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DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

SUMMARIES OF TECHNICAL REPORTS, VOLUME XI

Prepared by Participants in

NATIONAL EARTHQUAKE HAZARDS REDUCTION PROGRAM

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The research results described in the following summaries were submitted by the investigators on October 31, 1980 and cover the 6-month period from April 1, 1980 through September 30, 1980. These reports include both work performed under contracts administered by the Geological Survey and work by members of the Geological Survey. The report summaries are grouped into the four major elements of the National Earthquake Hazards Reduction Program:

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Open File Report No. 81-167

The data and interpretations in these progress reports may be reevaluated by the investigators upon completion of the research. Readers who wish to cite findings described herein should confirm their accuracy with the author.

CONTENTS

Earthquake Hazards Reduction Program

Seismicity and Related Data for Hazard Analysis

9950-02145

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Investigations

1. Work continues on review of the entire U.S. earthquake catalogue for larger events (I>V) and revision and (or) preparation of isoseismal maps. Work on this project has been coordinated with and supported a project in the Branch of Global Seismology aimed at the preparation of seismicity maps. for all 50 states.

2. Attention has been focused on a careful investigation of the distribution of intensity for larger earthquakes of the United States (I_o>VI) with the aim of: (a) developing attenuation relations for each area; and (b) identifying areas of anomalously high or low intensity attenuation.

3. A field investigation of the effects of the northern Kentucky earthquake of July 27, 1980 was undertaken and an open-file report is currently in preparation.

Results

1. In cooperation with Project 9920-01222 in the Branch of Global Seismology, five additional state seismicity maps have been issued as MF maps (Wisconsin, Michigan, North Carolina, South Carolina, West Virginia).

Technical review of a USGS open-file report "An Evaluation of the Effects of the January 5, 1843, Memphis, Tennessee Earthquake" is complete and awaits Director's approval.

2. Currently, isoseismal maps for large earthquakes in the Western United States are being digitized for analysis.

3. A field investigation of the northern Kentucky earthquake of July 27, 1980.

Reports

Hopper, M. G., and Algermissen, S. T., 1980, An evaluation of the effects of the October 31, 1895, Charleston, Missouri earthquake: USGS Open-file Report 80-778.

Hopper, M. G., 1980, Potential for liquefaction, slumping and landsliding in the Puget Sound, Washington area, USGS Open-file Report 80-

Stover, C., Reagor, G., and Algermissen, S. T., 1980, Seismicity maps of the State of Michigan, U.S. Geological Survey, MG-1228.

Stover, C., Reagor, G., and Algermissen, S. T., 1980, Seismicity maps of the State of North Carolina, U.S. Geological Survey, MF-1224.

Stover, C., Reagor, G., and Algermissen, S. T., 1980, Seismicity maps of the State of South Carolina, U.S. Geological Survey, MF-1225.

Stover, C., Reagor, G., and Algermissen, S. T., 1980, Seismicity maps of the State of West Virginia, U.S. Geological Survey, MF-1226.

Stover, C., Reagor, G., and Algermissen, S. T., 1980, Seismicity maps of the State of Wisconsin, U.S. Geological Survey, MF-1229.

Southern California Seismic Arrays

Contract No. 14-08-0001-16719

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This semi-annual report summary covers the six-month period from 1 April 1980 to 30 September 1980. The contract's purpose is the partial support of the seismological arrays of the joint USGS-Caltech SCARLET (Southern California Array for Research on Local Earthquakes and Teleseisms), which is also supported by other groups, as well as by direct USGS funding through its own employees at Caltech. According to the contract, the primary visible product will be a joint USGS-Caltech catalog of earthquakes in the Southern California region, to be issued on a yearly basis, although quarterly epicenter maps and preliminary catalogs are also required. Figure 1 shows the epicenters of all shocks of M = 3.0 and greater that occurred during the reporting period, in addition to a number of smaller events in some parts of the region. Complete data analysis is still underway.

Some of the seismic highlights in the southern California-region during the six-month reporting period are as follows:

Estimated total number of earthquakes to be located: 8,000
Number of earthquakes of M = 3.0 and greater: 950 (89 non-Mammoth)
Number of earthquakes of M = 4.0 and greater: 102 (8 non-Mammoth)
Number of earthquakes of M = 5.0 and greater: 13 (1 non-Mammoth)
Number of earthquakes of M = 6.0 and greater: 4 (1 non-Mammoth)
Number of earthquakes for which systematic telephone notifications made: 21
Largest earthquake: m = 6.5 (5-25-80, near Mammoth)
Smallest earthquake reported felt: 1.9 (5-4-80, near corner of Huntington Drive and Main Street, Alhambra)

Certainly the major seismic event during the reporting period was the earthquake swarm near Mammoth, punctuated by 3 shocks of magnitude 6.0 and greater, and continuing to the time of writing. Earlier high seismic activity in the same area was noted in the previous 6-month report. These shocks occurred over a relatively wide area along the southern side of Long Valley (Fig. 1), and detailed studies using portable instruments clearly indicate that they did not all occur along a single fault. Although minor surface displacement was discovered by field crews from Caltech and other organizations along the Hilton Creek fault, much of the activity took place farther west -- closer to Convict and Laurel Lakes. Caltech field crews took three portable seismographs into the area immediately following the largest shock, as well as helping the USGS and other groups with the deployment of their instruments. Final epicentral locations will depend on data gathered by the USGS-Caltech, Berkeley, and Nevada networks, together with data added by the California Division of Mines and Geology.

The fourth damaging earthquake during the reporting period was a M = 6.1 shock on 6-9-80 near Victoria, Baja Califonia, Mexico. Although the epicenter was almost directly on the trace of the Cerro Prieto fault, field studies by Kerry Sieh of Caltech, working together with Mexican geologists, surprisingly failed to reveal any evidence of surface displacements along the fault.

The one other area of high activity during the reporting period was in the Huntoon Valley area along the California-Nevada border east Mono Lake. This swarm activity is continuing vigorously at the time of this writing, the largest shock to date having been a M = 5.7 event on 9-7-80. Although closely related in time and general geological environment to the nearby Mammoth events, the Huntoon Valley swarm is geographically distinct (Fig. 1). This area is, of course, on the very edge of our network, and better locations should be forthcoming from the Nevada network.

The past year has clearly been a period of remarkably high seismicity in the southern California region. Whereas an earthquake of M = 6.0 or greater has occurred on the average of once every 2-1/2 years over the past 50 years, 5 such events have occurred within the past year alone -- 4 of these during the present 6-month reporting period.

No new stations were added to the array during the reporting period, although one CIT station (CAMP ELLIOTT) was permanently lost due to continuing vandalism; a new site is now being developed. On the other hand, a number of new signals from stations of other networks were added to the CEDAR recording system during the period, primarily to aid in locating earthquakes near the northern boundary of our network area. These stations include PRIEST, JAMESTOWN, and FRIANT (all from Berkeley), OROVILLE (from the Calif. DWR), BOUNDARY PEAK (from Nevada), and NASA MOUNTAIN, MONTEZUMA PEAK. GOLD MOUNTAIN, LAST CHANCE RANGE, MAGRUDER MOUNTAIN, SILVER PEAK, and PIPER MOUNTAIN (all from the USGS Nevada network).

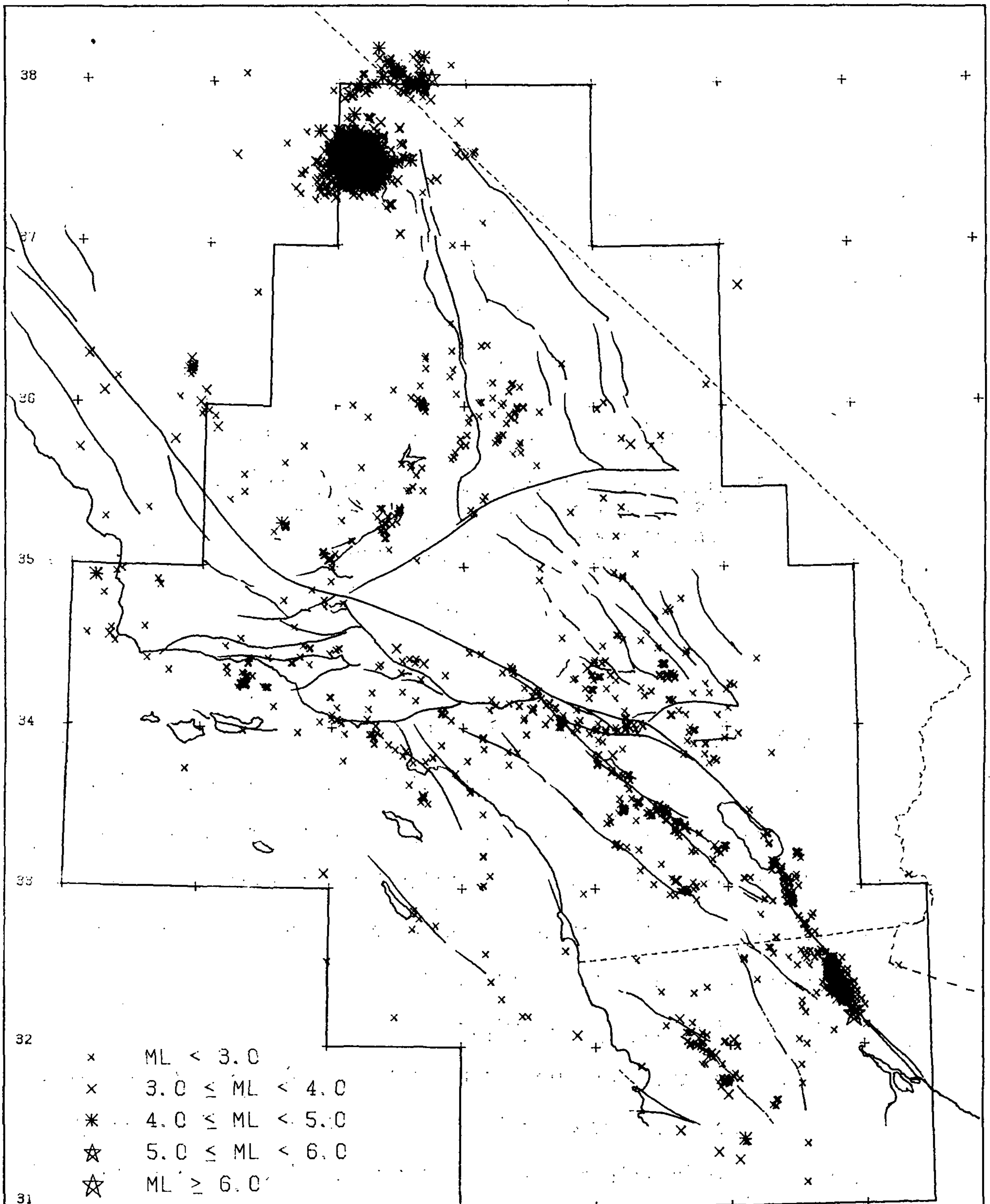

Figure 1.--Epicenters of earthquakes in the southern California region, 1 April 1980 to 30 September 1980. Data should be complete for M = 3.0 and larger events.

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

CONTRACT #14-08-0001-18216

by

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I. Northern Baja Seismic Array (RESNOR)

Winter rains and an extended delay in some equipment deliveries have prevented installation of the telemetering seismic array. A key radio link is yet to be delivered. Sites have been chosen, bases are being prepared and stations can be installed as soon as roads are repaired and all equipment is delivered.

II. Studies of Historical Seismicity

The relocation of historic Northern Baja California earthquakes $M \geq 6.0$, has been completed. S-P times from Southern California and Tucson were used to relocate the twelve events, which occurred since 1927. Six of the original Caltech locations were substantiated. For the remaining six, sufficient data exists to warrant moving the epicenters from 10 to 90 km. Three of these now lie most probably on the San Miguel Fault. These include the two events from the 1954 sequence previously located on the Agua Blanca Fault. These studies will be continued to lower magnitude and to estimate rupture lengths of the larger events so that seismic gaps can be identified.

III. The Mexicali Earthquake of 15 Oct 1979

Digital and smoked-paper drum recorders were installed in the aftershock region of the 15 Oct 1979 Mexicali earthquake within six hours of the main event. First stations were set up south of the border, along the Imperial Fault, to insure epicentral control for aftershocks occurring there. Recording continued for approximately one month. CICESE is handling most of the data processing, concentrating first on those events which occurred in Mexico.

IV. Laguna Salada Earthquake Swarm

The Laguna Salada earthquake swarm occurred during late 1975 and through the first half of 1976. Over 100 events for which local Mexican data is available have been relocated. The epicenters suggest a diffuse zone trending north toward the 1934 (M_L = 6.5) epicenter. Fault plane solutions from Southern California data suggest both strike-slip and normal faulting events occurred. Surface waves of the larger events are being examined to check those mechanisms.

The Laguna Salada region has been interpreted as a graben, based on aeromagnetic and gravity data. The seismicity data suggests that it is still actively spreading, with earthquake sequences much like those which occur in the nearby Imperial Valley. The regional historic seismicity will be examined to determine the relative levels of seismicity in the two regions. This would have some bearing on the seismic hazards along the Elsinore Fault system, the extension to the northwest of the Laguna Salada eastern boundary.

V. Continuation of Research

Research under this contract will continue under USGS Contract 14-08-0001-19163. We hope to have the array installed this summer. In the meantime, we will continue operation of the portable stations and will continue studies of the historic seismicity and current larger earthquakes.

Reanalysis of Instrumentally-Recorded U.S. Earthquakes

9920-01901

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Investigations

1. Relocate instrumentally-recorded U.S. earthquakes using the method of joint hypocenter determination (JHD) or the master event method, using subsidiary phases (Pg, S, Lg) in addition to first-arriving P-waves, using regional travel-time tables, and expressing the uncertainty of the computed hypocenter in terms of confidence ellipsoids on the hypocentral coordinates.

2. Evaluate the implications of the revised epicenters on regional tectonics and seismic risk.

Results

These results cover the researches of J. Dewey and D. Gordon on U.S. seismicity east of 105°W.

(1) We have compared our reviewed hypocenters with results from regional microearthquake networks that were installed in the 1970's in eastern North America. In some regions, such as the regions near Attica, New York, Giles County, Virginia, and Charleston, South Carolina, our hypocenters of pre-network earthquakes occur at or very near the same locations as small shocks recorded by the microearthquake networks. In the region of La Malbaie, Quebec, our locations support Stevens' (1980, Bull. Seism. Soc. Am.) result that the largest instrumentally recorded earthquakes have occurred near one end of the microearthquake zone defined by a local network. In much of New England and northeast New York there is not a strong correlation between pre-network hypocenters and recent network-recorded hypocenters. For example, the epicentral regions of the New York earthquake of 1931.04.20, the New Hampshire earthquake of 1940.12.20 and 1940.12.24 and the Maine-Quebec-New Hampshire earthquake of 1973.06.15 have not yet been distinguished by clusters of intense activity on maps of epicenters located by the regional networks.

(2) Although individual focal depths are not precisely determined, the focal depths of seventy percent of the most reliably determined of the recomputed hypocenters lie in the upper 10 kilometers of the Earth's crust, suggesting that the typical small regionally recorded earthquake in eastern North America has a very shallow focal depth. We view this observation as support for the suggestion of Sbar and Sykes (1977, Jour. Geophys. Res.) that occurrence of shocks

deeper than 10 kilometers in eastern North America is somewhat unusual and may indicate the presence of deep fractures capable of producing large earthquakes.

(3) In some regions (La Malbaie, Quebec; Blue Mountain Lake, New York; Attica, New York; Anna, Ohio; Giles County, Virginia; Charleston, South Carolina) regionally recorded earthquakes clustered in source zones of tens of kilometers or less in extent that were active for periods longer than a year. On the other hand, 46 percent of all studied earthquakes did not occur in such persistent source zones but occurred as essentially isolated events, having been farther than 20 kilometers from any other regionally recorded event in the period from 1925 through 1976.

(4) Preliminary JHD-computer runs have been completed for approximately 150 instrumentally-recorded earthquakes in the central United States (85°W to 105°W).

Reports

Herrmann, R. B., Dewey, J. W., Park, S-K, 1980, the Dulce, New Mexico earthquake of January 23, 1966, Bull. Seism. Soc. Am. (in press).

Dewey, J. W., and Gordon, D. W., 1980 (abstract), Instrumental seismicity of the eastern United States and adjacent Canada, approved by the Director for presentation at the meeting of the Eastern Section of the Seismological Society of America, University Park, PA, October 28-30, 1980.

STRONG GROUND MOTIONS IN TWO SEISMIC GAPS: SHUMAGIN ISLANDS, ALASKA AND NORTHERN LESSER ANTILLES, CARIBBEAN

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The objectives of this project are the instrumentation of two major seismic gaps with a sufficient minimum number of seismic strong-motion accelerographs to obtain good strong-motion coverage from future great earthquakes in these gaps and from any incidental moderate to large earthquakes nearby. To date a total of ten strong motion recording sites are operated by Lamont-Doherty Geological Observatory in the Shumagin Gap region of the eastern Aleutian arc, Alaska; of these, six sites were newly established in 1980. Tigger signals from five remote sites in the Shumagin gap are interfaced with the Shumagin seismic network and centrally recorded at Sand Point for accurate determination of accelerograph trigger times. A magnitude 5.3 earthquake near Nagai Island occurred in late August 1980, only three weeks after installation of the new Shumagin Islands strong motion accelerographs. The central trigger monitor at Sand Point indicate that strong motion instruments at apparently four sites were triggered by this event. Retrieval of the strong motion records from these remote sites is not feasible until the field season in summer 1981.

Only three preexisting strong-motion instruments are presently operated in the Caribbean. Additional strong-motion sites, all of which will be interfaced with the L-DGO-operated Caribbean seismic network (for transmission of trigger signals) will be established early in 1981.

PROJECT TITLE: A Study of Earthquake Prediction and the Tectonics of the Northeastern Caribbean: A Continuing Experiment in Two Major Seismic Gaps

CONTRACT NUMBER: USGS-14-08-0001-16748

PRINCIPAL INVESTIGATORS: A.L. Kafka, W.R. McCann, L.R. Sykes

INSTITUTION: The Trustees of Columbia University in the City of New York

TELEPHONE NUMBER: 914-359-2900

Status of the Seismic Network

The network continues in good working order. The Digital Event Recording System is operational and running well.

Significant Observations from On-Going Research

Focal mechanisms in the northeastern portion of the Caribbean plate can be explained easily in terms of plate tectonics. Low-angle thrust events indicate convergence between the North American and Caribbean plates in a N70E direction. Normal faulting events occur both seaward of the trench and within the Caribbean plate itself. Analysis of one shallow (h = 15 km) and one deeper (h = 50 km) in the region north of the Virgin Islands is underway.

The clustered pattern of seismicity for the last 25 years appears to be related to the subduction of a fracture zone with more than 1 km of relief. Magnetic, morphologic and seismic data all indicate major disruption of regional tectonic features where this ridge interacts with the subduction process. A catalog of precisely located events of $m_b \geq 3.0$ will help to underscore the significance of the data collected using other geophysical means.

A first approximation of the structure of the subducted North American plate has been obtained. To determine the relationship between the upper envelope of the seismicity and the upper surface of the subducted plate a detailed analysis of shocks in 1979 is underway. This study will attempt to determine composite focal mechanisms and explain the presence of secondary arrivals as converted phases.

Digital seismograms are being used to study source parameters of earthquakes and the attenuation of seismic radiation. Static stress drops of shocks occurring in the Virgin Islands basin varied by an order of magnitude (from 0.2 to 2 bars) although the events all occurred within 1 km of each other; stress drops increased systematically with the seismic moments. Q for P-waves is estimated to be 390 ± 30 and for S-waves 670 ± 70.

A Field Study of Earthquake Prediction Methods in the Central Aleutian Islands

14-08-0001-16716

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Investigations and Results

Detailed monitoring of the seismicity within the seismic zone covered by the Adak network continues to be the main routine task under this project. Standard procedures are now developed for rapid location of all detectable local earthquakes, the level of detectability depending primarily on the weather conditions. Various analyses show that the catalogue of Adak earthquakes compiled since August, 1974 is complete down to coda-duration magnitude of 2.2. The association of the spatial distribution of the small to moderate earthquakes with the tectonic features of the island-arc - subduction zone system is now reasonably well-defined, but the question remains of the interrelation of the small active seismic source regions during a large event.

Temporal variations in the patterns of occurrence of small earthquakes and premonitory changes in the orientation of their focal mechanisms appear to be the most promising indicators of the approach of a larger event. In order to monitor the former, monthly maps of the seismicity and plots of the cumulative number of earthquakes in each sub-region are now being prepared as standard products of the analysis procedure. The earthquake counts are also displayed for various magnitude bands, because changes within limited ranges of magnitude, equivalent to changes in "b-value," have been seen to be diagnostic of an impending earthquake in some other studies.

Two independent approaches to determining focal mechanisms of the small earthquakes, in spite of the limitations imposed by the inadequate azimuthal coverage of the observations imposed by the geography of the region, have been developed and applied. One of these compares the observed first motion polarities with all of the mathematically possible combinations that could be produced by the 13 stations of the network and objectively classifies the set (usually containing fewer than 13 observations) for each earthquake. The results to date have produced mechanism types that are physically, as well as mathematically, possible and show changes in time of the predominant orientation of the fault planes, even though reliable focal mechanism solutions cannot be derived from the observations. The other method uses the distribution of SV to P wave amplitude ratios at stations of the network as input to a procedure for solving fault strike, dip and slip direction. This technique shows promise of providing more focal mechanism solutions from the data, now that digital seismograms are available for amplitude analysis.

Observations of gravity have now been made twice at all of the seismograph station locations, as well as at a net of points on Adak Island. These are spaced one year apart, tied to the annual major maintenance trip, and will be repeated in the future. More-frequently spaced observations are very desirable for detecting secular elevation changes, but are not feasible under the current mode of operation.

The tiltmeters in the Adak network are working well, with their stability improved by better installations. Recent results show slow tilt changes on two adjacent instruments that track very well over many months. The possible tectonic significance of these tilts is not yet known.

Technical Advances

Slow but steady progress has been made toward the conversion of the seismogram analysis to a fully automatic system using digital data and the PDP 11/70 computer. Analogue FM tapes from Adak are played back at four times the original recording speed through a system designed and built by the project, events are automatically detected and a digital seismogram tape written for use in further analysis. This first part of the procedure is carried out on the PDP 11/34. The digital tapes are then used as input to the PDP 11/70. Events detected are displayed and non-earthquakes are discarded. Using software developed at the University of Washington, the operator can then read the times of arrival of phases from CRT display and a location for the event is rapidly calculated. This entire analysis capability came on-line only at the end of the contract period.

The principal remaining problem is with the use of the event detecting algorithm. Work is in progress to insure that all readable events are picked for storage on the digital event tapes, with the number of non-seismic triggers reduced to a minimum.

Reports

Kisslinger, C., The application of body-wave amplitude ratios from local network seismograms to prediction studies, presented at the Ewing Symposium on Earthquake Prediction, New Paltz, New York, 1980.

Billington, S., and E.R. Engdahl, Changes in the seismicity and focal mechanism of small earthquakes prior to an M_s 6.7 earthquake in the central Aleutians, (abstr.) EOS, 61, 293, 1980.

Kisslinger, C., Evaluation of S to P amplitude ratios for determining focal mechanisms from regional network observations, Bull. Seism. Soc. Amer., 70, 999-1014, 1980.

Kisslinger, C., and K.-P. Bonjer, Wann, Wo und wie stark? Probleme und Moglichkeiten der Erdbebenvorhersage, Umschau in Wissenschaft und Technik, 80, 425-431, 1980.

Harrison, J.C., J.M. DeMay, and C. Meertens, Tiltmeter results from Adak, in Proceedings of the Int. Wrkshp. on Monitoring Crustal Dynamics in Earthquake Zones (A. Vogel, editor), Friedr. Vieweg & Sohn, Braunschweig, 1980.

Billington, S., E.R. Engdahl, and S. Price, Changes in the seismicity and focal mechanism of small earthquakes prior to an M_s 6.7 earthquake in the central Aleutian island arc, submitted to the Fourth Ewing volume, 1980.

Microearthquake Data Analysis

9930-01173

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Investigations

1. The primary focus of this project is the development of state-of-the-art computation methods for analysis of data from microearthquake networks.

2. The principal effort during the past six months has been devoted to a) completing the review paper "Principles and applications of microearthquake networks" by W. H. K. Lee and S. W. Stewart, and b) organizing a workshop on the Coyote Lake earthquake of August 6, 1979.

Results

1. The review paper "Principles and applications of microearthquake networks" by Lee and Stewart was completed (450 manuscript pages). It will appear in the Advances in Geophysics Series, published by the Academic Press, New York, in 1981.

2. In July, some 70 scientists from 16 U.S. and foreign institutions participated in a one-month-long workshop on the Coyote Lake earthquake. An integrated seismic study, headed by K. Aki of M.I.T., is underway to systematically investigate the Coyote Lake earthquake sequence. A detailed survey of the crustal structure beneath Coyote Lake area has been planned (headed by Walter Mooney of USGS), and a short explosion profile across the Gilroy-Hollister valley has been made. In addition to these two multiperson investigations, several other individual studies on various aspects of the Coyote Lake earthquake are underway.

Seismic Data Library of WWSSN Seismograms

9930-01501

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This is a nonresearch project, and its main objective is to keep the WWSSN seismograms up to date and properly filed. Everything is now up to date.

Earthquake and Seismicity Research Using SCARLET and CEDAR

Contract No. 14-08-0001-18331

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Research along four main lines of investigation was accomplished during this contract period. These are 1) a study of applicability of the UC diagram analysis technique to Lg waves, 2) an application to Lg recorded on SCARLET through CEDAR, 3) a theoretical analysis of dispersion and attenuation due to multiple scattering, and 4) an analysis of P_n velocity anisotropy in Southern California.

1. Rayleigh-type Lg propagating in a laterally homogeneous continental crust can be synthesized by adding only a few overtones at periods greater than 2 seconds. We have shown that wave number analysis of Lg recorded on a several hundred kilometers long linear array of 10 stations should allow us to isolate the different overtones, providing a tool to study both crustal structure and excitation of the overtones at the source. As an example, we have applied a stacking algorithm (UC-diagram technique) to two sets of synthetic Lg computed (1) for a simple one layer continental crust, and (2) for a realistic crustal model of southern California.

2. The UC diagram technique described in 1. was applied to Lg phases recorded through the CEDAR system in Southern California. A clear image of the signal is obtained in time-frequency-wavenumber space, and we discuss in particular observations at 2.5 sec period, for events 200-300 km outside the profiles. The corresponding phase velocity dispersion curves are compared on Figure 1 with theoretical curves from the crustal model of Hadley and Kanamori (1979). From the gross features of UC diagrams we conclude that a representation of Lg as a single coherent multimode wavetrain propagating across southern Califonia is oversimplified. For example, peaks observed at group velocities smaller than 3.2 km/sec are not predicted by realistic crustal models of the area, and are probably due to lateral heterogeneities. On the other hand, for group velocities between 3.2

and 3.6 km/sec, observed peaks can generally be interpreted in terms of overtones excited at the source and propagating through a spatially averaged structure, although care must be taken to monitor the stability of the algorithm on actual short period records. A numerical experiment with synthetic Lg signals, involving random as well as coherent phase fluctuations along a typical profile shows that the technique yields stable estimates of spatially averaged phase velocities when 1) random phase perturbations are spread over less than half a cycle, and 2) coherent phase velocity changes over half of the profile are less than 5% at 2.5 sec period. The degree of stability of our observations shows that these conditions are nearly, if not clearly satisfied in this study.

3. The propagation of elastic waves in a medium containing many inclusions is considered. Under the assumption that the spatial distribution of inclusions is uniform, a general equation is derived for the determination of velocity dispersion and attenuation coefficient of the effective waves. A simple example is presented where scatterers are infinitesimally thin cracks. The calculated results show that the attenuation coefficient Q^{-1} takes a peak value for the wavelength nearly equal to twice the crack length.

4. We isolated a 22 station, 150 km aperture subarray of the SCARLET network to investigate the apparent velocity of P_n as a function of azimuth near the central Transverse Ranges, southern California. We analzed signals from 78 earthquakes and explosions, with epicentral distances ranging from 150 km to 400 km, overing all azimuths but a 40^o gap from the SW and a smaller gap from the NE direction. For each source, the P_n apparent velocity was estimated by fitting a cone to the arrival times using a One-Norm measure of misfit.

The apparent P_n velocity does not show any systematic variation with epicentral distance, but exhibits a strong azimuthal dependence. Observations cannot be satisfactorily explained by simple moho dip alone, nor by transverse anisotropy of upper mantle material alone. The smoothed data (running average with a 20^o azimuth window) are well approximated by an excentered elipse. We obtained a good fit to the data with a moho dip of 2^o to 2.5^o in the N 38 W direction, coupled with a 3 to 3.5% transverse anisotropy of subcrustal material (Figure 2). "True" P_n velocity is found to be 7.93 km/sec in the N 50 W direction and 7.65 km/sec in the perpendicular direction. In contrast, for a smaller data set in the eastern Mojave, we found a small westerly moho dip of about 1^o, and an azimuthally isotropic P_n velocity of 8.1 km/sec. The near coincidence of the fast direction of P_n propagation with the azimuth of relative plate motion near the San Andreas fault system appears to be consistent with shear-induced preferential orientation of upper mantle material near the plate boundary.

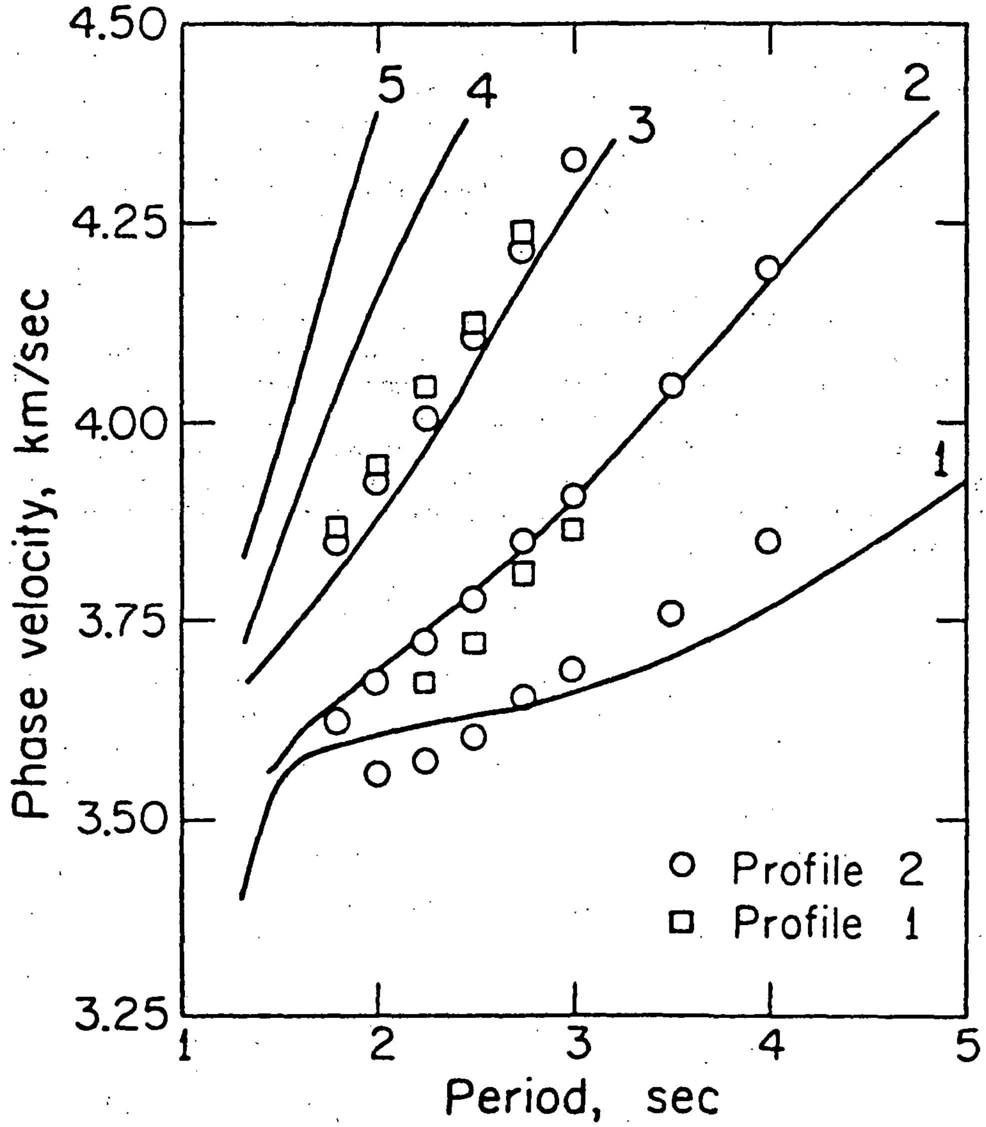
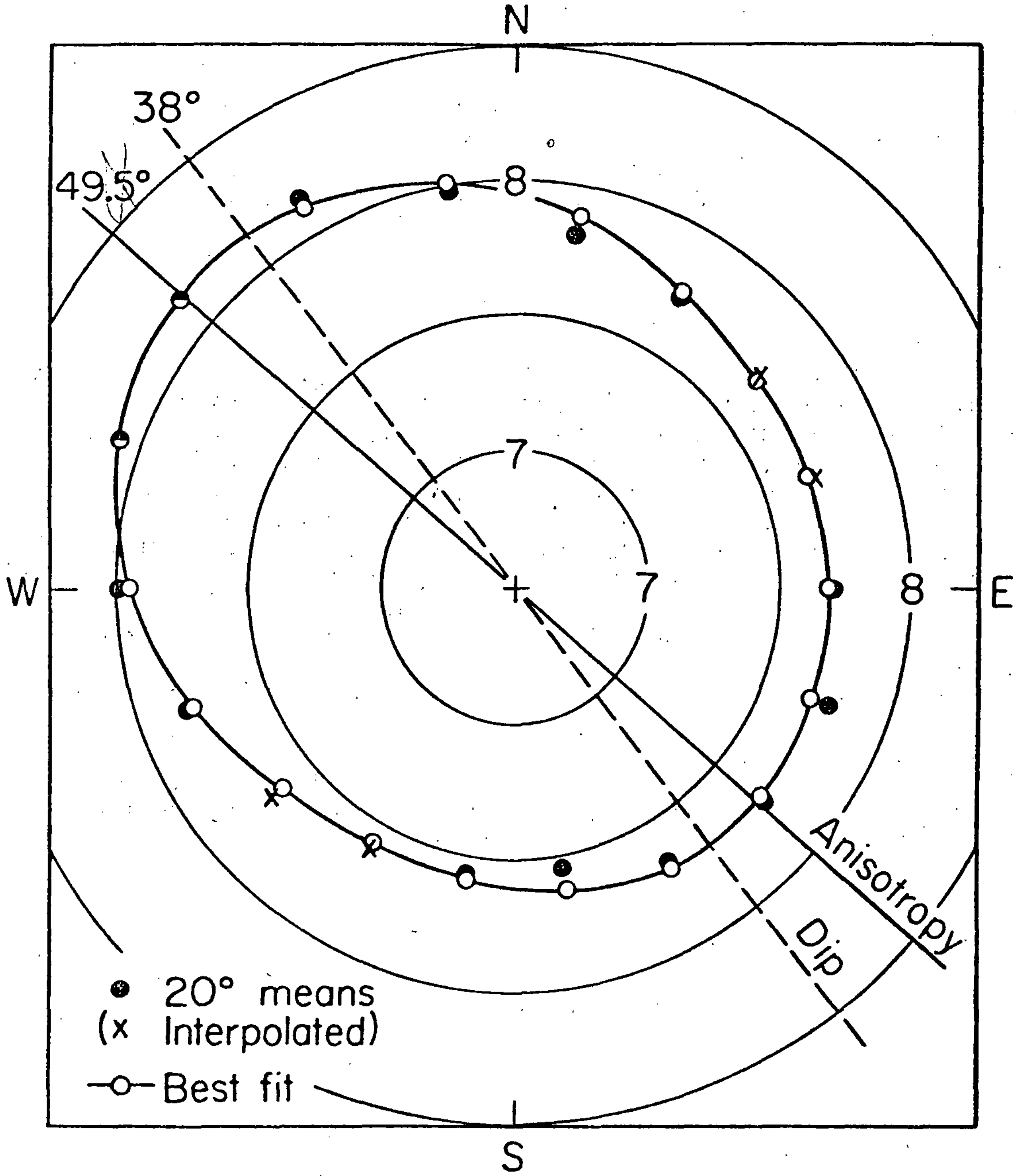

4.50
4.25
4.00
3.75
3.50
3.25
Phase velocity, km/sec
1
2
3
4
5
Period, sec
5
4
3
2
1
Profile 2
Profile 1

Figure 1


N
38°
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8
7
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Anisotropy
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● 20° means
(x Interpolated)
—o— Best fit
S

Figure 2

NDSN Design Studies

9920-02143

Jon Peterson
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Investigations

The objective of this project is to design a triaxial seismograph that will produce seismic data in the frequency band from .01 to 20 Hz and operate linearly over an amplitude range from ambient earth noise at a quiet site to an acceleration level of .1 g. Preliminary studies indicate that three types of seismometers will be needed: conventional short-period seismometers with flat velocity response from 1 to 10 Hz, broadband seismometers with flat velocity response from .05 to 5 Hz, and force-balance accelerometers that will accommodate high input amplitudes over the entire band. The dynamic range and linearity of the instruments chosen for this seismograph are the most important characteristics that must be tested. Two types of force-balance accelerometers are being tested and modified long-period seismometers are being tested as broadband instruments. A high-resolution digital recorder is being assembled. Investigations have been delayed by the long delivery times for instruments. However, all essential components are now on hand and assembly and testing are now underway.

Earthquake Research and Network Operations in the Intermountain Seismic Belt--Wasatch Front
14-08-0001-16725

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Investigations

1. Analyses of earthquakes recorded by the Wasatch Front seismic network.
2. Installation and implementation of the PDP-11/34, 11/70 computer systems for network recording and data processing.
3. Source parameters and seismic moment tensors of Utah earthquakes.
4. Earthquake prediction in the Intermountain seismic belt.
5. Flexure and normal faulting in an elastic-perfectly plastic plate and implications for seismicity along the Wasatch Front.

Results

1. Quarterly epicenter bulletins for the Wasatch Front study area for the period: April 1 - September 30, 1980, include 255 earthquakes ($M_L \leq 4.4$). Felt shocks occurred (1) near Elberta, Utah, on April 6 (M_L=3.8) and on May 24 (M_L=4.4, MMI = V-VI), and (2) near Logan, Utah, on August 15 (M_L=2.9) and on September 16 (M_L=2.9). The earthquakes near Elberta were located within 15 km of (but clearly removed from) the Wasatch fault, and they occurred within a 100 x 300-km-long anomalously quiet sector of the Intermountain seismic belt that had experienced only one mainshock larger than magnitude 3.5 since 1967 (see previous semi-annual summary).

