near the Geodimeter lines, suggesting that with increased frequency of measurements, effective earthquake warnings may be possible for the first time.

ACKNOWLEDGMENT

The recommendations of the late Dr. Hugo Benioff, Seismologist, Professor Emeritus, of the California Institute of Technology and consultant to the Department, were instrumental in the initiation of the fault monitoring program.

Also acknowledged are the support and recommendations offered at the initiation of this program by Rear Admiral Charles Pierce, Assistant Director of the U. S. Coast and Geodetic Survey, and Dr. Don Tocher, Seismologist, then of the University of California, now Director of the Earthquake Mechanism Laboratory of the U. S. Environmental Science Service Administration.

Guidance from the Department's Consulting Board for Earthquake Analysis later helped shape progress in this effort.

Drs. Pierre St. Amand, Roland von Huene and others at the China Lake U. S. Naval Ordnance Test Station provided material help resulting in improved balloon-lofted temperature sondes.

Guidelines for the program were formulated by the Department's Fault Strain Committee, headed by Mr. Tracy L. Atherton (deceased), Coordinator of Surveying and Mapping.

Many others provided substantial help and guidance. Current and past crew members deserve special thanks. Among them are crew chiefs Norman L. Meade, Albert J. Gonelli and Roger M. Bennett, and crew members Kenneth R. Townzen, Jeffrey M. Dander, Burton Plecas, Vernon McClary, Donal O. Beckstead and James R. Nicholas. Vinton Moore and Chester Lao, Department engineering geologists, also participated in the early years of the program, particularly in station mark selection. C. Eugene Hill performed much of the computer programming and suggested some of the methods of mathematical data reduction used in the programs. Department engineering student trainees William H. Long, Robin L. Rivett and Steven C. Schwartz participated in field work and analysis.

CHAPTER I. INTRODUCTION

Major active faults are crossed over a dozen times by the two billion dollar California State Water Project. This bulletin concerns the Department's program to provide engineering data by measuring the continuing movement of these active faults.

Need

During the 1950's, the Department of Water Resources was engaged in an extensive planning investigation to evaluate various alternative aqueduct routes to convey surplus Northern California water to the arid, heavily populated southland.

The proposed water facilities would of necessity cross some of the most active faults in North America. Faulting in California is extensive and pervasive. Avoiding these fractures and attendant seismic areas would be a little like walking down the street without crossing cracks in the pavement.

Fault movement, whether or not it generates an earthquake, presents a potential hazard to the Project. Many of the Project's pumping plants and storage reservoirs are, by necessity, located very near major active faults among their ancillary fracture systems. The tremendous energy released by large earthquakes suggests that strains accumulate over a large area prior to being suddenly relieved. Major State Water Project facilities could be affected by those strains and by possible movements along ancillary fracture systems as well as by movements on major faults.

Little was known of the quantitative amount and direction of crustal movements and distortions along the San Andreas and the other major fault systems in California except for a few long-term investigations by the Division of Geodesy of the U. S. Coast and Geodetic Survey (USC&GS). Its program has consisted of repeat measurements, at about ten-year intervals, of fault zone triangulation and traverse networks at a few specific locations principally along the San Andreas fault. More frequent observations were not practical because of the limited resolution of conventional geodetic surveying and the slow rate of fault movement.

The quantitative magnitude of movement in the vicinity of State Water Project development sites, the full extent of the possible zones of distortion or movement, the influence of earthquakes, and the variability of movement with respect to time were largely a matter of conjecture. Some means of obtaining quantitative measurements of this movement was clearly required.

Early History of the Program

Various alternative means were explored which might yield a reasonably short-term evaluation of these unknowns. In 1958, discussions with the late Dr. Benioff of the California Institute of Technology, Pasadena Seismological Laboratory, resulted in a scientific program to investigate critical faults in connection with the development of statewide water facilities. One of Dr. Benioff's proposals was a continuing program of crustal strain measurements to be accomplished with a Model 2A Geodimeter, which at that time had only recently been developed. In his letter of August 1, 1958, to the Director of the Department, he stated:

> "In view of the many existing and projected aqueducts which cross major faults within the state it is of very great importance to have accurate knowledge as to the strain patterns and habits of these faults. The only information available at present on this problem is derived from geodetic measurements which are necessarily of insufficient sensitivity to give any but rough indications of the strain patterns--and then only after many years of observation. In order to speed up accumulation of knowledge in this field, it is my recommendation that a program of research be started as soon as possible with the recently developed optical method of triangulation using an instrument known as the Geodimeter."

The program received the wholehearted support and recommendation of various other individuals and organizations. Work was initiated in May 1959.

The Geodimeter Network

A Fault Strain Committee was formed within the Department to detail the initial survey network and operating procedures for the fault monitoring program. It was determined that a network of essentially single lines, rather than one of closed figures and triangulation, would economically provide the most data over the greatest possible area. Movement rates would be determined by direct comparison of repeated measurements.

Criteria for line selection were (a) an assumed optimum operating range for the Geodimeter of 12-20 miles and (b) station marks need not be at a distance greater than 3-5 miles from the fault zone. The latter was based on Dr. Benioff's recommendation that the greatest portion of measurable crustal strain occurs within a few miles of either side of the fault zone. Figure 1 illustrates these criteria.

A basic network of lines to be monitored was thus established along the San Andreas fault from the San Francisco Peninsula southerly to the vicinity of Palm Springs in Riverside County, a distance of approximately 450 miles. Several additional lines were selected to cross the Hayward and Calaveras faults in the east San Francisco Bay area and the White Wolf and Garlock faults in Southern California. This zone of active faulting directly involved the State Water Project.

Triangulation stations from the national horizontal control network were used where possible so the fault movement record could be tied to later long-term resurveys of major geodetic control networks. Additional stations where needed were established by Department personnel at geologically stable sites.

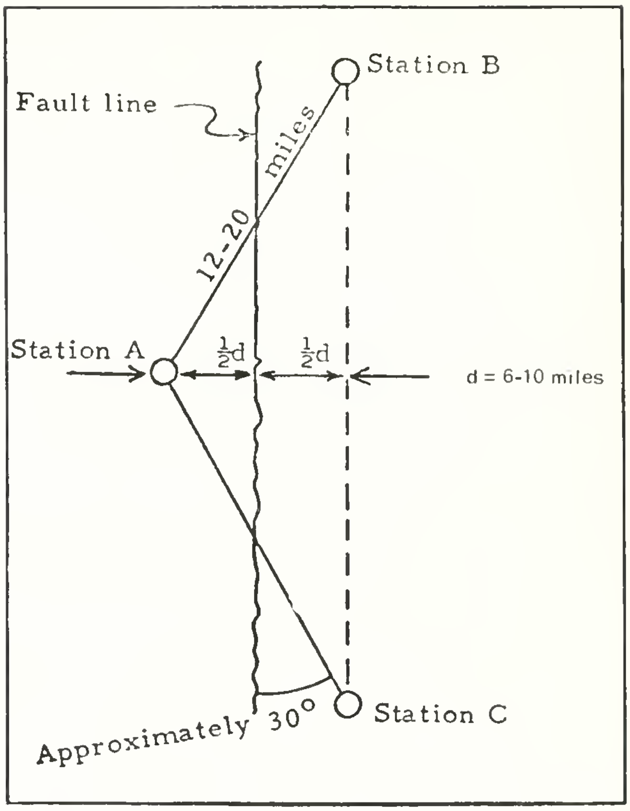


Figure 1. CRITERIA FOR GEODIMETER LINES

During 1965, 1966 and 1967, about 50 lines have been added to the Department's original network, many in the form of closed figures. One of these is a pentagon-shaped network established near Cholame and Parkfield in San Luis Obispo County in October 1965. This figure was completed just a few months prior to the Parkfield earthquakes of June 1966 and yielded valuable data upon reobservation after the earthquakes. Others are the networks north of the San Francisco Peninsula and in the Upper Eel area completed in 1967. Also, lines of the U. S. Navy's China Lake calibration range were used early in the program to check accuracy by closure before the Department had established closed figures and to work out analysis techniques for near surface inversion problems.

Measurements have been made on more than 100 lines (Figure 2). The number of measurements varies from a single determination to as many as ten. On the average, six measurements have been completed for 60 of the initially established lines which constituted the basic program.

Originally, repeat measurements were planned on an annual basis. However, numerous factors resulted in deviations from this schedule. These include:

(1) Access to certain stations is sometimes restricted because of fire hazard regulations, ranching operations, etc. The field crew can reach these stations only during certain periods of the year.

(2) Highly variable weather conditions throughout the Project area preclude adherence to other than a generalized reobservation schedule.

(3) Certain lines are measured more frequently because the stations are easily reached and good visibility prevails between them. The crew can often measure these lines when it is operating in the area and other lines are inaccessible.

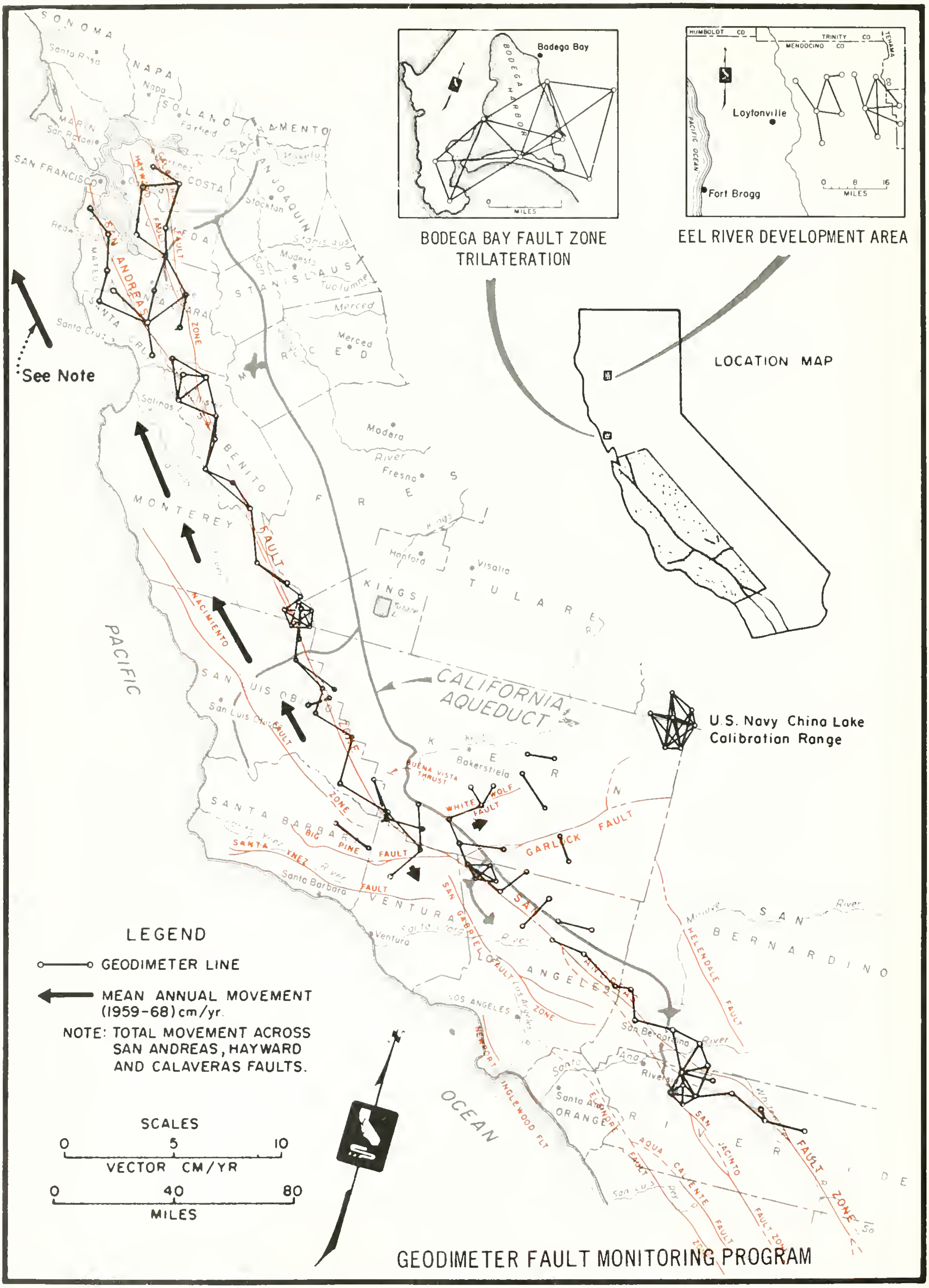
(4) Lines which have exhibited unusual movement patterns are measured more frequently.

For those unfamiliar with Geodimeter techniques, a review of Chapters V and VI may be helpful in interpreting preceding chapters.

U. S. Coast and Geodetic Survey Cooperation

Although not directly involved in the Geodimeter program, the U. S. Coast and Geodetic Survey has cooperated with the Department in

FIGURE 2


BODEGA BAY FAULT ZONE TRILATERATION
Bodega Bay
BODEGA HARBOR
MILES
EEL RIVER DEVELOPMENT AREA
HUMBOLDT CO
TRINITY CO
MENDOCINO CO
TEHAMA
Laytonville
Fort Bragg
PACIFIC OCEAN
0 8 16
MILES
LOCATION MAP
U.S. Navy China Lake Calibration Range
See Note
LEGEND
GEODIMETER LINE
MEAN ANNUAL MOVEMENT (1959-68) cm/yr.
NOTE: TOTAL MOVEMENT ACROSS SAN ANDREAS, HAYWARD AND CALAVERAS FAULTS.
SCALES
0 5 10
VECTOR CM/YR
0 40 80
MILES
SONOMA
NAPA
SOLANO
MARIN
SAN FRANCISCO
COSTA
SAN JOAQUIN
STANISLAUS
MERCED
SAN ANDREAS
FAULT ZONE
SAN BENITO
MONTEREY
FAULT
FRESNO
KINGS
TULARE
PACIFIC
NACIMIENTO
SAN LUIS OBISPO
CALIFORNIA AQUEDUCT
KERN
BUENA VISTA THRUST
WHITE WOLF FAULT
GARLOCK FAULT
SANTA BARBARA
BIG PINE FAULT
SANTA YNEZ FAULT
VENTURA
LOS ANGELES
SAN GABRIEL FAULT ZONE
SAN BERNARDINO
HELENDALE FAULT
NEWPORT INGLEWOOD FLT
OCEAN
ORANGE
SAN JACINTO FAULT ZONE
AGUA CALIENTE FAULT
FAULT ZONE
GEODIMETER FAULT MONITORING PROGRAM

providing additional information about fault movements. Most of these efforts were accomplished through the cost-sharing Federal-State Cooperative Agreement for Geodetic and Seismological Investigations, initiated in 1963. Three major programs to determine fault movement have been conducted under this cooperative agreement.

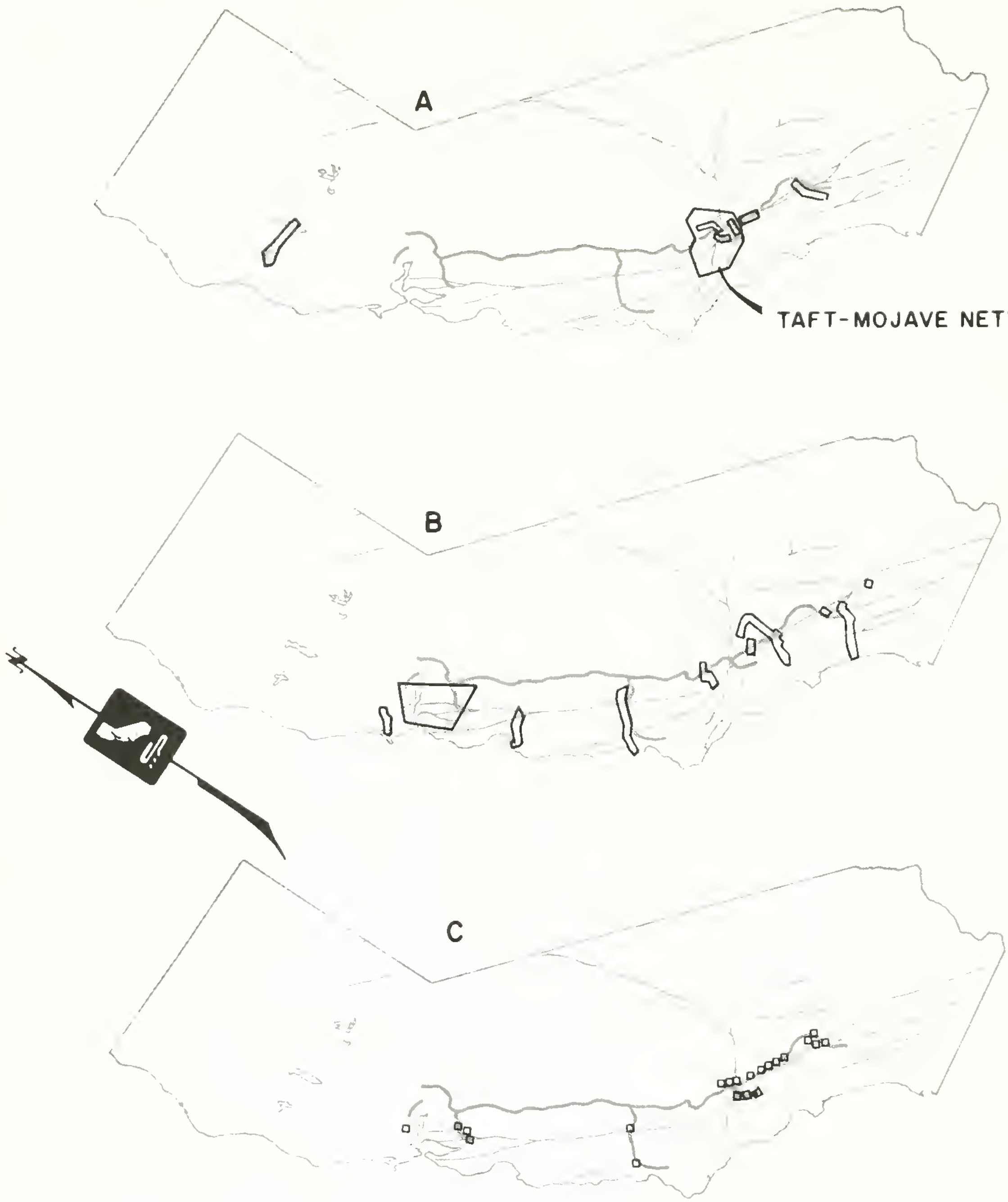
Fault Zone Triangulation

Several networks of first-order triangulation have been established where the State Water facilities are located near major fault zones (Figure 3A).

The largest of these, the "Taft-Mojave" network, was initiated concurrently with the Department's Geodimeter program in recognition of the mutual interest in ground movement investigations in California. This network in the Tehachapi Mountains region (see Figure 3A) encompasses the intersection of the San Andreas, Garlock, White Wolf, Big Pine and San Gabriel faults, including the most heavily shaken area of the Fort Tejon earthquake of 1857. Base lines within the network were measured by the Coast and Geodetic Survey with their Model 2A Geodimeter. The Department's geodetic crew participated in the measuring program with its Model 2A Geodimeter.

Since 1959, several of these base lines have been remeasured periodically as a part of the Department's program.

During September-December 1967, the U. S. Coast and Geodetic Survey completed the first reobservation of the network. This reobservation should provide the first regional picture of ground movements in this geologically complex area. The Department cooperated with the USC&GS in this project by conducting the network Geodimeter measurements.



A. Geodetic networks measured or remeasured.

B. Special analysis of previously measured USC+GS networks to provide fault movement information needed for design of the State Water Project.

C. Fault measurement quadrilaterals at fault crossings of the State Water Project.

DWR-USC+GS COOPERATIVE FAULT MEASUREMENT

Four additional first-order triangulation networks were established during Fiscal Year 1963-64 and another in 1965-66. These were laid out to straddle the aqueduct or other Project facilities through major fault zones. It is intended that these networks or portions of them will be reobserved in future years. These networks also provide primary horizontal control for Project survey purposes (see Figure 3A).

One existing USC&GS fault zone triangulation network located across the San Andreas fault in northern Los Angeles County was reobserved during Fiscal Year 1964-65. Previous observations of this network were completed in 1938 and 1949.

Analysis of Previous USC&GS Surveys

This activity provided for analysis and reporting of previous fault movement surveys conducted by the USC&GS at a few locations primarily on the San Andreas fault (Figure 3B). Emphasis was placed on locations near the State Water facilities.

Fault Movement Quadrilaterals

Twenty-one small survey figures were established at or near locations where aqueduct facilities cross major faults (Figure 3C). Periodic reobservation of these figures provides a measure of both vertical and horizontal fault slippage. Larger networks and the Geodimeter lines measure "movement", defined as a combination of fault creep or slippage, and strain or distortion of the earth's surface. The stations of the quadrilaterals are so close to the fault that strain would be undetectable by survey methods. Consequently, only fault slippage is measured. This provides a means of separating the amount of fault slippage from the combined strain and slip measured in the Geodimeter program. However, the stations are often in alluvium which may not always react in a linear manner to fault slippage in the underlying hard rock.

CHAPTER II. CONCLUSIONS

The Department's Geodimeter program was established initially to determine the location and magnitude of displacements which would have a major effect on the design and subsequent safety of the State Water Project. Subsequent to design decisions on the State Water Project, the program has been maintained to provide specific knowledge of major fault behavior in California. The program is meeting its basic objective of quantitatively defining the movement of the San Andreas and other major active faults.

The major conclusions of the program are:

1. From 1959 to 1967, average annual fault movement on the San Andreas fault was greatest just south of Hollister--4.4 cm/year--diminishing further southward until almost indiscernable in the Carrizo Plains. Movement near Hollister appears to be primarily slip. Continued displacement at this rate would amount to nearly seven feet in 50 years.

North of Hollister, where the Calaveras and Hayward faults have splintered off from the San Andreas, the annual total shift of about 4 cm/year is distributed among the three faults. The proportion of movement carried by each fault changes with time.

Near San Bernardino, movement has continued for the past two years where none had been observed for the six previous years. This movement appears to be primarily strain with a measurable component of north-south compression. This is unlike the movement near Hollister, which appears to be primarily slippage.

A better understanding of fault movement in California would be achieved by extending these observations to cover the entire San Andreas fault system and other active faults throughout the State.

2. Earthquakes are often preceded by changes in movement rate of faults near them. The effect is noticed for shocks above Magnitude 4-1/2 but does not otherwise seem consistently related to the size. In areas where the frequency of Geodimeter observations is significantly greater than the rate of occurrence of earthquakes, many of the shocks have been preceded by changes in movement rate as measured on one or more Geodimeter lines. With an increase in the frequency of Geodimeter observations, effective earthquake warnings may someday be possible.

3. A low movement rate in the Parkfield area between zones of higher movement to the north and south had suggested that the accumulating strain would have to be relieved. In anticipation, the Department established a pentagon-shaped network of Geodimeter lines over the fault in this area in October 1965. The strain was suddenly relieved in June 1966 with accompanying earthquakes near Parkfield. The resultant movement was over 20 cm. The area thus achieved an average movement rate, for the seven years of observation, equal to the highest observed. Adjustment was initially restricted to a zone about 12-18 miles long. Rates of movement outside this zone to the north have since increased, tending to raise the movement rate of almost the entire zone from Cholame to Hollister to the maximum observed.

4. In the northern zones of the San Andreas fault between Hollister and Cholame computed movement vectors are more nearly parallel to the fault if stations on the west side of the fault are assumed to remain the same distance apart. If stations on the east side of the fault are assumed to

remain the same distance apart, movement vectors are oblique, not parallel to the fault. Thus, if movement is assumed to be primarily slippage, it follows that the continental side of the fault must undergo significant north-south compression.

5. Under all but the poorest of conditions, 8- to 20-mile-long distance measurements with the Model 2A Geodimeter can be made with an accuracy of better than 2 cm. Network closures, where they can be made, are often within a few millimeters if conditions are good. Monitoring of temperature at both ends of the line, with temperature sampling at elevations above the influence of surface radiation, including a vertical profile near midline up to the line elevation, is required. Lines at high relative elevations above the surface (e.g., 2,000 feet) and lines whose ends do not differ greatly in elevation yield the best results.

6. Long-term movement rates determined by the U. S. Coast and Geodetic Survey (USC&GS) from analyses of their triangulation networks at a few locations along the San Andreas system show general agreement with those from the Department's measurements. Both show little movement in the zone from the Carrizo Plains in San Luis Obispo County to the vicinity of San Bernardino. USC&GS measurements in 1944 and 1963 indicate movement of 3.0 cm/year south of Hollister (Meade, 1965). The Department's program indicates about 4 cm/year between 1959 and 1968. The USC&GS indicates little movement on the San Andreas and Hayward faults near Hayward between 1957 and 1963 (Pope et al, 1966). The Department's program also shows little movement between 1961 and 1963, but indicates that movement then began on the San Andreas and Hayward

faults and that previously observed small movements on the Calaveras ceased. Total movement across the three faults remained at about 4 cm/year.

7. This program, as a pioneering effort, has continually sought to upgrade its techniques and procedures. Although a considerable measure of success has been achieved, there is still room for improvement. Following are several promising areas for further enhancing the effectiveness of this program.

a. Improve the California fault monitoring network by installing systems of closed figures where possible, particularly in active zones.

By measuring closed geometrical patterns of lines rather than single lines, accuracy is more precisely assessable and is improved. Astronomic azimuths should be observed with these networks and they should be tied to the National Geodetic Control network. This allows large regional movements to be distinguished from local ones. Because the closed figures cover more area than single lines, additional knowledge of earth strain patterns in the vicinity of active faults can be obtained.

b. Increase the frequency of Geodimeter observations to improve earthquake warning capability.

Fault movement rate changes often precede earthquakes. The present average of one measurement per year for each Geodimeter line, however, is too infrequent to fully assess the nature and magnitude of these anomalies. A more intensified effort in terms of both number of lines and frequency of observations should be undertaken. When precursors are observed, the area should be continuously monitored to more closely warn of the expected time of earthquakes.

c. Development of laser techniques should be actively pursued to increase the accuracy and reduce the costs of fault monitoring.

Consideration should be given to development of new instrumentation for fault monitoring. The Model 2 Geodimeter can be used only after sunset and requires supplementary equipment to measure changes in atmospheric variables that affect the machine's operation. Moreover, increasing smog levels are making long Geodimeter measurements increasingly difficult. The Department has cooperated with North American Aviation, Inc., which is seeking to develop laser techniques for distance measurement. Such an instrument could be used at any time of the day or night and without measurement of atmospheric variables. This would increase accuracy and reduce the cost of monitoring activities. More powerful instruments will eventually be necessary and all avenues for applying laser techniques should be explored.

CHAPTER III. FAULT MOVEMENT IN AREAS OF INVESTIGATION

Movement of the San Andreas fault system has been monitored from the San Francisco area to south of San Bernardino. Measurements include the Hayward and Calaveras faults in the San Francisco Bay area, the White Wolf and Garlock faults in the Tehachapi Mountains area, and recently, the San Jacinto fault near San Bernardino, as well as the main San Andreas zone and smaller associated fractures.

Measurements in 1959 and 1960 are generally thought to be less accurate than those of later years because midline balloon measurements, a computer program, and other refinements were not all in effect.

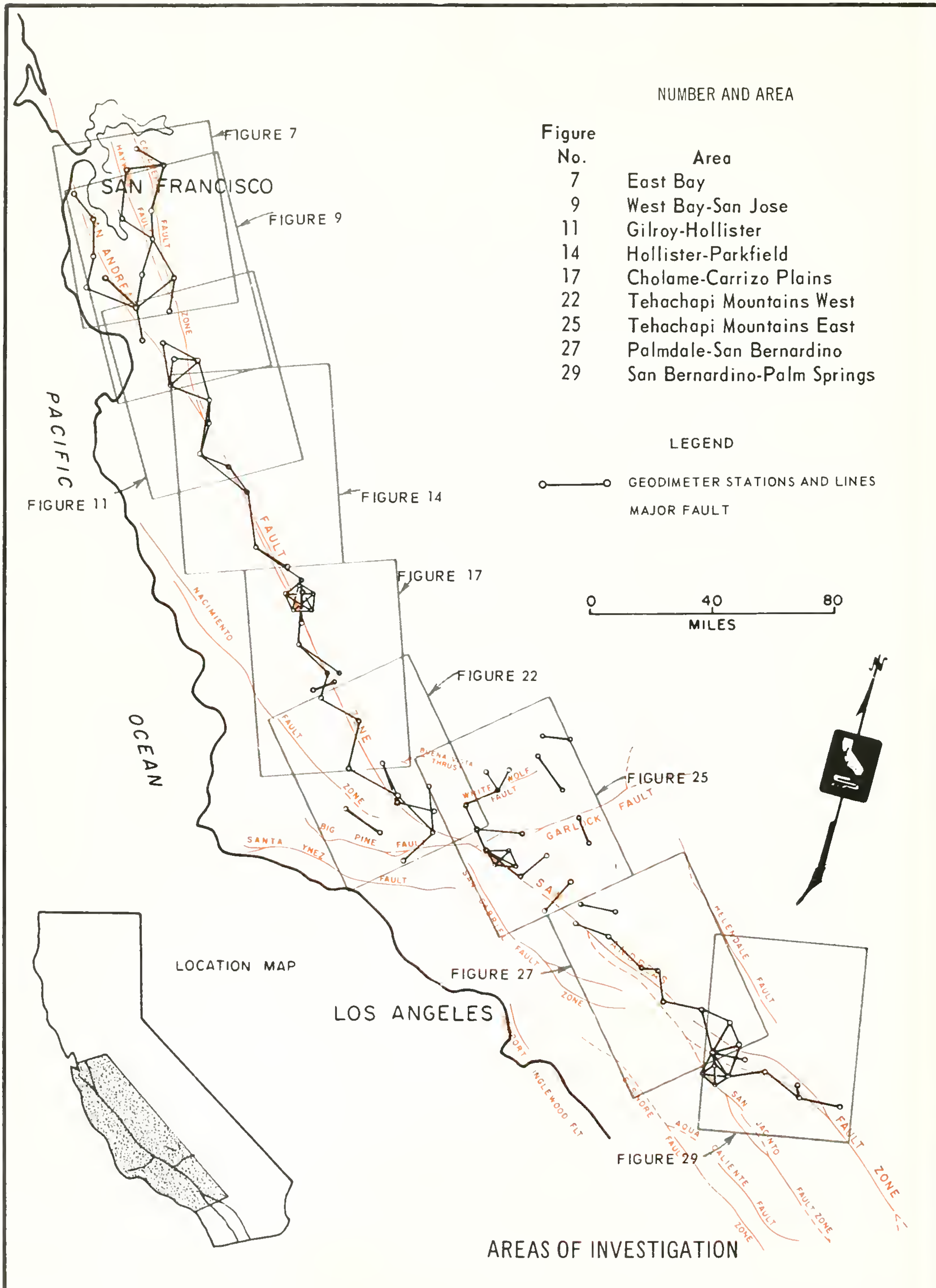
"Movement" in this report refers to a possible combination of fault creep or slippage, and strain or distortion of the earth's surface.

Methods of Data Presentation

Graphs of the behavior of the better lines in each area covered by the Geodimeter program are presented and the general movement of the faults are discussed in this chapter. An assessment of measurement problems for each area is given. More detailed discussions of line behavior are given in the following chapter on earthquake prediction.

Each description includes a map of faults, Geodimeter lines and earthquakes. Figure 4 is an index map for the areas investigated.

The Geodimeter lines associated with each area discussed in the text are represented by solid lines on the respective area map; other Geodimeter lines on each map are dashed. The lines are numbered to correspond to those in the computer listing, Appendix A.



AREAS OF INVESTIGATION

Faults on the area maps are taken directly from the Earthquake Epicenter and Fault Map of California published by the California Department of Water Resources in 1964.

Earthquakes

Area maps identify earthquakes occurring between 1959 and 1966 whose epicenters lay within 20 miles of the Geodimeter lines and whose magnitudes exceeded 3.5. Most 1967 shocks of magnitude greater than 4.5 are also included. To reduce clutter, the maps show only the main shocks of the 1966 Parkfield series. Appendix B lists other 1966 Parkfield earthquakes. Area maps also locate an occasional earthquake of more distant epicenter or smaller magnitude which early USC&GS data placed within the area of study. In such cases, the epicenter appears as located by more recent data supplied by the seismograph station networks of the University of California at Berkeley and the California Institute of Technology, unless specifically labeled "USC&GS". The seismic stations in these two networks, being more closely spaced than those of the USC&GS network, provide more detailed data than do the USC&GS stations. In the area between networks, an average of the two most closely agreeing epicenters is used unless otherwise indicated.

Data of the University of California at Berkeley was obtained from the quarterly Bulletin of the Seismographic Stations; that of the California Institute of Technology, from its Seismological Laboratory Bulletins of Earthquakes in Southern California; that of the USC&GS, from its PDE (Preliminary Determination of Epicenter) cards, MSI series (Monthly Seismological Bulletins), MSA series (Quarterly Abstracts of Earthquake Reports), and its annual series, United States Earthquakes.

Estimates of magnitude and location reported in these publications vary sometimes because the number of significant figures of the data differ--more often, because seismic records from different stations were used. When more than one agency reported, differences in location of earthquakes averaged about 18 miles and differences in magnitude estimates averaged about 0.35 magnitude units--the greatest being 1.1 magnitude units.

Earthquake data from the University of California and the California Institute of Technology are plotted on the maps in the areas occupied by their respective seismograph station networks.

Epicenters of shocks larger than M=4.5 on the area maps are identified with a series of numbers corresponding to the month, day, year and Richter magnitude respectively. Those between M=3.5 and 4.5 are labeled with the month and year only.

Graphs of Geodimeter Line Length Changes

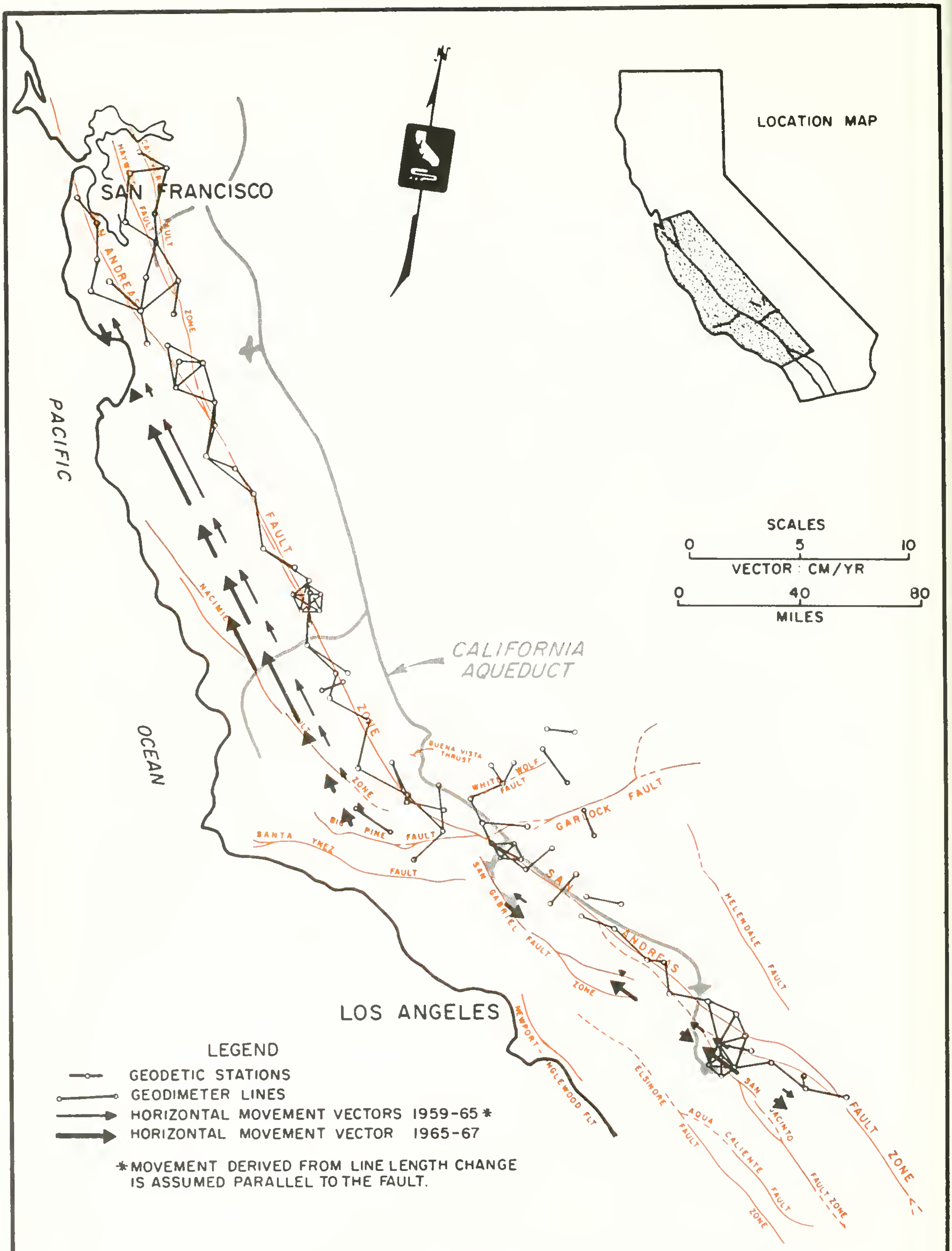
Graphs of deviations from the initially measured length of the Geodimeter lines are plotted. Positive length changes represent an increase in length; negative ones, a decrease. The straight lines connecting measurements on the graphs do not necessarily mean that length change occurred at a uniform rate throughout the interval between two measurements. For example, on Figure 15, the graph for Line 31 shows a marked deviation in 1966 and Line 32 does not, even though the lines are very close together. The reason for this apparent difference is that a measurement on Line 31 detected this deviation; but no 1966 measurement was made on Line 32. This consideration will be of some importance in Chapter IV, Earthquake Prediction. Occasionally the text discusses lines in adjacent areas.

The graphs are numbered to correspond to the Geodimeter lines. An earthquake is indicated by a short, vertical line plotted at the time of occurrence; if of Magnitude 4.5 or greater, it is represented by a heavier line and is labeled with its magnitude. Earthquakes of $M \geq 5$ are indicated on all lines within 15 miles; those of magnitudes from 4.5 - 4.9, within 5 miles--the normal ranges of effect. These shocks are also indicated on additional lines crossing the associated fault system as far as an effect is perceived (up to about 80 miles). Only eight shocks of $M \geq 4.5$ were more than 5 miles from a major fault. These are indicated on the nearest lines but with a question mark added. Shocks of $M < 4.5$ are indicated only on lines within 5 miles.

The radius of each small circle on the graphs represents the 50% probable error of observation for the particular length determination. Most are based upon at least 12 measurements taken on two different dates, usually within a few days of each other. The probable error circles are to the same scale as the length changes. Bomford (1962), Page 509, states that there is a probability of only one in twenty that the actual error can exceed three times the probable error. These are further discussed in Chapter VI, Estimates of Accuracy.

Summary of Fault Movement

Average annual movement for the period 1959-65 and 1965-67 shows changes in the pattern of fault movement (Figure 5). The movement vectors, based on nearby Geodimeter lines (as in Figure 21) are calculated assuming movement is parallel to the fault. This assumption is probably less valid south of the Tehachapi Mountains than to the north. However, even here the vectors provide an indication of changes in activity between the two periods of time.



AVERAGE ANNUAL FAULT MOVEMENT, 1959-65 AND 1965-67

Only lines across the San Andreas were used. Where rates on adjacent lines were nearly the same, a representative value was used to provide a less cluttered appearance.

Movement of the earth near the San Andreas fault system changes with location as well as time.

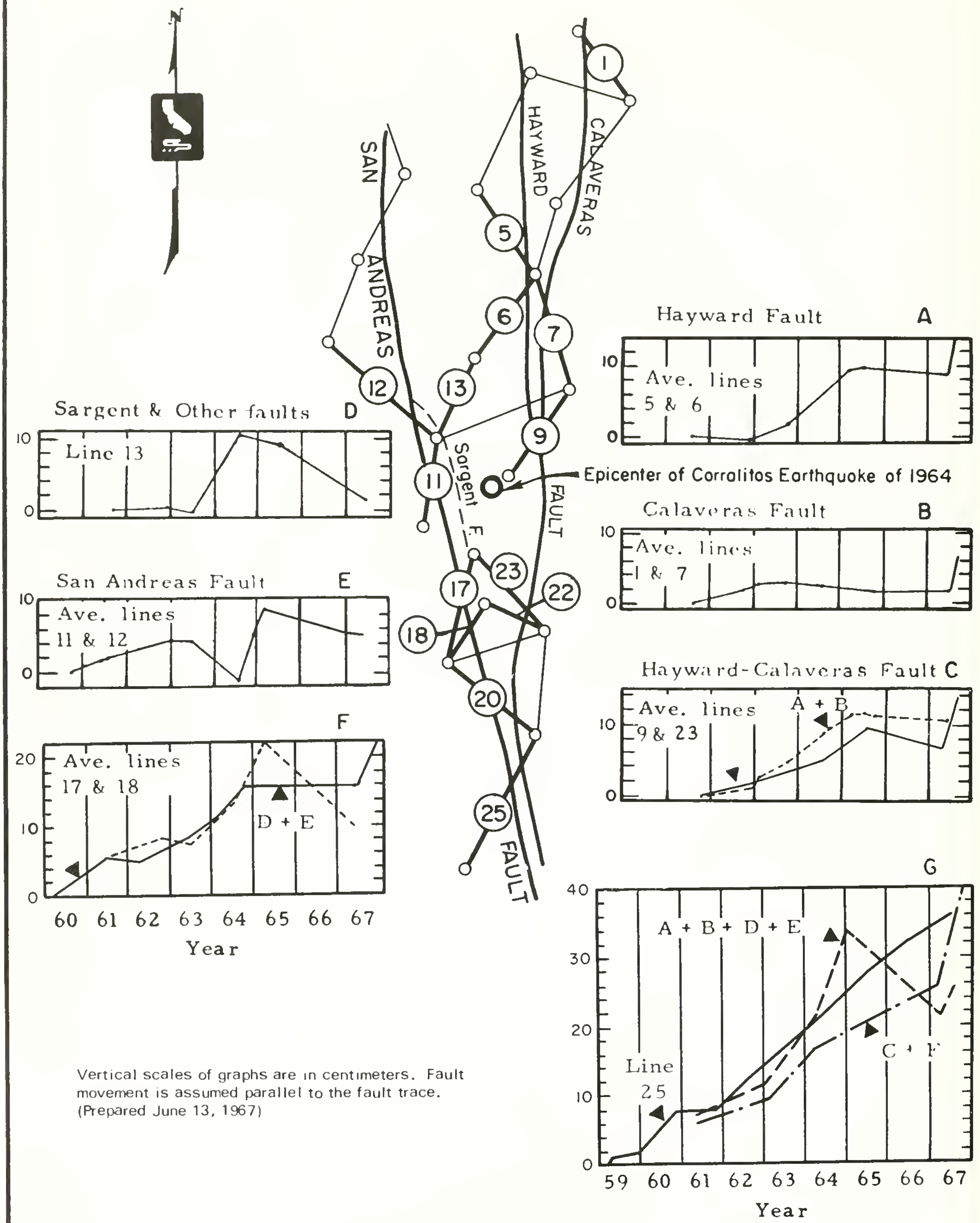
Visible damage and distortions in man-made structures across these faults verify that much of this movement is slippage of one side of the fault past the other. Examples of structures damaged by fault slippage are discussed, for example, by Steinbrugge (1960), and Cluff (1966). A brief discussion follows on differences in activity between fault segments north of Hollister and those south of it.

North of Hollister

The description of fault movement in this region is based on findings explained in more detail under later sections of this chapter: East Bay, West Bay-San Jose and Gilroy-Hollister areas. Movement is distributed among three faults--the San Andreas, Hayward and Calaveras. Other faults have also shared some of the regional movement. The total movement--over 4 cm/year from 1959 to 1968--matches that near Hollister to the south where the three faults merge.

The distribution of movement among the faults is depicted on Figure 6. The movement (assumed parallel) along each of the major faults was calculated from changes in the lengths of appropriate Geodimeter lines.

In Figure 6G, Line 25 indicates a steady rate of movement of over 4 cm/year. To the north, however, the sum of movements (A +B +D +E) in Figure 6G rapidly reversed in 1965.



Vertical scales of graphs are in centimeters. Fault movement is assumed parallel to the fault trace. (Prepared June 13, 1967)

CUMULATIVE FAULT MOVEMENT, SAN FRANCISCO BAY REGION

This phenomenon is not unusual. In 1964, similar activity occurred on Lines 11 and 12, as shown in Figure 6E. Line 13, which does not cross the San Andreas fault, shortened rapidly, indicating a relative northward movement of the Santa Cruz Mountains, which are bounded by the San Andreas and an extension of the Sargent and other faults. The San Andreas fault may have locked between Lines 17 and 11, driving the Santa Cruz Mountains northward, causing movement on the extension of the Sargent fault and a temporary reversal of the normal direction of movement on the San Andreas fault as measured by Lines 11 and 12.

After the Corralitos earthquake in 1964, to the east of Line 11, Line 13 slowly returned to its original length, suggesting that the earthquake resulted in unlocking of the San Andreas fault, which released the stress applied to the Santa Cruz Mountains and allowed them to return to their original position. Lines 11 and 12 quickly assumed lengths about equal to those that would have resulted had the usual right-lateral movement continued without interruption by the Corralitos episode.

In 1965, however, a reversal again appears in the combined average movement of Lines 11 and 12. Line 13 did not react as it had previously, but the line extending from the juncture of Lines 11 and 13 to that of Lines 7 and 9 shortened in 1965 (Line 10, Figure 9). This suggests that another fault further east than the end of Line 13 could be moving. The 1965 anomalies, however, also involve the East Bay faults, Figure 6C (A+B). This, coupled with similar anomalies in the southern part of the State, might suggest a different kind of episode than seen previously, or these phenomena may only be occurring fortuitously at the same time.

Earthquakes of near Magnitude 5 occurred in the San Francisco Bay area. Two were near Corralitos, 9/7/67 and 12/18/67, and one near Mt. Hamilton (at the juncture of Lines 7 and 9) on 9/28/67. In general, the usual right-lateral fault movement in the San Francisco Bay area has resumed. See "Mt. Hamilton Earthquake 1967" in Chapter IV for additional details.

South of Hollister

South of Hollister, the fault movement rate diminishes until it is almost indiscernable just south of Cholame.

The zone of little movement extends from just south of Cholame to the vicinity of the bend in the San Andreas near the intersection of the Garlock fault. Here there is evidence of approximately north-south compression and accompanying east-west extension. Still further south near San Bernardino and Palm Springs, the pattern is even less clear, suggesting north-south compression and some possible fault slip but no evidence of east-west extension. The area has many thrust faults which may be responding to compressive forces. This could account for the observed line length changes.

The steady decrease of movement along the San Andreas south from Hollister had persistently contained a small anomaly--a zone of smaller average movement rate than adjacent zones. The Parkfield earthquakes of 1966 were accompanied by an interval of rapid fault slip in this area, which more than compensated for the deficiency in movement rate. The 20 cm of movement along the fault near Parkfield, when averaged with previous annual measurements from 1959, resulted in an average annual movement rate equal to that just south of Hollister, the largest observed. This left only a small zone between Cholame and the San Francisco Bay area (near San Benito) with an average annual movment rate less than 4 cm/year for the interval 1959-1966.

East Bay Area (Figures 7 and 8)

The Hayward and Calaveras faults angle southeastward through the East Bay communities, merging south of Mt. Hamilton to form the Calaveras-Hayward fault. This fault continues through the city of Hollister, which is located south of the region shown on Figure 7. If movement is assumed parallel to the faults, the Calaveras-Hayward has averaged about 3 cm/year right-lateral. This movement is distributed between the Hayward and the Calaveras to the northwest. The rate and distribution vary with time, but the Hayward fault has moved more than the Calaveras.

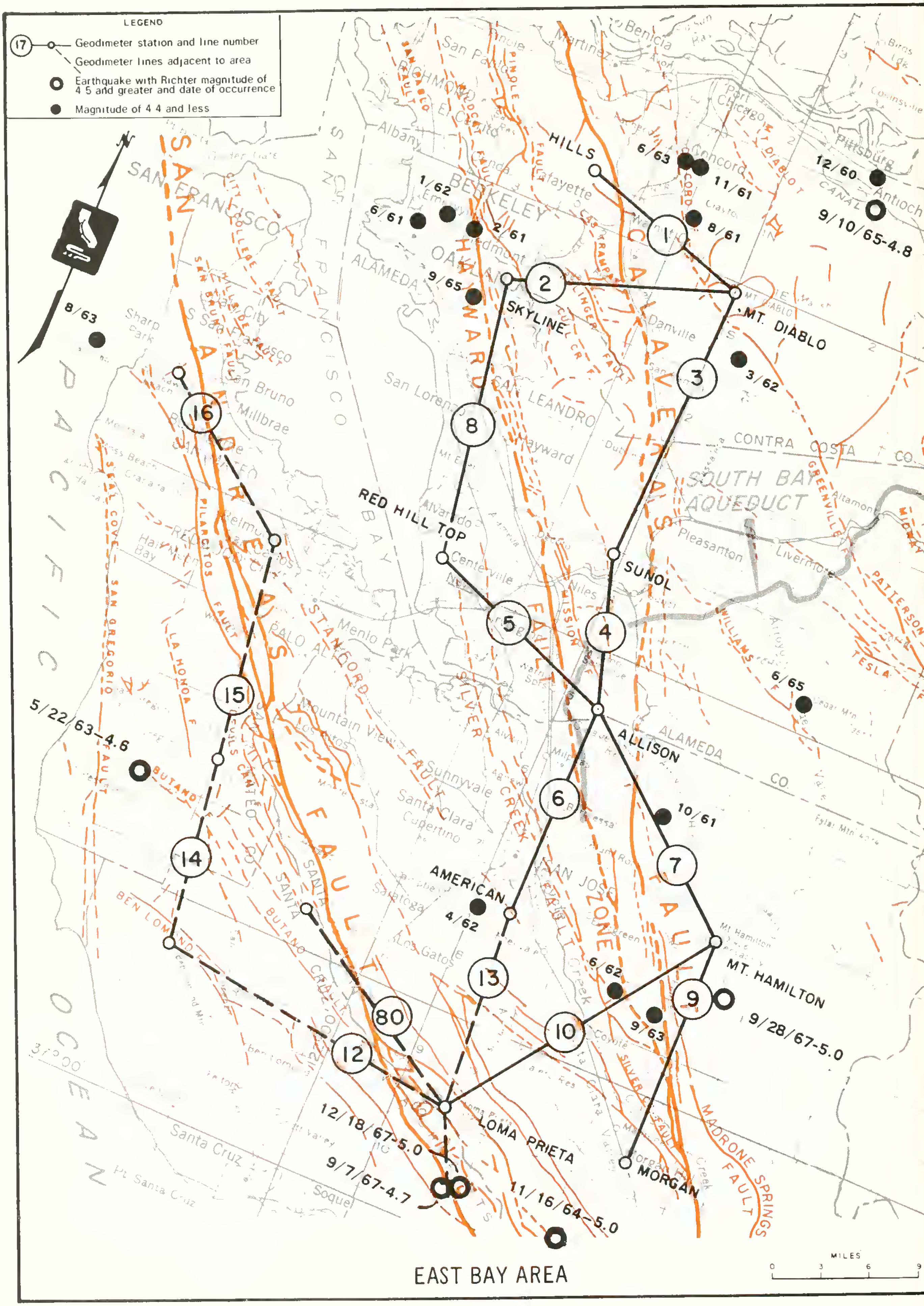
A summary of Geodimeter lines in the East Bay area follows:

Line No.	Station Mark Names	Faults Crossed
5	Allison-Red Hill Top	Hayward fault
6	Allison-American	" "
1	Mt. Diablo-Hills	Calaveras fault
2	Mt. Diablo-Skyline	" "
3	Mt. Diablo-Sunol	" "
7	Mt. Hamilton-Allison	" "
9	Mt. Hamilton-Morgan	Both Hayward and Calaveras faults
10	Mt. Hamilton-Loma Prieta	" "

Line 4, Allison-Sunol, lies between the Hayward and Calaveras faults.

Line 8, Skyline-Red Hill Top. No measurements have been made.

Line 3, Mt. Diablo-Sunol. Results are not plotted because of doubtful validity. Station Sunol temperatures generally are characteristic of Bay area weather. Mt. Diablo is more influenced by Sacramento-San Joaquin Valley weather. The line is too high for midline temperature sampling with the balloon. Measurement data are tabulated in Appendix A.

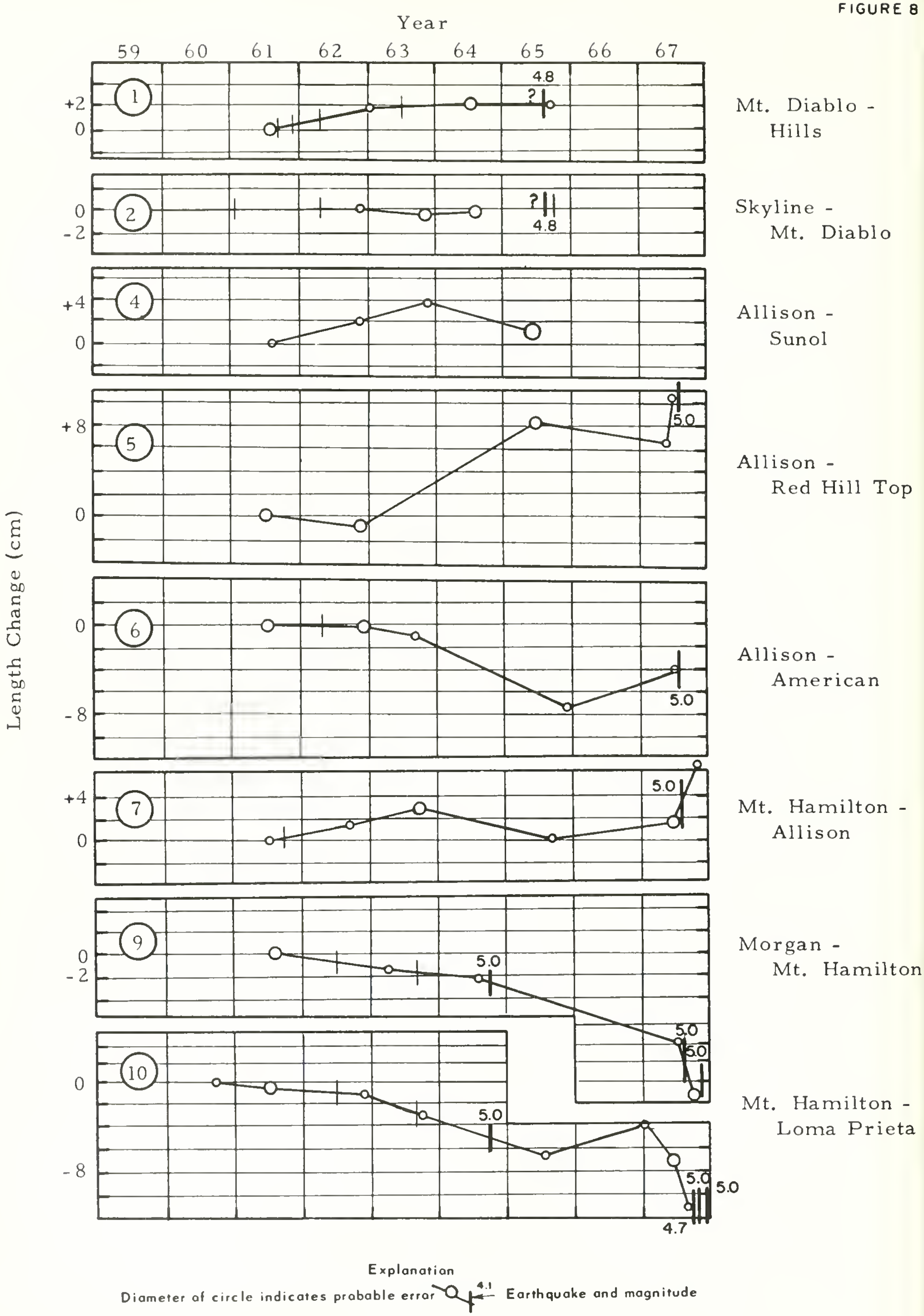


EAST BAY AREA

Lines 1 and 7, crossing the Calaveras fault, indicate right-lateral distortion (i. e., the terrain across the fault from the observer moves to the right) from 1961 to 1963, though differences are small. Lines 9 and 10, which cross both the Calaveras and Hayward faults, indicate similar movements. During the same interval, little, if any, activity is indicated on the Hayward fault. More recent measurements since 1963 indicate a significant increase in movement on the Hayward fault and little or no motion on the Calaveras fault. Length changes on Lines 5 and 6 indicate the Hayward fault moved about 10 cm between 1963 and 1965, if movement is assumed parallel to the fault. Motion began after a period of quiescence without an accompanying earthquake on the Calaveras-Hayward system as might have been expected. This movement may be related to the 1964 Corralitos episode. Movement from the San Andreas fault could have been transferred to the Calaveras-Hayward system as well as the Sargent fault.

Line 4 in the East Bay area (Figures 7 and 8) and Line 14 in the West Bay area (Figures 8 and 9) have approximately the same azimuth and neither cross major faults. These lines lengthened during the period that the Hayward fault was apparently inactive and returned to their original lengths when motion began on the Hayward. Thus, these changes appear related to the general strain pattern in the Bay area and are only indirectly influenced by slippage on faults.

Results of USC&GS triangulation observations in the East Bay region indicate movement on the Hayward fault of approximately one foot between 1951 and 1957, with little or no movement between 1957 and 1963 (Meade, 1965, pp. 13, 14). Radbruch (1968, in press) summarizes visible evidence of movement on the Calaveras fault.



LINE LENGTH CHANGES, EAST BAY AREA

There also appears to be a time-varying relationship between the Geodimeter measurements and observed creep on the Hayward fault. Cluff (1966) reports that no cultural damage or dislocations could be ascribed obviously to creep on the Hayward fault after 1957. The June 1967 Geodimeter measurement indicates that no additional movement has occurred since 1965, although creep-recorder observations in a drain tunnel at the University of California at Berkeley indicate movement continues sporadically across the fault (Bolt, 1966). It may be that strain produced by movement of basement rock on either side of the Hayward fault is gradually released in the alluvium above the fault.

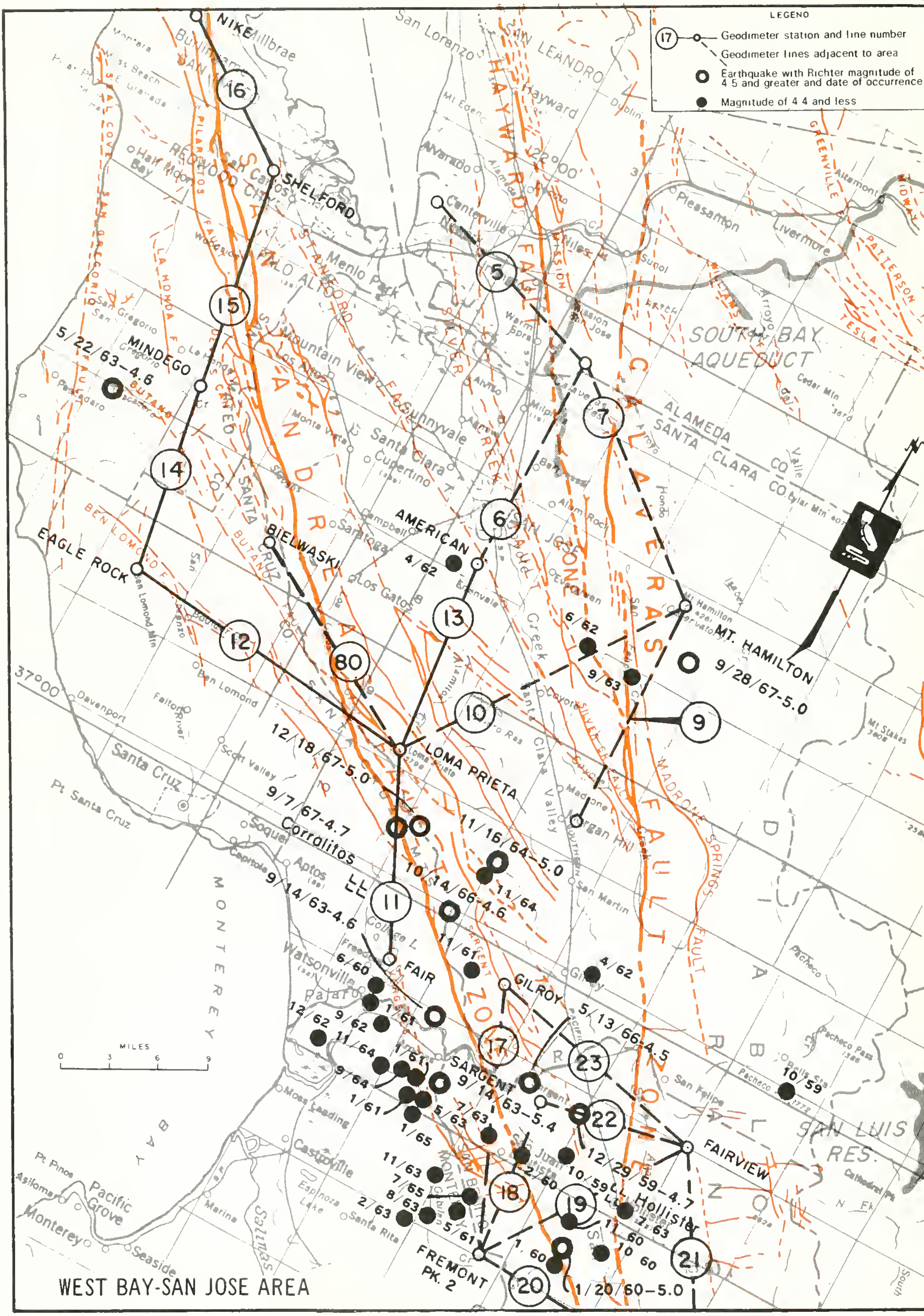
West Bay-San Jose Area (Figures 9 and 10)

> The San Andreas fault is the principal feature with some activity occurring on the Sargent and its northwestward extension around the base of the Santa Cruz Mountains. Movements on these faults are strongly influenced by earthquakes in the vicinity of Corralitos but are generally in a right-lateral sense over a period of several years.

Four lines radiate from Loma Prieta, one of the higher peaks in the Santa Cruz Mountains, south of San Jose. Two of these, Line 11 (Loma Prieta to Fair) and Line 12 (Loma Prieta to Eagle Rock) cross the San Andreas fault. Line 13 (Loma Prieta to American) crosses several lesser faults which lie between the San Andreas and the city of San Jose. Line 10 (Loma Prieta to Mt. Hamilton) crosses these same faults and the Hayward-Calaveras fault system (see Figures 9 and 10).

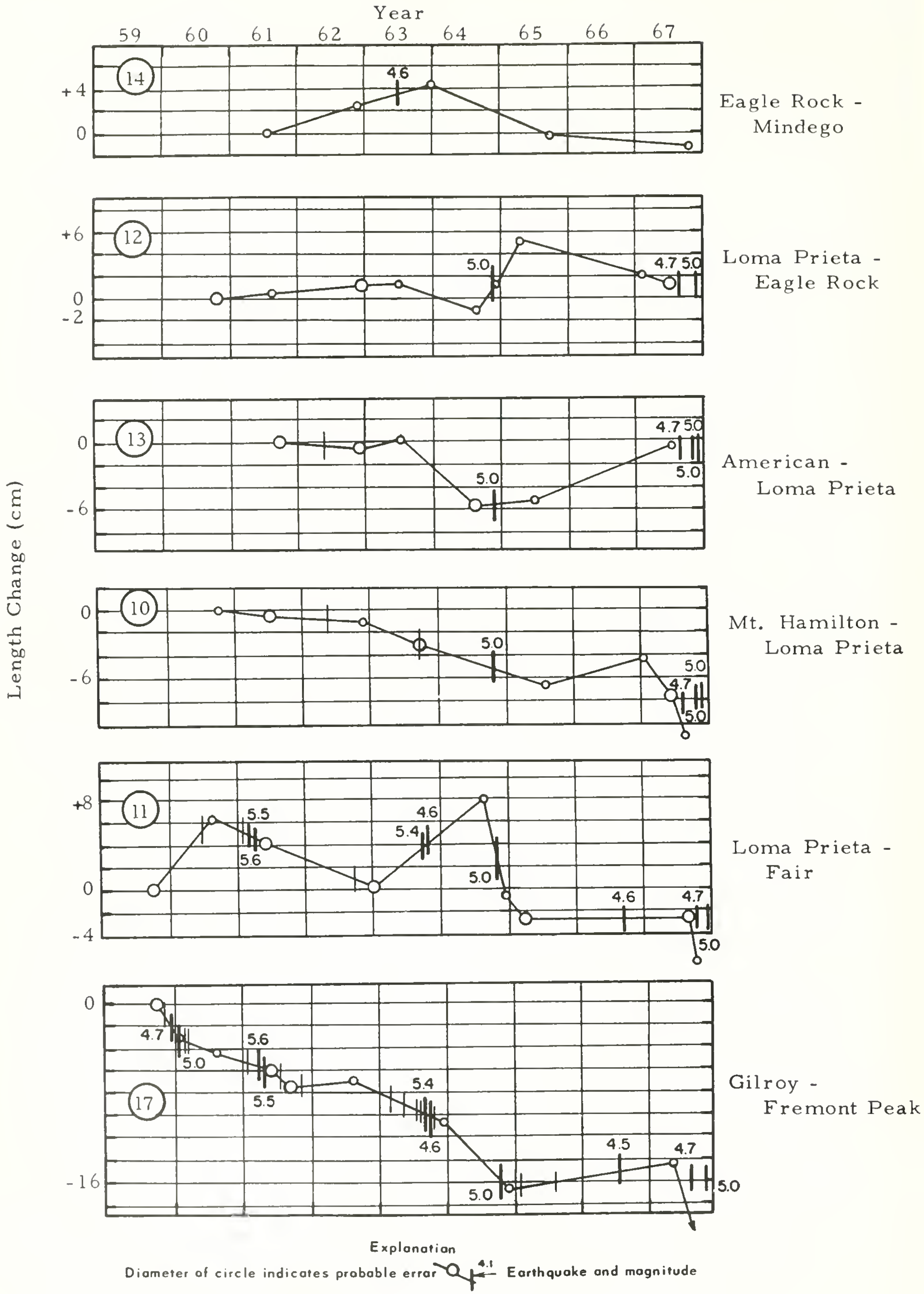
Line 10 has generally shortened, as would be expected from cumulative right-lateral distortion of the Calaveras-Hayward fault system.

FIGURE 9


LEGEND
Geodimeter station and line number
Geodimeter lines adjacent to area
Earthquake with Richter magnitude of 4.5 and greater and date of occurrence
Magnitude of 4.4 and less
MILES
0 3 6 9
WEST BAY-SAN JOSE AREA
NIKE
SHELFORD
MINDEGO
EAGLE ROCK
BIELWASKI
AMERICAN
LOMA PRIETA
MT. HAMILTON
FAIR
GILROY
SARGENT
FAIRVIEW
FREMONT PK. 2
5/22/63-4.6
9/28/67-5.0
12/18/67-5.0
9/7/67-4.7
11/16/64-5.0
10/14/66-4.6
9/14/63-4.6
5/13/66-4.5
9/14/63-5.4
12/29/59-4.7
1/20/60-5.0
SAN ANDREAS FAULT
HAYWARD FAULT
CALAVERAS FAULT ZONE
SARGENT FAULT
SOUTH BAY AQUEDUCT
ALAMEDA CO
SANTA CLARA CO
MONTEREY BAY
SAN LUIS RES.
Santa Cruz
Watsonville
Hollister
San Jose
Monterey
Corralitos
37°00'
122°00'

Of the two lines crossing the San Andreas, Line 12 is considered the better line. Line 11 has about 4,000 feet of elevation difference between ends, which makes adequate temperature sampling more difficult.

The lines from the Loma Prieta station showed unusual behavior prior to the Corralitos earthquake of 1964. An explanation is offered in Chapter IV, Earthquake Prediction. Most of the movement can be attributed to fault slip; however, Line 14, entirely on the coastal side of the San Andreas, appears to have lengthened prior to the earthquake. Movement on the San Andreas after the earthquake, as evidenced by the length changes on Lines 11 and 12, may have relieved this tension. Data from Lines 15 and 16 could indicate whether the earthquake relieved the suspected strain. Unfortunately, movement on the fault to the north cannot be accurately checked because Lines 15 and 16 (Figure 7) are steep lines, descending from mountain peaks cooled by ocean winds, into the thermally stratified air of the enclosed San Francisco Bay area. The steep-wooded hillsides, prevalent fog, and dense aircraft traffic make midline temperature sampling with a balloon nearly impossible. Most of the distance along these lines could be close to either end temperature, which temperatures often differ by 10°C. Hence, the average temperature calculated from end point measurements could be in error by 5°C., and could account for a 5 cm distance measurement error on a 10 km line. Measurements of Lines 15 and 16 are included in the computer listing but are not considered reliable.



LINE LENGTH CHANGES, WEST BAY-SAN JOSE AREA

From 1960 to 1965, shortening of Line 17 suggests movement parallel to the fault of about 15 cm or about 3 cm/year. This compares well with the sum of movements across the faults to the north as evidenced by Lines 11, 12 and 13. If movement is considered parallel to the San Andreas fault, it averages a little over 3 cm/year at both Loma Prieta and near Line 17. After 1965, however, Line 12 again shows an apparent reversal and Line 17 indicates little movement to mid-1967 (see Figure 10). The fault, apparently stuck, resumed its normal direction of movement after an earthquake in late 1967. This is discussed in Chapter IV, Earthquake Prediction.

Thus, within a short segment of the San Andreas fault, a few miles northeast of Watsonville, movement has recently stopped and apparently reversed direction. Prior to the Corralitos earthquake of 1964, a similar apparent reversal also occurred because movement was transferred to the Sargent and other faults. Line 10 now shows an unusual shortening, in much the same manner as Line 13 had previously, suggesting the possibility that movement has been transferred to the Stanford or other fault in the vicinity. Another possibility is that movement north of Hollister has all but stopped and the area is under compression. New measurements are needed on several lines to resolve these possibilities.*

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*Earthquakes occurred near Corralitos, M = 4.7, September 1967 and south of Mt. Hamilton, M = 5, September 28, 1967, after completion of this manuscript. The normal direction of movement may have resumed as a consequence. Such a trend can be seen in October 1967 measurements, Appendix A.

Gilroy-Hollister Area (Figures 11 and 12)

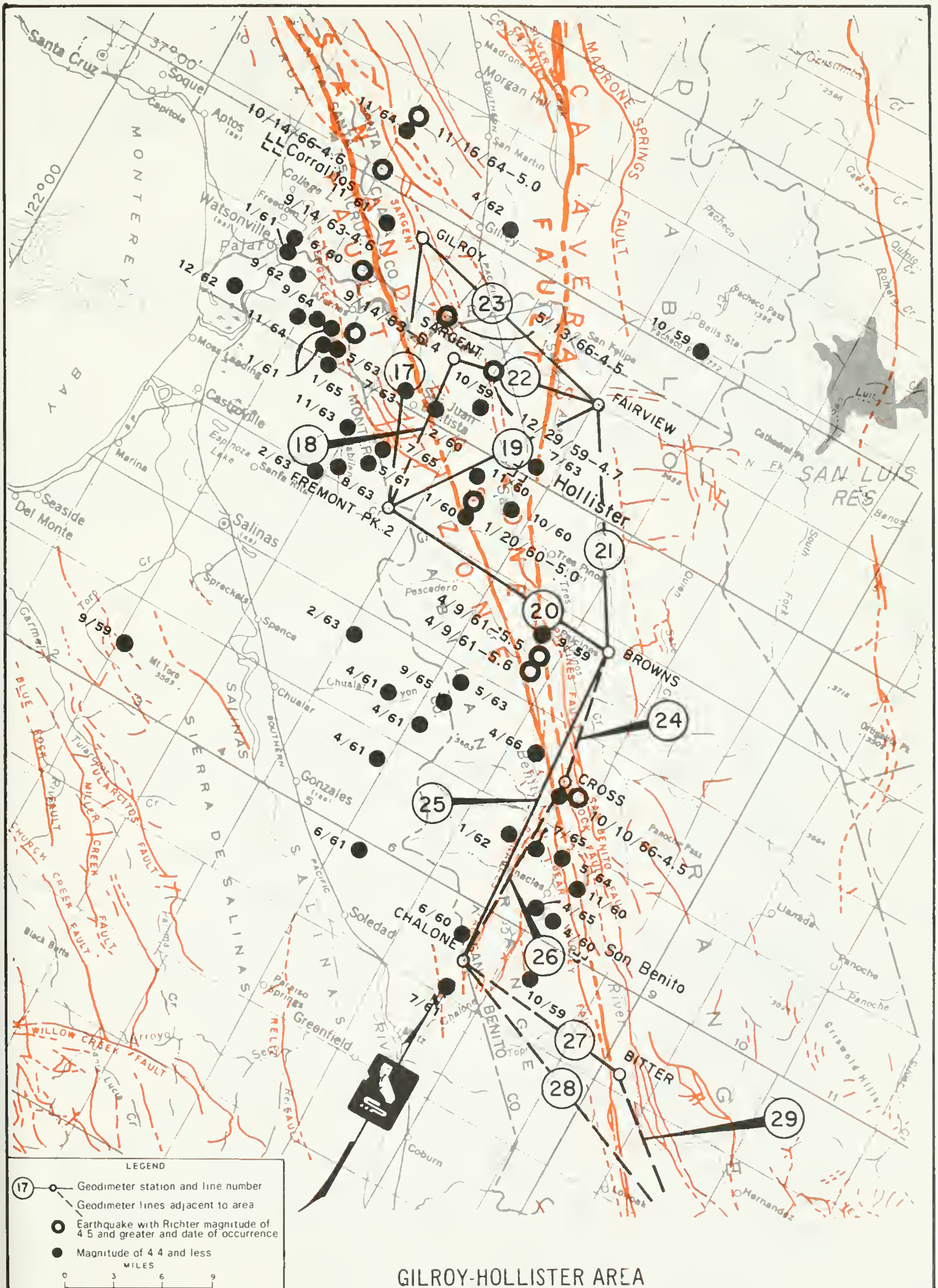
> The San Andreas and Calaveras-Hayward faults merge just south of Hollister. The movement rate is about 4 cm/year across the San Andreas in this vicinity. The Sargent fault also exhibits activity in this area. Earthquakes are frequent and fault movements somewhat irregular.

At least three active faults contribute to length changes on the several lines in the area. The movement of these faults apparently merges into the San Andreas zone south of Hollister. Movement across the system has been relatively large, about 4 cm/year for the interval 1959-1967. There have been several earthquakes associated with changes in the line lengths.

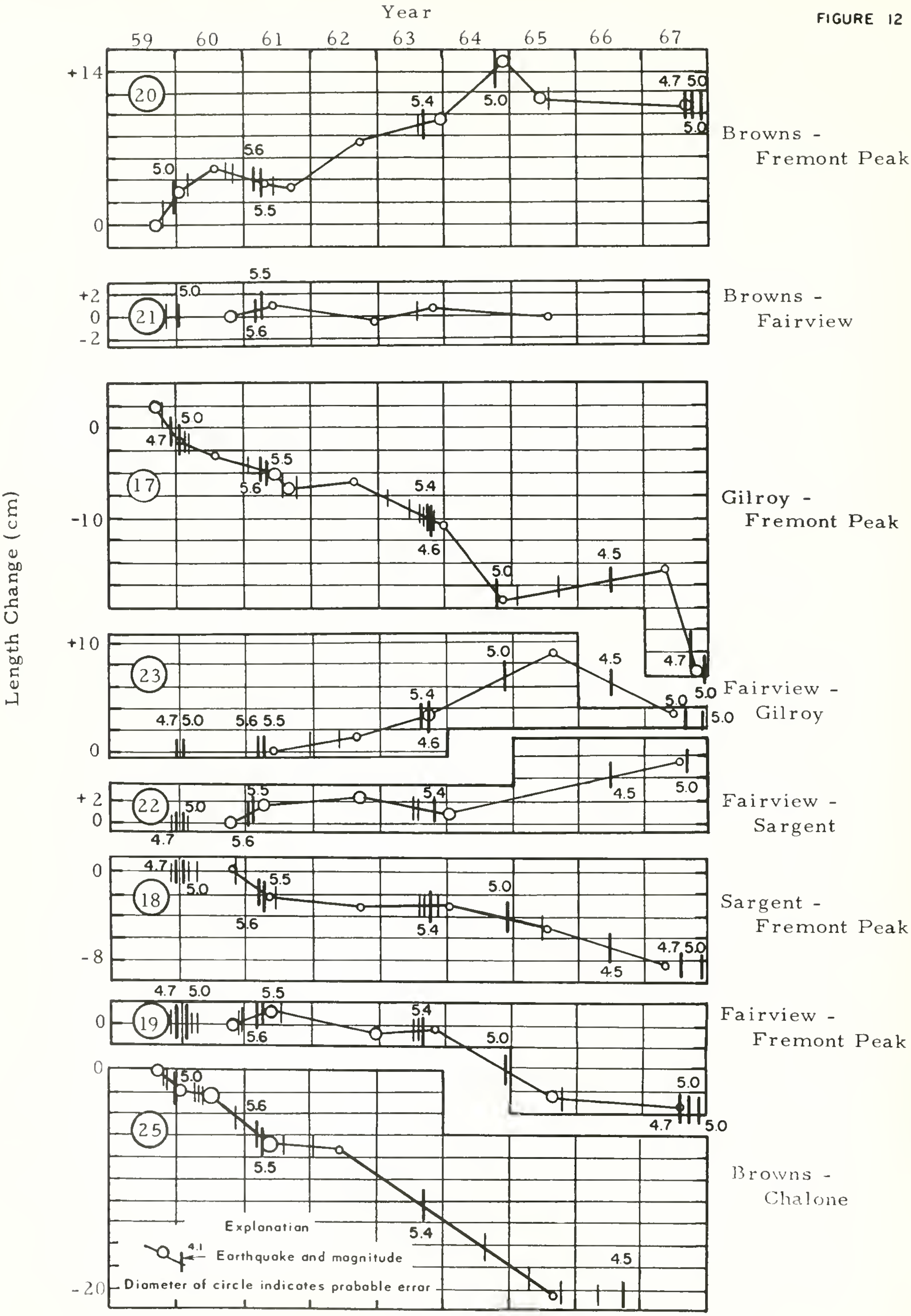
The area map and graphs of length change are shown in Figures 11and 12. Lines in the area are:

Line No.	Station Mark Names	Faults Crossed
17	Gilroy-Fremont Peak	San Andreas; Sargent
18	Sargent-Fremont Peak	San Andreas
19	Fairview-Fremont Peak	San Andreas; Hayward (perpendicularly)
20	Fremont Peak-Browns	San Andreas; Hayward
21	Browns-Fairview	None
22	Fairview-Sargent	Hayward; Sargent?
23	Fairview-Gilroy	Hayward
24	Browns-Cross	Part of San Andreas zon
25	Browns-Chalone	San Andreas
26	Cross-Chalone	Part of San Andreas zon

The average rate of movement, assumed parallel to the San Andreas fault, from December 1960 to December 1964 as measured by Line 17 which crosses both the Sargent and San Andreas faults is 3.4 cm/year and 1.5 cm/year as measured by Line 18 which apparently crosses only the San Andreas. This suggests that some movement was taking place on the Sargent fault, although not



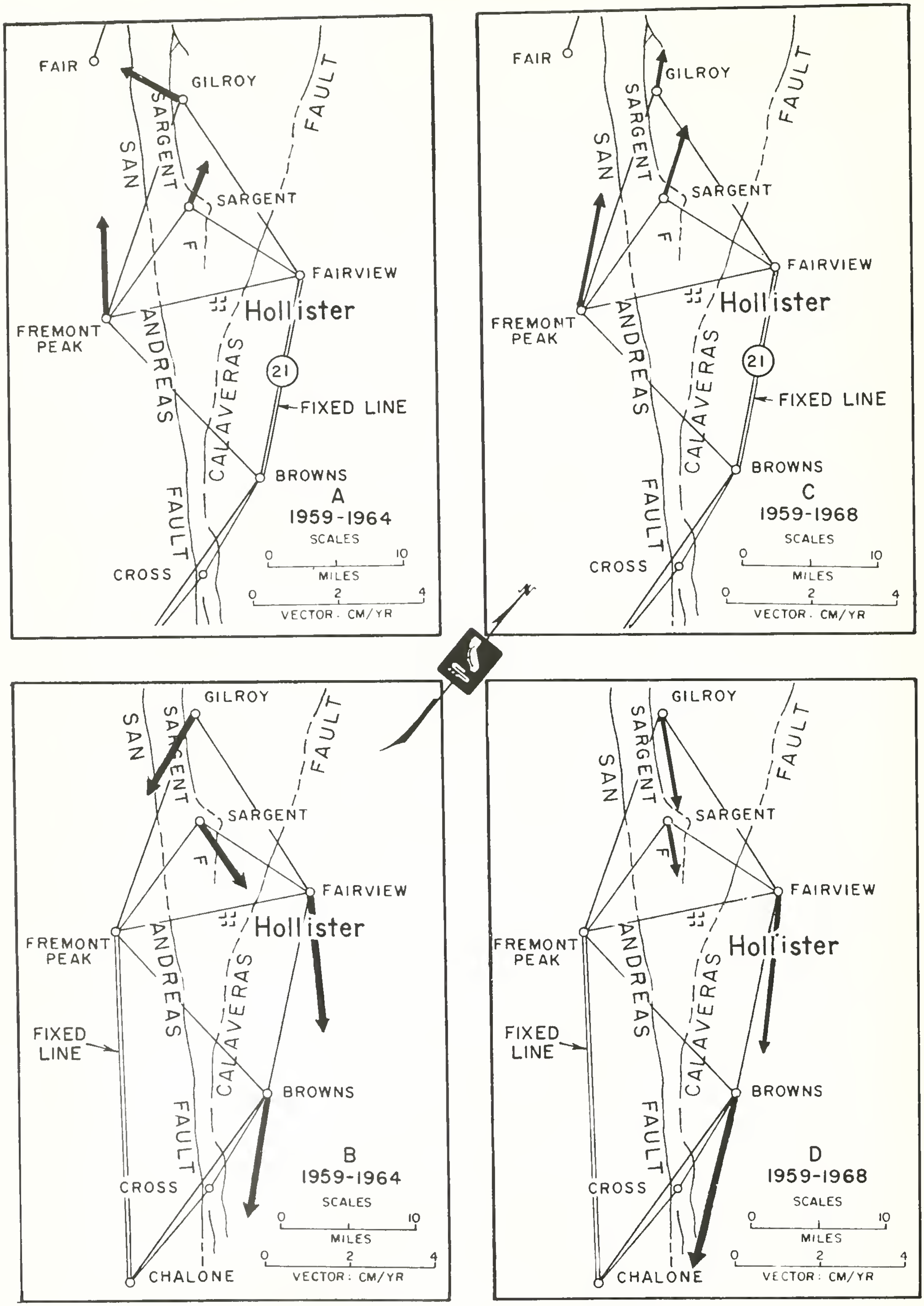
GILROY-HOLLISTER AREA



LINE LENGTH CHANGES, GILROY-HOLLISTER AREA conclusively because vectors are not exactly parallel to the fault. The northward extension of the Sargent fault around the base of Loma Prieta (Figure 9) in the Santa Cruz Mountains was also involved during the 1964 Corralitos earthquake. This extension is apparently unnamed and has been identified as a part of the many small faults merging with it. After the Corralitos earthquake, movements were again re-sorted among the many faults in the area resulting in about the same average movement rates from 1959 to 1967, as indicated by Lines 17 and 18. Line 23 indicated a large change rate on the Hayward-Calaveras fault. This movement seems to have accelerated when movement commenced on the Hayward fault in 1963. See graph for Lines 5 and 6 (Figure 8).

Movement vectors for the interval 1959-1967 can be roughly derived for the area by assuming one line of the network remains fixed. One solution results from holding Line 21 (Browns to Fairview, Figure 13A and 13C); another, by holding the unmeasured distance between stations Fremont Peak and Chalone (Figure 13B and 13D). In either case, the movement vectors are roughly parallel to the fault, with the exception of station Sargent near the end of the Sargent fault. However, between 1959 and 1964, movement vectors near both stations Sargent and Gilroy deviate strongly from the fault orientation. This suggests the existence of strain or movement on the Sargent fault which appears to have been reduced after 1964, apparently a consequence of the 1964 and 1967 Corralitos earthquakes.

Non-uniform line length variations associated with earthquakes are superimposed on the general trend of Lines 17, 20 and 25 (Figure 12). Earthquakes over Magnitude 4 are plotted on Figure 11. Measurement of



MOVEMENT VECTORS HOLLISTER QUADRILATERAL

Line 20 (Browns to Fremont Peak) after the April 1961 Magnitude 5.6 earthquake appears to indicate a reversal in direction of San Andreas movement. Measurements of Line 25 (Browns to Chalone) after the earthquake indicated that this line had almost ceased moving. No simple explanation is obvious.

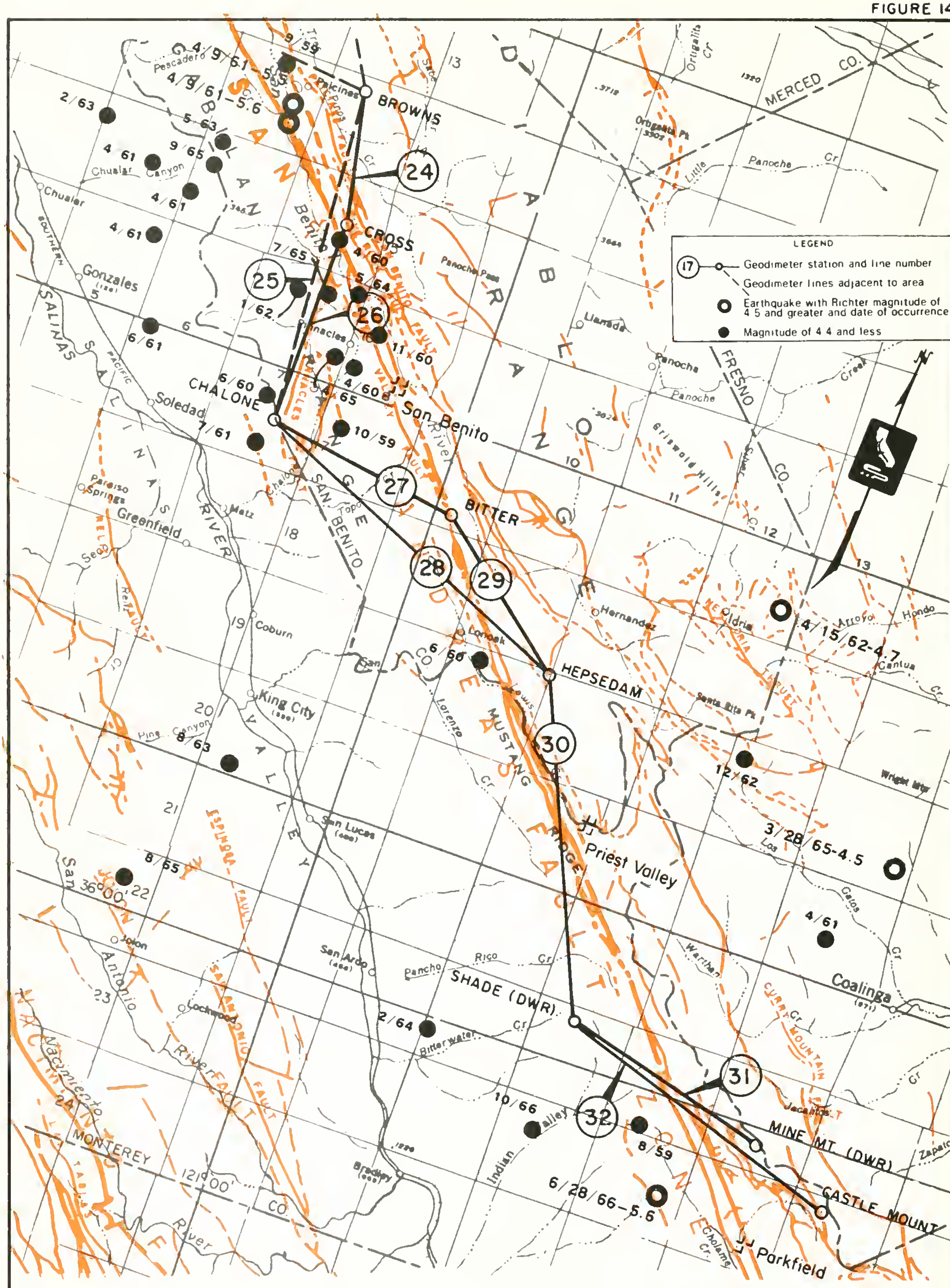
A particularly interesting correlation is the small reversal measured at the Taylor Winery quadrilateral of the San Andreas fault by the U. S. Coast and Geodetic Survey at about the same time (Meade, 1964).

Hollister-Parkfield Area (Figures 14 and 15)

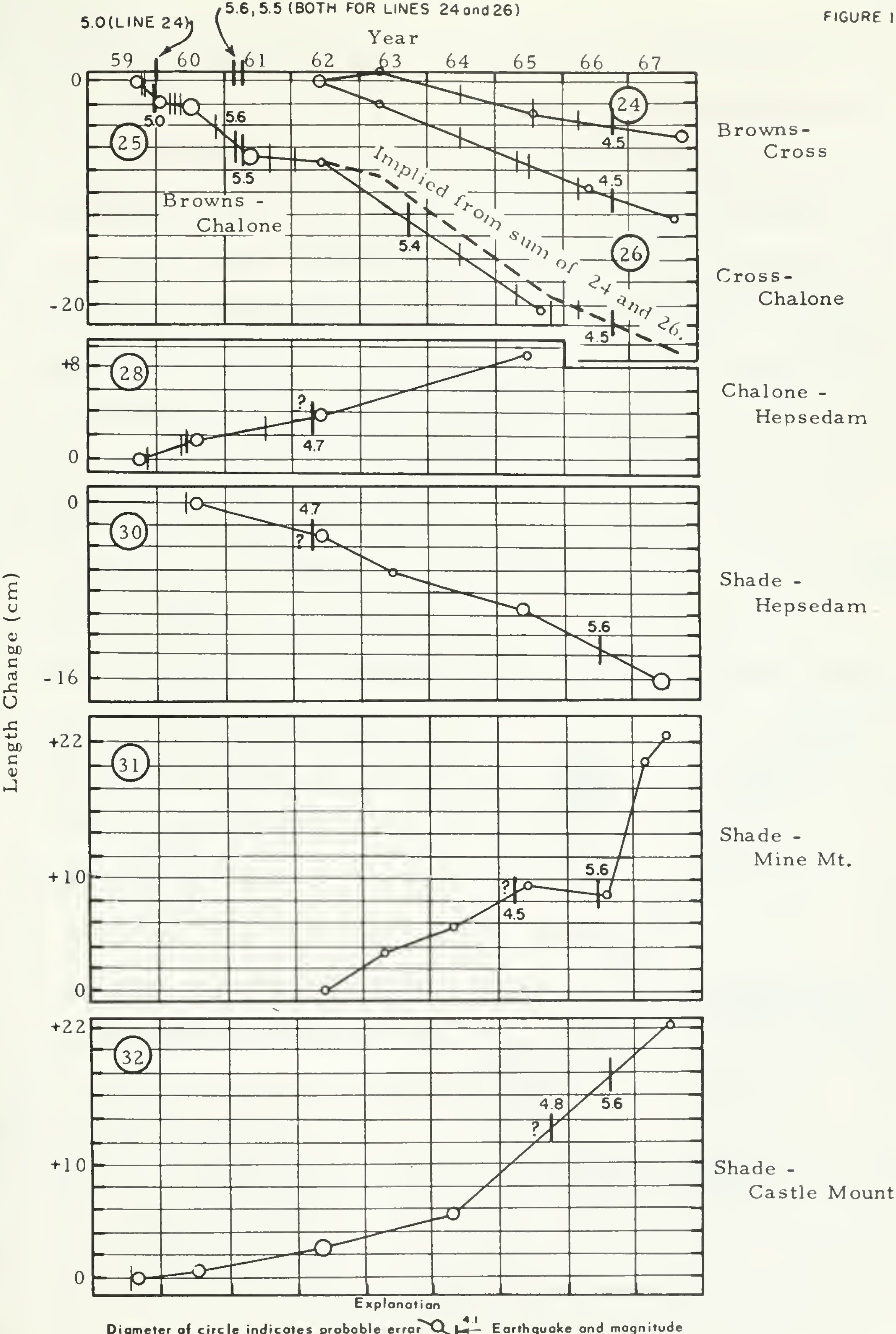
> Movement along the San Andreas, the only major fault, is at a relatively high rate, regular and well-defined by accurate measurement. Earthquakes are relatively infrequent throughout most of this area although fault movement is high. Prior to the June 1966 Parkfield earthquake, there was a roughly linear decrease in fault movement from near Hollister (about 4 cm/year) to Parkfield (about 2 cm/year). Movements associated with this earthquake increased the annual average rate throughout the area to nearly that at Hollister.

Geodimeter measurements along the San Andreas fault between the cities of Hollister and Cholame, where stations are well located and temperatures are relatively uniform, are considered to be among the best in the network. Results obtained on these lines, in an area of few earthquakes from 1959-67, show little variation from a smooth curve and thus indicate continuing movement. This contrasts with the irregular appearance of graphs of lines further north where earthquakes are frequent. This suggests that irregularities observed on the lines to the north (e.g., Lines 17 and 21 on Figure 12) are caused by earthquakes rather than by errors in observation. High accuracies are further demonstrated by measurements to station Cross in the fault zone near the middle of Line 25. Measurements

FIGURE 14



HOLLISTER-PARKFIELD AREA



LINE LENGTH CHANGES, HOLLISTER-PARKFIELD AREA on each of the two halves, Lines 24 and 26, when added together, provide the same changes observed on Line 25.

The Hollister-Parkfield area is one of relatively large regular movement which before 1965 gradually decreased toward the southeast from Line 25 to Line 32. The graph for this area (Figure 15) appears much smoother than that for the Gilroy-Hollister area to the northwest (Figure 11) where seismic activity is greater. The Parkfield earthquakes of 1966 broke this orderly progression. Lines 31 and 32 and lines farther south show obvious changes in the rate of fault movement.

Figure 16 illustrates movement measured in the Hollister-Parkfield area prior to the 1966 earthquakes. If stations along one side of the fault are assumed to remain the same distance apart, the direction and amount of fault movement can be estimated. Vectors on Figure 16 diagram these estimates for the period of record: dashed vectors, if stations west of the fault are held fixed; dotted vectors, if stations east of the fault are held fixed.

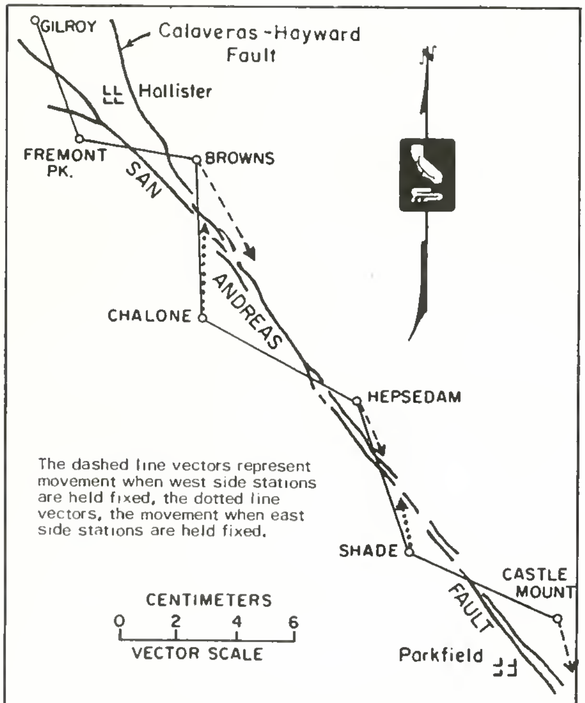


Figure 16 MOVEMENT VECTOR ESTIMATE, HOLLISTER-PARKFIELD AREA

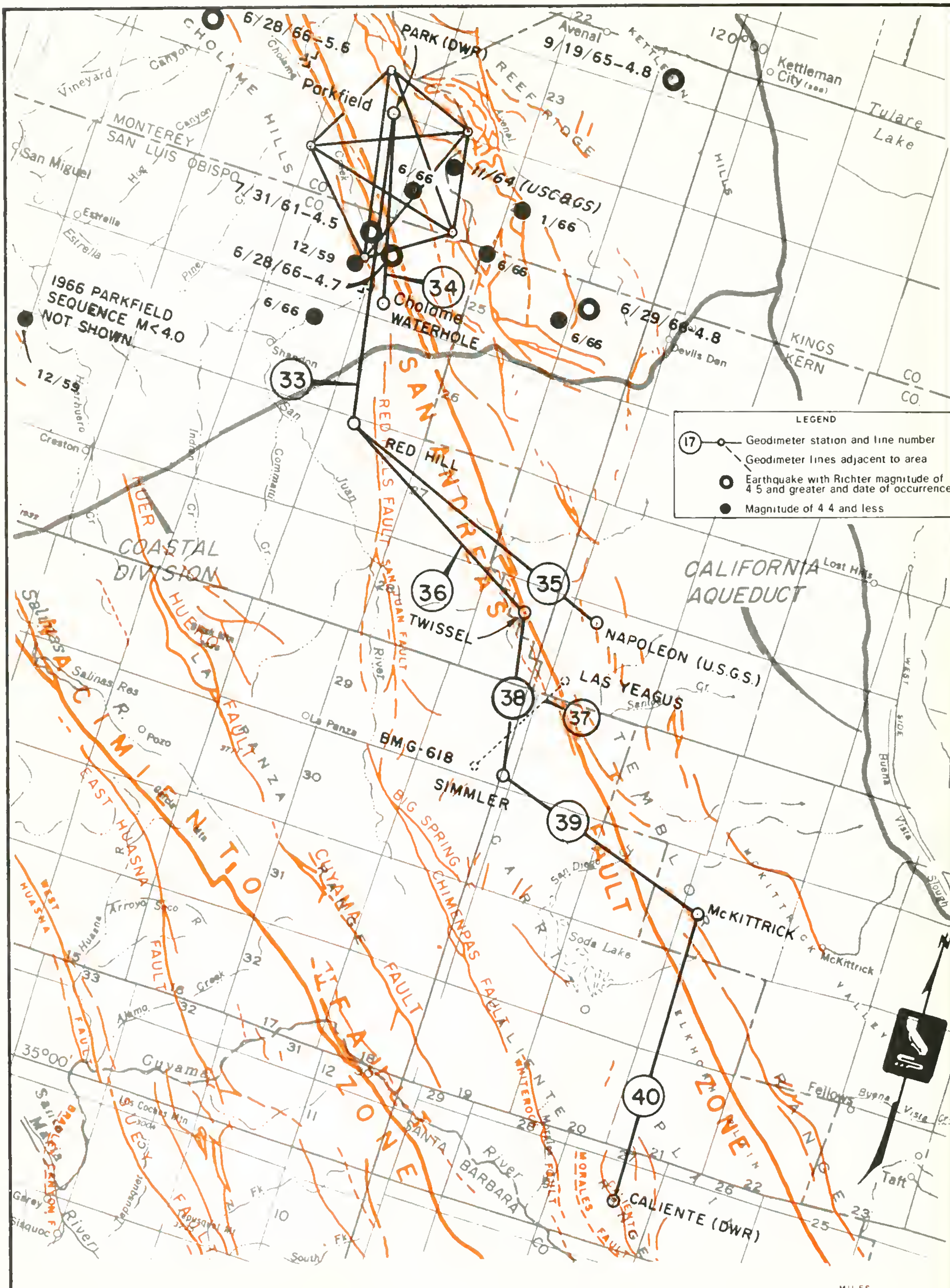
If fault movement resulted primarily from slippage and if stations west of the fault are held fixed, the dashed vectors suggest that the continental (east) side of the fault was more severely strained than the coastal (west) side. Several factors, however, suggest that additional complexities may modify this simple explanation.

Pure slippage would result in vectors which paralleled the fault, a condition not true of either set of vectors. Not only do vector angles deviate more from the parallel as distance from the fault increases (an indication of strain) but also they deviate most from the parallel at a point where strain might most reasonably be expected--that point where the Calaveras-Hayward fault splits off from the San Andreas fault. Here, the same force field should produce greater strain in the sedimentary rocks to the east of the fault than in the harder, massive granites to the west, not only because the rock type differs, but also because the shifting of some movement to the Calaveras-Hayward fault would cause compression on the inside of its bend away from the San Andreas. The deviation of the vectors from parallel is greatest in this area, especially when stations on the east side of the fault are assumed to remain the same distance apart.

In general, the angles of the vectors deviate more from parallel for stations at greater distances from the fault. This also suggests that some of the movement measured by the Geodimeter lines in this area is strain rather than slippage. A similar effect from triangulation data has been reported by Burford (1965). This points out the need for a finer network of closed figures to separate the two types of movement.

<u>Cholame-Carrizo Plains Area (Figures 17 and 18)</u>

Adjacent Geodimeter lines near Cholame showed differing rates of movement. Because the increasing strain suggested unusual fault movement might follow, the Department of Water Resources installed a pentagon-shaped



CHOLAME-CARRIZO PLAINS AREA

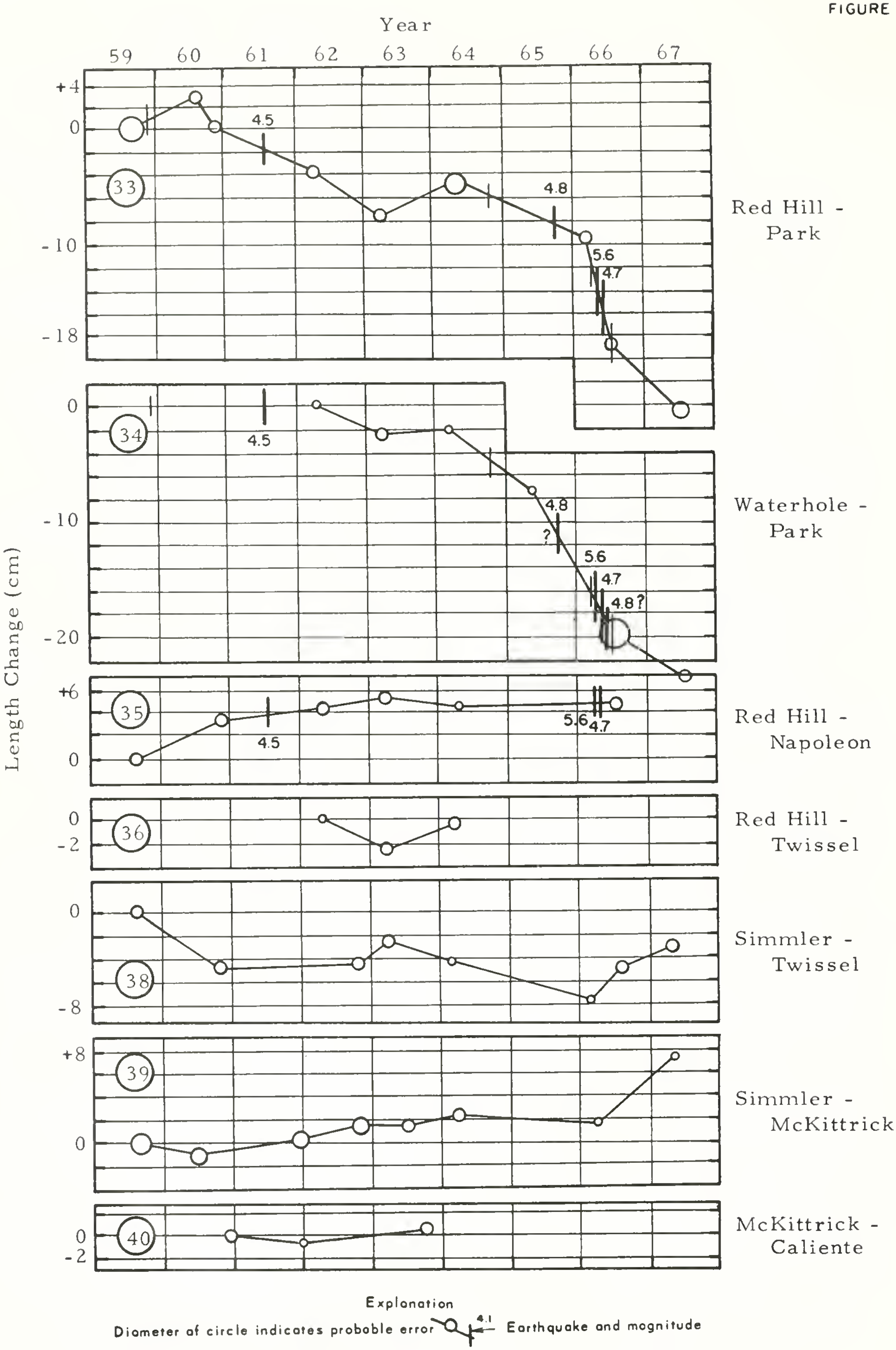
network (Figure 17) in this area. Shortly thereafter, in June 1966, the Parkfield earthquakes occurred. Remeasurement of the pentagon indicated right-lateral movement of 20 cm.