2. During the period April 1 - September 30, 1980, final shipments of hardware were received for PDP-11/34 and 11/70 computer systems provided by the USGS for network operations and research. Major efforts were made to: (a) implement the UNIX operating system on the 11/70 and RSX-11M system software on the 11/34, (b) convert an initial 50 stations to on-line recording on the 11/34, (c) implement and debug trigger software, and (d) initiate routine data analysis procedures with the 11/70.

3. Spectral parameters were calculated for 19 of Utah's larger historical earthquakes. Estimates of stress drop (<20 bars) appear low compared to other intraplate earthquakes of similar magnitude ($3\frac{1}{2}<M_L<6\frac{1}{2}$), and apparent stresses for sampled earthquakes of M_L<4.5 are 6 to 10 times

*Final Tech. Report includes contributions from G. Zandt, W. D. Richins, D. Doser, T. J. Owens, and B. W. Hawley.

lower than published values for comparable intraplate shocks. Estimates of average fault displacement from moment calculations agree well with observed displacements on Holocene faults. Seismic moment tensors show an extensional strain component at N79°E and a near-vertical compressional strain of equal magnitude. The intermediate strain component is near-horizontal (N6°W) and compressional in northern Utah; in southern Utah it is also near-horizontal (N12°W) but extensional. Focal-mechanism differences in northern and southern Utah reflect this change.

4. A review paper of earthquake prediction efforts in the Intermountain seismic belt (see reference by Arabasz and Smith, below) summarizes important observations to date and assesses inherent problems for predicting moderate to large earthquakes in an intraplate setting with characteristics such as the ISB. Negative results from monitoring quarry blasts on a daily to weekly basis for temporal velocity variations contrast with more promising results involving space-time seismicity changes. Statistically significant changes in space-time patterns--both on a local and regional scale--have been documented in the Utah region. Best results to date relate to seismicity changes before the March 1975 Pocatello Valley earthquake (M_L=6.0). Significant problems for earthquake prediction in the ISB (apart from near-exclusive reliance on seismic observations) include: (a) a lack of understanding of the seismic cycle on a major normal faults and whether specific segments of active faults are in the initial or later stages of a long strain-accumulation cycle, (b) the uncertain importance of listric faulting as a seismogenic mechanism, and (c) uncertainties resulting from a relatively low seismic flux and short historical record.

5. A mathematical model of normal faulting in the lithosphere that consists of a thin plate supported by a fluid substratum has been developed to analyze the deformation and stress in the lithosphere that is associated with displacement on a normal fault. In this analysis the thin plate has an elastic-perfectly plastic rheology that allows no increase in stress in the plate beyond a specified yield value. When constrained by observed data in the Wasatch Front region, it is found that the lithospheric layer in the eastern Basin and Range has an effective mechanical thickness of about 20 km, a low elastic modulus of 0.8 to 1.5×10^{10} n/m^2 and a low yield strength of 1 to 2 kb, which is consistent with the existance of a thin, weak lithosphere in the region. The results indicate that the flexure associated with normal faulting could be important in evaluating the time-variation of seismicity in the region and should be incorporated into normal-faulting earthquake cycle studies.

Reports and Publications

Arabasz, W. J., Smith, R. B., and Richins, W. D., 1980, Earthquake studies along the Wasatch Front, Utah: Network monitoring, seismicity, and seismic hazards: Seismol. Soc. America Bull., v. 70, p. 1479-1499.

Smith, R. B., Zandt, G., and Gaiser, J. E., 1980, Temporal monitoring of seismic velocity along the Wasatch Front using quarry blasts: Seismol. Soc. America Bull., v. 70, p. 1527-1546.

Zandt, G., and Owens, T. J., 1980, Crustal flexure associated with normal faulting and implications for seismicity along the Wasatch Front, Utah: Seismol. Soc. America Bull., v. 70, p. 1501-1520.

Pavlis, T. L., Smith, R. B., 1980, Slip vectors of faults near Salt Lake City, Utah, from Quaternary displacements and seismicity: Seismol. Soc. America Bull., v. 70, p. 1521-1526.

Griscom, M., 1980, Space-time seismicity changes in the Utah region and an evaluation of local magnitude as the basis of a uniform earthquake caltalog: University of Utah, M.S. thesis, 134 p.

Doser, D. I., 1980, Earthquake recurrence rates from seismic moment rates in Utah: University of Utah, M.S. thesis, 164 p.

Owens, T. J., 1980, Flexure and normal faulting in lithospheric plates with application to the Wasatch Front, Utah: University of Utah, M.S. thesis, 64 p.

Arabasz, W. J., and Smith, R. B., 1980, Earthquake prediction in the Intermountain seismic belt--An intraplate extensional regime: submitted (Sept. 1980) for inclusion in Proceedings of the Third Maurice Ewing Symposium--Earthquake Prediction.

Hawley, B.W., Zandt, G., and Smith, R. B., 1980, Simultaneous inversion for hypocenters and lateral velocity variations: An iterative solution with a layered model: submitted (Oct. 1980) to Jour. Geophys. Research.

National Earthquake Catalog

9920-02648

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Investigations

1. Coordinate the preparation of a national earthquake catalog.

2. Collect earthquake event lists for the catalog and check them against original sources.

3. Investigate the relation between the size of large shallow earthquakes and the duration of their signals recorded on long-period seismograms of the World-Wide Standardized Seismograph Network.

4. Check the attenuation coefficient in the 1962 International Formula for the estimation of M_s magnitude.

Results

1. A plan prepared early in 1980 identifies four principal elements in the development and publication of the national earthquake catalog: data preparation, related research, data base development, and catalog preparation. The appointment of a data base administrator has been postponed for a year, but data preparation and research on earthquake parameters are progressing according to the plan.

The Bulletin of the Seismological Society of America is being searched for research papers on parameters of United States earthquakes. Indexing is more than half completed on this work. Other journals, reports and theses will be searched for useful data. Much of the current research on United States earthquakes is listed in the Summary of Technical Reports, Volume X, of the National Earthquake Hazards Reduction Program. Published data resulting from these researches will be screened for inclusion in the catalog.

2. W. H. K. Lee, A. C. Tarr and J. N. Taggart have collected many of the available magnetic tape listings of earthquakes. Over 5400 events on the NOAA/EDIS hypocenters tape for the United States, Puerto Rico, Guam and Samoa have been checked against original sources by two people working together. Less than 1% of much of this data is erroneous, except for the case of Hawaiian earthquakes where manual conversion of degrees and decimal minutes to decimal degrees resulted in about 25% erroneous values. Approximately 300 events per day can be checked in two one-hour sessions, which is about the maximum time during which high-level performance can be maintained. Because events commonly are listed in more than one source, it may be necessary to check as many as 75,000 separate listings.

3. Total durations of 16 large shallow earthquakes, for which focal mechanisms and seismic moments have been estimated, were measured on film or paper copies of long-period vertical seismograms from the World-Wide Standardized Seismograph Network. Duration time was measured where the amplitude of the ground motion at periods between 12 and 24 sec. decays below 1.0 micrometer. Between 40 and 75 observations in the epicentral distance range of about 5° to 170° are available for each earthquake. Additional data have been collected on durations from horizontal components, contamination from aftershocks and background noise at each station.

The durations are related to the size of the earthquakes, but azimuthal dependence is not evident. The data will be checked for distance dependence, path effects, significance of station terms and correlation with individual or combined source terms.

4. All observations of maximum 20-sec. Rayleigh wave ground motions have been extracted from Earthquake Data Reports for 1979. The mean value of the Log Distance attenuation coefficient will be estimated by least squares. If this coefficient departs significantly from the value of 1.66 used in the 1962 International Formula for the estimation of M_S magnitude, then observations for 1971-1978 will be extracted from ISC magnetic tapes, and included in the investigation.

Regional and National Seismic Hazard and Risk Assessment

9950-01207

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Investigations

1. Reassessed estimates of earthquake losses in the San Francisco Bay area and Los Angeles and Orange Counties, California.

2. Continued review of the seismotectonics and seismicity of various regions of the country through a series of meetings with geologists and seismologists from within and outside the Survey.

3. Continued investigation of relationship between average return periods obtained from analysis of historical seismicity data and return periods developed from field investigations of fault slip.

4. Continued development and computation of revised probabilistic national acceleration and velocity maps.

Results

1. Comprehensive reports on estimated losses to facilities critical to disaster preparedness and mitigation had been prepared for the San Francisco Bay area (1972) and the Los Angeles-Orange County area (1973). These reports were reviewed and reassessed as part of a larger Survey effort prepared for the Federal Emergency Management Agency (FEMA). Additional monetary loss estimates not considered in the original reports were also computed. The reassessment is being published as an open-file report.

2. A meeting was held on September 10 and 11 to review the seismotectonics and seismicity of the Northeastern United States. This meeting completes the series of discussions held over the past year for the purpose of increasing the utilization of seismotectonic data in the delineation of seismic source zones for probabilistic ground motion calculations.

3. A variety of techniques have been used to compute the parameters (a) and (b) in log N=a-bM relationship for various seismic source zones in the Western United States derived from seismotectonic considerations. In general, the magnitude distributions obtained from historical seismicity agree rather well with distributions obtained from geological field studies (fault scarp investigations) in the Basin and Range Province when the historical seismicity is averaged over rather large areas of Holocene faulting.

4. Acceleration and velocity maps are currently being prepared for the Western and Central portions of the country. In the West, maps are being prepared for those areas not previously considered in the offshore probabilistic ground motion mapping project already completed.

Reports

Perkins, D. M. Bender, B., and Shedlock, K., 1980, Rules of thumb relating to issues in probabilistic ground motion mapping: USGS, Open-file Report 80-

Algermissen, S. T., Thenhaus, P., and Askew, B., 1980, New probabilistic hazard maps for the United States--a progress report 80-

Algermissen, S. T., and Steinbrugge, K. V., 1980, Estimation of earthquake losses, USGS, Open-file Report 80-

Steinbrugge, K. V., Lagorio, H., and Algermissen, S. T., 1980, Earthquake insurance and microzoned geologic hazards: United States Practice, 8th World Conference, Earthquake Engineering, September, 1980

Steinbrugge, K. V., Shader, E. E., and Algermissen, S. T., 1980, Earthquake damage to mobile homes in California, California Geology, California Division of Mines, Vol. 33, No. 10, pp. 225-232.

Algermissen, S. T., 1980, Seismic risk, in McGraw-Hill Encyclopedia of Science and Technology, (in press).

Seismic Wave Attenuation in Conterminous United States

9950-01205

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Investigations

1. Data reduction and analysis of 136 events in the magnitude range of 2.0 to 6.4, recorded on short period instruments throughout the United States, for the Pg, Pn and Sn phases is in progress.

2. Continuation on the attenuation study of strong-ground motion displacements (cm) from 67 earthquakes recorded in the Western United States is in progress.

3. Data selection and tabulation of earthquakes recorded on Wood-Anderson instruments in the Western United States is in progress.

4. Data selection tabulation and analysis obtained from the control explosion Early Rise in Lake Superior, which was recorded on short period instruments, is in progress.

Results

1. The seismic moment, M_o, for the Imperial Valley earthquake of October 15, 1979, computed from the tabulated strong-motion data is 1.1 x 10^{26} dyne-cm. This value compares fairly well with the M_o determined for the 1940 Imperial Valley earthquake of 3.0 x 10^{26} dyne-cm (Hanks and others, 1975).

2. The local magnitude, M_L, determined using the maximum horizontal acceleration recorded at 30 U.S. Geological Survey and at 7 Mexican accelerograph stations is $(M_L) = 6.61 \pm 0.27$. This value is in excellent agreement with PAS Wood-Anderson M_L determination of 6.6.

3. The observed maximum horizontal ground accelerations from the October 15, 1979, Imperial Valley earthquake, are in fairly good agreement with the ground level accelerations, expected for a similar-size event, derived from the empirical attenuation law for the Western United States by Espinosa (1980a).

4. Eighty-one percent of the mean observed magnitude at each station, recording the 1979 Imperial Valley event, falls within a 60% variation of one magni-

tude unit of the mean attenuation curve (6.6 ± 0.3). Ninety-seven percent of the observed mean M_L's at each station falls within an 80% variation (6.6 ± 0.4). The comparison of the Imperial Valley earthquake of 1979 observed data (Espinosa, 1980b) with the empirical magnitude scaling law (M_L) derived by Espinosa (1980a) are in excellent agreement.

5. An empirical relationship correlating half of the peak-to-peak amplitude with the maximum horizontal particle velocity (cm/sec) and/or with the maximum horizontal acceleration (cm/sec^2) has been derived from the strong-motion accelerograms of the 63 most significant Western United States earthquakes (see Figure 1).

Reports

Espinosa, A. F., 1980, Attenuation of strong horizontal accelerations in the Western United States and their relation to M_L: Seismological Society of America Bulletin, v. 70, 583-616.

Espinosa, A. F., 1980b, M_L and M_0 determination from strong-motion accelerograms and expected intensity distribution--October 15, 1979 earthquake: U.S. Geological Survey Open-File Report 80-1094, 28-42.

Dwyer, J. J., Herrmann, R. B., and Nuttli, O. W., 1980, Numerical study of attenuation of high frequency Lg waves in the New Madrid Seismic Region: U.S. Geological Survey Open-File Report 80- , 1-131.

Espinosa, A. F., 1980c, Attenuation of strong-motion accelerations and velocities and their application to Earthquake Engineering: II Seminario Latino Americano de Ingenieria Sismo-Resistente, Lima, Peru, 1-32.

Espinosa, A. F., 1980d, Seismic Risk in Nicaragua, Central America: II Seminario Latino Americano de Ingenieria Sismo-Resistente, Lima, Peru.

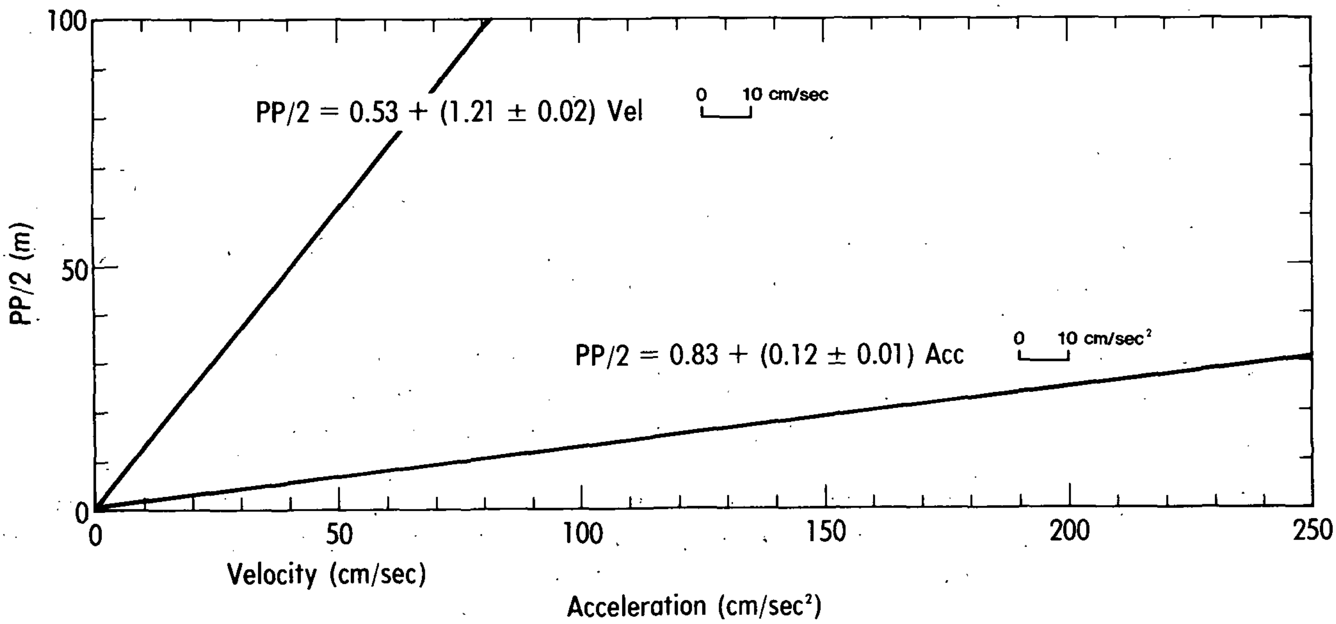

Figure 1.--One-half peak-to-peak amplitude (PP/2), on the Wood-Anderson seismogram (m) as a function of the maximum horizontal particle velocity (cm/sec) and/or horizontal acceleration (cm/sec^2). The data base used in this figure are listed in Kanamori and Jennings (1978), Espinosa (1979), Boore (1980), and, Espinosa (1980a, 1980c).

RESEARCH APPLICATIONS
9900-90027

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Investigations

1. The objective is to develop and to foster effective communication between producers of information in the USGS's Earthquake Hazards Reduction Program and users in Federal, State, and local governments, academic and private sectors.

Results

1. The Office of Earthquake Studies joined with FEMA and NSF to sponsor the 1980 Summer Institute on Multiprotection Design. The Institute presented a course on earthquake hazards to 30 University and College staff members during the week August 11-15 in Battle Creek, Michigan.

2. A conference on, "Evaluation of Regional Seismic Hazards and Risk" was attended by 35 scientists, engineers, and other disciplines in Santa Fe, New Mexico, August 25-27, 1980. The objective was to discuss the technical issues and the state-of-knowledge concerning the evaluation of seismic hazards and risk in various geographic regions of the U.S. The conference proceedings will be published.

Reports

1. Hays, W. W. (Editor), 1980, Earthquake Prediction Information, Proceedings of Conference XII, January 28-30, 1980, Los Angeles, Ca., U.S. Geological Survey Open-file Report 80-843, 328 p.

Seismogenic Zones of the United States

9950-01849

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Investigations

1. Conducted seismic source zoning meetings for the Central and Northeastern parts of the United States.

Results

1. Six non-Survey and eight Survey earth scientists participated in the zoning meeting for the Central United States. Nine zones were delimited for the region. The information and rationale for the zones were summarized in a report by Dave Russ and sent to the participants for any comments they cared to make. Russ has subsequently revised the report and zone map slightly.

Nine Survey and nine non-Survey earth scientists participated in the zoning meeting for the Northeastern United States, and Bill Diment is preparing a report of the results of the meeting. The region was zoned into nine parts.

The seismic zones for both the Central and Northeastern United States were delimited largely on the basis of historical seismicity, and a few geologic structures with which some seismicity is or appears to be assoiated. This basis of zonation is in contrast to that used for much of the Western United States where the zones were based largely on the age of Quaternary faulting and the relative homogeneity of ages of faulting.

It is too soon to evaluate the impact that the zones delimited at the five zoning meetings held in FY-80 will have on the final probabilistic ground-motion maps. Initial opinion is that significant changes in the distribution of ground-motion values may result locally from using both geology and seismicity rather than seismicity alone. The Nevada seismic zone, the Wasatch fault zone, and the buried rift zone in the New Madrid region may be examples of areas where the distribution of ground motion values may differ significantly from those shown on the 1976 ground-motion map.

Perhaps the chief value of the seismic source zone meetings has been that through an informal workshop format the knowledge of many of the best informed earth scientists in the country has been used to construct seismic source zone maps which are generally acceptable to most everyone.

Fault Scarp Morphology: Indicator of Paleoseismic Chronology

Contract Number 14-08-0001-19109

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Investigations

1. Profile fault scarps and fluvial terraces in the obsidian sand deposits south of Hebgen Lake Montana.

2. Collect materials with which to date the fault scarps and fluvial terraces.

3. Date the terraces and fault scarps by the morphologic dating technique outlined by Nash (1980).

Results:

1. Approximately 200 profiles were collected of four fault scarps and four fluvial terraces. The structure of the shear zone and the history of faulting as revealed in a trench across the fault scarp were more complex than anticipated.

2. No datable organic material was collected from the trenched fault scarps. Obsidian clasts were collected from the fault shear zone for obsidian hydration rim dating. A datable ash and log were discovered in a conical depression on the lowermost fluvial terrace along the Madison River.

3. Analysis of the fault and terrace profile data is in progress.

References:

Nash, D. B., 1980a, Morphologic dating of degraded normal fault scarps: Journal of Geology, v. 88, p. 353-360.

Neotectonic Synthesis of U.S.

9540-02191

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Investigations

1. The manuscript on an Atlantic Coast domain of northwest-southeast compression and resultant reverse faulting and earthquakes was carried through extensive review and author revision. It will be submitted for publication as part of the second USGS Professional Paper on the 1886 Charleston earthquake.

2. A manuscript on episodic subsidence of the Atlantic margin has been prepared, reviewed, and revised. The Atlantic-coast structure-contour maps have been submitted for technical review.

3. A study was carried out on the use of drainage-basin shape and channel-geometry parameters to assess tectonic uplift rates and relative uplift across possible faults using multivariate analysis of variance and linear discriminant analysis. The results are promising.

4. The eight research contracts on neotectonics were all extended for periods of 2 to 6 months, to permit the contractors to take advantage of unanticipated data sources and to assure the best possible products. The scope of the contract on the Ventura basin, California, was expanded to include horizontal as well as vertical deformation, with an additional cost of about $3,100.

5. The possibility of preparing computer-drawn digital terrain maps at 1:250,000 was explored, mapping parameters were selected, and a large suite of experimental maps was prepared for southern California and the Coast Ranges north into Oregon.

Results

1. Compression of the Atlantic Coast domain along the eastern seaboard is approximately northwest-southeast, perpendicular to the Appalachian orogen, the continental margin, and the Atlantic spreading axis. This implies a causal relation between the compression and something related to the margin. A further constraint is provided by evidence of decreasing rates of reverse faulting through time: for the Stafford fault zone in Virginia, from 2.4 m/m.y. in the Late Cretaceous to as little as 0.2 m/m.y. in the past 55 m.y., and for the Cooke fault in the 1886 Charleston meizoseismal area, from at least 1.7 m/m.y. in the Jurassic and Early Cretaceous to as little as 0.4 m/m.y. in the past 55 m.y. This decline, and the possibility that Cooke fault movement began soon after continental rifting, suggests an inverse relation between the rate of reverse faulting and the duration of Atlantic spreading.

2. The relatively low frequency of damaging earthquakes in the Atlantic Coast domain inferred from the historic record and reverse fault histories (10^{-5} per 1000 km^2 per year) and the long and, at least recently, complex sequence of

aftershocks from the 1886 Charleston earthquake suggest a long recovery time for the regional stress field following the strain release of large earthquakes. The 1886 Charleston earthquake probably resulted from northeast-trending reverse faulting, based on its occurrence within the best documented part of the Atlantic Coast domain of reverse faulting, the presence of northeast-trending Cretaceous-Cenozoic reverse faults in the meizoseismal area, and inference from intensity data of a northeast-striking source. Recent aftershocks, however, yield both northeast- and northwest-striking reverse source mechanisms. This seems explainable by inferring that horizontal stresses are now approximately equal in the area perturbed by the 1886 shock, that the regional stress pattern has not yet been reimposed in the area, and that the geometries of continuing aftershock adjustments are sensitive to both existing structures of various orientations and to the effects of preceeding adjustments.

3. The character of the Atlantic Coast domain of reverse faulting, microearthquakes recorded at North Anna Reservoir in Virginia, and geomorphic analysis across the Spotsylvania lineament suggest that the Stafford fault system extends southwestward 35 km to North Anna Reservoir and is generating small earthquakes in the vicinity of the reservoir. The reservoir lies on strike with and 35 km southwest of the Dumfries fault in the Stafford system. Statistical analysis by Larry Mayer of geomorphic parameters of drainage basins on either side of the Stafford system and the Spotsylvania lineament on strike to the southeast indicates differences that are consistent with west-side-up faulting, and are not otherwise explainable. Microearthquakes at North Anna Reservoir (Dames and Moore, 1976) yield composite focal mechanism solutions with subhorizontal pressure axes and one reverse focal plane in common, which on the average is similar to the attitude of the Dumfries fault.

4. Digital terrain maps at 1:250,000 were prepared from a file of average altitudes by 15 second cell (900 cells per 7 1/2 minute quad) for 1 x 2 degree sheets west of Lat. 116 in southern California and throughout the Coast Ranges north to Long. 44. Four mapping parameters were selected for contouring to provide information bearing on possible tectonic influence on topography: (1) 15 second average altitudes, yielding a slightly simplified version of the real topography on which form, features, and altitudes are readily seen, (2) maximum altitudes per 1 minute cell, yielding an envelop over the terrain that emphasizes high surfaces and the bulk distribution in the terrain, (3) minimum altitudes per 1 minute cell, yielding a subenvelop representing the surface on which the streams and rivers flow, and (4) the range in altitude per 1 minute cell, yielding a relief map. The maps are experimental, and are considered potentially valuable tools in geologic, geomorphic, and tectonic interpretation. Copies are available on request to Wentworth.

Reports

Heller, P. L., Wentworth, C. M., and Poag, C. W., 1980, Episodic post-rift subsidence of the eastern U.S. continental margin (abs.): Geological Society of America, Abstracts with Programs, v. 12, p. 445.

Wentworth, C. M., and Mergner-Keefer, Marcia, 1980, Atlantic-Coast reverse-fault domain: probable source of east-coast seismicity (abs.): Geological Society of America, Abstracts with Programs, v. 12, p. 547.

Southwestern Utah Seismotectonic Studies

9950-01738

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Investigations

1. Most of the report period was devoted to work on two manuscripts dealing with general reviews of the Cenozoic tectonic history of the Basin and Range province. One of the manuscripts is approved for publication and the other is unfinished.

2. Completed field studies of Cenozoic structures in the Conger and Confusion Ranges, Utah, and sampled, for isotopic dating, tuffs interbedded with assemblages of Oligocene coarse clastic strata.

3. Studied Cenozoic fault-fold relationships in the Aurora, Utah, area near Salina, Utah.

Results

1. A review of subsurface data from the Great Basin section of the Basin and Range province and the Rio Grande Rift area indicates that as the young basins of these regions mature, they grow larger and less complex structurally. Complexities seen in early-formed parts of the young basins suggest complex patterns of extensional stress domains that become larger and less complex with time.

2. In the Conger and Confusion Ranges and adjacent areas of west-central Utah and in the Schell Creek Range of east-central Nevada, field studies by Anderson and age data supplied by Harald Mehnert and Bob Bohannon provide extensive documentation of major episodes of Oligocene deformation some (and possibly most) of which is associated with extensional tectonics of pre-basin-range vintage. Locally, pre-basin-range normal faulting produced extension of as much as 70 percent of original cross-strike dimensions.

3. Unconformities seen on published maps of Tertiary strata on the east flank of the Pavant Range near Aurora, Utah, are mostly nondepositional. They result from the tectonic smearing of contacts by complex faults and sheared folds all of which postdate Oligocene and Miocene (?) volcanic rocks of the area. Though available data do not allow a simple kinematic solution, there appears to have been coeval NE-SW extension and strike-slip displacement on NE-SW faults.

Reports

Anderson, R. E., 1980, The status of seismotectonic studies of southwestern Utah: U.S. Geological Survey Open-File Report 80-801, p. 519-547.

Anderson, R. E., 1980, Factors that complicate determination of the neotectonic stress field in southwestern Utah: Geological Society of America, Abstracts with Programs, v. 12, no. 6, p. 265-266.

Bucknam, R. C., Algermissen, S. T., and Anderson, R. E., 1980, Patterns of late Quaternary faulting in western Utah and an application in earthquake hazard evaluation: U.S. Geological Survey Open-File Report 80-801, p. 299-314.

Zoback, M. L., Anderson, R. E., and Thompson, George, 1981, Extensional tectonics in the western United States: Transactions Royal Society of London, in press.

Tectonic Framework San Francisco Bay Region

9540-01618

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Investigations

1. Began map of fault potential for San Mateo County seismic zonation (I-1257 series).

2. Continued evaluation of different kinds of slope maps for San Mateo County.

3. Began map showing general direction and amount of dip of bedrock units in San Mateo County.

4. Continued final preparation of material for Weber-Lajoie open-file map of San Gregorio fault zone and Dupre-Tinsley map of surficial deposits and liquefaction potential for northern Monterey County.

5. Conferred with several potential authors about products for the San Mateo County seismic zonation series.

6. Reviewed, edited, mocked-up, and had reproducibles prepared for 17 geologic maps by Tom Dibblee of quadrangles in Contra Costa and Alameda Counties.

Results

1. Fault lines from bedrock mapping, geomorphic studies, and geophysical investigations for all faults in San Mateo County are being combined on a single scale (1:62,500) so that the hazard, if any, associated with the faults can be properly assessed.

   Conferred with Bill Ellsworth and Jean Olson about adding epicenters to the fault map. They believe that the epicenters are located with sufficient precision to be displayed at 1:62,500 scale. Jean has derived several fault plane solutions, many of a thrust character, that provide the basis for new speculations about the movement potential of several faults.

2. Four slope maps of part of San Mateo County have been produced, one from the photomechanical combination of contour lines and three from different programs to manipulate digital elevation data. Slope maps are needed to prepare maps in the seismic zonation series showing which slopes are likely to fail by landsliding during earthquakes and which are likely to be triggered by rainfall.

The consideration of which slope map to use has resurrected an old question--how accurate are standard Survey topographic maps and digital data in forested areas. In order to evaluate and compare the slope maps produced by the various methods, a contract has been awarded to prepare about 4000 m of profiles on a variety of slopes in the northwest one-quarter of the La Honda 7.5' quadrangle. When the profiles are finished, the various slope maps will be analyzed and the best one picked for publication in color.

3. The direction of bedding in relation to slope may be one of the factors contributing to slope instability. In order to evaluate this factor, a new map has to be produced to generalize dip directions from attitudes on the geologic map. Apparently this kind of a map has never been prepared before on a regional scale. The map will be reproduced by computer methods and will be part of the seismic zonation series for San Mateo County.

4. The Dupre-Tinsley map is finally at the printer and the Weber-Lajoie map is in the final stages of preparation for open-files.

5. Discussions with Carl Wentworth and Steve Ellen indicate that the hillside materials map of San Mateo County can be modified to fit the I-map format and the seismic zonation series. Information on the map pertaining to strength of materials, fracture spacing and cut-slope stability probably has a direct relation to slope stability and ground response.

   Jeannie Perkins of the Association of Bay Area Governments was persuaded to write a text for her maps showing earthquake risk to wood-frame dwellings, tilt-up concrete buildings, and concrete block and steel frame buildings as part of the San Mateo seismic zonation series. The map and text are now in technical review.

   The Fumal-Gibbs map of seismically distinct units in San Mateo County was programmed by Bob Mark and Evelyn Newman from the digital tape of basic geology used to prepare map I-1257A. Derivative maps like this are relatively simple to prepare once the basic geology has been digitized. Another map that may be prepared from the same tape is the one on ground response in preparation by Bill Joyner, Jim Gibbs and others.

6. The geologic maps prepared by Tom Dibblee are used on a daily basis by consultants in determining the kind of geologic hazards that might offset a development, and by city and county geologists in evaluating the consultants' reports, in reviewing and revising seismic and public safety elements of the general plan, for general reference, and in reviewing environmental impact reports and statements. The maps are particularly valuable because they are at reasonably large scale (1:24,000) and they cover large areas with a uniform approach to the geology, i.e., no faults are required at quadrangle boundaries.

   The geologic maps of Contra Costa and Alameda Counties are also in demand as one of the basic building blocks for understanding landslide processes and for predicting slope stability in hillside areas. One example, is a study by the Association of Bay Area Governments for the University of California, Berkeley, and the East Bay Municipal Utility District. The slope stability analysis will be used to reduce road maintenance and to control erosion.

Status of Seismic Zonation Maps for San Mateo County
Miscellaneous Field Investigations I-1257 Series

Authors	Maps	Comments
Brabb, Pampeyan	Geology I-1257A	In press
Wieczorek, et al.	Earthquake induced landslide	Map finished, text being written.
Uncertain	Slope	Elevation data in digital form. Need ground data to determine best best program to use.
Brabb, Taylor	Geologic, scenic, and historic sites	Almost ready for branch review.
Brabb	Dip direction and amount	Map in preparation.
Youd	Liquefaction potential	Almost ready for branch review.
Brabb	Fault potential	Map nearly finished. Need text.
Olson	Epicenters	Map nearly finished. Need text. Will probably combine with fault map.
Brabb, Pampeyan	Landslide inventory	Revision of MF map in progress.
Brabb, et al.	Landslide susceptibility	Will be done by computer when landslide inventory and slope map finished.
Perkins (ABAG)	Building risk	In branch review.
Brabb?	Dam inundation	Map in preparation.
Fumal, Gibbs	Seismic units	Nearly ready for branch review.
Joyner, Gibbs	Ground response	In preparation.
Uncertain	Tsunami	New Corps Eng. data available 1981.
Uncertain	Flood prone areas	From WRD maps.
ABAG?	Land use	Map available in digital form. Need text.
Wentworth, Ellen	Hillside materials	In TRU review.
Uncertain	Vegetation	Available in digital form. May be used to make landslide susceptibility map.
Brabb	Composite hazards	Will begin when all other maps are finished

REPORTS

Dibblee, Thomas W., Jr., 1980, Preliminary geologic map of the Walnut Creek quadrangle, Contra Costa County, California: U.S. Geological Survey Open-File Report 80-351, scale 1:24,000.

Dibblee, Thomas W., Jr., 1980, Preliminary geologic map of the Benicia quadrangle, Contra Costa and Solano Counties, California: U.S. Geological Survey Open-File Report 80-400, scale 1:24,000.

Dibblee, Thomas W., Jr., 1980, Preliminary geologic map of the La Costa Valley quadrangle, Alameda County, California: U.S. Geological Survey Open-File Report 80-533A, scale 1:24,000.

Dibblee, Thomas W., Jr., 1980, Preliminary geologic map of the Livermore quadrangle, Alameda and Contra Costa Counties, California: U.S. Geological Survey Open-File Report 80-533B, scale 1:24,000.

Dibblee, Thomas W., Jr., 1980, Preliminary geologic map of the Niles quadrangle, Alameda County, California: U.S. Geological Survey Open-File Report 80-533C, scale 1:24,000.

Dibblee, Thomas W., Jr., 1980, Preliminary geologic map of the Byron Hot Springs quadrangle, Alameda and Contra Costa Counties, California: U.S. Geological Survey Open-File Report 80-534, scale 1:24,000.

Dibblee, Thomas W., Jr., 1980, Preliminary geologic map of the Midway quadrangle, Alameda and San Joaquin Counties, California: U.S. Geological Survey Open-File Report 80-535, scale 1:24,000.

Dibblee, Thomas W., Jr., 1980, Preliminary geologic map of the Antioch South quadrangle, Contra Costa County, California: U.S. Geological Survey Open-File Report 80-536, scale 1:24,000.

Dibblee, Thomas W., Jr., 1980, Preliminary geologic map of the Dublin quadrangle, Alameda and Contra Costa Counties, California: U.S. Geological Survey Open-File Report 80-537, scale 1:24,000.

Dibblee, Thomas W., Jr., 1980, Preliminary geologic map of the Altamont quadrangle, Alameda County, California: U.S. Geological Survey Open-File Report 80-538, scale 1:24,000.

Dibblee, Thomas W., Jr., 1980, Preliminary geologic map of the Briones Valley quadrangle, Alameda and Contra Costa Counties, California: U.S. Geological Survey Open-File Report 80-539, scale 1:24,000.

Dibblee, Thomas W., Jr., 1980, Preliminary geologic map of the Tassajara quadrangle, Alameda and Contra Costa Counties, California: U.S. Geological Survey Open-File Report 80-544, scale 1:24,000.

Dibblee, Thomas W., Jr., 1980, Preliminary geologic map of the Las Trampas Ridge quadrangle, Alameda and Contra Costa Counties, California: U.S. Geological Survey Open-File Report 80-545, scale 1:24,000.

Dibblee, Thomas W., Jr., 1980, Preliminary geologic map of the Diablo quadrangle, Alameda and Contra Costa Counties, California: U.S. Geological Survey Open-File Report 80-546, scale 1:24,000.

Dibblee, Thomas W., Jr., 1980, Preliminary geologic map of the Clayton quadrangle, Contra Costa County, California: U.S. Geological Survey Open-File Report 80-547, scale 1:24,000.

Dibblee, Thomas W., Jr., 1980, Preliminary geologic map of the Cedar Mountain quadrangle, Alameda and San Joaquin Counties, California: U.S. Geological Survey Open-File Report 80-850, scale 1:24,000.

Seismic Hazards of the Hilo 7 1/2' quadrangle

9550-02430
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Investigations

Geologic mapping within the Hilo quadrangle, and studies of ash and saprolite deposits in selected portions of the Hilo, Papaikou, Akaka Falls and Pi'ihonua quadrangles are continuing.

Results

C14 dating of charcoal collected from beneath Mauna Loa lava flows during geologic mapping has confirmed the existence of at least two ashes in the study area. The older ash (B) is no younger than 14,500 years and is believed to be an eruptive product of Mauna Kea volcano. The younger ash (A) is between 4,000 and 9,000 years old and its source has not been determined.

Geotechnical tests for a map of susceptibility to earthquake-induced landslides were conducted by members of the Engineering Geology Branch, Menlo Park. Two sites believed to represent the two age-units of ash were selected for testing. Ash B is more weathered and has higher water content and sensitivity than ash A. The results indicate that only ash B deposits are sensitive enough to pose a substantial risk of earthquake induced flow.

Ash B is underlain by a locally thick, yellow-gray clay bed (C) that appears to be widespread in the study area. Both ash B and the clay overlie the saprolite. Bed C may act as a slip surface for the overlying ash. Its higher clay content relative to the ash deposit makes it less permeable and hence water may accumulate at the base of the ash. The clay bed is being mapped as a separate unit.