The Cholame-Carrizo Plains area of the San Andreas fault is a zone of transition between fairly large displacement to the north and little or none to the south.

Lines 33 and 34 cross the San Andreas fault near Cholame. Similarly oriented and positioned, they behave in similar fashion. Annual changes in their length, averaging about 4.4 cm between 1962 and 1967, increased during the periods preceding the December 1964 and September 1965 earthquakes. Such deviations are associated with occasional moderate earthquakes (Magnitude 4.5). Line 33 may not have recovered completely from these deviations at the time the June 1966 Parkfield earthquake struck.

The Department of Water Resources anticipated the Parkfield earthquake. The low, 1.3 cm average annual rate of change on Line 32 (Figure 15) and the higher rates of change on adjacent lines implied an impending adjustment of strain on the San Andreas fault. So also did the near cessation of movement south of Line 34. Line 35, for example, shows a slight right-lateral trend of only .7 cm annually from 1959 to 1967, most of which appears between the 1959 and 1960 measurements. Line 38 confirms such movement, although it has a generally irregular behavior probably resulting from valley floor temperature inversions which distort calculations of average temperatures. Lines 36 and 40 show only small changes in the few measurements made. Brown and Wallace (1968, in press) also report a sudden cessation of movement in this area as evidenced by displacement, or lack of it, along old fences.

Curious about these points--the negligible movements south of Line 34 and the imbalance of movement between Line 32 and Lines 33 and 34--



LINE LENGTH CHANGES, CHOLAME-CARRIZO PLAINS AREA the Department in October 1965 established a closed, pentagon-shaped network of Geodimeter lines across the fault in this area. The Department needed precise information regarding fault movement where rupture seemed imminent in an area where the Coastal Branch of the California Aqueduct crosses the San Andreas fault.

A few months later, in June 1966, large fault displacements accompanied a series of earthquakes near Parkfield. The displacements were greatest in the segment of the fault straddled by the pentagon. The pentagon itself made extremely precise documentation of movement possible for the first time. The pentagon was measured before and immediately following the earthquake and was adjusted by means of the computer program described in Chapter V. The average line adjustment was only about 3 mm. The resulting length changes are shown in Figure 19. Movement vectors were derived assuming Line 111 remained fixed in length and in azimuth. Maximum displacement was about 20 cm. This was over twice the initial 7.5 cm reported by Allen and Smith (1966) as evidenced by displacement of the divider line where State Highway 46 crosses the fault east of Cholame. No length change was found on Line 31 (Figure 15), 10 km northwest of the pentagon nor on Line 35, 20 km southeast.

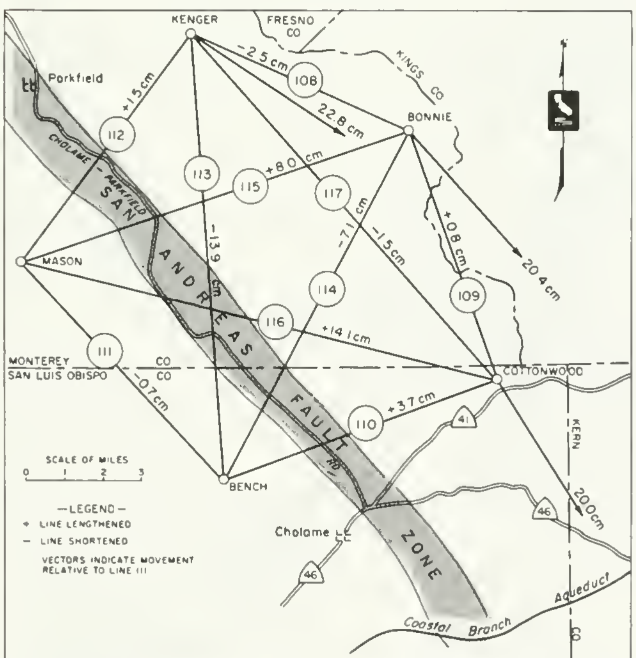


Figure 19 MOVEMENT VECTORS, 1966 PARKFIELD EARTHQUAKE
Movement between October 1965 and July 1966

An analysis of the relative movement along the fault can be made by using station Napoleon, southeast and out of the zone of movement, as a reference and by assuming all changes in line lengths are caused by motion parallel to the fault. The results are on Figure 20. No change of the Line 35 (Red Hill to Napoleon) fixes the position of station Red Hill.

Line 33, Red Hill-Park, decreased in length 9.5 cm from three months prior to the earthquake until just afterward. This represents about 11 cm of movement along the fault. Line 34, Waterhole-Park, had been measured about nine months prior to Line 33. Both lines had indicated

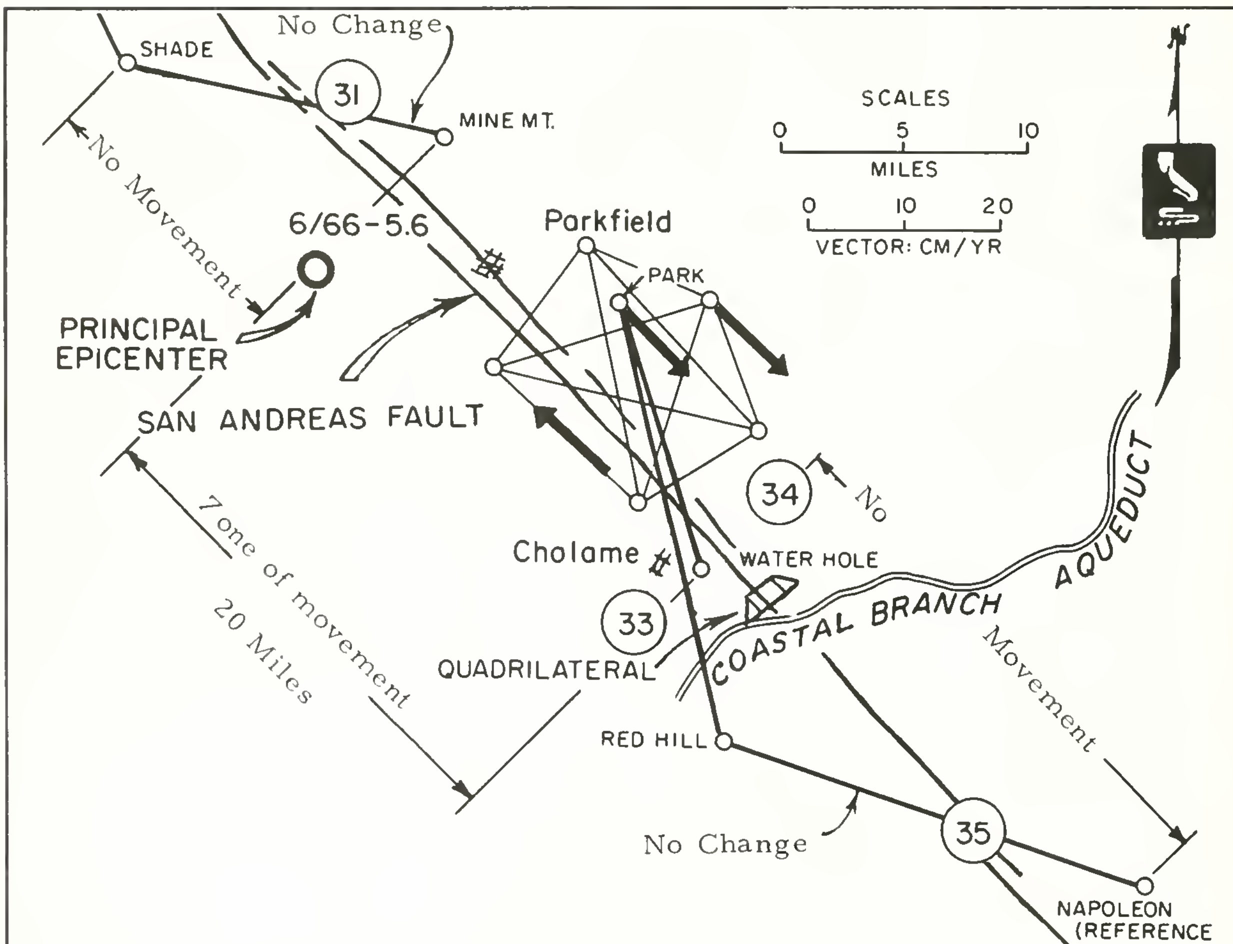


Figure 20. RELATIVE MOTION
JUNE 1966 PARKFIELD EARTHQUAKE

about the same movement rate. If this rate continued on Line 34 to the same date as the last measurement on Line 33, the same amount of fault movement (11 cm) is indicated. This places the southerly limit of movement very near station Waterhole.* Thus, the pentagon stations near station Park on the east side of the fault can be assumed to have also moved southeastward along the fault about 11 cm. The differential movement between pentagon stations on either side of the fault was about 21 cm, so the west side of the fault moved north 10 cm relative to station Park.

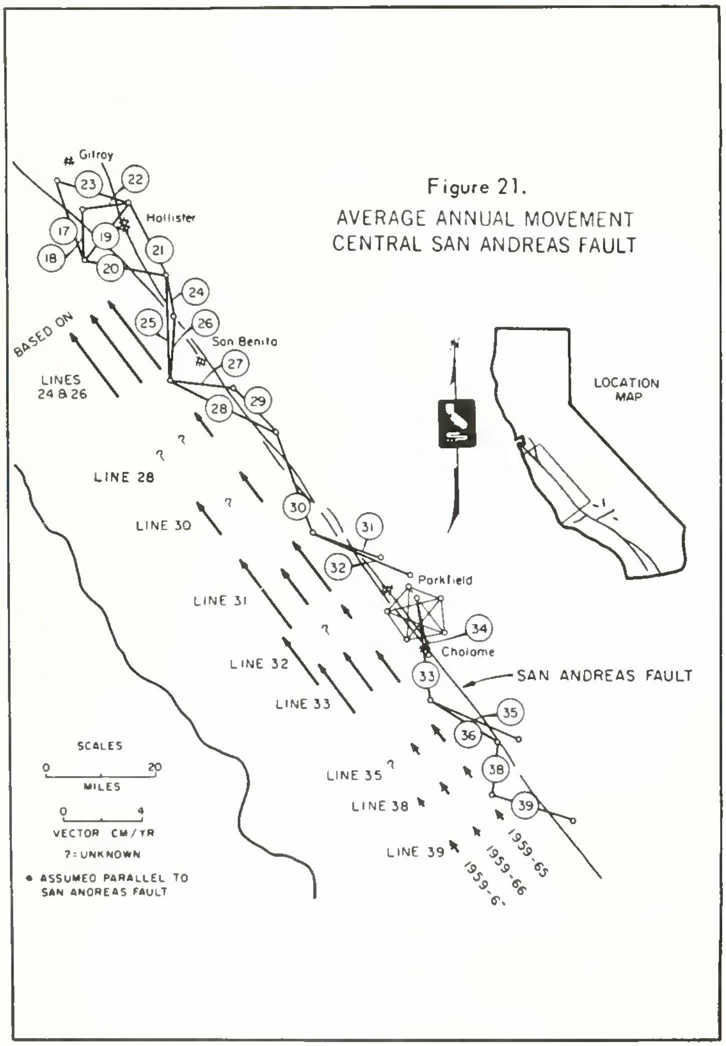
Consequently, within a zone of about 20 miles both sides of the fault appear to have moved; the west side northward about 10 cm and the east side southward about 10 cm along the strike of the fault. Movement was apparently a maximum near the center of this zone diminishing to zero toward either end.

Additional information is available from measurement of the DWR-USC&GS cooperative fault movement quadrilateral over the fault southeast of Cholame (Figure 20). This indicated about 0.1 foot (3 cm) of right-lateral movement between April 1965 and September 1966. The 3 cm of movement in 1.4 years is less than but comparable to the average movement rate observed on Lines 33 and 34 before the earthquake. However, no movement was detected from the June 1964 and April 1965 measurements of the quadrilateral. Whether this movement occurred during the June 1966 earthquake or afterward is unknown. Cultural dislocations in Parkfield-Cholame are described by Brown and others (1967).

*This agrees with the lack of visible evidence of recent fault movement to the south. However, this does not preclude the possibility of some movement on the fault between stations Waterhole and Red Hill.

The two long diagonals of the pentagon, Bench to Kenger and Mason to Cottonwood, were remeasured in May 1967 and results indicated that approximately 4-5 cm of additional right-lateral movement has taken place since the measurements obtained just after the earthquake.

With the occurrence of the Parkfield earthquake, this area has more-or-less "caught up" with total movement observed in the Hollister area, and large attendant changes for the segment of the fault near San Benito might be expected in the near future. A larger average movement rate is indicated by later measurements of Line 31 (Figure 21) which underwent no movement during the earthquake. The measurement (Line 31) of February 1967 indicated a line lengthening in excess of 10 cm. The "traveling" of high movement rates along the fault to the north may not necessarily result in a significant earthquake to the northwest because of the apparent easy slip of the fault. However, to the southeast near the Carrizo Plains, the recent movement in the Cholame area must have increased the



stress on this section of the fault where it is not easily released.

Tehachapi Mountains West Area (Figures 22 and 23)

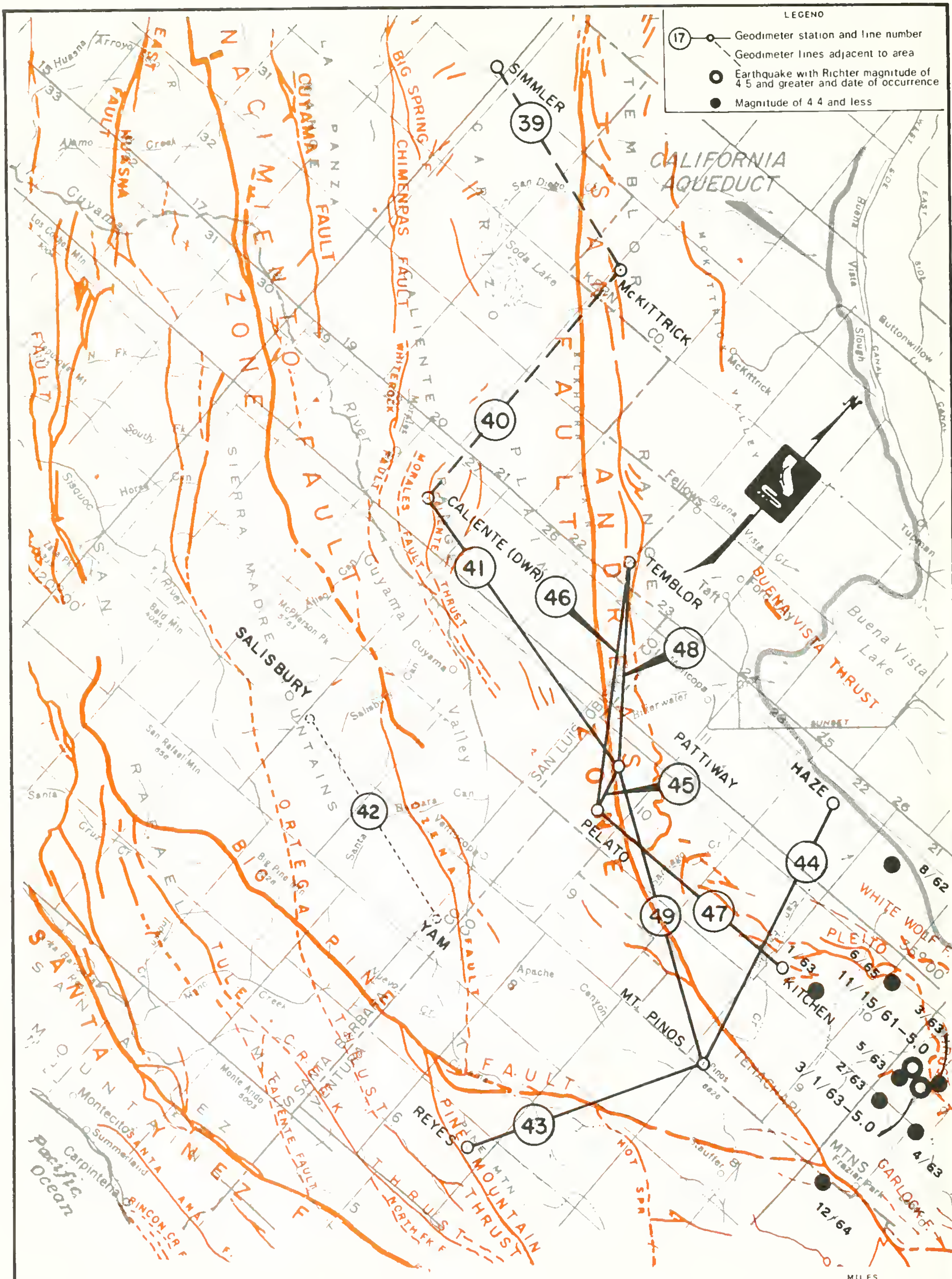
> The San Andreas, including part of the "bend" just northerly of its intersections with the Garlock and Big Pine faults, is the principal feature in this area. Although some of the line length changes can be construed as fault slippage, the area as a whole seems to be undergoing strain. In general, the changes are small.

Geological complexities of this region have created design problems for the California Aqueduct as it crosses the Tehachapi Mountains. Great damaging earthquakes have struck at this area where the San Andreas, Garlock, Big Pine, San Gabriel and White Wolf faults converge (Figure 22, lower right). Although existing measurements evidence strain south of Maricopa at the easterly bend of the San Andreas, only more Geodimeter lines, more widely distributed, can fully define the smaller, complex movements in this area.

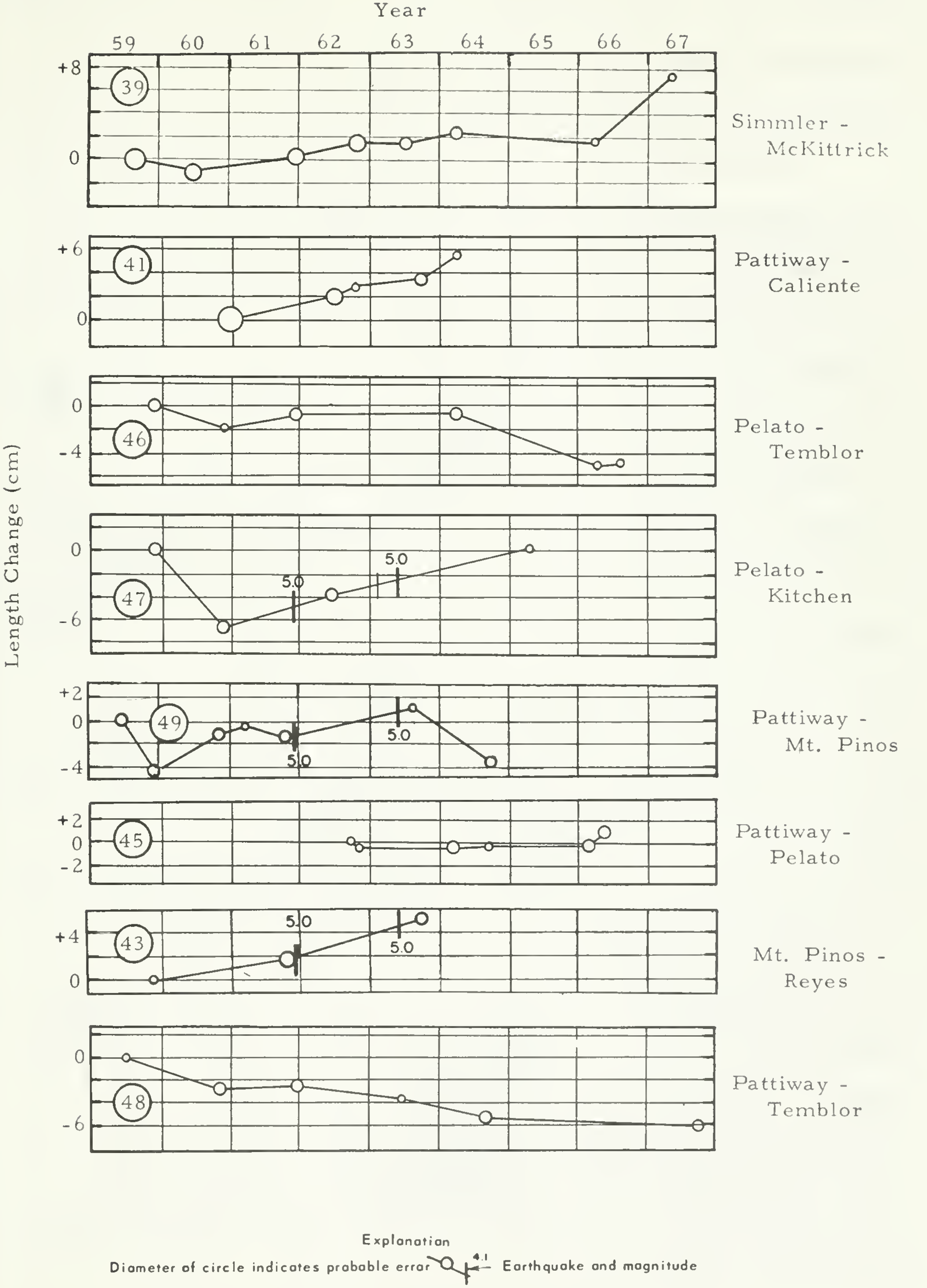
From the Tehachapi Mountains south, smog has reduced visibility and hindered regular monitoring. The use of a higher intensity or more efficient light source will soon be required to conduct a continuing program in these areas.

Figure 23 graphs length changes of up to 7 cm between 1961 and 1965 for Lines 39, 41, 46 and 47. Although these changes imply either a general right-lateral strain or slip near the bend in the San Andreas fault, the similar change on Line 48, which does not cross the fault, implies regional strain rather than fault slip. Furthermore, Line 45, which does cross the San Andreas fault, has shown virtually no change between 1962 and 1966. Although length changes of Line 43 imply right-lateral motion of

FIGURE 22



TEHACHAPI MOUNTAINS WEST AREA



LINE LENGTH CHANGES, TEHACHAPI MOUNTAINS WEST AREA the Big Pine fault, the lack of measurements since 1963 render the implication inconclusive. The sense of movement is contrary to that indicated by geological evidence (e.g., Hill and Dibblee, 1953).

Because Lines 49 and 44 have large elevation differences, average temperatures are likely to be less accurate than desired. However, the established lengths will be of value in the event of large fault movement.

Most existing lines in this area are a part of the "Taft-Mojave" triangulation network established by the USC&GS in 1959-60 (Figure 3A). Although the time required to detect minute accumulated movements by triangulation may be substantial, the area of this network is large so its remeasurement should yield a broad picture of regional strain. Many stations of this network are intervisible only when towers are used. Consequently, only a

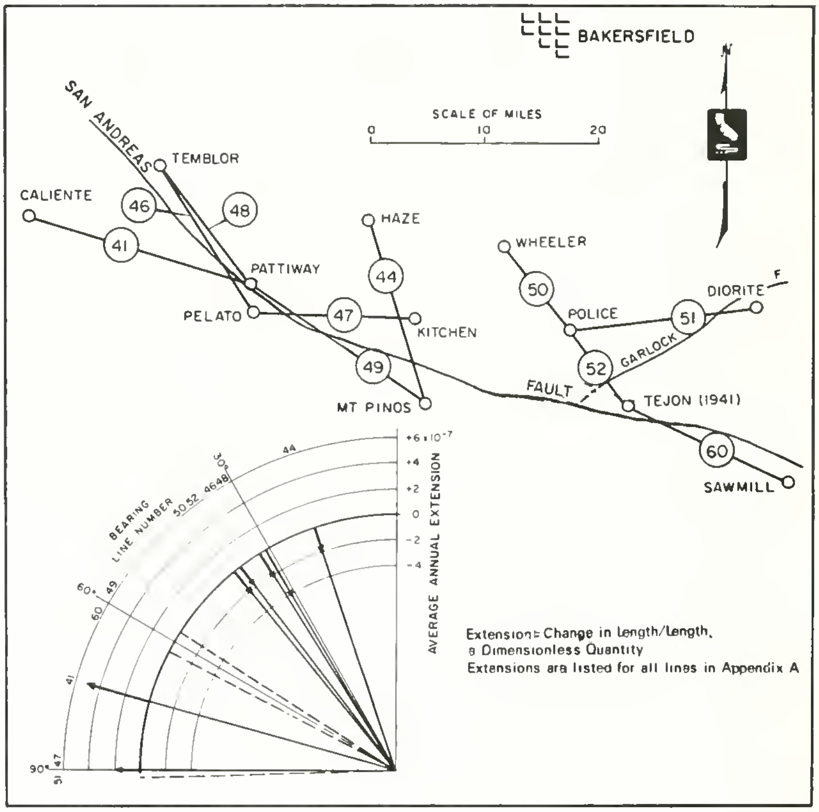


Figure 24. EXTENSION RATE VS LINE DIRECTION, TEHACHAPI MOUNTAINS AREA

Line	Azimuth	Extension/Yr	Probable Error of Extension Rate (±)*
44 Haze-Mt. Pinos	N 10° W	-2.4×10^{-7}	3.5×10^{-7}
48 Pattiway-Temblor	N 30° W	-4.5	0.2
46 Pelato-Temblor	N 32° W	-2.5	0.4
52 Police-Tejon	N 39° W	-1.9	0.8
50 Police-Wheeler	N 40° W	-2.4	1.6
49 Pattiway-Mt. Pinos	N 58° W	0.0	0.9
60 Tejon-Sawmill	N 63° W	-0.1	0.9
41 Pattiway-Caliente	N 75° W	+5.2	0.3
51 Police-Diorite	N 82° W	-0.6	1.3
47 Pelato-Kitchen	N 90° W	+2.0	2.0

* Probable error of the slope of extension vs time is based on the assumption that the movement rate is linear. This is not always a valid assumption.

few of the lines are measured easily with the Geodimeter on an annual basis.

Strains along these lines, taken from computer print-outs, appear on Figure 24. Linear strains are dimensionless because by definition they equal change in line length divided by line length.

The orientation of most lines (Figure 24) is between north and west or within about 90° of azimuth. Strain data sampled over 180° of azimuth is desirable for determination of the direction of major and minor strain axes. However, extension of Line 47 (N90°W) and compression of Line 44 (N10°W) both average about 2.5×10^{-7}/year. Lines 49 and 60 (near N60°W) show little change. The presence of major faults and many small thrust faults both confirms that compression is common and suggests that movement along zones of weakness will distort the expected pattern of strain.

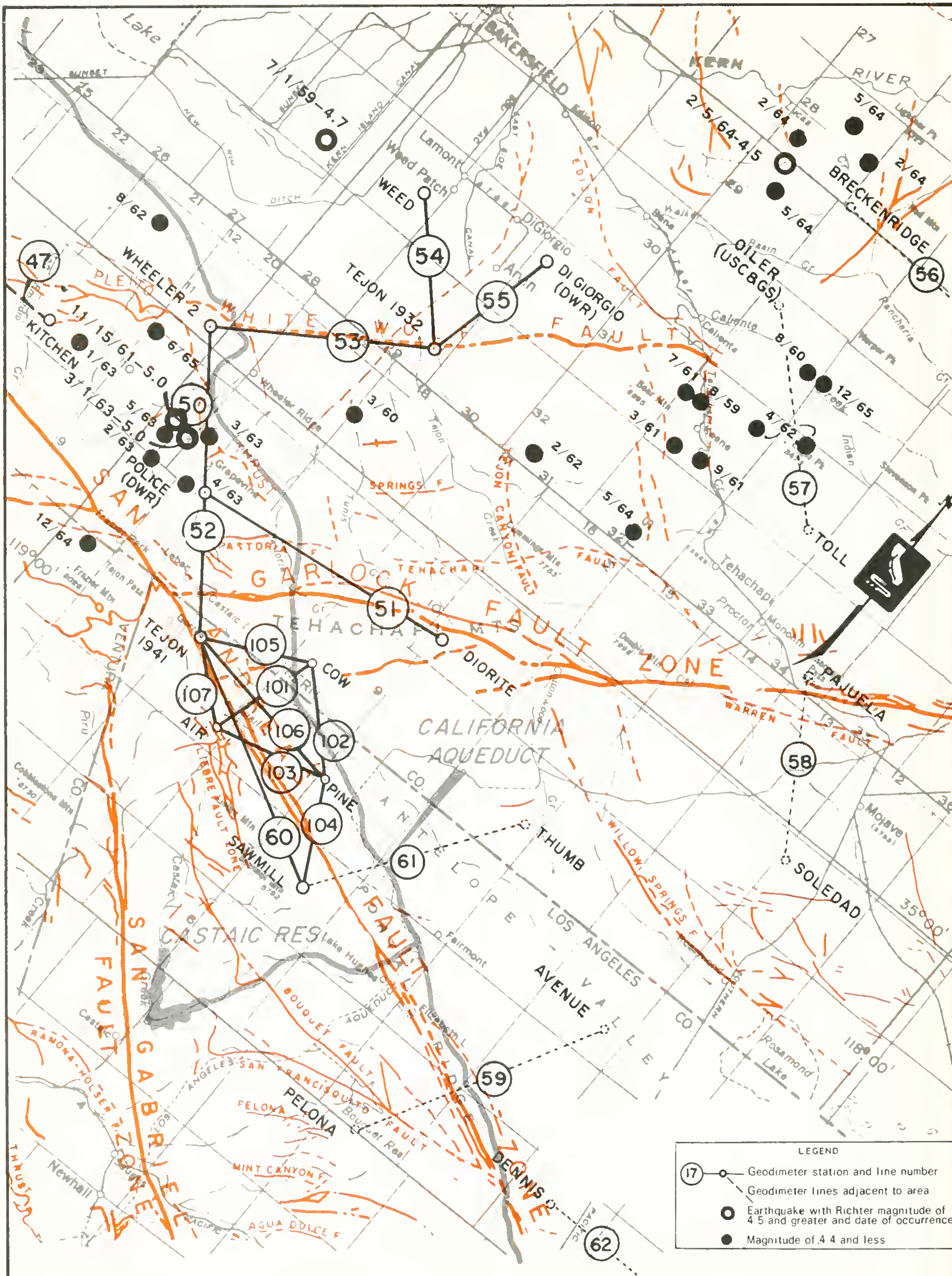
Tehachapi Mountains East Area (Figures 25 and 26)

The San Andreas south of the "bend", the White Wolf, Garlock and Big Pine faults are principal faults in this area. Although the network of lines is not dense enough to determine the difference accurately, strain rather than fault slippage probably predominates.

The White Wolf fault has moved an average of about 1.4 cm/year left-lateral between late 1962 and early 1967.

The Garlock fault showed little activity from mid-1960 to early 1964 except a possible temporary distortion relieved in 1961 by a nearby earthquake.

The San Andreas just southeast of the "bend" exhibited little movement from 1959 to early 1965 except for the reaction prior to the 1961 earthquake. However, the most recent measurement, at the end of 1965, suggests a 2 cm right-lateral movement.



TEHACHAPI MOUNTAINS EAST AREA

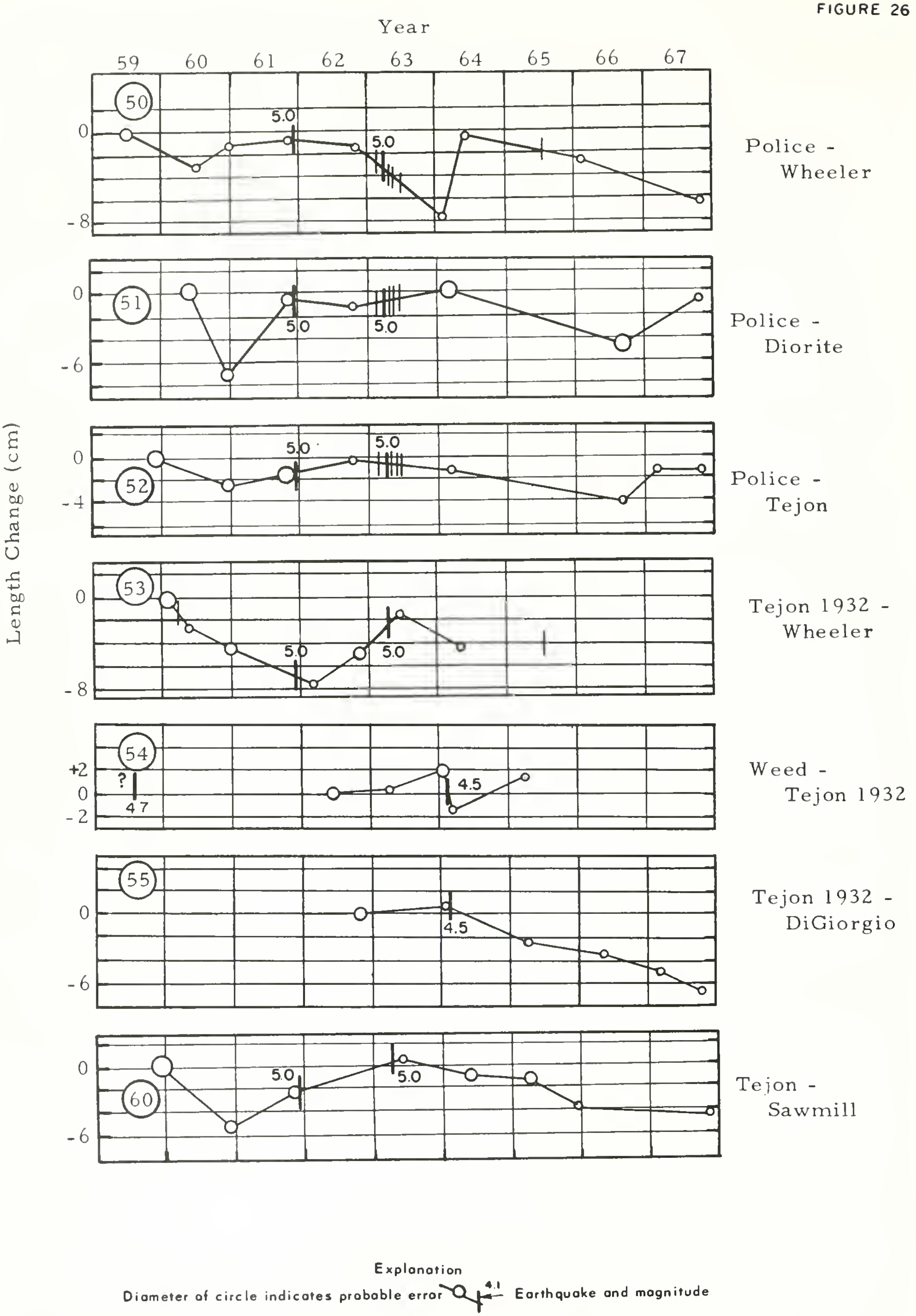
Four Geodimeter lines are located adjacent to the White Wolf fault and Pleito thrust near Wheeler Ridge. This is the epicentral area of the Arvin-Tehachapi earthquake of July 1952.

Station Wheeler is on Wheeler Ridge, station Police is on Grapevine Peak, and station Tejon is on a low ridge immediately south of the trace of the White Wolf fault (Figure 25). Stations Weed and DiGiorgio are located on the valley floor approximately 8 km northerly of the fault trace.

Only Line 55 (Tejon to DiGiorgio) is so oriented that small lateral strains or slippage of the White Wolf fault can be detected from Geodimeter measurements. Repeat measurements of this line since January 1964 indicate a shortening consistent with left-lateral movement at a rate of approximately 2 cm/year. Line 54, perpendicular to the fault, shows little change except for a possible reaction to an earthquake in 1964. The epicenter as reported initially by the USC&GS was adjacent to the Geodimeter lines. Later, the California Institute of Technology reported it several miles distant. Line 54 lengthened 2 cm prior to the earthquake, then shortened and later returned to normal length.

Line 50, across the Pleito thrust, has changed very little except for the January 1964 measurement which was 6 cm shorter than expected--apparently in response to several earthquakes in the area. Remeasurement after this activity indicates a return to the original length.

Large deviations appear in the late 1960 measurements for Lines 47, 51 and 60. Reobservations of Lines 51 and 60 in 1961 showed return to normal. However, a few days after these reobservations, a Magnitude 5 earthquake was



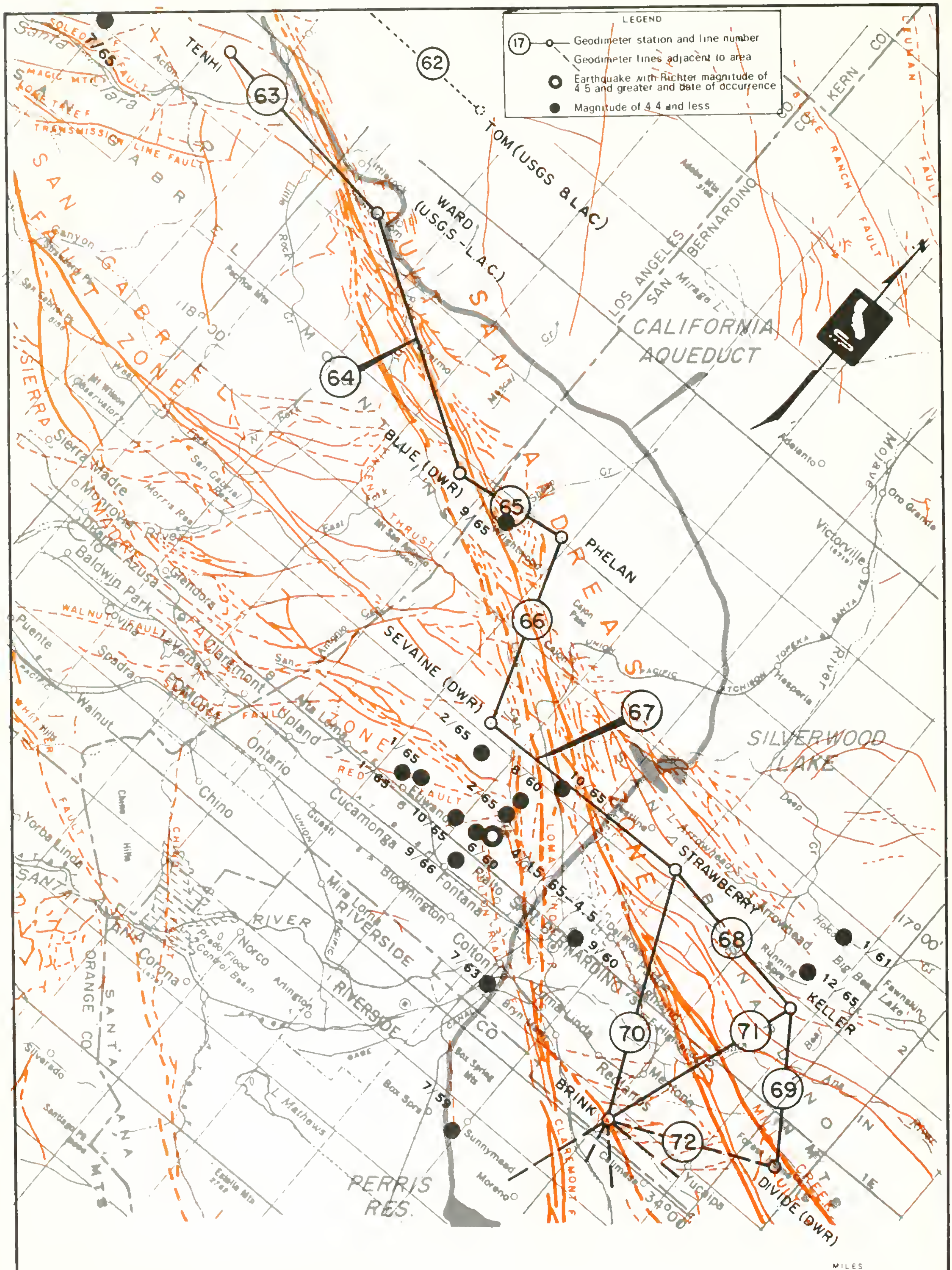
LINE LENGTH CHANGES, TEHACHAPI MOUNTAINS EAST AREA reported between stations Police and Kitchen. These lines are all approximately radial from the reported epicenter. Some unusual changes again appear on recent measurements of these lines. A small network, Lines 101-107, established in 1965 was remeasured once, November 1966. Poor visibility caused difficulties in making measurements. Closures were not up to standards, but in general, the observed length changes have not supported fault slip.

Palmdale-San Bernardino Area (Figures 27 and 28)

> The San Andreas immediately south of the "bend" appears remarkably stable. Further south in the highly shattered zone where the San Jacinto breaks from the San Andreas, there is movement on the lines but in a confused manner, possibly a combination of regional compression and local fault slip.

Most lines in this area showed little movement until 1965. Then, Lines 64 and 70 shortened about 10 cm, but the intervening Line 67 showed only a temporary change, apparently in response to an earthquake in 1965. Line 68 behaved similarly to Line 70 although it crosses no major fault. This suggests that strain may be partially responsible for the line length changes.

The first line crossing the San Andreas southeast of the Tehachapi Mountain area is Line 63 (Ward to Tenhi) south of Palmdale. Little change in length is indicated from 1960 to 1967. The next line to the southeast, Line 64 (Ward to Blue W.) also indicates little change from 1960 to 1963. However, when measured in 1965, the line had shortened 10 cm. In 1966, an additional reduction of 2.5 cm was observed, suggesting a strong right-lateral displacement. Station Blue W., however, is poorly located and must be considered a potentially unstable monument.



PALMDALE-SAN BERNARDINO AREA

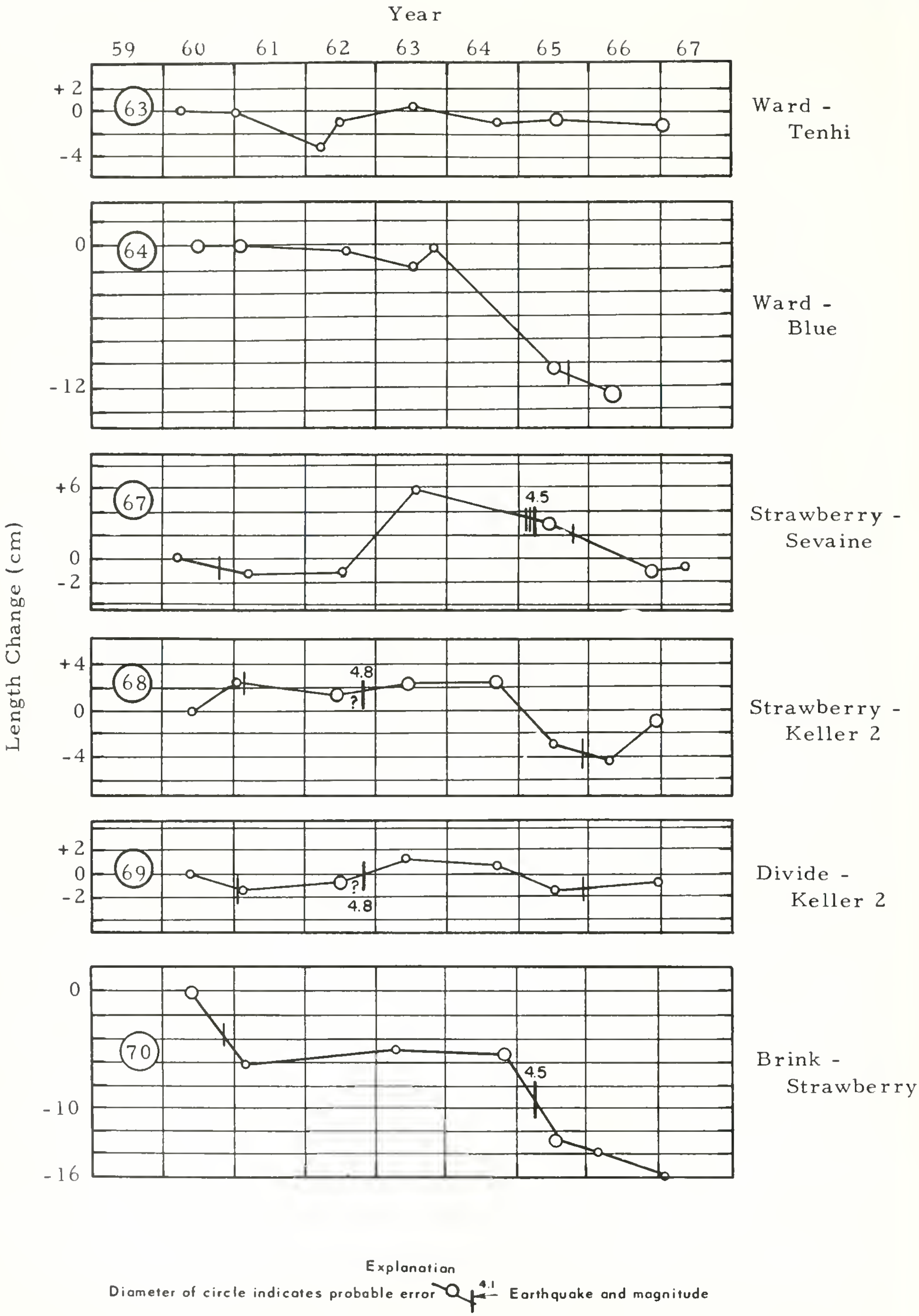
Micro-earthquake studies indicate a rapid increase in micro-seismicity on the San Andreas near the midpoint of Line 64 with virtually no activity near the adjacent Line 63, Ward to Tenhi (Brune and Allen, 1966). They also report that micro-earthquake activity is almost always associated with geodetic or surficial evidence of fault movement.

The two adjacent lines to the southeast, Lines 65 and 66 (Blue E. to Phelan and Phelan to Sevaine) have not been remeasured since triangulation station Phelan was reset by the USC&GS in 1964. In 1963, the mark was found to be loose in the soil so previous measurements should be discounted.

Measurements of Line 67 suggest a strong right-lateral distortion. However, the length of this line has gradually returned to normal after the 1965 earthquakes. Recent measurements indicate little difference from the initial length.

Line 70, across the San Andreas, demonstrates no change from 1961 to 1964, then a 7 cm shortening in 1965 followed by additional decreases in 1966 for a total change of -9. 5 cm. Movement is again in the right-lateral sense. Considerable change is also indicated between the 1960 and 1961 measurements; however, because early measurements are thought to be less accurate, they are assigned less significance.

Line 68 (Strawberry to Keller) crosses no known major faults and would not be expected to change in length. Yet, here again is a large distortion that appeared in the 1965 measurements and now appears to be diminishing. This should be an excellent line for measurement purposes. Stations are at similar elevations with consistently uniform temperature



LINE LENGTH CHANGES, PALMDALE-SAN BERNARDINO AREA measurements. Line 69 (Divide to Keller) crossing the Mill Creek fault, shows little change since 1960.

There is no obvious explanation for these changes. However, a combination of regional compression and localized fault movement could and probably does produce a variety of local effects. The San Andreas fault clearly does not freely move here, as it does to the north, but the area is locally responding in a similar sense and direction.

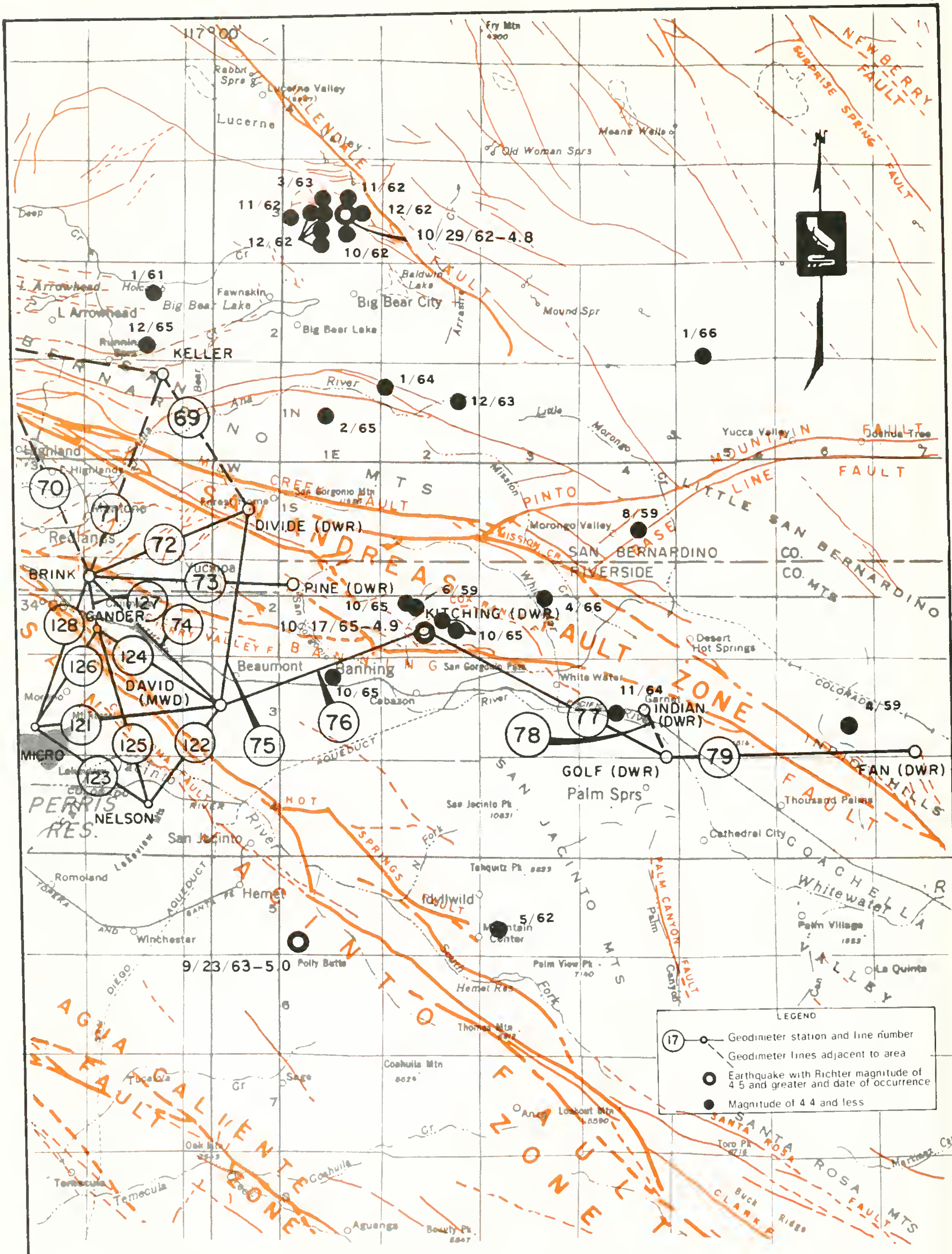
San Bernardino-Palm Springs Area (Figures 29 and 30)

Length changes in this area are relatively small and inconsistent with simple slip on major faults or simple compression. The lines are generally difficult to measure because of smog, haze, and large differences in end elevations of the lines.

Five lines, 70-74, radiate from station Brink which is adjacent to and just south of the Banning fault near Redlands. Line 70, discussed in the previous section, shortened considerably in 1965. Lines 72 and 74 show little movement. Recent measurements have not been made on Lines 71 and 73. Length deviations on each of Lines 71-74 are within 2 cm of each other. This degree of repeatability is good, particularly for an area where measurements are made with difficulty.

Line 75, crossing the San Andreas and Banning faults in a north-south direction, indicates a 6 cm shortening between 1963 and 1966 and a confirming additional decrease of 3 cm in 1967. These length changes, like those on Line 70, suggest a general compression, possibly greatest in a direction a little west of north.

FIGURE 29

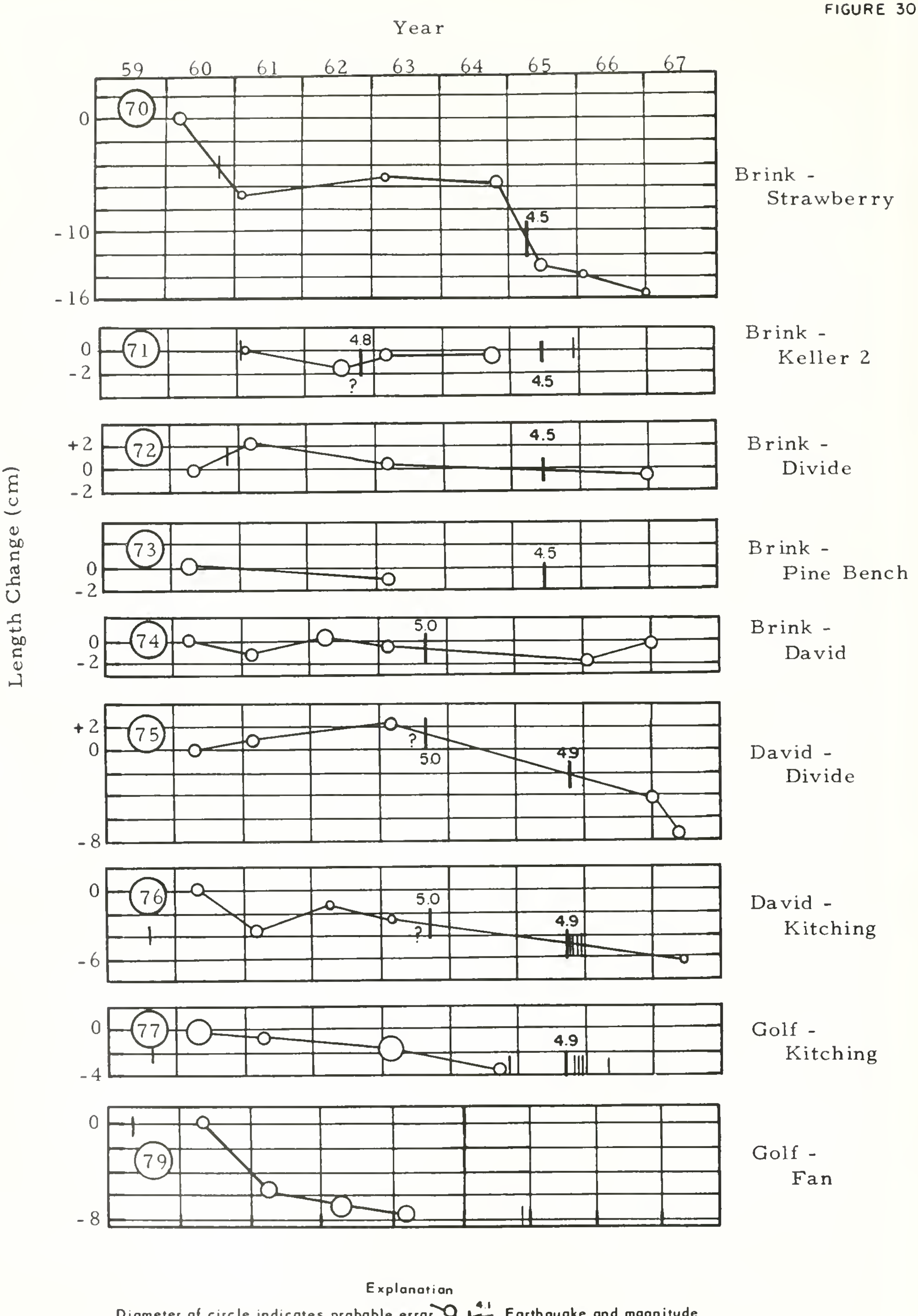


SAN BERNARDINO-PALM SPRINGS AREA

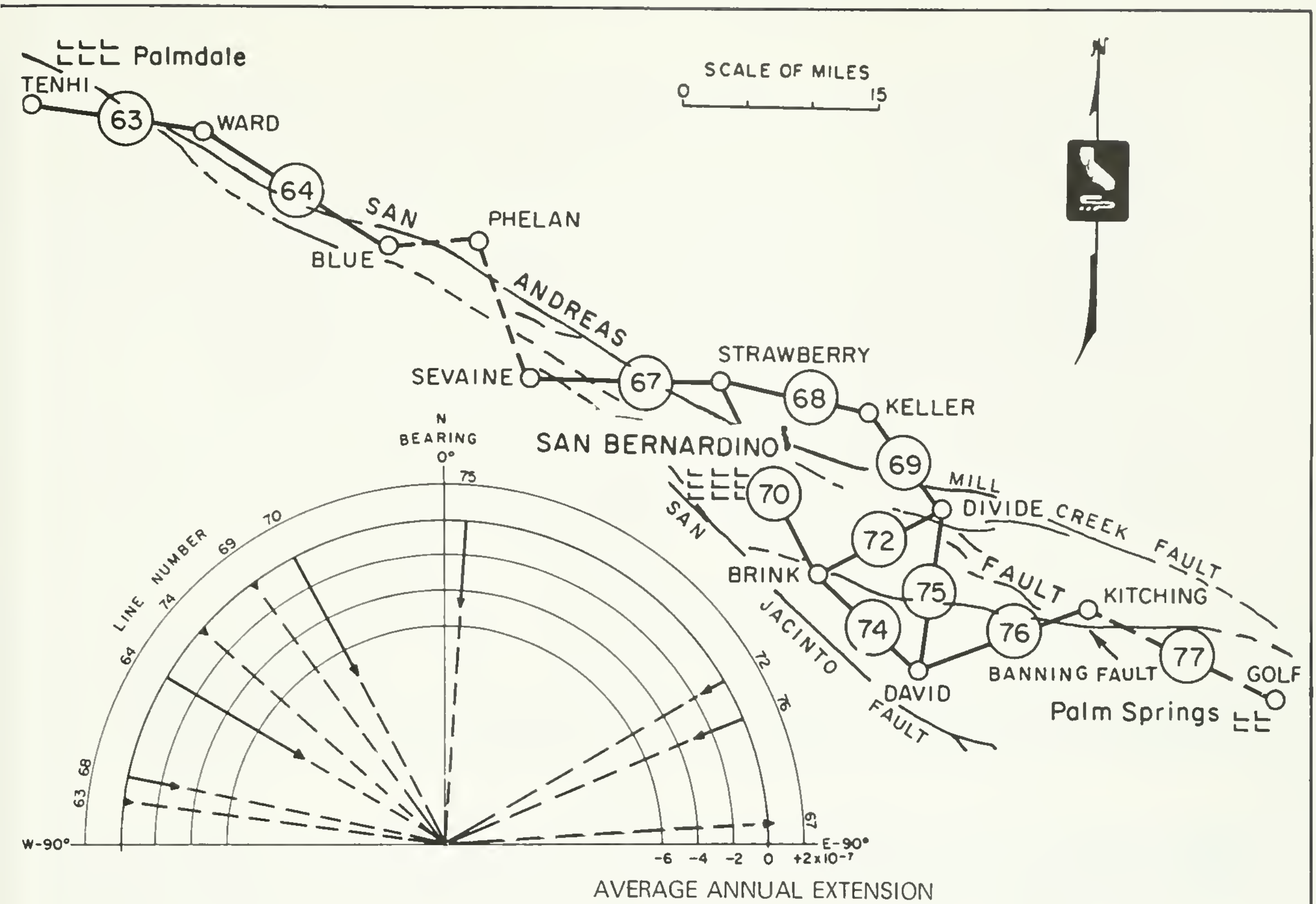
Line 76 shortened between 1963 and 1967. Lines 77 and 79, Kitching to Golf and Golf to Fan (see computer listing), have also shortened. They are not the best of lines, however. For example, Line 79 skims the ground for a considerable distance, crossing a golf course. An apparent length difference of several centimeters can occur when the sprinklers are turned on. Although care is taken to avoid measuring through the sprinklers, this line remains suspect because of its sensitivity to near surface atmospheric variations. Lines 76 and 77 through San Gorgonio Pass are subject to air masses of differing temperatures moving through the Pass from the San Bernardino area to the west or Palm Springs area to the east.

A small quadrilateral (Lines 121 to 126) was established in 1965 over the San Jacinto fault just beyond its separation from the San Andreas. However, not enough measurements have been made to establish the movement rate.

In general, lines in this area either shorten or show no regular movement. This suggests a general compression without attendant elongation in a complementary azimuth. If so, vertical movements or activation of the many thrusts in the area might be expected. There appears to be no systematic compression and dilation as observed in the Tehachapi area (see Figure 31). However, faulting in the area is complex and the network of lines does not bracket the entire zone so more complex interfault relationships could go undetected.



LINE LENGTH CHANGES, SAN BERNARDINO-PALM SPRINGS AREA



Extension = (change in length/length), a Dimensionless Quantity.

Extensions are listed for all lines in Appendix A.

Figure 31. EXTENSION RATE VS LINE DIRECTION, PALMDALE TO PALM SPRINGS

CHAPTER IV. EARTHQUAKE PREDICTION

Changes in the rate of fault movement are often related to the occurrence of earthquakes. Figure 32 illustrates the general irregularity of graphs of Geodimeter line length changes where earthquakes are numerous and the smooth progression in length change where few earthquakes occur.

Changes in rates of lengthening for several Geodimeter lines were obviously followed by earthquakes in the immediate area. Some of these were discussed in the descriptions of fault movement. A summary of these occurrences follows.

Definition of "PREDICTION":

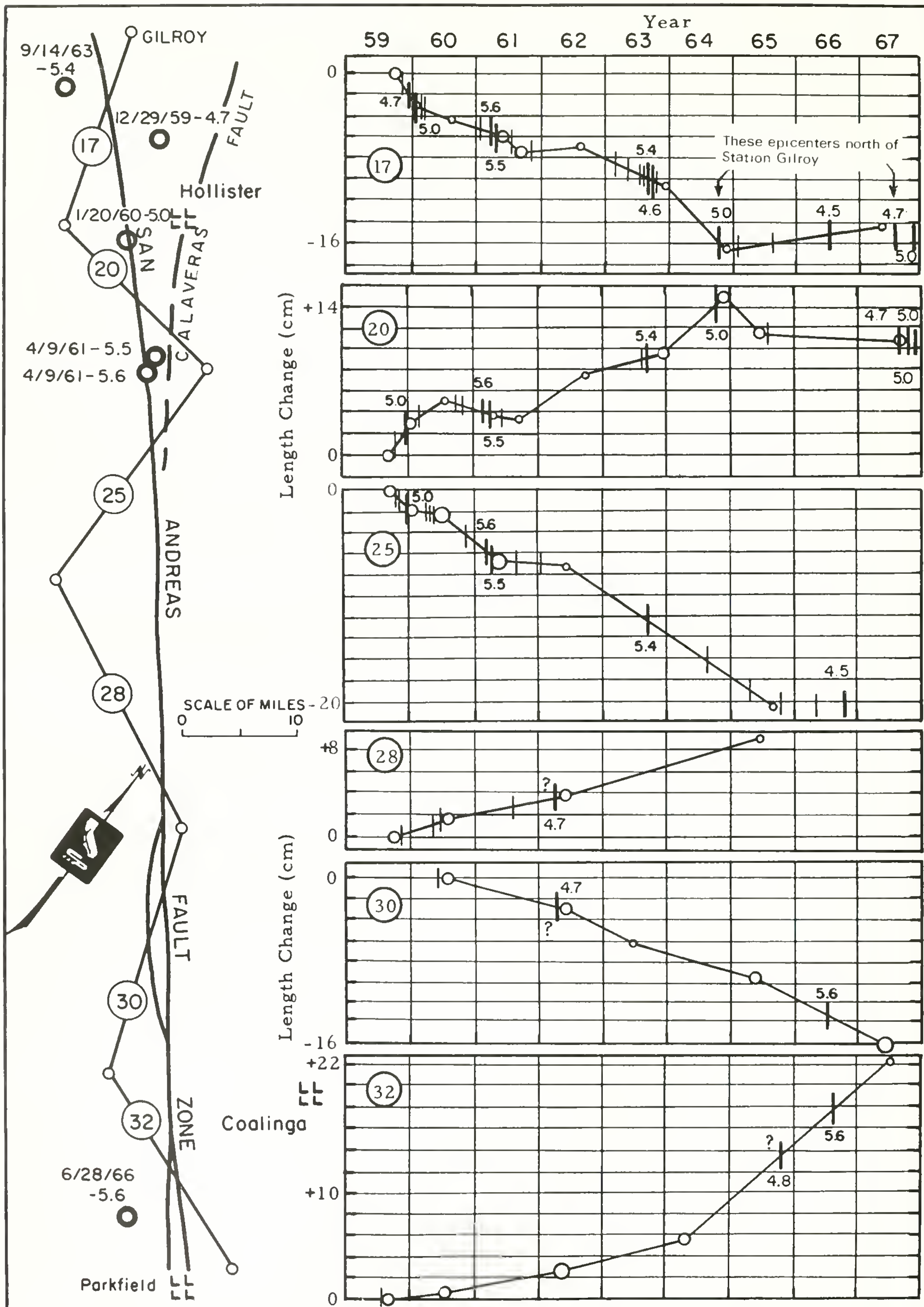
"PREDICT is closely synonymous with FORTELL; it may be preferred in today's English to suggest or apply to inference from facts and laws of nature [if we can trace certain changes slowly at work in the period preceding our own we may be able to predict with some probability that these changes will continue for some time at least to operate in the same direction--W. R. Inge] ...." from FORTELL in Webster's Third New International Dictionary, 1966.

In this sense, earthquakes can be predicted in terms of how many of a certain magnitude are likely to occur in a given area in a specified period of time. In this report, however, "prediction" is defined to have more specific dimensions in space and time. Earthquakes are shown to be predictable within a time accuracy equivalent to the current interval between measurements (usually a year or somewhat more) and a dimensional accuracy near that of the length of Geodimeter lines affected (usually about 20 miles on the earth's surface). Successful "predictions" are possible only when the measurements meet certain criteria. These are discussed later in this chapter. Only earthquakes of magnitude less than 6 have occurred in the area and time of this investigation. Consequently, the effectiveness of this prediction method for larger shocks remains to be tested as do also implied improvements in prediction accuracy which may result from improved measurements.

Earthquakes Preceded by Fault Movement Anomalies

Corralitos Earthquakes of 1964 and 1967

The group of lines radiating from station Loma Prieta (Figure 33) on top of the Santa Cruz Mountains exhibited unusual length changes prior to the Corralitos earthquake of November 1964. This resulted in recognition that measurable anomalies may occur prior to seismic activity. From 1960 to 1963, Line 11 shortened, Line 12 lengthened and Line 13 was relatively undisturbed--the expected behavior for right-lateral movement along the San Andreas fault. Then in 1964, the pattern changed; Line 11 lengthened and Line 12 shortened--an apparent reversal in direction of fault movement.



FAULT MOVEMENT AND EARTHQUAKES HOLLISTER TO PARKFIELD

However, Line 13, not across the San Andreas, also shortened. A possible explanation is that the San Andreas fault ceased moving south of Loma Prieta and the movement was transferred to the Sargent and other faults around the base of the Santa Cruz Mountains. The mountains could have moved northward as a unit carrying the Loma Prieta station mark with it. If some distortion of the surface is allowed, this will account for the line behavior (see Figures 33 and 34).

Unusual length changes associated with the 1964 Corralitos earthquake also appeared on Lines 4, 5, 6, 7, 12 and 14. These may be related to the transfer of movement between faults discussed on Pages 25 and 35.

Following the Corralitos earthquake of 1964, Line 13 slowly returned to its initial length. This suggests that Loma Prieta peak returned to its original position after the applied stress, caused by sticking of the San Andreas, was relieved. Movement on Line 10 (Figures 9 and 10) can also be interpreted as a relaxation of Loma Prieta to its original position. Line 12 reacted to the shock by quickly lengthening in response to accelerated movement on the San Andreas. However, sometime between early 1965 and early 1967, the apparent movement of the fault, as indicated by Line 12, again reversed.

In June 1967, Line 10 showed a 3 cm reduction in length within five months, a rate similar to that observed on Line 13 prior to the 1964 shock. This very limited information, considered in the context of events occurring at the time of the 1964 Corralitos shock, could be interpreted as a possible recurrence of San Andreas sticking. If so, the movement was not transferred to the unnamed extension of the Sargent fault, but possibly

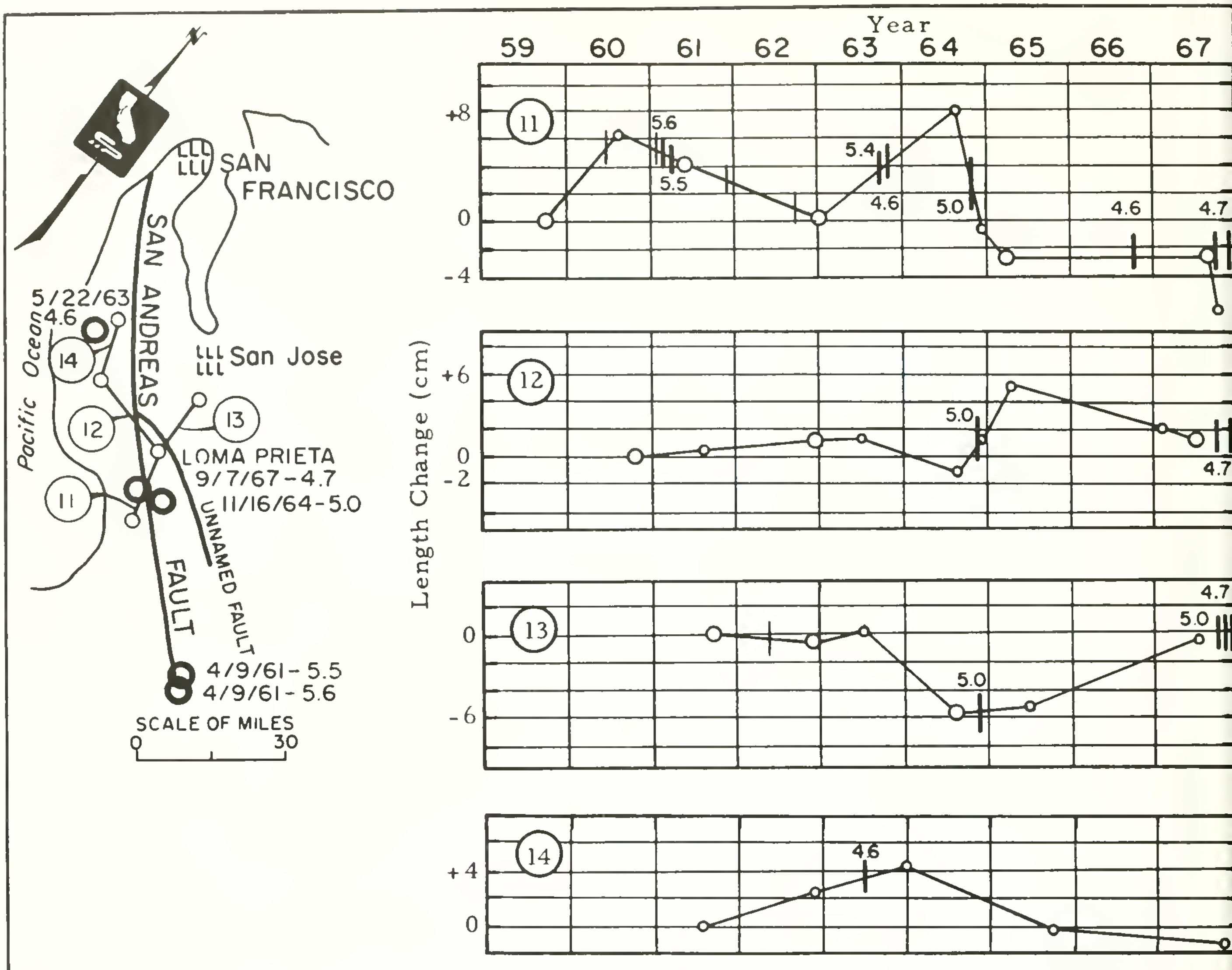


Figure 33. FAULT MOVEMENT AND THE CORRALITOS EARTHQUAKE OF 1964

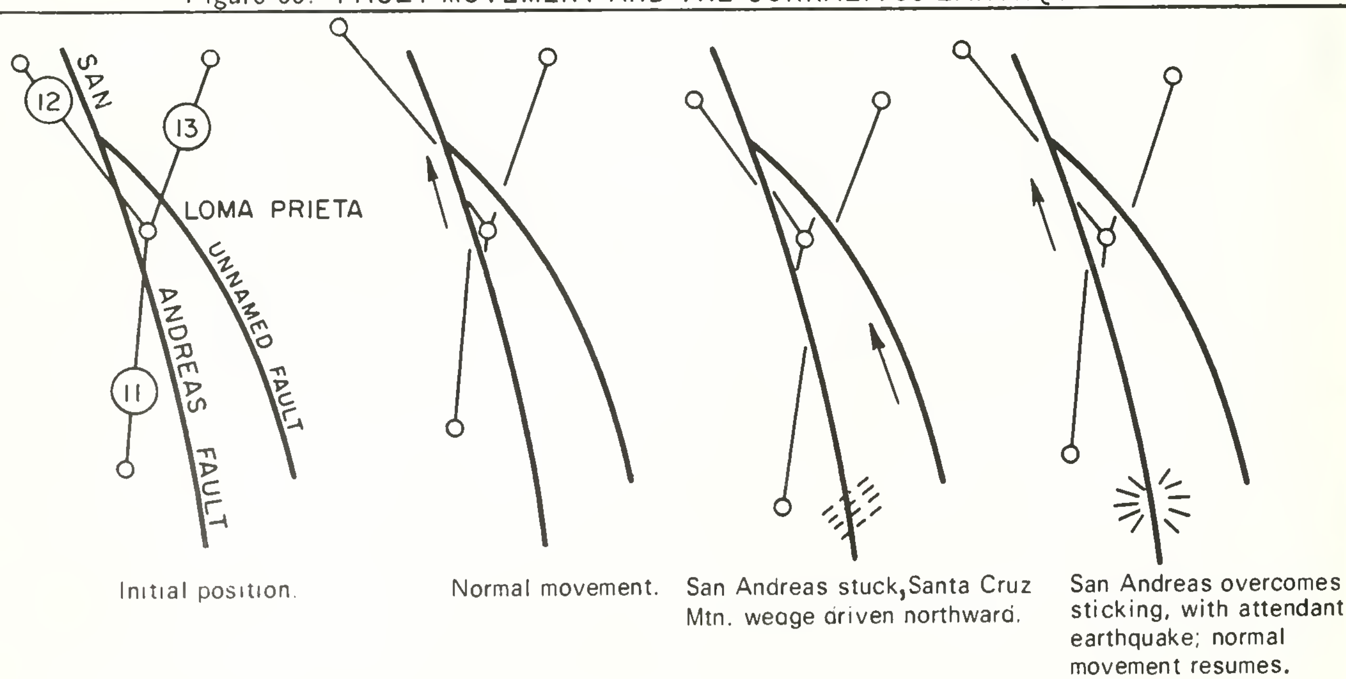


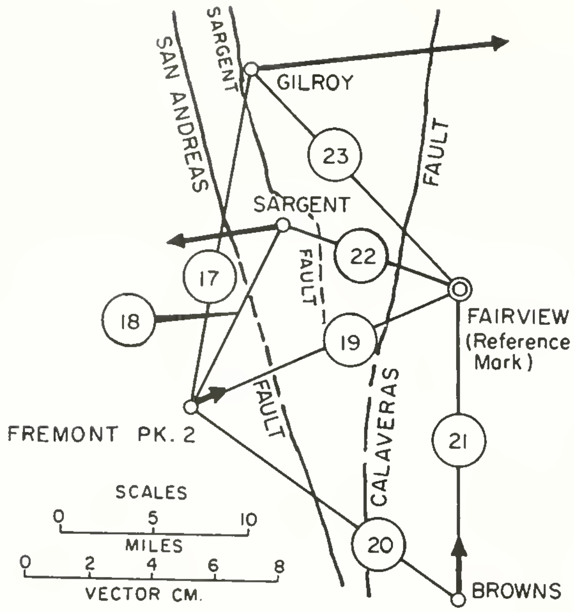
Figure 34. POSSIBLE SEQUENCE OF FAULT MOVEMENTS
Amount of movement greatly exaggerated

to a fault further east, crossed by Line 10 but not Line 13. A possible alternative which does not cross lines measured in early 1967 is the Stanford fault (Figure 7). Two earthquakes with magnitudes reported at 4.7 and 5.0 occurred near Corralitos on September 7 and 28, 1967.

Mt. Hamilton Earthquake of September 1967 (Figure 36)

This Magnitude 5 shock occurred in or near the Calaveras-Hayward fault zone about 20 miles northeast of the 1967 Corralitos epicenter on the San Andreas fault. Geodimeter lines across both fault zones showed unusual behavior prior to these earthquakes, making the location of the expected events difficult to estimate. Line 25 and its equivalent, the sum of Lines 24 and 26, seem unaffected (Figure 15). However, anomalies on Lines 7, 9 and 10, radiating from Mt. Hamilton, and on Lines 5 and 6 to the north, were indicated from measurements in early 1967. These anomalies consisted of reversals or a higher than normal movement rate and were observed for nearly 100 miles along the fault zone from the vicinity of Walnut Creek to south of Hollister. Following the Mt. Hamilton earthquake in September, resumption of right-lateral movement was indicated by all lines measured and at a higher than normal rate. Line 17 across the San Andreas shares a common end point with Line 23 across the Calaveras-Hayward fault. Line 17 also indicated left-lateral movement on the San Andreas during the same interval Line 23 showed a reversal. A possible explanation of these movements follows.

1. Lines 18, 19 and 20 all shortened in response to a force with a large component normal to the San Andreas. Relatively large strains, near normal to the San Andreas, have been reported by Burford (1965). Sticking on both the San Andreas and Calaveras-Hayward north of this



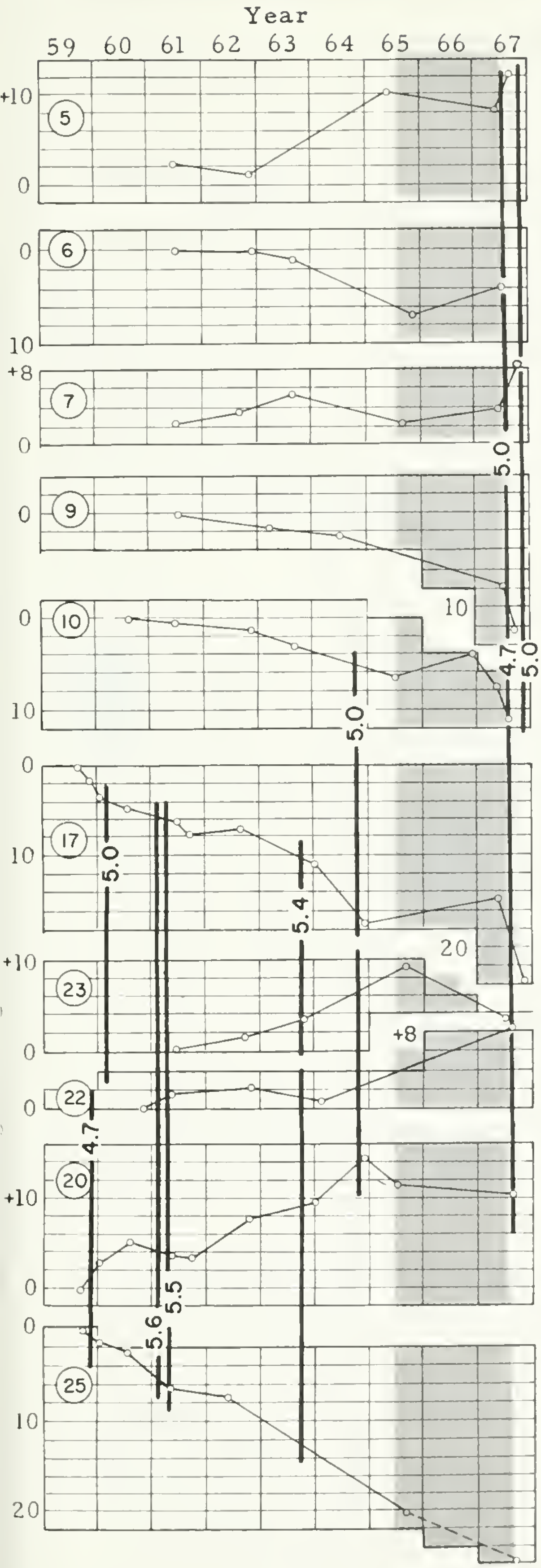
Relative movements of station marks in the Hollister quadrilateral just prior to the 1967 Corralitos and Mt. Hamilton earthquakes are determined by holding station Fairview and the azimuth of Line 21. There is evidence of compression both parallel and normal to the main fault system and movements parallel to the bend in the Sargent The latter movement resulted in an overall movement from 1959-1968 for station marks Sargent and Gilroy, parallel to the main fault system. This is shown on Figures 11C and 11D.

Figure 35. POSSIBLE MOVEMENT VECTORS, HOLLISTER QUADRILATERAL July 1965 – May 1967

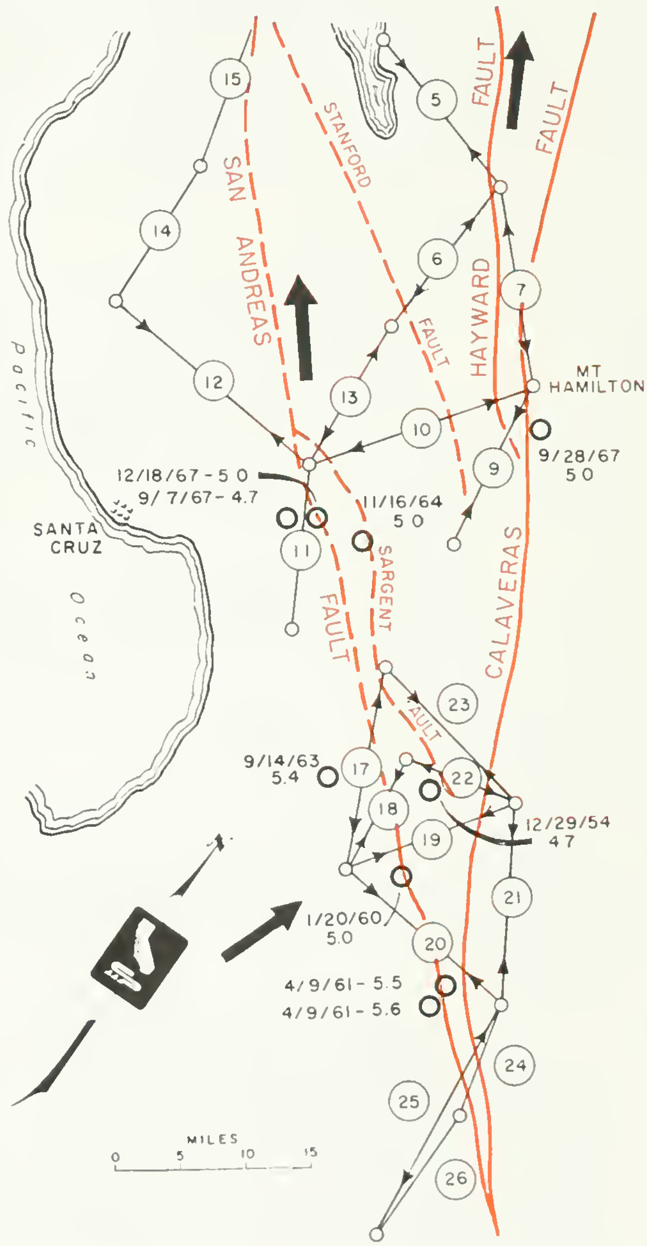
area allowed regional forces to build which would otherwise be relieved by fault movement. Lines 17 and 22 may be lengthening in response to local strike slip movement and strain on the Sargent fault (Figure 35). Figure 35 shows movement vectors of the closed network in the Hollister area for the interval July 1965 to May 1967.

2. The resulting compression drives material, in the wedge between the two faults, northward. Movement takes place on subordinate faults between the San Andreas and Calaveras-Hayward zones--possibly on the Sargent, or Stanford, and on the major faults north of where sticking occurs. The result is that the Santa Cruz Mountains again move to the northwest as they appeared to do prior to the 1964 Corralitos shock. Again, lines radiating from Loma Prieta show movements contrary to general right-lateral fault slippage (Figure 36).

3. The same mechanism is evoked for the wedge bounded by the Hayward and Calaveras faults. This results in Lines 5 and possibly 6 showing left-lateral movement, but Lines 7 and 9 indicating movement in the usual right-lateral sense.



The small arrow heads on the Geodimeter lines indicate whether they became shorter or longer between mid 1965 and mid 67. Movement of the areas between major faults in the direction of the large arrows could account for the pattern of line length changes. This scissoring and extrusion northward may be caused by locking of the faults near the Corralitos and Mt. Hamilton earthquakes of 1967. This could have prevented relief for a N-S component of regional stress by the usual parallel displacement on the San Andreas and related faults.



FAULT MOVEMENT AND THE MT. HAMILTON EARTHQUAKE OF 1967

4. Earthquakes in December 1967 near Corralitos mark resumption of right-lateral movement on the San Andreas fault as indicated by recent measurements on Lines 11 and 17.

5. An earthquake in September 1967 near Mr. Hamilton marked resumption of right-lateral movement on the Calaveras-Hayward and Hayward faults. Verification is expected when Lines 6, 20, 22 and 23 are remeasured in the future.

This analysis is largely qualitative. A more precise interpretation could be made with frequent measurements and more closed networks of Geodimeter lines.

San Bernardino Earthquakes of 1965

These were preceded by a lengthening of Line 67, the closest line to the epicenters (Figure 37). This line crosses both the San Andreas and the San Jacinto faults. If the line length change is attributed to fault slip, the movement is right-lateral. However, there is little evidence of fault slip in this area. The principal shocks on January 1 and April 15 were rated by the California Institute of Technology as having Magnitudes 4.4 and 4.5 respectively. The U. S. Coast and Geodetic Survey rated them 5.2 and 5.1. Following these shocks, Line 67 slowly returned to its normal length.

Other lines in the area, 68 and 70, showed a large reaction following the earthquake. Line 68 does not cross major faults. This suggests that strain as well as slip is involved. Line 68 is some distance from the epicenter, however, and its change in length preceded the shock in December, whose epicenter was near the juncture of Lines 68 and 69.

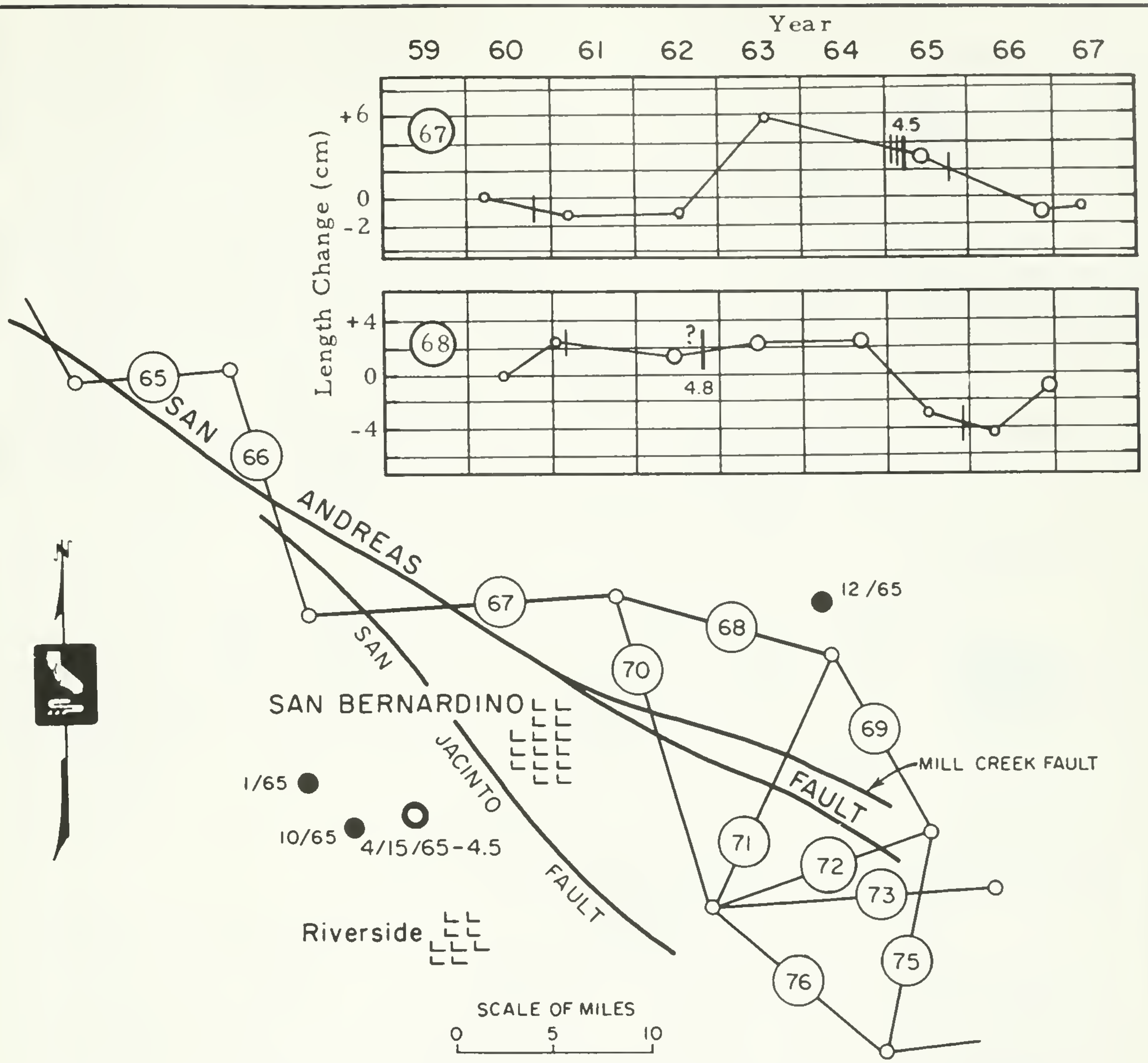


Figure 37. FAULT MOVEMENT AND THE SAN BERNARDINO EARTHQUAKES OF 1965

Although this shock is small (Magnitude 3.5 according to the California Institute of Technology; 4.3 according to the USC&GS), its close proximity suggests that some effect on the lines could be expected.

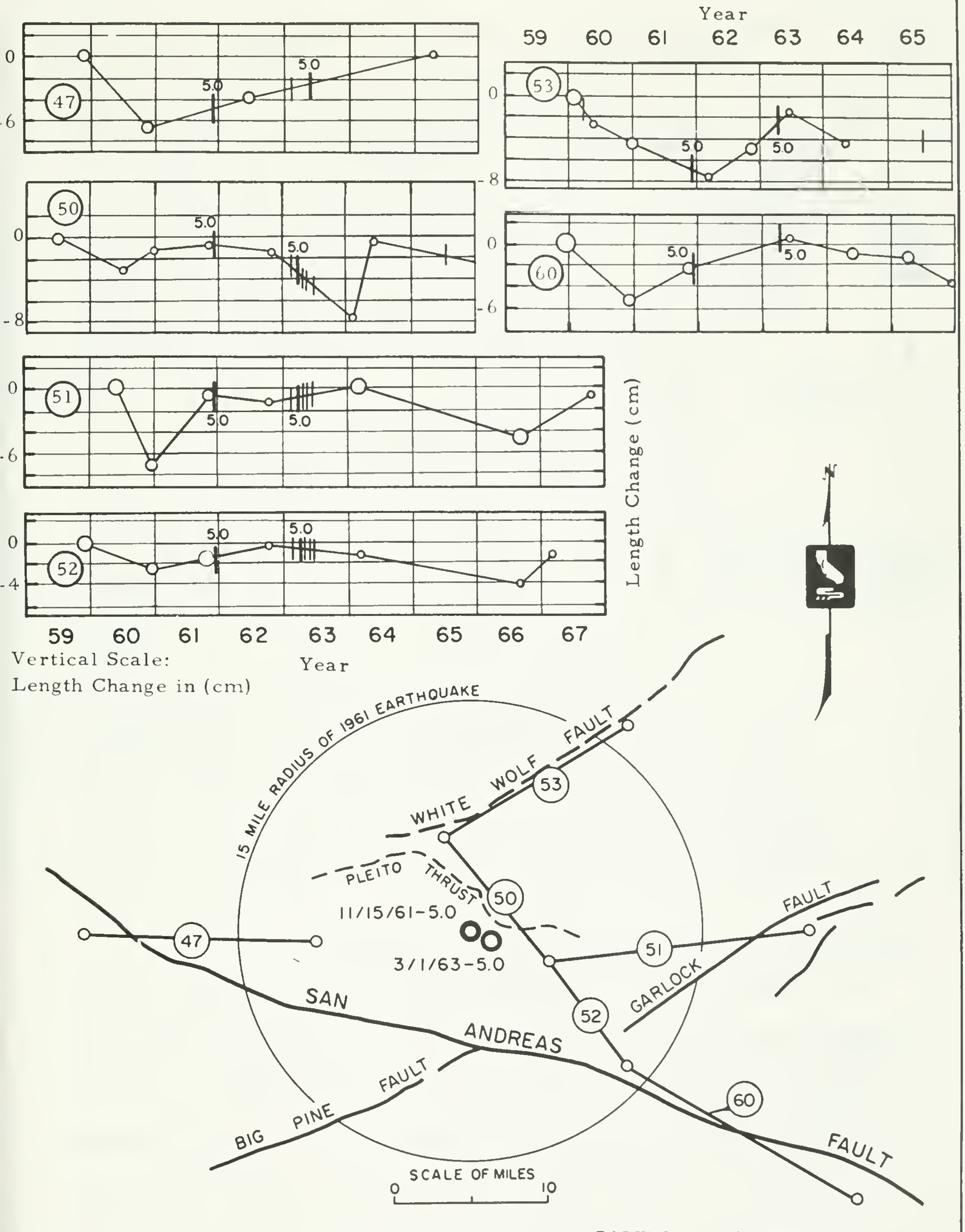
Wheeler Ridge Earthquake of November 1961

This is another example where several lines showed anomalous length changes prior to an earthquake (Figure 38). The magnitude is given as 5.3 by the University of California and 5.0 by the California Institute of Technology. The area is near the convergence of the White Wolf, Garlock and San Andreas faults (Figures 23, 26 and 38). The Pleito and other thrust faults are also in the area. Some of the affected lines cross faults; others do not. Most decreased 3-7 cm the year prior to the earthquake but returned nearly to their former length a few days prior to the shock. Another shock of similar size (5.1 by the University of California and 5.0 by the California Institute of Technology) occurred about a year later. With only one measurement in the interim, little can be said about length changes prior to the second event.

Change in line length in this general area is not attributable to simple fault slip but generally seems to indicate a north-south compression. No simple explanation of the general compression of the area and the following earthquake is obvious from the data at hand.

Cholame Earthquakes of 1961 and 1965 (Figure 39)

These were preceded by small left-lateral movements indicated by Line 33 about one year prior to the events. Line 34 corroborated the change prior to the 1965 shock, which, however, is more distant from the Geodimeter lines than most earthquakes plotted in this investigation (see Pages 21 and 46). This anomalous movement may be associated with the Parkfield sequence which followed in 1966. If so, both the reversals on Line 33 were characterized by a return to right-lateral movement prior to the shock. Line length changes have not been found prior to earthquake smaller than Magnitude 4.5 (as reported by the universities), but because of the possible close proximity of the 1964 Magnitude 4.0 shock (as reported by the USC&GS) to the Geodimeter lines, an effect on the lines cannot be completely discounted.



FAULT MOVEMENT AND THE WHEELER RIDGE EARTHQUAKE OF 1961

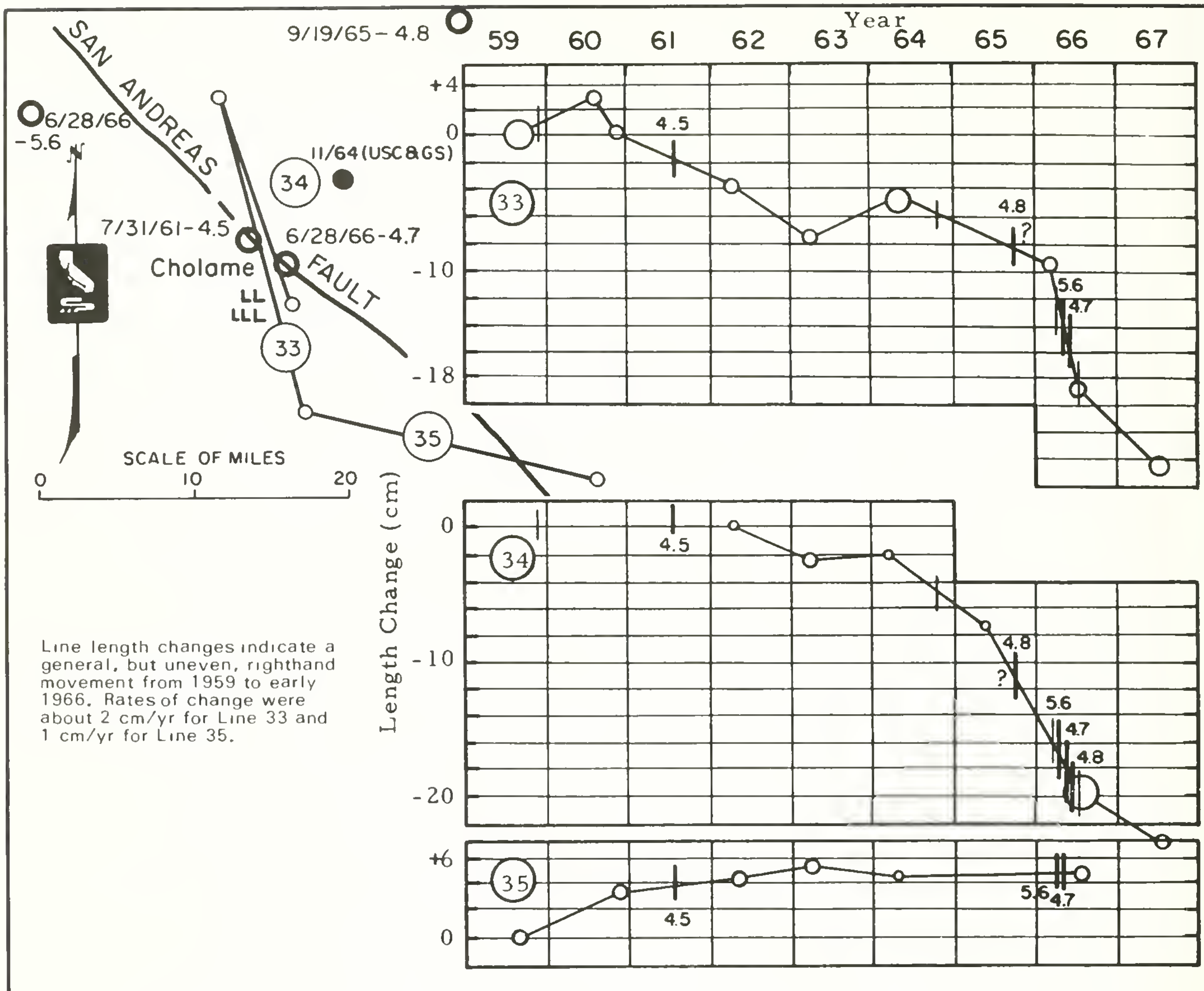


Figure 39. FAULT MOVEMENT AND THE 1961 AND 1965 CHOLAME EARTHQUAKES

Hollister Earthquake of January 1960

This shock, apparently on the San Andreas, was reported to have a magnitude of 5.0 by the University of California and 5.5 by the California Institute of Technology. The principal line affected was Browns to Fremont Peak, Line 20 (Figure 11). Measurements had been initiated only months earlier, in September 1959. Consequently, no history of line behavior was available to provide a basis for anticipating the earthquake.

However, on January 19, 1960, the day of the earthquake, a series of measurements was underway--the first and only such measurements ever obtained across an active fault at the time of an earthquake.

In the first years of this program, six measurements were usually made during one night and their mean value listed as the length determination for that date. In this instance, five measurements were made--two prior to the earthquake and three afterward. The length changes are plotted with time on Figure 40.

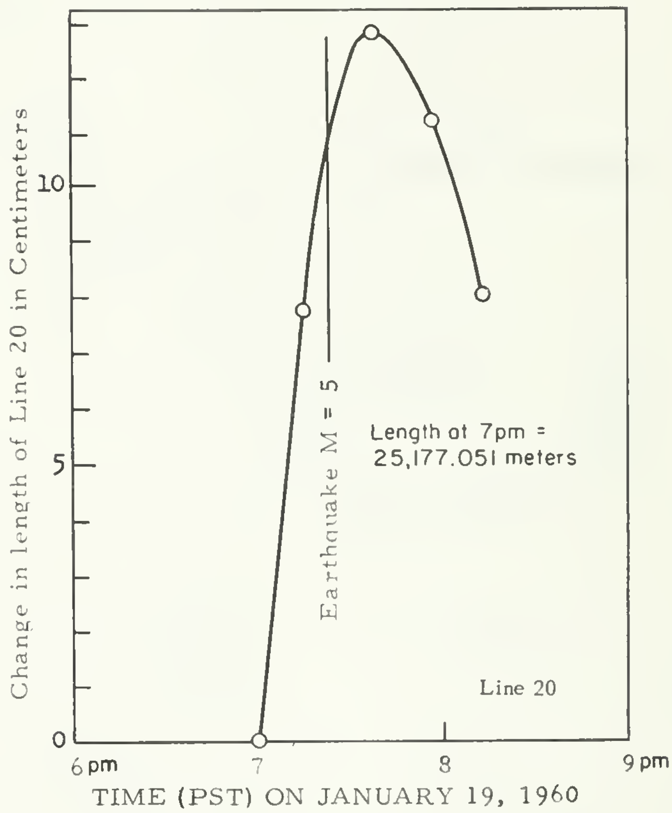


Figure 40. SHORT-RANGE ANOMALY

These measurements show an extremely high rate of movement prior to and during the earthquake with some relaxation following. This suggests that large movements and high rates of movement a few hours or minutes prior to an earthquake may provide an effective criterion for short-range earthquake warnings. Continuous or near continuous monitoring of suspected sites would be necessary to provide this kind of forecast. Because of the unusual circumstances, the mean of measurements for this date is not reported in the computer listing of line lengths, Appendix A.