Quaternary Deposits and Tectonics of the Antelope Valley-Western Mojave Region, California

9940-02090

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Investigations and results

The data storage structure of the MAT_DISPLAY system on Multics has been revamped to increase the system's efficiency and utility for other projects. These computer programs are designed to facilitate the study of subsurface stratigraphy and seismic engineering properties of Quaternary materials. When compiled, data from diverse sources such as water well logs, civil engineering test borings, and seismic velocity profiles can be handled in the system to produce displays of well and boring logs in both map view and cross-section, isometric views and contour maps of stratigraphic surfaces, and tabulations of a variety of geotechnical properties. Information on any of the following can now be compiled and manipulated in the system:

- lithologic description
- unified soil classification
- grainsize mode
- grainsize median
- grainsize mean
- grainsize std. deviation
- grainsize skewness
- grainsize kurtosis
- void ratio
- in-place dry density
- in-place bulk density
- in-place moisture
- liquid limit
- penetration resistance
- penetrometer driving rate
- shear strength
- S-wave velocity
- P-wave velocity
- whole-rock weathering
- clast weathering
- fracture spacing
- hardness
- bedding thickness
- color
- radiometric age
- plasticity index

Information from about 600 water wells, 150 highway and bridge borings, 20 oil and gas wells, 325 aqueduct test borings and trenches, and 250 near-surface grainsize samples are now compiled for most of the lowlands of northern Los Angeles County. Test studies in the eastern third of the region indicate:

1. A 100 m thick, deformed bed of massive lacustrine(?) silty clay underlies interbedded alluvium and thin lake beds within the eastern Antelope Valley basin. Its extent to the west in the basin and its correlation with sequences of alluvium in the adjacent San Gabriel

Mountains are not yet known, but the bed may be a useful marker horizon for Quaternary deformation in the region.

2. Steep gradients and isolated closed depressions as deep as 2 km characterize basement relief in the eastern basin. Some relief is controlled by active structures that are recognized at the surface but much has no obvious recently active structural control. Integration with velocity profiling in progress by John Healy et al. should improve this subsurface model.

3. Large and abrupt lateral and vertical variations in the grainsize of Quaternary deposits occur along the length of the Antelope Valley owing to shifts of the outlets of major drainages of the San Gabriel Mountains where they cross the San Andreas fault. The timing of these shifts in the context of the Quaternary alluvial stratigraphy suggests that the San Andreas rift valley in the area began to be eroded about 300,000 years ago and that the San Andreas fault has had a maximum slip rate between 2.4 and 4.2 cm/yr since that time.

4. In spite of a similarity in penetration resistance between Holocene and latest Pleistocene deposits in the Antelope Valley and in the San Francisco Bay region, limited data thus far suggests that void ratios are lower in the Antelope Valley deposits and that shear wave velocities may be appreciably higher.

In conjunction with James Gibbs, Thomas Fumal, et al., 11 test holes were selected and drilled in the Antelope Valley to determine shear wave velocity characteristics and subsurface stratigraphy of Quaternary units. Digestion of most data remains in progress. Drilling confirms the existence of the thick massive clay bed mentioned above and has supplied samples for possible C^{14} and paleomagnetic age determinations.

Reports

Ponti, D. J., Burke, D. B., Marchand, D. E., Atwater, B. F., and Helley, E. J., 1980, Evidence for correlation and climatic control of sequences of late Quaternary alluvium in California: Geological Society of America, Abstracts with Programs, v. 12, no. 7, p. 501.

Ponti, D. J. and Burke, D. B., 1980, Map showing Quaternary geology of the eastern Antelope Valley and vicinity, California: U. S. Geological Survey Open-File Map 80-1064, scale 1:62,500.

Vertical Tectonics

9950-01484

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Investigations

1. Continued studies of historic crustal deformation based on the results of repeated levelings and both continuous and discontinuous sea-level measurements and how this deformation may be related to the late Cenozoic tectonics in selected parts of California.

2. Completed report on the results of the 1978 general releveling of southern California (in review).

3. Reopened investigation of the charge that the results of geodetic levelings are seriously contaminated by an inexplicit (slope-related) height dependent error associated with unequal refraction in the atmospheric boundary layer.

Results

1. Nothing to report at this time.

Reports

Vaníček, Petr, Castle, R. O., and Balazs, E. I., 1980, Geodetic leveling and its applications: Reviews of Geophysics and Space Physics, v., 18, no. 2, p. 505-524.

Castle, R. O., 1980, Geological considerations in the development and maintenance of the new North American vertical network [abs.]: Technical Program and Abstracts. Second International Symposium on Problems Related to the Redefinition of North American Vertical Geodetic Networks, May 26-30, Ottawa, Canada, p. 29-30.

Castle, R. O., and Vaníček, Petr, 1980, Interdisplinary considerations in the formulation of the New North American vertical datum: Proceedings of the Second International Symposium on Problems Related to the Redefinition of North American Vertical Geodetic Networks, May 26-30, Ottawa, Canada, p. 262-276 (?).

Burford, R. O., and Harsh, P. W., 1980, Slip on the San Andreas fault in central California from alinement array surveys: Bulletin of the Seismological Society of America, v. 70, no. 4, p. 1233-1261.

Anchorage-Susitna Lowlands Earthquake Hazards Mapping

9310-02078

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Investigations

1. Completed basic surficial/engineering-geologic field mapping and Quaternary stratigraphic studies, leaving only minor field checking to be completed.

2. Completed monitoring slope indicator casings in the Anchorage area at the buttress of the 4th Avenue landslide, and near the "L" Street, Turnagain Arm, and Government Hill landslides. Many of these casings were installed soon after the 1964 Alaskan earthquake, but a few have been installed within the last two years.

3. Continued collection and synthesis of subsurface engineering soils data.

Results

1. Completed preliminary surficial/engineering geologic maps of part of the study area.

2. Obtained logs and soils analyses from boreholes. These data, obtained from private, state, and federal organizations, have been cataloged in a card file and currently are being synthesized.

3. Completed a comprehensive engineering soils study of the Government Hill area in Anchorage. The report and map present systematic geologic descriptions, facies changes, and engineering characteristics of the Bootlegger Cove Clay.

4. Discovered a conspicuous lineament that appears to be an active segment of a fault which splays out from the Castle Mountain Fault to the north and extends under Cook Inlet to the south. This lineament trends northeast-southwest and crosses a portion of the Susitna Lowland which is underlain by sediments of late Wisconsinan age, and it is located only 17 kilometers northwest of the city of Anchorage.

5. Observed that normally unstable bluffs in the Anchorage area are relatively stable in areas where ground-water drainage is good. This suggests that unstable bluff areas might be buttressed by installing horizontal drains which would accelerate and localize drainage of ground water.

Compilation of Regional Geological and Seismic Site Characteristics

9940-02087

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Investigations

1. Investigate dependencies of measured site amplification, observed 1906 earthquake intensities, and physical properties of near surface geologic units on downhole velocity and geologic logs, to develop generalized guidelines for predicting earthquake ground motions on a regional scale.

2. Collect seismic velocity data, physical property data, and geologic data in drill holes to develop an improved data base for seismic zonation of the metropolitan Los Angeles Basin.

3. Provide site characteristics (shear and compressional wave velocities, geologic logs, etc.) at locations of important strong motion records.

Results

1. A map showing units with a distinct range of shear wave velocity has been completed for San Mateo County, Calif. The digitized map combines geologic units on the basis of similar near surface geotechnical and physical property data. In situ measurements of shear wave velocities are used to differentiate the seismically distinct units. The purpose of the map is to provide a basis for defining the earthquake shaking hazard due to near surface geologic conditions.

2. Nineteen new locations were drilled in the Los Angeles area to supplement the seismic zonation data base in this region.

3. Of the 19 new drill holes in the Los Angeles area 16 are at locations of strong motion instruments. Most of these locations have recordings from the 1971 San Fernando, Calif. earthquake.

Reports

No reports were published during this report period.

Ground Response Along the Wasatch Front

9940-01919

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Investigations

1. Research to improve fundamental knowledge about how the local geology along the Wasatch front affects ground response was continued. The activities mainly involved processing and analysis of the 109 velocity time histories recorded at sites in Salt Lake City, Provo, Ogden, Logan, and Cedar City, Utah. Analysis consisted of correlating the characteristics of the time histories, response spectra, and site transfer functions with the local and regional geology. Drillers logs were acquired and some geological field work was performed in the Salt Lake City, Provo, Ogden areas to refine the preliminary correlations of ground response with the local geology.

Results

1. The horizontal ground response of sites underlain by unconsolidated material, relative to that of a rock site on the Wasatch front, is similar for the Salt Lake City and Provo areas, but it differs somewhat for the Ogden area. In Salt Lake City and Provo, the response in the 0.2-0.7 second period band increases from east to west from the front and correlates with an east to west increase in thickness, water content by weight, and percentage of fine-grained material. In Ogden, a relatively large area of low ground response exists for this period band west of the town in an area thought to be underlain by deep, saturated, fine-grained unconsolidated material. The ground response, relative to rock, suggests that this area may be underlain by dryer and/or coarser material. Field work is planned to resolve this apparent anomaly which could affect future seismic zoning decisions.

Reports

1. Hays, W. W., 1980, Earthquake Prediction: An opportunity to improve ground-shaking hazard maps in Latin American Cities (abs.), International Seminar on Earthquake Prediction and Evaluation of the Danger and Seismic Risk, October 20-24, 1980, San Juan Argentina.

2. Hays, W. W., Miller, R. D., and King, K. W., 1980, Ground Response in the Salt Lake City-Ogden-Provo, Utah, Urban Corridor, World Conference on Earthquake Engineering, 7th, Proceedings, v. 2, p. 89-96.

Sonoran Earthquake of 1887: Earthquake Tectonics of Southern Arizona, Sonora, and Chihuahua

9540-02685

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Investigations

1. A reconnaissance field investigation of the 1887 Sonoran earthquake fault near Agua Prieta, Sonora, was made during May and June of 1980. The earthquake, which occurred on a fault along the east side of San Bernardino Valley (in extreme northeastern Sonora) on May 3, 1887, was one of the most severe in interior North America. Probably of magnitude 7, the earthquake nearly leveled the village of Bavispe, Sonora (it damaged buildings throught southeastern Arizona), and was felt as far away as Mexico City (nearly 1600 km distant). The length of the fault was examined to establish whether the entire fault broke in 1887, and if there was evidence of pre-1887 displacement. Measurements of scarp height and slope angle were made systematically along the length of the fault. Two other neighboring, geologically recent faults in San Bernardino Valley, which occur west of the 1887 Sonoran rupture, were inspected to see if they broke in 1887.

2. A brief field examination was made of a small recently active fault at the east side of Animas Valley in extreme southwestern New Mexico (about 40 km northeast of the Sonoran earthquake fault), and of a second, larger fault that occurs in the next valley west of San Bernardino Valley, near Fronteras, Sonora.

3. A second reconnaissance field investigation of the 1887 rupture is planned for late November-December 1980

Results

1. Nearly the entire length of the recenty active fault at the foot of the Sierra de San Luis, on the extreme east side of San Bernardino Valley, appears to have ruptured in 1887. Except perhaps at the extreme northern end of the fault (north of Arroyo Cajon Bonito), the break appears to be almost completely of one age. There is rubble at the base of the scarp, but the scarp itself appears largely original. It is generally steep (from nearly vertical to 30-60^0 in dip) and relatively unbattered. Only one facet can be recognized along most of the fault scarp, suggesting that the break is entirely of 1887.

However, there is evidence that there may have been another faulting episode only several hundred years before the earthquake of 1887. Terraces flanking Arroyo de los Embudos are offset about 2.7 m by the 1887 fault, but the floodplain of the stream is displaced only 1.6 m. The difference in throw may record a pre-1887 earthquake that was accompanied by nearly 1 m of displacement. If true, this earthquake was presumably only several hundred, or at most a few thousand years before the Sonoran earthquake of 1887. There could not have been any significant time between these earthquakes, or presumably the fault scarp would record more than the single faulting event that is evident.

The recently active fault at the west side of San Bernardino Valley, opposite the 1887 break, does not appear to have been active in historic time. That fault scarp is degraded, low-dipping (about 20^0), and rilled. The third recently active fault in San Bernardino Valley, which follows the axis of the valley (paralleling the Río San Bernardino just to the east) may have been active in 1887. The location of the third fault crudely corresponds to ground breaks mapped west of the main fault by José Aguilera shortly after the earthquake in 1887. There is a small, fresh-looking facet along part of the fault, especially near Hacienda Cuchuverachic.

2. The small (less than 10-km long) fault break along the west side of Animas Valley in extreme southwestern New Mexico appears to have been active in latest Quaternary (Holocene?) time, but it apparently did not rupture in 1887. The east-facing scarp is slightly battered and back-wasted, and has no fresh-looking face. There is no apparent relationship between this fault and those in neighboring San Bernardino Valley.

Similarly, the fault southeast of Fronteras, Sonora, was not active in historic time. The fault, which borders the west front of Cerro Los Fresnos (east of Arroyo Fronteras), extends south to at least near Esqueda. The fault is nearly vertical to steeply west-dipping (normal), locally juxtaposing late Quaternary alluvium against older Mesozoic-age rocks. The fault nowhere appears to have been active in Holocene time.

Neotectonics of the San Francisco Bay Region, California

9540-01950

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Investigations

1. A study of the earthquake ground-acceleration hazard in the San Francisco Bay region was concluded. The project, a cooperative investigation with R.K. McGuire and K.M. Shedlock of the Branch of Earthquake Tectonics and Risk (Project No. 9950-01733, Methodologies for Seismic Risk Assessment), calculated future ground-shaking intesities in the San Francisco Bay région. Earthquake frequency in the Bay area was calculated from fault slip and seismic moment.

2. Historic earthquake frequency in the San Francisco Bay region was compared to that predicted from fault slip and seismic moment to determine if earthquake production in the Bay area is uniform through time. The apparent cyclic occurrence of earthquakes in the central Coast Ranges was explored cooperatively with William L. Ellsworth (Project No. 9930-02103, Seismic Studies of Fault Mechanics) and Allan G. Lindh (Project No. 9930-02098, Parkfield Prediction Experiment) of the Branch of Seismology.

3. Map syntheses (scale 1:250,000) of recently active faults and seismicity (1969-1977) in the San Francisco Bay region were prepared with William L. Ellsworth.

4. An international investigation of the December 12, 1979 Tumaco, Colombia earthquake (magnitude $\sim$8) was continued. The earthquake is being studied jointly with T. Leslie Youd of the Engineering Geology Branch (Project No. 9550-01629, Experimental Mapping of Liquefaction Potential), Waverly Person and Carlos Mendoza of the National Earthquake Information Service, and members of the Colombian Instituto Nacional de Investigaciones Geologico-Mineras (the Colombian Geological Survey).

Results

1. Earthquake frequency predicted from fault slip and seismic moment suggests that there should be, on average, magnitude-5 earthquakes in the San Andreas fault system north of Hollister every 1.0 years, magnitude-6 earthquakes every 3.6 years, and magnitude-7 events every 36.1 years. The annual activity of faults in the San Francisco Bay region is derived from Molnar's "rate of occurrence of seismic moments" by multiplying the annual seismic moment of a fault by the fractional moment contribution of a given range of earthquake magnitudes.

2. Earthquake production in the San Francisco Bay region is not uniform through time. During the nearly 100 years of recorded history before the

great 1906 San Francisco earthquake there were substantial numbers of M_I 5, 6, and 7 earthquakes in the San Francisco Bay region on the San Andreas and east Bay faults. Since 1906, damaging earthquakes (those generally of $M \geq 5$) have been infrequent in the northern Coast Ranges. There were no $M \geq 5$ earthquakes in the entire San Andreas fault system north of San Jose until 1955.

The discrepancy between the observed and predicted earthquake frequency can be explained by the long-term slip rates of faults having ben improperly estimated, or that the values chosen for the constants or the assumed forms of the functions used to calculate Bay area earthquake frequency are in error. However, the virtual absence of earthquakes of $M \geq 5$ since 1906 north of San Jose cannot be accounted for by uniform earthquake production. Earthquake activity in the San Francisco Bay region appears dependent on the cycle of stress release and recovery that accompanies very large earthquakes on the San Andreas fault.

Reports

Accepted for publication:

Herd, D.G., Youd, T.L., Meyer, Hansjurgen, Arango, C., J. L., Person, W.J., and Mendoza, Carlos, 1980, Tumaco, Colombia earthquake (M ~8) of 12 December 1979: Science article with cover.

Published:

Shedlock, K.M., McGuire, R.K., and Herd, D.G., 1980, Earthquake recurrence in the San Francisco Bay region, California, from fault slip and seismic moment: U.S. Geological Survey Open-file Report 80-999, 18 p.

PUGET SOUND LOWLAND FOCUSED GEOPHYSICAL STUDIES

9460-71110

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Investigations

1. The 175 line-kilometers of marine gravity data and 12 of the 16 air gun sonobuoy refraction profiles collected in central Puget Sound and Lake Washington during March 1980 (Fig. 1) have been reduced using standard procedures.

Results

1. The newly acquired marine gravity data have been combined with additional USGS land stations and existing data from other sources to produce a detailed Bouguer anomaly map for the central Puget Sound basin, including Lake Washington. The west-trending nose of the Lake Washington gravity minimum has been sharpened and extended to the west. The marine data show that the Bouguer gravity anomaly reaches a minimum value of -129 mgal over central Lake Washington. The gravity gradient south of this minimum reaches values up to 15 mgal/km over Puget Sound west of Seattle.

2. Several detailed land gravity lines were obtained over local topographic features in an effort to utilize the "Nettleton profiling" technique to derive the average density within the elevation range of the topography. Accurate density estimates for the sediment and rock units in the Puget Sound basin are necessary meaningful gravity modeling of subsurface density distribution. To date, only features composed of glacial deposits (Vashon Till) have been profiled; the average density of these sediments is 2.10 g/cc. The search is continuing for suitable topographic features composed of Tertiary rocks.

3. The airgun-sonobuoy refraction profiles were analyzed using the slope-intercept method. No corrections for dipping interfaces or sea-floor topography irregularities have been incorporated in the results. Severe interference from television audio and video broadcasts prevented the acquisition of usable data from the first six sonobuoys deployed. The problem was identified and modifications made to field procedures and instrument systems for the remaining refraction work. Results from the successful sonobuoy profiles are shown in Figure 2. The data show that greater thicknesses of low velocity material exist north of the east-west gravity gradient extending through Seattle than south of the gradient. Comparison of the various velocity units with seismic reflection and borehole data suggests the following correlations: 1.8 km/s — Holocene sediment; 2.1-2.6 km/s — Pleistocene deposits; 2.7-4.0 km/s — Tertiary sedimentary rocks; and 5.5 km/s Tertiary volcanics.

4. A least-squares inversion program has been developed to permit the modeling of the subsurface density distribution to a depth of 16 km in the central Puget Sound basin. The model has been used only in an unconstrained mode so far; data from the Nettleton density profiles and density data from various published compressional velocity versus density curves will be used to establish geologically realistic constraints for future modeling efforts. Results to date suggest that the steep east-west gravity gradient is associated with a shallow (<4 km) linear zone where the density contrast approaches 0.50

g/cc. There is also a deeper-seated regional component to the anomaly involving a density contast of only 0.05 - 0.10 g/cc. These preliminary results could be explained by a steep normal or reverse fault 5-7 km deep with an accumulation of low density sediment on the north side of the fault within the upper 3-4 km of section.

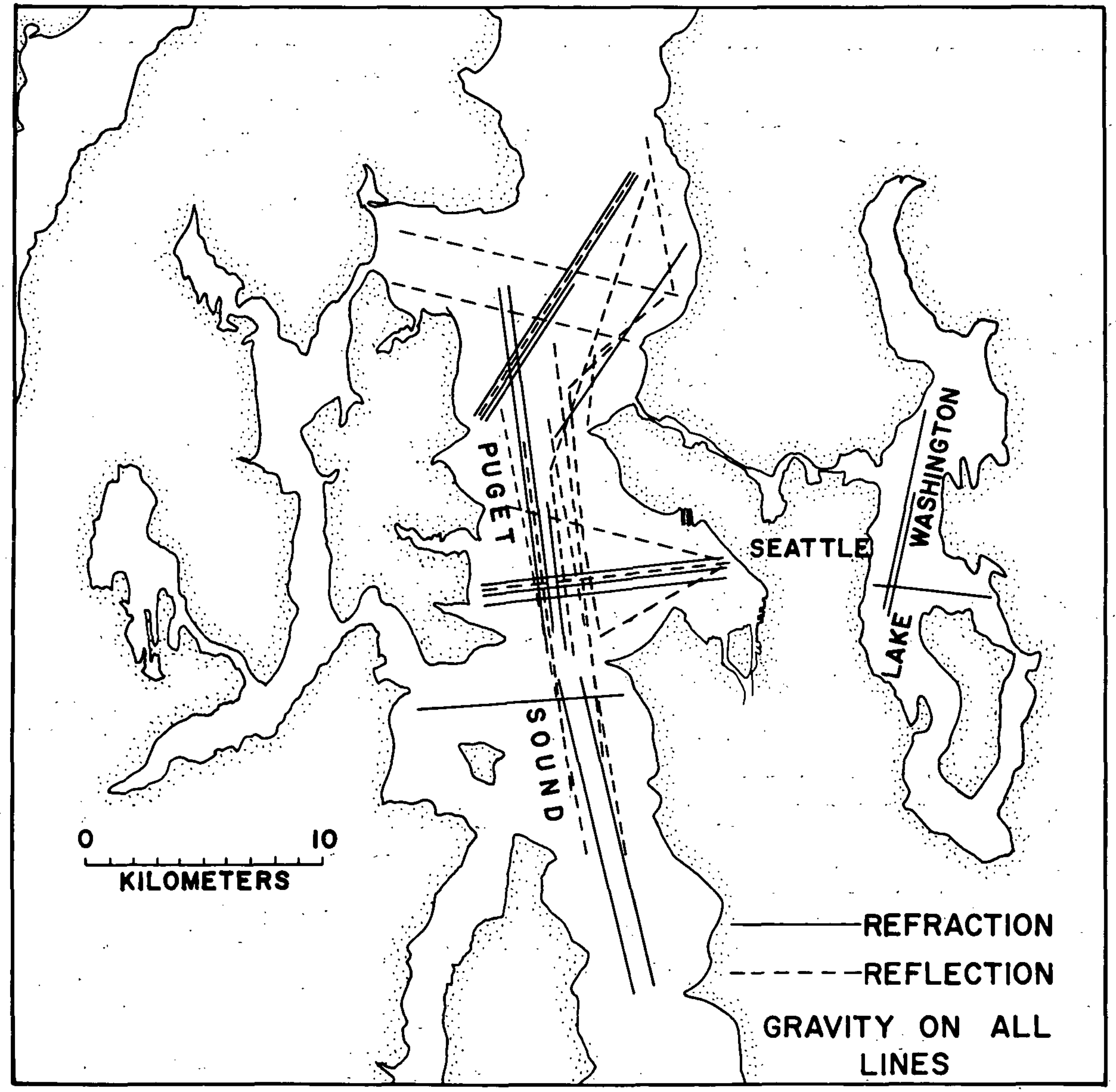

FIGURE 1. Geophysical track lines, central Puget Lowland.

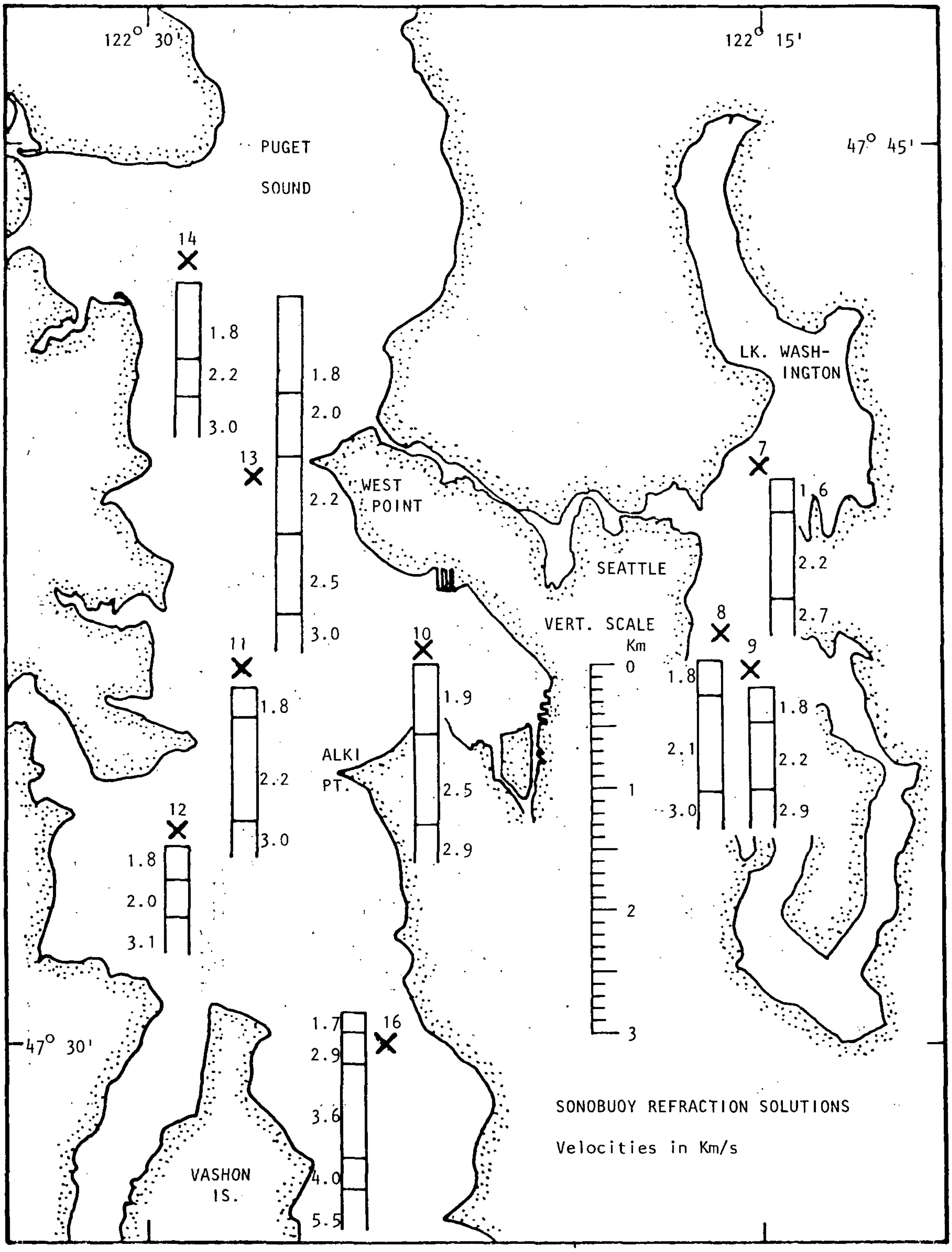

FIGURE 2. Sonobuoy refraction solutions, central Puget Lowland.

Tectonics of Central and Northern California

9950-01290

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Investigations

1. Tectonic relations of CO_2 discharges and seismicity, in collaboration with Ivan Barnes.

2. Paleomagnetic orientation of Eastern Klamath terrane, in collaboration with S. C. Gromme and E. A. Mankinen.

3. Dating of tectonically accreted oceanic terranes ("microplates") of central Klamath Mountains, in collaboration with D. L. Jones.

Results

1. The relation of carbon dioxide discharges to tectonically active regions of the conterminous United States is shown on a map that has been prepared for publication at a scale of 1/2,500,000 (Irwin and Barnes, in press). The carbon dioxide discharges occur in natural springs and in some wells that have been drilled for hydrocarbon gas and oil. The carbon dioxide rich springs are concentrated mainly along seismically active zones in the Pacific Coast region. Most of the carbon dioxide rich gas wells are in the western part of the North American craton, where the craton is being actively rifted. A map showing the worldwide distribution of carbon dioxide discharges in relation to seismicity is being revised.

2. A thick stratigraphic section of Upper Paleozoic volcanic rocks of the Eastern Klamath terrane was core drilled for paleomagnetic study. Paleomagnetic studies by other workers indicate that the Tertiary and older rocks north and east of the Klamath province have undergone substantial clockwise rotation, and a similar rotation has been postulated for the Klamath block. Paleomagnetic study of the upper Paleozoic section is important to determine whether the Klamath block participated in the tectonic rotational event, and also may point to the paleolatitude at which the upper Paleozoic volcanic arc developed. We previously core-drilled patches of Cretaceous sedimentary strata of the Great Valley sequence that lie on the older Klamath rocks, but these strata are remagnetized too strongly to yield their original magnetic imprint. Preliminary results of laboratory study of the drill cores of Paleozoic rocks are not yet available.

3. The ages of ophiolitic and other oceanic rocks, and the times of their incorporation into the continental borderland as "microplates", are best determined in some instances by study of radiolarians in associated ribbon cherts and tuffs. The North Fork terrane of the central Klamath Mountains was sampled for radiolarian-bearing cherts at several transects at intervals along its linear north-trending extent. Preliminary results of the sampling indicate that the cherts are dominantly late Paleozoic in age at the south end of the terrane, dominantly Early or Middle Jurassic at the middle latitudes, and dominantly Triassic in the Salmon River region to the north. The late Paleozoic radiolarian fauna found in the southern part of the terrane was previously unknown in North America. The differences in ages of the radiolarian faunas at the various transects may indicate that the North Fork terrane is more highly segmented than previously considered, and raise the possibility that the various segments may not have accreted to the continental borderland during a single tectonic event.

Reports

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A New Method of Alluvial Age Dating Based on Progressive Weathering, with Application to the Time-History of Fault Activity in Southern California

14-08-0001-17760

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Investigations

1. Using the standardized CSV method as discussed in the semi-annual report, several more deposit groups were tested.
2. Additional samples were collected from the oldest alluvial units for paleomagnetic measurements to provide an age constraint on these units.
3. All CSV data was evaluated and statistical tests applied to determine the reliability of the method.

Results

1. With the inclusion of the additional sites, the group means of the four age groups (Crook et al., 1979) are all separable at greater than 99 percent confidence using a one-tailed t-test.
2. Results of the paleomagnetic determinations indicate a high probability that the oldest deposit tested in San Gabriel Canyon was deposited during the Matuyama reversed-polarity epoch but that the soil developed at its surface was developed during the present normal polarity epoch, suggesting the deposit is approximately .73 million years old.

3. Using the paleomagnetic data in addition to a radiocarbon date of a deposit in San Gabriel Canyon obtained by William Bull, a first approximation of a velocity/age correlation curve was determined. This curve and the CSV data suggest that the alluvial deposits do not readily fit a simplified age classification but rather have a continuous age distribution. This affirms the need for a relative-dating technique such as the CSV method.

Paleomagnetic Dating of Holocene Deposits Along the San Andreas Fault in Southern California

14-08-0001-19101

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Goals

The primary objective of this study is to develop a new method of dating Holocene deposits adjacent to active faults. This will involve measuring the secular variation of the declination, inclination and intensity of the magnetic remnance of cores collected from various Holocene deposits in southern California.

The first phase of the study is to establish a magnetic standard for the Holocene in southern California, calibrated to various "absolute" age dates. This will be accomplished by measuring marine cores from deep basins within the southern California Borderland. There sedimentation is slow, continuous and at a constant rate; ideal conditions for preservation of the complete magnetic record for the Holocene. Age control will be provided by varve counts and radiocarbon dates.

The second phase of the study involves collecting cores or columns of sediment from shallow estuaries from Oceanside to San Diego and from dry lakes in the Mojave Desert. Both environments provide the most suitable conditions for establishing an on-land, Holocene secular variation curve. The final phase is collecting and measuring cores from faulted Holocene sediments along the San Andreas fault.

Investigations

The investigation to date has accomplished the following:

(1) Measured secular variation for three gravity cores from the southern California Borderland, obtained from Scripps Institution of Oceanography, two from the Santa Cruz Basin and one from the southern end of the Arguello fan.

Results: The mean inclination and the variation in inclination and declination recorded in the Arguello fan core are consistent with the dipole inclination and its secular variation. Provided several cores of sufficient time span can be collected from this area, they should provide a good control record.

(2) Two sites, Coyote Dry Lake and Koehn, have been trenched and columns of Holocene(?) sediment collected from the walls. Charcoal was collected from the Coyote Dry Lake site, and a lake clay previously dated at 14,700 ± 130 years B.P., was encountered at the Koehn Lake site. Paleomagnetic records from these sites are now being evaluated.

Alaska Seismic Studies

9940-01162

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Investigations

1. Seismic data are collected and analyzed from a network of stations extending across southern Alaska from the active volcanoes bordering western Cook Inlet to Juneau, Alaska and as far north as the Talkeetna Mountains. This data establishes an important base of information for the study of the tectonic deformation, the potential for moderate-to-large earthquakes, and the nature of strong ground motion in southern Alaska.

2. The coastal stations east of Kayak Island are funded by NOAA's Outer Continental Shelf Environmental Assessment Program (OCSEAP). Data obtained from this network are particularly important for establishing criterion for safe oil development on the shelf.

3. A network consisting of one three-component and four vertical component seismic stations is being established with Army Corps of Engineers' funding this fall to monitor the seismicity around the proposed Bradley Lake Hydroelectric Project. Although it is already known that the active Aleutian megathrust underlies the project area at about 45 km depth, detailed analysis of the data to be collected should help to establish whether there are any other active faults nearby.

4. Carry out long-term seismic and crustal deformation studies in the Kayak Island-Yakutat seismic gap area in order to document premonitory earthquake phenomena prior to large-to-moderate earthquakes.

Results

1. During the past six months, data processing has remained on schedule and preliminary earthquake locations have been obtained for February-July 1980. Aftershocks from the 1979 St. Elias earthquake continue to be the dominant feature in the distribution of epicenters. Two of the largest aftershocks ($M_b \simeq 5.2$, 5.1) in the sequence occurred on June 30, 1980 immediately east of Icy Bay. Another notable feature of the recent seismicity is a concentration of earthquakes along a north-northeast trending zone located about 50 km northwest of Anchorage. These events are located within the Benioff zone at a depth of 40 km, consistent with their occurrence on or near the thrust zone between the crust and the underthrust Pacific plate. Catalogs of earthquakes in southern Alaska for October-December 1979 and January-March 1980 have received Director's approval.

2. Since the 1979 St. Elias earthquake greater emphasis has been placed on instrumenting the remaining seismic gap between Icy Bay and Kayak Island (called the Yakataga gap) with strong motion instruments. The chance for a magnitude 7 or larger earthquake to occur within this region during the next several years is judged to be equal to or greater than that for any other seismic zone in the United States. Strong motion data from within 25 km of a magnitude 7 or 100 km of a magnitude 8 earthquake would make an important contribution to studies of the acceleration to be expected near large earthquakes.

This past summer 6 additional strong motion instruments were installed, bringing the total number operated by this project to 24. Of these, 9 are within, and 7 are less than 100 km from the region of the Yakataga gap.

3. The high-gain seismic network configuration is being modified in response to recent fiscal changes. Due to reduced OCSEAP funding, the telephone line between Cape Yakataga and Palmer will no longer be leased and 8 fewer components of seismic data from the eastern Gulf of Alaska will be recorded. A new station was established at Juneau, however, to improve coverage between Yakutat and Sitka.

One three-component and four single-component stations are being installed near the proposed Bradley Lake Hydroelectric Project with funding from the Army Corps of Engineers. Paper records from two of the stations recorded on a helicorder will be used in scanning for nearby earthquakes. The develocorder film-records will be utilized for timing phases.

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Coastal Tectonics, Western U. S.

9940-01623

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Investigations

1. Continuation of mapping and dating late Quaternary marine terraces and deposits from numerous coastal sites in western U. S. with emphasis on Humboldt County, Ventura County and San Diego Counties, California. Project personnel are George Kennedy, paleontologist/geologist; Scott Mathieson, geologist, and Samuel Morrison, PST. Cooperative projects are with Andrei Sarna-Wojcicki and Robert Yerkes (OEG) in the Santa Barbara-Ventura counties region, Gerald Weber (U.C. Santa Cruz) in San Mateo County, Philip Kern (San Diego State University) and Patricia McCrory (OMG) in San Diego County, Preston Cloud in Mono County and Yoko Ota on the Boso Peninsula, Japan. Cooperative dating projects are with John Wehmiller (University of Delaware), Steve Robinson (USGS) and Joseph Liddicoat (Lamont-Doherty Geological Observatory).

2. Visited logged trenches across faulted terraces in Humboldt Bay region excavated by Tom Stephens (Woodward/Clyde Consultants).

3. Reviewed marine terrace soils in coastal San Mateo County with Terry Cooke and Jim Kashiwagi (U.S. Soil Conservation Service).

4. Visited Japan to attend International Geographical Congress and tour tectonically deformed fluvial and marine terraces in coastal regions of central Honshu. Funds for travel from UNESCO/IGCP Project 61 and personal savings.

Results

1. *Thrust faults exposed in trench (Woodward/Clyde Consultants) cut marine* terrace deposits north of the College of the Redwoods in Humboldt County. Age of terrace uncertain, probably late Pleistocene.

2. Radiocarbon dates on wood and fossil shells from Holocene terraces in Humboldt and Ventura Counties show no consistent pattern of increasing age with increasing elevation. All ages are less than 8 kA and yield tectonic uplift rates of greater than 1 m/kA. Experiments to evaluate the ^{14}C dates were not conclusive.

3. A marine terrace at an elevation of 150 m in Ventura County was predicted to be 26 kA based on uplift rates derived from other dated terraces. Marine fossils from this terrace yield a ^{14}C age of 26 kA. However, other shell samples from older terraces in the area yield younger ^{14}C ages. The veracity of all the ^{14}C dates on shell in this area must be checked carefully.

4. The cool temperature aspect of the marine molluscan fauna from the Cojo Canyon area at Point Conception tentatively places the age of the faulted and folded marine terrace on which it is found at 85 kA. Amino-acid data from this fauna yield an age of 40-85 kA. Temperature aspect and amino-acid data correlate this fauna with those found to the east on the lowest terrace at Gaviota and Arroyo Hondo.

5. Summarized sea-cliff erosion data along a tectonically downwarped marine terrace in Half Moon Bay, San Mateo County. Man's activities in the shoreline area have greatly accelerated sea-cliff erosion where unconsolidated marine terrace deposits are exposed to wave action but are normally protected by broad sandy beaches at dynamic equilibrium. Other tectonically downwarped areas along the California coast also may be sensitive to the artificial modification.

6. Active geologic process (erosion and sedimentation) on emergent marine terraces generally dominate pedogenic processes so soils can not be used for dating and correlating.

7. Shells from a new marine fossil locality on the third emergent marine terrace on Mt. Soledad in San Diego County yield amino-acid ratios consistent with its' geologically estimated age of 200-300 kA. At least five emergent terraces on Mount Soledad dip southward toward Mission Bay. Previous work by others documented one major warped terrace on Mount Soledad.

8. Calcite-cemented defluidization structures in littoral sands on the south shore of Mono Lake in Mono County are associated with shallow-water tufa deposits. Similar structures in old deposits in the basin mark paleo-lake highstands.

9. Four Holocene emergent marine terraces on the Boso Peninsula near Tokyo, Japan (mapped by Yoko Ota) record at least four major tectonic events over the past 6 kA in that region. Maximum vertical uplift associated with the 1703 earthquake was 4.5 m; maximum uplift associated with the 1923 earthquake was 1.5 m. Study of these terraces in Japan will assist in the interpretation of similar features along the California coast near Point Conception, Point Buchon, and Pitas Point.