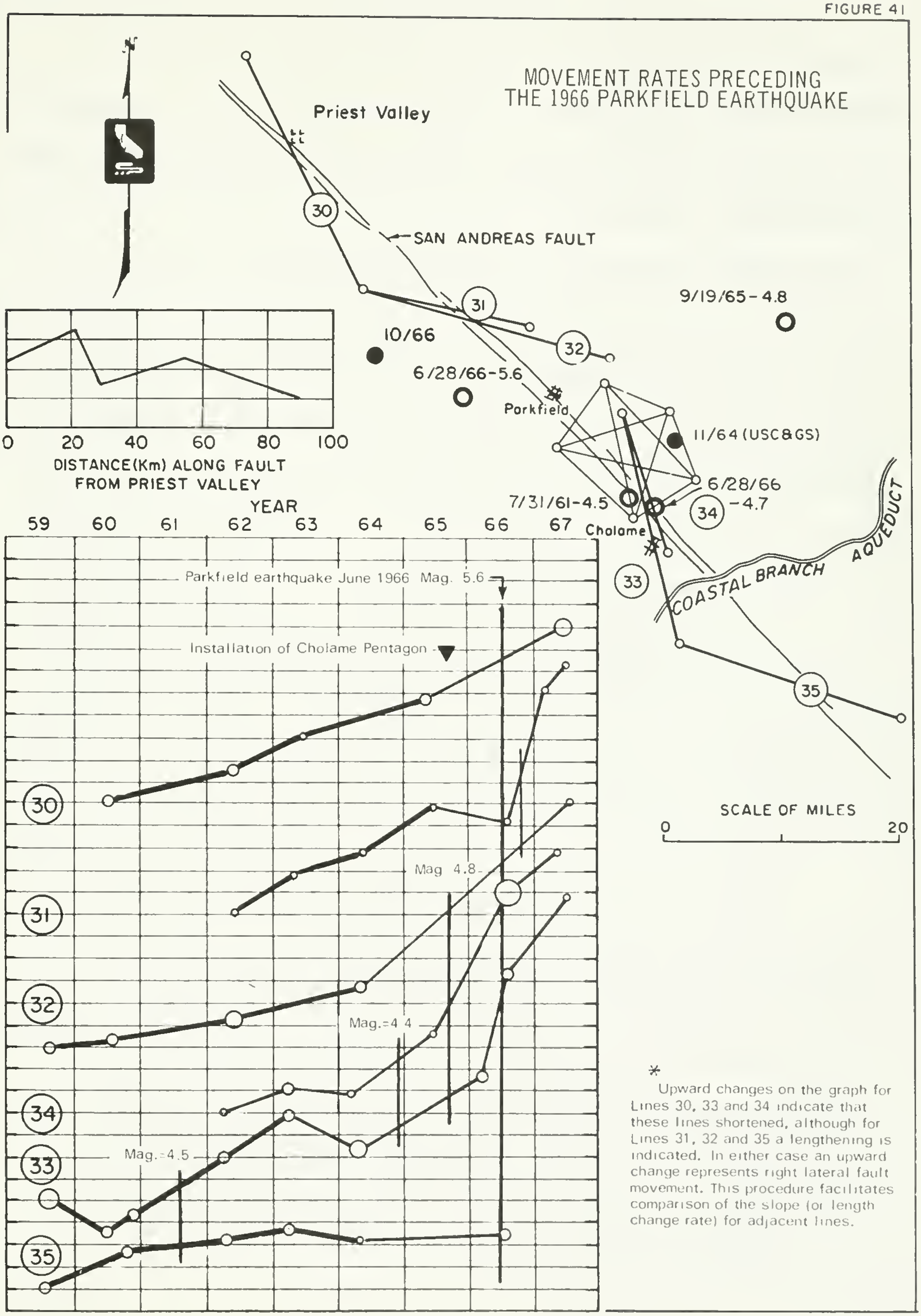
The accuracy of any single measurement under good conditions is generally regarded to be less than 2 cm as discussed in the chapter on accuracy estimates. However, in 1959 and early 1960, before field procedures were refined as well as they are now, a single measurement would sometimes deviate as much as 4 cm from the mean. The smooth fit of a single curve through the points and the very large length changes observed (13 cm) rather than smaller random deviations from a mean suggest that expected errors in themselves are not the sole explanation for this set of observations.

Parkfield-Cholame Earthquake of 1966

The kind of length change anomaly which occurred prior to earthquakes in the previous examples in this chapter were not obvious for this shock. An earthquake occurred in this vicinity in 1965. Only one line, in this area, Line 33 (Figure 41), was measured in the nine-month interval between the 1965 and 1966 earthquakes--too few observations to detect a possible precursor to the later event.

However, a different kind of anomaly, a persistent low rate of fault movement, indicated by Line 30, between adjacent zones of more rapid movement was cause for anticipation of a "catching up episode" likely to be accompanied by an earthquake (Figure 41).

Because of this anomaly and the proximity of the State Water Project Coastal Branch Aqueduct, a closed pentagon network of Geodimeter lines was installed astride the fault as near to the anomalous zone as topography would permit. These same reasons influenced the Department to proceed in a cooperative program with USC&GS to install an array of strong-motion seismographs at this site. These are described in the Department's Bulletin No. 116-4, "Earthquake Engineering Programs Progress Report".



* Upward changes on the graph for Lines 30, 33 and 34 indicate that these lines shortened, although for Lines 31, 32 and 35 a lengthening is indicated. In either case an upward change represents right lateral fault movement. This procedure facilitates comparison of the slope (or length change rate) for adjacent lines.

In late June 1966, the Magnitude 5.6 Parkfield earthquake and a series of aftershocks occurred. The earthquakes were accompanied by about 20 cm of movement parallel to the San Andreas fault as determined from remeasurement of the pentagon. The fault movements are described in more detail in Chapter III.

These events raised the average movement rate indicated by Line 32, to a value more similar to the higher rates of adjacent lines.

Line 30, crossing the fault near Priest Valley, still indicated a lower rate of fault movement after the earthquake than Line 25 (Figure 15) to the north on Lines 31 and 32 to the south. This anomaly has not been as severe as the one at Line 32. Both Lines 28 and 30 have indicated a lower rate relative to Line 25 further north and Line 31 to the south (Figure 21).

The abrupt change between barely discernable movement along the fault south of Cholame and the present high rate to the north is significant, suggesting an extremely high strain gradient. This area of transition is near the northwest terminus fault rupture reported during the 1857 Fort Tejon earthquake.

The zone of little movement continues southeastward to the San Bernardino area where there is evidence of regional compression. Geodimeter measurements are not made further south than the Palm Springs area but reports by Brune and Allen (1966) and others review visible evidence of fault slippage in the Imperial Valley which like the zones of slippage near Hollister and the San Francisco Bay is marked by high seismic activity. Major movements to equalize the strain along this 250-mile segment of the fault can be expected.

Other Earthquakes

Anomalous fault movements have been observed preceding some earthquakes. This suggests that regular fault movement observations might lead to understanding and identification of earthquake precursors. A further testing of this capability is attempted here, although the average interval of about one year between observations of each line precludes full assessment of potential.

Other earthquakes of magnitudes greater than 4.5 near the Geodimeter lines were investigated to determine if unnoticed line length change anomalies had preceded any of them. The investigation disclosed no new precursors but showed:

1. These shocks had occurred in the Hollister area where earthquakes are more frequent than line measurements; or

2. No more than two and often one or no preceding measurement had been made following the most recent earthquake in the area.

A list of these earthquakes follows. The month, day, year and magnitude are given in sequence followed by the latitude and longitude of the epicenter.

Hollister Area Earthquakes

1. 12/29/59 - 4.7, 36°54'N, 121°29'W

   This event was accompanied by several smaller shocks in the Hollister area. Only one measurement of the lines was made prior, so no trend was established.

2. 1/20/60 - 5.0, 36°47'N, 121°26'W

   This earthquake occurred just after initiation of measurements in this area. Prior observations are insufficient to establish a pattern for prediction. There is a slight excess right-lateral motion occurring during the event on Lines 17, 20 and 25 which accompanied numerous smaller earthquakes during this interval. Measurements were being made at the time of the shock.

3. 4/9/61 - 5.6, 36°41'N, 121°18'W
4/9/61 - 5.5, 36°41'N, 121°18'W

A limited trend was established prior to these events, but no marked deviation appears. The high frequency of earthquakes in this area preclude effective prediction on an annual measurement basis regardless of what deviations appear, since effects are difficult to assign to particular earthquakes. Line 25 shows characteristic right-lateral motion during the event, but Line 20 implies a slight reversal from normal behavior.

4. 9/14/63 - 5.4, 36°52'N, 121°38'W

A small distortion appears on Line 17, nearest the epicenter, but the amount is hardly enough to eliminate the chance of slight measurement error.

Earthquakes Preceded by Inadequate Data

1. 7/1/59 - 4.7, 35°12'N, 119°03'W (south of Bakersfield)

This event occurred prior to measurements in this area.

2. 3/1/63 - 5.0, 34°56'N, 118°59'W (near Gorman)

No definite precursor appeared for this event, but only one measurement had been made following the previous shock in this area in 1960.

3. 5/22/63 - 4.6, 37°16'N, 122°19'W (west of San Jose)

This event occurred near Line 14. There is some distortion of the measurements observed on this line, but the two measurements taken prior to the event are insufficient to have established a trend. (See graph of Line 14, Figure 10.)

4. 10/17/65 - 4.9, 33°58'N, 116°46'W (near Banning)

There was no obvious precursor in the measurements taken near the time of this earthquake, but the better line (Line 76) was measured 30 months prior to the event and 18 months afterward. The available measurements were outside the time of influence of this size earthquake. Line 77 has not been remeasured since 13 months prior to the earthquake. This measurement may be within the time of influence of the earthquake but the line is poor--there are several thousand feet difference in elevation between end points and the average probable error is the largest of any line graphed in this report.

Other Fault Movements

Although as a result of studies to date, fault movement anomalies have been shown to precede some earthquakes of Magnitude 4.5 or greater, the uniqueness of these anomalies also bears investigation. The anomalies which preceded earthquakes, in this study, were generally deviations greater than 2-1/2 cm and were often a reversal of the usual sense of line length change. For example, a line may have shortened rather than continued to lengthen--then be followed by an earthquake within a year or so. Consequently, line length changes which fit these criteria, but had not been recognized as earthquake precursors, were investigated. They fell into three categories: those which followed earthquakes of magnitudes greater than 4.5; those which were accompanied by "swarms" of smaller shocks; and those apparently not associated with significant earthquakes or swarms. Anomalies on some lines are the result of poor temperature measurement conditions. These Lines, 3, 16, 44, 49, 61 and 79, (designated line quality of 5 or 6) in Appendix A are not included in the discussion.

Anomalous Fault Movements Following Earthquakes of M≥4.5

Line No.	
11	Mid-1960, large peak possibly associated with some nearby Hollister earthquakes (Figure 10).
14	December 1963, a peak occurred on the length graph following a local Magnitude 4.6 earthquake (Figure 10).
20	Dip following 1961 5.6, 5.5 earthquakes (Figure 12).
31	Dip following Parkfield earthquake (Figure 15).
32	Extra movement following Parkfield earthquake (Figure 15).
33&34	Large movement in 1966 associated with the Parkfield earthquakes (Figure 18).

Anomalous Fault Movements Accompanying "Swarms" of Local Earthquakes

Line No.	
50	Large dip in early 1964 across Pleito thrust following numerous local earthquakes. The line returned to normal in mid-1964 (Figure 26).
53	Changes in length are accompanied by local earthquakes at distances greater than the normal range of effect. Two Magnitude 5 earthquakes may be close enough to influence this line which parallels the White Wolf fault. Its southern terminus is near the surface expression of the Pleito thrust (Figures 25 and 26).
68	Movements observed 1960-61, 1964-65-66, associated with earthquake swarms at distances greater than the normal range of effect (Figures 27 and 28).
70	Large movements in 1960, -65, and -66, apparently associated with numerous small earthquakes at distances greater than the normal range of effect (Figures 27 and 28).

Anomalous Fault Movements Not Obviously Associated with Earthquakes of M≥4.5

5&6	A strong, right-lateral shift appeared on the Hayward fault in the 1965 measurements. This would normally be called a prediction but no notable earthquake appeared. Apparently, movement commenced without an earthquake (Figure 8). See also discussions on Pages 25 and 35.
35	More rapid than usual movement on the San Andreas fault near Cholame in 1959-60, possibly associated with a M - 4.5 earthquake in 1961 near Parkfield which followed this deviation (Figure 18).
38	More rapid than average movement on the San Andreas fault east of La Panza in 1960 and early 1966, no apparent reason (Figure 18).
46	More rapid than average changes between 1964 and 1966 across the San Andreas fault near Taft and Maricopa. No significant earthquake associated (Figure 23).
52	This line, perpendicularly across the Garlock fault and the Pastoria thrust fault near Lebec shortened slightly in 1966 for no apparent reason (Figure 26).

Line No.	
54	This line, perpendicular and across the White Wolf fault, lengthened slightly then suddenly shortened in 1964. This would be a prediction if the USC&GS epicenters were used. The California Institute of Technology places the shocks (2/5/64 and 5/6/64) about 28 miles more distant than did the USC&GS (Figure 26).
63	This line, normally quiescent, across the San Andreas near Palmdale and Littlerock shortened 3 cm in 1962 (indicating movement inconsistent with right-lateral slippage), no apparent reason (Figure 28).
64	Large movement is indicated across the San Andreas fault near Valyermo in 1965-66. This movement may be the result of an unstable bench mark (Blue W). Only one small earthquake (M=3.5) in 1965 although Brune and Allen (1966) have pointed out that special studies indicate micro-earthquakes are prevalent in this area (Figure 28).
75	Large length decrease between 1963 and 1967 on this line perpendicular to and across the San Andreas fault near Beaumont and Yucaipa. Measurement intervals are so large that the meaning of deviations is difficult to assess. The movement in 1967 may be a precursor to an earthquake which had not yet occurred or a consequence of the 1965 shock (Figure 30).
76	More rapid than usual change of this line across the Banning fault between Beaumont and the San Gorgonio Pass in 1961, no apparent reason--may be reaction and recovery to the M=4.0 shock in 1959 (Figure 30).

Computer Program for Earthquake Warnings

Prior to the universities' publication of epicenters covering the time span of our Geodimeter measurements, an attempt was made to assess warning capability using USC&GS published earthquake information. The computer program is described in Chapter V, Equipment and Procedures--Length Change Analysis Program. The basic logic of this program is a comparison of observed line lengths with that extrapolated from previous measurements by means of a straight line. "Prediction" criteria were obtained through a regression analysis of characteristics of obvious fault movement precursors to the USC&GS epicenters and magnitudes. Because of this and the many complexities in logic which needed refinement, the regression analysis has not been repeated with the university data. Initially, in early 1966, the program predicted about half of the earthquakes of Magnitude 4.0 or greater as reported by the USC&GS to have occurred near the Geodimeter lines exclusive of those in the Hollister area (Lines 17-29). It produced an almost equal number of false flags (prediction not followed by an earthquake).

The prediction program is currently run with the line length determination program. A series of three asterisks following a measurement in Appendix A indicates a greater than average likelihood of an earthquake occurring near that line.

Each new observation on a given line is likely to change the characteristics of the least squares straight line fit to the data. Hence, as the quantity of measurements increases, the straight line representing long-term fault movement rate usually becomes better defined and the program makes some earthquake predictions in retrospect. That is, the earthquake was not predicted when the measurement preceding it was first processed but at a later date, after the rate of movement had been better defined, the measurement preceding the earthquake appears anomalous.

An analysis of the predictions made by the program in the current line-length analysis run (Appendix A) follows. Evaluation of the program performance is based upon how well it predicts earthquakes of Magnitude ≥ 4.5 as located by the university networks. Aftershocks and Hollister area activity are not included in this analysis. The program does not test measurements with Line Quality 5 and 6 (see Chapter V). Generally, results are less satisfactory than with manual analysis because of the limited logic used. However, they are sufficiently promising to warrant further development of the program.

Results from Computer Prediction Program

A. Earthquakes > 4.5 Predicted

Date	Prediction	Location
5/22/63 M=4.6	Predicted 10/30/62 on Line 14 but not until recent observations had better established the movement rate.	Near Line 14
11/16/64 M=5.0	Predicted July 1964 on Lines 11, 12 and 13.	Near Corralitos
7/31/61 M=4.5	Predicted 1960 on Lines 33 and 35.	Near Cholame
9/19/65 M=4.8	Predicted 1964 on Lines 33 and 34.	NE of Cholame
11/15/61 M=5.0	Predicted 1960-61 on Lines 47, 50, 51, 52 and 60.	Near Gorman
4/65 M=4.5	Predicted on Line 67	Near Corralitos
Fall 1967 M=4.7	Predicted on Lines 12 and 13.	Near Mt. Hamilton
Fall 1967 M=5.0	Predicted on Line 10.	Near Mt. Hamilton

B. Earthquakes Not Predicted

Date	Prediction	Location
3/1/63 M=5.0	Too soon after 1961 earthquake and too few measurements for prediction.	Near Gorman
10/17/65 M=4.9	Nearest measurement 32 months before event.	East of Banning
6/28/66 M=5.6	Insufficient measurements between this shock and preceding one.	Parkfield

C. Flags Not Associated With Earthquakes > 4.5

Line No.	Date	Comments
5&6	6/65 12/65	Apparent accelerated movement on Hayward fault (may be associated with 1964 Corralitos earthquake).
11	8/60	May be precursor to 4/61, M=5.6, M~5.5 Hollister earthquakes.
46	4/66	Excessive right-lateral movement confirmed by subsequent measurements. No notable earthquakes.
54	1/64) 3/65)	These were followed by earthquakes east of the area. Outside normal range of effect, as defined on Page 21.
55	1/64)	
64	6/65)	
4	6/65	No nearby earthquakes but might be associated with general strain change in Bay area which may be related to the 1964 Corralitos earthquake.
7	12/65	" "
14	9/65	" "
38	10/60	No earthquakes.
38	2/66	"
42	12/60	"

Line No.	Date	Comments
51	8/66	Slight shortening, probably result of poor measurement. (The measurement is the average of only 4 length determinations made on a single night).
52	8/66	No earthquakes.
62	2/63	"
63	3/62	"
72	2/61	No earthquake, small deviation.

D. New Predictions Not Yet Tested

Line No.	Date	Comments
39	4/67	Simmler-McKittrick - not yet confirmed by subsequent measurement.
50	11/67	Confirmed by subsequent measurement. (Made after Appendix A was printed.)

The program predicted eight earthquakes. One of these was predicted in retrospect after later observations better established the rate of fault movement. Three earthquakes were not predicted and there were 17 false or uncertain predictions and two new predictions.

Compared to manual analysis, the program can be improved. This can be accomplished with additional logic and by using local network epicenters to redefine optimum prediction criteria.

Assessment of Warning Capability

Criteria for adequate data to define fault movement anomalies are:

1. At least two measurements on lines in the area following the preceding shock. Consequently, the earthquake must be in an area where line measurements are significantly more frequent than earthquakes.

2. Measurements must have been made within a year (preferably less) prior to the earthquake.

All shocks of magnitudes greater than 4.5, for which data were adequate, were preceded by obvious fault movement anomalies. Fault movement anomalies occur at other times than preceding earthquakes. Some are associated with swarms of smaller earthquakes.

Evidence is limited but suggests that with an increased frequency of measurements, earthquakes of magnitudes greater than 4.5 can be predicted, most within a time accuracy about equal to the measurement interval. Unless additional criteria can be found, about an equal number of false alarms will have to be tolerated. That most of the larger earthquakes were preceded by anomalies observed on several lines and most false alarms are indicated by only one measurement line provides reason to be optimistic that these phenomena may be developed as a criterion to reduce the number of false flags.

Although a larger than desired percentage of false alarms is produced, results from this program appear significant as a two-dimensional warning system (both time and location along about 500 miles of California's active faults).

A certain percentage of false alarms must be tolerated in most time-space warning systems for natural phenomena. Examples are warnings of hurricanes and tornados. After many years of development most are predicted within a few days or even hours but many that are predicted change course or dissipate. Tsunami (earthquake-caused "tidal waves") warnings are now almost always predicted but about 9 of 10 warnings are not followed by significant wave action--yet these warnings save lives, for example at Crescent City in 1964.

The possibility of providing earthquake warnings is demonstrated. Evidence suggests that with continuous or near continuous measurements, a prediction capability might be developed in the sense discussed by Macelwane (1946)--that is, a forecast within days or hours.

This potential could be tested by sending a second field crew to make closely spaced measurements in areas where anomalous movements were detected by the basic program.

Knowledge of the absolute state of strain will probably be required to estimate magnitudes of forthcoming earthquakes with the desired degree of accuracy. This would require, in addition to more frequent measurements, a supplementary program of strain measurements possibly from overcoring in deep drill holes.

CHAPTER V. EQUIPMENT AND PROCEDURES

Equipment

The Geodimeter

The Geodimeter is a highly precise, electro-optical distance-measuring system (Figure 42). Essentially, it is an electronic interferometer which measures distance by phase comparison between a transmitted modulated light beam and the returning beam reflected from a distant prism.

The mechanics of the instrument are shown in the simplified diagram on Figure 43. The light source (either a tungsten or mercury vapor arc lamp) is directed through a polaroid lens, a Kerr cell, another polaroid lens, and then through a telescopic optical system which projects the light toward a distant reflector. The axes of the polaroid lenses are oriented 90 degrees apart so no light can be transmitted to the telescope unless the Kerr cell is operating. The Kerr cell consists of a pair of electrodes immersed in highly purified nitrobenzine contained in a windowed chamber. The plane of polarization of light passing through the device is rotated when an electric potential is applied to the electrodes, the degree of rotation being proportional to the potential. When the plane of polarization is rotated, light passes through the second of the crossed polaroids and through the lens system on to the reflector.

The modulation system is essentially a high-power oscillator, similar to a radio transmitter, producing a varying voltage applied to the Kerr cell. The modulation frequency is very precisely controlled to within one part in ten million.

Figure 42. THE MODEL 2A GEODIMETER

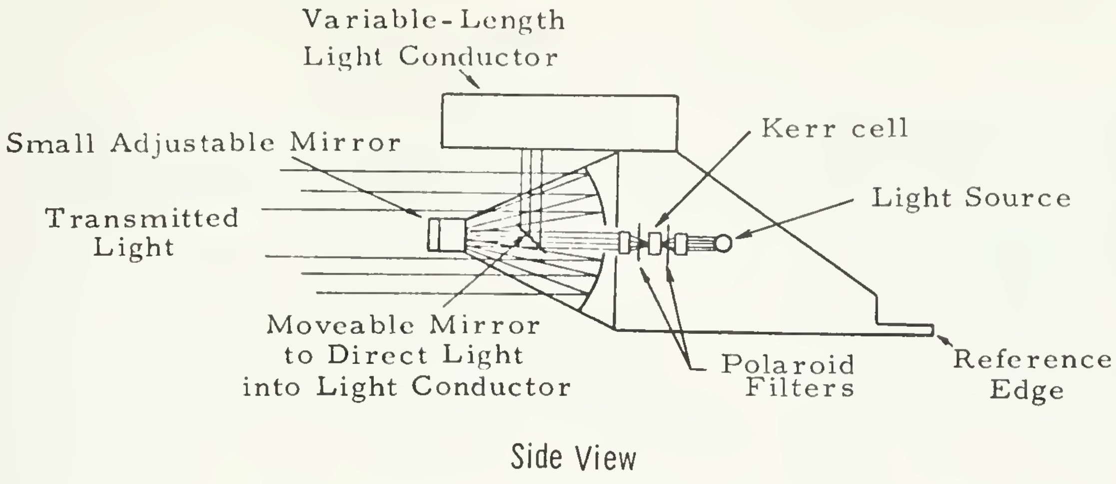


Figure 43. GEODIMETER OPTICAL SYSTEM

The conventional Geodimeter light source is a 4-volt tungsten filament lamp. It does not always provide sufficient light power to cope with adverse atmospheric conditions. In 1963, the Department's Geodimeter was modified to use a mercury-vapor arc-lamp light source, which is much brighter than the tungsten lamp. This has allowed operation under a broader range of weather conditions.

The receiving system consists of another telescopic optical system which directs the light to a sensitive photomultiplier tube. This tube detects the variations of the light, reproducing an electrical signal like that coming from the modulation system. However, there is a delay in the time required for the light to travel to the reflector and return. This time delay is equivalent to some number of whole wavelengths of the modulated light plus a portion of a wavelength, the total of which corresponds to the distance from the Geodimeter to the reflector. This is diagrammatically shown in Figure 44.

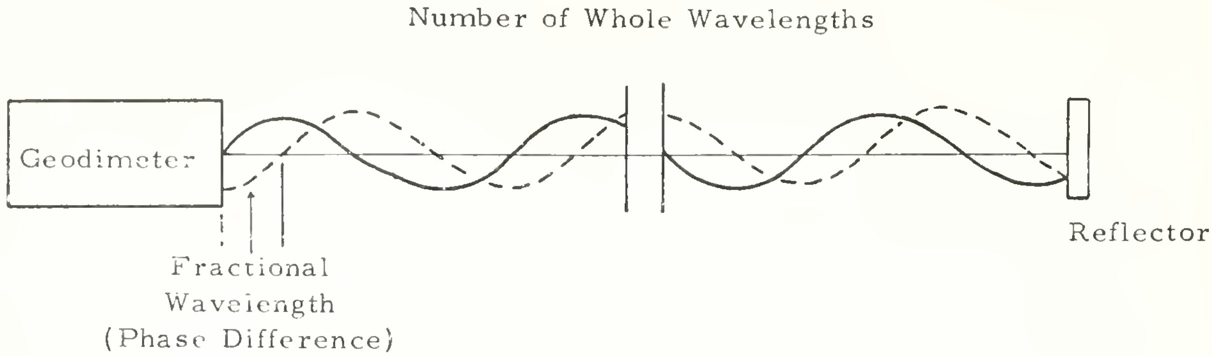


Figure 44. PHASE SHIFT IN RETURNING MODULATED LIGHT

In this report, the wavelength (or color) of the light source is always preceded by the word "effective". Any other usage of "wavelength" in this report refers to the modulated beam.

The wavelength of the modulated light beam is a function of both the frequency of modulation and the speed of light. The speed of light is determined by the "effective wavelength" of the source light (through the atmosphere) as well as the index of refraction. The tungsten bulb and arc lamp light sources have different predominant colors resulting in differing "effective wavelengths", which in turn affect the "wavelength" of the modulated light.

The Geodimeter does not measure the number of whole wavelengths directly but does measure the length of that portion of a wavelength left over. The time difference, equivalent to this fractional wavelength, constitutes a phase difference between the transmitted and received light. A variable electrical delay is connected to the modulating signal and adjusted so that its output is in phase with the signal from the light-receiving network, as indicated by a phase-detector nullmeter. The time required for the signal to pass through the electrical delay is equivalent to the time required for the modulated light beam to travel the fractional wavelength under determination. The electrical delay is then calibrated in units of length (Figure 45).

The Model 2A Geodimeter is calibrated for each measurement of distance by inserting a known optical distance, in the form of the variable-length light conductor, into the path of the transmitting and receiving optics (Figure 46).

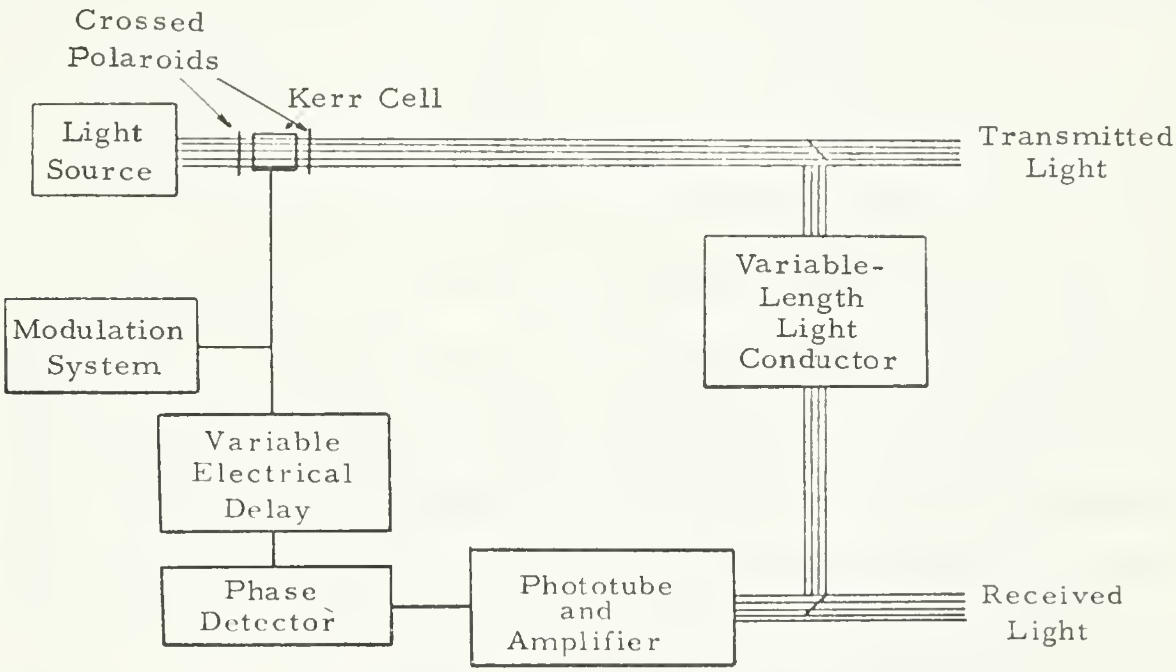


Figure 45. BLOCK DIAGRAM OF MODEL 2A GEODIMETER

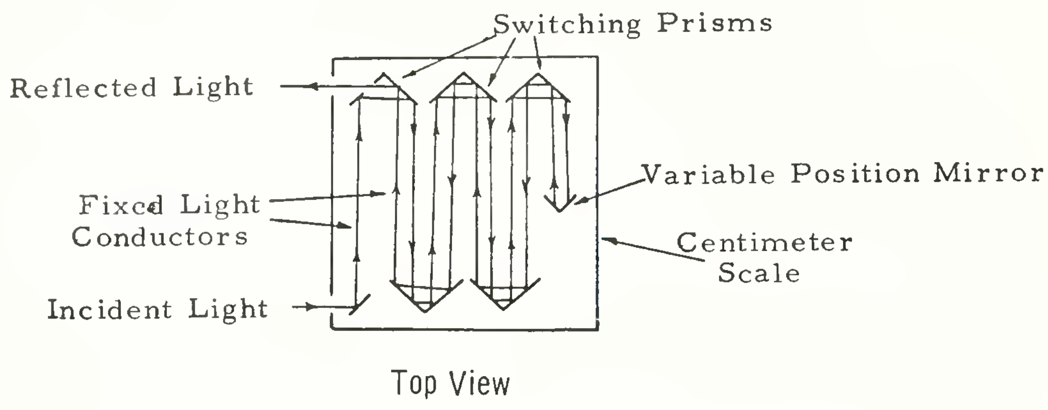


Figure 46. VARIABLE-LENGTH LIGHT CONDUCTOR

The variable-length light conductor is adjusted to yield the same value of electrical delay as that determined from the reflex measurement; and since the light conductor has a known length, this length is exactly equal to that fractional wavelength we are attempting to measure. This variable-length light conductor is a principal distinguishing feature of the Model 2A Geodimeter. Other models use a fixed-length light conductor to obtain a less accurate calibration of the electrical delay.

In practice, the measurement procedure is slightly more complex:

(1) The Kerr cell connections and nullmeter circuitry are sequentially reversed so that four readings are obtained on the electrical delay to eliminate small errors.

(2) Readings are actually obtained on the light conductor by setting it slightly below and then slightly above the desired value and interpolating, because the exact setting is difficult to attain.

(3) An additional reflector reading is made after the calibration readings to minimize effects of electrical drift.

(4) The null-detector only differentiates over one-fourth of a whole wavelength rather than a total wavelength.

The lengths of the unmeasured whole wavelengths are calculated from the modulation frequency, velocity of light, and appropriate index of refraction of air as determined from meteorological measurements. If the total length is known within about 7-1/2 meters (one-quarter wavelength) from previous measurement, the number of wavelengths can be calculated and the precise distance determined.

In 1959, when the program started, line determinations were averaged from six groups of measurements. Each group consisted of two sets of phase readings on the light conductors and one set on the reflex. Inspection of the early observations indicated a tendency for the measured lengths derived from the initial readings to be somewhat lower than the mean of the six groups of readings taken in the line measurement. It was concluded that this was due to drift in the electronics, and that this drift was most apparent early in the warm-up period. An increased warm-up period of approximately 60 minutes was initiated to compensate for this problem. An additional set of six measurements was also initiated to reduce random variations in the electronic phase detection circuit, allowing a more accurate determination of the mean distance.

The reflector used with the Geodimeter is a retrodirective prism device, designed so that light is returned at exactly the same angle it enters. This eliminates the need for accurate positioning of the reflector that would be required with a simple mirror. Several prisms, each about 2 inches in diameter, are retained in housings. Normally, a total of 21 prisms is used for the typical long measurements required in fault monitoring. The overall optical system is of such quality that the diameter of the visible returning reflection is only about 3 meters on a 20 km line.

A calibrated reflex mount (Figure 47) allowing the prisms to be moved away from and toward the Geodimeter during the course of the observations, has been used for the past three years. This device allows phase comparisons on different portions of the electrical delay line. Six of the twelve length determinations for each line measurement are made with the mirror forward on the reflex mount. The remaining six are made with the mirror at the rear of the reflex mount. The optical and electrical delays in the Geodimeter are different for the two reflex positions. Thus, small errors in electrical and optical dial calibrations will be reduced by averaging.

For most applications of the Model 2, the primary benefit is derived from the two sets of different readings, which reduce the possibility of a repeated reading error going undetected.

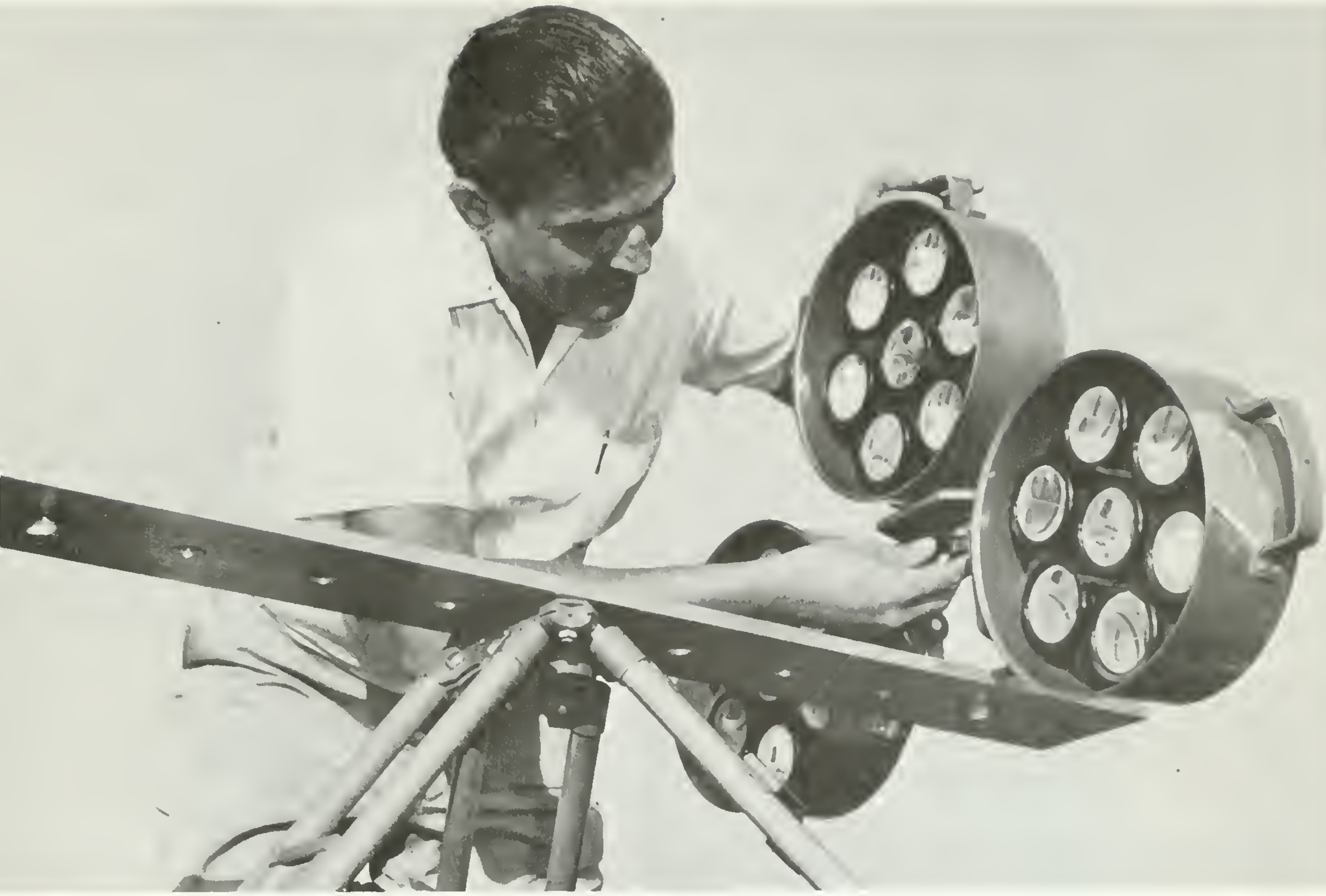


Figure 47. GEODIMETER REFLEX PRISMS

Meteorological Instruments

The greatest single factor limiting the overall accuracy of the Geodimeter measurement process is the determination of a representative temperature along the measurement path. In a 10 km line, a $1^{\circ}C$ change has the effect of a 1 cm change in the line length or 1 part per million. Pressure and relative humidity must also be determined although they are less important in determining the refractive index of air for visible light.

Initially, temperature, of necessity, had been assumed to be the average end-line temperatures observed about six feet above the ground. This procedure is generally inadequate to obtain the precision necessary for measurements for this purpose. Differences in elevation of the end points, terrain characteristics, wind patterns, and temperature inversions can have an important influence on the mean temperature along the light path, which is difficult to assess with end temperatures at ground level only.

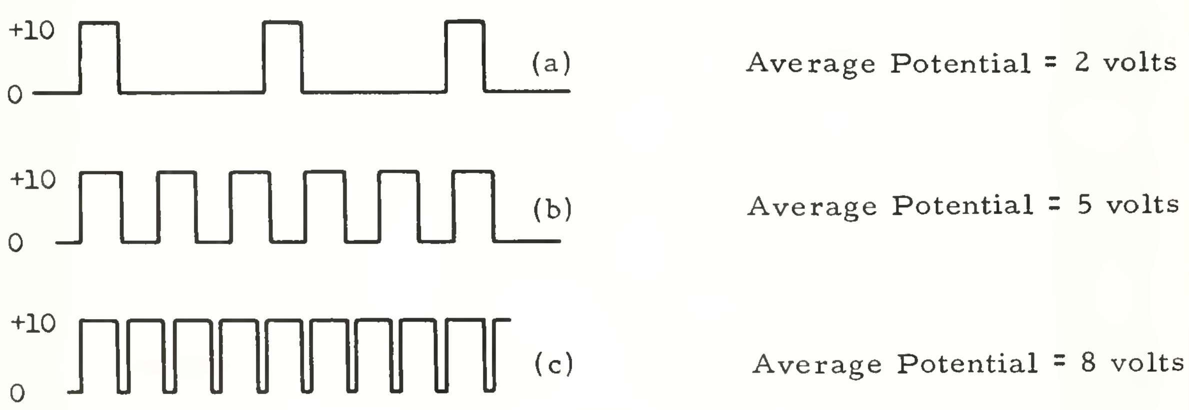
Radio Temperature Telemetering Unit. A practical solution to this problem was found in 1962 with the development of a radio temperature telemetering device. This radiosonde system, used for remote temperature measurement, was developed at the China Lake Naval Ordnance Test Station for use in the Geodimeter program. The system consists of a lightweight, battery-powered transmitter, receiver, and frequency meter (Figure 48).

The transmitter has a thermistor in a relaxation oscillator circuit (employing a unijunction-type transistor), which generates a series of pulses. The pulse repetition rate is determined by the resistance of the thermistor which in turn is temperature-dependent. The pulses trigger a bistable multivibrator (flip-flop), which generates a square wave signal. The square wave is filtered to a quasi sine wave, in the audio frequency range, used to modulate a low-powered transmitter.

The receiver is a commercial AM battery-powered unit. The radio frequency carrier is detected and the audio frequency modulated subcarrier reproduced through the audio section of the receiver. An audio tone is also reproduced through the receiver's speaker, allowing the operator to monitor the operation of the transmitter.

Figure 48. TEMPERATURE RADIOSONDE SYSTEM

The frequency-metering unit measures the tone pitch coming from the receiver. This unit includes additional amplifying circuits and a special type of pulse generator. This pulse circuit is a monostable (one-shot) multivibrator with a low-impedance output. It generates a pulse of fixed height and duration for each cycle in the tone being measured. If the frequency is low, the pulses have relatively wide separation; at high frequencies, the pulses are close together (Figure 49). The average voltage varies with the pulse repetition rate. This pulse train is connected through a nullmeter to a ten-turn potentiometer. The dial reading of the potentiometer corresponds to the average voltage, which is a linear function



Pulse generator output at (a) low frequency input-- 200 cps. (b) medium frequency input-- 500 cps, and (c) high frequency input-- 800 cps.

Figure 49. PULSE GENERATOR OUTPUT

of tone frequency. In practice, it is possible to make the unit linear so that the dial reading (0-1000) is equal to input frequency with three-digit accuracy. A change of 1 cps in tone is slightly less than 0.1°C.

The radiosondes are temperature-calibrated at periodic intervals. Readings are accurate to one-tenth degree C. A special temperature oven is used specifically for this purpose. The sonde is placed in the oven and the frequency is counted at various temperatures through the operating range. These data can be either plotted on semi-log graph paper or submitted directly to the computer program, which generates a calibration table.

The lifting device for the sondes is a kytoon, a specially designed captive balloon developed for vertical stability in moderate wind velocities.

The kytoon (Figure 50) is a Zeppelin-shaped airfoil balloon with a free lift of two pounds and an additional dynamic lift of about two pounds for each five miles per hour of wind speed. It has an outer casing of special nylon cloth, with lightweight cotton balloon cloth for the tailfins. Neoprene bladders, easily replaced when necessary, hold the helium lifting gas. The kytoon is 10.7 feet long and 4.1 feet in center diameter with an inflated volume of 82 cubic feet. Normally, one balloon is employed, but more can be used to obtain a greater number of temperature samples.

Figure 50. KYTOON

Elevated Thermistors for End-Temperatures. Another serious temperature problem frequently occurs at certain stations situated on level terrain, particularly in valleys. When there is no wind, cold air will settle near the surface, creating what is described as a ground-level inversion. This layer generally has been found to be only 10-20 feet deep, but temperature differentials have been observed up to 7°C. It is apparent that in these instances, observation of surface temperatures is not representative of the average for the line.

This potential source of error was eliminated in 1963 with the construction of a wired resistance thermometer. This device is essentially an amplified Wheatstone Bridge circuit with modifications to eliminate thermistor heating and effects of lead resistance. Readout is directly in ohms resistance which can be converted to temperature manually by a calibration graph or automatically in the computer program. The thermistors are elevated to a maximum of 50 feet on a television antenna-type telescoping mast attached to the vehicles (see Figure 51). The thermistors, calibrated in the same oven used for the radiosondes, are accurate to 0.1 degree C.

Barometers. Pressures are measured by high-quality aneroid barometers, periodically calibrated against a mercurial barometer in the office. Originally, the aneroid barometers were compared at various airport weather stations in the field. However, difficulty was experienced in obtaining sufficiently accurate absolute station pressures. Pressures are read in inches of mercury and feet of elevation on the barometers, and the values are compared in the computer program to check for reading errors.

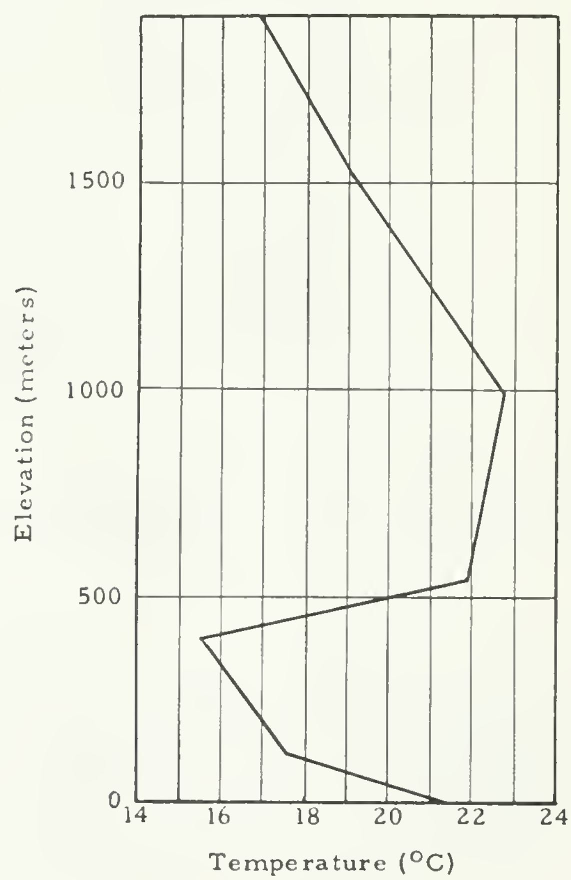
Hygrometer. The aqueous vapor pressure is measured at each end-point by a standard wet- and dry-bulb hygrometer. The two temperature readings are converted to a vapor pressure in the computer program.

Figure 51. MAST FOR ELEVATED END-TEMPERATURES

Line Selection Criteria

Accuracies of individual line measurements vary from a few millimeters to as much as several centimeters for extremely poor lines. The attainable accuracy is primarily dependent upon the field party's ability to determine a representative index of refraction by sampling temperature, pressure, and humidity at the ends of the line and temperature near midline. Geographical factors which contribute to temperature errors cannot always be avoided, but consideration of them can often improve results. The prime factors are:

1. Large differences in station elevations should be avoided. Temperature inversions are generally stratified between topographic barriers. If stations are at approximately the same elevation, temperatures taken at the endpoints will more nearly represent the correct mean value. If the light path passes through inversion levels, error will be introduced, depending on the severity of the inversion and its location relative to the sampling points. Figure 52 is a graph of a typical inversion measured at



Elevation- temperature relationship
observed September 1, 1961
(From U. S. Weather Bureau Northern
Hemisphere Data Tabulations)

Figure 52. COMPLEX INVERSION, OAKLAND

Oakland, California. The error which could be introduced by sampling at elevations differing only a few hundred meters is easily seen. The error can be reduced by taking more samples with airborne instruments.

2. Ground level inversions are a source of significant error in areas of flat terrain. Cold air tends to settle near the ground in the absence of mixing winds, particularly during periods of cooler temperatures. Figure 53 is a graph of a typical ground level inversion derived from data measured by the Geodimeter crew in the South San Joaquin Valley. The observed temperature differential is severe but concentrated near the ground. Most of the lines have one or both ends at high elevations; thus, only a very small percentage of the line is at the surface temperature. Thermistors elevated on poles attached to the trucks sample a more representative temperature. This measurement problem can be largely avoided if both the Geodimeter station and reflex stations are located on topographic highs not subject to this condition. High Geodimeter and reflex elevations are also advantageous in hazy areas where smog and fog

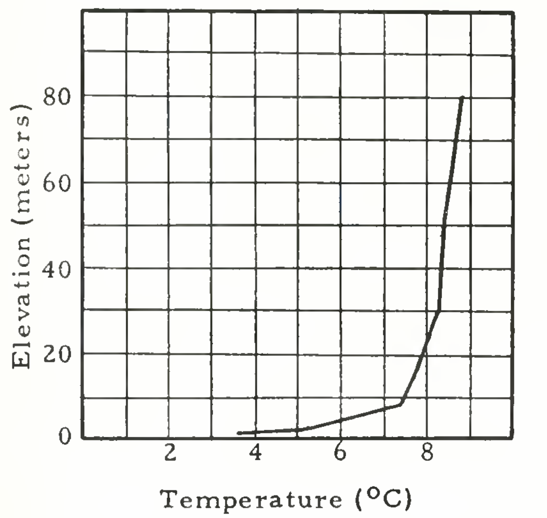


Figure 53. GROUND LEVEL INVERSION, SAN JOAQUIN VALLEY

are confined below inversion levels. The problem can be reduced by adequate instrumentation to measure temperatues above the inversion. If these data are unavailable, the ground-level inversion error can be reduced by correcting observed ground temperatures to conform to values derived from sample experiments. The degree of inversion is primarily a function of ground temperature and wind velocity. A dead calm produces inversions with the approximate relationships:

Ground Temperature	Temperatures at 50-foot Elevation
0°C	5°C
10	12
20	21

A slight wind (5 mph) reduces this error about 50%. Higher wind velocities (10 mph or more) usually prevent formation of an inversion.

3. Topographic climate barriers must be considered.

San Francisco Bay area topography is an example of a barrier which creates measurement problems (Figure 54). The west side of the Bay,

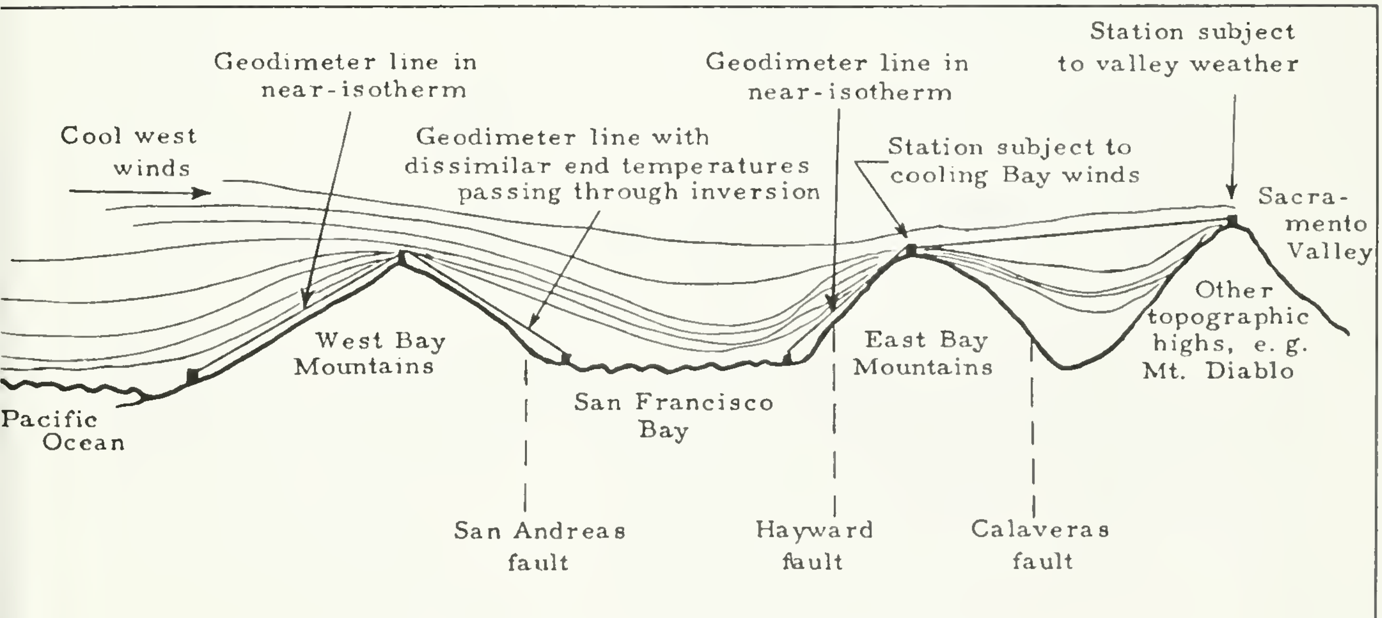


Figure 54. BAY AREA TEMPERATURE PROBLEMS

the San Francisco Peninsula, is primarily a range of hills running roughly parallel to the San Andreas fault zone, which is a barrier to prevailing westerly winds from the sea. Measurements obtained from the high stations atop these mountains generally are more representative of temperatures prevailing on the west side. Consequently, when lines are measured from these hilltops to low elevation stations near the Bay shore, they penetrate the layered air mass enclosed by the surrounding mountains (see Figure 54). If the cooling west winds chance to flow down the peninsular mountains and skim the Bay surface, most of the line temperature will be near that of the mountain top. If the winds remain high most of the line will be near the Bay shore temperature.

On the east side of the Bay, strong updrafts prevail. These provide a convenient isotherm for Geodimeter lines from the Bay shore across the Hayward fault to the East Bay mountain tops. Lines from these stations across the Calaveras fault to stations still further east can be troubled by the same phenomena as occur in the West Bay area but to a lesser degree. Another problem arises, however, because the East Bay topographic highs are a natural barrier between the weather prevalent in the San Francisco Bay area and that in the Sacramento-San Joaquin Valley.

To attain the absolute maximum accuracy, each line must be considered individually because the atmospheric conditions have been found to be so variable. The basic conclusions are:

1. Lines up to 15 km in length with exposure to relatively uniform meteorological conditions and measured with midline and elevated end-line temperatures can be measured accurately to within ± 1cm.

2. Many lines show unusual deviations which should not be arbitrarily rejected as errors caused by temperature determinations or by other sources. This is particularly true of those lying within complicated fault structures and in seismically active areas. A large deviation from the normal may be related to an earthquake rather than a measurement error.

3. The best indication of accuracy on a given line is considered to be the relationship of previous measurements on the same line, with due consideration to Point 2.

4. Atmospheric conditions which usually prevail throughout the Department's Geodimeter network are now reasonably well known. New lines can be selected which take into consideration those factors that allow better temperature estimates and consequent higher accuracy.

Procedures

Equations of the Length Computation

The index of refraction in air at standard temperature and pressure is given by the equation:

$$Ng = 1 + (2876.4 + 3 \frac{16.288}{\lambda^2} + 5 \frac{0.136}{\lambda^4})\ 10^{-7}$$

where λ is the effective wavelength. This is a function of the color of the transmitted light and the response curve of the photomultiplier tube. Typical values are 0.555 micron with a tungsten lamp and 0.546 micron with a mercury-arc lamp light source.

The index of refraction as a function of atmospheric variables is given by the equation:

$$Na = 1 + (Ng-1)\frac{P}{760}\ \frac{273}{T} - (5.5 \times 10^{-8})\ e\ \frac{273}{T}$$

where T is the absolute temperature ($t^{o}C + 273$), P the pressure in millimeters of mercury, and e the pressure of water vapor in the air expressed in millimeters of mercury.

The basic length equation is:

$$L = N \frac{(C)}{4fn} + frac + Km$$

where

L = the slope distance between points

N = the number of one-quarter wavelengths

C = the velocity of light in a vacuum

f = the frequency of modulation

n = the index of refraction in air

frac = the fractional wavelength

Km = various constants of the measurement

To resolve distances not known within 7-1/2 meters (1/4 wavelength), the Geodimeter uses two additional frequencies of modulation. The three frequencies yield three length determinations in the form:

$$(1)\quad L_1 = N_1\,(QWL_1) + frac_1 + Km_1$$

$$(2)\quad L_2 = N_2\,(QWL_2) + frac_2 + Km_2$$

$$(3)\quad L_3 = N_3\,(QWL_3) + frac_3 + Km_3$$

where QWL is the length of the quarter-wavelength at frequencies 1, 2, and 3 (10,000,000; 10,049,810; and 10, 300,008 cps).

In this situation, the terms QWL, frac and Km are known for each frequency. N_1, N_2, and N_3 must be determined so that L_1, L_2, and L_3 are equal. Solutions are not unique. They can recur at multiples of 1,500 meters. The procedure (see Geodimeter manual, Nygaard 1959 and Poling 1959) to determine the number of quarter wavelengths is:

> The ratios of N_1, N_2, and N_3 are approximately those of f_1, f_2, and f_3. The length solution is an iterative process. A rough length, L_1, is scaled from a map and substituted in equation (1) to solve for a rough N_1. N_2 is found from $N_1 : N_2 \approx f_1 : f_2$, and rounded to the nearest whole integer. The integer value is substituted in equation (2) to yield a new length, L_2, which will differ from L_1 (unless the initial length was accurate to less than 7-1/2 meters). Some whole number of wavelengths must now be added or substracted to bring L_1 and L_2 to the same value. QWL_1 is 4 cm longer than QWL_2, so adding quarter-wavelengths increases L_1 more than L_2 and conversely, subtracting decreases L_1 more than L_2.

The iteration formula $dN = \frac{QWL_1 - QWL_2}{L_2 - L_1}$ is repeated until

$L_1 - L_2 < 0.04$ meter. Then N_3 is computed from the frequency ratio and substituted in equation (3). If $L_1 - L_3 < 0.04$ meter, N_3 is correct. If not, N_1, N_2, and N_3 are raised or lowered one digit to seek a solution.

A discrete solution of equations (1) and (2) can be found at 1500-meter intervals. If a solution is not found during the above process, one can be found at $L_1 + 1500$ M, or $L_1 - 1500$ M.

The slope distance of a measured line is given by the equation:

$$\text{Slope Distance} = \left(\frac{C}{4fNa}\right) N + Lc + FD + Kg + Kr + \text{focus} + \text{ecc} + Tc$$

C = velocity of light in a vacuum = 299,792,800 meters/second
f = frequency of modulation
Na = index of refraction in air
N = the number of 1/4-wavelengths of modulated light
Lc = the length of fixed light conductors (= number of light tubes x length of one light tube)
FD = fine delay, the length of the variable light conductor
Kg = calibration constant of the Geodimeter
Kr = correction for the particular reflector used
ecc = eccentricity of the Geodimeter and reflector (location with respect to bench mark)
focus = focus correction (-ft -fr + .0040, read from scales on focus controls)

$Tc = 0.17\left(\frac{\text{Geodimeter elevation - reflex elevation}}{\text{slope distance}}\right)$; tilt correction resulting from displacement of the optical axis by tilting of the Geodimeter.

$$\text{Sea Level Distance} = \left[\frac{SD^2 - (H1 - H2)^2}{\left(1 + \frac{H1}{R}\right)\left(1 + \frac{H2}{R}\right)}\right]^{1/2} + \frac{1}{24R^2}\left[\frac{SD^2 - (H1 - H2)^2}{\left(1 + \frac{H1}{R}\right)\left(1 + \frac{H2}{R}\right)}\right]^{3/2}$$

where H1 = Geodimeter station elevation + Geodimeter height, H2 = reflex station elevation + reflex height, and R = radius of curvature of the earth for the particular azimuth and latitude of the line.

Calibration

The calibration of the Geodimeter essentially involves determination of the effective dimensions of the optical system components in the device. These are described as the Geodimeter constant (Kg) and the length of the variable light conductor (FD) used to convert the electrical phase delay into physical length (see section on the Geodimeter).

The rear edge of the Geodimeter is taken as the reference point for the measurements. The Geodimeter constant is primarily a combination of two internal lengths:

1. The distance from the fiducial edge to the apparent optical source of light in the Geodimeter.

2. The light path length from the Kerr cell to the variable light conductors and the return path to the photomultiplier.

The path lengths to and from the light conductors are the longest part of the internal circuit, resulting in the necessity of adding a constant, of approximately one meter, to each length measured. The constant for Model 2A Serial 138 remains close to 1.1333 meters.

The variable-length light-conductor consists of a number of fixed length tubes and a final one which is made continuously variable by a movable mirror.

Any number of eleven fixed-length light tubes can be mechanically switched into the light path by movable prisms; the total "length of the light conductor" is the sum of the lengths of the individual tubes used, added to the variable length which is always in the light path. Although the actual length of the light conductor tubes remains fixed and is accurately known, their effective lengths may differ because of the position of the switching prisms and other optical and electrical components. Consequently, the length of an individual tube must be determined in the calibration. The final variable length is read from a centimeter scale that indicates the position of the movable reflector. Any index errors of this scale are included in the Geodimeter constant. The arrangement of the optical components is shown schematically in Figures 43 and 46.

The calibration procedure involves measuring a group of known distances previously marked off with an invar tape. The arrangement is like that of Figure 55. The distances are selected so that each fixed light-conductor is used and a number of length determinations is made with each in the optical path. Because the calibration range is a short distance and the transmitter and receiver optics of the Model 2A Geodimeter are physically separated, a special reflector system is used to align the transmitted and received light along the optical axes of the Geodimeter. A group of length equations is obtained in the form:

$$L_1 = WL + N_1 (Lc) + FD_1 + Kg + focus_1 + Kr$$

$$L_n = WL_n + N_n (Lc) + FD_n + Kg + focus_n + Kr$$

where

L	=	known distance
WL	=	length of integral 1/4-wavelengths
N	=	number of fixed light-conductors
Lc	=	length of fixed light-conductor
FD	=	length of variable light-conductor
Kg	=	Geodimeter calibration constant
focus	=	focus correction
Kr	=	reflex constant

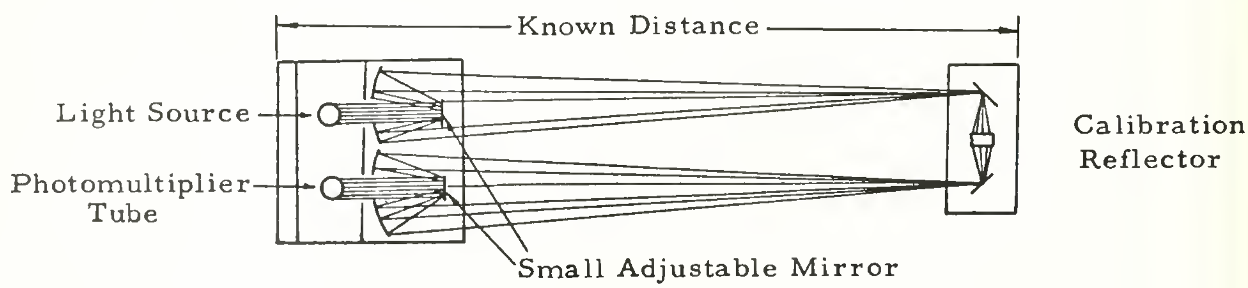


Figure 55. SETUP FOR CALIBRATION

The lengths of the integral 1/4-wavelengths and reflex constant are known. The focus correction is derived from the positioning of a small mirror, which is adjusted to focus the Geodimeter light beam on the reflex for each distance. The mirror position is read on a micrometer attached to the mirror. The mirror and its micrometer mount are attached to a horizontal bar mounted in front of the large external transmitting mirror. A similar mirror is mounted on the other end of the horizontal bar in front of the large receiving mirror. Light gathered by the receiving mirror is focused on the second small adjustable mirror and then reflected through a system of lenses to the photo-multiplier tube. Adjustment of this small mirror refines the focus on the photo-multiplier tube. The setting of this mirror is algebraically added to that of the small transmitting mirror to obtain the total focus correction. The focus settings for a reflex at infinity is the standard setting.

Focus corrections are then the difference between small mirror settings for a reflex at infinity and reflex positions at calibration distances. The settings at infinity are approximated by adjusting the mirrors for maximum light return, using the photo-multiplier output as an indicator, when the reflex is several miles distant. In calibration, the standard setting can be assumed to be 2 mm with adjustments made for maximum light return when the instrument is used in the field. Thus, in practice, focus corrections seldom change although they are entered for each measurement.

The fine delay (FD) is interpolated from readings made on the centimeter scale attached to the variable light conductor as described in the section on the Geodimeter. The group of equations $L_i = WL_i + N_i (Lc) + FD_i + Kg + focus_i + Kr$ is solved by a least square computation for the best values of Lc, the length of the fixed light tubes, and Kg, the Geodimeter constant.

Computer Programs

Computer programs developed for the Geodimeter investigation include (a) length computation, (b) length change analysis, (c) quadrilateral and pentagon closures and adjustments, and (d) calibration-calculation constants for the tele-temperature measuring devices. A modification of Robert O. Burford's (1965) program is used to compute strain changes from geodetic data.

Length Computation. The length computation program is the most complex of the group. It computes the geodetic distance directly from the field recording sheets. Edit routines check input cards for non-allowable entries. The basis of the program is the equation of the length computation discussed previously. Terms of the length equation are obtained directly or are computed from the input data.

Data input to the program come from several sources. Data sheets are prepared during the field measurements at the Geodimeter, reflex, and midline balloon. The data include instrument readings and characteristics, instrument position with respect to the station, and meteorological data. Data which do not often change are entered on control cards or retained on a history tape. These include approximate distances between stations, standard elevations of the stations, positions of eccentric stations with respect to the main station and some calibration data. The source of each term of the length equation follows:

Effective wavelength is listed on the recording sheet by the operator. There are two possible entries depending on whether the arc lamp or incandescent bulb is used.

Temperatures at the Geodimeter, both ground level and elevated, are recorded directly at the start and finish of each of the two reflex readings which are a part of each individual length determination. The times of readings are used to correlate temperatures with those taken at the reflex and from the midline balloon. Readings from thermistors elevated by the balloon or poles are converted by an exponential function into temperatures. Coefficients of the function are determined for thermistor bridge or telemetry units.

The program is designed to solve the length equation with whatever temperature information is available, and label the solution according to the data used. Balloon or elevated temperatures are not always available. The program interpolates the readings in time and by prorating the horizontal position of the balloon between the Geodimeter and reflex. The analyst may also insert a temperature derived by other means. For example, average temperatures may be derived from helicopter flown thermistors or from special analyses of vertical temperature profiles when inversion problems are encountered.

Pressure readings are entered on the data sheets at the Geodimeter and reflex. The computer interpolates the readings with time to provide a best average value for the line at the instant of measurement. Pressure is read in both feet of elevation and millimeters of mercury and these values are compared in the program. These values are also compared against those published in the "U. S. Standard Atmosphere" for the known elevation of the station. Station elevations are stored in the program. If a discrepancy is detected, an appropriate message is included in the output.

Relative humidity is recorded at the start and finish of each set of measurements at both the Geodimeter and reflex stations. The wet and dry bulb readings are converted into vapor pressure in mm in the program and the values interpolated with respect to time throughout the set.

Modulation frequency, one of three possible settings, is recorded at the Geodimeter at the start of each measurement of a group of lines. The frequencies from the most recent instrument calibration are entered on the recording sheet before it is punched on cards. Because of high oscillator stability in the Model 2A Geodimeter, these values remain fixed for a long period of time. Also read in at the start of the computation of a group of measurements are the Geodimeter constant (Kg), length of the fixed light-conductor (Lc), and reflector constant (Kr).

Fine delay is calculated from a phase comparison between the reflector reading and a similar reading taken on the variable-length light path built into the Geodimeter.

Eccentricity of the Geodimeter (distance between reference edge of the Geodimeter and the station) and reflex are read from the recording form where they are entered in meters and inches. Two values are compared for agreement.

Focus correction is computed from the focus mirror micrometer settings used during measurement and adjusted to the values used during the calibration.

Tilt correction is the lateral shift of the optical center of the Geodimeter when it is tilted. The correction arises because the optical axis of the Geodimeter is 17 cm above the reference edge of the instrument. When the instrument is tilted appreciably in the measurement of steeper lines, the axis is moved forward or backward. The program computes the correction from the elevations of the Geodimeter and reflex and the approximate slope distance.

Number of quarter wavelengths is computed from the approximate distance through an iterative process using values obtained from the readings taken on three frequencies. If three frequencies are not measured, or if the iterative process fails to close, the program goes to a historical line data tape which contains values used during previous measurements.

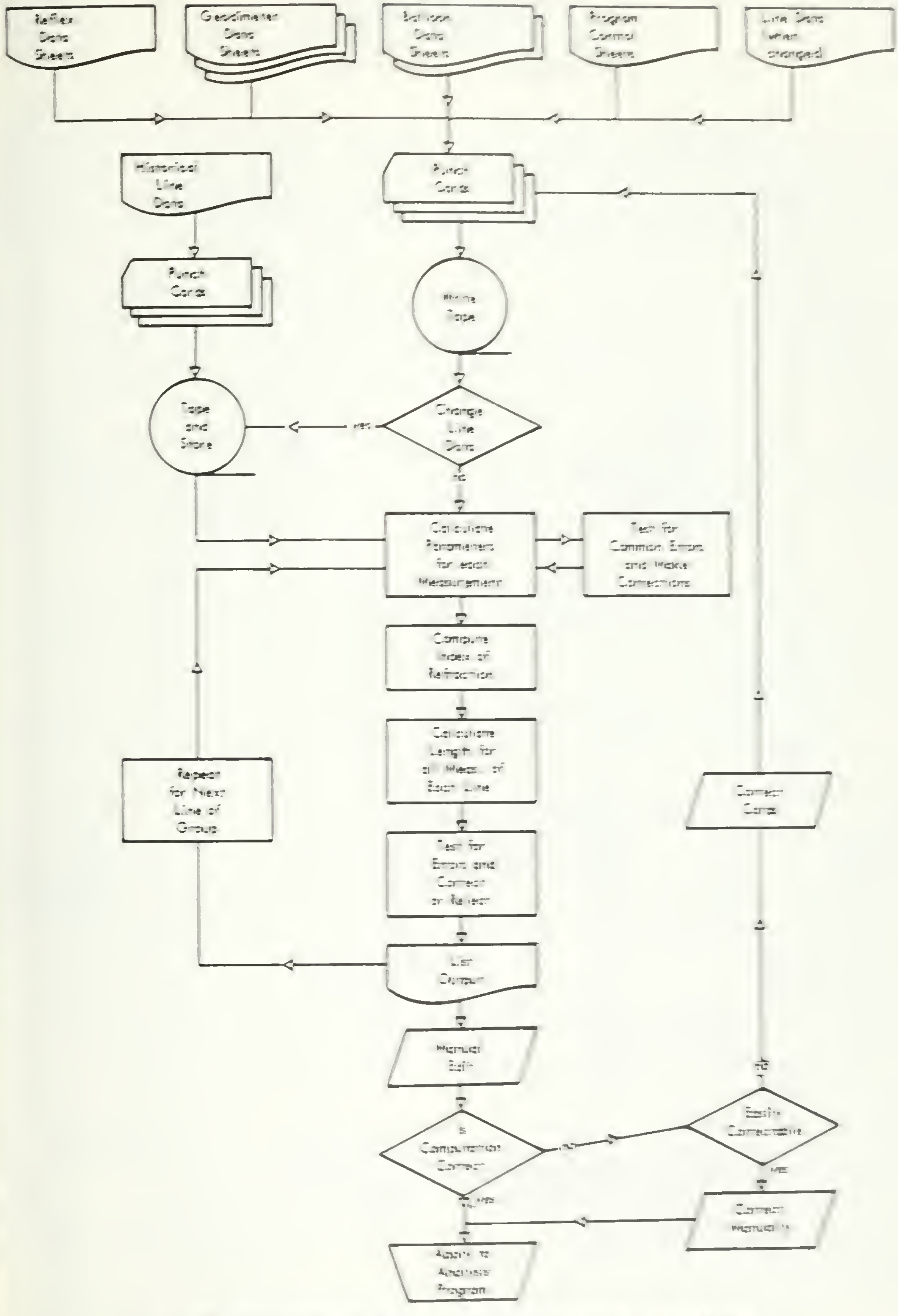
Sea level correction changes the straight line optical distance to a curved line which approximately conforms to the surface of the earth (the geoid). It is computed from station elevations and the radii of curvature stored on the historical tape for each line. The radii were initially derived from the Clarke Spheroid (1866), e.g., Reynolds (1955). Although new tables for a revised geoid are available, their effect on changes in Geodimeter line length is negligible.

Off line correction is derived from the taped distance and angle to the main station monument from an eccentric station. This is stored on the historical tape and updated if a new eccentric station is used. The historical line-data tape contains seldom changing characteristics of each line. Changes and additions can be made on program control cards.

The program also contains a rejection routine which eliminates poor measurements due to errors or electrical noise. An abbreviated flow chart of the machine process is shown in Figure 56. Sample input and output listings are shown in Figures 57-62 and Appendix A. Complexity of the program precludes a full description here. A standard program write-up is on open file in the Department.

Length Change Analysis Program. This program compares the observed lengths and dates of measurement to compute characteristics of the length change graph for each line. The output contains length changes, extension (dL/L), time interval, and change rate (dL/dT) between succeeding measurements. The slope of the best straight line representing movement rate is derived from the observed data. The slope of this least-squares line is an estimate of the average annual rate of change in meters per year. This rate is divided by the length to yield the line extension or linear strain rate. The difference between the observed value and the length computed from the least-squares line is tabulated for each measurement date. These values provide some indication of the measurement quality and probable error of

FIGURE 56



FLOW DIAGRAM OF LENGTH COMPUTATION PROGRAM

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
STAFF AND SERVICES MANAGEMENT

FIGURE

GEODIMETER MEASUREMENTS

PAGE 1 OF

Card Code 100 (69–71)

G Sta 1 SIMMLER ECC 1962 (5–29) R Sta 2 TWISSEL 1959 (35–59) Line No. 038 (72–74)

Card Code 600 (69–71) ← CARD CODE FOR SORTING

Geodimeter Sta Elev 611.03 m (1–6) Reflex Sta Elev 909.21 m (7–12) Date 04/05/67 (75–80)

COLOR OF LIGHT

Eff λ 5460 A (17–20) Geod Ht .92 m (13–16) RH Start 4.2/ 5.4 °C (25–30) Focus T 2.5 (21 22) N Freq 1.2 (48 4)

CALIBRATION CONSTANTS OF THERMISTOR (WHEN USED)

Temp Calculation B . (37–43) Ro (44–47) RH End 4.2/ 5.4 °C (31–36) Focus R 3.6 (23 24) ← FOCUS SETTIN

Observer	D. CLAWSON	Time Heater on	~~Hg~~ 1840	State	CALIF
Recorder	J. NICHOLAS	Lamp ~~Voltage~~/Type	Hg	Locality	PASO ROBL
Balloon Tender	D. BECKSTEAD	Time Hg Lamp on	1855	Remote Temp Sensor	–
Reflex Tender	B. PLECAS	Phototube Sens	180	Measuring Unit	–
Chief of Party	D. CLAWSON	Nullmeter Sens	60	Elev of Sensor	–

INDICATES RELATIVE LIGHT RETURNING

Card Code 601 (69–71)

ELECTRICAL DELAY DIAL SETTINGS

		Sign	Ph 1	Ph 2	Ph 3	Ph 4	Sum	Manual Computation
Freq 1 (1)	C.D. 2 F.D.	– (2)	541 (3–5)	567 (6–8)	579 (9–11)	507 (12–14)	FIRST REFLECTOR READING	Mean Ref
LC1 (LIGHT CONDUCTOR LENGTH)	05-52 (52 53 54 55)	– (15)	530 (16–18)	550 (19–21)	537 (22–24)	498 (25–27)	FIRST LIGHT CONDUCTOR READ	LC1-Ref
LC2	05-62 (56 57 58 59)	–	611 (28–30)	637 (31–33)	611 (34–36)	597 (37–39)	SECOND " "	LC2-LC1
	C.D. 2 F.D.	–	541 (40–42)	553 (43–45)	555 (46–48)	490 (49–51)	SECOND REFLECTOR READING	Fine Delay

Card Code 602 (69–71)

METEORLOGICAL OBSERVATIONS

FIRST REFLECTOR READING

Geod Ecc To (Away)	Time	P - in Hg	P - ft Alt	T obs	Dial	T ~~vem~~	Reflex Observations P - in Hg	Reflex Observations T obs
-0.032 m (1–6)	1945 (13–16)	27.99 (17–20)	1900 (21–24)	7.2 (25–27)	– (28–31)			
-1.250 in (7–12)	1948 (32–35)	27.99 (36–39)	1900 (40–43)	7.0 (44–46)	– (47–50)			

UNNUMBERED SPACES USED FOR MANUAL LENGTH COMPU.

Card Code 603 (69–71)

SECOND REFLECTOR READING

Reflex Ecc	Time	P - in Hg	P - ft Alt	T obs	Dial			
	1956 (7–10)	27.99 (11–14)	1900 (15–18)	6.7 (19–21)	– (22–25)			
+.400 m (1–6)	1958 (26–29)	27.99 (30–33)	1900 (34–37)	6.2 (38–40)	– (41–44)			

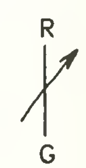
Weather: Sharp <u>Clear</u> Haze Smoke Fog

. . (45–47) External Temperature ← USED FOR SPECIAL TEMPERATURE SOLUTIONS

Arrow in Wind Direct

Thermometer: 2 m Above Ground at Geodimeter
2 m Above Ground at Reflex

Wind: Calm <u>Light</u> Moderate Hard



Remarks:

GEODIMETER INPUT DATA SHEET

DWR 1040 (REV. 6/67)

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
STAFF AND SERVICES MANAGEMENT

FIGURE 58

REFLEX OBSERVATIONS

Reflex Station TWISSEL (DWR) 1959 Geodimeter Station SIMMLER
Reflex Tender B PLECAS Reflex Ecc. +.400, -.400 Meters ± 15 3/4 Inches
Altimeter No. 2653 Thermistor No. —
Reflex Type 3 7-BUCKETS Therm. Bridge No. —
Reflex Height 27 1/2 Inches Thermistor Ht. —

Card Code 2 0 0 (69–71) Line No. 3 8 (72–74) Date 04/05/67 (75–80)

Reflex Ht. .70 M (1–4) Temp. Calc. Constants B (5–11) R_o (12–15)

RH Start 5.5/5.8 (16–21) RH End 3.7/4.2 (22–27) No. of Obs. 20 (28–30)

	Time	Temp	Therm Bridge	P-in Hg	P- ft alt	Card Code
1	19 45	4.4		26.98	2900	
2	50	4.4		"	"	
3	55	4.3		"	"	201
4	20:00	4.3		"	"	
5	:05	4.3		"	"	
6	:10	4.3		"	"	202
7	:15	4.2		"	"	
8	:20	4.1		"	"	
9	:25	4.1		"	"	203
10	:30	4.2		27.00	2885	
11	:35	4.2		"	"	
12	:40	4.3		"	"	204
13	:45	4.3		"	"	
14	:50	4.3		"	"	
15	:55	4.3		"	"	205
16	21.00	4.3		"	"	
17	:05	4.3		"	"	
18	.10	4.3		"	"	206

WEATHER:

ARROW IN WIND DIRECTION:

VISIBILITY: SHARP CLEAR HAZE SMOKE FOG RAIN
WIND: CALM LIGHT MODERATE HARD
REMARKS: Thermometer and Altimeter must be at least 50 ft. up wind from any vehicle or building.
List below other geodimeter and/or Reflex Stations, observed same night. Record below time of noticeable changes in weather.

REFLEX INPUT DATA SHEET

DWR 2460 (REV. 6/67)

FIGURE 5

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
STAFF AND SERVICES MANAGEMENT

BALLOON TEMPERATURE OBSERVATIONS

Geodimeter Station: SIMMLER

Place X at Balloon Location

G - - - - X - - - - R

Radiosonde Type/No. 5
Time on 1915 Time off 2120
Discriminator Type/No. 2

Temperature Calculation Constants: B -3043.10; R_o 234

Reflex Station: TWISSEL
Balloon Tender: O. BECKSTEAD
Geodimeter Station Elevation: 1910
Reflex Station Elevation: 2910
Desired Balloon Elevation: 2410
Borometric Ground Elevation: 2220

Calibration Test Obs Temp: 9.4 | 9.3
Dial: 342 | 338
Graph Temp: 9.4 | 9.2

Balloon Position Weight: 5
(Geod = 0, Reflex = 10)
Line no 38 (72–74) Date 4/ 5/67 (75–80)

	Dial	Time	Temp	String Length	Balloon Angle	Balloon Elevation	Ground Temp	Card Code
1	337	1922	9.1	15'	90°		9.4	
2	339	1923	9.3	50'	90°		9.3	
3	335	1925	9.0	75'	90°		9.2	
4	332	1926	9.1	100'	85°		9.2	
5	331	1927	8.7	150'	"		9.3	401 (69–71)
6	334	1929	8.9	200'	"		9.4	
7	327	1945	8.4	"	"		8.3	
8	326	1950	8.3	"	"		8.2	
9	326	1955	8.3	"	"		8.0	
10	325	2000	8.2	"	"		6.0	402 (69–71)
11	321	2005	7.9	"	"		5.6	
12	320	2010	7.8	"	"		5.6	
13	317	2015	7.6	"	90°		5.6	
14	319	2020	7.7	"	"		5.7	
15	315	2025	7.4	"	"		5.6	403 (69–71)
16	320	2030	7.8	"	"		5.6	
17	321	2035	7.9	"	"		5.5	
18	317	2040	7.6	"	"		5.5	
19	317	2045	7.6	"	"		5.3	
20	316	2050	6.0	"	"		5.2	404 (69–71)

G / R — WEATHER:

ARROW IN WIND DIRECTION:

VISIBILITY: SHARP CLEAR HAZE SMOKE FOG RAIN
WIND: CALM LIGHT MODERATE HARD
REMARKS:

MIDLINE BALLOON INPUT DATA SHEET

DWR 2459

```
GEODIMETER   REFLEX                                      CONFIDENCE INTERVAL                 CARD CODE ,LINE NO AND DATE
CONSTANTS  CONSTANTS    MODULATION FREQUENCIES           -COEFFICIENTS                            (USED FOR SORTING)
03411333-02501000000010049810103000008 2576099                                                    050000041567
   SIMMLER (ECC.) 1962                        TWISSEL 1959 — STATION NAMES                       100038040567
070              55 58 37 42020 — REFLEX HEIGHT AND RH                                            200038040567
945 44      269829001950 44      269829001955 43      26982900                                   201038040567
000 43      269829002005 43      269829002010 43      26982900                                   202038040567
015 42      269829002020 41      269829002025 41      26982900                                   203038040567
030 42      270028852035 42      270028852040 43      27002885                                   204038040567
045 43      270028852050 43      270028852055 43      27002885                                   205038040567
100 43      270028852105 43      270028852110 43      27002885                                   206038040567
115 43      270028852120 43      27002885                                                        207038040567
1026 234-304310       5 — RADIOSONDE CALIBRATION CONSTANTS                                        400038040567
3371922      3391923      3351925      3361926      3311927                                       401038040567
3341929      3271945      3261950      3201955      3252000                                       402038040567
3212005      3202010      3172015      3192020      3152025                                       403038040567
3202030      3212035      3172040      3172045      3162050                                       404038040567
3142055      3132100      3152105      3152110      3122115                                       405038040567
3132120                                                                                           406038040567
61103 90921 0925460253604205404205 4                   12*                                        600038040567
-541567579507-530550537498611637611597541553555490055205 62**                                     601038040567
-0032 -1250194527991900 72      194827991900 70                                                   602038040567
 0400195627991900 67      195827991900 62                                                         603038040567
-541553555490-527539545499613632629574546553538512055205 62                                       604038040567
-0032        195627991900 67      195827991900 62                                                 605038040567
 04  200227991900 61      200427991900 61                                                         606038040567
-483491500457-475499492452529555555510460464466430060506 15                                       607038040567
-0032        200527991900 61      200727991900 61                                                 608038040567
 04  201627991900 61      201727991900 58                                                         609038040567
-460464466430-453498490427500550550504469462460461060506 15                                       610038040567
-0032        201627991900 61      201727991900 58                                                 611038040567
 04  202027991900 58      202227991900 58                                                         612038040567
-478468460450-418492476400528578560490485486452447100210 12                                       613038040567
-0032        202327991900 58      202527991900 59                                                 614038040567
 04  203427991900 57      203527991900 54                                                         615038040567
-485486452447-418495474390508562564494452480481420100210 12                                       616038040567
-0032        203427991900 57      203527991900 54                                                 617038040567
 04  203827991900 51      204027991900 51                                                         618038040567
-521509512490-483558530450560638621517530523510484110211 12                                       619038040567
-0032        204227991900 49      204527991900 48                                                 620038040567
-04  204727991900 49      204827991900 50                                                         621038040567
-530523510484-475546536449562626619532528538539480110211 12                                       622038040567
-0032        204727991900 49      204827991900 50                                                 623038040567
-04  205027991900 51      205327991900 51                                                         624038040567
-490502493461-451550527432520600592491470468469461070507 15                                       625038040567
-0032        205327991900 51      205727991900 51                                                 626038040567
-04  210027991900 48      210127991900 45                                                         627038040567
-470468469461-447533508426520598580481462450462465070507 15                                       628038040567
-0032        210027991900 48      210127991900 45                                                 629038040567
-04  210327991900 44      210427991900 44                                                         630038040567
-480470456452-431466470405496543532488488433458471065206 62                                       631038040567
-0032        210528001890 44      210728001890 40                                                 632038040567
-04  210928001890 40      211028001890 44                                                         633038040567
-488433458471-436477468418514554532500492441440487065206 62                                       634038040567
-0032        210928001890 40      211028001890 44                                                 635038040567
-04  211328001890 50      211528001890 51                                                         636038040567
```

REFLEX METEORLOGICAL MEASUREMENTS (cards 201–206)

RADIOSONDE READINGS (TIME AND FREQUENCY) (cards 401–405)

METEORLOGICAL READINGS (cards 602–603)

1st (cards 601–603) — 2nd (cards 604–606) — ADDITIONAL OBSERVATIONS (cards 607–633) — LAST (cards 634–636)

*STATION ELEVATIONS, GEODIMETER HEIGHT, EFFECTIVE WAVE LENGTH, FOCUS SETTING, WET AND DRY BULB TEMPERATURES

**DELAY READINGS AND LIGHT CONDUCTOR SETTINGS FOR FIRST OBSERVATION

INPUT DATA LISTING

SIMMLER (ECC.) 1962   TWISSEL 1959   LINE NO. 38   04/15/67

GEODIMETER CONSTANTS

CALIBR	REFLEX	TUBE	FREQUENCY 1	FREQUENCY 2	FREQUENCY 3
1.1333	-0.0250	.8034	10000000	10049810	10300008

DATE	TIME	F	PRESS	RH	LC	ECC	FOCUS	FDELA	ELEVATION G STA	ELEVATION R STA	INST HEIGHT GEOD	INST HEIGHT RFLX	TILT
40567	1945	1	698.12	6.20	3.21360	.3680	-0.00210	.53510	611.03	909.21	.92	.70	-0.00335
40567	1956	1	698.12	6.15	3.21360	.3680	-0.00210	.53006	611.03	909.21	.92	.70	-0.00335
40567	2005	2	698.12	6.11	4.01700	.3680	-0.00210	.03160	611.03	909.21	.92	.70	-0.00335
40567	2016	2	698.12	6.05	4.01700	.3680	-0.00210	.03644	611.03	909.21	.92	.70	-0.00335
40567	2023	3	698.25	6.02	7.23060	.3680	-0.00210	.04081	611.03	909.21	.92	.70	-0.00335
40567	2034	3	698.37	5.97	7.23060	.3680	-0.00210	.04123	611.03	909.21	.92	.70	-0.00335
40567	2042	3	698.37	5.93	8.03400	-0.4320	-0.00210	.02587	611.03	909.21	.92	.70	-0.00335
40567	2047	3	698.37	5.91	8.03400	-0.4320	-0.00210	.03923	611.03	909.21	.92	.70	-0.00335
40567	2053	2	698.37	5.88	4.82040	-0.4320	-0.00210	.02819	611.03	909.21	.92	.70	-0.00335
40567	2100	2	698.37	5.84	4.82040	-0.4320	-0.00210	.02717	611.03	909.21	.92	.70	-0.00335
40567	2105	1	698.50	5.82	4.01700	-0.4320	-0.00210	.54322	611.03	909.21	.92	.70	-0.00335
40567	2109	1	698.50	5.80	4.01700	-0.4320	-0.00210	.53860	611.03	909.21	.92	.70	-0.00335

NUMBER OF QUARTER WAVE LENGTHS FOR FREQUENCY 1 = 2016,   FOR FREQUENCY 2 = 2026,   FOR FREQUENCY 3 = 2076

Data not affected by temperature, used to check input data for obvious errors.

INTERMEDIATE COMPUTATIONS LISTING

GROUND-BALLOON TEMPERATURE CODE 3 SIMMLER (ECC.) 1962 TWISSEL 1959 LINE NO. 38 04/15/6

DATE	TIME	F	TEMP	REF IND	1/4WL	SLOPE DIST	SL-S-A	DISTANCE
40567	1945	1	6.90	1.00027275	7.49276887	15110.6416	4.74260	15105.8990
40567	1956	1	6.68	1.00027297	7.49276723	15110.6332	4.74260	15105.8906
40567	2005	2	6.48	1.00027316	7.45562926	15110.6243	4.74260	15105.8817
40567	2016	2	6.36	1.00027328	7.45562839	15110.6274	4.74260	15105.8848
40567	2023	3	6.34	1.00027335	7.27452285	15110.6517	4.74260	15105.9091
40567	2034	3	6.31	1.00027343	7.27452225	15110.6509	4.74260	15105.9083
40567	2042	3	6.11	1.00027363	7.27452082	15110.6359	4.74260	15105.8933
40567	2047	3	6.11	1.00027363	7.27452080	15110.6493	4.74260	15105.9067
40567	2053	2	5.98	1.00027376	7.45562483	15110.6153	4.74260	15105.8727
40567	2100	2	5.90	1.00027384	7.45562421	15110.6131	4.74261	15105.8705
40567	2105	1	5.86	1.00027393	7.49276003	15110.6353	4.74260	15105.8927
40567	2109	1	5.92	1.00027387	7.49276044	15110.6315	4.74260	15105.8889

MEAN DISTANCE + OFF LINE CORRECTION = 15105.8915 + 33.7633

PROBABLE ERROR OF THE MEAN	STANDARD ERROR	OVERALL MEAN	99 PER CENT CONFIDENCE INTERVAL
.0025078	.0128794	15139.6548	15139.6216 TO 15139.6880

I FTN 060 (STOP)

DISTANCE COMPUTATION AND STATISTICS LISTING

FIGURE 62

the computed slope where the earth is assumed to move in a linear relationship with time. (This, however, is not a valid assumption in many areas of the investigation.)

When irregularities in the projected line behavior were noticed before the occurrence of some earthquakes, an attempt was made to program an "earthquake prediction" subroutine into the length analysis program. A regression analysis was made to establish the relationship among such factors as length change, deviation from the expected value based on the least-squares fit, quality of the specific line, etc. The function which yielded the best results for all data using USC&GS epicenters and magnitudes (restricted to those greater than 4) was:

Let X = 0.079 x Line Quality x $\sigma^{1/2}$

where

Line Quality = A number from 1 to 6 assigned by the staff to represent their judgment as to the difficulty in obtaining accurate measurements for a given line once the equipment is in place.

σ = Standard deviation of observed line lengths from a least-squares fit to the line length vs. time graph.

COMP = The line length computed from a least-squares straight line through the time vs. line length graphs.

OBS = The line length observed at a particular time.

OBS-COMP = The difference between the length observed and the length computed from the least-squares straight line.

X = A number compared to OBS-COMP such that if the absolute value of the algebraic difference between any two subsequent values of OBS-COMP >X, the measurement is flagged by the program indicating a higher than normal probability of an earthquake occurring.

This program tests all observed line lengths, each time the length calculation program is run. If the test is affirmative, three asterisks are printed opposite the measurement on the length determination program output, Appendix A.

The program did not differentiate between deviations which occur after or during earthquakes and those which precede earthquakes. Thus, measurements taken after an earthquake were indicated on the input data so the program will not predict on the basis of these observations. This and other associated problems led to a modification which prevents the program from printing a flag if:

1. OBS-COMP <2 cm
2. line quality is 5 or 6 (Lines 3, 16, 44, 49, 61 and 79)
3. fewer than four measurements have been made on the line
4. the prior measurement has been flagged by an earthquake
5. the measurement follows an earthquake near that line by nine months or less
6. less than two measurements have been made following the most recent earthquake near that line.

The program has been only partially satisfactory because of obviously limited logic. Being based on linear movement rates, it can detect only short-term excursions, and it cannot differentiate in cases where creep is transferred from one major fault to another, as in the San Francisco Bay area. A skilled analyst can differentiate between these short-term variations and long-term discontinuities based on established geologic patterns. A manual evaluation also allows a more complete comparison of adjacent lines for correlation of deviations.

The program constitutes a simple method of obtaining an unbiased look at the change in rate of movement with time and provides a possible earthquake warning procedure. However, interpretations from the program are limited because the average interval between earthquakes of magnitude greater than 4.5 is often less than the line measurement interval, and the location accuracy of many earthquakes appears limited to 20 miles or more. Experimental analyses to date have been based on flagging criteria derived from USC&GS epicenters rather than from the university epicenters which are used throughout this report. The experiment may be repeated with revised logic and updated flagging criteria at some time in the future. See Chapter IV, Earthquake Prediction for description of results.

Quadrilateral Closure and Adjustment. This program computes the closure and adjusts a trilaterated quadrilateral, a geometric figure in which length determinations have been made of four sides and the two diagonals.

The first half of the program essentially considers each line sequentially redundant and computes a value based on the other five. Differences between observed and computed values are tabulated for the six lines comprising the figure.

The sides are then adjusted through a least-squares procedure in which the lengths of the lines are changed slightly to make angular computations balance. A practical description of this procedure is given by Murphy and Smith (1957).

Results derived from this program are discussed separately in this report.

Pentagon Adjustment. Seven lengths will define this figure but five sides and five diagonals can be measured. There are, then, three redundant lines. Corrections are made to all lines to make the figure close. Weights may be assigned to each line to allow larger correction on doubtful lines. The method is an extension of the quadrilateral adjustment of G. J. Thorton-Smith (1963), which specifies that the sum of angles around a point after correction for spherical excess must equal 360°. The three redundant lines of the pentagon are also redundant lines of three quadrilaterals contained by the pentagon. The program finds a simultaneous solution for three quadrilateral closures with the condition that the sum of the squares of adjustments is minimal.

Temperature-Sonde Calibration Curve Fitting Program. Oven calibrations of thermistor bridge units and FM subcarrier temperature-radiosondes result in empiracle curves. These curves may be expressed by an equation of the form:

$$R = R_o e^{B(1/T - 1/T_o)}$$

This is the generalized thermistor response equation. For the purpose of curve fitting,

R = dial reading for an unknown temperature, T.

R_o = dial reading at known temperature, T_o.

B = a constant.

A least-squares fit for the sequence of "R" and "T" measurements taken during calibration is used to evaluate the best single value for R_o and B, with $T_o = 273.18^oK$, for each instrument. Equations of this type with properly evaluated coefficients are used in the length determination program to translate dial readings into temperatures. The curve fit program also generates a table which can be used for manual calculations and calibration checks.

CHAPTER VI. ESTIMATES OF ACCURACY

Instrumental Accuracy

The internal length corrections and dimensions of the variable length light conductor of the Geodimeter are determined by comparison of Geodimeter measurements with a short invar-taped baseline. Using normal measurement procedures, the usual difference between taped and measured length is about 2 mm. Because this accuracy limitation is independent of line length, it should also apply for the much longer lines in the network.

The instrumental accuracy of the Model 2A Geodimeter can best be determined by measurement of a known length which is short enough to preclude atmospheric errors. Some length comparisons are cited in the following examples: (1) Measurements made during Geodimeter calibrations using invar-taped lines 20-25 meters in length, (2) measurements of a 368 meter baseline of one of the DWR-USC&GS cooperative fault movement quadrilaterals, (3) measurements made by the USC&GS on a 2900 meter baseline in Florida, and (4) comparative measurements made on a relatively short (5 km) line crossing the San Andreas fault near Taft, California.

(1) Data from the 1963 and 1966 calibration measurements are tabulated below:

1963 CALIBRATIONS

Taped Length (Meters)	Measured Length (Meters)	Difference, v. (mm)
24.000	23.992	-8
24.000	23.997	-3
24.000	24.003	+3
24.500	24.500	0
24.500	24.502	+2
25.000	25.005	+5
25.000	24.999	-1
26.000	26.008	+8
26.000	26.000	0
26.000	25.999	-1

1963 CALIBRATIONS
(Continued)

Taped Length (Meters)	Measured Length (Meters)	Difference, v. (mm)
27.000	26.998	-2
27.000	27.002	+2
27.000	27.000	0
27.000	27.000	0
20.000	19.993	-7
20.000	19.987	-13
20.000	19.988	-12
20.000	19.992	-8
21.000	20.999	-1
21.000	20.996	-4
22.000	21.991	-9
22.000	21.996	-4
23.000	23.001	+1
23.000	22.991	-9
23.500	23.504	+4
24.000	23.494	-6
24.000	24.004	+4
24.000	23.996	-4
25.000	25.006	+6
25.000	25.002	+2

Probable error of a single measurement = 3.2 mm
Average absolute v = 4.3 mm

1966 CALIBRATIONS

Taped Length (Meters)	Measured Length (Meters)	Difference, v. (mm)
24.000	23.990	-10
24.000	23.996	-4
24.000	23.998	-2
24.000	23.991	-9
24.500	24.499	-1
24.500	24.497	-3
24.500	24.510	+10
24.500	24.505	+5
25.000	25.016	+16
25.000	25.006	+6
25.000	25.006	+6
25.000	25.010	+10
26.000	25.997	-3
26.000	26.016	+16
26.000	25.997	-3
26.000	25.997	-3
27.000	27.007	+7
27.000	27.005	+5
27.000	27.002	+2
27.000	27.012	+12
20.000	19.992	-8

1966 CALIBRATIONS
(Continued)

Taped Length (Meters)	Measured Length (Meters)	Difference, v. (mm)
20.000	19.988	-12
20.000	19.989	-11
20.000	19.989	-11
21.000	20.987	-13
21.000	20.992	-8
21.000	20.988	-12
21.000	20.991	-9
22.000	22.001	+1
22.000	22.006	+6
22.000	21.998	-2
22.000	22.009	+9
23.000	23.002	+2
23.000	22.996	-4
23.000	23.001	+1
23.000	22.988	-12
23.500	23.510	+10
23.500	23.508	+8
23.500	23.510	+10
23.500	23.510	+10
24.000	24.002	+2
24.000	24.005	+5
24.000	23.999	-1
24.000	23.985	-15
25.000	24.998	-2
25.000	24.999	-1
25.000	24.997	-3
25.000	25.004	+4

Probable error of a single measurement = 5.45 mm
Average absolute v = 6.77 mm

Each of these individual length determinations will contain random errors such as electrical noise and operator variations. The average absolute value of the difference between a taped and measured length was 4.3 mm for the 1963 calibrations and 6.77 mm for the 1966 calibrations. Each field observation consists of the average of 12 or more individual determinations. This could improve the accuracy as much as the square root of the number of observations or in this case about three and one-half times. Thus instrumental errors inherent in field measurements are probably about 2 or 3 mm most of the time.

(2) A series of length measurements of a short baseline, TEM B - TEM D are compared. This invar-taped baseline was measured by the USC&GS at the "TEM" fault movement quadrilateral site in San Luis Obispo County. Three tape measurements of this baseline in June 1964, April 1965, and September 1966, resulted in identical measurements of 368.491 meters. This line was measured by the Department's Model 2A Geodimeter in December 1965 and July 1966. The length observed on the first date was 368.487 meters (±2 mm probable error from the 12 measurements). This is 4 mm less than the taped length. The length observed in 1966 was 368.486 meters ±3 mm probable error, 5 mm less than the taped value. The Geodimeter work was very consistent and as noted, agrees well with the taped value.

(3) Measurements made by the USC&GS on a baseline in Florida during the period 1961-64 provides an estimate of accuracy attainable. (Reference, Meade, B. K., Comparison Tests of Electro-Optical and Microwave Distance Measuring Instruments, 1965.) This comparison is particularly significant because the length of the baseline was used to check calibration values for the Geodimeter.

Geodimeter No.	Date	Length Measurements (Meters)	Difference, v. (mm)
114	11-4-61	2949.985	-4
	11-5-61	2949.991	+2
145	11-4-61	2949.992	+3
	11-4-61	2949.991	+2
	12-13-62	2949.999	+10
	1-13-63	2949.988	-1
	1-12-64	2949.984	-5
	5-12-64	.987	-2
	5-14-64	.985	-4
	MEAN	2949.989	Standard Deviation of v = 4.7 mm
	TAPED LENGTH	2949.989	Probable Error of the Mean = 1.1 mm
			Average Absolute v = 3.7 mm

(4) A group of measurements made on Line 45, Pattiway-Pelato, a relatively short line (5 km), crossing the San Andreas fault near Taft, California provides an estimate of precision for the DWR Model 2A Geodimeter and field procedures. On a line of this length, atmospheric variables begin to affect the measurements, but they are sufficiently well defined to yield a quantitative indication of the repeatability of the Geodimeter measurements. No taped length is available for comparison.

Date	Measured Length, M	v, mm
9-3-62	5030.124	+1
10-5-62	5030.120	-3
2-12-64	5030.120	-3
9-16-64	5030.122	-1
1-25-66	5030.122	-1
4-27-66	5030.131	+8
MEAN	5030.123	Standard Deviation of v = 4.2 mm
		Probable Error of the Mean = 1.1 mm
		Average Absolute v = 2.8 mm

Accuracy can be limited by stability of the modulation frequencies, which are regulated by quartz crystals maintained at a constant temperature. The modulation frequencies are measured by an 11-digit frequency counter calibrated with the time signal broadcast by the National Bureau of Standards, WWV radio station (one of the three modulation frequencies is exactly 10 mc, and is tuned to match WWV). After a standard warm-up time of one hour, frequency variation is less than ±1 cps, and the modulation frequency has been observed to remain stable within 1 cps during the nine years of operation. The maximum length error caused by a 1-cps frequency stability limitation is 1 part in 10^7 or 1 mm for every 10 km of line length.

Other small errors may originate from measuring the instrument's position in relation to the monument, positioning of the reflex system, etc. These should not exceed 1-2 mm when normal observing procedures are followed.

Atmospheric Limitations

Determination of the index of refraction of air, which in turn determines the speed of light, is the greatest potential source of error in the measurement process. The atmospheric parameters have the following relationship to the length determination.

Temperature: An error of one degree centigrade in the mean air temperature equals one part per million of the distance or 1 cm in a 10-km line.

Pressure: An error of one millimeter of mercury in barometric pressure equals four parts per ten million or four millimeters of length in a 10-km line.

Relative Humidity: An error of ten percent relative humidity equals approximately one part per ten million of length, or one millimeter in a 10-km line.

The large potential for error in the index determination has occasionally been a basis for criticism of the Geodimeter capability. It was often pointed out that an error of one degree centigrade would affect a typical 25-km line by 2.5 cm which would make strain figures of 1 or 2 cm meaningless, and that common nonlinearities in the atmosphere could easily produce such deviations.

However, experience indicates that temperatures above the immediate surface zone, especially at higher elevations above ground level (e.g., 1,000 feet), do not change rapidly with distance. Mixing by winds over 5 mph further reduces lateral temperature variations.

A number of factors contribute to more reliable operation on most lines in the existing measurement network. Many of the lines are established on adjacent mountain peaks at similar elevations. Similar elevations and the prevailing strong winds often found at higher elevations tend to reduce variability in the atmosphere. Atmospheric data from these lines are usually consistent and often similar for measurements in successive years. Conversely, lines with one end atop a high mountain and the other end low on a valley floor show more variations in length corresponding with greater variability. The use of elevated thermistors at the line ends and temperature profiles from a radiosonde balloon on the line improve the average temperature evaluation.

Because the fault monitoring program is primarily concerned with comparison of line lengths rather than the actual distance, some potential inaccuracies of the Geodimeter system for determining absolute distances are not of consequence in fault monitoring. For example, if a Geodimeter line is higher at one end than the other, it is curved, because of the normal change in atmospheric temperature and density with elevation. Most lengths are the product of more than one night's observations, which affords an opportunity to both check varying atmospheric conditions and detect accidental errors. Adjacent lines across a particular fault system permit confirmation of results when the observations are made at about the same time.

Estimates of Precision From Field Data

Repeat Measurements of Stable Lines

Field data from several lines provide a basis for accuracy estimates.

Fairview to Browns, Line 21 (Figures 11 and 12), lies entirely east of the San Andreas fault near Hollister in the low hills bordering the Salinas

Valley. Both stations are located atop hills at approximately the same elevation. Prevailing winds and other climatological factors contribute to consistent, uniform temperature measurements. The line lies roughly parallel to the major fault systems of the area and little movement would be anticipated. Measurements of this line have been:

Date	Length
10-60	24,004.128 meters
5-61	.139
12-62	.124
10-63	.135
7-65	.127

The average length change is nil, and any one measurement lies within less than 1 cm of the mean.

Similar results have been obtained on Lines 52 and 62, Police-Tejon and Denis-Tom, respectively. Length determinations on certain other lines are relatively poor because of indeterminate representative atmospheric parameters. An example is Shelford to Nike, Line 16, which extends from San Carlos in the West Bay area to the top of the hills on the San Francisco Peninsula. This line must traverse the various inversions common to this area, and, in addition, terminate at the westerly end on a mountain top subjected to cold ocean winds. Measuring representative atmospheric data is obviously difficult. Consequently, this line is inadequate for short-term strain measurement.

Other typical poor lines are Haze to Mt. Pinos, which extends from the San Joaquin Valley floor at elevation 600 feet to the top of Mt. Pinos at 8,600 feet, and Golf to Fan, in the Palm Springs area, which lies very close to the ground over most of its length.

Trilateration of Closed Networks

Recently, a few closed networks were established to more adequately check the accuracy of Geodimeter measurements and to more adequately evaluate patterns of distortion. Two quadrilaterals and one pentagon have been measured. Lines in these figures were selected, to the extent possible, with consideration of the index of refraction problem. Consequently, they are among some of the higher quality lines in the program.

For a trilaterated quadrilateral a computer program computes (a) the singular redundant length based upon each of the other five lines in the figure and (b) a least squares adjustment of the figure. Typical closures of a quadrilateral are in the order of 1-2 cm, and adjustments have averaged about 4 mm per line.

Closure is computed for each of the lines, but "the closure" of a quadrilateral is usually derived from a diagonal.