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Wasatch Front Surficial Geology

9550-01622

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Investigations

1. The Wasatch Front Surficial Geology project area has been separated into two segments; a northern segment that contains the urbanized east and southern portions of the Great Salt Lake valley, and a southern segment that contains the urbanized portion of Utah Lake valley. The surficial deposits in both segments are being grouped into map units based on selected physical properties so that others can use the data in ground response and microzonation studies along the Wasatch Front.

Results

The project was unfunded during the last six months of fiscal year 1980. During that interval the following was accomplished:

1. A basic-data report of geotechnical tests on samples from test holes at five sites along the Wasatch Front, and of in-hole geophysical results at those sites has received peer technical review and Branch approval for open-file release.

2. The Utah Lake valley surficial geologic map (1:100,000) that was previously compiled was field checked and additions added to the map using the Kern stereoplotter. It is waiting completion.

3. The selection of physical property data obtained from tests on samples collected as part of the earlier field study is complete and ready for placing on the base map of the northern segment of the Wasatch Front area.

4. Two papers were presented at the Rocky Mountain Section of the Geological Society of America at Ogden, Utah.

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Earthquake Hazards Studies, Upper Santa Ana Valley and Adjacent Areas, Southern California

9540-01616

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Investigations

1. Studies of the Quaternary history of the upper Santa Ana Valley. Emphasis is currently on: (a) the three-dimensional distribution of the valley fill and its lithologic, lithofacies, and pedogenic character; and (b) generation of liquefaction susceptibility and liquefaction opportunity maps.

2. Studies of the Banning Fault zone. The study has focused on: (a) mapping fault strands that deform crystalline basement rocks, Tertiary sedimentary rocks, and Quaternary surficial units; (b) evaluating the sedimentary and tectonic evolution of Tertiary sedimentary units within the fault zone; and (c) identification of Quaternary units to establish Quaternary depositional patterns and the relative ages of fault strands within the Banning Fault system.

3. Studies of fault zones of the southeastern San Bernardino Mountains and the eastern San Gabriel Mountains. The emphasis focuses on identifying the relative ages and activity along various fault strands within the San Andreas-San Jacinto system. Current emphasis is on: (a) geometry and kinematics of interactions between San Andreas-type right-lateral faults and Transverse Range-type reverse and thrust faults; and (b) further refinement of ground-rupture recurrence intervals, based on fault scarp morphology.

4. Studies of Quaternary surficial materials within the Perris block. The emphasis focuses on delineation of surficial materials in terms of their ground response characteristics.

Results

1. Geologic mapping in the San Gorginio Pass area has resulted in our being able to extend what is termed the "Banning Fault zone" from Whitewater on the east to the Calimesa area on the west. The oldest structure within this zone, the Banning "A" strand, juxtaposes basement rocks of the southern San Bernadino Mountains against Tertiary sedimentary rocks. West of Cabazon, the Banning "A" strand appears not to have had ground-rupturing displacements during the last 500,000 to (?) 1.0 m.y. The Banning "A" strand is overlain by young Quaternary alluvium north of Beaumont and west of the Calimesa area. Faults west of Calimesa, in the lower San Timoteo-Live Oak Canyon area, previously assigned to the Banning Fault, most likely are tectonic features associated with the Crafton Hills tectonic block, a horst-like feature bounded by geomorphically young normal-appearing faults that break young Holocene alluvium. Throughout the Banning Fault system, a group of intermediate age

strands, here termed the Banning "B" group, offset crystalline basement, Tertiary rocks, and some dissected alluvial units possibly as young as 5000-8000 years (based on a preliminary comparison of their pedology with the soils chronosequence proposed by Bull, Menges, and McFadden in the San Gabriel Mountains). Faults of the Banning "B" group extend from Whitewater west to the vicinity of Live Oak Canyon. Faults comprising the Bannning "C" group offset very young alluvium probably less than 1000 years old. The Banning "B" and "C" strands probably are all thrust faults and reverse faults that probably are all related to each other, and the modern (younger Quaternary) history of the Banning Fault zone is distinctly Transverse Range in flavor. Interaction between Transverse-Range elements of the Banning Fault zone and right-lateral elements of the San Andreas-San Jacinto family remains troublesome. At the eastern extent of the Banning "A","B", and "C" strands (where the right-lateral segment of the Banning Fault exits the Coachella Valley and enters San Gorgonio Pass), we can identify at least three miles of right-lateral displacement in the last 500,000 years, and at least 11 miles of right-lateral displacement in the last 7 million years--both displacements occurring on the Banning "A" strand. Because the Banning "A" strand has been inactive along its westward extent during the last 0.5 to (?) 1.0 m.y., we conclude that during the late Quaternary, minor right-lateral displacements along the Banning "A" have been shunted northwestward to the south branch of the San Andreas fault via Potrero Canyon and Burro Flats. Older right-lateral displacements accounting for part of the 11-mile minimum offset must have occurred on a through-going Banning "A" strand, identified today as far west as Calimesa.

2. Based on mapping in the southeastern San Bernadino Mountains, we conclude that the Mill Creek Fault (Allen, 1957; Dibblee, 1968, termed this structure the north branch of the San Andreas Fault) is locked or is abandoned as a right-lateral fault. The Mission Creek Fault (Allen, 1957; extended by Ehlig, 1977), possibly a major strand of the San Andreas family, also appears to be locked up or abandoned. Field observations indicate that the Mill Creek Fault is younger than the Mission Creek Fault. The Mill Creek system apparently represents a renewed episode of right-lateral slip that developed after the Mission Creek system had locked up or had been abandoned. Following left-lateral shearing and/or faulting that locked up the Mission Creek system, slip along or near the former trace of the Mission Creek fault re-established an episode of right-lateral displacements represented by the Mill Creek fault system. Both faults may now be extinct or temporarily abandoned strands. These preliminary conclusions suggest that the Mill Creek/Mission Creek connection may be a fossil analog for competitive interaction between Transverse-Range and right-lateral fault systems--an interaction presently observed in the Banning Fault zone and at the intersection between the San Jacinto and Cucamonga Fault zones.

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Geologic Earthquake Hazards in Alaska
9310-01026

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Investigations

1. Marine terraces in the Icy Bay segment of the Yakataga seismic gap were investigated to provide information on the rate and amount of Holocene uplift.

Results

1. A sequence of as many as three marine terraces extend for 52 km between Icy Cape and Cape Yakataga in an area identified as a seismic gap along the Pacific-North American plate margin. Raised shorelines at approximately 46 m, 24 ± 3 m, and 12 m near Icy Cape decrease in elevation westward toward Cape Yakataga. Each terrace is characterized by remarkably similar sequences of beach and lagoonal deposits on surfaces cut into both older unconsolidated deposits and bedrock. These sequences are in turn overlain by younger stream deposits as thick as 15 m. Layers containing peat, wood, or organic sediment occur within the lagoonal facies on each terrace. Preliminary C^{14} dates on the organic materials indicate terrace ages of about 5,000, 2,500, and 1,000 B.P. Episodic emergence during a period of rising to stable eustatic sea level requires that the terraces be primarily tectonic in origin, although their heights may be accentuated near Icy Bay by an isostatic component. The indicated average uplift rate is 9 mm/yr near Icy Cape and possibly half this rate near Cape Yakataga. If terrace uplifts correlate with major tectonic earthquakes, the indicated recurrence interval would be 1,500 to 2,500 yr, with maximum uplift steps of 12 to 22 m. Because plate-convergence rates along this part of the Pacific margin are 5-6 cm/yr, the terraces probably record only part of the seismic record in this structurally complex and tectonically active region.

Reports

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Seismic Zonation Studies in L.A. Basin

9940-01730

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Investigation

Statistical analysis of site transfer functions (STF) and tests of equality between nuclear and earthquake derived STP.

Results

Geographical grouping of alluvium and base station sites for earthquake and nuclear STF computations results in improved correlations, indicating that path and source effects are present in the earthquake data that are not present in the nuclear data. Calculation of 95% confidence bounds for the grouped data indicates that the nuclear and earthquake functions are statistically equal for a high percentage of the data.

One open-file report and one paper for outside publication describing these results are nearly complete.

Basement Tectonic Framework Studies
San Andreas Fault System

9950-01291

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Investigations

1. Continuation of field studies of the basement framework rocks on both sides of the Kern Canyon-Breckenridge fault.

2. Complete first draft of Professional Paper entitled: Tectonic framework of the metamorphic and plutonic rocks of the southernmost Sierra Nevada, California (North to 35° 30' N).

3. Petrographic study of thin sections of metamorphic and granitic rocks in the area of the Kern Canyon-Breckenridge fault zone.

Results

1. Additional field work along the Kern Canyon-Breckenridge fault zone has in several localities "reduced" the width of the fault zone, but has by no means diminished its significance as a fundamental basement structure in the southern Sierra Nevada. Rather wide zones of foliated, and in part sheared granitic rocks on the east side of the fault zone, are sufficiently discordant to the fault strike to suggest, at least in part, that they are non-fault-related, older structures. Yet their general localization near the fault zone is tantalizing and still being agonized over.

2. A distinctive belt of felsic metavolcanic rocks with well developed flow structure has been traced to the east side of the fault zone, where it is abruptly cut off--and so far has not been found across the fault. The flow banding in this belt is easily confused with mylonite (at least I was fooled until thin section study and closer field examination revealed well-preserved quartz phenocrysts or clasts, which would have been invariably crushed and ground down in a mylonite environment).

3. The most extensive metamorphic rock type on the west side of the fault zone is a distinctive granular to pebbly quartzite that is surprisingly dark for such a quartz-rich rock. The quartz grains are variable-sized, commonly angular, and largely unsorted, which suggests that they represent a rapidly "dumped" sediment. This unit has been identified across the fault on the east and supports significant right-lateral offset on the fault zone.

Report

Ross, D. C., 1980, A tectonic mystery--Basement rock clasts in the Temblor Range, San Luis Obispo and Kern Counties, California: California Geology, v. 33, n. 7, p. 153-157.

Quaternary Stratigraphy of the Wasatch Front

9530-02174

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Investigations

1. Conducted field investigations along the Wasatch Front and at Little Valley near Promontory Point. Strip-mapping of faults and related deposits was initiated in the Salt Lake Valley between Corner Canyon and Salt Lake City, in the northern Utah Valley near Alpine, and in the southern Utah Valley between Provo and Spanish Fork. In addition, stratigraphic studies of foundation excavations and scarp measurements were continued in Salt Lake City.

2. Led Rocky Mountain Section-Geological Society of America field trip to view faults and Quaternary stratigraphy in the Big Cottonwood area.

3. W. D. McCoy, University of Colorado, collected additional calcareous fossils from key stratigraphic units for amino-acid studies.

Results

1. Stratigraphic investigations yielded additional materials for radiocarbon dating and amino-acid analysis (laboratory results pending) that will better define the history of the last two cycles of Lake Bonneville. A tephra (identification and age pending) was discovered at Little Valley that will aid in our understanding of pre-150,000-year-old lake history.

2. Two areas in the Utah Valley contain evidence that suggests that rates of faulting during the late Quaternary have varied considerably, a possibility that needs to be addressed in estimates of earthquake risk.

At the mouth of Dry Creek Canyon near Alpine, in the northern Utah Valley, studies (in conjunction with R. R. Shroba) of faulted glacial and alluvial deposits reveal that the average rate of faulting during latest Pleistocene-Holocene time is greater than the average rate for the preceding 125,000-year (or longer) interval. Alluvium of latest Pleistocene or Holocene age has a net offset of about 6-7 m--an average rate of about 0.5-1.0 m/Kyr. Till and fan alluvium that are at least 140,000 years old have net offsets of no more than 15-25 m. Subtracting the latest Pleistocene-Holocene displacement of 6-7 m leaves a maximum of 8-19 m of offset over an interval of about 125,000 years--a maximum average rate of 0.06-0.15 m/Kyr.

The 50- to 60-m-high fault scarps in the southern Utah Valley are probably the highest, nearly continuous fault scarps along the Wasatch Front. These scarps are formed in sediments deposited between about 19,000 and 14,000 yr B.P. during the last cycle of Lake Bonneville. Net offsets (eliminating the effects of back-tilt, graben formation, and scarp burial) are difficult to measure or estimate but are probably at least 20-30 m. Alluvial surfaces which are graded to lake levels below the Provo shoreline and which are no less than about 12,000 years old have net offsets of about 10 to 12 m. Apparently one-half to two thirds of the offset of 20-30 m observed in the Bonneville deposits (14,000 to 19,000 years old) occurred prior to 12,000 yr B.P. At present, the distribution of this offset in time is not well constrained, however, the range of values of 1.5 to 10 m/Kyr implies a faster average rate than the average rate of 0.8 to 1.0 m/Kyr estimated from the 12,000-year-old datum.

Salton Trough Tectonics and Quaternary Faulting

9940-01292
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Investigations

1. Continuation of monitoring afterslip of the October 15, 1979 earthquake on the Imperial fault.

2. Field check for surface faulting associated with the M_S 6.3 earthquake of June 9, 1980, in the Colorado River delta region in Mexico.

3. Trenching of fault suspected to be the San Andreas northwest of Bombay Beach.

4. Geologic effects of the Mammoth Lakes earthquakes of May, 1980.

5. Late Quaternary history of the Hilton Creek fault south of the Long Valley caldera.

Results

1. Repeated measurements made at canals offset by the Imperial fault generally indicate that cumulative right-lateral slip continues to grow in linear relation to the logarithm of time. Although the distribution of cumulative slip along the length of the fault rupture shows that most segments of the fault that had small coseismic slip relative to adjacent parts tend to have the largest afterslip, some parts of the fault seem to have remained comparatively "stuck".

2. The instrumental epicenter of this event was located near the Cerro Prieto fault about 55 km south of the international boundary with Mexico (figure 1). The Imperial fault was checked for triggered surface movement in the U.S. and Mexico, and the Cerro Prieto fault was checked where paved roads cross it in Mexico. New surface movements that showed some characteristics of faulting rather than secondary shaking effects of the earthquake, such as liquefaction, were found at the following locations.

   Seven kilometers northwest of the epicenter, en echelon cracks were found crossing the pavement of BCN-4 2.1 km east of its intersection with BCN-3 (open circle in figure 1). Although one crack showed about 1 cm of right-lateral offset, fractures could not be found in hard-packed soil in fields adjacent to the road; the cracking on the road surface therefore is not considered to represent faulting. Cracks found 3 km southeast of the epicenter (open circle in figure 1 shown about 3.8 km southwest of Coahuila) also lay close to the probable location of the Cerro Prieto fault trace, but they could be explained as secondary fractures associated with lateral spreading near a deep ditch that parallels the road.

Left-stepping en echelon fractures with maximum observed right-lateral displacement of 16.5 cm were found along a one kilometer zone just west of the settlement of Ejido Saltillo (figure 1). These cracks are considered to be tectonic fractures or possibly triggered faulting because no evidence of liquefaction or other secondary breakage of the ground surface was detected in the nearby area. These surface breaks lie northeast of the trace of the Cerro Prieto fault and beyond the southeasternmost limit of the Imperial fault rupture, according to its documentation after the 1940 Imperial Valley earthquake by J. P. Buwalda and C. F. Richter. Although surface faulting has not been reported at this location before, the zone of fractures lies near the southeastward projection of the Imperial fault. Because no checking for additional 1940 fault rupture was made beyond the end of the Imperial fault as shown in figure 1, there is no information on whether one or possibly more additional fault strands near the present location of Ejido Saltillo might have been active in 1940. The 1980 fractures are located near a similar trending epicentral zone of numerous recent small earthquakes and swarms, but whether any aftershocks of the June 9, 1980, earthquake may have centered near this surface rupture is unknown at present. Residents of Ejido Saltillo became aware of the surface ruptures shortly after the time of the earthquake in the evening of June 8 (local time).

3. A shallow trench cut into the fault southeast of the surficially expressed trace of the San Andreas fault near Bombay Beach revealed a 1-meter wide shear zone in lake sediments deposited probably early in the existence of ancient Lake Cahuilla. The sediments cut by the fault (1) contain fossil fresh water mussels characteristically found in deposits of Lake Cahuilla, (2) are moderately consolidated, and (3) are mildly folded near the shear zone. Trenches cut at other locations in the Salton Trough indicate initial creation of the lake a few thousand years before present, and the sediments exposed in the new trench may be of about this age. The width of the shear zone in the young sediments suggests large displacement and correspondingly great length. Demonstration of possible continuity of this shear zone with the only other surficially expressed faults in this area, the San Andreas to the north and a previously trenched Quaternary fault to the south at Bombay Beach, will require additional investigation.

4. A 17-km-long zone of intermittent surface ruptures along the Hilton Creek fault was associated with the Mammoth Lakes earthquakes. The ruptures extended northwestward from McGee Creek for 6 1/2 km along a single strand of the fault and then splayed into the Long Valley caldera, mostly along 4 major strands. Width of the splayed zone

reached 4 km. Displacement was extension, roughly normal to the trends of the ruptures. Most of the ruptures followed older scarps, and at these places a vertical component, consistent with past movement, was present. Although most measured displacements were less than 50 mm, at many places slip exceeded 100 mm, and at a few it was greater than 200 mm. At most places horizontal (opening) and vertical components of slip were roughly equal. Southeast of the caldera the ruptures followed a part of the Hilton Creek fault that dips NE and has a prominent NE-facing 500-1000-m-high scarp. In the caldera, however, the ruptured splays dip either NE or SW at the boundaries of horsts and graben.

Although the 1980 ruptures offset late Quaternary lavas in a few places in the caldera, most ruptures occurred in or at the boundaries of unconsolidated deposits on the faces of scarps. Hence a component of downslope movement was probably present to some degree in all of these places.

One of the main questions about the surface ruptures is whether or not they represent true fault slip, or merely slumping and consolidation of loose material on downthrown blocks or scarp faces.

Evidence favoring a non-tectonic origin for the ruptures is:

1. Ruptures are very discontinuous.

2. Slip varies greatly along strike of the ruptures.

3. Largest slip tends to occur on high scarps that have large piles of unconsolidated debris.

4. Slip vectors are roughly normal to the variable local strike of ruptures, rather than to the average strike of the fault.

Evidence favoring a tectonic origin for the ruptures is:

1. Ruptures are almost entirely along scarps and previously recognized faults. Almost no ruptures occur along similar but non-tectonic scarps or slopes of unconsolidated material near the faults.

2. Ruptures did not extend SE of McGee Creek along the Hilton Creek fault, even though that area was as close to epicenters as parts of the fault that do show ruptures.

3. Ruptures offset bedrock locally.

Among the most impressive geologic effects of the earthquakes were the large numbers of rock-snow avalanches and individual rock falls in the Sierra Nevada, particularly in the metamorphic terrane of Convict and McGee Creeks. For example, large rock-snow avalanches with prominent flow structures and dimensions approaching 1 km descended the east face of Mt. Baldwin above McGee Creek and across the trail below Sevehah Cliff at Convict Creek. Shaking dislodged thousands of boulders from outcrop and deposits on the walls of both canyons. Dimensions of some of these boulders exceeded 3 m. They rolled and skipped to the bottoms of the canyons, smashing down full-grown trees and gouging elongate holes in the earth. Had the earthquake occurred later in the summer, when people travel and camp in these canyons, many would have died.

5. Southeastward from Long Valley caldera, the late Quaternary trace of the Hilton Creek fault enters the Sierra Nevada and follows the base of a 500 to 1000-m-high older bedrock scarp, except where it crosses the large glaciated canyons of McGee and Hilton Creeks and the mouth of a small glaciated tributary to Rock Creek about 1 km NW of Rock Creek Lake. The late Quaternary trace dies out southward along the west wall of the canyon of Rock Creek.

Late Quaternary displacement across the Hilton Creek fault has been dominantly dip-slip, NE side relatively down. No evidence was found of a significant component of strike-slip. Apparent right-offset of moraine crests on the west side of McGee Creek is the result of dip slip on an inclined fault plane that strikes obliquely across the moraine crests.

Late Quaternary displacement is difficult to estimate along the active, high angle slopes that characterize the main scarps of the Hilton Creek fault. At the three glaciated canyons, however, the fault displaces relatively stable, low-gradient glacial deposits of different ages. Tentative correlations and ages of these deposits and their fault displacements are shown in the following table.

Glaciation (approx. age, in) 10^3 y bp)	Vertical component of normal faulting of glacial deposits along Hilton Creek fault, in meters		
	McGee Creek	Hilton Creek	Rock Creek Tributary
Latest Tioga (10)	17	2-4	1-3
Maximum Tioga (20)	25	7	-
Tenaya(?) (25-40?)	40	-	-
Tahoe (60-130)	130	14-17	-

These figures demonstrate variability of late Quaternary offset from one place to another along the Hilton Creek fault, a not surprising finding. They are not reliable enough, however, to either establish or deny uniformity of late Quaternary displacement rates.

Reports

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Sharp, Robert V., Lienkaemper, James J., Bonilla, M. G., Burke, D. B., Cox, B. F., Herd, D. G., Miller, D. M., Morton, D. M., Ponti, D. J., Rymer, M. J., Tinsley, J. C., Yount, J. C., Kahle, J. E., Hart, E. W., and Sieh, K. E., 1981, Surface faulting in the central Imperial Valley, in The Imperial Valley, California, earthquake of October 15, 1979: U.S. Geol. Survey Prof. Paper (in press).

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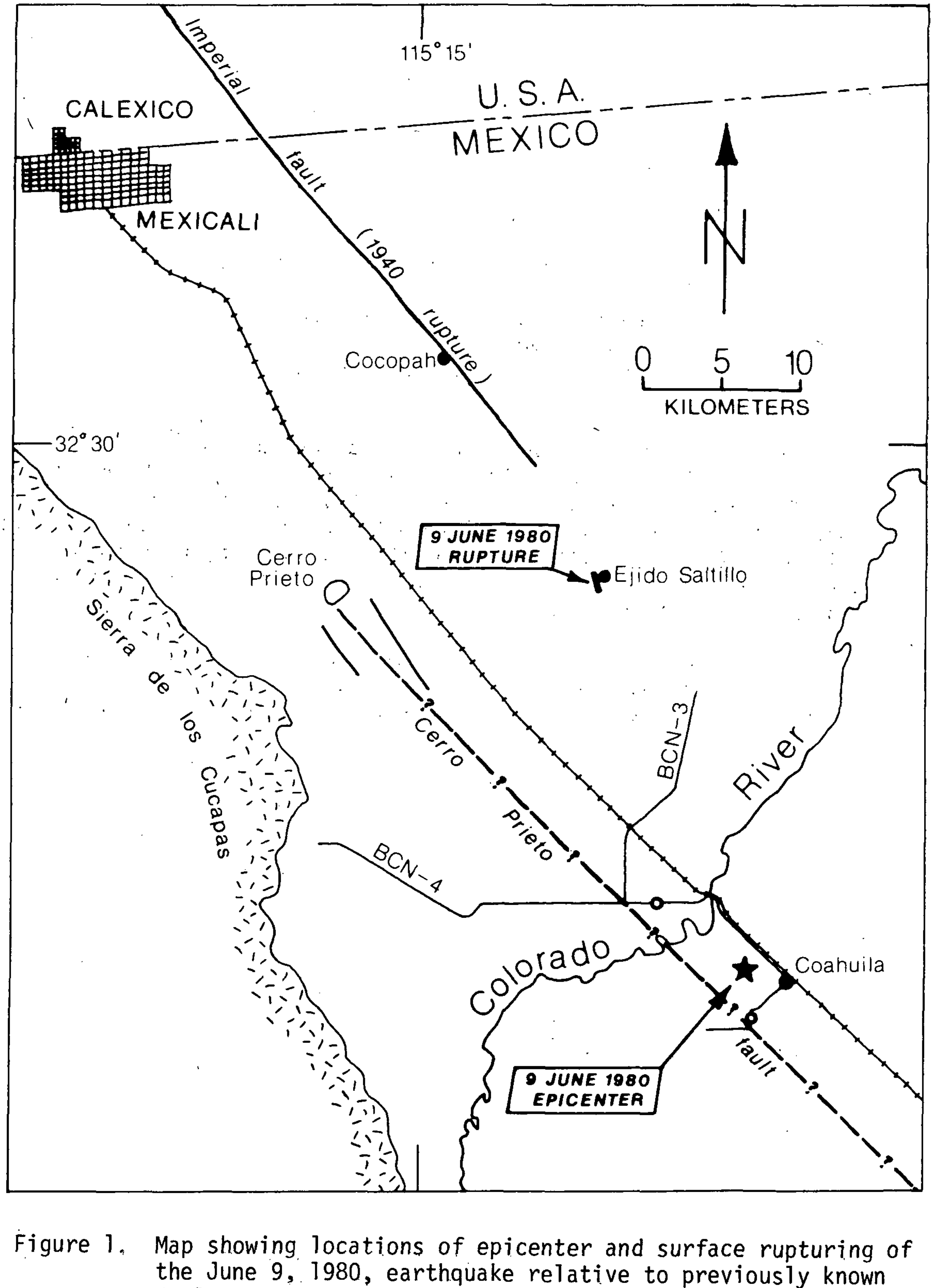

Figure 1. Map showing locations of epicenter and surface rupturing of the June 9, 1980, earthquake relative to previously known faults in the delta region of the Colorado River.

Determination of Epicenter and Magnitude for the Southern California-Baja California Earthquake of February 23, 1892

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On the basis of old newspapers, diaries, and personal interviews, 96 localities have been assigned intensity values for the northern Baja California earthquake of February 23, 1892 based on the Revised Intensity Scale of 1979. Iso-intensity contours place the apparent epicenter near the northern end of the Sierra Cucapah, possibly on the Laguna Salada fault (Barnard, 1968). The intensity near the epicenter was at least X.

Using the relation between seismic moment of an earthquake and the area within isoseism VI (Hanks and others, 1975) calculations show that the earthquake had an intensity between 7.5 and 7.8.

Quaternary Framework for Earthquake Studies, Los Angeles, California

9540-01611

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Investigations

1. Completed describing, sampling, and laboratory analyses of pedogenic soils in a transect across southern California from the Los Angeles basin through San Gorgonio Pass across the Mojave Desert to the Vidal area (L. McFadden and J. Tinsley).

2. Assisted M. M. Clarke with field studies of surface faulting and ground failure associated with the Mammoth lakes earthquake sequence, May 25-27, 1980.

3. Completed initial compilation of ^{14}C dates, southern California and Los Angeles basin areas (C. Hastorf and J. Tinsley).

4. Continued 1/24,000 geomorphic/photogeologic/soil stratigraphic mapping of surficial geology in the Los Angeles basin and in the upper Santa Ana Valley, California.

5. Commenced installing on the USGS computer the geotechnical data base for the San Fernando Valley prior to completing assessment of liquefaction susceptibility. This effort uses programs written by D. Ponti (USGS)

6. With G. Wieczorek (Engineering Branch, Menlo Park), conducted a study of rock-falls in Yosemite National Park generated by the Mammoth lakes earthquake sequence of May 25-27, 1980.

Results

1. Chemical analyses of iron oxyhydroxides formed on lithic arkosic alluvium under different climates in southern California indicate that the ratio of ferrihydrite (NH_4-oxalate soluble) to total free iron oxyhydroxides (dithionite soluble) changes with time. Maximum ratios (0.2-0.6) of ferrihydrites to total free iron oxides characterize late Pleistocene soils and early Holocene soils. The ratio decreases progressively in older soils as initial kinetically metastable ferrihydrite is transformed into more stable hematite, presumably by crystal aggregation and dehydration. A similar trend in this ratio occurs between horizons of pedons. Minimum ratios occur in the argillic horizons and maximum ratios generally occur in Cox horizons, respectively the oldest and youngest parts of the soil profile. Minimum ratios (0.01-0.08) characterize old soils whose ages are at least 0.5 m.y. The technique using the oxyhydroxide ratio provides means of distinguishing among the soils of this chronosequence. The youngest soils (Holocene) are

best differentiated according to other criteria such as thickness and character of the A horizon and the Cox horizon and the presence/absence of a textural B horizon.

2. Field notes, maps, and photographs were transmitted to M. M. Clark for inclusion in a forthcoming report of investigations of the Mammoth Lakes earthquake sequence.

3. A miscellaneous Field Studies Map showing localities dated by ^{14}C techniques and an explanatory text is in TRU map review.

4. Surficial geologic mapping is 70% completed in the LA Basin.

5. Installation of San Fernando Valley geotechnical data base is 3% completed.

6. The results of the study of rockfall hazards in Yosemite Valley, California were transmitted to the Superintendent via an administrative letter. In part, the report concluded that new and recurring rockfalls could be anticipated if earthquakes occur having local intensities approaching or exceeding those of the May 25-27 eathquakes. The talus deposits on the Valley's floor indicate areas subjected to rockfall during post-Tioga time (last 12000 years) and these areas are most likely to be the sites of future rockfalls. In general, new rockfall appeared to occur where joints in the wall rock were rather closely-spaced. Verbal accounts describing the effects of the earthquakes experienced by rockclimbers while climbing. Climbers observed that exfoliating slabs or towers of rock vibrated vigorously during the earthquakes. In several instances, rock debris which had accumulated on ledges on these slabs was displaced by the earthquake shaking and fell between the oscillating slab and the adjacent rock wall. The effects of this process, when repeated during moderate or great earthquakes, would be to weaken the slab near its base and gradually split the slab from its former position adjacent to the wall, ultimately causing catastrophic failure of the slab through this gravity-driven ratchet-like mechanism.

<u>Reports</u>

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McFadden, L. D., Hendricks, D. M., and Tinsley, J. C. Changes in pedogenic iron oxyhydroxide with time in soils formed on lithic arkosic alluvium, southern California. Abstract approved by the Director 9/80

Geothermal Tectonic Seismic Studies

9930-02097

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Investigations

1. Seismicity. During the last half of the fiscal year, 5 additional seismic stations were installed in the Olympic network, completing the basic network. A study has been initiated to test the hypothesis that active, northwest-striking, right-lateral strike-slip fault zones may be present in the upper 20 km of the crust in western Washington.

2. Crustal Structure Studies. Two temporary refraction lines were deployed across the Olympic Peninsula in western Washington to record a series of blasts set off during a Canadian study of the crustal structure of Vancouver Island, British Columbia. Twenty-three stations were placed to record not only the Canadian blasts but also to continue crustal studies using the Centralia, Washington, strip-mine blasts as seismic sources.

Results

1. In the short time the network has been operating, only two earthquakes have been located within the network. One event was deep (approximately 25 km) and was recorded only on the Olympic network stations, so it is possible that the Olympic Peninsula is not as seismically quiet as has been concluded from studying data collected with stations to the east.

2. The preliminary data from the refraction experiment show that clear arrivals were recorded at both the permanent and temporary stations from shots in the Strait of Juan de Fuca (crustal phases at distances of 100-200 km) and from Jervis Inlet on the Canadian mainland (mantle arrivals at distances to 400 km). The crustal phases from these blasts indicate that P-wave arrivals on the Olympic Peninsula tend to be delayed by approximately one second relative to arrival times in the Puget Sound region. This result initially collaborates earlier work using the Centralia strip mine blasts to delineate differences between Puget Sound and Olympic structures. The preliminary data do suggest that the structural differences are not simple and will require careful analysis. As analysis proceeds on this data, a refinement of the velocity model used in the earthquake location process will result.

Reports

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GEOLOGIC INVESTIGATION OF RECURRENCE INTERVALS AND RECENCY OF FAULTING ALONG THE SAN GREGORIO FAULT ZONE, SAN MATEO COUNTY, CALIFORNIA

Contract No. 14-08-0001-16822

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During the past two years we have examined a portion of the San Gregorio fault zone near Point Año Nuevo in southern San Mateo County, California. Our study has focused primarily on two reverse faults within the San Gregorio fault zone - the Año Nuevo thrust fault and an unnamed fault, referred to in this report as the Cascade Quarry reverse fault.

Reverse faults appear to be particularly amenable to studies of sequential fault movement. Over a period of years the scarp associated with each faulting event is eroded, and the sediment is washed off of the hanging-wall block onto the footwall block, forming a colluvial wedge. This sedimentary record is preserved by subsequent movement which pushes the hanging-wall block over the sedimentary sequence on the footwall block.

The geologic and geographic setting at Point Año Nuevo makes this area very productive for a study of late Pleistocene sequential movement along reverse faults. First, exposures of the late Pleistocene marine terrace deposits and the faults both in sea cliffs and in man-made cuts are excellent. Second, both the Año Nuevo thrust fault and the Cascade Quarry reverse fault offset the wave-cut platform and the deposits of the first marine terrace. The presence of the marine terrace is of utmost importance to the study because both the age of the marine terrace and the original orientation of the wave-cut platform are known. The terrace therefore provides a well-defined datum plane from which to measure structural deformation. It also provides an ideal starting point in time for the reconstruction of the faulting events; the wave-cut platform was created in the surf zone of a transgressing sea that reached a highstand 105,000 years B.P. Third, low rates of erosion and deposition allowed the evidence of sequential fault movement in the terrace sediments to be preserved.

We conducted detailed surface mapping and logged numerous exposures of reverse faults in sea cliffs, exploratory trenches, and an abandoned quarry. This examination of stratigraphic and structural relationships, supplemented by amino-acid and radiocarbon dates, enabled us to make reasonably complete reconstructions of the late Pleistocene history of faulting. Detailed mapping of exposures of the Año Nuevo thrust fault in an exploratory trench indicates repeated fault movement with the most recent faulting event offsetting deposits of an interdune pond. Organic material in the matrix of the pond deposits has yielded a ^{14}C date of 6060 ± years B.P. Hence, there is strong evidence of Holocene activity along this fault.

Analysis of the fault pattern near Point Año Nuevo indicates that the San Gregorio fault zone is a large right-lateral strike-slip fault zone undergoing local convergence. The geologic data and the pattern of faulting indicate the presence of two principal displacement shears - the Frijoles fault and the Coastways fault. These two faults have been the loci of essentially all of the middle to late Pleistocene movement.

In addition to the principal displacement shears there are numerous secondary faults that have experienced late Pleistocene movement. It is possible to relate the amount of movement on one secondary fault, the Cascade Quarry reverse fault, to movement on the Frijoles and Coastways faults. If our analysis of marine terrace deformation is correct, the Cascade Quarry reverse fault experiences only 5% of the total movement across the fault zone.

It appears that there is a general relationship between the thickness of a colluvial wedge on the footwall block of a reverse fault and the height of the fault scarp that must have been eroded to form the wedge. Consequently, it is possible to approximate the initial scarp height (in this study) as 1.6 to 2.2 times the measured thickness of the colluvial wedge. This scarp height-wedge thickness ratio can be used to approximate the magnitudes of earthquakes associated with each faulting event.

It appears that movements on the Cascade Quarry reverse fault are relatively large, with vertical surface displacements of 3 - 8 ft. and horizontal displacements of up to 12-13 ft. It therefore appears as if the sizes of the individual surface displacements along the secondary traces studied, the Cascade Quarry reverse fault and the Año Nuevo thrust fault, are similar to the size of the surface displacements along the primary faults, the Coastways fault and the Frijoles fault.

Because of these observations, we question the concept that secondary faults experience only small surface displacements. We suggest that faulting events along both the Cascade Quarry reverse fault and the Año Nuevo thrust fault occur infrequently. When an earthquake accompanied by surface rupture on a secondary trace does occur, the secondary trace temporarily acts as the primary locus of faulting, and surface displacements are greater on the "secondary" fault than on the principal displacement shear. We see no evidence to suggest that the secondary faults in the San Gregorio fault zone regularly experience small displacements during major faulting events on the primary faults.

The magnitude of the maximum credible earthquake that could occur along the San Gregorio fault zone was estimated in three ways. First, we determined the maximum surface displacements that have occurred along the Cascade Quarry reverse fault. Using the regression analysis of Bonilla and Buchanan (1970) we determined that earthquakes must have varied from 6.0 to 8.0 Richter magnitude to produce the calculated surface displacements.

Two additional methods that we used to estimate the maximum credible earthquake magnitude were: (1) to estimate the surface rupture length and (2) to estimate the size of the area of rupture on the fault plane (Wyss, 1979). The estimates for the maximum credible earthquake vary from 7.3 to 7.6 for a fault 115 miles long and from 7.6 to 7.8 for a fault 260 miles long. We conclude that the maximum credible earthquake for the San Gregorio fault zone is at least 7.6 - 7.7 and may be greater than 8.0 Richter magnitude.

We have attempted to determine the recurrence interval for major earthquakes along the San Gregorio fault zone at Point Año Nuevo using three methods. (1) Long-term slip rates determined from offset marine terrace shoreline angles suggest that the recurrence interval for 7.5 magnitude earthquakes is 220-400 years. (2) Our study of the Cascade Quarry reverse fault indicates that the maximum recurrence interval ranges from 375 to 440 years for a 7.0 - 7.5 magnitude earthquake. (3) An analysis of cyclical sag pond deposits exposed along the south shore of Point Año Nuevo indicates a recurrence interval of about 365 years for an earthquake of magnitude 6.5 or greater. Consequently, we conclude that a realistic estimate of the recurrence interval for major earthquakes (M=7.5) along the San Gregorio fault zone is between 225 and 400 years, with a best estimate of 300-325 years.

Tectonic Tilt Measurements Using Lake Levels

9950-02396
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Investigations

Measurements of land-surface tilt were made using water-level records from large lakes in southern Alaska and Utah. Water levels are recorded simultaneously at an array of stations on a lake. These records are referred to local bench marks. In June, 1980, measurements were made on Eyak, Bering, Harlequin, Klutina, and Kenai Lakes. The latter two were measured in 1964, 1966, 1979, and 1980. Stations at Eyak and Bering Lakes were established in 1979. Stations at Harlequin Lake were established in 1980. An additional station was established on the Great Salt Lake, Utah, and measured in May and September, 1980.

Results

The 16-year record of water-level differences on Kenai and Klutina Lakes is shown in Figure 2. The 1964 measurements were made in June, following the earthquake. Water levels were read on a rod placed in the water and referenced by leveling to nearby benchmarks. 1966 measurements by A. Grantz and D. McCulloch were improved by using a stilling well and recording water levels over several hours in order to eliminate the effect of periodic seiches. The 1979 and 1980 measurements used one-to-four-day continuous recordings of lake levels with a Stevens 'F' recorded on a stilling well. The strip-chart record is twice referred to permanent bed-rock benchmarks by precise level and rod.

Records from other lakes (Salton Sea, Great Salt Lake, and published data from Scandanavian Lakes) suggest the noise level of annual measurements of differenced lake levels is 20 to 40 mm. Simultaneous recordings during times of little or no wind show water levels of large lakes can be very stable and fluctuate only a few millimeters. The most serious noise is long period, and seasonal. The major cause may be seasonal variations in inflow. Therefore, records of lake levels will not easily detect small land surface tilt that develops over periods of a few months to a year. Nevertheless, small tilt rates over several years are resolvable.