Data observed on a trilaterated quadrilateral near Gorman in Los Angeles County are summarized below. The long diagonal was calculated from the other five lines and this computed length was compared with the observed length. The calculated distance was 1.08 cm longer than the measured value. The results from a least-squares adjustment of this figure are:

Line	Observed Length (meters)	Adjusted Length (meters)	Adjustment (mm)
Air-Cow	10647.6704	10647.6730	2.6
Cow-Pine	11784.4370	11784.4349	-2.1
Air-Pine	12081.7968	12081.7936	-3.2
Cow-Tejon	11018.3695	11018.3669	-2.6
Pine-Tejon	19018.7385	19018.7433	4.8
Air-Tejon	8826.9767	8826.9736	-3.1

Some systematic errors are eliminated by taking all measurements during a short time interval. In addition, having a figure of several lines allows strain analysis, which is not possible with the single lines of the basic network.

In the adjustment of trilaterated figures, a redundancy of length measurement occurs wherever a point is enclosed by a set of adjacent triangles or wherever a diagonal is inserted between adjacent triangles creating a quadrilateral. The network to be adjusted is separated into as many centerpoint polygons and double-braced quadrilaterals as there are separate redundancies. For each redundancy, an angular discrepancy must be described at whatever point (pole) is chosen in each figure. Each redundancy at each pole will thus give rise to discrepancies from which condition equations are written.

Two sets of measurements have been made over the pentagon described on Figure 19. (Length changes are the result of the Parkfield-Cholame earthquake sequence of June 1966.) The observed lengths and the individual length adjustments resulting from the least squares adjustment of the figure are tabulated below. The mean and maximum adjustment to the 1965 measurements are 2.0 and 3.8 millimeters, respectively. For the 1966 measurements the mean and maximum adjustments are 4.0 and 7.4 millimeters, respectively. Data from the Cholame Pentagon follow:

	Measured Length (meters) October 1965	Adjustments (mm)	Measured Length (meters) July 1966	Adjustments (mm)
Bonnie - Kenger	8,526.525	0.8	8,526.508	-6.8
Bonnie - Cottonwood	10,651.841	2.2	10,651.857	-6.0
Bench - Cottonwood	12,553.073	-0.4	12,553.112	-2.4
Bench - Mason	12,717.975	-2.2	12,717.968	-2.2
Mason- Kenger	12,484.308	-2.1	12,484.324	-3.5
Bench - Kenger	18,654.902	3.8	18,654.766	1.2
Bonnie - Bench	16,643.098	-2.3	16,643.023	1.6
Bonnie - Mason	16,935.471	1.2	16,935.549	3.3
Mason - Cottonwood	20,541.615	1.8	20,541.757	7.4
Cottonwood - Kenger	17,956.180	-3.4	17,956.156	5.8
Absolute Average Adjustment		2.0		4.0

Assuming an average line length of 15,000 meters, an average adjustment of 3 mm represents approximately one part in 5,000,000. Ratynskiy (1964) shows that an accuracy of one part in 5,000,000 is attainable under favorable conditions and work methods. Observation conditions during the 1965 measurements were considered excellent.

Error Evaluation Based on Separate Nights of Measurement

Calculations of probable errors for the Geodimeter data have yielded some remarkably low values, often less than $\pm$ 2 mm. The calculations assume the observed variations are random. Temperature errors, which have the greatest effect on the computed lengths, tend to be systematic over a short period of time. A particular weather pattern may exist over a line for hours or days. When a line is not remeasured on a second night, probable errors will invariably be low for the set, yet errors caused by an inadequate average temperature evaluation could be relatively high.

Bomford (1962), Page 510, outlines a method for estimation of accuracy from the difference of two measurements. He states that the RMS value of the differences between a number of sets equals twice the standard deviation of the means of those sets.* Examples from a few lines follow. These "probable errors of the means" vary from 4 to 10 mm. The figures are tentative, however, because of the relatively small sample of paired sets of observations available for each line. Continued observation of these lines would provide a more significant sample in future years. Generally, relatively large probable errors of paired sets are observed for lines with large line quality numbers (lines thought to be of poor quality). Usually, the time between measurements in a pair is longer for lines regarded as poor. Consequently, there is more opportunity for tectonic movement to have taken place. Measurements in a pair that are several months apart probably cannot be used to assess accuracy. This is often the situation for lines with large line quality numbers.

After a sufficient number of years of observation, enough paired sets of measurements will be available even for lines which are difficult to measure. The probable error of the mean of paired sets could then replace the line quality number.

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*Thus, where sets of measurements from two different nights' work are available, all the differences between the means of measurement sets for a given line can be used to assess the probable error of observations for that line.

Line	Date	Length (m)	PE ** (mm)	dL (mm)	RMS (mm)	50% PE Mean (mm)
46: Pelato -	11/11/59	25356.353				
Temblor	11/24/59	.323	3.8	30		
	11/16/60	.322				
Line quality -	11/17/60	.316	2.2	6		
2	11/28/61	.324				
	12/17/61	.334	3.9	10		
	2/24/64	.315				
	3/1/64	.342	4.4	27	21.0	7.1
48: Pattiway -	6/2/59	20336.555				
Temblor	6/4/59	.557	1.8	2		
	10/26/60	.530				
Line quality -	11/14/60	.524	3.3	6		
2	12/1/61	.550				
	12/20/61	.512	5.4	38		
	8/11/64	.510				
	8/13/64	.492	2.7	18	21.3	7.2
49: Pattiway -	5/27/59	30880.861				
Mt. Pinos	6/12/59	.881	3.4	20		
	11/23/59	.840				
Line quality -	12/2/59	.816	3.2	24		
5	9/28/61	.870				
	9/29/61	.842	3.6	28		
	8/12/64	.842				
	9/18/64	.825	2.3	17	22.6	7.6
50: Police -	5/14/59	15587.965				
Wheeler	5/20/59	.953	4.9	12		
	6/20/60	.928				
Line quality -	6/22/60	.930	2.8	2		
2	11/30/60	.946				
	12/15/60	.948	2.1	2		
	10/30/61	.950				
	10/31/61	.952	3.0	2		
	10/9/62	.955				
	10/10/62	.937	2.4	18		
	1/8/64	.894				
	1/9/64	.874	2.6	20		
	5/12/64	.944				
	5/13/64	.968	2.7	24	14.4	4.9

**Based on standard PE function: $PE = .6745 \sqrt{\frac{\sum v^2}{n(n-1)}}$

Line	Date	Length (m)	PE/ (mm)	dL (mm)	RMS (mm)	50% PE Mean (mm)
51: Police-Diorite	5/9/60	26662.924				
	5/10/60	.932	5.8	8		
	12/21/60	.865				
Line quality - 2	12/23/60	.851	3.7	14		
	11/9/61	.930				
	11/12/61	.914	2.9	16		
	10/24/62	.918				
	10/25/62	.914	1.6	2		
	2/26/64	.937				
	2/27/64	.919	3.7	18	13.0	4.4
52: Police - Tejon	11/30/59	13701.760				
	12/1/59	.762	4.7	2		
	12/12/60	.736				
Line quality - 2	12/13/60	.730	4.0	6		
	10/26/61	.764				
	11/2/61	.728	5.6	36		
	10/9/62	.759				
	10/10/62	.759	2.1	0		
	1/9/64	.754				
	2/10/64	.742	2.7	12	17.2	5.8

Equations:

$$RMS = \sqrt{\frac{\Sigma v^2}{n}}$$

$$\sigma = \frac{RMS}{2}$$

$$PE = .6745 (\sigma)$$

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APPENDIX A. LINE LENGTH DATA LISTING

Explanation of Headings, Geodimeter Data Printout

DELTA L - The difference in line length between two subsequent observations, in meters.

EXTENSION - The length change divided by length, or linear strain observed between two subsequent measurements.

DELTA T - The time interval between measurements, in years.

DELTA L/DELTA T - The rate of change observed between two subsequent measurements, in meters/year.

SUM OF EXTENSIONS - $\left[\frac{\sum \text{Delta L}}{L} \right]$ The total linear strain observed between the first and last measurements.

SUM OF DELTA L - The total length change of the line since the first measurement, in meters.

COMP. DL/DT - The mean annual rate of change computed from a least squares fit of the best straight line to fit the measured points, in meters/year.

EXTENSION RATE - $\left[\frac{\text{Comp. DL/DT}}{L} \right]$ The mean annual rate of strain.

COMP. D - A length computed from the least squares straight line indicating the calculated length on the date of measurement.

OBS-COMP. - The difference between the measured length and the length calculated from the least-squares line. A test of fit.

STANDARD DEVIATION - Standard deviation calculated from OBS-COMP.

PROBABLE ERROR OF THE SLOPE - The probable error of the COMP. DL/DT is based on an assumption that movement of the crust is a linear function of time. (Apparently not valid in many areas).

LINE QUALITY - A qualitative grading, based upon the judgment of the staff, of the difficulty in obtaining accurate measurements over a given line. The number was primarily derived from consideration of geographical-climatological factors which affect temperature determination and of the experience of the staff in making field measurements. A quality 1 line indicates a high confidence in the measurement; a quality 6 line indicates a very difficult line to evaluate. Most lines are of quality 2 or 3.

LINE NO 1 MT DIABLO TO HILLS LINE QUALITY 3

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP	
1	8 17 61	19749.502	0	0	0	0	19749.507	-0.0048	
1	1 14 63	19749.520	.018	9.114146E-07	1.410	.01277	19749.514	.0064	
1	7 10 64	19749.523	.003	1.519024E-07	1.487	.00202	19749.521	.0021	
1	9 13 65	19749.523	0	0	1.177	0	19749.527	-0.0037	

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
1.06331696E-06	.021	.004890	2.47589936E-07	.00449	.00099

LINE NO 2 SKYLINE TO MT DIABLO LINE QUALITY 3

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP	
2	11 29 62	23934.817	0	0	0	0	23934.816	.0006	
2	11 7 63	23934.813	-0.004	-1.671206E-07	.939	-0.00426	23934.814	-0.0015	
2	7 9 64	23934.814	.001	4.178015E-08	.671	.00149	23934.813	.0009	

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
-1.25340442E-07	-0.003	-0.002016	-8.42399700E-08	.00106	.00062

LINE NO 3 MT DIABLO TO SUNOL LINE QUALITY 5

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP	
3	8 2 61	29038.308	0	0	0	0	29038.355	-0.0473	
3	11 20 62	29038.374	.066	2.272855E-06	1.300	.05075	29038.340	.0341	
3	7 29 64	29038.366	-0.008	-2.754976E-07	1.689	-0.00474	29038.320	.0461	
3	6 10 65	29038.294	-0.072	-2.479485E-06	.865	-0.08322	29038.310	-0.0156	
3	9 15 65	29038.317	.023	7.920569E-07	.266	.08661	29038.306	.0105	
3	7 13 67	29038.257	-0.060	-2.066240E-06	1.823	-0.03291	29038.285	-0.0278	

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
-1.75631036E-06	-0.051	-0.011856	-4.08272195E-07	.03332	.00473

LINE NO 4 ALLISON TO SUNOL LINE QUALITY 2

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP	
4	8 3 61	14187.197	0	0	0	0	14187.208	-0.0107	
4	11 19 62	14187.217	.020	1.409720E-06	1.295	.01544	14187.212	.0045	
4	11 13 63	14187.235	.018	1.268746E-06	.983	.01831	14187.216	.0189	
4	6 1 65	14187.209	-0.026	-1.832637E-06	1.550	-0.01678	14187.222	-0.0128	***

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
8.45829207E-07	.012	.003691	2.60164890E-07	.01281	.00309

LINE NO 5 ALLISON TO RED HILL TOP LINE QUALITY 3

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP	
5	7 10 61	20663.566	0	0	0	0	20663.557	.0089	
5	11 19 62	20663.558	-0.008	-3.871550E-07	1.361	-0.00588	20663.580	-0.0222	
5	6 8 65	20663.649	.091	4.403869E-06	2.552	.03566	20663.623	.0256	***
5	5 15 67	20663.633	-0.016	-7.743072E-07	1.933	-0.00828	20663.656	-0.0232	
5	7 17 67	20663.670	.037	1.790582E-06	.172	.21451	20663.659	.0109	

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
5.03298884E-06	.104	.016947	8.20126400E-07	.01940	.00244

LINE NO 6 ALLISON TO AMERICAN LINE QUALITY 3

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP	
6	7 19 61	23449.206	0	0	0	0	23449.209	-0.0035	
6	12 4 62	23449.205	-0.001	-4.264537E-08	1.377	-0.00073	23449.196	.0087	
6	9 19 63	23449.198	-0.007	-2.985177E-07	.791	-0.00885	23449.189	.0093	
6	12 13 65	23449.133	-0.065	-2.771957E-06	2.234	-0.02909	23449.167	-0.0343	***
6	7 17 67	23449.172	.039	1.663172E-06	1.591	.02452	23449.152	.0199	

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
-1.44994881E-06	-0.034	-0.009573	-4.08257515E-07	.01670	.00263

LINE NO 7 MT HAMILTON TO ALLISON LINE QUALITY 2

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP	
7	7 18 61	26695.923	0	0	0	0	26695.926	-0.0033	
7	9 20 62	26695.937	.014	5.244244E-07	1.175	.01192	26695.932	.0052	
7	9 30 63	26695.948	.011	4.120476E-07	1.027	.01071	26695.937	.0115	
7	9 2 65	26695.924	-0.024	-8.990136E-07	1.925	-0.01247	26695.945	-0.0214	***
7	6 17 67	26695.938	.014	5.244244E-07	1.788	.00783	26695.954	-0.0157	
7	7 18 67	26695.944	.006	2.247532E-07	.085	.07069	26695.954	-0.0101	
7	10 4 67	26695.989	.045	1.685646E-06	.214	.21072	26695.955	.0339	

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
2.47228236E-06	.066	.004629	1.73391843E-07	.01744	.00188

LINE NO 9 MORGAN TO MT HAMILTON LINE QUALITY 4

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP	
9	8 15 61	23241.477	0	0	0	0	23241.488	-0.0106	
9	4 2 63	23241.463	-0.014	-6.023717E-07	1.629	-0.00859	23241.461	.0024	
9	8 3 64	23241.454	-0.009	-3.872391E-07	1.339	-0.00672	23241.438	.0156	
9	7 19 67	23241.414	-0.040	-1.721066E-06	2.957	-0.01353	23241.389	.0246	
9	10 3 67	23241.354	-0.060	-2.581605E-06	.208	-0.28836	23241.386	-0.0319	

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
-5.29228170E-06	-0.123	-0.016580	-7.13365377E-07	.01994	.00251

LINE NO 10 MT HAMILTON TO LOMA PRIETA LINE QUALITY 2

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP	
10	9 29 60	31214.494	0	0	0	0	31214.501	-0.0070	
10	7 13 61	31214.489	-0.005	-1.601820E-07	.786	-0.00636	31214.491	-0.0020	
10	12 6 62	31214.483	-0.006	-1.922185E-07	1.399	-0.00429	31214.473	.0097	
10	10 3 63	31214.469	-0.014	-4.485100E-07	.824	-0.01699	31214.463	.0061	
10	8 5 65	31214.427	-0.042	-1.345532E-06	1.840	-0.02283	31214.440	-0.0126	
10	1 18 67	31214.453	.026	8.329475E-07	1.454	.01788	31214.421	.0318	***
10	6 15 67	31214.421	-0.032	-1.025167E-06	.405	-0.07897	31214.416	.0049	
10	7 18 67	31214.384	-0.037	-1.185351E-06	.090	-0.40952	31214.415	-0.0309	

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
-3.52401277E-06	-0.110	-0.012655	-4.05420314E-07	.01708	.00160

LINE NO 11 LOMA PRIETA TO FAIR LINE QUALITY 4

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP	
11	10 1 59	20031.428	0	0	0	0	20031.475	-0.0466	
11	8 23 60	20031.492	.064	3.194969E-06	.895	.07149	20031.466	.0260	***
11	5 30 61	20031.470	-0.022	-1.098272E-06	.767	-0.02870	20031.459	.0113	
11	1 7 63	20031.429	-0.041	-2.046784E-06	1.607	-0.02551	20031.443	-0.0143	
11	7 28 64	20031.507	.078	3.893866E-06	1.555	.05016	20031.428	.0786	***
11	11 22 64	20031.422	-0.085	-4.243333E-06	.320	-0.26535	20031.425	-0.0034	
11	2 23 65	20031.401	-0.021	-1.048354E-06	.255	-0.08248	20031.423	-0.0219	
11	8 29 67	20031.401	0	0	2.511	0	20031.399	.0021	
11	10 9 67	20031.366	-0.035	-1.747260E-06	.112	-0.31180	20031.398	-0.0318	

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
-3.09516755E-06	-0.062	-0.009567	-4.77604277E-07	.03474	.00286

LINE NO 12 LOMA PRIETA TO EAGLE ROCK LINE QUALITY 2

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP	
12	9 29 60	31465.553	0	0	0	0	31465.557	-0.0037	
12	7 28 61	31465.559	.006	1.906847E-07	.827	.00726	31465.559	-0.0002	
12	12 5 62	31465.566	.007	2.224654E-07	1.355	.00517	31465.563	.0026	
12	6 6 63	31465.568	.002	6.356154E-08	.501	.00399	31465.565	.0030	
12	7 28 64	31465.543	-0.025	-7.945199E-07	1.144	-0.02185	31465.568	-0.0255	***
12	11 21 64	31465.568	.025	7.945193E-07	.318	.07872	31465.569	-0.0015	
12	2 23 65	31465.605	.037	1.175887E-06	.257	.14377	31465.570	.0347	
12	1 17 67	31465.574	-0.031	-9.852037E-07	1.897	-0.01634	31465.576	-0.0021	***
12	6 15 67	31465.570	-0.004	-1.271231E-07	.408	-0.00981	31465.577	-0.0074	

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
5.40271352E-07	.017	.003086	9.80893519E-08	.01471	.00154

LINE NO 13 AMERICAN TO LOMA PRIETA LINE QUALITY 3

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP	
13	8 26 61	19701.727	0	0	0	0	19701.720	.0074	
13	12 4 62	19701.723	-0.004	-2.030279E-07	1.273	-0.00314	19701.713	.0096	
13	6 5 63	19701.728	.005	2.537848E-07	.501	.00998	19701.711	.0170	
13	7 24 64	19701.669	-0.059	-2.994670E-06	1.136	-0.05193	19701.705	-0.0365	***
13	6 17 65	19701.676	.007	3.552997E-07	.898	.00779	19701.701	-0.0251	
13	6 11 67	19701.719	.043	2.182551E-06	1.982	.02169	19701.691	.0275	***

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
-4.06062838E-07	-0.008	-0.004849	-2.46142573E-07	.02293	.00338

LINE NO 14 EAGLE ROCK TO MINDEGO LINE QUALITY 2

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP	
14	7 11 61	19143.181	0	0	0	0	19143.204	-0.0229	
14	10 30 62	19143.206	.025	1.305946E-06	1.303	.01918	19143.198	.0076	***
14	12 19 63	19143.225	.019	9.925182E-07	1.136	.01672	19143.194	.0315	
14	9 7 65	19143.180	-0.045	-2.350707E-06	1.719	-0.02617	19143.186	-0.0062	***
14	8 10 67	19143.168	-0.012	-6.268555E-07	1.922	-0.00624	19143.178	-0.0100	

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
-6.79097524E-07	-0.013	-0.004255	-2.22272069E-07	.01851	.00261

LINE NO 15 SHELFORD TO MINDEGO LINE QUALITY 4

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
15	8 1 61	22153.258	0	0	0	0	22153.255	.0025
15	11 28 62	22153.276	.018	8.125209E-07	1.325	.01358	22153.282	-0.0060
15	11 20 63	22153.305	.029	1.309060E-06	.977	.02967	22153.302	.0034

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
2.12158067E-06	.047	.020020	9.03695873E-07	.00425	.00175

LINE NO 16 SHELFORD TO NIKE LINE QUALITY 6

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
16	8 7 61	19549.126	0	0	0	0	19549.151	-0.0252
16	11 16 62	19549.188	.062	3.171487E-06	1.276	.04860	19549.153	.0352
16	12 14 65	19549.148	-0.040	-2.046125E-06	3.077	-0.01300	19549.157	-0.0086
16	7 27 67	19549.137	-0.011	-5.626847E-07	1.615	-0.00681	19549.159	-0.0217
16	8 16 67	19549.179	.042	2.148428E-06	.055	.76702	19549.159	.0203

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
2.71110538E-06	.053	.001257	6.42901774E-08	.02379	.00291

LINE NO 17 GILROY TO FREMONT PK LINE QUALITY 3

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP	
17	9 21 59	26648.712	0	0	0	0	26648.694	.0179	
17	1 27 60	26648.680	-0.032	-1.200810E-06	.350	-0.09131	26648.686	-0.0062	
17	8 21 60	26648.669	-0.011	-4.127786E-07	.567	-0.01941	26648.673	-0.0044	
17	5 23 61	26648.652	-0.017	-6.379310E-07	.753	-0.02258	26648.656	-0.0044	
17	9 18 61	26648.637	-0.015	-5.628806E-07	.323	-0.04643	26648.649	-0.0121	
17	8 30 62	26648.643	.006	2.251522E-07	.947	.00633	26648.628	.0153	
17	12 16 63	26648.606	-0.037	-1.388440E-06	1.295	-0.02857	26648.598	.0076	
17	11 23 64	26648.546	-0.060	-2.251530E-06	.939	-0.06389	26648.577	-0.0312	
17	5 17 67	26648.568	.022	8.255603E-07	2.478	.00888	26648.521	.0467	***
17	10 10 67	26648.483	-0.085	-3.189675E-06	.400	-0.21265	26648.512	-0.0292	

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
-8.59333290E-06	-0.229	-0.022586	-8.47532453E-07	.02202	.00171

LINE NO 18 SARGENT TO FREMONT PK LINE QUALITY 3

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
18	10 8 60	16597.056	0	0	0	0	16597.050	.0055
18	5 2 61	16597.034	-0.022	-1.325538E-06	.564	-0.03901	16597.044	-0.0104
18	8 30 62	16597.026	-0.008	-4.820141E-07	1.328	-0.00602	16597.030	-0.0041
18	1 2 64	16597.026	0	0	1.342	0	16597.016	.0103
18	7 29 65	16597.005	-0.021	-1.265289E-06	1.572	-0.01336	16596.999	.0062
18	5 18 67	16596.972	-0.033	-1.988314E-06	1.802	-0.01832	16596.979	-0.0075

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
-5.06115513E-06	-0.084	-0.010749	-6.47633714E-07	.00770	.00091

LINE NO 19 FAIRVIEW TO FREMONT PK LINE QUALITY 3

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
19	10 17 60	22846.805	0	0	0	0	22846.820	-0.0149
19	5 4 61	22846.818	.013	5.690070E-07	.545	.02386	22846.813	.0052
19	12 13 62	22846.796	-0.022	-9.629359E-07	1.610	-0.01367	22846.792	.0039
19	10 16 63	22846.802	.006	2.626188E-07	.841	.00714	22846.781	.0207
19	8 26 65	22846.743	-0.059	-2.582425E-06	1.862	-0.03169	22846.757	-0.0144
19	8 2 67	22846.732	-0.011	-4.814693E-07	1.933	-0.00569	22846.732	-0.0005

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
-3.19520434E-06	-0.073	-0.012867	-5.63169411E-07	.01222	.00142

LINE NO 20 BROWNS TO FREMONT PK LINE QUALITY 3

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP	
20	9 12 59	25177.116	0	0	0	0	25177.139	-0.0225	
20	1 28 60	25177.148	.032	1.270994E-06	.378	.08470	25177.144	.0037	
20	7 14 60	25177.167	.019	7.546520E-07	.460	.04131	25177.151	.0157	
20	4 24 61	25177.154	-0.013	-5.163411E-07	.778	-0.01672	25177.163	-0.0092	
20	9 19 61	25177.149	-0.005	-1.985928E-07	.405	-0.01234	25177.169	-0.0204	
20	9 14 62	25177.193	.044	1.747613E-06	.986	.04464	25177.184	.0086	
20	12 31 63	25177.212	.019	7.546507E-07	1.295	.01487	25177.204	.0079	
20	11 20 64	25177.266	.054	2.144792E-06	.890	.06069	25177.218	.0483	
20	8 1 65	25177.235	-0.031	-1.231271E-06	.695	-0.04458	25177.228	.0067	
20	8 24 67	25177.221	-0.014	-5.560582E-07	2.062	-0.00679	25177.260	-0.0388	***

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
4.17043887E-06	.105	.015256	6.05934831E-07	.02298	.00196

LINE NO 21 BROWNS TO FAIRVIEW LINE QUALITY 2

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP	
21	10 4 60	24004.128	0	0	0	0	24004.136	-0.0077	
21	5 1 61	24004.139	.011	4.582543E-07	.572	.01922	24004.134	.0050	
21	12 13 62	24004.124	-0.015	-6.248926E-07	1.618	-0.00927	24004.129	-0.0050	
21	10 23 63	24004.135	.011	4.582544E-07	.860	.01280	24004.126	.0086	
21	7 27 65	24004.127	-0.008	-3.332760E-07	1.760	-0.00454	24004.121	.0059	
21	8 24 67	24004.108	-0.019	-7.915312E-07	2.075	-0.00916	24004.115	-0.0068	

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
-8.33191146E-07	-0.020	-0.003045	-1.26859967E-07	.00664	.00077

LINE NO 22 FAIRVIEW TO SARGENT LINE QUALITY 1

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP	
22	10 3 60	14858.181	0	0	0	0	14858.184	-0.0033	
22	4 21 61	14858.199	.018	1.211452E-06	.548	.03287	14858.189	.0104	
22	9 5 62	14858.205	.006	4.038173E-07	1.374	.00437	14858.199	.0056	
22	1 2 64	14858.190	-0.015	-1.009544E-06	1.325	-0.01132	14858.210	-0.0198	***
22	8 3 67	14858.245	.055	3.701648E-06	3.584	.01535	14858.238	.0070	

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
4.30737388E-06	.064	.007869	5.29616802E-07	.01088	.00135

LINE NO 23 FAIRVIEW TO GILROY LINE QUALITY 2

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP	
23	5 24 61	23844.933	0	0	0	0	23844.942	-0.0088	
23	9 12 62	23844.947	.014	5.871265E-07	1.303	.01074	23844.954	-0.0070	
23	10 17 63	23844.966	.019	7.968139E-07	1.095	.01735	23844.964	.0017	
23	8 9 65	23845.023	.057	2.390436E-06	1.812	.03145	23844.981	.0417	
23	7 25 67	23844.972	-0.051	-2.138816E-06	1.958	-0.02605	23845.000	-0.0277	***

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
1.63556064E-06	.039	.009386	3.93611246E-07	.02295	.00319

LINE NO 24 BROWNS TO CROSS LINE QUALITY 1

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
24	5 30 62	13302.676	0	0	0	0	13302.683	-0.0066
24	3 25 63	13302.684	.008	6.013824E-07	.819	.00977	13302.674	.0097
24	7 14 65	13302.647	-0.037	-2.781401E-06	2.305	-0.01605	13302.651	-0.0038
24	8 27 67	13302.630	-0.017	-1.277943E-06	2.119	-0.00802	13302.629	.0008

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
-3.45796171E-06	-0.046	-0.010185	-7.65661051E-07	.00619	.00102

LINE NO 25 BROWNS TO CHALONE LINE QUALITY 2

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP	
25	9 3 59	32340.088	0	0	0	0	32340.089	-0.0014	
25	1 29 60	32340.069	-0.019	-5.875065E-07	.405	-0.04689	32340.076	-0.0068	
25	7 18 60	32340.066	-0.003	-9.276419E-08	.468	-0.00641	32340.060	.0059	
25	5 26 61	32340.021	-0.045	-1.391465E-06	.854	-0.05268	32340.031	-0.0104	
25	5 29 62	32340.016	-0.005	-1.546072E-07	1.008	-0.00496	32339.998	.0184	***
25	8 25 65	32339.883	-0.133	-4.112569E-06	3.242	-0.04103	32339.889	-0.0058	

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
-6.33891165E-06	-0.205	-0.033552	-1.03747774E-06	.00969	.00133

LINE NO 26 CROSS TO CHALONE LINE QUALITY 2

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
26	5 28 62	19264.955	0	0	0	0	19264.954	.0011
26	3 25 63	19264.935	-0.020	-1.038156E-06	.824	-0.02427	19264.935	.0000
26	3 23 66	19264.862	-0.073	-3.789282E-06	2.995	-0.02437	19264.866	-0.0040
26	8 26 67	19264.836	-0.026	-1.349609E-06	1.426	-0.01823	19264.833	.0029

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
-6.17704707E-06	-0.119	-0.023035	-1.19570357E-06	.00251	.00040

LINE NO 27 BITTER TO CHALONE LINE QUALITY 1

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
27	5 17 62	19469.656	0	0	0	0	19469.659	-0.0027
27	3 21 63	19469.668	.012	6.163433E-07	.843	.01423	19469.665	.0034
27	3 24 66	19469.685	.017	8.731523E-07	3.009	.00565	19469.686	-0.0007

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
1.48949562E-06	.029	.007031	3.61103107E-07	.00253	.00060

LINE NO 28 CHALONE TO HEPSEDAM LINE QUALITY 2

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
28	8 29 59	36416.144	0	0	0	0	36416.144	-0.0001
28	6 28 60	36416.160	.016	4.393654E-07	.832	.01922	36416.157	.0028
28	5 3 62	36416.182	.022	6.041270E-07	1.845	.01192	36416.186	-0.0043
28	5 18 65	36416.236	.054	1.482855E-06	3.042	.01775	36416.234	.0016

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
2.52634748E-06	.092	.015788	4.33549516E-07	.00271	.00042

LINE NO 29 BITTER TO HEPSEDAM LINE QUALITY 2

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
29	5 18 62	18099.727	0	0	0	0	18099.727	.0000
29	6 11 63	18099.731	.004	2.209978E-07	1.065	.00376	18099.731	-0.0000

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
2.20997760E-07	.004	.003757	2.07549851E-07	.00000	.00000

LINE NO 30 SHADE TO HEPSEDAM LINE QUALITY 2

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
30	7 1 60	34098.973	0	0	0	0	34098.980	-0.0071
30	5 10 62	34098.943	-0.030	-8.797927E-07	1.856	-0.01616	34098.937	.0057
30	6 19 63	34098.912	-0.031	-9.091199E-07	1.109	-0.02796	34098.912	.0002
30	5 20 65	34098.877	-0.035	-1.026427E-06	1.919	-0.01824	34098.868	.0094
30	6 9 67	34098.812	-0.065	-1.906225E-06	2.053	-0.03165	34098.820	-0.0083

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
-4.72156412E-06	-0.161	-0.023037	-6.75588179E-07	.00692	.00087

LINE NO 31 SHADE TO MINE MT LINE QUALITY 2

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
31	5 1 62	23304.098	0	0	0	0	23304.087	.0110
31	3 26 63	23304.132	.034	1.458969E-06	.901	.03775	23304.122	.0104
31	4 8 64	23304.155	.023	9.869485E-07	1.038	.02217	23304.161	-0.0065
31	5 12 65	23304.190	.035	1.501876E-06	1.092	.03204	23304.203	-0.0134
31	7 13 66	23304.182	-0.008	-3.432860E-07	1.169	-0.00684	23304.248	-0.0663
31	2 20 67	23304.299	.117	5.020533E-06	.608	.19250	23304.272	.0273
31	6 2 67	23304.320	.021	9.011205E-07	.279	.07520	23304.282	.0376

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
9.52616040E-06	.222	.038409	1.64814382E-06	.03165	.00441

LINE NO 32 SHADE TO CASTLE LINE QUALITY 2

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP	
32	8 28 59	32454.524	0	0	0	0	32454.496	.0276	
32	7 7 60	32454.531	.007	2.156864E-07	.860	.00814	32454.521	.0095	
32	4 26 62	32454.551	.020	6.162464E-07	1.802	.01110	32454.574	-0.0229	***
32	4 9 64	32454.579	.028	8.627442E-07	1.955	.01432	32454.631	-0.0518	
32	6 2 67	32454.760	.181	5.576994E-06	3.146	.05754	32454.722	.0376	

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
7.27167091E-06	.236	.029112	8.96994437E-07	.03309	.00358

LINE NO 33 RED HILL TO PARK LINE QUALITY 3

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP	
33	8 10 59	32504.381	0	0	0	0	32504.419	-0.0384	
33	7 11 60	32504.411	.030	9.229517E-07	.920	.03261	32504.393	.0182	***
33	12 2 60	32504.382	-0.029	-8.921874E-07	.394	-0.07356	32504.381	.0006	
33	4 24 62	32504.344	-0.038	-1.169075E-06	1.391	-0.02732	32504.341	.0028	
33	3 12 63	32504.304	-0.040	-1.230606E-06	.882	-0.04537	32504.316	-0.0117	
33	4 2 64	32504.334	.030	9.229538E-07	1.060	.02831	32504.285	.0490	***
33	3 2 66	32504.287	-0.047	-1.445963E-06	1.914	-0.02456	32504.230	.0573	
33	7 11 66	32504.192	-0.095	-2.922700E-06	.359	-0.26488	32504.219	-0.0273	
33	6 27 67	32504.141	-0.051	-1.569031E-06	.961	-0.05307	32504.192	-0.0505	

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
-7.38365657E-06	-0.240	-0.028925	-8.89874769E-07	.03485	.00292

LINE NO 34 WATERHOLE TO PARK LINE QUALITY 2

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP	
34	4 20 62	20990.047	0	0	0	0	20990.076	-0.0294	
34	3 11 63	20990.024	-0.023	-1.095759E-06	.890	-0.02585	20990.034	-0.0103	
34	3 12 64	20990.027	.003	1.429250E-07	1.005	.00299	20989.987	.0403	***
34	5 19 65	20989.974	-0.053	-2.525015E-06	1.185	-0.04471	20989.931	.0434	
34	7 5 66	20989.849	-0.125	-5.955260E-06	1.128	-0.11082	20989.877	-0.0282	
34	6 27 67	20989.815	-0.034	-1.619833E-06	.977	-0.03479	20989.831	-0.0159	

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
-1.10529415E-05	-0.232	-0.047343	-2.25552492E-06	.03035	.00462

LINE NO 35 RED HILL TO NAPOLEON LINE QUALITY 2

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP	
35	8 3 59	29544.757	0	0	0	0	29544.775	-0.0181	
35	11 4 60	29544.790	.033	1.116948E-06	1.257	.02626	29544.783	.0073	**
35	4 23 62	29544.801	.011	3.723159E-07	1.465	.00751	29544.791	.0096	
35	3 27 63	29544.811	.010	3.384689E-07	.925	.01081	29544.797	.0140	
35	4 6 64	29544.802	-0.009	-3.046221E-07	1.029	-0.00874	29544.803	-0.0011	
35	7 12 66	29544.805	.003	1.015407E-07	2.264	.00132	29544.817	-0.0117	

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
1.62465162E-06	.048	.005989	2.02720676E-07	.01161	.00142

LINE NO 36 RED HILL TO TWISSEL LINE QUALITY 2

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
36	4 11 62	25545.167	0	0	0	0	25545.160	.0072
36	3 12 63	25545.145	-0.022	-8.612204E-07	.917	-0.02399	25545.158	-0.0134
36	3 30 64	25545.163	.018	7.046344E-07	1.051	.01712	25545.157	.0062

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
-1.56586024E-07	-0.004	-0.001567	-6.13324949E-08	.00948	.00459

LINE NO 37 BM G-618 TO LAS YEGUAS LINE QUALITY 3

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
37	7 10 59	12506.273	0	0	0	0	12506.271	.0015
37	3 7 62	12506.280	.007	5.597188E-07	2.658	.00263	12506.286	-0.0056
37	3 7 63	12506.295	.015	1.199396E-06	.999	.01501	12506.291	.0041

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
1.75911478E-06	.022	.005319	4.25312059E-07	.00410	.00103

LINE NO 38 SIMMLER TO TWISSEL LINE QUALITY 2

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP	
38	8 11 59	15139.687	0	0	0	0	15139.666	.0213	
38	10 19 60	15139.639	-0.048	-3.170485E-06	1.191	-0.04030	15139.660	-0.0215	**
38	10 18 62	15139.643	.004	2.642070E-07	1.996	.00200	15139.652	-0.0088	
38	3 5 63	15139.662	.019	1.254982E-06	.378	.05029	15139.650	.0119	
38	2 18 64	15139.645	-0.017	-1.122880E-06	.958	-0.01774	15139.646	-0.0009	
38	2 2 66	15139.609	-0.036	-2.377869E-06	1.958	-0.01839	15139.637	-0.0284	**
38	7 18 66	15139.639	.030	1.981553E-06	.454	.06601	15139.635	.0036	
38	4 5 67	15139.655	.016	1.056827E-06	.715	.02239	15139.632	.0227	

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
-2.11366410E-06	-0.032	-0.004373	-2.88868039E-07	.01757	.00163

LINE NO 39 SIMMLER TO MCKITTRICK LINE QUALITY 3

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP	
39	8 8 59	22943.580	0	0	0	0	22943.569	.0110	
39	6 23 60	22943.572	-0.008	-3.486815E-07	.876	-0.00913	22943.576	-0.0039	
39	12 19 61	22943.582	.010	4.358517E-07	1.489	.00671	22943.588	-0.0056	
39	10 18 62	22943.597	.015	6.537772E-07	.830	.01808	22943.594	.0028	
39	6 18 63	22943.596	-0.001	-4.358515E-08	.665	-0.00150	22943.599	-0.0034	
39	3 19 64	22943.605	.009	3.922662E-07	.753	.01195	22943.605	-0.0004	
39	3 8 66	22943.597	-0.008	-3.486812E-07	1.969	-0.00406	22943.621	-0.0239	
39	4 20 67	22943.653	.056	2.440762E-06	1.117	.05013	22943.630	.0233	**

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
3.18170939E-06	.073	.007882	3.43542393E-07	.01276	.00123

LINE NO 40 MCKITTRICK TO CALIENTE LINE QUALITY 3

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
40	12 9 60	28218.275	0	0	0	0	28218.272	.0032
40	12 14 61	28218.269	-0.006	-2.126282E-07	1.013	-0.00592	28218.274	-0.0051
40	9 5 63	28218.280	.011	3.898182E-07	1.725	.00638	28218.278	.0019

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
1.77190022E-07	.005	.002313	8.19606264E-08	.00366	.00126

LINE NO 41 PATTIWAY TO CALIENTE LINE QUALITY 3

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
41	12 8 60	31122.614	0	0	0	0	31122.612	.0019
41	6 6 62	31122.634	.020	6.426191E-07	1.492	.01340	31122.636	-0.0022
41	10 5 62	31122.642	.008	2.570476E-07	.331	.02415	31122.642	.0005
41	8 27 63	31122.650	.008	2.570475E-07	.893	.00896	31122.656	-0.0059
41	3 3 64	31122.670	.020	6.426184E-07	.517	.03865	31122.664	.0057

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
1.79933262E-06	.056	.016143	5.18686747E-07	.00391	.00106

LINE NO 42 SALISBURY TO YAM — LINE QUALITY 3

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP	
42	11 10 59	23101.937	0	0	0	0	23101.913	.0236	
42	12 20 60	23101.856	-0.081	-3.506212E-06	1.112	-0.07287	23101.906	-0.0496	***
42	6 11 62	23101.914	.058	2.510614E-06	1.473	.03938	23101.895	.0187	
42	2 20 64	23101.897	-0.017	-7.358703E-07	1.695	-0.01003	23101.883	.0136	
42	1 5 68	23101.850	-0.047	-2.034469E-06	3.874	-0.01213	23101.856	-0.0063	

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
-3.76593671E-06	-0.087	-0.007003	-3.03123124E-07	.02680	.00283

LINE NO 43 MT PINOS TO REYES — LINE QUALITY 3

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
43	11 19 59	23732.077	0	0	0	0	23732.074	.0029
43	9 27 61	23732.095	.018	7.584665E-07	1.856	.00970	23732.101	-0.0057
43	8 28 63	23732.131	.036	1.516931E-06	1.916	.01878	23732.128	.0028

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
2.27539732E-06	.054	.014338	6.04141993E-07	.00404	.00102

LINE NO 44 HAZE TO MT PINOS — LINE QUALITY 6

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
44	10 2 61	28142.732	0	0	0	0	28142.747	-0.0152
44	7 22 63	28142.777	.045	1.598989E-06	1.802	.02498	28142.735	.0417
44	8 4 64	28142.702	-0.075	-2.664989E-06	1.038	-0.07228	28142.728	-0.0264

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
-1.06599999E-06	-0.030	-0.006617	-2.35128495E-07	.02983	.00990

LINE NO 45 PATTIWAY TO PELATO — LINE QUALITY 1

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
45	9 3 62	5030.124	0	0	0	0	5030.121	.0033
45	10 5 62	5030.120	-0.004	-7.952097E-07	.088	-0.04566	5030.121	-0.0008
45	2 12 64	5030.120	0	0	1.355	0	5030.123	-0.0027
45	9 16 64	5030.122	.002	3.976047E-07	.594	.00337	5030.124	-0.0015
45	1 25 66	5030.122	0	0	1.358	0	5030.125	-0.0035
45	4 27 66	5030.131	.009	1.789218E-06	.252	.03573	5030.126	.0052

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
1.39161283E-06	.007	.001413	2.80834241E-07	.00317	.00061

LINE NO 46 PELATO TO TEMBLOR — LINE QUALITY 2

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP	
46	11 24 59	25356.338	0	0	0	0	25356.340	-0.0017	
46	11 17 60	25356.319	-0.019	-7.493201E-07	.983	-0.01933	25356.332	-0.0133	
46	12 17 61	25356.329	.010	3.943789E-07	1.081	.00925	25356.324	.0048	
46	3 1 64	25356.330	.001	3.943788E-08	2.204	.00045	25356.308	.0223	
46	4 25 66	25356.287	-0.043	-1.695832E-06	2.149	-0.02001	25356.292	-0.0046	***
46	8 17 66	25356.291	.004	1.577518E-07	.312	.01282	25356.289	.0017	
46	12 26 67	25356.270	-0.021	-8.281975E-07	1.358	-0.01546	25356.279	-0.0091	

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
-2.68178101E-06	-0.068	-0.007491	-2.95438301E-07	.01074	.00094

LINE NO 47 PELATO TO KITCHEN — LINE QUALITY 2

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP	
47	11 25 59	23228.516	0	0	0	0	23228.479	.0370	
47	11 21 60	23228.447	-0.069	-2.970496E-06	.991	-0.06962	23228.484	-0.0366	***
47	6 13 62	23228.477	.030	1.291518E-06	1.558	.01926	23228.491	-0.0138	
47	3 29 65	23228.517	.040	1.722021E-06	2.793	.01432	23228.504	.0134	

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
4.30438037E-08	.001	.004612	1.98541579E-07	.02772	.00463

LINE NO 48 PATTIWAY TO TEMBLOR — LINE QUALITY 2

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
48	6 4 59	20336.556	0	0	0	0	20336.548	.0077
48	11 14 60	20336.527	-0.029	-1.426006E-06	1.448	-0.02002	20336.537	-0.0099
48	12 20 61	20336.531	.004	1.966904E-07	1.098	.00364	20336.528	.0027
48	6 13 63	20336.519	-0.012	-5.900715E-07	1.478	-0.00812	20336.517	.0023
48	8 13 64	20336.501	-0.018	-8.851080E-07	1.169	-0.01540	20336.508	-0.0066
48	12 26 67	20336.485	-0.016	-7.867633E-07	3.368	-0.00475	20336.481	.0038

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
-3.49125795E-06	-0.071	-0.007834	-3.85203030E-07	.00617	.00061

LINE NO 49 PATTIWAY TO MT PINOS LINE QUALITY 5

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
49	6 12 59	30880.871	0	0	0	0	30880.858	.0131
49	12 2 59	30880.828	-0.043	-1.392450E-06	.474	-0.09078	30880.858	-0.0300
49	10 27 60	30880.860	.032	1.036241E-06	.903	.03542	30880.858	.0019
49	3 14 61	30880.869	.009	2.914426E-07	.378	.02382	30880.858	.0109
49	9 29 61	30880.856	-0.013	-4.209728E-07	.545	-0.02386	30880.858	-0.0022
49	7 22 63	30880.889	.033	1.068622E-06	1.810	.01823	30880.858	.0307
49	9 18 64	30880.834	-0.055	-1.781040E-06	1.161	-0.04738	30880.858	-0.0244

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
-1.19815725E-06	-0.037	.000091	2.93835548E-09	.01977	.00286

LINE NO 50 POLICE TO WHEELER LINE QUALITY 2

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
50	6 5 59	15587.959	0	0	0	0	15587.965	-0.0056
50	6 22 60	15587.929	-0.030	-1.924566E-06	1.049	-0.02861	15587.954	-0.0248
50	12 15 60	15587.947	.018	1.154738E-06	.482	.03736	15587.949	-0.0019
50	10 31 61	15587.951	.004	2.566085E-07	.876	.00457	15587.940	.0111
50	10 10 62	15587.946	-0.005	-3.207607E-07	.942	-0.00531	15587.930	.0158
50	1 9 64	15587.884	-0.062	-3.977448E-06	1.248	-0.04966	15587.917	-0.0334
50	5 13 64	15587.956	.072	4.618951E-06	.342	.21038	15587.914	.0421
50	1 18 66	15587.934	-0.022	-1.411348E-06	1.684	-0.01307	15587.897	.0374
50	11 14 67	15587.898	-0.036	-2.309484E-06	1.821	-0.01977	15587.878	.0201
50	12 21 67	15587.858	-0.040	-2.566100E-06	.101	-0.39486	15587.877	-0.0188
50	1 18 68	15587.834	-0.024	-1.539662E-06	.077	-0.31307	15587.876	-0.0420

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
-8.01907153E-06	-0.125	-0.010275	-6.59167460E-07	.02670	.00180

LINE NO 51 POLICE TO DIORITE LINE QUALITY 2

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP	
51	5 10 60	26662.928	0	0	0	0	26662.907	.0209	
51	12 23 60	26662.858	-0.070	-2.625375E-06	.621	-0.11263	26662.907	-0.0491	
51	11 12 61	26662.922	.064	2.400337E-06	.887	.07215	26662.907	.0149	***
51	10 25 62	26662.916	-0.006	-2.250317E-07	.950	-0.00632	26662.907	.0089	
51	2 26 64	26662.928	.012	4.500631E-07	1.339	.00896	26662.907	.0208	
51	8 24 66	26662.882	-0.046	-1.725245E-06	2.491	-0.01846	26662.907	-0.0252	***
51	11 16 67	26662.916	.034	1.275179E-06	1.229	.02766	26662.907	.0087	

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
-4.50071955E-07	-0.012	.000027	1.01948112E-09	.02477	.00239

LINE NO 52 POLICE TO TEJON LINE QUALITY 2

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP	
52	12 1 59	13701.761	0	0	0	0	13701.752	.0091	
52	12 13 60	13701.733	-0.028	-2.043537E-06	1.035	-0.02706	13701.750	-0.0170	***
52	11 2 61	13701.746	.013	9.487842E-07	.887	.01466	13701.748	-0.0023	
52	10 10 62	13701.759	.013	9.487833E-07	.936	.01388	13701.747	.0125	
52	2 10 64	13701.748	-0.011	-8.028173E-07	1.336	-0.00823	13701.744	.0040	
52	8 15 66	13701.720	-0.028	-2.043539E-06	2.511	-0.01115	13701.739	-0.0192	***
52	2 9 67	13701.744	.024	1.751602E-06	.487	.04925	13701.738	.0057	
52	11 16 67	13701.744	0	0	.767	0	13701.737	.0072	

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
-1.24072413E-06	-0.017	-0.001898	-1.38500134E-07	.01118	.00095

LINE NO 53 TEJON 1932 TO WHEELER LINE QUALITY 3

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
53	1 11 60	21528.952	0	0	0	0	21528.933	.0187
53	5 11 60	21528.924	-0.028	-1.300576E-06	.331	-0.08452	21528.930	-0.0059
53	12 1 60	21528.908	-0.016	-7.431868E-07	.559	-0.02865	21528.924	-0.0161
53	2 20 62	21528.875	-0.033	-1.532825E-06	1.221	-0.02703	21528.911	-0.0363
53	10 15 62	21528.902	.027	1.254128E-06	.649	.04161	21528.905	-0.0026
53	5 9 63	21528.935	.033	1.532821E-06	.564	.05851	21528.899	.0363
53	4 29 64	21528.907	-0.028	-1.300577E-06	.975	-0.02873	21528.889	.0185
53	12 20 67	21528.838	-0.069	-3.205003E-06	3.641	-0.01895	21528.851	-0.0126

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
-5.29521931E-06	-0.114	-0.010420	-4.84018165E-07	.02175	.00214

LINE NO 54 WEED TO TEJON 1932 LINE QUALITY 2

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP	
54	6 7 62	14860.324	0	0	0	0	14860.334	-0.0102	
54	4 18 63	14860.327	.003	2.018798E-07	.862	.00348	14860.329	-0.0024	
54	1 24 64	14860.344	.017	1.143984E-06	.769	.02210	14860.325	.0189	***
54	2 29 64	14860.309	-0.035	-2.355267E-06	.099	-0.35510	14860.325	-0.0155	
54	3 28 65	14860.338	.029	1.951503E-06	1.076	.02695	14860.319	.0195	***
54	12 19 67	14860.293	-0.045	-3.028204E-06	2.727	-0.01650	14860.303	-0.0102	

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
-2.08610391E-06	-0.031	-0.005603	-3.77064251E-07	.01411	.00221

LINE NO 55 TEJON 1932 TO DIGIORGIO LINE QUALITY 2

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP	
55	10 15 62	13042.268	0	0	0	0	13042.279	-0.0110	
55	1 22 64	13042.275	.007	5.367162E-07	1.270	.00551	13042.261	.0144	***
55	3 28 65	13042.242	-0.033	-2.530240E-06	1.180	-0.02797	13042.243	-0.0014	
55	4 11 66	13042.230	-0.012	-9.200881E-07	1.038	-0.01156	13042.228	.0017	
55	2 14 67	13042.218	-0.012	-9.200889E-07	.846	-0.01418	13042.216	.0020	
55	12 19 67	13042.198	-0.020	-1.533484E-06	.843	-0.02372	13042.204	-0.0057	

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
-5.36718444E-06	-0.070	-0.014550	-1.11557924E-06	.00787	.00123

LINE NO 56 BRECKENRIDGE TO PIUTE LINE QUALITY 3

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
56	5 5 60	18362.943	0	0	0	0	18362.956	-0.0130
56	10 19 61	18362.959	.016	8.713193E-07	1.457	.01098	18362.936	.0233
56	8 20 63	18362.900	-0.059	-3.213000E-06	1.834	-0.03216	18362.910	-0.0103

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
-2.34168086E-06	-0.043	-0.013878	-7.55761082E-07	.01648	.00477

LINE NO 57 OILER TO TOLL LINE QUALITY 3

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
57	5 2 60	23198.608	0	0	0	0	23198.608	.0000
57	1 9 68	23198.541	-0.067	-2.888113E-06	7.688	-0.00872	23198.541	0

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
-2.88811266E-06	-0.067	-0.008715	-3.75666461E-07	.00000	.00000

LINE NO 58 PAJUELA TO SOLEDAD LINE QUALITY 3

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
58	5 20 60	18116.787	0	0	0	0	18116.786	.0013
58	12 7 61	18116.778	-0.009	-4.967771E-07	1.550	-0.00581	18116.778	-0.0003
58	7 15 63	18116.769	-0.009	-4.967773E-07	1.602	-0.00562	18116.771	-0.0017
58	1 6 68	18116.750	-0.019	-1.048753E-06	4.479	-0.00424	18116.749	.0008

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
-2.04230762E-06	-0.037	-0.004785	-2.64098701E-07	.00112	.00013

LINE NO 59 AVENUE TO PELONA LINE QUALITY 5

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
59	3 4 60	26978.429	0	0	0	0	26978.411	.0179
59	12 30 60	26978.342	-0.087	-3.224809E-06	.824	-0.10557	26978.419	-0.0772
59	3 31 61	26978.481	.139	5.152254E-06	.249	.55791	26978.422	.0593

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
1.92744550E-06	.052	.009902	3.67044497E-07	.05716	.04854

LINE NO 60 TEJON TO SAWMILL LINE QUALITY 3

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP	
60	12 3 59	26301.462	0	0	0	0	26301.448	.0138	
60	12 16 60	26301.408	-0.054	-2.053122E-06	1.038	-0.05204	26301.446	-0.0378	***
60	11 6 61	26301.439	.031	1.178643E-06	.890	.03484	26301.444	-0.0046	
60	5 1 63	26301.466	.027	1.026559E-06	1.481	.01823	26301.440	.0259	
60	5 14 64	26301.452	-0.014	-5.322900E-07	1.038	-0.01349	26301.438	.0144	
60	3 30 65	26301.448	-0.004	-1.520829E-07	.876	-0.00457	26301.436	.0125	
60	12 2 65	26301.423	-0.025	-9.505189E-07	.676	-0.03697	26301.434	-0.0109	
60	11 16 67	26301.416	-0.007	-2.661454E-07	1.955	-0.00358	26301.429	-0.0132	

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
-1.74895771E-06	-0.046	-0.002392	-9.09271252E-08	.01925	.00183

LINE NO 61 THUMB TO SAWMILL LINE QUALITY 6

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
61	1 8 60	22880.080	0	0	0	0	22880.069	.0111
61	1 4 61	22880.031	-0.049	-2.141605E-06	.991	-0.04944	22880.073	-0.0423
61	3 29 61	22880.116	.085	3.715016E-06	.230	.36960	22880.074	.0416
61	11 8 61	22880.061	-0.055	-2.403840E-06	.613	-0.08968	22880.077	-0.0161
61	8 29 63	22880.091	.030	1.311184E-06	1.804	.01663	22880.085	.0057

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
4.80754491E-07	.011	.004521	1.97583135E-07	.02808	.00703

LINE NO 62 DENIS TO TOM LINE QUALITY 3

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP	
62	4 19 60	22445.892	0	0	0	0	22445.898	-0.0065	
62	3 23 61	22445.910	.018	8.019278E-07	.925	.01945	22445.897	.0127	
62	12 16 61	22445.872	-0.038	-1.692962E-06	.734	-0.05179	22445.896	-0.0243	
62	2 15 63	22445.906	.034	1.514753E-06	1.166	.02915	22445.895	.0112	***
62	7 1 63	22445.907	.001	4.455155E-08	.372	.00269	22445.894	.0126	
62	12 7 67	22445.883	-0.024	-1.069238E-06	4.435	-0.00541	22445.889	-0.0057	

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
-4.00967794E-07	-0.009	-0.001285	-5.72593145E-08	.01362	.00153

LINE NO 63 WARD TO TENHI — LINE QUALITY 3

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP	
63	3 8 60	21489.005	0	0	0	0	21488.999	.0062	
63	1 6 61	21489.004	-0.001	-4.653543E-08	.832	-0.00120	21488.998	.0059	
63	3 27 62	21488.974	-0.030	-1.396065E-06	1.218	-0.02462	21488.997	-0.0231	***
63	6 28 62	21488.995	.021	9.772444E-07	.255	.08248	21488.997	-0.0019	
63	7 11 63	21489.007	.012	5.584251E-07	1.035	.01160	21488.996	.0109	
63	9 29 64	21488.995	-0.012	-5.584254E-07	1.221	-0.00983	21488.995	-0.0001	
63	7 12 65	21488.997	.002	9.307089E-08	.783	.00255	21488.995	.0025	
63	1 28 67	21488.993	-0.004	-1.861418E-07	1.547	-0.00259	21488.993	-0.0003	

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
-5.58427053E-07	-0.012	-0.000794	-3.69653159E-08	.00960	.00105

LINE NO 64 WARD TO BLUE W — LINE QUALITY 4

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP	
64	6 2 60	24930.892	0	0	0	0	24930.918	-0.0263	
64	1 13 61	24930.892	0	0	.616	0	24930.905	-0.0128	
64	7 3 62	24930.889	-0.003	-1.203327E-07	1.467	-0.00204	24930.873	.0164	
64	7 11 63	24930.873	-0.016	-6.417746E-07	1.021	-0.01567	24930.850	.0228	
64	10 8 63	24930.889	.016	6.417741E-07	.244	.06566	24930.845	.0442	
64	6 24 65	24930.789	-0.100	-4.011105E-06	1.711	-0.05844	24930.807	-0.0183	***
64	4 4 66	24930.764	-0.025	-1.002777E-06	.778	-0.03215	24930.790	-0.0262	

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
-5.13421470E-06	-0.128	-0.021941	-8.80054705E-07	.02569	.00328

LINE NO 65 BLUE E TO PHELAN — LINE QUALITY 3

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
65	3 31 60	11914.355	0	0	0	0	11914.347	.0080
65	1 12 61	11914.335	-0.020	-1.678650E-06	.786	-0.02545	11914.347	-0.0122
65	7 14 62	11914.352	.017	1.426851E-06	1.500	.01133	11914.348	.0042

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
-2.51799555E-07	-0.003	.000362	3.04069362E-08	.00880	.00361

LINE NO 66 SEVAINE TO PHELAN — LINE QUALITY 3

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
66	3 18 60	19901.788	0	0	0	0	19901.798	-0.0096
66	2 28 61	19901.804	.016	8.039472E-07	.950	.01684	19901.788	.0161
66	7 26 62	19901.767	-0.037	-1.859131E-06	1.405	-0.02634	19901.774	-0.0065

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
-1.05518418E-06	-0.021	-0.010240	-5.14538560E-07	.01147	.00462

LINE NO 67 STRAWBERRY TO SEVAINE — LINE QUALITY 3

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP	
67	3 2 60	23562.432	0	0	0	0	23562.438	-0.0056	
67	3 1 61	23562.420	-0.012	-5.092855E-07	.997	-0.01204	23562.438	-0.0179	
67	7 1 62	23562.421	.001	4.244046E-08	1.333	.00075	23562.438	-0.0172	
67	7 12 63	23562.491	.070	2.970823E-06	1.029	.06800	23562.438	.0525	***
67	6 26 65	23562.461	-0.030	-1.273212E-06	1.958	-0.01533	23562.439	.0220	
67	11 30 66	23562.422	-0.039	-1.655178E-06	1.429	-0.02729	23562.439	-0.0174	
67	5 6 67	23562.423	.001	4.244046E-08	.430	.00233	23562.439	-0.0165	

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
-3.81970765E-07	-0.009	.000263	1.11823542E-08	.02525	.00249

LINE NO 68 STRAWBERRY TO KELLER 2 — LINE QUALITY 2

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
68	5 27 60	17490.276	0	0	0	0	17490.298	-0.0218
68	1 31 61	17490.299	.023	1.315015E-06	.682	.03374	17490.294	.0055
68	6 26 62	17490.290	-0.009	-5.145712E-07	1.399	-0.00643	17490.285	.0052
68	6 28 63	17490.299	.009	5.145710E-07	1.005	.00896	17490.278	.0205
68	9 22 64	17490.299	0	0	1.238	0	17490.271	.0282
68	7 6 65	17490.246	-0.053	-3.030260E-06	.786	-0.06745	17490.266	-0.0199
68	4 13 66	17490.234	-0.012	-6.860972E-07	.769	-0.01560	17490.261	-0.0270
68	12 18 66	17490.266	.032	1.829589E-06	.682	.04694	17490.257	.0092

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
-5.71754059E-07	-0.010	-0.006248	-3.57223239E-07	.01923	.00203

LINE NO 69 DIVIDE TO KELLER 2 — LINE QUALITY 3

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
69	5 31 60	15035.430	0	0	0	0	15035.427	.0026
69	2 2 61	15035.416	-0.014	-9.311349E-07	.676	-0.02070	15035.427	-0.0112
69	7 23 62	15035.424	.008	5.320768E-07	1.467	.00545	15035.427	-0.0026
69	6 27 63	15035.442	.018	1.197171E-06	.928	.01939	15035.426	.0157
69	9 26 64	15035.436	-0.006	-3.990573E-07	1.251	-0.00480	15035.426	.0102
69	7 8 65	15035.414	-0.022	-1.463212E-06	.780	-0.02819	15035.426	-0.0116
69	12 19 66	15035.422	.008	5.320769E-07	1.448	.00552	15035.425	-0.0030

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
-5.32079293E-07	-0.008	-0.000366	-2.43218028E-08	.00949	.00110

LINE NO 70 BRINK TO STRAWBERRY LINE QUALITY 4

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP	
70	3 14 60	25777.263	0	0	0	0	25777.250	.0133	
70	1 17 61	25777.196	-0.067	-2.599197E-06	.846	-0.07920	25777.233	-0.0375	
70	2 4 63	25777.212	.016	6.207033E-07	2.048	.00781	25777.194	.0179	***
70	9 23 64	25777.205	-0.007	-2.715578E-07	1.634	-0.00428	25777.163	.0424	
70	6 27 65	25777.134	-0.071	-2.754379E-06	.758	-0.09362	25777.148	-0.0141	
70	1 17 66	25777.125	-0.009	-3.491468E-07	.559	-0.01611	25777.137	-0.0123	
70	12 18 66	25777.110	-0.015	-5.819116E-07	.917	-0.01635	25777.120	-0.0097	

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
-5.93548860E-06	-0.153	-0.019229	-7.45970127E-07	.02431	.00260

LINE NO 71 BRINK TO KELLER 2 LINE QUALITY 4

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
71	1 19 61	21830.881	0	0	0	0	21830.876	.0050
71	7 11 62	21830.866	-0.015	-6.871005E-07	1.473	-0.01018	21830.875	-0.0092
71	2 4 63	21830.876	.010	4.580668E-07	.569	.01756	21830.875	.0011
71	9 24 64	21830.877	.001	4.580668E-08	1.637	.00061	21830.874	.0030

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
-1.83227046E-07	-0.004	-0.000556	-2.54595238E-08	.00547	.00140

LINE NO 72 BRINK TO DIVIDE LINE QUALITY 3

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP	
72	4 15 60	17208.692	0	0	0	0	17208.704	-0.0120	
72	2 6 61	17208.716	.024	1.394642E-06	.813	.02952	17208.702	.0141	***
72	2 4 63	17208.696	-0.020	-1.162203E-06	1.993	-0.01003	17208.697	-0.0006	
72	12 19 66	17208.685	-0.011	-6.392121E-07	3.871	-0.00284	17208.686	-0.0015	

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
-4.06773118E-07	-0.007	-0.002632	-1.52940618E-07	.00931	.00122

LINE NO 73 BRINK TO PINE BENCH LINE QUALITY 3

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
73	2 25 60	21382.214	0	0	0	0	21382.214	-0.0000
73	2 4 63	21382.204	-0.010	-4.676786E-07	2.943	-0.00340	21382.204	0

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
-4.67678636E-07	-0.010	-0.003398	-1.58914398E-07	.00000	.00000

LINE NO 74 BRINK TO DAVID LINE QUALITY 2

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
74	3 28 60	17581.831	0	0	0	0	17581.829	.0024
74	2 19 61	17581.820	-0.011	-6.256463E-07	.898	-0.01225	17581.828	-0.0076
74	3 23 62	17581.834	.014	7.962764E-07	1.087	.01288	17581.826	.0075
74	2 3 63	17581.826	-0.008	-4.550153E-07	.868	-0.00922	17581.826	.0005
74	1 16 66	17581.812	-0.014	-7.962774E-07	2.951	-0.00474	17581.822	-0.0104
74	12 13 66	17581.829	.017	9.669074E-07	.906	.01876	17581.821	.0076

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
-1.13755202E-07	-0.002	-0.001066	-6.06215200E-08	.00691	.00078

LINE NO 75 DAVID TO DIVIDE LINE QUALITY 3

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
75	4 13 60	19011.985	0	0	0	0	19012.004	-0.0186
75	2 20 61	19011.994	.009	4.733854E-07	.857	.01050	19011.995	-0.0008
75	2 2 63	19012.006	.012	6.311801E-07	1.949	.00616	19011.975	.0313
75	12 19 66	19011.942	-0.064	-3.366305E-06	3.877	-0.01651	19011.935	.0071
75	5 8 67	19011.912	-0.030	-1.577958E-06	.383	-0.07827	19011.931	-0.0190

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
-3.83969763E-06	-0.073	-0.010268	-5.40088021E-07	.01862	..00192

LINE NO 76 DAVID TO KITCHING LINE QUALITY 3

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP	
76	4 1 60	22171.382	0	0	0	0	22171.374	.0082	
76	2 21 61	22171.345	-0.037	-1.668821E-06	.893	-0.04145	22171.367	-0.0220	***
76	3 14 62	22171.371	.026	1.172683E-06	1.057	.02460	22171.359	.0120	
76	2 5 63	22171.356	-0.015	-6.765486E-07	.898	-0.01670	22171.352	.0038	
76	5 2 67	22171.318	-0.038	-1.713926E-06	4.235	-0.00897	22171.320	-0.0021	

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
-2.88661195E-06	-0.064	-0.007581	-3.41923239E-07	.01196	.00147

LINE NO 77 GOLF TO KITCHING LINE QUALITY 4

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
77	4 13 60	26604.327	0	0	0	0	26604.329	-0.0020
77	3 8 61	26604.322	-0.005	-1.879394E-07	.901	-0.00555	26604.321	.0008
77	2 12 63	26604.308	-0.014	-5.262306E-07	1.933	-0.00724	26604.304	.0036
77	9 19 64	26604.288	-0.020	-7.517585E-07	1.602	-0.01249	26604.290	-0.0025

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
-1.46592847E-06	-0.039	-0.008679	-3.26225138E-07	.00244	.00048

LINE NO 78 GOLF TO INDIAN LINE QUALITY 4

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
78	7 24 62	4975.334	0	0	0	0	4975.334	0
78	6 29 63	4975.403	.069	1.386822E-05	.931	.07412	4975.403	0

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
1.38682233E-05	.069	.074124	1.48982429E-05	0	0

LINE NO 79 GOLF TO FAN LINE QUALITY 5

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
79	4 13 60	26262.916	0	0	0	0	26262.903	.0131
79	3 7 61	26262.862	-0.054	-2.056135E-06	.898	-0.06013	26262.880	-0.0184
79	3 26 62	26262.852	-0.010	-3.807660E-07	1.051	-0.00951	26262.854	-0.0021
79	2 2 63	26262.840	-0.012	-4.569194E-07	.857	-0.01400	26262.833	.0073

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
-2.89382071E-06	-0.076	-0.025012	-9.52385950E-07	.01193	.00380

LINE NO 80 LOMA PRIETA TO BIELWASKI LINE QUALITY 3

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
80	9 24 59	25441.324	0	0	0	0	25441.324	0
80	8 29 60	25441.324	0	0	.931	0	25441.324	0

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
0	0	0	0	0	0

LINE NO 81 CHINA LAKE SB TO CHINA LAKE NB LINE QUALITY 4

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
81	2 1 62	21606.983	0	0	0	0	21606.991	-0.0082
81	4 30 63	21607.012	.029	1.342157E-06	1.240	.02338	21606.998	.0142
81	1 11 65	21607.001	-0.011	-5.090943E-07	1.703	-0.00646	21607.007	-0.0060

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
8.33062637E-07	.018	.005359	2.48033616E-07	.01005	.00325

LINE NO 82 CHINA LAKE SB TO SNORT NB LINE QUALITY 3

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
82	1 30 62	17937.918	0	0	0	0	17937.918	0
82	3 1 65	17937.920	.002	1.114956E-07	3.083	.00065	17937.920	0

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
1.11495647E-07	.002	.000649	3.61603849E-08	0	0

LINE NO 83 CHINA LAKE SB TO TUNNEL LINE QUALITY 3

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
83	1 16 62	27124.556	0	0	0	0	27124.556	0
83	1 27 65	27124.547	-0.009	-3.318028E-07	3.031	-0.00297	27124.547	.0000

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
-3.31802776E-07	-0.009	-0.002970	-1.09483708E-07	.00000	.00000

LINE NO 84 SNORT NB TO TUNNEL LINE QUALITY 2

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
84	1 18 62	13573.081	0	0	0	0	13573.081	.0000
84	1 28 65	13573.106	.025	1.841878E-06	3.028	.00826	13573.106	0

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
1.84187761E-06	.025	.008256	6.08278597E-07	.00000	.00000

LINE NO 85 SNORT SB TO TUNNEL LINE QUALITY 3

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
85	1 12 62	21751.307	0	0	0	0	21751.307	.0000
85	1 26 65	21751.327	.020	9.194841E-07	3.039	.00658	21751.327	0

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
9.19484131E-07	.020	.006581	3.02575545E-07	.00000	.00000

LINE NO 86 M-58 TO TUNNEL LINE QUALITY 3

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
86	1 31 62	27001.090	0	0	0	0	27001.090	.0000
86	1 21 65	27001.096	.006	2.222132E-07	2.973	.00202	27001.096	0

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
2.22213202E-07	.006	.002018	7.47423764E-08	.00000	.00000

LINE NO 87 M-58 TO SNORT NB LINE QUALITY 3

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
87	1 26 62	13626.607	0	0	0	0	13626.607	0
87	1 20 65	13626.619	.012	8.806293E-07	2.984	.00402	13626.619	0

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
8.80629304E-07	.012	.004021	2.95086648E-07	0	0

LINE NO 88 CHINA LAKE SB TO SNORT SB LINE QUALITY 3

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
88	1 11 62	11299.904						

LINE NO 89 M-SB TO SNORT SB LINE QUALITY 4

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
89	1 25 62	22012.045	0	0	0	0	22012.045	-0.0000
89	1 12 65	22012.054	.009	4.088669E-07	2.965	.00304	22012.054	0

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
4.08866887E-07	.009	.003035	1.37883041E-07	.00000	.00000

LINE NO 90 CHINA LAKE SB TO M-SB LINE QUALITY 3

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
90	1 29 62	13427.017	0	0	0	0	13427.017	0
90	1 8 65	13427.018	.001	7.447670E-08	2.943	.00034	13427.018	0

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
7.44767006E-08	.001	.000340	2.53034637E-08	0	0

LINE NO 91 SNORT SB TO SNORT NB LINE QUALITY 3

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
91	2 2 62	18861.067	0	0	0	0	18861.067	0
91	1 19 65	18861.086	.019	1.007365E-06	2.962	.00641	18861.086	-0.0000

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
1.00736511E-06	.019	.006414	3.40062500E-07	.00000	.00000

LINE NO 92 SNORT MID BASE TO SNORT NB LINE QUALITY 2

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
92	1 17 62	9434.793						

LINE NO 93 SNORT MID BASE TO SNORT SB LINE QUALITY 2

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
93	1 17 62	9426.239						

LINE NO 94 CHINA LAKE NB TO SNORT SB LINE QUALITY 4

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
94	3 4 65	27791.350						

LINE NO 95 CHINA LAKE NB TO M-SB LINE QUALITY 2

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
95	3 4 65	9203.581						

LINE NO 96 PEAK TO SNORT NB LINE QUALITY 3

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
96	3 3 65	17108.779						

LINE NO 97 PEAK TO SNORT SB LINE QUALITY 4

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
97	3 3 65	35612.629						

LINE NO 98 PEAK TO CHINA LAKE NB LINE QUALITY 3

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
98	3 2 65	17594.678						

LINE NO 99 PEAK TO CHINA LAKE SB LINE QUALITY 4

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
99	3 2 65	34542.211						

LINE NO 100 PEAK TO M-SB LINE QUALITY 4

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
100	3 2 65	25634.060						

LINE 101 AIR TO COW LINE QUALITY 2

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
101	8 11 65	10647.670	0	0	0	0	10647.670	.0000
101	8 31 66	10647.644	-0.026	-2.441855E-06	1.054	-0.02467	10647.644	-0.0002
101	11 18 66	10647.639	-0.005	-4.695877E-07	.216	-0.02312	10647.639	.0001

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
-2.91144241E-06	-0.031	-0.024486	-2.29968236E-06	.00012	.00009

LINE 102 PINE TO COW LINE QUALITY 2

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
102	8 12 65	11784.437	0	0	0	0	11784.437	0
102	11 21 66	11784.436	-0.001	-8.485769E-08	1.276	-0.00078	11784.436	.0000

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
-8.48576886E-08	-0.001	-0.000784	-6.65205751E-08	.00000	.00000

LINE 103 PINE TO AIR LINE QUALITY 2

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
103	8 12 65	12081.797	0	0	0	0	12081.795	.0019
103	8 22 66	12081.754	-0.043	-3.559086E-06	1.027	-0.04188	12081.764	-0.0101
103	11 19 66	12081.765	.011	9.104630E-07	.244	.04514	12081.757	.0082

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
-2.64862288E-06	-0.032	-0.030110	-2.49217222E-06	.00761	.00538

LINE NO 104 SAWMILL TO PINE LINE QUALITY 2

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
104	8 17 65	9393.393						

LINE 105 COW TO TEJON LINE QUALITY 2

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
105	8 18 65	11018.370	0	0	0	0	11018.370	.0000
105	11 21 66	11018.342	-0.028	-2.541217E-06	1.259	-0.02223	11018.342	0

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
-2.54121718E-06	-0.028	-0.022232	-2.01775299E-06	.00000	.00000

LINE 106 TEJON TO PINE LINE QUALITY 2

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
106	8 18 65	19018.738	0	0	0	0	19018.738	0
106	2 7 67	19018.761	.023	1.209332E-06	1.473	.01561	19018.761	0

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
1.20933220E-06	.023	.015615	8.21024067E-07	0	0

LINE 107 AIR TO TEJON LINE QUALITY 2

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
107	8 19 65	8826.977	0	0	0	0	8826.974	.0031
107	8 25 66	8826.952	-0.025	-2.832235E-06	1.016	-0.02461	8826.969	-0.0167
107	11 19 66	8826.981	.029	3.285381E-06	.235	.12317	8826.967	.0135

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
4.53146763E-07	.004	-0.005112	-5.79107628E-07	.01253	.00899

LINE 108 BONNIE TO KENGER LINE QUALITY 2

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
108	10 26 65	8526.525	0	0	0	0	8526.525	0
108	7 19 66	8526.508	-0.017	-1.993782E-06	.728	-0.02334	8526.508	-0.0000

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
-1.99378221E-06	-0.017	-0.023343	-2.73770867E-06	.00000	.00000

LINE 109 BONNIE TO COTTONWOOD LINE QUALITY 2

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
109	10 27 65	10651.841	0	0	0	0	10651.841	.0000
109	7 27 66	10651.857	.016	1.502086E-06	.747	.02141	10651.857	0

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
1.50208550E-06	.016	.021407	2.00968401E-06	.00000	.00000

LINE 110 BENCH TO COTTONWOOD LINE QUALITY 2

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
110	10 25 65	12553.073	0	0	0	0	12553.080	-0.0074
110	7 6 66	12553.112	.039	3.106799E-06	.695	.05608	12553.099	.0130
110	6 7 67	12553.118	.006	4.779689E-07	.920	.00652	12553.124	-0.0056

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
3.58476823E-06	.045	.026740	2.13018110E-06	.00922	.00543

LINE 111 BENCH TO MASON LINE QUALITY 2

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
111	9 29 65	12717.975	0	0	0	0	12717.970	.0052
111	7 25 66	12717.968	-0.007	-5.504024E-07	.819	-0.00855	12717.991	-0.0228
111	2 15 67	12718.041	.073	5.739878E-06	.561	.13006	12718.005	.0357
111	6 7 67	12717.995	-0.046	-3.616922E-06	.307	-0.15001	12718.013	-0.0182

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
1.57255299E-06	.020	.025737	2.02369227E-06	.02321	.01221

LINE 112 MASON TO KENGER LINE QUALITY 2

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
112	9 30 65	12484.308	0	0	0	0	12484.308	0
112	7 20 66	12484.324	.016	1.281607E-06	.802	.01995	12484.324	-0.0000

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
1.28160724E-06	.016	.019945	1.59763366E-06	.00000	.00000

LINE 113 BENCH TO KENGER LINE QUALITY 3

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
113	9 28 65	18654.902	0	0	0	0	18654.882	.0198
113	7 14 66	18654.766	-0.136	-7.290362E-06	.791	-0.17188	18654.804	-0.0382
113	5 23 67	18654.738	-0.028	-1.500959E-06	.857	-0.03267	18654.720	.0183

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
-8.79132132E-06	-0.164	-0.098580	-5.28444049E-06	.02699	.01562

LINE 114 BONNIE TO BENCH LINE QUALITY 2

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
114	10 27 65	16643.098	0	0	0	0	16643.098	.0000
114	7 26 66	16643.023	-0.075	-4.506393E-06	.745	-0.10071	16643.023	0

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
-4.50639286E-06	-0.075	-0.100712	-6.05128606E-06	.00000	.00000

LINE 115 BONNIE TO MASON LINE QUALITY 2

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
115	10 26 65	16935.471	0	0	0	0	16935.471	.0000
115	7 26 66	16935.549	.078	4.605697E-06	.747	.10436	16935.549	0

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
4.60569657E-06	.078	.104358	6.16205495E-06	.00000	.00000

LINE 116 MASON TO COTTONWOOD LINE QUALITY 3

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
116	1 27 66	20541.615	0	0	0	0	20541.647	-0.0321
116	7 7 66	20541.757	.142	6.912749E-06	.441	.32215	20541.709	.0483
116	5 21 67	20541.814	.057	2.774828E-06	.871	.06547	20541.830	-0.0162

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
9.68757647E-06	.199	.139659	6.79881327E-06	.03479	.02486

LINE 117 COTTONWOOD TO KENGER LINE QUALITY 3

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
117	10 28 65	17956.180	0	0	0	0	17956.180	.0000
117	7 21 66	17956.156	-0.024	-1.336589E-06	.728	-0.03295	17956.156	0

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
-1.33658897E-06	-0.024	-0.032954	-1.83524894E-06	.00000	.00000

LINE NO 118 TEM-B TO TEM-E LINE QUALITY 1

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
118	7 28 66	527.007						

LINE NO 119 TEM-B TO TEM-D LINE QUALITY 1

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
119	12 22 65	368.487	0	0	0	0	368.487	0
119	7 28 66	368.486	-0.001	-2.713807E-06	.597	-0.00168	368.486	0

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
-2.71380731E-06	-0.001	-0.001675	-4.54686319E-06	0	0

LINE NO 120 NOT USED LINE QUALITY 0

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
120	0 0 0	0						

LINE 121 DAVID TO MICRO LINE QUALITY 3

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
121	1 12 66	18364.775	0	0	0	0	18364.776	-0.0011
121	12 17 66	18364.788	.013	7.078764E-07	.928	.01401	18364.778	.0101
121	1 26 67	18364.769	-0.019	-1.034590E-06	.110	-0.17349	18364.778	-0.0091

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
-3.26713255E-07	-0.006	.001929	1.05050473E-07	.00788	.00659

LINE 122 DAVID TO NELSON LINE QUALITY 2

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
122	1 11 66	11661.186	0	0	0	0	11661.186	0
122	12 13 66	11661.186	0	0	.920	0	11661.186	0

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
0	0	0	0	0	0

LINE 123 MICRO TO NELSON LINE QUALITY 2

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
123	1 13 66	12517.718	0	0	0	0	12517.721	-0.0027
123	12 15 66	12517.764	.046	3.674778E-06	.920	.05000	12517.740	.0241
123	1 27 67	12517.721	-0.043	-3.435130E-06	.118	-0.36525	12517.742	-0.0214

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
2.39647615E-07	.003	.020841	1.66489912E-06	.01866	.01566

LINE 124 DAVID TO GANDER — LINE QUALITY 2

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
124	1 12 66	12095.379	0	0	0	0	12095.379	.0000
124	12 16 66	12095.407	.028	2.314928E-06	.925	.03026	12095.407	0

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
2.31492830E-06	.028	.030258	2.50159379E-06	.00000	.00000

LINE 125 NELSON TO GANDER — LINE QUALITY 2

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
125	1 11 66	15309.872	0	0	0	0	15309.872	.0000
125	12 16 66	15309.882	.010	6.531729E-07	.928	.01077	15309.882	0

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
6.53172898E-07	.010	.010775	7.03775024E-07	.00000	.00000

LINE 126 MICRO TO GANDER — LINE QUALITY 2

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
126	1 13 66	11528.494	0	0	0	0	11528.494	-0.0001
126	12 16 66	11528.479	-0.015	-1.301126E-06	.923	-0.01626	11528.478	.0011
126	1 27 67	11528.475	-0.004	-3.469670E-07	.115	-0.03479	11528.476	-0.0009

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
-1.64809264E-06	-0.019	-0.017522	-1.51991325E-06	.00081	.00068

LINE 127 BRINK TO GANDER — LINE QUALITY 1

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
127	1 14 66	8268.815	0	0	0	0	8268.815	.0000
127	12 16 66	8268.834	.019	2.297785E-06	.920	.02065	8268.834	0

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
2.29778467E-06	.019	.020654	2.49782170E-06	.00000	.00000

LINE 128 BRINK TO MICRO — LINE QUALITY 2

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
128	1 15 66	19195.267	0	0	0	0	19195.272	-0.0051
128	12 15 66	19195.313	.046	2.396418E-06	.914	.05030	19195.268	.0453
128	1 26 67	19195.227	-0.086	-4.480280E-06	.115	-0.74789	19195.267	-0.0402

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
-2.08386210E-06	-0.040	-0.004716	-2.45687016E-07	.03507	.02965

LINE NO 129 MIME MT RM2 DWR TO MASON — LINE QUALITY 3

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
129	5 22 67	18193.953						

LINE NO 130 CONNERS TO DOS RIOS — LINE QUALITY 1

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
130	6 28 66	1478.034						

LINE NO 131 TURNER TO NOMILACK — LINE QUALITY 2

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
131	6 29 66	12879.233						

LINE NO 132 TURNER TO MIDDLE — LINE QUALITY 2

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
132	8 2 66	11761.802	0	0	0	0	11761.802	.0000
132	9 14 67	11761.787	-0.015	-1.275316E-06	1.117	-0.01343	11761.787	0

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
-1.27531641E-06	-0.015	-0.013428	-1.14165180E-06	.00000	.00000

LINE NO 133 TURNER TOPOONKINNEY — LINE QUALITY 3

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
133	8 4 66	14661.215	0	0	0	0	14661.215	.0000
133	9 14 67	14661.209	-0.006	-4.092432E-07	1.112	-0.00540	14661.209	-0.0000

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
-4.09243194E-07	-0.006	-0.005397	-3.68095082E-07	.00000	.00000

LINE NO 134 TRAMP TO NOMILACK — LINE QUALITY 1

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
134	8 3 66	6081.644	0	0	0	0	6081.644	.0000
134	9 12 67	6081.638	-0.006	-9.865763E-07	1.109	-0.00541	6081.638	0

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
-9.86576314E-07	-0.006	-0.005411	-8.89725794E-07	.00000	.00000

LINE NO 135 TRAMP TO ANTHONY PEAK — LINE QUALITY 5

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
135	8 3 66	14195.316	0	0	0	0	14195.316	0
135	10 19 67	14195.324	.008	5.635659E-07	1.210	.00661	14195.324	.0000

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
5.63565862E-07	.008	.006611	4.65692923E-07	.00000	.00000

LINE NO 136 TURNER TO BRUSHY LINE QUALITY 3

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
136	9 14 66	15073.999	0	0	0	0	15073.999	0
136	9 14 67	15073.986	-0.013	-8.624129E-07	.999	-0.01301	15073.986	-0.0000

SUM OF EXTENSIONS	SUM OF DELTA L	COMP. DL/DT	EXTENSION RATE	STANDARD DEVIATION	PROBABLE ERROR OF THE SLOPE
-8.62412901E-07	-0.013	-0.013009	-8.62993229E-07	.00000	.00000

LINE NO 137 POONKINNEY TO NOMILACK LINE QUALITY 3

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
137	9 15 66	13189.908						

LINE NO 138 POISON TO HAM LINE QUALITY 2

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
138	9 14 67	16055.448						

LINE NO 139 POISON TO BALD LINE QUALITY 2

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
139	9 13 67	12984.813						

LINE NO 140 POISON TO BLACK BUTTE LINE QUALITY 2

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
140	9 13 67	13543.972						

LINE NO 141 POISON TO VIEW LINE QUALITY 2

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
141	9 13 67	18159.015						

LINE NO 142 POISON TO ANTHONY PEAK LINE QUALITY 2

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
142	9 14 67	14173.249						

LINE NO 143 NOMILACK TO MIDDLE LINE QUALITY 2

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
143	10 17 67	14151.247						

LINE NO 151 LOMA PRIETA TO ALLISON LINE QUALITY 3

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
151	7 24 67	43102.855						

LINE NO 171 SAWMILL TO PELONA LINE QUALITY 3

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
171	12 8 67	23866.161						

LINE NO 172 BODEGA HEAD TO GAFFNEY LINE QUALITY 1

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
172	9 28 67	1408.870						

LINE NO 173 DORAN TO GAFFNEY LINE QUALITY 1

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
173	9 27 67	1104.698						

LINE NO 174 FINBACK TO DORAN LINE QUALITY 1

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
174	928 67 0	1697.347						

LINE NO 175 BODEGA HEAD TO FINBACK LINE QUALITY 1

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
175	928 67 0	929.061						

LINE NO 176 BODEGA HEAD TO DORAN LINE QUALITY 1

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
176	928 67 0	1725.766						

LINE NO 177 FINBACK TO GAFFNEY LINE QUALITY 1

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
177	9 28 67	1959.361						

LINE NO 178 DORAN TO KNOB LINE QUALITY 1

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
178	9 27 67	1106.760						

LINE NO 179 SALMON TO KNOB LINE QUALITY 1

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
179	9 28 67	1316.983						

LINE NO 180 GAFFNEY TO SALMON LINE QUALITY 1

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
180	9 28 67	1610.912						

LINE NO 181 DORAN TO TIDE LINE QUALITY 1

LINE NO.	DATE	OBS. D	DELTA L	EXTENSION	DELTA T	DELTA L/DELTA T	COMP. D	OBS-COMP
181	9 27 67	2574.102						

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                   LINE NO 182  DORAN TO SALMON               LINE QUALITY  1
LINE NO.  DATE     OBS. D      DELTA L    EXTENSION    DELTA T  DELTA L/DELTA T   COMP. D    OBS-COMP
  182   9 27 67    1812.140

                   LINE NO 183  DORAN TO ASTER                LINE QUALITY  1
LINE NO.  DATE     OBS. D      DELTA L    EXTENSION    DELTA T  DELTA L/DELTA T   COMP. D    OBS-COMP
  183   9 27 67    1665.237

                   LINE NO 184  GAFFNEY TO KNOB               LINE QUALITY  1
LINE NO.  DATE     OBS. D      DELTA L    EXTENSION    DELTA T  DELTA L/DELTA T   COMP. D    OBS-COMP
  184   9 28 67    1786.368

                   LINE NO 185  SALMON TO TIDE                LINE QUALITY  1
LINE NO.  DATE     OBS. D      DELTA L    EXTENSION    DELTA T  DELTA L/DELTA T   COMP. D    OBS-COMP
  185   9 28 67    1402.789

                   LINE NO 186  ASTER TO TIDE                 LINE QUALITY  1
LINE NO.  DATE     OBS. D      DELTA L    EXTENSION    DELTA T  DELTA L/DELTA T   COMP. D    OBS-COMP
  186   9 28 67    1987.577

                   LINE NO 187  ASTER TO SALMON               LINE QUALITY  1
LINE NO.  DATE     OBS. D      DELTA L    EXTENSION    DELTA T  DELTA L/DELTA T   COMP. D    OBS-COMP
  187   9 28 67    2288.291
I FTN 060 ( STOP )
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APPENDIX B

CALIFORNIA EARTHQUAKES OF MAGNIDUTE 4 AND GREATER WHICH OCCURRED NEAR THE GEODIMETER LINES

The epicenters were derived from:

1. University of California at Berkeley Bulletins of the Seismographic Stations for July 1959 through December 1965.

2. California Institute of Technology Seismological Laboratory Local Bulletins of Earthquakes in Southern California for July 1959 to December 1966.

3. U. S. Coast and Geodetic Survey publications. These are listed in Chapter III.

Earthquakes of Magnitude 4. 5 and greater which have occurred more recently than those published in the available bulletins are on the graphs and charts of this report but are not listed in Appendix B. Information concerning these earthquakes was received informally from the universities, usually by telephone.

The meanings of the abbreviations in the following tabulations are:

O. T.	-	Origin time--the time the earthquake began at its source.
Lat.	-	Latitude of epicenter.
Long.	-	Longitude of epicenter.
Mag.	-	Richter magnitude.
Berkeley or BRK	-	University of California at Berkeley Seismograph Stations.
Pasadena or PAS	-	California Institute of Technology Seismological Laboratory

APPENDIX B. CALIFORNIA EARTHQUAKES NEAR GEODIMETER LINES WITH MAGNITUDES 3.5 OR GREATER FROM 1959 THROUGH 1966

DATE	BERKELEY O. T.	PASADENA O. T.	USC&GS O. T.	BERKELEY LAT.	BERKELEY LONG.	PASADENA LAT.	PASADENA LONG.	USC&GS LAT.	USC&GS LONG.	BRK. MAG.	PAS. MAG.	USC&GS MAG.	BRK. VOL.	USC&GS SOURCE (MSI # unless otherwise indicated)
1959														
July 1		23 49 24				35 12	119 03				4 7			
July 23		03 21 03				33 56	117 15				3.5			
Aug 5	03 00 34	03 00 32		35 57	120 29	35 59	120 32			3.5	3.8		29 #3	
Aug 26		05 32 51				34 03	116 33				4.3			
Aug 30		16 51 33				35 14	118 34				3.5			
Sept 5	05 45 34			36.5	121.7					3.8			29 #3	
Sept 11	18 05 03			36.7	121.3					4.0			29 #3	
Oct 11	02 03 09			36 27	121 07					4.1			29 #4	
Oct 14	08 37 51			36 52	121 29					3.6			29 #4	
Oct 25	09 59 52			37.0	121.3					3.6			29 #4	
Dec 11	05 55 26			35.6	120.6					3.5			29 #4	
Dec 29	02 32 53		02 32 53	36 54	121 29			37	121.5	4.7		4.5-4.75	29 #4	228
Dec 29		14 53 08				35 45	120 18				3.5			
1960														
Jan 20	03 25 53	03 25	03 25 50	36 47	121 26	Not Given		36.5	122	5.0	5.5	5.0	30 #1	229
Jan 20	03 47 51			36 47	121 26					3.6			30 #1	
Feb 13	17 16 49			36 51	121 32					3.7			30 #1	
Mar 6		04 26 42				35 02	118 50				3.5			
April 9	08 01 14			36 30	121 08					3.6			30 #2	
April 18	02 16 21			36 37	121 14					3.5			30 #2	
June 11	17 39 48			36.3	120.9					3.7			30 #2	
June 24	18 13 12			36 27	121 13					3.5			30 #2	
June 28	12 40 44			36 55	121 45					3.5			30 #2	
June 28		20 00 48				34 08	117 26				4.1			
Aug 9		02 26 34				35 19	118 30				3.8			
Aug 21		23 07 03				34 11	117 25				3.8			
Sept 1		07 35 05				34 07	117 17				3.5			
Oct 23	03 43 07			36 48	121 24					3.8			30 #4	
Nov 3	06 50 24	06 50.4	06 50 24	36 32	121 08	37.0	121.1	36 32	121 08	4.1	4.8	4.1	30 #4	108
Nov 20	23 50 01			36 49	121 27					3.5			30 #4	
Dec 15	05 40 26			38 02	121 50					3.9			30 #4	
1961														
Jan 3	23 00 21			36 52	121 40					3.6			31 #1	
Jan 4	00 30 17	00 30.2	00 30 17	36 52	121 40	36.5	121.2	36 52	121 40	4.1	4.0	4.1	31 #1	109
Jan 10		18 55 01				34 17	117 04				3.8			
Jan 13	08 36 12			36 55	121 45					3.5			31 #1	
Feb 16	20 12 58			37 50	122 13					3.6			31 #1	
Mar 9		02 10 39				35 12	118 33				3.6			
April 7	22 04 42			36 33	121 23					3.5			31 #2	
April 8		09 29 48				36 10	120 27				3.8			
April 9	07 23 16	07 23.3	07 23 16.0	36 41	121 18	Not Given		36.7	121.4	5.6	5.5	5.5	31 #2	244
April 9	07 25 41			36 41	121 18					5.5			31 #2	
April 28	01 02 52			36 36	121 22					4.2			31 #2	
April 28	14 05 50			36 37	121 25					3.5			31 #2	
May 26	12 58 35			36 47	121 33					3.5			31 #2	
June 25	13 15 26			36 29	121 21					3.6			31 #2	
June 27	18 27 08			37 49	122 17					3.5			31 #2	
July 10		23 25 46				35 14	118 35				3.9			
July 22	18 01 55.0			36 24	121 12					4.0			31 #3	
July 31	00 07 08	00 07 07	00 07 07.0	35 49	120 22	35 47	120 19	35.7	120.4	4.7	4.5	4.5	31 #3	247
Aug 18	01 30 37			37 56	122 00					3.9			31 #3	
Sept 1		16 51 49				35 12	118 32				4.0			
Oct 19	08 08 47			37 25	121 46					3.5			31 #4	
Nov 12	04 20 11			36 58	121 40					3.7			31 #4	
Nov 15	05 38 54	05 38 55	05 38 54.3	34 09	119 01	34 56	118 59	34.9	119.1	5.3	5.0	4.9	31 #4	251
Nov 17	02 16 56			37 58	122 02					3.8			31 #4	
1962														
Jan 24	15 13 05.5			37 50	122 15					3.7			32 #1	
Jan 31	03 17 21.3			36 33	121 13					3.9			32 #1	
Feb 6		08 45 23				35 07	118 40				3.6			
Mar 17	21 38 44.5		21 38 43.8	37 49	121 53			37.7	122.3	4 1		4 75(Brk)	32 #1	255
April 1		09 09 24				35 14	118 32				3.5			
April 2		03 05 41				35 15	118 30				3.7			
April 2	16 41 57.28			37 00.9	121 32.9					3.5			32 #2	
April 7	07 19 37.51			37 17.0	121 54 5					3.5			32 #2	
April 15	08 41 02.32			36 24.9	120 37.0					4 7			32 #2	
May 5		14 17 24				33 42	116 43				3.6			
June 7	04 20 58.89			37 15.7	121 43.4					3.8			32 #2	
Aug 10		19 18 42				35 03	119 07				3.6			
Sept 26	10 19 30.57			36 53.7	121 43.7					3.6			32 #3	
Oct 29		02 42 54	02 42 55.5			34 20	116 52	34 1	117.0		4.8	4.75-5.0		262
Oct 29		05 35 05				34 19	116 52				3.7			
Nov 9		06 05 14				34 21	116 52				3.5			
Nov 30		23 51 05				34 20	116 55				4.3			
Dec 1		00 35 49	00 35 50.1			34 19	116 53	34.3	116.9		4 3	4.25		264
Dec 1		00 37 01				34 19	116 53				3.8			
Dec 1		10 36 13				34 20	116 54				3.7			
Dec 2		00 41 38				34 20	116 53				4.4			
Dec 2		03 06 36				34 20	116 51				3.6			
Dec 15		00 40.3				36.3	120.6				3.8			
Dec 24	00 16 23.37			36 50.9	121 47.4					3.7			32 #4	
1963														
Jan 9		06 04 03.8				34 55.3	119 06.2				4 0			
Feb 2	13 58 20.1			36 44.7	121 36.0					3.7			33 #1	
Feb 8	09 44 24.1			36 37.9	121 29.3					3.6			33 #1	
Feb 12		21 45 49 0				34 54.5	118 58.8				3.5			

DATE	BERKELEY O.T.	PASADENA O.T.	USC&GS O.T.	BERKELEY LAT.	BERKELEY LONG.	PASADENA LAT.	PASADENA LONG.	USC&GS LAT.	USC&GS LONG.	BRK. MAG.	PAS. MAG.	USC&GS MAG.	BRK. VOL.	USC&GS SOURCE MSI # unless otherwise indicated)
Mar 1	00 25 57.6	00 25 57.9	00 25 56.0	34 54.5	119 04.5	34 55.9	118 58.5	34.9	119.0	5.1	5.0	5.0	33 #1	267
Mar 4		20 10 42.3				34 56.7	118 58.1				4.0			
Mar 16		09 35 54.0				34 20.4	116 53.1				3.5			
April 12		05 20 44.4				34 54.5	118 57.1				3.9			
May 6	03 04 28.8			36 38.7	121 21.0					3.7			33 #2	
May 7	07 07 48.0		07 07 45.1	36 51.6	121 39.3			36.7	121.9	4.4		4.5 (Brk)	33 #2	269
May 22	22 41 04.8		22 41 02.9	37 16.3	122 19.1			37.1	122.8	4 6		4.5-5 (Brk)	33 #2	269
May 28		11 37 54.5				34 56.0	118 59.0				3.6			
June 7	12 04 42.2			37 58.5	122 02.9					3.9			33 #2	
July 16	18 17 54.6			36 51.9	121 36.8					3.6			33 #3	
July 26		07 33 51.5				34 02.3	117 19.4				3.6			
July 31	06 45 53.4			36 50.6	121 24.0					3.9			33 #3	
Aug 4	17 35 03.6			37 36.5	122 34.2					4.0			33 #3	
Aug 15			21 02 33.8					36.1	121.1			4.0		272
Aug 31	16 31 14.2		16 31 12.6	36 45.7	121 35.0			36.6	121.8	4.2		4.7	33 #3	272
Sept 14	19 46 17.0		19 46 17.6	36 52.0	121 38.3			36.9	121.6	5.4		5.4	33 #3	273
Sept 14	20 28 11.2			36 55.0	121 39.3					4.6			33 #3	
Sept 21	04 32 45.2			37 15.9	121 40.8					3.8			33 #3	
Sept 23		14 41 52.6				33 42.6	116 55.5				5.0			
Nov 29	20 49 36.0			36 47.6	121 35.8					3.6			33 #4	
Dec 10		22 26 11.4	22 26 10			34 09.9	116 44.3	34.1	116.7		3.7	4.8		276
1964														
Jan 30		11 50 34.8				34 11.0	116 49.3				3.5			
Feb 5		19 46 00.8	19 45 58.0			35 26.8	118 39.1	35.1	118.8		3.5	4.5		278
Feb 7		22 07 50.3	22 07 49.9			35 27.3	118 36.3	35.3	118.8		4.4	4.3		278
Feb 10		05 47 28.7				35 59.0	120 49.2				3.8			
May 6		16 54 04.9	16 54 02.0			35 27.7	118 38.9	35.1	118.8		3.9	4.6		281
May 13	12 18 37.2		12 18 34.8	36 32.9	121 09.7			36.4	121.2	4.0		4.4	34 #2	281
May 24		16 26 42.4				35 07.1	118 32.1				3.6			
Sept 1	19 49 16.5			36 52.2	121 41.1					3.8			34 #3	
Nov 8	01 19 19.0	01 19 18.0	01 19 17	36 00.0	120 00.1	35 57.5	120 02.0	35.8	120.2	4.0	4.0	4.4	34 #4	287
Nov 16	02 46 41.7		02 46 43	37 03.3	121 41.5			36.9	121.8	5.0		5.2	34 #4	287
Nov 17		14 52 28.2	14 52 26.5			33 53.9	116 34.1	33.8	116.5		4.0	4.5		287
Nov 23	09 05 08.0			37 02.4	121 42.9					3.5			34 #4	
Nov 30	21 16 18.2			36 52.2	121 42.2					3.7			34 #4	
Dec 23		19 51 21.2				34 48.0	118 57.8				3.5			
1965														
Jan 1		07 41 32.9				34 07.4	117 31.4				3.9			
Jan 1		08 04 18.0	08 04 16.2			34 08.4	117 30.9	34.0	117.6		4.4	5.2		289
Jan 1	09 56 51.3			36 50.5	121 39.3					3.5			35 #1	
Feb 14		20 05 47.6				34 09.2	116 52.9				3.5			
Feb 19		17 46 28.1				34 10.5	117 28.2				3.5			
Feb 25		11 21 56.5				34 09.7	117 25.6				3.7			
Mar 28			02 32 21.4					36.2	120.4			4 5		291
April 11	05 41 56.6			36 30.6	121 09.0					3.5			35 #2	
April 15		20 08 33.3	20 08 31.8			34 07.9	117 25.6	34.1	117.5		4.5	5.1		292
June 23		16 17 18.3				34 58.8	119 03.4				3.8			
June 28	11 15 11.4		11 15 08.8	37 33.5	121 40.1			37.6	121.8	3.6		4.3	35 #2	294
July 16		07 46 22.4				34 29.1	118 31.2				4.0			
July 18	19 03 43.3			36 47.4	121 33.9					3.6			35 #3	
July 31	06 54 27.5			36 33.1	121 12.0					3.5			35 #3	
Aug 15		23 06 52.5				36 00	121 12.0				4.0			
Sept 10		14 55 15.7				34 21.9	117 37.3				3.5			
Sept 10	21 28 34.3		21 28 34.9	38 00.6	121 49.4			37.8	122.0	4.9		4.9	35 #3	297
Sept 14	09 09 24.2			36 37.7	121 21.6					4.0			35 #3	
Sept 19		15 42 07.8				35 59.2	120 02.3				4.8			
Sept 20	01 15 47.5			37 47.6	122 11.1					3.5			35 #3	
Oct 10		23 23 12.4				34 07.6	117 27.4				3.7			
Oct 17		09 45 19.0				33 58.5	116 46.5				4.9			
Oct 17		15 36 52.8				33 59.7	116 48.4				3.9			
Oct 19		21 33 13.7				33 56.4	116 52.5				3.7			
Oct 20		01 16 43.8				33 58.6	116 45.7				3.5			
Oct 21		08 43 02.4				33 58.7	116 45.5				3.6			
Oct 31		21 56 15.8				34 13.3	117 22.9				3.5			
Dec 3		07 34 59.3				35 19.3	118 29.4				3.6			
Dec 3			22 49 50.9					34.2	117.1			4.3		PDE
1966														
Jan 22		02 19 46.9				34 12.7	116 29.4				3.5			
Jan 28		01 49 49.4				35 50.3	120 09.8				3.5			
April 18		09 21 20.1				33 59.8	116 39.2				3.5			
April 29	08 09 27.2		08 09 27	36 37	121 15			36.6	121.3	3.8		4.5	36 #2	PDE
May 13	17 25 55.9		17 25 56	36 55	121 34			36.9	121.6	4.5		4.6	36 #2	PDE
June 28	01 00 31.5	01 00 33.8		35 56.9	120 30.7	35 50.0	120 15.2			3.1	3.5		36 #2	
June 28	04 08 56.2	04 08 57.7	04 08 54.7	35 57.6	120 30.3	35 46.6	120 17.6	35.8	120.6	5.1	4.7	5.0	36 #2	PDE
June 28	04 26 13.4	04 26 13.6	04 26 12	35 57.3	120 29.9	34 54.9	120 32.0	35.9	120.5	5.5	5.6	5.3	36 #2	PDE
June 28	04 32 50	04 32 48.0	04 32 48	Not Given		35 48.9	120 16.8	35 48.9	120 16.8(P	3.5	4.0	4.0	36 #2	130
June 28	04 34 59.1	04 35 22.0		35 49.3	120 23.5	35 42.3	120 20.1			3.0	4.1		36 #2	
June 28	04 39 08	04 39 07.4		Not Given		35 51.7	120 15.2			3.0	3.5		36 #2	
June 28	05 00 59.5	05 01 03.1		35 50.6	120 23.5	35 50.6	120 14.7			3.1	3.6		36 #2	
June 28	05 45 59.1	05 46 01.3		35 44.7	120 19.5	35 52.6	120 15.7			3.2	3.7		36 #2	
June 28	06 32 17.9	06 32 18.3		35 56.2	120 31.0	35 51.1	120 24.2			3.4	3.8		36 #2	
June 29	02 19 39.9	02 19 43.8		35 54.6	120 31.3	35 44.8	120 05.4			3.6	4.1		36 #2	
June 29	13 11 59.7	13 11 58.7		35 48.7	120 22.9	35 51.8	120 19.7			3.1	3.8		36 #2	
June 29	19 53 25.9	19 53 29.5	19 53 24	35 56.6	120 31.5	35 46.9	120 04.0	35.8	120.5	5.0	4.8	4.9	36 #2	PDE
June 30	01 17 36.1	01 17 37.8		35 51.9	120 26.9	35 48.2	120 10.8			4.1	4.3		36 #2	
July 1		09 41 20.6				35 58.6	120 25.2				3.7			
July 2		12 08 33.5				35 54.9	120 18.1				3.6			
Aug 3		12 39 04.3				35 45.8	120 29.3				3.9			
Aug 7		17 03 24.1				35 54.4	120 28.3				3.5			
Aug 19		22 51 20.5				35 49.1	120 21.1				3.5			
Sept 2		11 06 29.9				34 06.8	117 25.5				3.7			
Oct 10			06 53 46					36.6	121.2			4.5		PDE
Oct 14			20 34 29					37.0	121.7			4.6		PDE
Oct 27		12 06 01.3	12 06 01			35 56.9	120 41.4	35.8	120.6		4.2	4.3		PDE