The record from Klutina Lake indicates downtilt of the land surface toward the west between 1964 and 1966 amounting to about 70 mm over a distance of 25 km. Since the 1964 measurements may have been crude, the 1964 value may differ from the rest because of an erroneous or crude measurement. From 1966 to 1980, the changes are small and within the noise level.

The record from Kenai Lake (Fig. 2) also indicates downtilting to the southwest. Since the 1966 and 1964 differences are about the same, as are the 1979 and 1980 pair, this tilt of 200 mm appears to be significant and may be related to crustal uplift of similar magnitude and timing reported from leveling comparisons by Brown et. al. (1977).

Water level records from the Great Salt Lake, Utah, have been found to be influenced by damming of the recording area by sediment. Apparent tilt in that area is being re-examined.

Reference

Brown, L.D., Reilinger, R.E., Holdahl, S.R., and Balazs, E.I., 1977, Postseismic crustal uplift near Anchorage, Alaska: J. Geophys. Res., 82, 3369 - 3378.

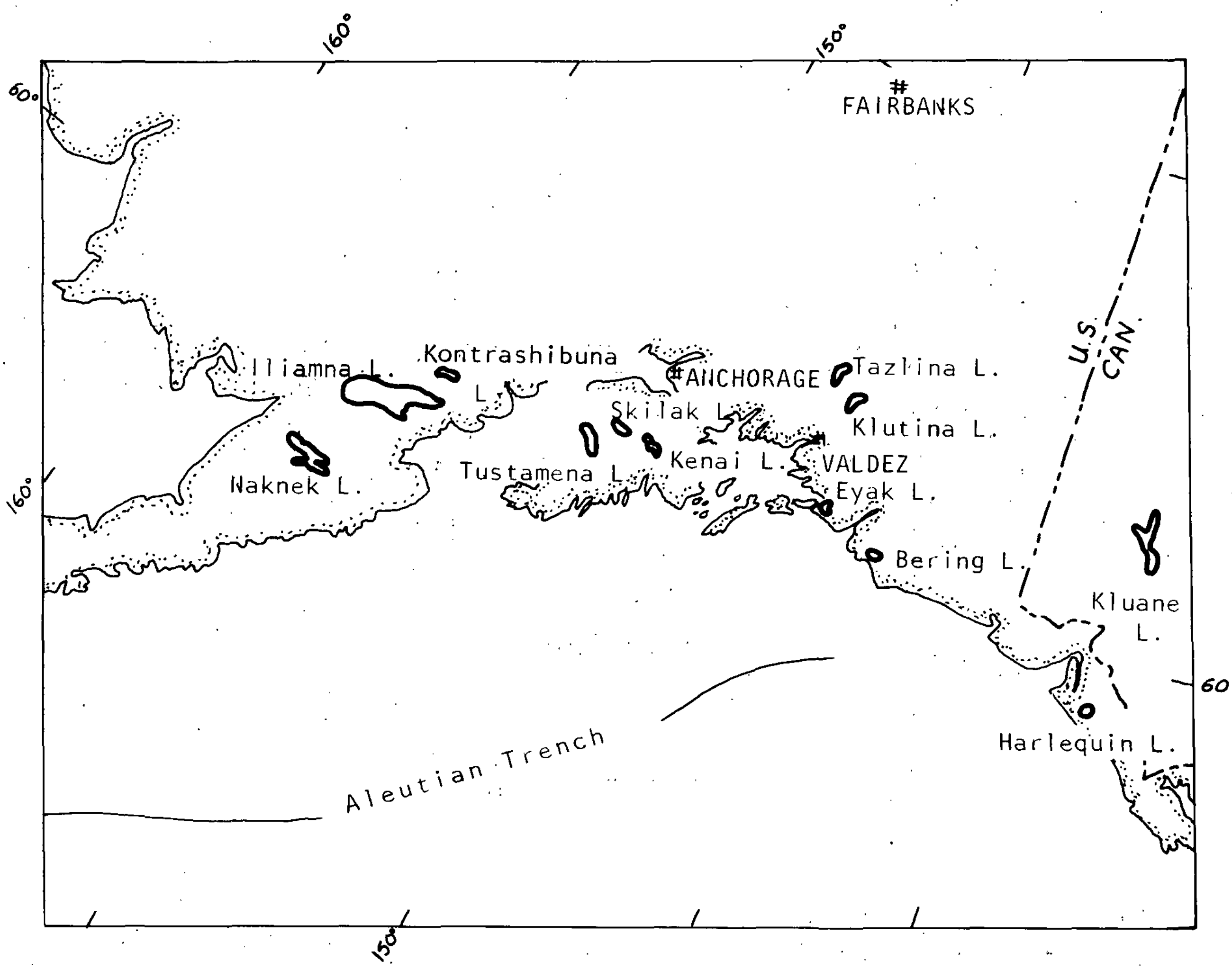

Figure 1. Location of large lakes in southern Alaska and Yukon Territory used to monitor tectonic tilt. Only those lakes with stations re-measured or established in 1979 or 1980 are shown.

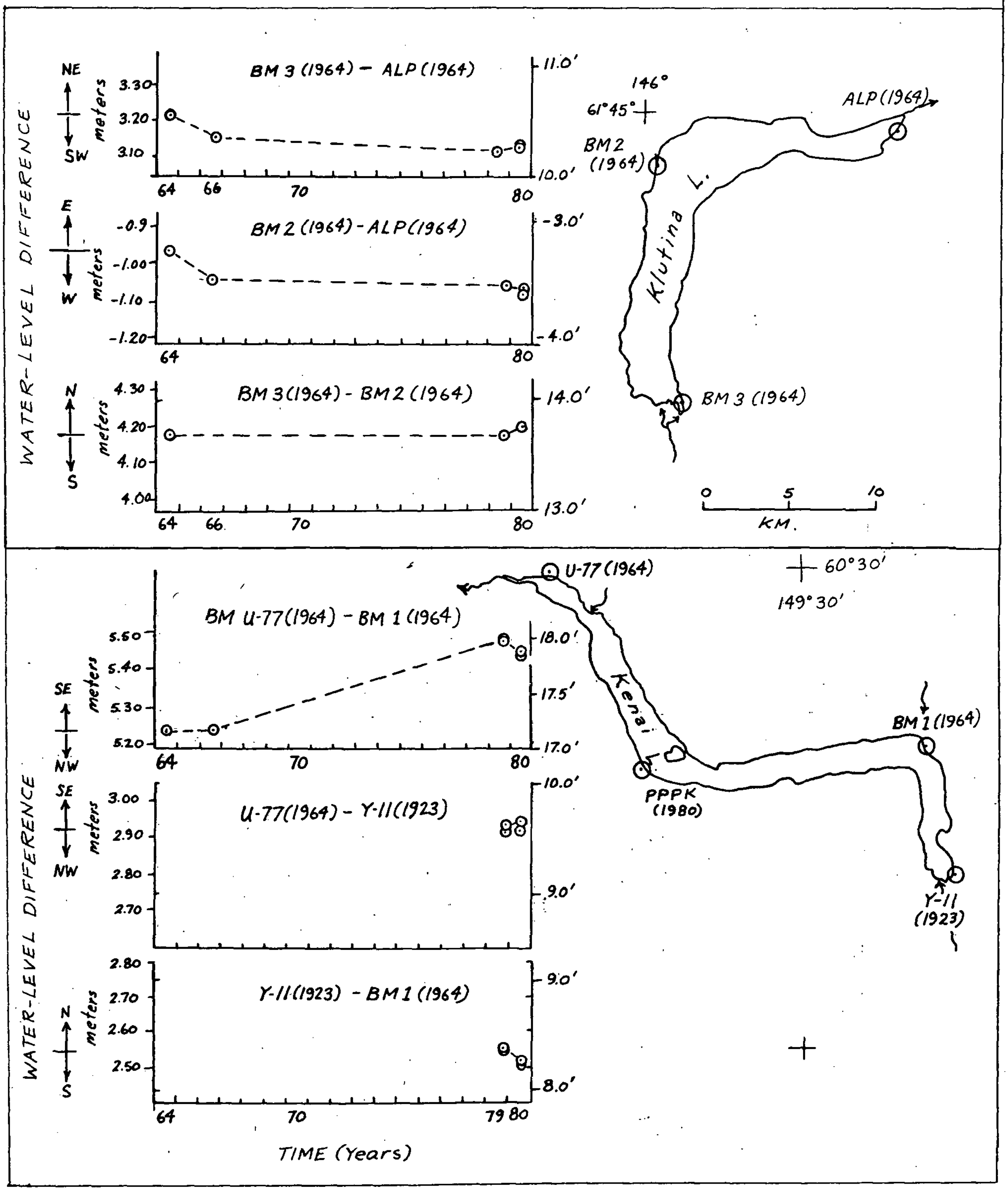

Figure 2. History of water-level differences between pairs of stations on Klutina and Kenai Lakes, southern Alaska. Differences are obtained by simultaneous measurement of the elevation of the bench marks above the water surface. The differences are calculated by subtracting one bench-mark elevation from another bench-mark elevation. This difference will remain constant through time if the water surface or the land surface do not tilt. Changes in the difference can be interpreted as either a temporary tilting of the water surface to a non-level surface or as a change in elevation of one bench mark with respect to the other. Arrows and compass directions on the left indicate direction of downtilting if the difference is interpreted as a change in the relative bench-mark elevations (land-surface tilt).

Earthquake Hazards Studies, Metropolitan Los Angeles-western Transverse Ranges region

9540-02907

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Investigations (Yerkes)[1/]

1. Compiled and evaluated unpublished deep-drill and geophysical data bearing on structural-tectonic history of Santa Barbara Channel-Ventura basin.

2. Completed map at 1:1,000,000 of southern California showing faults and distribution of seismicity since 1812.

3. Collected, evaluated, and began compiling at 1:250,000 fault map of project area incorporating latest offshore and onshore data, including results of numerous OES contracts to outside workers and agencies. Map will show age and attitude data on faults.

4. Began retrieval and processing of post-1932 instrumental seismic data for relocation and focal-plane analysis program.

5. Began collection and evaluation of deep-drill and density-layer data to derive updated seismic-velocity model of Los Angeles basin.

Sarna-Wojcicki[2/]

6. Sampled section west of Ventura in core of Ventura Avenue anticline for paleomagnetic stratigraphy (with Jack Hillhouse, BP&RS, Menlo Park). We sampled stratigraphically below the Bailey ash (dated at 1.2 m.y. by fission track method) to refine age control on the basal part of the section in the Pico Formation. We wish to identify the Olduvai and Gilsa normal events within the Matuyama reversed epoch, and to define the Plio-Pleistocene boundary within this section of late Cenozoic turbidites. We have also sampled a putative correlative ash of the Pearlette type B ash (dated at 1.8-1.9 m.y. by fission-track on zircons; Naeser and others, 1973) in the South Mountain area to determine whether the anomalous magnetic directions for this formation found at other locations can be detected at this locality.

7. Continued mapping, collection, and identification of mid- to late-Pleistocene ashes in the Ventura-South Mountain area of the western Transverse Ranges, including collection of fossil mollusks for amino-acid racemization age dating (in cooperation with K. R. Lajoie and G. Kennedy, BGM&F, 9940-01623.

Results (Yerkes)[1/] Previously reported (in Vol. IX, p. 48-49).

(Sarna-Wojcicki)[2/]

An ash in the basal part of the San Pedro Formation north of Ventura has been identified as the Pearlette type O ash on the basis of chemical and petrographic characteristics. The Pearlette type O ash locality in the Ventura area is the westernmost found to date, and is the first locality where the ash is interbedded with marine strata. The Pearlette type O ash has been dated (Naeser and others, 1973) in the midwestern U.S. (1700 km to the ENE, in Meade County, Kansas), and at its near-source locality (1400 km to the NE, at Yellowstone Park, Wyoming), at 0.6 m.y., both by K-Ar and fission-track dating. The San Pedro Formation is the uppermost marine Pleistocene formation on the south flank of the Ventura Avenue anticline. A previous estimate of the age of the uppermost part of this unit is about 0.2 m.y. on the basis of amino-acid racemization analyses on fossil mollusks (Wehmiller and others, 1977), situated about 600 m stratigraphically above the type O Pearlette. About 300 m stratigraphically below this ash, we have previously identified the Bishop-Friant ash, in the underlying Santa Barbara Formation. The latter ash has been dated elsewhere by others at 0.74 m.y. Thus, the stratigraphic sequence for this section is in agreement with radiometric and amino-acid ages, and confirms our earlier observations regarding acceleration of basin filling in this area during late Pleistocene time.

Reports

Meyer, C. E., M. J. Woodward, A. M. Sarna-Wojcicki, and C. W. Naeser, 1980, Zircon fission-track age of 0.45 million years on ash in the type section of the Merced Formation, west-central California: U.S. Geological Survey Open-File Report No. 80-1071, 9 p.

Sarna-Wojcicki, A. M., Susan Shipley, R. B. Waitt, Daniel Dzurisin, W. H. Hays, J. O. Davis, S. H. Wood, and Thomas Bateridge, 1980, Areal distribution, thickness, and volume of downwind ash from the May 18, 1980 eruption of Mount St. Helens. U.S. Geological Survey Open File Report No. 80-1078, 14 p.

Sarna-Wojcicki, A. M., and R. B. Waitt, 1980, Areal distribution, thickness, and composition of volcanic ash erupted from Mount St. Helens on May 18, 1980. Abs : Geological Society America, Abstracts with Programs, v. 12-7, 1980, p. 515.

1/ Assigned to other projects for 2.5 mos., 40% of reporting period.

2/ Assigned to Mt. St. Helens investigation for 5 mos., 80% of reporting period.

Earthquake Hazards of the Puget Sound Region, Washington

9540-02197

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Investigations

1. Bedrock geologic mapping in the Seattle 1:100,000 and Port Townsend 1:00,000 map areas has been done in order to delineate known Tertiary tectonic features which might still be capable of generating earthquakes.

2. Compilation of available subsurface data in the Port Townsend 1:100,000 map area and Bremerton East and Bremerton West 7-1/2' quadrangles is being done in order to portray the nature and depth distribution of various Quaternary units in the Puget Lowland which likely control ground response to seismic shaking and potential for liquifaction.

3. An investigation of late Pleistocene to Holocence geology in the eastern Strait of Juan de Fuca using marine seismic reflection profiles was undertaken so that the extent and character of faulting in this offshore area can be evaluated.

4. Continuing investigation of the deep (40 to 70 km) suite of earthquakes beneath the Puget Lowland and their relationship to major geologic trends in the region has led to refinement of a seismotectonic model for the Puget Sound Region.

Results

1. The bedrock geologic map of the Seattle 1:100,000 scale sheet has been completed and is in review. The main features of tectonic importance are a series of roughly east-west trending faults running from south of Bremerton East to Issaquah near the top of the steep gravity gradient marking the southern rim of the Seattle Basin. These faults cut progressively younger parts of the Eocene and Oligocene section going from north to south toward the Seattle Basin, with the youngest Tertiary outcrops (Miocene?) just east of Lake Sammamish being overturned to the south.

2. The bedrock geologic map of the Port Townsend 1:100,000 scale sheet is nearing completion. The most significant features shown are: 1) heretofore unrecognized north to north-east trending normal faults which offset Mesozoic trust plates in the Cultus Mountain area. 2) additional traces and extension of the east-west trending Devil's Mountain fault zone. 3) detailed expression of north to northeast trending normal faults cutting Eocene conglomerates in the Sunset Lake area southeast of Discovery Bay.

3. A 1:250,000 scale seismotectonic map of the Puget Sound Region has been

completed and is in review. This map supersedes Open-File Report 78-426 and in addition to showing faults, principal folds, and sites of Quaternary deformation, also includes locations of earthquakes from 1970 to 1978, and a short discussion of earthquake distribution as related to geologic setting and major geologic trends.

4. A preliminary investigation of subsurface conditions in the Bremerton area has delineated a few localities that are underlain by Quaternary deposits which might be susceptible to stong ground shaking due to their nature and possible amplifaction effects from near surface Tertiary bedrock. The Gorst Creek Valley, the Heins Creek Valley south of Kitsap Lake, and the Waterman-Enetai Region along Port Orchard appear particularly susceptible.

5. A workshop on earthquake hazards in the Puget Sound Region was held this past October (1980), with some 32 geologists and geophysicists discussing various aspects of neotectonism, earthquake distribution, current stress fields, plate tectonic setting, and slope stability problems in the Puget Lowland. Papers presented are to be published as an Open-File Report in the continuing series of conference volumes of the Earthquake Hazards Reduction Program of the USGS, sometime early in 1981.

Reports

Gower, H. D., 1980, Bedrock geologic and Quaternary tectonic map of the Port Townsend area, Washington: U.S. Geological Survey Open-File Report 80-1174.

Wagner, H. C., and Wiley, M. C., 1980, Preliminary map of offshore geology in the Protection Island-Point Partridge area northern Puget Sound Washington: U.S. Geological Survey Open-File Report 80-548.

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Geophysical and Tectonic Investigations of the Intermountain Seismic Belt

9950-02669

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Investigations

1. Field measurement of slip indicators (slickensides) within the Wasatch fault zone. Emphasis was placed on exposed Holocene bedrock scarps along various segments of the Wasatch.

2. Analysis of the late Cenozoic evolution of the state of stress and tectonic style of extensional deformation in the Basin and Range province. Both a change in the stress orientation and the timing of this change were evaluated.

3. Constraints on sources of Central and Eastern United States seismicity implied by regional stress patterns.

Results

1. Measured Holocene slip directions along the Wasatch fault zone in Central Utah have horizontal aximuths (extension directions) ranging between N 76° W to N 134° W on normal faults which range in strike between N 35° W to N 42° E. This pattern of basin-range horizontal extension is quite different from northern Nevada where measured extension directions vary between N 55° W to E-W on faults whose strikes vary between N 15° W to N 75° E (Zoback and Zoback, 1980). An analysis of the Utah slip data is presently underway to determine the orientation and relative magnitudes of principal stresses responsible for the Wasatch Holocene slip events. The analysis involves a least-squares determination of a mean stress tensor for the slip events on a family of faults assuming each observed slip direction represents the direction of maximum resolved shear stress on each fault.

2. Extensional tectonism responsible for the modern physiography of the Basin and Range province appears to represent a unique late stage episode of a much longer period of extension initiated in an "intra-arc" setting contemporaneously with calc-alkaline magmatism. Basin-range extension is distinguished from early extension on the basis of angular unconformities, differences in fault trends and spacing, and associated magmatism (basaltic). Pre-basin-range extension (i.e. extension preceding the breakup of the region into ranges resembling the modern ones) was underway locally by at least 30 Ma. and is now recognized by faulted and highly tilted strata exposed in uplifted range blocks, by large regions of the crust underlain by passively emplaced subvolcanic batholiths, and by the thickness and distribution of stratigraphic units. Data on preferentially oriented dike swarms and fault sip vectors indicate a strikingly uniform WSW-ENE least principal stress orientation in the period ca. 20-10 Ma, during this early extension (see Figure 1). The change from early extension to basin-range faulting of the upper 15 km of crust and resulting in broadly spaced ranges (25-35 km crest-to-crest spacing) was time-transgressive and probably not abrupt; locally both types occurred

concurrently. Southern Basin and Range block faulting largely occurred in the period 13-10 Ma., in response to a stress field oriented similarly to that responsible for the early extension. In contrast, northern Basin and Range block faulting developed after 10 Ma. and continues to the present in response to a stress field oriented approximately 45^{o} clockwise to the earlier stress field. This modern stress field, with a WNW-ESE to E-W directed least principal stress, characterizes the entire modern Basin and Range province and the Rio Grande rift region. The 45^{o} change in least principal stress orientation is consistent with superposition of dextral shear associated with the development of the San Andreas transform. Inclusion of pre-basin-range extension may help resolve the discrepancy between estimates of 15-30% for basin-range block faulting and total extension estimates for the Basin and Range of 100-300%.

3. Utilizing a compilation of principal stress orientations for the conterminous United States (Zoback and Zoback, 1980 — described in the last semi-annual report) sites and sources of central and eastern U.S. seismicity have been analyzed. The stress data indicate relatively uniform regional stress patterns contradicting the hypothesis that local stress concentrations (e.g. due to mafic intrusions) may affect orientations of the principal stresses. Earthquakes and young faulting along the Atlantic coast region (including the coastal plain in the south and much of the New England Appalachian belt in the north) result from generally NW-SE compression. Seismicity and faulting in this region may coincide with and result from reactivation (in a reverse sense) of NE-trending Triassic (?) rift faults related to the opening of the Atlantic. Recent detailed field investigations along these fault zones has lead to the suggestion (by several geologists) that Paleozoic mylonite zones have localized both the late Cenozoic slip and the Triassic (?) grabens. Source of the NW-SE compression in the Atlantic coast region is unknown. Generation of this NW-SE compressional stress field by gravitational backsliding along a major gently eastward-dipping decollement presently believed to underlie the southern Appalachians is inconsistent with stress indicators suggesting compressional not extensional tectonism in the topographically high, "breakaway" region of the fold belt. Central U.S. seismicity, dominated by the New Madrid region, also appears localized in a region of favorably oriented pre-existing faulting. This faulting is thought to be related to a pre-Late Cambrian continental rift underlying the Mississippi embayment. Restriction of seismicity to the axis of the old rift and not along the bounding faults with $\sim$2 km of basement offset seem to require a weakening mechanism along the axis of the rift.

Reports

Zoback, M. L., Anderson, R. E., and Thompson, G. A., 1980, Cenozoic evolution of the state of stress and style of tectonism of the Basin and Range province of the Western United States, Philosophical Trans. Royal Society London, in press.

Zoback, M. D. and Zoback, M. L., 1980, State of stress and intraplate earthquakes in the central and eastern United States, submitted to Science.

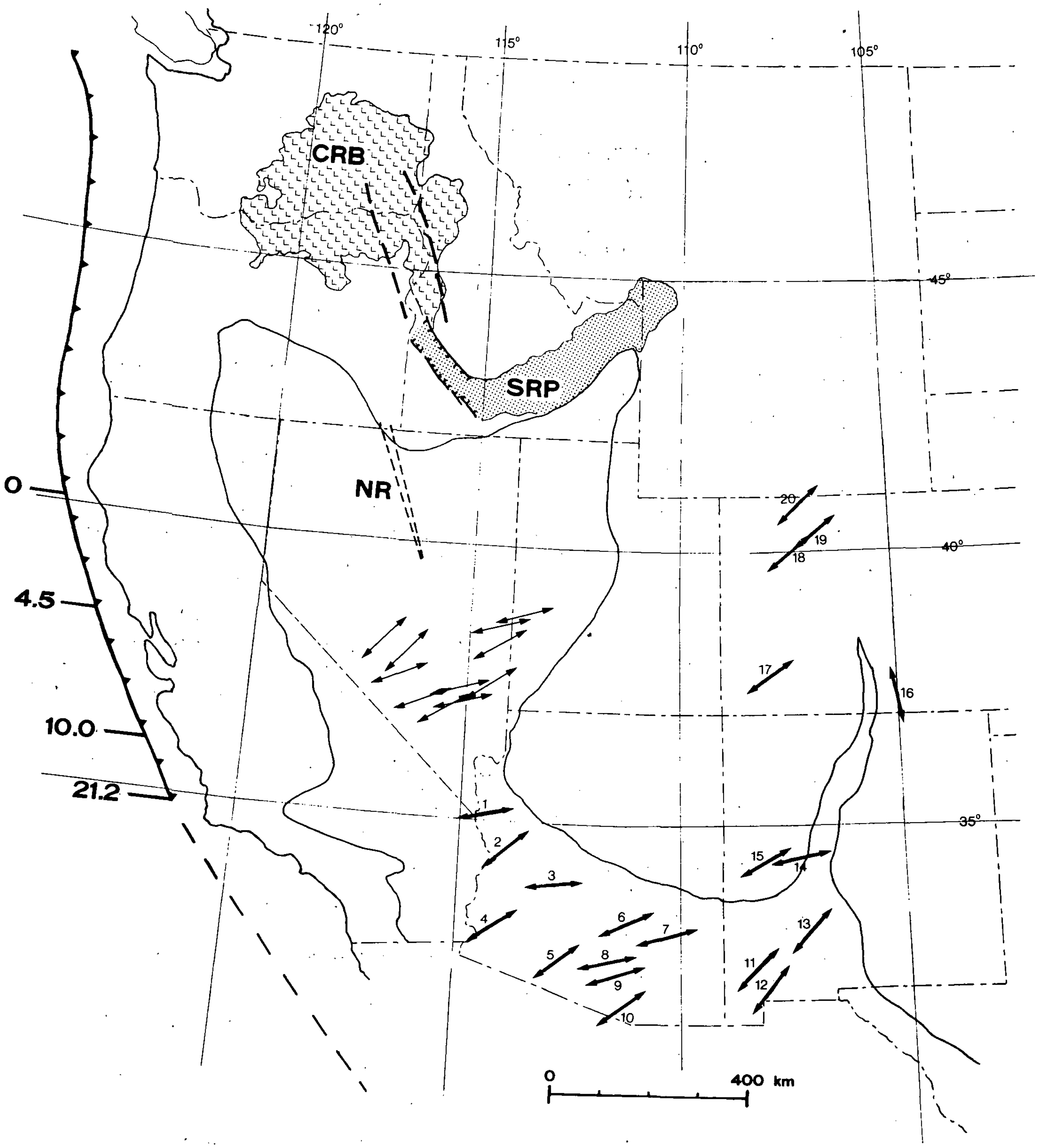

Figure 1: Miocene (ca. 20-10 Ma.) extensional tectonism. NNW-trending zone of rifting in the north includes a broad zone of feeder dike swarms (heavy dashed lines) for the Columbia River basalts (CRB), western graben of the Snake River Plain (SRP), and the Nevada rift (NR) (short dashed lines). Modern Basin and Range and Rio Grande rift province is outlined. Light arrows in southern Nevada are Miocene extension directions inferred from fault trends and stratal tilts within ranges. Heavy arrows are Miocene least principal stress directions inferred from dike trends. Numbers along subduction zone (barbed line) show southern extent of subduction (in m.y.B.P.). Dashed lines offshore indicate probable trend of subduction zone now replaced by transform fault.

Late Tertiary and Quaternary Shoreline Datum Planes and Tectonic Deformation in the Southeastern United States

9590-02744

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Investigations

1. Uplift rates for the last 3.0 m.y. were calculated for South Carolina and southern North Carolina from comparison of the present position of emerged marine shorelines and current models for eustatic sea level.

2. Geologic mechanisms that might account for the observed uplift rates were investigated.

3. Final field work in Georgia could not be performed due to travel and budget restrictions.

Results

1. Emerged marine shorelines and sediments in South Carolina and southern North Carolina have been uplifted at rates of about 1 to 3 cm/1000 yr for at least the last 3.0 m.y. and perhaps at rates as high as 5 to 10 cm/1000 yr for the last few hundred thousand years.

2. Two mechanisms appear responsible for the observed trends. Lithospheric flexure from Mesozoic-Cenozoic sediment loading (and perhaps thermal contraction) offshore in the Carolina Trough may have caused upwarping of the adjacent emerged Coastal Plain over intervals of millions of years. Hydroisostasy, the flow of mantle material from under the oceans to the continents due to deglacial meltwater from ice sheets entering and depressing ocean basins, would, in theory, also cause uplift and may be responsible for relatively rapid uplift during the past few hundred thousand years.

3. Different marine depositional sequences and neotectonic histories have been determined for different regions in the Coastal Plain. Neotectonic vertical crustal movements of a particular region are in part a function of its proximity to a primary subsiding depositional trough of the Atlantic Continental Margin, such as the Carolina and Baltimore Canyon Troughs.

Reports

Blackwelder, B.W., 1979, Stratigraphic revision of late Pleistocene marine deposits, North and South Carolina: USGS Bulletin 1482-A, p. A52-A61.

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TRENCHING THE ROSE CANYON FAULT ZONE SAN DIEGO, CALIFORNIA

U.S.G.S. Contract No. 14-08-0001-19118

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INTRODUCTION

The Rose Canyon Fault zone, in the San Diego area, has been mapped by investigators who have reported evidence of tectonic displacement of Late Pleistocene and younger sediments (Kennedy, 1975; Kennedy and others, 1975; Kennedy and Welday, 1977; Kennedy and others, 1978; Kennedy and Welday, 1980; Moore and Kennedy, 1975). The Rose Canyon Fault zone has been shown to extend on land from the La Jolla Cove Shores area for approximately 15 km south (Kennedy, 1975; Kern, 1973; Ziony, 1973). Fault branches have been mapped into and across downtown San Diego and the City of Coronado (Kennedy, 1975; Leighton and Associates, 1978; Wiegand, 1970).

GOAL

The goal of this research program is to develop geological data that will aid in evaluating the degree of fault activity in the Rose Canyon Fault zone.

INVESTIGATIONS

1. We have logged and evaluated the geological conditions of a 1,700-m (5,400-foot) long, 1.9- to 7-m (6- to 22-foot) deep excavation through downtown San Diego. The excavation was generally perpendicular to previous mapped fault locations. Geological samples were collected for dating, and various absolute dating techniques were used, including radiocarbon, racemization, and uranium/thorium. Ages of units were estimated by regional correlation based on physical properties, faunal assemblages, and existing criteria developed by Quaternary soil specialists.

2. We are preparing to complete a 2- to 5-m deep, 70- to 130-m long test excavation across a scarp in the City of Coronado. The scarp has been identified as the Coronado Fault branch of the Rose Canyon Fault zone (Kennedy and Welday, 1977; Kennedy and Welday, 1980). We will log the trench and evaluate geological conditions. We will collect faunal samples and have them dated by absolute techniques and faunal assemblages. We will regionally correlate units and ages of soil units by using existing criteria developed through previous studies.

RESULTS

San Diego Trench

The stratigraphic sequence in the east-west excavation has been disrupted by faulting at one general location. The strike of faulting is generally north-south in the vicinity of Broadway between Front Street and First Avenue.

The main shears are approximately .6 to 1.25 cm (1/4 to 1/2-inch) wide; short, discontinuous shears were observed within a few centimeters of the main shears. Several paper-thin, clay-lined fractures occur subparallel to the main shears. Displacements along these fractures were usually less than a few centimeters.

Some weathered zones extend down into the shears. The sheared material is composed primarily of brecciated and discolored sand containing silt and clay binder. In some areas, the sheared materials have been altered to clay. A vertical fracture, backfilled with red oxidized sand, grades upward into an overlying paleosol. No clay gouge or slickensided surfaces were observed along any of the shears.

The uppermost formational sand beds exposed in the trench have apparent vertical displacements of 2 to 3 m. Based on test boring correlations in the nearby area, there appears to be a stratigraphic separation of 3 to 4 m in a series of clay beds at depths between 16 to 20 m. The results of eight amino-acid tests indicate the sands represent a continuous depositional environment and are approximately 360,000 to 560,000 years old.

No shears or fractures extended up into an overlying paleosol (estimated to be at least 20,000 years old) and no irregularities that could be construed to be displacements were noted at the base of a recent topsoil contact or the paleosol. No other faults were observed in the trenches.

The fault area does not correspond to any gravity anomolies (interpreted to be faults) identified in gravity surveys performed in downtown San Diego (Harrington, 1980).

The fault appears to be a normal dip-slip (vertical) feature with the east side down relative to the west side. Based on observations of the exposures, there is no evidence to indicate significant strike-slip (horizontal) separation. The fault is not typical of the strike-slip faulting that characterizes major active faults in the Imperial Valley and Baja California. The fault appears to be the result of an extensional stress environment present in western San Diego. That environment is also the cause of similar faults in the area, such as the Texas Street Fault and the Florida Canyon Fault.

Coronado Trench

The investigation in the City of Coronado will involve excavating a trench down a city street. We are coordinating our study with the City of Coronado to coincide with a city street repair operation. At present, this part of our study is scheduled to take place in the middle part of November 1980.

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Seismotectonics of Northeastern United States

9950-02093

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Investigations

1. Compilation and interpretation of regional earth science information relevant to the seismicity of the eastern United States continued.

2. An attempt was begun to define seismic source zones for the northeastern United States.

Results

1. A preliminary version of the gravity map of Pennsylvania was exhibited. A final version at a scale of 1:250,000 with a contour interval of two milligals is being prepared. Progress has been slowed by the necessity of making terrain corrections for some stations.

2. An average elevation map of the conterminous United States was produced at a scale of 1:2,500,000; 20 m contours in the east, 100 m in the west. This map will appear as GP-933, and is now scheduled for printing.

3. Several regional cross-trending gravity features were identified from a new regional gravity map of New York and Pennsylvania and their relationship to seismicity explored. Additional geophysical information regarding these features is being evaluated.

4. It was noted that some of the aseismic regions of the eastern United States exhibit geologic conditions which tend to suppress shallow earthquake activity (e.g. soft sediments, geopressured zones, bedded salt, pre-existing bedding-plane thrusts, and the like). Cautions are expressed that the historical seismicity, based largely on felt reports, may not adequately reflect the stress regime at depth because of decoupling or aseismic slip near the surface.

5. An extensive review of the geology and geophysics of geothermal areas was published, a part of which may be useful in problems of earthquake genesis and distribution.

Reports

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Tectonic History of Eastern Ozark Uplift

9530-01930

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Investigations

1. Continued compilation of structure and isopach maps of Paleozoic units in the Newport and Pocahontas areas, Arkansas, for comparison with gravity and magnetic intensity maps.

2. Began revision of maps of the western part of the upper Mississippi Embayment (scale 1:250,000) showing structure contours drawn on the contact of Paleozoic and post-Paleozoic rocks. New data were obtained from the Missouri Geological Survey, the Arkansas Geological Commission, the Arkansas Oil and Gas Commission, and the Arkansas Power and Light Company. Fieldwork in problem areas of Missouri and Arkansas was continued.

3. Continued compilation of descriptions of cuttings from wells drilled in northeastern Arkansas, for publication by the Arkansas Geological Commission.

Results

A northeast-trending graben about 70 kilometers wide that developed during late Precambrian and early Paleozoic time crosses northeast Arkansas and southeast Missouri. The central part of the graben was uplifted during middle and late Paleozoic time after having accumulated a very thick sequence of sedimentary rock. The general area became seismically quiet during much of Mesozoic time when a nearly featureless erosion surface developed across the truncated Paleozoic rocks. That surface was depressed regionally to form a southward-plunging trough, the Mississippi Embayment, which was filled with Cretaceous and younger deposits. The 300-kilometer-wide embayment appears to have been positioned with little regard to the graben or other major structural features of the underlying Paleozoic and Precambrian sequence. Its axis crossed the graben at an angle of about 20°. However, nearly all of the local structural features developed in the area during latest Cretaceous, Tertiary, and Quaternary time appear to be results of recurrent igneous activity, uplift, and faulting along the linear trend of the graben.

Local uplift of Tertiary deposits that overlie the deeply buried Newport pluton of northeastern Arkansas is clearly defined by surface and subsurface data; uplift associated with other plutons along the northwestern edge of the graben is suggested by some of the preliminary evidence from agency files. High angle reverse faulting in eastern Arkansas along the southeastern margin of the graben is indicated by subsurface data. Local post-Cretaceous silicification of the upper part of the Paleozoic sequence within the graben is now thought to be associated with igneous activity that accompanied this recurrent reverse faulting at the edge of the graben. Seismic data outline post-Cretaceous faults in the axial portion of the graben.

Although work by other geologists has indicated that some post-Crètaceous faulting has taken place in the upper part of the Mississippi Embayment well beyond the geographic limits of the underlying graben, evidence that clearly substantiates such faulting in southeastern Missouri was not found during a reappraisal of surface and subsurface data. That investigation is being continued.

Reports

Haley, B. R., Glick, E. E., Caplan, W. M., Holbrook, D. F., and Stone, G. G., 1979, The Mississippian and Pennsylvanian Systems in the United States--Arkansas: U.S. Geological Survey Professional Paper 1110-O, p. O1-O14.

Eastern U.S. Seismicity and Tectonic Studies

9950-02303

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Investigations

1. Continuing analysis of land and marine seismic reflection profiles from the Charleston, S.C., area with J. C. Behrendt and H. D. Ackermann.

2. Planning for additional reflection profiling in the Charleston area with John Costain and Lynn Glover, Virginia Polytechnic Institute and State University.

3. Participating in a seismic refraction survey of the northern Mississippi Embayment with J. H. Healy, S. S. Wegener, W. D. Mooney, and others from Menlo Park.

Results

1. In the Charleston, S.C., area, evidence has been found on seismic reflection profiles for a northeast-striking fault, which we have named the Cooke fault, in the vicinity of a cluster of recent epicenters. The fault offsets the Jurassic-age basalt layer by 50 m, southeast side down, at a depth of about 750 m. The amount of offset decreases with decreasing depth. A deeper reflection is offset by 190 m in the same sense. The fault is at a much shallower depth than the hypocenters, which are 3-13 km, so the relationship with seismicity is unclear.

2. In the offshore Charleston, S.C., area, marine seismic profiles delineate a northeast-striking reverse fault, which is at least 60 km long. Single-channel, high-resolution data show that the fault reaches to within 10 km of the sea bottom. Deep structure is also revealed in the profiles, including strong diffractions that occur systematically at a two-way time of 3 to 4 seconds. These diffractions may define a sub-horizontal zone of detachment.

3. A seismic refraction survey in the northern Mississippi Embayment during September and October 1980 involved explosions at nine widely distributed shot points. Each shot point was fired several times. The shots were recorded on 100 portable seismographs. The data show excellent records of 1) the direct P wave through the poorly consolidated Cenozoic and Upper Cretaceous sediments, 2) the refracted P wave through Paleozoic and Precambrian rocks, 3) later arrivals that may be refractions and reflections from an intermediate crustal layer, and 4) Pn. Analysis of the data is just beginning.

Reports

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Zoback, M. D., Hamilton, R. M., Crone, A. J., Russ, D. P., McKeown, F. A., and Brockman, S. R., 1980, Recurrent intraplate tectonism in the New Madrid seismic zone: Science, v. 209, p. 971-976.

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Tectonic Framework of the New Madrid Seismic Zone from Geophysical Studies

9730-01035

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Investigations

1. Continued analyses of aeromagnetic and gravity data to determine the tectonic evolution of the upper Mississippi Embayment.

2. Compiled a map of digital magnetic data of east-central United States.

3. Collected magnetic data, utilizing a truck-mounted magnetometer.

Results

Compilation of a magnetic map of east-central United States was carried out to determine the northern terminus of the graben geophysically observed in the Mississippi Embayment and to investigate possible geographic relationships between the graben and other midcontinent structures. The northeast-trending graben, called the Mississippi Valley graben, probably formed during early stages of rifting in late Precambrian or early Paleozoic time and presently contains the area of principal seismicity in the embayment. The delineation of its northern terminus, consequently, plays an important role in determining seismic risk in the midcontinent. The data indicates that the Mississippi Valley graben, defined as a 70 km-wide depression with a series of plutonic masses along its margins, terminates in western Kentucky. A geophysical lineament does, however, extend northeastward from the embayment. This lineament may be an expression of a major crustal flaw, formed possibly in Archean time when the crust was thin and susceptible to internal stresses. We propose that the graben tectonically developed along this crustal flaw in the embayment and that although the graben terminates in western Kentucky, the crustal flaw extends northeastward to the Great Lakes region.

The magnetic map of east-central United States reveals several northeast- and northwest-trending megalineaments corresponding to crustal flaws. These lineaments display a mosaic pattern resembling blocks. Each block contains either a Paleozoic basin such as the Illinois, Michigan, and Appalachian basins, or uplifts, that include the Cincinnati Arch, Nashville Dome, Ozark Uplift, and Wisconsin Uplift. To gain a better understanding of the tectonics and characteristics of the crustal flaws, studies are being conducted to determine their relationship to present-day seismicity and past igneous activity.

Magnetic data, gathered with a truck-mounted magnetometer, have supplied detailed information on igneous bodies within the seismotectonic zone in the embayment and on faults that border the Mississippi Valley graben. Interpretational models for a particular magnetic gradient observed 25 miles northwest of Memphis suggest that a 1 km offset in magnetic basement occurs at a depth of 3.5 km. Because this gradient lies near the southeast margin of the graben, we interpret the associated offset as a high-angle normal fault formed during the initial phases of rifting.

Reports

Hildenbrand, T. G., and Kane, M. F., 1980, Tectonics of the Mississippi Valley graben (abs.): American Geophysical Union Midwest meeting, program and abstracts, p. 16.

Central and Eastern U.S. Earthquake Study

9730-02176A

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Investigations

1. Compilations of gravity, aeromagnetic and digital terrain data covering extensive regions of the central and eastern United States were compared with seismicity distribution maps as a means of investigating the structural causes of earthquakes.

Results

1. Wavelength filtered gravity maps prepared by Robert W. Simpson for extensive regions of eastern North America were examined for correlation with seismicity trends. The high-pass filtering method, which removes mantle and some broad crustal and near-surface sources, emphasizes sharp anomalies which for the most part can be attributed to structural boundaries or to structural blocks or plutons with steep sides. The map with wavelengths greater than 100 km removed shows that the Anna, Ohio, seismicity is located in part of a region where anomalies are distinctively sharper than those in the surrounding areas. The cause of the anomaly contrast is not completely clear except that it occurs in the upper, perhaps shallow, crust. Aeromagnetic data indicate that the sources are at least partly igneous. The map with wavelengths greater than 250 km removed shows a cross-trend that correlates with the Virginia-Alabama seismicity belt; a correlation between the belt and a digital terrain feature had been previously noted. The cross-trend appears as a disruption of an anomaly pattern that is defined by an elongation of anomaly axes along the Appalachian trend. The precise cause of the cross-trend is not clear, but it appears to involve near-surface rocks as well as igneous masses within the basement. A puzzling aspect of the cross-trend is that it also correlates with the orientation of surface thrusts which, according to recent seismic work, should only involve superficial rocks above a master decollement.

2. Study of terrain maps has concentrated on the causes of terrain relief. Part of the relief is caused by differential erosion where carbonate rocks have been removed by dissolution at a much faster rate than those removed by mechanical erosion. More than one third of the mass of the southernmost Appalachians may have been removed in this manner. As a result, there is a substantial change in the lateral distribution of the surface load represented by the terrain. A possible source of deformation might be isostatic response to the change in load distribution.

Reports

Hildenbrand, T. G., and Kane, M. F., 1980, Tectonics of the Mississippi Valley graben (abs.): Program with abstracts, 1980 American Geophys. Union Midwest meeting, De Kalb, Illinois.

Kane, M. F., Hildenbrand, T. G., and Hendricks, J. D., A model for the tectonic history of the Mississippi Embayment: approved by Director, submitted to Geology.

Kane, M. F., and Simpson, R. W., Residual regional Bouguer anomaly fields of eastern North America (abs.): approved by Director, submitted for presentation at Northeastern GSA meeting.

Puerto Rico Seismic Program

9950-01502

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Investigations

The Puerto Rico seismographic network has continued operation throughout the last six months at a reduced level. Only eleven of the fifteen stations are currently transmitting data because of instrument malfunctions that could not be repaired owing to a lack of spare parts. The University of Puerto Rico has tentatively agreed to assume responsibility of the network operation and data analysis beginning sometime in late 1980, with continued technical assistance provided by the USGS.

Results

The Puerto Rico Seismic Program has contributed significantly to an increased understanding of the rate and distribution (spatial and temporal) of seismic activity within the region of Puerto Rico. A greater awareness of the nature of earthquakes occurring on-island has been gained through the detailed study of ten seismogenic zones. Study of these zones has provided important information that is being incorporated into a Professional Paper concerning the tectonics and seismicity of Puerto Rico and to the compilation of a seismicity map of recent Puerto Rican earthquakes. The map and Professional Paper will summarize the results of the Puerto Rico Seismic Program during the six-year period between early 1975 and the end of 1980.

Reports

Dart, R. L., Tarr, A. C., Carver, D. L., and Wharton, M. K., 1980, Puerto Rico seismic network data report of earthquakes located by the programs HYPO71 and HYPOELLIPSE, July 1, 1975-December 31, 1977: U.S. Geological Survey Circular 821, 43 p.

Dart, R. L., 1980, Suggestions on the analysis of 16-mm seismic data from local networks: U.S. Geological Survey Open File Report 80-990, 26 p.

Quaternary Stratigraphy and Bedrock Structural Framework of Giles County, Virginia

9510-02463

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Investigations

1. Investigations of Quaternary deposits by Hugh Mills continued. Mapping of colluvial deposits in the Mountain Lake area was completed, New River alluvium was sampled for mineralogical analysis. The data is to be used in a search for a means of identifying and describing neotectonic activity in the area.

2. A detailed map of the Paleozoic bedrock is under compilation, and the bedrock structure is being analyzed, in order to determine the relationship, if any, of the bedrock to current seismicity.

Results

1. Study of colluvial deposits has provided evidence on their origin and support for the Pleistocene age of some of them. No direct evidence of seismic effects has yet been identified.

2. Mapping of the "Hurricane Ridge" syncline has shown a somewhat more complex relationship between the southern and central Appalachians at the "Allegheny Front" than has been heretofore recognized. Structures of the two provinces appear to interesect and interfere rather than pass from one province into the other. Geometric relationships at the juncture appear to indicate that central Appalachian structures were developed before those of the southern Appalachians. Seismicity in Giles County, just to the southeast of the juncture, shows a trend more compatible with central structures than with the southern structures below which it occurs.

Reports

Mills, H. H., 1980, The influence of boulder deposits on the retreat of mountain slopes in the Valley and Ridge Province, Giles County, Virginia [abs.]: Geological Society of America Abstracts Programs, v. 12, no. 7, p. 484.

Ground Failure Related to the New Madrid Earthquake

9550-02160

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Investigations

1. Completed a 1:250,000 scale map showing distribution of sand blows caused by the 1811-12 New Madrid earthquakes in the Mississippi alluvial valley. The map shows the percent of the land surface covered with extruded sand, and is based on airphotos taken in the late 1930's supplemented with extensive field checks.

2. Completed computer-assisted analysis of field engineering test data (500 Standard Penetration Tests, and about 3500 blow count data points) to determine relative susceptibility of large regions in Mississippi alluvial valley to liquefaction during 1811-12 earthquakes. Completed maps showing locations of Standard Penetration tests and regions with significantly different susceptibilities to sand blow development during 1811-12.

Results

1. Areas with major sand-blow development extend large distances eastward and northward from regions shown by Fuller in USGS Professional Paper 494, "The New Madrid Earthquake," and go approximately to the Chickasaw Bluffs in western Tennessee. These extensions must be viewed as a major sand-blow development area when considered in terms of the areal distribution of sand subject to liquefaction, character of sand extruded onto the ground surface, and quantity of sand extruded onto the ground surface.

2. Large areas in the Mississippi River alluvium west of Sikeston's Ridge are only weakly susceptible to sand-blow development because the sands are either coarse or have high relative densities (as reflected by high Standad Penetration Test blow counts). In contrast, alluvium further south is much finer grained and has significantly lower blow counts, and thus was much more susceptible to sand-blow development during 1811-12. Thus, surface evidence of previous earthquakes would be much less manifest in the northern parts of the valley.

3. The sand blow distribution map and the liquefaction relative susceptibility map prepared as part of this study are very

supportive of the location of the New Madrid fault made using recent seismic-reflection profiles, and reported by Zoback and others, in Science, Vol. 209, pp. 971-976.

Reports

None

Northeastern U.S. Seismicity and Tectonics

9510-02388

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Investigations

1. Relationship of ductile and brittle faults in southeastern New York and adjacent New Jersey and relationship to zones of seismicity.

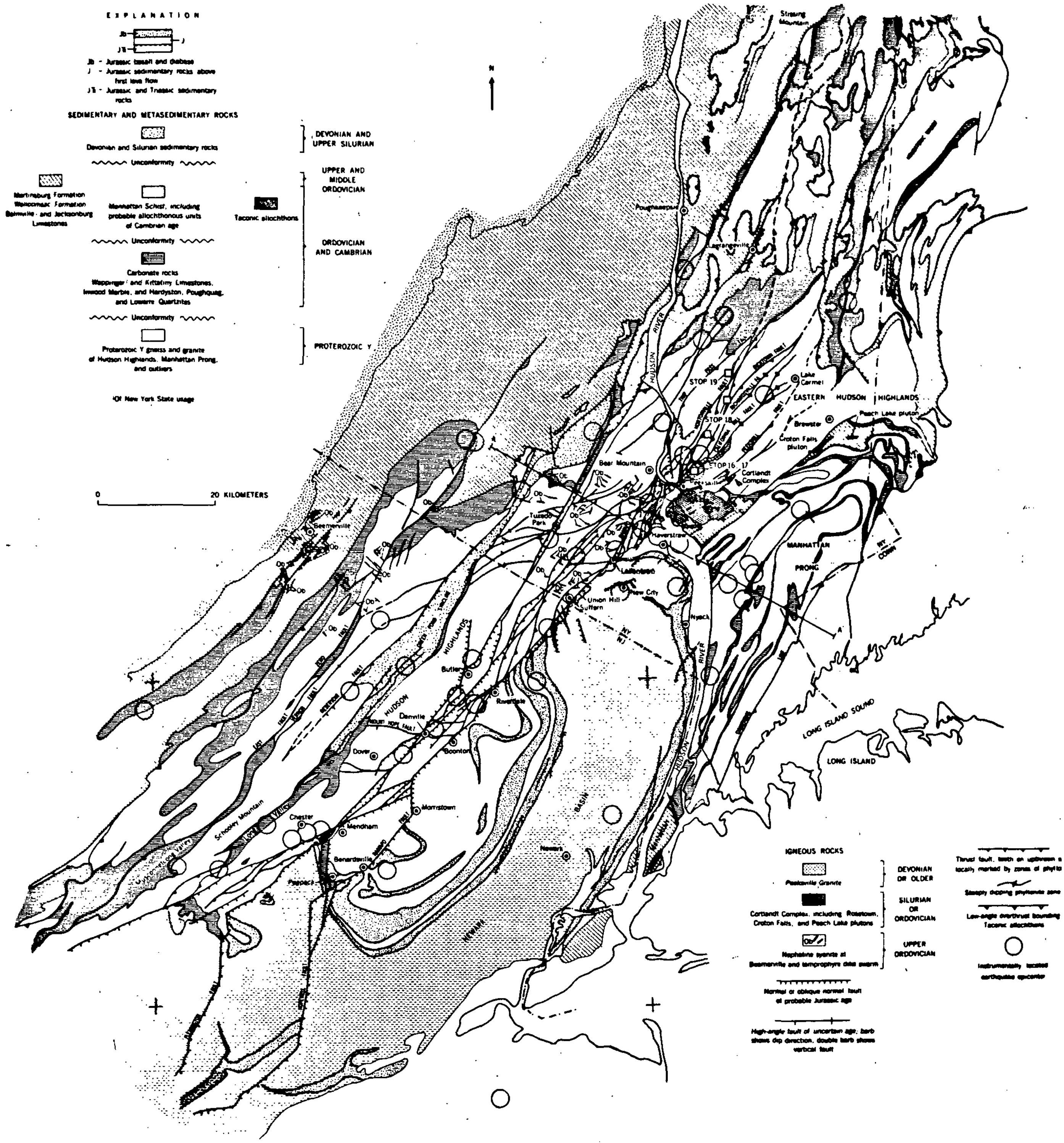
Results

1. A preliminary tectonic map (Fig. 1) for the Ramapo seismic zone has been produced based on reconnaissance and detailed study of exposed faults.

2. Comparison of epicentral data with this map reveals that:

   a.) Mesozoic faults (although more widely developed than previously believed) do not satisfy the distribution of earthquakes.
   b.) Seismicity in the Ramapo zone decreases markedly north of 41.5°N and west of the Green Pond syncline although Mesozoic type faulting extends well beyond these boundaries.
   c.) A broad area in the northern Reading Prong, east of the Hudson River, is marked by extensively developed phyllonitic shear zones of Proterozoic Y and Ordovician age and by deep seismic activity.
   d.) A linear zone of earthquake activity east of the Hudson River in Westchester County, New York, has earthquakes extending to 11 km. This zone can not be correlated with any known Mesozoic faults although more ductile faults of Paleozoic age are present.

3. These investigations indicate that the assumption that reactivation of Mesozoic faults (the Ramapo fault) to produce current seismicity in the New York area is too simple. Instead, recurrent earthquakes in the Ramapo seismic zone appear to be restricted to areas where appreciable thicknesses of penetratively faulted Proterozoic Y rocks are exposed or are near the surface, whereas earthquakes appear to be absent where crystalline basement forms thin overthrust sheets. The key to current seismicity here probably lies in understanding the attitude and distribution of major through-going Paleozoic and older fault zones in basement rocks extending from near the surface to depths of 15 km. These faults are ancestral to Mesozoic border faults as a rule.


EXPLANATION
Jb - Jurassic basalt and diabase
J - Jurassic sedimentary rocks above first lava flow
JTr - Jurassic and Triassic sedimentary rocks
SEDIMENTARY AND METASEDIMENTARY ROCKS
Devonian and Silurian sedimentary rocks
DEVONIAN AND UPPER SILURIAN
Unconformity
UPPER AND MIDDLE ORDOVICIAN
Martinsburg Formation
Walloomsac Formation
Balmville- and Jacksonburg Limestones
Manhattan Schist, including probable allochthonous units of Cambrian age
Taconic allochthons
Unconformity
ORDOVICIAN AND CAMBRIAN
Carbonate rocks
Wappinger and Kittatinny Limestones, Inwood Marble, and Hardyston, Poughquag, and Lowerre Quartzites
Unconformity
Proterozoic Y gneiss and granite of Hudson Highlands, Manhattan Prong, and outliers
PROTEROZOIC Y
Of New York State usage
0
20 KILOMETERS
N
Stissing Mountain
Poughkeepsie
Lagrangeville
HUDSON RIVER
STOP 19
STOP 18
STOP 16
17
Lake Carmel
EASTERN HUDSON HIGHLANDS
Peach Lake pluton
Brewster
Croton Falls pluton
Cortlandt Complex
Bear Mountain
Peekskill
Tuxedo Park
Haverstraw
Beemerville
MANHATTAN
PRONG
NY
CONN
New City
Union Hill
Suffern
Nyack
Butler
HUDSON
HIGHLANDS
Denville
Riverdale
Dover
Boonton
Morristown
Chester
Mendham
Bernardsville
Peapack
Schooley Mountain
Newark
NEWARK
BASIN
LONG ISLAND SOUND
LONG ISLAND
IGNEOUS ROCKS
Peekskill Granite
DEVONIAN OR OLDER
Cortlandt Complex, including Rosetown, Croton Falls, and Peach Lake plutons
SILURIAN OR ORDOVICIAN
Nepheline syenite at Beemerville and lamprophyre dike swarm
UPPER ORDOVICIAN
Normal or oblique normal fault of probable Jurassic age
High-angle fault of uncertain age; barb shows dip direction, double barb shows vertical fault
Steeply dipping phyllonite zone
Low-angle overthrust bounding Taconic allochthons
Instrumentally located earthquake epicenter

Reports

Ratcliffe, N. M., 1980, Brittle fault (Ramapo fault) and phyllonitic ductile shear zones in the basement rocks of the Ramapo seismic zone, New York and New Jersey, and their relationship to current seismicity, in Field Studies of New Jersey Geology and Guide to Field Trips, 52nd Ann. Mtg. N. Y. Geol. Assoc., Rutgers Newark, p. 278-311.

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Ratcliffe, N. M., The Cortlandt-Beemerville magmatic belt: a late Taconic alkalic crosstrend in the central Appalachians: submitted to Geology.

Mississippi Valley Seismotectonics

9950-01504

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Investigations

1. Cenozoic faults exposed in sediments in quarries near Cape Girardeau, Missouri, and Paragould, Arkansas, were mapped and studied.

2. An exploratory trench was excavated across the surface projection of Cottonwood Grove fault, 5 km southwest of Ridgely, Tennessee. This fault lies in an area of relatively intense seismicity, is reverse in nature, and has the largest known Cenozoic vertical offset (~80 m) of any fault in the New Madrid seismic zone.

3. Assisted in planning and executing a seismic refraction survey in the Mississippi Embayment with J. R. Healy, S. Wegener, R. Hamilton, and K. Shedlock.

4. Ray-Wave theory modeling of faults and igneous bodies from data obtained from Mississippi Embayment seismic reflection profiles was carried out with S. Harding.

5. A report was prepared on Seismic Source Zones of the Central Interior United States based on notes and maps compiled at a meeting on June 10-11, 1980. The source zone map was a cooperative effort of a number of geoscientists and was drawn on the basis of historical seismicity and, where applicable, geologic and geophysical knowledge.

6. Samples of igneous rock cuttings from Mississippi Embayment wells were collected from the Missouri Division of Geology and Land Survey and from colleagues working in the area for radiometric age-dating, petrologic, and possibly, geochemical analysis. This study is a cooperative effort with R. Zartman and B. Doe of the Branch of Isotope Geology. It is being done to characterize the igneous history of the Mississippi Embayment and to determine its relationship to tectonics and seismicity.

7. Sediment samples of the Festus Terrace (late Pleistocene) were collected from sites along Mississippi River tributaries in southeast Missouri. Heavy minerals have been separated from the samples and will be analyzed by scanning electron microscopy as a means of establishing stratigraphic correlations of various terrace surfaces. The terrace surfaces are being investigated for evidence of Quaternary deformation.

8. A detailed mineralogical description of sediment samples from the New Madrid Test Well (using a binocular microscope) was completed.

Results

1. A quarry 3 km northwest of Cape Girardeau, Missouri, exposes faulted sand and gravel sequences of part of the Pliocene (?) deposit formerly known as the "Lafayette Gravel." The largest outcrop in the quarry shows several stepping faults of gravel against sand and clay. The largest measured offset was 1 m. Though reversal of dips suggest that some of the deformation may be the result of slump, the overall dip direction indicates that the majority of the deformation is tectonic. A quarry located along the northwest edge of Crowleys Ridge, about 25 km northwest of Paragould, Arkansas, exposes faults that displace beds of the Eocene Wilcox(?) Formation. Previous studies of faults in a roadcut located 0.5 km south of the quarry revealed that some offsets were the result of landsliding, but geological relationships observed in the quarry suggest that the faults here are tectonic in origin.

2. Cottonwood Grove fault trends to the northeast from near the town of Cottonwood Grove, Tennessee, to the southern shore of Reelfoot Lake. As seen on seismic reflection profiles, the fault displaces strata as young as middle Eocene age in a reverse sense. The fault can be traced on the profiles to within ~150 m of the ground surface where the measured offset is about 65 m. In September 1980, a 120-m-long exploratory trench was dug across the surface projection of the fault in the small town of Cottonwood Grove to determine whether or not the offset is present at the ground surface. Easily mappable strata of alluvium were evident in the trench walls providing good control for the detection of possible faulting. The sediments, however, showed no evidence of faulting, indicating that either the Cottonwood Grove fault has not ruptured since the time of deposition of the sediments (<6,000 yr BP) that the projection of the fault to the surface is incorrect, or that possible recent displacement of the fault did not propagate to the surface.

3. Ray- and wave-theory techniques were used to generate synthetic cross sections from data obtained from seismic reflection profiles run in the New Madrid seismic zone. The techniques were used to determine if physical models of intrusive masses and faults could produce geologic configurations similar to those observed on the profiles. Results show that modeled structures reproduce those seen on the reflection profiles quite closely. Margins of igneous bodies, especially those beneath the bodies, are not well resolved by either the profiles or the synthetic cross sections. The ray- and wave-theory results support interpretations made earlier from the reflection profiles. More detailed results and figures are included in S. Harding's semi-annual report.

4. Based on opinions offered by geoscientists from mid-continent universities, NRC, and the U.S.G.S. at a meeting held in Golden, Colorado, on June 10-11, 1980, nine seismic source zones were delineated for the Center Interior United States. The source zones were defined on patterns of historical seismicity and, where possible, geological and geophysical knowledge. Source zone 1 is the area where the largest earthquakes to affect the central U.S. have occurred. It is generally coincident with the Reelfoot rift or graben as defined by Hildenbrand and others (1977) and was assigned a maximum estimated magnitude of m_b 7.5 and a recurrence time of 600-700 years. Source zone 2 occupies a postulated extension of the rift in southeast Illinois and southwest Indiana and includes the Wabash Valley fault zone. It was assigned

a maximum estimated magnitude of m_b 6.5 and a recurrence time of 1,000 years. Source zone 6 is a north-northeast trending area of seismicity in central and eastern Ohio and northeast Kentucky that includes the general area of the Sharpsburg, Kentucky, earthquake sequence of July-August 1980.

Reports

Crone, A. J., 1980, Deformation of the Paleozoic bedrock surface in the New Madrid seismic zone, northern Mississippi Embayment [abs.]: Geological Society of America Abstracts with Programs, 1980 Annual Meetings, v. 12, no. 7, p. 408.

Harding, S. T., and Russ, D. P., 1980, Ray- and wave-theory modeling of seismic-reflection profiles to interpret geologic structure in the New Madrid seismic zone [abs.]: American Geophysical Union Midwest Meeting, 1980, Program and Abstracts, p. 15.

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Russ, D. P., 1980, Holocene deformation and earthquake recurrence in the northern Mississippi Embayment [abs.]: Geological Society of America Abstracts with Programs, 1980 Annual Meetings, v. 12, no. 7, p. 513.

Zoback, M. D., Hamilton, R. M., Crone, A. J., Russ, D. P., McKeown, F. A., and Brockman, S. R., 1980, Recurrent intraplate tectonism in the New Madrid seismic zone: Science, v. 209, p. 971-976.

TRENCHING STUDIES OF THE SAN ANDREAS FAULT BORDERING WESTERN ANTELOPE VALLEY, SOUTHERN CALIFORNIA

Contract No. 14-08-001-18200

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Investigations

1) One trench was dug across the active fault zone in area of ponded alluvium, with the objective of recognizing and radiometrically dating the succession of recent great earthquakes.

2) Two trenches were dug near the edge of a large landslide which has been bisected and offset some 40 metres by displacement on the main trace of the fault. The objective was to obtain a radiometric age for the landslide and thereby determine an average rate of fault displacement.

Results

Evidence was found for a sequence of four faulting events, ending with the faulting associated with the 1857 earthquake. Dates for the prehistoric events cannot be proposed until final age determinations are available from a series of charcoal samples collected from the trench. These radiometric dates, together with dates from charcoal found within the landslide deposit, have been promised soon.

Northeast Tectonics and Geophysics

9730-00364

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Investigations

1. Compilation of available gravity data for the Northeast. Publication of contoured gravity maps at various scales suitable for regional and local studies.

2. Compilation and digitization of available aeromagnetic data from the Northeast, and collection of additional data from areas of interest. Publication of contoured maps and digitized data sets.

3. Collection of gravity, magnetic and other geophysical data in areas of tectonic or seismic significance.

4. Interpretation of regional geophysical anomalies and their relation to tectonic features and the plate tectonic history of the region.

5. Modelling and interpretation of local geophysical anomalies to test specific hypotheses for the origin of seismicity.

Results

1. A Bouguer gravity map of the Northeastern U.S. at a scale of 1:1,000,000 is now on open file. This map was prepared from a data base of 90,000 gravity stations both onshore and offshore. All U.S. land stations have been computer terrain corrected into a distance of .895 km. This map is compatible with Harwood's geologic compilation of this area.

2. Colored gravity and terrain maps have been prepared which cover the Northeastern U.S. and the East Central U.S. at a scale of 1:2,500,000. These maps include free air gravity, Bouguer gravity, horizontal gradient of Bouguer gravity, first and second vertical derivatives of Bouguer gravity, and residual Bouguer anomaly maps.

3. Correlations appear to exist between the patterns of seismicity in the Eastern U.S. and the gradients and residuals of the Bouguer anomaly field. In particular, areas with low gravity gradients and small Bouguer residual anomalies appear to have a significantly lower level of seismicity than a random distribution of earthquakes would warrant. Conversely, however, it is not true that all areas with high gravity gradients and large residual Bouguer anomalies have high levels of seismicity. This may reflect the shortness of the earthquake record or the possibility that areas with a particular structural grain are being preferentially reactivated.

4. In order to test whether or not the correlation of earthquakes with gravity features could be accounted for by the stresses in the crust needed to support these features, a series of load induced stress maps was prepared. The starting point was the free air gravity field which to first approximation is a measure of the total mass under a given spot. An equivalent source in the form of a two-dimensional sheet of mass is easily calculated and this sheet is imagined to be spread over the top of a semi-infinite elastic half space, so that the stress tensors at any desired depth can be calculated. Several crude assumptions intervene between the free air gravity field and the stress field, but the results probably are good enough to support or refute a possible correlation of load induced stresses with earthquakes. It appears that although several loci of earthquakes are near persistently high levels of load induced stress, the correlation in general is pretty poor. Since the variable rock mechanical properties of different geologic terrains has not been incorporated into this analysis, it is possible that the load induced stresses are indeed an important factor in localizing earthquakes. However, without a great deal of more detailed geologic parameters built in, load induced stress maps will not likely be good predictors of earthquake occurrence in the Eastern U.S.

5. My impression at this stage is that many of the gravity gradients and residual anomalies which correlate well with seismicity patterns are marking fundamental structures in the crust which are being reactivated in complicated ways by the regional tectonic stress field. My impression is that areas with a NE grain to the gravity field experience more earthquakes than areas with other trends or with random patterns of anomalies. There is a suggestion that major NW trending cross structures in Precambrian basement which interrupt and offset Bouguer residual anomalies may serve to localize seismicity.

Reports

Hodge, D. S., Bothner, W. A., and Simpson, R. W., 1980, Preliminary Bouguer gravity map of Eastern Maine and adjacent Canada: U.S. Geological Survey Open File Report 80-618, scale 1:250,000.

Bothner, W. A., Simpson, R. W., and Diment, W. H., 1980, Bouguer gravity map of the Northeastern United States and adjacent Canada: U.S. Geological Survey Open File Report 80-2012, scale 1:1,000,000.

Structural Framework of Eastern United States Seismic Zones

9950-02653

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Investigations

1. New and existing data and understanding of central Appalachian structures and tectonics were used to identify the most likely types of faults responsible for seismicity in and near Giles County, southwestern Virginia. Efforts were coordinated with faculty at Virginia Polytechnic Institute and State University (J. Costain, L. Glover III, and especially G. A. Bollinger), with other USGS projects (especially 9510-02463 of R. C. McDowell), and with other pertinent investigators. See results 1 and 2, reports 1, 2, and 7.

2. Work continued to improve a pattern recognition program developed in the USSR and at M.I.T., in order to use it to seek seismically-associated patterns in geological, geophysical, and topographic characteristics of the Southeastern United States. See result 3, report 3.

3. Work continued to characterize, locate, and interpret cross-strike structural discontinuities (CSD's), which are transverse alignments of structural disruptions (for instance, anticlinal noses) in the Appalachian and other thrust belts. Some CSD's occur over long-active basement faults otherwise masked by overlying thrust complexes. See report 6.

4. Work continued to develop efficient methods to map intensity of systematic joints (joint surface area per unit volume of rock). CSD's are characterized by high joint intensity, and it is possible that joints are more intensely developed in exposures above seismogenic faults. See report 8.

5. Mathematical and statistical collaboration was provided to other projects, through work of K. M. Shedlock. See reports 4 and 5.

   a. K. M. Shedlock began work on a manuscript with D. G. Herd and others on "The next great San Francisco Bay area earthquake," intended for submittal to Science. Travel and computer work supported by project 9540-01950, D. G. Herd, and project 9930-02103, W. L. Ellsworth.

   b. K. M. Shedlock continued work on evaluating sensitivity of risk calculations to various parameters used in the calculations, with D. M. Perkins, computer work supported by project 9950-01207, S. T. Algermissen.

Results

1. New relocations of Giles County seismicity by G. A. Bollinger (VPI and SU) define a seismic zone, which strikes N37°E for about 32 km and dips vertically to a depth of about 25 km. Exposed folds and faults in Giles County, all detached, trend about N60°E. Wheeler synthesized knowledge of structures in the detached Paleozoic sedimentary rocks in and near Giles County (mostly published cross sections, measurements and estimates of stratigraphic thicknesses, and basement depths inferred from stratigraphic thicknesses, wells, and aeromagnetic data). He concluded that the relocated hypocenters are below the deepest detachment faults, which lie in Lower Cambrian and Middle Ordovician shales. The hypocenters are in undetached early Paleozoic sedimentary rocks or the underlying metamorphic and igneous basement rocks. Accordingly the seismicity probably has no simple relationship to surface or near-surface geology. Three Phanerozoic tectonic episodes produced northeast-striking, high-angle, basement-cutting faults in the Virginias. (1) The youngest such episode formed Mesozoic normal faults as the Atlantic Ocean opened, but they are apparently unknown as far west as Files County. (2) In the central Appalachians and elsewhere, crustal loading by emplacement of thrust sheets has recently been observed or inferred to have faulted basement rocks, in a brittle analogue of isostatic depression caused by much lighter continental glaciers. If the basement fault or fault zone that may be associated with the N37°E-trending seismic zone did form by such thrust loading, the basement fault would have formed coevally with central Appalachian thrusts, because it shares their characteristic north-northeast trends. However, the thrusts now overlying the seismic zone trend east-northeast, an orientation characteristic of the southern Appalachians, and do not appear to be cut by the inferred would have been emplaced before those of the southern Appalachians. This deduced relative age of southern and central Appalachian detachment is contradicted by three of the four extant local field determinations of relative ages of structures of central and southern Appalachian orientations. Therefore the sparse existing evidence makes it unlikely that the seismicity occurs on a fault formed by thrust loading. (3) Early Paleozoic opening of the Iapetus Ocean also produced north-northeast-striking normal faults, which occur as far west as western-most West Virginia. It is reasonable to expect such faults to occur as far east as the Iapetan continental edge in central Virginia, and so under Giles County as well. Thus, reasonable interpretation of the sparse data available indicates that the most likely source of the N37°E-trending seismic zone is an Iapetan normal fault reactivated in today's compressional stress regime. Because such faults may be common in the Eastern United States, it becomes important to zoning efforts to learn why Giles County seismicity is concentrated in such a small zone.

2. We are studying computer-generated, colored contour maps of digitized terrain and Bouguer gravity data, produced respectively by M. F. Kane and coworkers (project 9730-02176A) and R. Simpson (project 9730-00364). In particular, location of the Iapetan continental edge of North America has long been inferred to be at a large gravity gradient that extends from New York State to Alabama. The most striking offset in the gradient is several tens of km southeast of Giles County. Bouguer and derivative maps provided by Simpson appear consistent with the suggestion that a major Iapetan transform fault or fault zone strikes northwest through the Giles County area. Testing that suggestion may help explain why the N37°E-trending

seismic zone may be only about 32 km long, and why there is also diffuse seismicity elsewhere in and near Giles County. Results of such testing may also be useful in zoning for hazard and risk in the urbanized States near Washington, D.C.

3. M. Jones-Cecil has completed a substantially revised and improved version of an existing pattern recognition program, for application to seismicity of the Southeastern United States. Use of statistical rather than arbitrary selection criteria now make any detected patterns more reliable than when using the original version. Local patterns can now also be detected, in addition to patterns occurring over the entire region being investigated. A test application to the Southeastern United States detected patterns which Jones-Cecil interprets as indicating that four areas of large or moderate earthquakes, including Giles County and Charleston, South Carolina, may have different causes of seismicity than does the rest of the Southeast. Maps of detected patterns suggest that pattern recognition may be a useful adjunct to historical seismicity in hazard zoning of the Eastern United States, where seismogenic structures are so rarely exposed or clearly identified. An open-file report of 141 pages has passed technical review and is in editorial review. The report includes details of descriptions, analyses, and usage recommendations for the new version of the pattern recognition program.

Reports

Bollinger, G. A., and Wheeler, R. L., 1980(?), The Giles County, Virginia, seismic network--monitoring results, 1978-1980 (abs.): submitted for presentation at meeting of Eastern Section of Seismological Society of America, 28-30 October 1980, University Park, Pa., and for publication in Earthquake Notes.

Bollinger, G. A., and Wheeler, R. L., 1980, The Giles County, Virginia, seismogenic zone (abs.): Geological Society of America Abstracts with Programs, v. 12, no. 7 (in press) (to be presented at national meeting of Geological Society of American, 17-20 November 1980, Atlanta, Ga.).

Jones-Cecil, M., Wheeler, R. L., and Dewey, J. W., 1980(?), Modified pattern recognition technique used to study Southeastern United States seismicity (abs.): submitted for presentation at meeting of Eastern Section of Seismological Society of American, 28-30 October 1980, University Park, Pa., and for publication in Earthquake Notes.

McGuire, R. K., and Shedlock, K. M., 1981(?), Statistical uncertainties in seismic hazard evaluations in the United States: Bulletin of the Seismological Society of America, 38 ms. p. (in press).

Shedlock, K. M., McGuire, R. K., and Herd, D. G., 1980(?), Earthquake recurrence in the San Francisco Bay region, California, from fault slip and seismic moment: U.S. Geological Survey Open-File Report 80-999, est. 20 ms. p. (in press).

Wheeler, R. L., 1980, Cross-strike structural discontinuities: possible exploration tool for natural gas in Appalachian overthrust belt: Bulletin of American Association of Petroleum Geologists, v. 64 (in press).

Wheeler, R. L., and Bollinger, G. A., 1980(?), Types of basement faults probably responsible for seismicity in and near Giles County, Virginia (abs.): submitted for presentation at meeting of Eastern Section of Seismological Society of America, 28-30 October 1980, University Park, Pa., and for publication in Earthquake Notes.

Wheeler, R. L., and Dixon, J. M., 1980, Intensity of systematic joints: methods and application: Geology, v. 8, p. 230-233.

Surface Faulting Studies

9940-02677

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Investigations

1. Study of rupture fraction.

2. Trench investigation of faults.

3. Census of surface faulting in U.S., 1979-1984.

4. Preparation of reports.

5. Other activities.

Results

1. Studies of the rupture fraction (rupture length/total fault length) in historic faulting are in progress. Twenty-nine faults with well-determined rupture lengths were chosen for the study. Landsat imagery was obtained, examined for quality and coverage, and new imagery ordered for the few places not adequately covered. Skylab photography is being obtained. Topographic maps at various scales have been acquired for nearly all the study areas and assembled in convenient format. A listing was made of aerial photography for the U.S. faults and selected photo-indexes have been acquired. Bibliographic search for pertinent geological and geophysical literature was begun and is complete for two events. Maps of several dozens of faults active in Quaternary time were examined to learn what kinds of geometric patterns occur in the terminal areas of faults. Of the faults examined, termination by cross faults was the most common pattern. (Coinvestigator J. J. Lienkaemper.)

2. Data from a trench across the 1915 Pleasant Valley, Nevada fault was re-evaluated in collaboration with R. E. Wallace and H. A. Villalobos. The data suggest that the numerous late Pleistocene and Holocene displacements at the trench site were consistently small, probably 1 m or less. Further, the recurrence time of faulting is apparently shorter than previously thought. Although age controls are poor, the evidence suggests that at least two episodes of displacement occurred before 1915, possibly in the last 5,000 years.

3. The census of surface faulting in the U.S. was continued. This involves encouragement of (and limited participation in) a search for surface faulting in the epicentral areas of all shallow-focus earthquakes on land of $M \geqslant 5$ in the U.S. during the 5-year period 1979-1984. The compiled data, supplemented by data on earlier well-investigated earthquakes, will be used to estimate the probability of surface faulting as a function of earthquake magnitude and focal depth. A reconnaissance was made of the faulting that accompanied the Mammoth Lakes, California earthquakes of May 25, 1980 and support was given to a field reconnaissance of the epicentral area of the Kentucky earthquake of July 27, 1980.

4. The manuscript on the Pleasant Valley, Nevada, trench was substantially revised. The first draft of a short, overview report on faulting in the U.S. was prepared.

5. Other activities: Participated in revision of draft of American Nuclear Society Criteria and Guidelines for Assessing Capability for Surface Faulting at Nuclear Power Sites; prepared and presented lecture on surface faulting at University of California, Berkeley, course called "Advances in Earthquake Engineering."

Report

Bonilla, M. G., Lienkaemper, J. J., and Tinsley, J. C., 1980, Surface faulting near Livermore, California associated with the January 1980 earthquakes: U.S. Geological Survey Open-File Report 80-523.

SURFACE FAULT TRACES AND HISTORICAL EARTHQUAKE EFFECTS NEAR LOS ALAMOS VALLEY, SANTA BARBARA COUNTY, CALIFORNIA

U.S.G.S. Contract No. 14-08-0001-18255

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Investigations

The evaluation of surface faulting near Los Alamos included interpretation of 1:24,000-scale, low-sun-angle aerial photographs covering approximately 325 square miles. Major and minor lineaments were compiled on 1:24,000-scale maps. Based on the aerial photographic interpretations, geomorphic features indicative of fault activity along the lineaments were identified. Examination of the lineaments and geomorphic features in the field led to the selection of two trench sites across a fault 3.5 miles southeast of Los Alamos. Both sites were associated with sag depressions at the foot of a fault scarp. A comprehensive accumulation of newspaper accounts of the 1902 and 1915 earthquakes has been collected to allow for review of geologic effects of the earthquakes with respect to the known faults.

Results

Two strong lineament trends were identified north of Lake Cachuma that extended to the northwest as far as the central Santa Ynez Valley. Both trends coincide with prominent scarps in Pliocene and Pleistocene sediments. Toward the west the scarps diminish in height and prominence. Together, the two lineaments bound an apparent structural graben. The southern lineament coincides with the Baseline fault and is evidenced by deflected and antecedent streams. The northern lineament is geomorphically expressed as a south-facing scarp accompanied by numerous faceted ridges. No fault is yet mapped along this northern trend, although along its western segment, a highly dissected Pleistocene terrace surface is systematically down-dropped to the south.

West of the Santa Ynez Valley, the most prominent lineament coincides with the Los Alamos fault trending along the northern edge of Los Alamos Valley. The fault is marked by a hillside scarp, linear trenches, and a few sag depressions aligned along the fault trace. The fault trace projects westward from the north side of Los Alamos Valley at Confaglia Ranch to the south side of the valley and apparently dies out west of Los Alamos along the north flank of an overturned anticline.

East of Los Alamos Valley, the fault is not clearly marked by the topography, but a vague lineament has been traced to Los Olivos approximately along the axis of a syncline. Two Pleistocene terraces, possibly vertically offset across the lineament, may be evidence for the location of a connection between the Los Alamos fault and the Baseline fault.

Two trenches were excavated across the Los Alamos fault on the north side of Los Alamos Valley. The fault exposed in both trenches consists of a series of low-angle (10°-40°), south-dipping sheared surfaces with a reverse sense of slip. Observed slickensides on the sheared surfaces are consistently down dip. The fault is quite youthful, having offset the base of a "B" soil horizon in one location and the base of an "A" soil horizon in another location. Although age dating of offset lithologic units could not be accomplished because of the absence of datable materials, it is probable that the offset "A" soil is Holocene or latest Pleistocene in age. Based on the proximity of the fault to Los Alamos and the youthfulness in offsets, the Los Alamos fault is the most likely source of the 1902 and 1915 earthquakes.

The Baseline fault scarp morphology is strikingly similar to the Los Alamos fault, with the south side uplifted forming a scarp facing upstream. Antecedent streams across the scarp have no lateral offset, which suggests that the Baseline fault is dip slip and probably a thrust style of faulting similar to the Los Alamos fault.

The development of faulting in the central Santa Maria district is apparently due to north-northeast compression across the basin. This regional compression has caused extensive Plio-Pleistocene folding and associated reverse faulting. With the available geologic data, no component of strike-slip faulting is postulated.

Physical and Mathematical Description of Active Faults

9950-01538

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No report received.

HOLOCENE BEHAVIOR OF THE SAN ANDREAS FAULT AT DOGTOWN POINT REYES NATIONAL SEASHORE, CALIFORNIA

by

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During the last year, seven exploratory trenches were excavated across the 1906 trace of the San Andreas fault at a site northwest of San Francisco near Bolinas and Point Reyes. The site is approximately 1 kilometer northwest of the small hamlet of Dogtown (Woodville) and along the San Andreas rift valley which separates Bolinas Ridge and Inverness Ridge.

Shortly after the 1906 earthquake, G. K. Gilbert (Lawson, 1908) traced the fault through this area and compiled notes documenting the location and amount of offset due to surface faulting. South of the Dogtown site he noted a stand of eucalyptus trees offset approximately 4 meters, and at the Strain Ranch north of the site a fence was offset nearly 3.5 meters. The Dogtown site is approximately equidistant between these two points and is in line with several fault-related geomorphic features. From the stand of eucalyptus trees to the trench site, the trace of the fault can be followed across the valley floor by a series of features such as offset stream channels, a low east-facing scarp and a sag pond (Figure 1). The most striking feature is the offset stream bank of Pine Gulch Creek, located immediately to the northwest of the research site. Here the stream bank is approximately 2 meters high and has been displaced along the 1906 trace for a distance of nearly 4.5 meters. Seven exploratory trenches were excavated across the suspected trace of the fault where it crosses the valley floor southeast of Pine Gulch Creek (Figure 1).

The walls of the exploratory excavations were logged geologically, and samples of carbonaceous materials were collected for radiocarbon dating. All of the excavations revealed clear evidence of the 1906 rupture. In addition, at least four seismic events that occurred before 1906 were indicated. The geologic data exhibited within the exploratory trench excavations have been compiled as a "schematic composite" of all of the trench logs (Figure 2). The locations of four preliminary radiocarbon dates that we feel are our most accurate values are shown on the composite log. Carbonaceous materials were sampled selectively to bracket the four pre-1906 seismic events. The reported ages are:

<u>1906 Event</u>

380 ± 85 years

<u>Pre-1906 Event - I</u>

740 ± 115 years

<u>Pre-1906 Event - II</u>

880 ± 75 years

<u>Pre-1906 Events - III and IV</u>

1410 ± 100 years

As a result of our subsurface work, we now believe that at least four pre-1906 earthquakes can be demonstrated to have occurred at the Dogtown site. The two most recent events are defined by rupture surfaces that are truncated by unconformities while the two remaining events are recognized by decreasingly similar stratigraphic juxtapositions across the fault surface (Figure 2). These dissimilar stratigraphic juxtapositions could have resulted only from continued lateral movements. Indeed, there may be several seismic events recorded by each of these older stratigraphic offsets. Consequently, we are planning to do additional work in this area.

A proposal for a research grant that will enable us to continue our investigation of the Dogtown site during the academic year 1981-1982 has been tentatively approved. We believe this location to be the most informative locality north of Pallett Creek for establishing recurrence intervals on the San Andreas fault. At present we have evidence that five, and perhaps more, seismic events causing significant ground rupture have occurred in this region during the last 1410 ± 100 years.

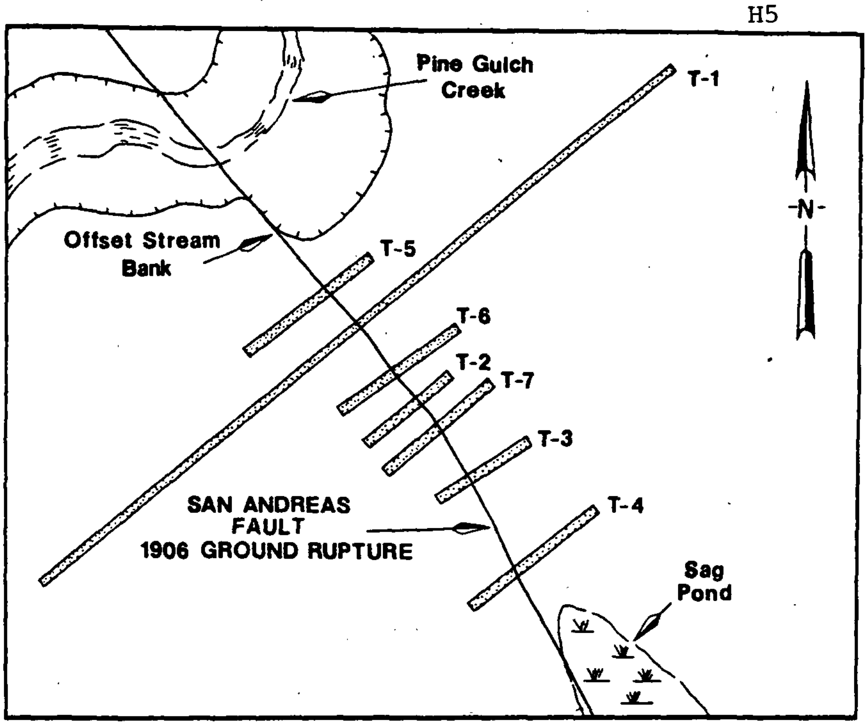

FIGURE 1. SCHEMATIC DISTRIBUTION OF THE DOGTOWN EXPLORATORY TRENCHES

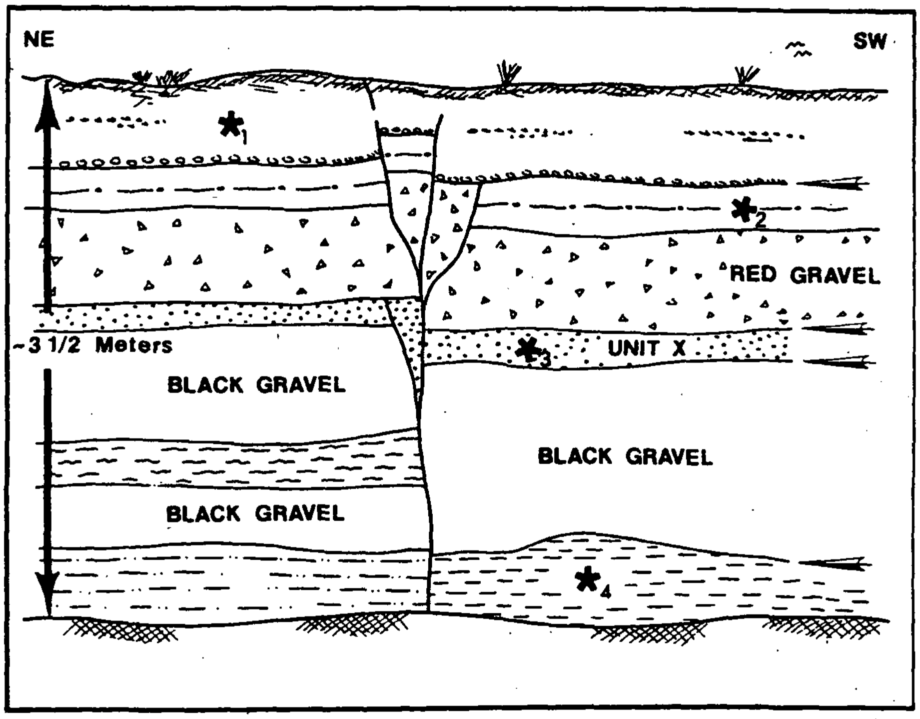

FIGURE 2. SCHEMATIC COMPOSITE OF SEVEN EXPLORATORY TRENCH LOGS

✱ Radiocarbon ages at locations shown

1. 380 ± 85 years
2. 740 ± 115 years
3. 880 ± 75 years
4. 1410 ± 100 years

Horizons formed following a seismic event.

Fault Activity of the Three Points and Pine Canyon Segments, San Andreas Fault Zone, Los Angeles County, California

14-08-0001-18244

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Investigations

Annotated fault maps of the Pine Canyon and Three Points segments of the San Andreas fault zone, in Los Angeles County have been prepared on orthophoto bases, at a scale of 1:12,000. Field mapping on stereopairs of aerial photographs as well as interpretation of several sets of aerial photographs has been the primary activity on this project.

Results

Mapping of fault traces and fault-related features within a 20 km stretch of the San Andreas fault zone that lies 15 km east-southeast of Gorman and 35 km west-northwest of Palmdale has been completed. Within the 114 square km area covered by the segment maps a cumulative total of more than 40 km of recently active fault traces and shear zones has been mapped.

An abundant and varied assemblage of geomorphic fault features and local geologic data provides extremely strong evidence for recent fault activity not only along the main trace of the San Andreas fault but also along many branch and secondary faults. Local widening of the fault zone is caused by faults clustered in complex concentrations of both right-stepping and left-stepping, en echelon, short fault strands. These zones of well-preserved faults are commonly less than 100 m wide but may be as much as 400 m wide, locally. Away from the San Andreas fault zone, longer faults (greater than 1 km) with well-preserved or youthful fault features occur both north and south of the main trace, although there appear to be more south of the fault.

Rocks of the pebbly arkose member of the Hungry Valley Formation (late Pliocene and early Pleistocene?) occur north of the San Andreas fault in the Pine Canyon area and appear to be offset right-laterally from lithologically similar rocks south of the fault which crop out 15 to 31 km to the west. The undivided rocks of the Hungry Valley Formation have apparently been offset about the same amount or at least within the same range of offsets.

The upper member of the Hungry Valley Formation north of the San Andreas fault is estimated to be offset right-laterally 12 to 27 km from like rocks south of the fault. The rocks north of the fault were deposited on early Miocene Neenach Volcanic rocks. Rocks of the Sandberg Formation, possibly late Pleistocene in age, derived from sources south of the San Andreas fault, were deposited on the upper Hungry Valley rocks north of the fault, and have subsequently been offset 6-9 km right laterally.

Tectonic Geomorphology and Earthquake Hazard: North Flank, Central Ventura Basin, California

14-08-0001-17678

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Investigations

1. Evaluation of the earthquake hazard associated with a newly defined zone of active and potentially active reverse faults near Oak View, California.

2. Evaluation of the earthquake hazard and alluvial fan deformation along the San Cayetano fault, Central Ventura Basin, Ventura, California.

3. Develop a tentative soil chronology to assist in the evaluation of deformed geomorphic surfaces in the Central Ventura Basin.

Results

1. A zone of active and potentially active reverse faults near Oak View, California (Figure 1) indicates a need for re-evaluation of the significance of the Ojai Valley to the tectonics of the western transverse ranges. The zone is more than 15 kilometers in length and up to 7 kilometers wide, strikes approximately east-west, and contains at least 7 mappable faults that cut terrace gravels of late Pleistocene age. Individual faults are south dipping and displacements range from high angle reverse to thrust. The south-side-up relative displacement is in marked contrast with the seismically active San Cayetano and Red Mountain, north-dipping faults, which bound the zone to the northeast and southwest respectively.

The Red Mountain fault is interpreted to die out to the east in a set of tight overture folds east of the Ventura River. Crustal shortening inferred along the San Cayetano fault which apparently terminates to the west near Ojai and the Red Mountain fault may be taken up in part by the newly identified zone of south-dipping, south-side-up faults.

Geomorphic expression of faulting which suggests late Pleistocene tectonism include: Linear escarpments separating several levels of the Oak View

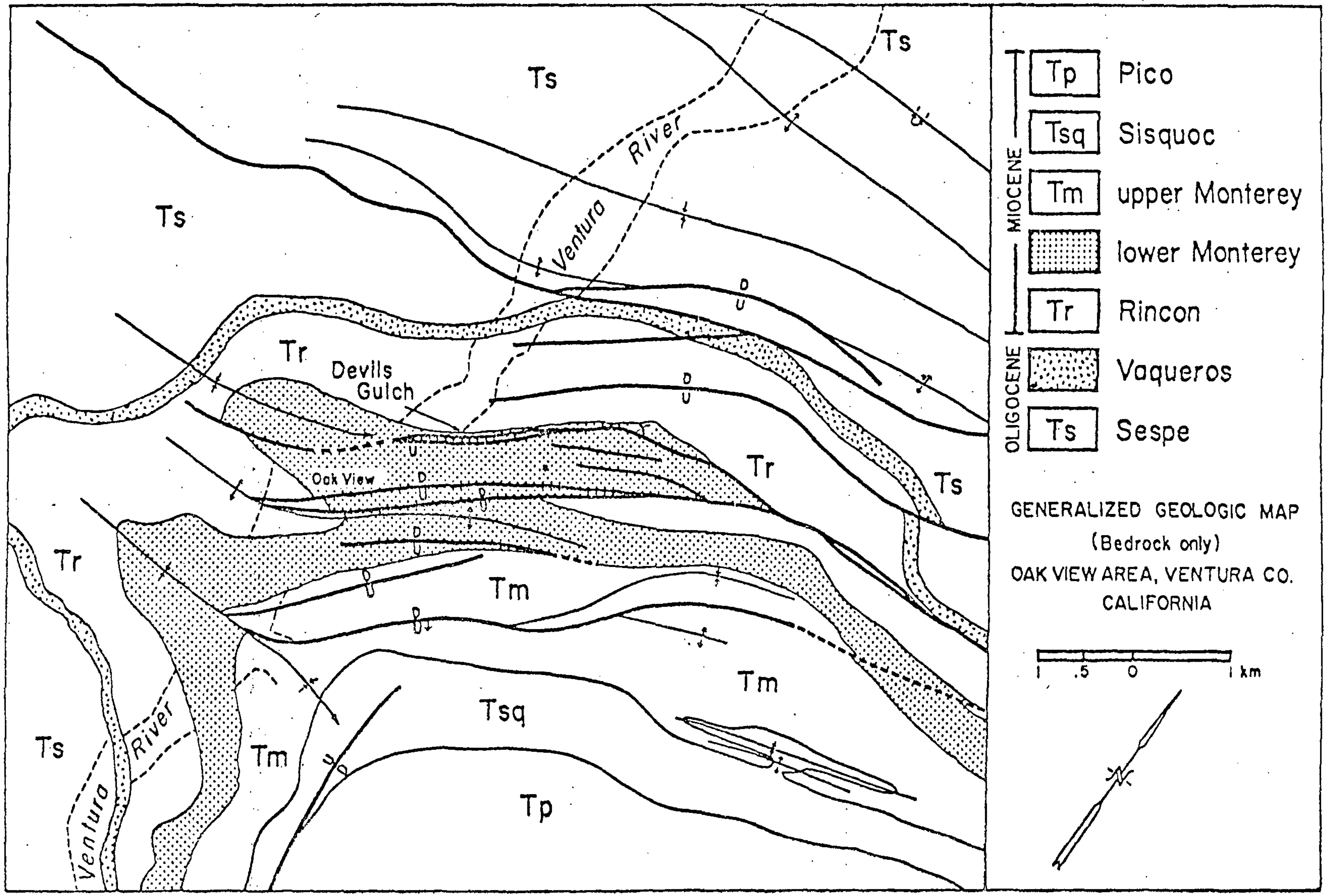

Figure 1 Generalized map (bedrock only) showing synclinorium and zone of active and potentially active south-dipping and south-side-up reverse faults.

strath terrace (dated by radiocarbon at 29,360 + 2,610 y.b.p.) along which faults outcrop in several exposures, faulting Miocene sedimentary rocks over Oak View terrace gravels; and tilted Oak View terrace surfaces with sag ponds internal drainage, and possible drainage reversals.

Several active and potentially active faults near Oak View show bedding-plane or flexural-slip that offset the Oak View terrace as well as Holocene colluvium and soil. Faulted surfaces tilt toward the axis of an underlying synclinorium which suggests that movement along the bedding-plane faults is due to the folding of the syncline. Fault planes project along bedding planes into the underlying synclinal trough region rather than cut across the structure. Movement along bedding planes occurs in part in incompetent bentonitic layers and apparently does not extend downward into the basement complex. Thus, it is concluded that movement along these faults (at Oak View) is only capable of producing earthquakes of small magnitude. Since the faults are several kilometers long and some of them are active (cut Holocene material), they may be incorrectly evaluated as capable of producing earthquakes of moderate to large magnitude. However, several kilometers to the east, the faults apparently coalesce and probably are capable of producing larger earthquakes.

The Oak View faults do represent a potential ground rupture hazard. The displacement rate associated with the Oak View flexural-slip faulting is estimated to be 3.5 mm/year during the last 30-40,000 years. Surface rupture may be intrinsically induced by compression associated with folding of the bedrock, or sympathetically triggered by earthquakes along major faults in the area such as the Red Mountain or San Cayetano faults. Thus Ojai and nearby cities and towns are located in a seismically active area and will remain vulnerable to potentially damaging seismic shaking. In addition, continued vertical displacement along flexural-slip faults is a potential ground rupture hazard which may damage any structure or road constructed across these faults. A potential landslide hazard associated with unconsolidated terrace deposits along fault scarps also exists.

2. Pleistocene and Holocene alluvial fans on the north side of the Santa Clara River Valley, California, are being actively deformed in conjunction with active thrust faulting along the San Cayetano fault (Figure 2). Several generations of alluvial fans in Orcutt Canyon display tilting and uplift in proportion to the relative ages as determined from their soil profile development. The oldest fan remnants are tilted to 17 degrees with intrafan fault offsets of up to 100 meters. Present unfaulted fans have slopes of about 6 degrees at the same proximity to the San Cayetano fault indicating at least 11 degrees of basinward tilting. Faulting of the fan occurs both directly by the San Cayetano fault and by bedding-plane faults induced by regional north-south covergence.

In Orcutt Canyon, alluvial fans begin at the main fault trace where bedrock is faulted up and eroded, forming long, narrow valley-fill fan deposits. These deposits are faulted by flexural-slip induced bedding plane faults with scarps up to 60 meters high in the oldest deposits. Moderate- to large-magnitude earthquakes would only be expected to be generated along the main San Cayetano fault zone which juxtaposes Eocene sandstones and shales over early to mid-Pleistocene conglomerates. The bedding-plane faults probably only produce small-magnitude earthquakes as they do not extend to depths where large earthquakes are generated. They

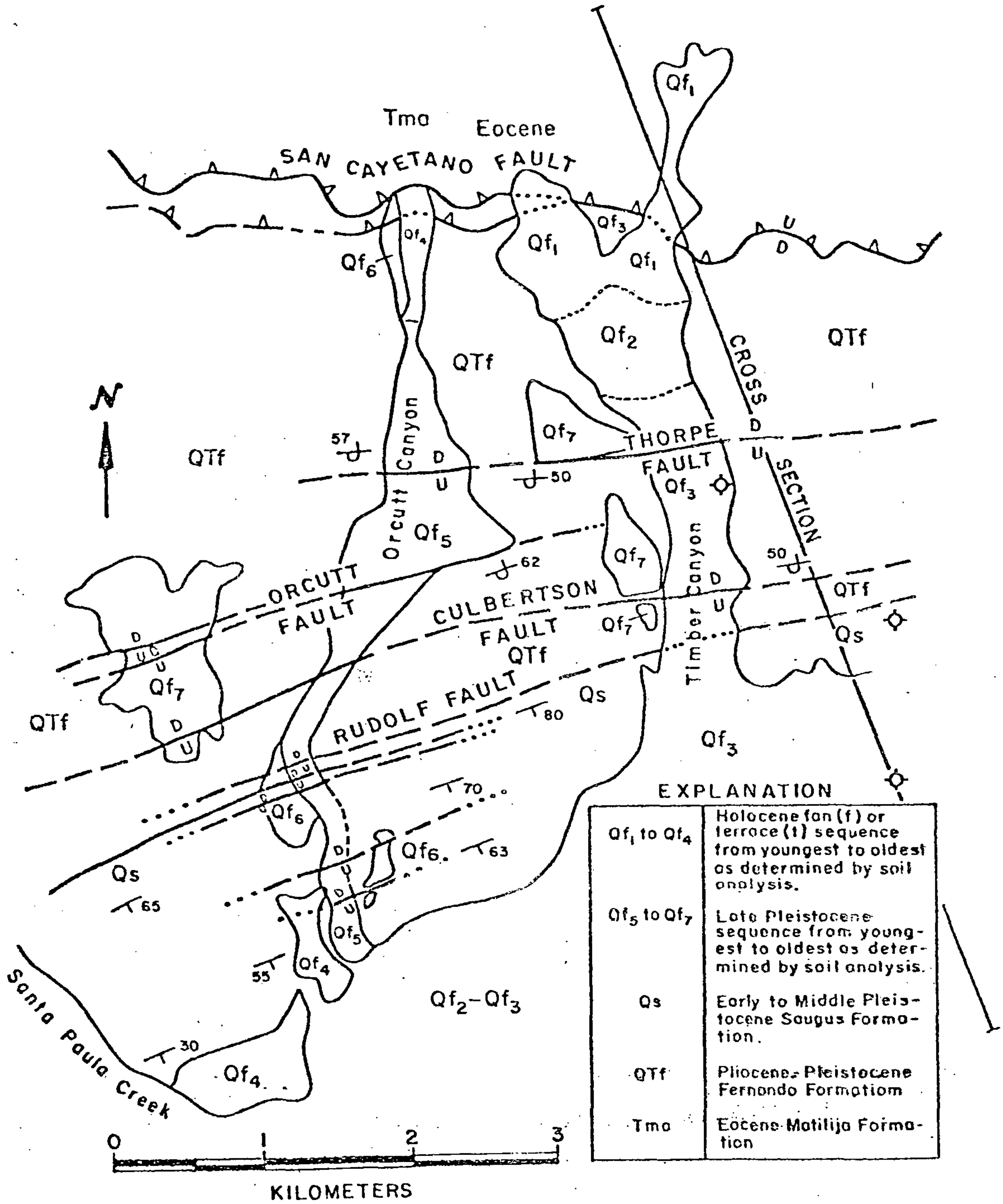

Figure 2 Orcutt and Timber Canyons on the north flank of the Santa Clara syncline.

do however produce potential ground rupture hazard.

The San Cayetano fault is potentially active with a both seismic shaking and ground rupture hazard; probably capable of producing a San Fernanco (1971) type earthquake of M6 to M7 (Yeats, Clark, Keller, Rockswell, in preparation) at Sisar Canyon, the main trace of the San Cayetano fault is represented by a 65 meter scarp in mid to late Plesitocene alluvial fan deposits, and at Bear Canyon alluvial fan deposits are being folded and faulted by a strand of the fault. Estimated slip rates vary from a maximum of 3.6 mm per year in the central portion of the fault to a minimum of 0.66 mm per year toward the western terminus. These rates are compatible as displacement per earthquake event as well as total displacement should die out toward end points of the fault.

3) Soils in the study area show a great range of variability in profile characteristics and in apparent age. Nevertheless, the older surfaces show stronger profile development and thus a soil chronosequence exists. The soil range from Holocene (Q_1) to late Plesitocene(Q_7). Two radiocarbon dates used in conjunction with known deformation of geomorphic surfaces facilitate the assignment of tentative ages to the seven members of the chronosequence, providing a tool to estimate deformation rates associated with folding and faulting.

Based on soils correlation it is provisionally concluded that the multiple terrace surfaces at different elevations in the Oak View area are all tectonically segmented portions of the Oak View terrace.

Palexeralfs in the study area appear to form in as short a period to 20,000 to 30,000 years, considerably faster than rates estimated for similar soils in the California interior. Fast rates of pedogenesis reflect texture and composition of the parent material, increase weathering, acidic conditions, stability of the geomorphic surface (although deformed, the surfaces are nearly horizontal), annual precipitation pattern, downward flow of soil moisture, and eolian input of salt and dust.

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Correlating and Dating Quaternary Sediments by Amino Acids

9460-01996

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Investigations

1. Completed a detailed study of the amino acid geochemistry of bones from Rancho La Brea, California, in order to evaluate (a) the effect of asphalt impregnation and (b) the usefulness of bones preserved in asphalt for amino acid dating.

2. Amino acid dating techniques were applied to bulk sediment samples collected by means of an hydraulic piston core on Leg 68 of the Deep Sea Drilling Project. This preliminary work compared amino acid parameters in a virtually continuous undisturbed section of late Neogene and Quaternary sediment and provided a test of amino acid dating over a span of about 8 million years.

Results

1. Amino acids in bones from the Rancho La Brea asphalt deposit in Los Angeles, California, are remarkably well preserved as compared with amino acids in bones of equivalent age that have not been preserved in asphaltic tar. In this study amino acids were recovered from seven samples ranging in age from less than 200 to 36,000 years as determined by radiocarbon. The rate of decrease with age of total amino acid concentrations and the rates of racemization of individual amino acids in the asphalt preserved bones are much less than the rates observed for bones from other localities. For example, the average rate constant for the racemization of aspartic acid in La Brea bones is $4.6 \times 10^{-6} yr^{-1}$ while in bone not preserved in asphalt from a southern California soil environment the rate constant is $1.08 \times 10^{-5} yr^{-1}$. The excellent state of preservation of amino acids in these asphalt impregnated bones may result from the asphalt reducing the permeability of the bone to water and protecting the bone from microbial activity. This study has shown that amino acids can be useful as a means of estimating ages of asphalt-preserved bones. The method can be used to date other La Brea samples for which there is no radiocarbon control and can be extended to other localities where bones are preserved in asphalt.

2. Preliminary amino acid analyses of four samples from a 228 m core of foram-bearing, nanno marl from the western Caribbean show in general an increase in extents of racemization and a decrease of concentrations with depth. Extents of racemization increase by about a factor of two whereas concentrations of protein amino acids decrease by about a factor of two over the time interval of about 8 million years represented by the core. The calculated rates of amino acid racemization are between 10^{-6} and $10^{-7} yr^{-1}$ which is the same range that has been reported previously for amino acids in calcareous clays. The non-protein amino acid, δ-aminobutyric acid,

increases in concentration with depth, and its concentration may be useful for estimating age. Although the trends in the data are as expected, the results are not systematic. For example, the amino acids in the deepest sample (210 m), which is of Miocene age, have lower extents of racemization and higher concentrations than do the amino acids in the sample at about 120 m (Lower Pliocene). These results may indicate the effects of different environmental conditions at these periods. Analyses of four additional samples will fill in the gaps and provide further information for evaluation of the amino acid dating method applied to a broad time span of 8 million years.

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Seismological Field Investigations

9950-01539

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Investigations

1. Kentucky aftershock study--regional investigation of the July 24, 1980, magnitude 5.2 (M_b) earthquake near Sharpsburg.

2. Utah aftershock study--regional investigation of the September 30, 1978, magnitude 5.3 (M_L) earthquake near Duchesne.

Results

1. The magnitude 5.2 (M_b) earthquake that occurred near Sharpsburg, Kentucky, on July 27, 1980, was felt throughout a thirteen-state area and also the Canadian province of Ontario. The main shock was located approximately 50 km ENE of Lexington (38.174° N latitude, 83.907° W longitude, depth = 8 km) and roughly 25 km north of the North Kentucky fault zone. Known or suspected faulting in this region have complex geometries (Randy Keller, personal communication) and are generally post-Pennsylvanian in age. Historically, this earthquake represents the first significant seismic event within the vicinity of Sharpsburg.

On July 28, a field-investigations team was dispatched from Golden, Colorado, to Lexington with fifteen portable seismographs (ten vertical-component smoked-paper recording systems and five three-component digital systems). Within two days, these instruments were incorporated into the ten-station temporary network installed shortly after the earthquake and jointly operated by the University of Kentucky (UK) at Lexington (R. L. Street) and the Tennessee Earthquake Information Center (TEIC), Memphis State University (J. E. Zollweg). Three additional vertical-component smoked-paper units from Virginia Poleytechnic Institute and State University (VPI & SU) at Blacksburg (G. A. Bollinger) were also included into the final seismograph network configuration that surrounded the epicenter of the main shock. The entire 28-station network was operational until August 8, when TEIC/UK removed all but two of their instruments. On August 9, the VPI & SU systems were removed and on August 10, the Golden team picked up the USGS equipment. An agreement was made by all parties involved with the aftershock monitoring that TEIC would be responsible for the initial reduction, analysis, and interpretation of the aftershock network records.

Preliminary results obtained from TEIC (J. E. Zollweg, written communication) indicate that at least 52 aftershocks with a magnitude range of approximately $-1.5 \leq M_L \leq 1.9$ were recorded by the network; three additional aftershocks with magnitudes between about 1.0 and 1.5 occurred prior to the deployment of the TEIC/UK portable seismographs. A set of 29 well-recorded aftershocks was located using joint hypocenter determination techniques with a local crustal model developed from quarry blasts and well logs. Typical relative locations appear to have a precision of about 0.6 km in epicenter and 1.0 km in depth. The relative hypocenters define a plane striking northeast and dipping at about 55° to the southeast; depths range from about six to sixteen km. The fault area defined by the aftershocks is about 40 km^2. A composite focal mechanism solution for some of the largest aftershocks indicates right-lateral strike-slip motion with a large component of reverse faulting along a plane striking at about N40°E.

2. A magnitude 5.3 (M_L) earthquake occurred on September 30, 1977, approximately 35 km north-northeast of Duchesne, Utah, near the boundary between the southern flank of the Uinta Mountains and the Uinta Basin. The main shock was followed by several hundred aftershocks, the largest of which was a magnitude 4.7 (M_L) earthquake on October 11. The epicentral region has historically exhibited a very low rate of seismic activity. No surface faulting was observed for this earthquake sequence.

Locations of 173 well-recorded aftershocks from data obtained by a twelve-station temporary seismograph network define an epicentral area of approximately 12 km^2 (3.3 km E-W; 3.5 km N-S). Depths range from about 4.5 km to 7.5 km and have an apparent dip to the east-southeast of approximately 45°. Composite focal mechanism solutions for seven sub-clusters of aftershocks agree remarkably well. The predominant mode of faulting is normal along planes striking about N18°E with an average dip of approximately 40° ESE.

Reports

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Soil Correlation and Dating, Western Region

9540-02192

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Investigations

About 120 soil profiles (≅670 samples) have been described and sampled for laboratory analysis to study changes of properties in eleven well dated time sequences (chronosequences) of soils in the western United States. Partial or complete laboratory data is now available for seven of these chronosequences. The chronosequence profiles are developed in alluvium, colluvium, till, and marine terrace deposits derived from granitic, volcanic, metamorphic, and sedimentary terrains in Colorado, western Washington, and California (table 1). Laboratory analyses are being conducted by the University of California (Davis) and the U.S.G.S. (Menlo Park and Denver). Ken Trott will continue the Menlo Park analytical work begun by Ann Walker. R. M. Burke, D. E. Marchand, J. W. Harden, and P. W. Birkeland have reconnoitered more than 15 potential new chronosequences in California, Washington, Idaho, Montana, Wyoming, Colorado, Arizona, New Mexico, and west Texas.

Soil data stored in Multics files for each profile and sample include 25 field properties, soil thin section information, quantitative mineralogy of very fine sand fractions, semiquantitative mineralogy of clay fraction, bulk density, complete particle size information, 25 chemical properties of the less-than-2 mm soil fraction, and bulk chemistry of the less-than-2 mm and silt-plus-clay fractions (13 elements by X-ray spectroscopy, 26 elements by neutron activation) for a total of more than 100 properties. We are also storing soil chronosequence data published by previous workers. Emily Taylor is developing programs to facilitate the loading of Multics files and to streamline plotting and statistical analysis by MINITAB and SPSS.

Our studies are coordinated with other projects involved in Quaternary dating, including uranium series and uranium-trend dating, amino acid dating, tephrochronology, thermoluminescence, magnetostratigraphy, and other studies involving soil chronosequences.

Results

Nearly all properties investigated thus far show changes with time. For some properties, the changes are irregular; for others the changes are systematic enough to be of use for correlation or dating purposes. Bulk density and organic-related properties such as nitrogen, carbon, and organic phosphorus change rapidly during the first few thousands of years, eventually reaching a steady state condition. Other properties such as free iron oxides, free aluminum oxides, particle size, clay mineralogy, and properties related to leaching appear to change more slowly, These properties are more valuable as time indices for older soils. Results from X-ray fluorenscence and neutron activation analysis continue to show striking and systematic changes in bulk soil chemistry with age. Aluminum, silicon, iron, calcium, magnesium, hafnium, and scandium yield the best age trends, but manganese, sodium, potassium, barium, nickel, zirconium, tantalum and thorium also give good plots against absolute time. Zirconium and hafnium appear to be very stable elements during soil formation.

Rates of changes in soil properties are clearly not linear. When plotted against linear time, most properties display an initial rapid increase followed by a slower rate of increase. Against log time (figures 1 and 2), many properties show an increasing slope with time. We do not know at this time whether the change in slope is a response to internal factors such as clay buildup, to external factors such as climatic change, or both. Rates of change are affected by both climate and parent material: soil properties change more rapidly in western Washington than in the drier San Joaquin Valley; rates are more rapid for volcanic and metavolcanic than for granitic parent materials and more rapid for silty than sandy deposits.

Jennifer Harden has formulated a quantitative index of soil development based on field morphological properties. This index yields a clear curvilinear plot against $\log_{10}$ time for the Merced River chronosequence (fig. 1). The index plotted here is based on soil hue and chroma, texture, clay films, dry consistency, wet consistencey, and thickness. A modified index now being developed will take into account such additional field properties as structure, degree of stratification, field pH, and moist consistency and will be applied to the other chronosequences.

Grain mounts of the very fine sand fraction of the Merced River soils show progressive etching, alteration, and depletion of weatherable minerals and buildup of stable minerals with time (fig. 2). We are still evaluating the utility of mineralogical analysis, given the time necessary for statistically significant grain counts, but it is clear that thin sections and grain mounts provide important information concerning the extent to which previously weathered materials are reworked into younger soil profiles.

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Table 1. Summary of information and research status for chronosequences under investigation by the project.

Chronosequence	Classification (mature soil)	Climate	Vegetation	Parent Material		Age Range	Number of Units	Number of Profiles	Number of Samples	Present Status[3]
				Provenance[1]	Texture[2]					
1. Western Sierra Nevada Foothills, CA	Palexerult	Mediterranean (Csa) MAT 60°F MAP 32"	Foothill Woodland	mv	psgr	9k-600k	5	12	40	9
2. Merced River, Northeastern San Joaquin Valley, CA	Typic Palexeralf	Mediterranean (Csa) MAT 62°F MAP 12"	Valley grassland	gr	sa	0-3my	9	34	209	7-9
3. Dry Creek, Northeastern San Joaquin Valley, CA	Typic Palexeralf	Mediterranean (Csa) MAT 62°F MAP 12"	Valley grassland	m,a	si,sa	0-1my	8	9	51	6-7
4. Front Range, Colorado	Borept	Highland (ET) MAT 25°F MAP 30-35"	Alpine fell-fields	gr	psbo,sa	0-10k	4	8	25	6-7
5. Cowlitz River, western WA	Paleudult	Marine West Coast MAT 52°F MAP 47"	Douglas fir forest	a	si/cogr	0-1.5my	9	13	80	6-7
6. Ventura area, CA - fine-grained	Natric to Mollic Palexeralf	Coastal Mediterranean (Csb) MAT 60°F MAP 15"	Coastal chaparral	s-2	si/psgr	0-85k	4	8	53	5-6
7. Ventura area, CA - gravelly	Natric or Typic Palexeralf	Coastal Mediterranean (Csb) MAT 60°F MAP 15"	Coastal chaparral	s-3	cogr	0-250k	5?	2	14	3-6
8. Palisades, eastern High Sierras, CA	Borept	Highland Tundra (ET) MAT 25°F MAP 35"	Alpine fell-fields	gr	psbo,sa	0-10k	3	7	23	5
9. Ano Nuevo, central CA coast	Natric or Mollic Palexeralf to Palexerult	Mediterranean to Marine West Coast (Csb) MAT 56°F MAP 37"	Coastal Prairie	s-2	psgr	0-320k	4	6	58	4-5
10. Honcut Creek, southeastern Sacramento Valley, CA - nongravelly	Mollic to Typic Palexeralf	Mediterranean (Csa) MAT 62°F MAP 21"	Valley grassland	a,mv,gr	si	0-250k	5	17	100	5

Chronosequence	Classification (mature soil)	Climate	Vegetation	Parent Material		Age Range	Number of Units	Number of Profiles	Number of Samples	Present Status[3]
				Provenance[1]	Texture[2]					
11. Honcut Creek - gravelly	Typic Palexeralf	Mediterranean (Csa) MAT 62°F MAP 21"	Valley grassland to Foothill Woodland	a,mv,gr	cogr	250k-3my	4	2	12	3-5
12. Rock Creek, southwestern Montana	Paleboroll to Paleargid	Continental Subarctic (Dwb) MAT 42°F MAP 16-22"	Sagebrush scrub	gr, s-2	cogr	0-600k	5-6	--	--	2-3
13. Bighorn Basin northern Wyoming	Gypsiferous Paleargid	Continental Subarctic (Dwb) MAT 45°F MAP 7"	Sagebrush-Creosote bush scrub	s-3,4	psgr	0-600k	5	--	--	2-3
14. Tuolumne River, northeastern San Joaquin Valley, CA	Typic Palexeralf	Mediterranean (Csa) MAT 61°F MAP 13"	Valley grassland	gr,and,m	sa	0-600k	11	8	41	3-6
15. Stanislaus River, northeastern San Joaquin Valley, CA	Typic Palexeralf	Mediterranean (Csa) MAT 61°F MAP 13"	Valley grassland	gr,and,m	sa	0-600k	11	7	32	3-6
16. Santa Cruz, CA	Mollic Palexerult to Palexeralf	Marine West Coast to Coastal Mediterranean (Csb) MAT 56°F MAP 37"	Coastal Prairie - Redwood Forest	gr	sa	0-1my	9	--	--	3
17. Colorado Piedmont	Paleboroll to Paleargid	Continental Subarctic (Dsa) MAT 52°F MAP 19"	Plains grassland	m,gr	sagr	0-1.5my	8	--	--	2
18. Kern River, southeastern San Joaquin Valley, CA	Paleargid	Dry Mediterranean (Csa) MAT 65°F MAP 6"	Dry Valley grassland	gr,s-2	cogr	0-260k	5	--	--	1
19. West-central San Joaquin Valley, CA	Paleargid	Dry Mediterranean (Csa) MAT 62°F MAP 8-11"	Dry Valley grassland	s-2,mv	psgr	0-260k	7	--	--	1
20. San Diego, CA	Palexeralf	Coastal Mediterranean MAT 63°F MAP 10"	Chaparral	gr	sa	?	?	--	--	1
21. Antelope Valley, CA	Palexeralf to Paleargid	Dry Mediterranean (Csa) MAT 55-60°F MAP 7-12"	Creosote Bush Scrub	s-2,m-gr	gr,sa	0-400k	7	--	--	1

	Chronosequence	Classification (mature soil)	Climate	Vegetation	Parent Material Provenance[1]	Parent Material Texture[2]	Age Range	Number of Units	Number of Profiles	Number of Samples	Present Status[3]
22.	Sonora Junction, eastern Sierra Nevada, CA	Paleboralf	Continental Subarctic (Dsb) MAT 43°F MAP 8-9"	Sagebrush scrub, edge of Montane Con. Forest	gr,and	sagr	0-450k	4	--	--	1
23.	Boise River, Idaho	Palexeroll	Continental Subarctic (Dsa) MAT 50°F MAP 12-15"	Grassland, edge of Montane Conif. Forest	b	cogr	?	?	--	--	1
24.	Wenatchee area, eastern Wash., Cascades	Paleudalf to Paleargid	Continental Subarctic (Dsa) MAT 51°F MAP 9-12"	Montane Conif. Forest, edge of sage brush scrub	and,m,gr	gr	0-3my	--	--	--	1

1 gr = granitic; a = andesitic; m = metamorphic (slate, schist); mv = metavolcanic; b = basalt; s-1, sedimentary, very stable mineralogy (chert, qtz); s-2, sedimentary, fairly stable mineralogy (qtz,alkali feld, clays); s-3, sedimentary, relatively unstable mineralogy (feldspars, mafic minerals; lithic fragments); s-4, sedimentary, unstable mineralogy (abundant mafics, calcic palgioclase, limestone).

2 si = silt, silty, sa = sand, sandy, gr = gravel, gravelly, co = cobble, cobbly, bo = boulders, bouldery (till, rock glacier deposits), ps = poorly sorted.

3 1 = reconnaissance, 2 = area selection, 3 = site selection, 4 = sampling, description, 5 = conventional soil analysis, 6 = neutron activation, x-ray fluorescence, 7 = data interpretation, 8 = report writing, 9 = report published.

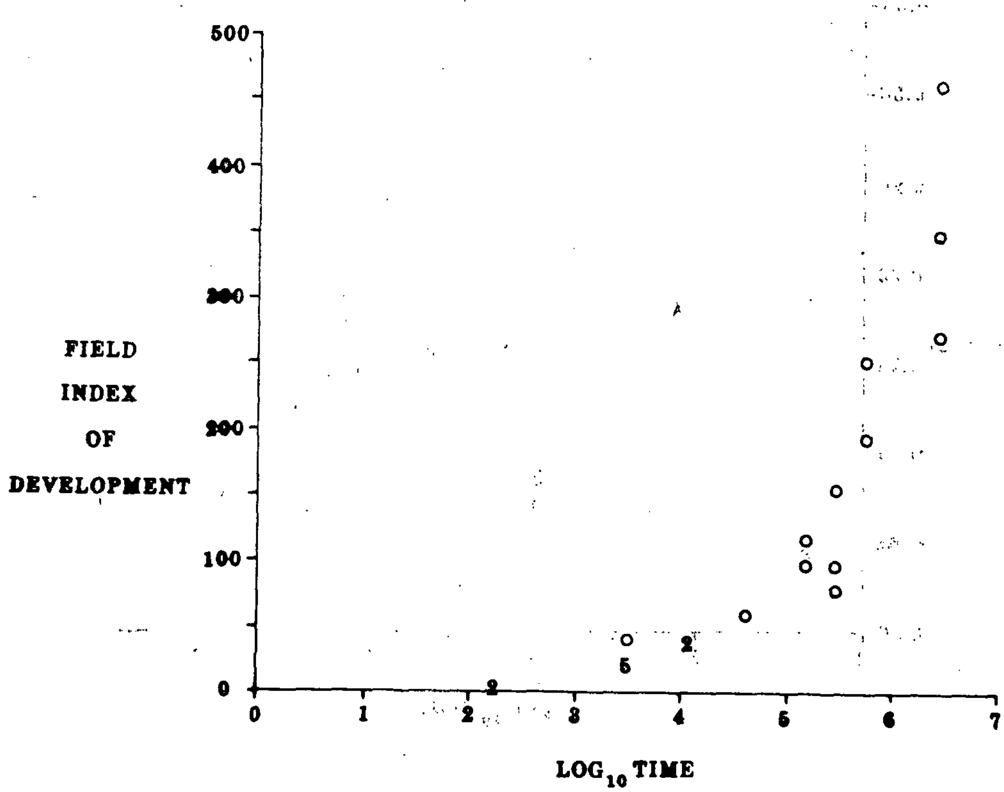

Figure 1. Index of development based on field morphological properties (see text) plotted against $\log_{10}$ time for the Merced River chronosequence, northeastern San Joaquin Valley, California (sandy, granitic source). Numbers indicate data points that fell on the same plotting position.

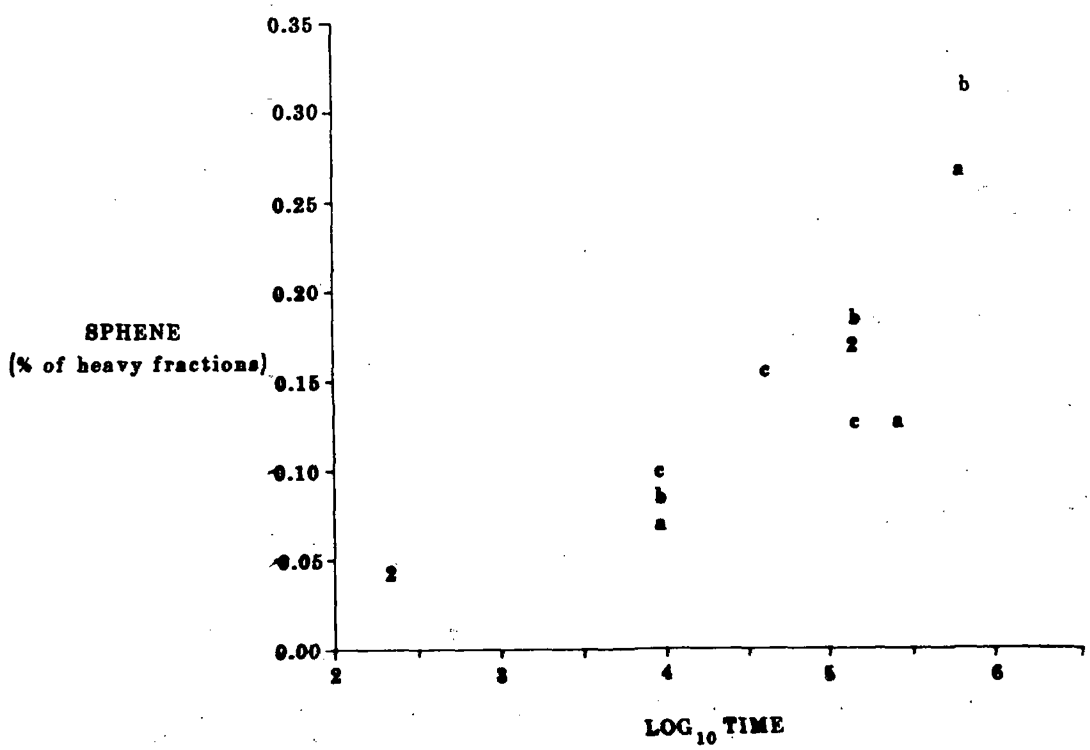

Figure 2. Percentage of sphene in the very fine sand fractions of Merced River soils, expressed as percentage of heavy materials and plotted against $\log_{10}$ time. a, b, and c refer to A, B, and C soil horizons. Numbers refer to data points that fell on the same plotting position.

Earthquake Intensity and Fault Creep

9940-02675

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Investigations

1. The modernization of the seismic intensity maps of the 1906 California earthquake has continued with data compilations in Santa Clara, Santa Cruz, Alameda and Contra Costa Counties, and in San Francisco.

2. Ground cracks were mapped at the May 1980 earthquake area at Mammoth Lakes, California, and portable invar-rod creepmeters were designed and installed at seven locations to measure post-earthquake movements.

Results

1. The distribution of 1906 earthquake damage in Santa Clara and Santa Cruz Counties indicates seismic intensity MM VIII and MM IX at most places within 25 km of the 1906 fault rupture.

2. The 1906 earthquake damage in Alameda and Contra Costa Counties indicates MM VIII and MM IX in the western part of the counties, 25-40 km from the 1906 fault rupture, and MM VII to MM VIII in the eastern part of the counties, 45-70 km from the 1906 fault rupture. The earthquake damage on sedimentary bedrock was similar to that on alluvium.

3. Significant ground failures, with deformed streetcar tracks and sunken buildings, occurred at several locations in the waterfront areas of Oakland and Alameda. Also, earthquake-caused fires occurred in Oakland, Berkeley, and Martinez.

4. The post-earthquake creepmeters at Mammoth Lakes indicate that additional movement of several centimeters occurred at a few sites.

5. Interviews at Mammoth Lakes indicate that the major earthquake damage occurred in an aftershock 16 minutes after the first main earthquake, rather than in the main earthquake itself. The aftershock was apparently located much closer to Mammoth Lakes. The seismic intensity of MM VII correlates with a nearby strong-motion instrument indicating a peak acceleration of more than 0.3g.

Reports

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Nason, Robert, 1980, Possible low-velocity zone under California suggested by 1906 earthquake intensity pattern: Earthquake Notes, vol. 50, no. 4, p. 12-13.

Nason, Robert, 1980, Seismic intensity study of the October 1979 Imperial Valley earthquakes: Earthquake Notes, vol. 50, no. 4, p. 38-39.

Burford, R.O., Nason, R.D., and Harsh, P.W., in press, Results of fault creep studies in Central California: U.S. Geological Survey, Earthquake Information Bulletin.

Nason, Robert, in press, Seismic intensity studies in the Imperial Valley: <u>in</u> Rojahn, C., ed., The Imperial Valley earthquake of October 15, 1979, U.S. Geological Survey, Prof. Paper.

Data Processing, Golden

9940-02088

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Investigations

1. The purpose of this project is to provide the day-to-day management, systems maintenance and development for the Golden Data Processing Center. The Center supports Golden based OES investigators with a variety of computer services. The systems include a PDP 11/40, an EAI 680 Analog Computer, Honeywell Level 6 RJE, a PDP 11/70, three PDP 11/03's, and PDP 11/23. To be delivered is a VAX/780 (Nov. 1980) and a PDP 11/34 (Jan. 1981). Total memory will be 2.4 Mbytes and disk space will be approximately 600 Mbytes. Peripherals will include three plotters, seven mag-tape units, an analog tape unit, three line printers, 5 CRT terminals with graphics and a Summagraphic digitizing table. Dial-up is available on all the major systems and hard-wire lines are available for user terminals on the upper floors of the building. Operating systems used are RSX11 (11/40 and 11/23), Unix (11/70 and 11/34), RT11 (11/03's) and VMS (VAX).

A security audit was performed by Dolph Cecula and stricter procedures for operations of the center are being implemented.

The VAX system is to be shared by the Branch of Global Seismology and the Branch of Earthquake Tectonics and Risk for NEIS and the Hazards Risk Map Program.

Results

Wave form data was processed (from analog tape, digital cassette tape, and real time phone input) from networks in South Carolina, Utah, Texas, Los Angeles, Nevada, and various U.S. Net stations. The PDP 11/70 is being used primarily for processing global net "day tapes" for ARPA and SEDAS program development. Version 3.2 of RSX11 was brought upon the PDP 11/40.

The U.S. Net event detection system has been developed on a PDP 11/03-PDP 11/40 system and will transfer to the PDP 11/23 as soon as all the peripherals arrive.

A Houston DP9 42" plotter and a Summagraphic 5 ft. digitizing table have been installed and may be shared by any of the systems through the terminal panel.

A Plessey DD11/80 67 Mbyte disk is now installed on the PDP 11/40 allowing three RK05 disk units to be distributed among the microprocessors.

Reports

Rogers, A. M., Covington, P. A., Park, R. B., Borcherdt, R. D., and Perkins, D. M., 1980, Nuclear event time histories and computed site transfer functions for locations in the Los Angeles region: U. S. Geological Survey Open-File Report (in press).

Quaternary Dating and Neotectonics

9530-01559

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Investigations

1. Near Arco, Idaho, profiled scarps of differing orientation, but of the same age (late Pleistocene), to determine effect of aspect on rate of fault-scarp degradation (K. L. Pierce).

2. Collected obsidian samples from two faults exposed in a trench excavated by Dave Nash across a fault scarp reactivated in the 1959 Hebgen Lake earthquake. If pre-1959 movements broke any of the obsidian pebbles, then such movements could be dated by obsidian-hydration methods (K. L. Pierce).

3. Completed compilation of Neogene and younger faults in Colorado. Field checked faults suspected of Quaternary movement. Measured scarp profiles of faults in the San Luis and upper Arkansas Valleys (S. M. Colman).

4. Completed manuscript on the clay mineralogy of weathering rinds and its importance for rates and processes of soil development (S. M. Colman).

5. Completed and submitted for technical review a Professional Paper entitled "Quaternary tectonic history of the La Jencia fault, central New Mexico" which includes a detailed series of trench logs and a complete description of soil stratigraphic units, scarp morphology, and paleoseismic interpretations (M. N. Machette).

6. Collected scarp-profile data and studied field relationships of about 25 late Quaternary faults in New Mexico and western Texas (M. N. Machette).

7. Completed geologic mapping of late Cenozoic deposits in the Beaver basin, central Utah (M. N. Machette).

8. Continued study of soil chronosequences and surface and buried soils at key stratigraphic localities along the Wasatch Front, with emphasis on soils formed in surficial deposits that are offset by range-front faults (R. R. Shroba).

Results

1. Stream undercut scarps that face north, south, east, and west have been profiled. Although these data have not yet been analyzed, field examination clearly shows that south-facing scarps are considerably more degraded than north-facing ones of the same age (K. L. Pierce, investigation No. 1).

2. For the first 20 thin sections of obsidian pebbles examined, only a few surfaces have hydration rims thinner than those originating when the obsidian-sand plain was constructed. More thin sections need to be examined before any firm conclusions can be drawn regarding fault movements younger than the 30,000-year-old obsidian-sand plain and older than the 1959 Hebgen Lake earthquake (K. L. Pierce, investigation No. 2).

3. Fieldwork on Quaternary faults in Colorado revealed that faults with clear displacements of Quaternary deposits are almost entirely confined to the Rio Grande Rift zone of the San Luis and upper Arkansas Valleys. Evidence for Quaternary movement on most other young faults is circumstantial because of the absence of Quaternary deposits in critical locations. Morphometric analysis of measured scarp profiles of faults in the San Luis and upper Arkansas Valleys should yield additional information about the age and history of their movement (S. M. Colman, investigation No. 3).

4. Although scarp-profile data have yet to be processed, field investigations of fault scarps in New Mexico and western Texas reveal many examples of long-term (middle and late Pleistocene) recurrent fault displacements with composite scarps commonly ranging up to 30 m in height. Scarps of Holocene(?) age are restricted primarily to short segments of longer faults or low, isolated faults. The most recent activity seen on most of the faults cutting surficial deposits within the rift is of late Pleistocene age (M. N. Machette, investigation No. 6).

5. The Beaver basin, located along the Colorado Plateau-Basin and Range boundary in central Utah, is a late Cenozoic structural depression. The exposed Miocene through early Quaternary basin-fill deposits record a complex sedimentary sequence which may be suitable host rocks for sedimentary uranium mineralization. The presence of an axial north-trending horst and coincident antiform indicate a history of uplift and subsequent tensional collapse within the basin. Faults associated with these structures have been recurrently active through the late Pleistocene. Along the eastern basin margin, normal faults associated with the uplift of the Colorado Plateau record recurrent uplift through the end of the Pleistocene. This basin contains exposures of some of the most structurally deformed Quaternary sediments in the Basin and Range Province (M. N. Machette, investigation No. 7).

6. Soil investigations on faulted fans and terraces that postdate the Provo shoreline, along the Wasatch Front between Ogden and Springville, Utah, indicate that soils on many of these landforms have weakly developed argillic B (Bt) horizons that are similar to, or are slightly less well developed than, those formed in Provo shoreline deposits. The Bt horizons of the soils on the fans and terraces commonly have a few thin clay films and are 20-55 cm thick. The soil data suggest that 1) much of the fan gravel and terrace alluvium below the Provo shoreline were deposited within a few thousand years of lake recession, and 2) most of these deposits are of latest Pleistocene or early Holocene age, about 14 thousand to about 8 thousand years old. Younger deposits, inferred to be of middle to late Holocene age, are much less extensive and are limited primarily to flood plains, low terraces, small fans, and areas immediately adjacent to drainageways on large fans. Soils formed in deposits considered to be of mid-Holocene age have weakly developed cambic B horizons

that lack clay films and are 15-35 cm thick. The widespread occurrence of alluvial surfaces in the ten-thousand-year range provides useful datums for determining the location and amount of offset on young faults along the Wasatch Front.

Reports

Colman, S. M., 1980, CHEMANAL: A MULTICS Fortran program to calculate chemical weathering data: U.S. Geological Survey Open-File Report 80-844, 23 p.

Colman, S. M., and Pierce, K. L., 1980, Weathering rinds on andesitic and basaltic stones as a Quaternary age indicator, western United States: U.S. Geological Survey Professional Paper 1210 (in press).

Cunningham, C. G., Steven, T. A., Machette, M. N., Mitler, W. R., Campbell, D. L., and Izett, G. A., 1980, Recommended drilling in the Beaver basin, west-central Utah: U.S. Geological Survey Administrative Draft Report prepared for U.S. Department of Energy, 17 p.

Scott, W. E., McCoy, W. D., Shroba, R. R., and Miller, R. D., 1980, New interpretations of the late Quaternary history of Lake Bonneville, western United States: American Quaternary Association Abstracts and program, sixth biennial meeting, Orono, Maine, p. 168-169.

Steven, T. A., Cunningham, C. G., and Machette, M. N., 1980, Integrated uranium systems in the Marysvale Volcanic Field, west-central Utah: U.S. Geological Survey Open-File Report 80-254, 39 p.

Steven, T. A., Cunningham, C. G., and Machette, M. N., 1981, Integrated uranium systems in the Marysvale Volcanic Field, west-central Utah: Symposium on uranium in volcanic and volcaniclastic rocks, American Association of Petroleum Geologists, in press.

Uranium Series Dating

9740-00378

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Investigations

1. Uranium-trend dating has been used to estimate the time of deposition of alluvium and eolian deposits over the time range of 3,000 years to about 800,000 years ago. The dating technique consists of determining an isochron from analyses of several samples covering the various soil horizons in a given alluvium unit; approximately 4 to 9 samples of each alluvium unit are analyzed. The results of these analyses are plotted where $(^{238}U-^{230}Th)/^{238}U$ vs. $(^{234}U-^{238}U)/^{238}U$ ideally yield a linear relationship where the measured slope changes in a predictable way with increasing age of alluvium for a given half period of the flux controlling the migration of uranium in the alluvium environment. An empirical model compensates for different climatic and enrivonmental regimes and the model has primary time calibrations at 11,000 years, 140,000 years (Bull Lake), 600,000 years (Pearlette Ash) and 720,000 years (Bishop Tuff). Calibrations have been made based on correlations with similar material that has been dated by radiocarbon and K-Ar.

2. Uranium-trend dating of marine terraces is being tested on sites collected in cooperation with Ken Lajoie (USGS) and Philip Kern (San Diego State U.). Three marine terraces were sampled in the San Diego, California, area in November 1979; previously four other marine terraces had been sampled in the Palos Verdes, California area. It appears that separate calibration points, provided by marine deposits of know age, will be required before final U-trend ages can be calculated from analyses of the $^{238}U-^{234}U-^{230}Th$ system in these type deposits.

Results

1. Horst Sterr, Institute of Arctic and Alpine Research, Univ. of Colo., working with Ernest Anderson, Earthquake and Tectonics and Risk Branch, collected and helped analyze four alluvium terraces in the Beaver Basin of southwest Utah for uranium trend dating. Soils are developed on the four different alluvial deposits, each distinct in age and stratigraphic position in the vicinity of Beaver, Utah (sec. 5 and 6, R.8W., T29S., Richfield , UT 1°x2° map). The purpose of this investigation is to determine age estimates for the faulted deposits from which seismotectonic trends may be established for the Beaver Basin since mid-Pleistocene time.

Profile LCB is from a prominent and widespread old erosion surface of mid-Pleistocene age named Last Chance Bench; surface was stabilized at about 30-40 meters above present streams between the major drainages of North Creek and Indian Creek. Profile HNCT was taken from a high-lying terrace remnant above

North Creek at a position 8-15 meters above stream level. Profile MT is developed on a middle terrace remnant in the South Creek drainage which lies 5-8 meters above stream level. Profile LNCT was collected from a natural stream bank exposure of North Creek, from the lowest and youngest pre-Holocene terrace in the basin which lies 2-5 meters above modern stream channels. Additional samples from the MT profile are required for collection and analyses to reduce the uncertainty in the age of this terrace. The results on the four terraces are listed in the following table.

Terrace	U-trend slope	X-intercept ^{232}Th Index	Half period of F(o) KA	Age KA
LCB($Qoes_1$)	-35.7	+ 0.126	530	370±60
HNCT(Qht)	+ 1.01	- .194	350	240±50
MT(Qit)	+ .599	- .354	190	135±95
LNCT(Qlt)	+ .259	- 5.2	10	5±3

2. Analyses have been completed on six marine terrace deposits from California. Only one of these deposits has a known age (Nestor Terrace, 120,000 ± 10,000 years), and it is used for a preliminary calibration point for U-trend dating of marine deposits. Additional deposits of known age are required for calibration points before a real evaluation of the reliability of U-trend dating can be made for marine terraces. Descriptions, locations, and preliminary estimates for U-trend ages of six marine terrace deposits are shown in the following table.

Description and Location	Age Estimate (KA)
Bay Point Terrace, San Diego, CA	30
Nestor Terrace, San Diego, CA (calibration point)	120
Linda Vista Terrace, San Diego, CA	290
Cabrillo Beach Terrace, San Pedro, CA	30
Woodring's 2nd marine terrace, Palos Verdes Hills, CA	100
Woodring's 12th marine terrace, Palos Verdes Hills, CA	540

Reports

Rosholt, J. N., 1980, Uranium-trend dating of Quaternary sediments: U.S. Geol. Survey Open-File Report 80-1087, 65 p.

Rosholt, J. N., Uranium and thorium disequilibrium in zeolitically altered rock: Nuclear Tech. (in press).

Teprochronology of the Western Region

9540-01947

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Summary

Continued sampling, chemical and petrographic analysis, and fission-track age dating of tephra (ashes and tuffs) of young geological age in order to provide age control for studies of recent tectonism in California, Nevada, Oregon, and Washington. Neutron activation, X-ray fluorescence and electron microprobe analyses of separated volcanic glass and crystals are used to identify widespread tephra units of known radiometric age. New tephra units identified by chemical and petrographic analysis are dated by appropriate radiometric age dating methods.

Investigations

Continued specific regional and topical tephrachronologic studies reported in Summaries of Technical Reports, Volume IX, December, 1979 (p. 117) and Volume X, June 1980 (p. 211). Additional studies include:

1. Expanded study of ash and other volcanic ejecta erupted from Mount St. Helens after eruption of May 18, 1980. Studies include wind dispersal patterns, areal distribution, thickness, volume, grain size, texture, petrography, and chemistry of the ash. Studies are in cooperation with scientists from the U.S. Geological Survey, U.S. Forest Service, and a number of individuals from other governmental, research, and educational institutions.

2. Continued to completion report on areal distribution, thickness, and volume of downwind ash from the May 18, 1980 eruption of Mount St. Helens.

3. Continued to completion report on zircon fission-track age of ash in type Merced Formation, west-central California.

4. Sampled stratigraphic section in axial region of Ventura Avenue anticline, western Transverse Ranges, for paleomagnetic stratigraphy (with Jack Hillhouse, BP & RS, Menlo Park) to develop better age control in the lower Pleistocene section below the 1.2 m.y. Bailey ash. We are specifically interested in identifying the Gilsa and Oldervai events and in defining the Plio-Pleistocene boundary in this section of rhythmic, deep-water turbidite sequences.

5. Sampled stratigraphic section west of South Mountain, western Transverse Ranges, to determine magnetic polarity and possible magnetic transition associated with putative Pearlette type B ash, dated elsewhere at 1.8 -1.9 m.y.

Results

1. Areal distribution, thickness, and mass of airborne ash from the eruptions of Mount St. Helens were documented by means of isopach (thickness) and isomass (mass per unit area) maps for the early, non-magnetic eruptions, the massive eruption of May 18, and the three subsequent major eruptions of May 25, June 12, and July 22. An isochron map was compiled for the May 18 eruption from NOAA satellite photos which shows the progress of the downwind tephra plume as a function of time. A travel-time curve along the maximum velocity trajectory and a velocity vs. distance map have been derived from the isochron map. Average velocities of the ash plume front thirteen minutes after start of eruption were greater than 180-200 km/hr. Comparison of the isochron and isopach maps indicates that lower-level shear winds displaced the ash northward relative to the position of the airborne plume. The grounded ash plume, in addition to being displaced northward relative to the axis of the airborne plume, also shows a transverse asymmetry in grain size and composition, a result of northward winnowing of fines, towards the axis of the grunded ash plume. Volumetric calculations derived from the isopach and isomass data for the May 18 eruption indicate that total downwind mass was 4.88×10^{14} g, average bulk density 0.45 g/cm^3, and uncompacted bulk volume of on-the-ground ash, about 1.1 km^3. This translates to a small <u>in situ</u> volume of 0.19 km^3 prior to eruption, assuming an initial density of about 2.6 g/cm^3 for the in-place rock. This volume is a small fraction of the 2.7 km^3 volume estimated to be missing from the summit of the volcano, and suggests that most of this volume is represented by the debris avalanche, the blast deposit, mudflows, pumice-ash flows, and melted ice. Volumes of airborne ash from subsequent eruptions, as well as from the early non-magnetic eruptions, were small compared to that of May 18 (table). Volume of the May 18 eruption, however, is small compared to volumes of many prehistoric eruptions from Mount St. Helens.

2. Found and identified Pearlette type O ash, dated elsewhere at 0.6 m.y., in deformed marine strata of the San Pedro Formation, Ventura area, southern California. See report under R. F. Yerkes, 9540-01615, this volume.

Reports

Meyer, C. E., Woodward, M. J., Sarna-Wojcicki, A. M., and Naeser, C. W., 1980, Zircon fission-track age of 0.45 million years on ash in the type section of the Merced Formaction, west-central California: U.S. Geological Survey Open File Report No. 80-1071, 9 p.

Sarna-Wojcicki, A. M., Shipley, Susan, Waitt, R. B., Dzurisin, Daniel, Hays, W. H., Davis, J. O., Wood, S. H., and Bateridge, Thomas, 1980, Areal distribution, thickness, and volume of downwind ash from the May 18, 1980 eruption of Mount St. Helens: U.S. Geological Survey Open File Report No. 80-1078, 14 p.

Sarna-Wojcicki, A. M., and Waitt, R. B., 1980, Areal distribution, thickness, and composition of volcanic ash erupted from Mount St. Helens on May 18, 1980: Abstract in Geological Society of America Annual Meeting, Atlanta, Georgia, Abstracts with Program.

Table. Mass, volume, and calculated bulk density for downwind ash erupted from Mount St. Helens, March 27 through July 22, 1980.

	Early phase[1]	May 18	May 25	June 12	July 22	TOTAL
Total mass, x 10^{14}g	0.008	4.88	0.42	0.45	0.04	5.80
Volume, rock, in km^3 using density = 2.6 g/cc	0.0003	0.19	0.016	0.017	0.001	0.22
Volume, bulk, in km^3 using calculated bulk density (below)	0.0006[2]	1.10	0.031	0.027	0.004[3]	1.16
Calculated uncompacted bulk density	1.25[2]	0.45	1.03	1.25	0.50[3]	--

1. Early non-magmatic eruptions, Mar. 27-Apr. 17, 1980

2. Thickness measurements were not reliable or ash-layers were too thin. Uncompacted density of 1.25 g/cc was used, comparable to wet ash values of June 12 eruption.

3. Ash too thin to measure at most sites. Uncompacted density of 0.5 g/cc was used, comparable to dry ash values of May 18 eruption.

Paleoseismic Indicators in Sediments

9950-01294

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Investigations

1. Detailed geologic mapping of an approximately 2-km-wide strip enclosing the San Andreas fault zone from San Juan Bautista to Cholame (scale 1:12,000). Actively mapping currently in Monarch Peak, Hepsadam Peak, and Bickmore Canyon 7-1/2 minute quadrangles.

Results

1. Detailed geologic of the San Andreas Fault zone to determine the geometry and history of movements within the zone is proceeding in three areas. Mapping of the fault zone in Monarch Peak 7-1/2 minute quad by M. J. Rymer is complete and the data being transferred to a reproducible base for publication. Rymer is currently doing field work in Hepsadam Peak 7-1/2 minute quad and had completed preliminary photo reconnaisance of Priest Valley 7/1/2 minute quad. Field mapping in Bickmore Canyon 7/1/2 minute quadrangle is being transferred to scale-stable base.

2. Mapping of the fault zone along Mustang Ridge in Monarch Peak and Hepsadam Peak quadrangles shows that the fault is located in Franciscan assemblage melange and serpentinite squeezed up along the fault zone Quaternary (?) time. The melange material is bounded by steeply dipping reverse faults (about 80^{o}) that are the lateral extent of the fault zone. In the south half of the area mapped the fault zone is characterized by a main trace and 17 subsidiary faults located only on the NE side of the main trace, and trend approximately N-S. However, in the north half of the area mapped the fault zone consists of at least two main traces and parallel to subparallel subsidiary faults. Along the southwest side of the fault zone is a Pliocene and/or Plesitocene sand and gravel unit that dips toward the fault zone. This unit, referred to as either the Paso Robles Formation or San Benito gravels, is composed of clasts from rocks of the Gabilan Range to the northwest. In the mapped area no clasts are observed in this unit that are derived from serpentinite or rocks of the Franciscan assemblage, in spite of the elevational difference between the unit and the melange (fault zone). This suggests that the presence of the fault zone along Mustang Ridge is a new development and that melange material and serpentinite have been squeezed up along the fault zone to their present elevation since deposition of the gravels to the southwest.

Reports

None.

Quaternary Reference Core, Clear Lake, California

9940-02394

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Investigations

1. Core drilling (14 June to 5 September) in Clear Lake, Lake County, California; two continuous wireline cores taken and geophysical logging of one hole.

2. Paleomagnetic investigations on one core (CL-80-1) from Clear Lake taken in July and August 1980.

3. Preliminary palynological investigations on one core (CL-80-1) from Clear Lake taken in July and August.

Results

1. Two cores 177- and 168-m long, designated CL-80-1 and CL-80-2, from the west basin of Clear Lake, Lake County, Calif. were taken during July and August 1980 for multidisplinary study of the stratigraphy, paleoclimate, and chronology of the sediments, and to produce a Quaternary reference section for at least northern California. Clear Lake is a large, intermontane, freshwater lake in the California Coast ranges adjacent to the Pleistocene Clear Lake volcanic field and north of the Geysers geothermal area. Adjacent to the lake north, east, and west are rocks of the Franciscan assemblage. The lake consists of three fault bounded basins with major faults parallel and subparallel to the Coast Range structure.

Core CL-80-1 was continuously cored in 7.5 m of water with 66.5 percent recovery. The sediments are composed of clay and silt similar to that deposited in the lake today, interbedded with coarse sand and volcanic ash beds. The core ended in coarse, rounded, gravel and cobbles of Franciscan lithology. Core CL-80-2, taken in 9.1 m of water, is between two earlier core localities; one of which is 115 m long (CL-73-4) and has a well defined, uninterrupted pollen and physical stratigraphic record from present to about 130,000 years ago. Intervals between 53 and 77 m, and 99 and 168 m were cored at site CL-80-2 with 80 percent recovery. Sediments in this core are composed of clay similar to core CL-73-4. Sampling of core CL-80-1 is complete with sample sets suitable for 18 separate investigations ready for distribution. Distribution of sample sets begins in Lake October to researchers that have already committed themselves to the different analyses.

2. Liddicoat, Sims and Bridge analyzed 515 paleomagnetic samples from core CL-80-1 from Clear Lake, Lake County, Calif. Samples for paleomagnetic

analysis were for every 25 cm or less of depth where there was core recovery and no distortion of the sediment. Only normal paleomagnetic polarity was recorded after alternating-field demagnetization and measurement in a cryogenic magnetometer. The remanence in the upper 50 m is weak (~1 x 10^{-6} emu/cm^3 or less) but increases at least tenfold in the remainder of the core. A shelf test of back-to-back samples was used to determine magnetic stability, and those passing had a median destructive field of about 300 oersteds.

Relative declination within and between each 3-m-long core segment is of no value because the core spun in response to rotation of the bit and core barrel. Thus, we made no attempt to interpret secular variation of the paleomagnetic field using this core. The paleomagnetic polarity determined from inclination is reliable, however, and, when interpreted in light of the 130,000-year record from a previous Clear Lake long core, indicates that deposits no older than mid-Brunhes (~200,000 yr B.P.) were penetrated.

3. Pollen data from core CL-80-1 (168 samples 300 pollen grains/sample) reflect changes in the vegetation and climate of the northern Coast Range of California throughout the time in which the 177 meters of sediment in the core were deposited. Comparison of the fossil pollen record with modern pollen data from 150 surface samples taken from north coastal California indicates an oscillation between pollen assemblages characteristic of oak woodland and pollen assemblages characteristic of conifer forest formations. An oak pollen assemblage similar to that found in the upper 13 m of core CL-80-1 occurs between 126-128 m depth in the core. This lower interval preceded by an interval in which *Ouercus* pollen is almost entirely absent, much like the interval at the end of the last glaciation in which the pollen assemblage is dominated by conifer pollen that includes *Pinus*, *Picea*, *Abies*, *Pseudotsuga*, *Tsuga heterophylla*, *T. mertensiana*, and members of the Taxodiaceae and Cupressaceae.

Reports

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Heuser, L. E., and Sims, J. D., in press, Palynology of core CL-80-1, Clear Lake, California: Geological Society of America Abstracts with Program, v. 13, p. .

Liddicoat, J. C., Sims, J. D., and Bridge, W. D., in press, Paleomagnetism of a 177-m-long core from Clear Lake, California; Geological Society of America Abstracts with program, v. 13, p. .

Blunt, D. J., Kvenvolden, K. A., and Sims, J. D., in press, Amino acid dating of sediments from Clear Lake, California: Geology, v. , p. .

Tectonic Analysis of Active Faults

9900-01270

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Investigations

1. Analysis of fault scarp data in northcentral Nevada and overview analysis of paleoseismicity and tectonics of Basin and Range province.

2. Compilation of recurrence-interval and slip rate from recent investigations of faults in western United States.

Results

Studies of large displacements and related earthquakes on faults - paleoseismology - show that average recurrence intervals for most active faults in the western United States are generally longer than 1,000 years; for many, the average recurrence is greater than 10,000 years. Only on the San Andreas fault and its major branches are average recurrence intervals as short as 10-200 years.

As shown in figure 1, recurrence intervals generally increase away from the San Andreas fault system, that is, away from the continental margin. Major fault activity in late Quaternary time is almost absent in the central Basin and Range province.

If the displacements on the faults are interpreted as related to interplate motion between the North American and Pacific plates, the San Andreas fault system is accommodating most, perhaps two-thirds, of the motion, and other faults, distributed across at least 5^{o} of longitude, accommodate the remainder in decreasing amounts away from the plate margin. The Wasatch fault zone is an exception and represents a perturbation in the general eastward decrease in rates of recurrence.

Reports

Wallace, R. E., 1980, Discussion -- Nomograms for estimating components of fault displacement from measured height of fault scarp: Bulletin of the Association of Engineering Geologist, v. XVII, no. 1, p. 39-45.

Wallace, R. E., 1980, Degradation of the Hebgen Lake Fault scarps of 1959: Geology, v. 8, no. 5, p. 225-229.

Wallace, R. E., and Teng, Ta-liang, 1980, Prediction of the Sungpang-Pingwu Earthquakes, August 1966: Bulletin of the Seismological Society of America, v. 70, no. 4, p. 1199-1223.

Wallace, R. E., (as member of Delegation: Jennings, Paul C., ed.,), 1980, Earthquake engineering and hazards reduction in China: CSCPRC Report no. 8, National Academy of Science, Washington, D. C.

Wallace, R. E., Active faults, paleoseismology and earthquake hazards in the western United States: in Proceedings Volume, Fourth Ewing Symposium, Earthquake Prediction (in press).

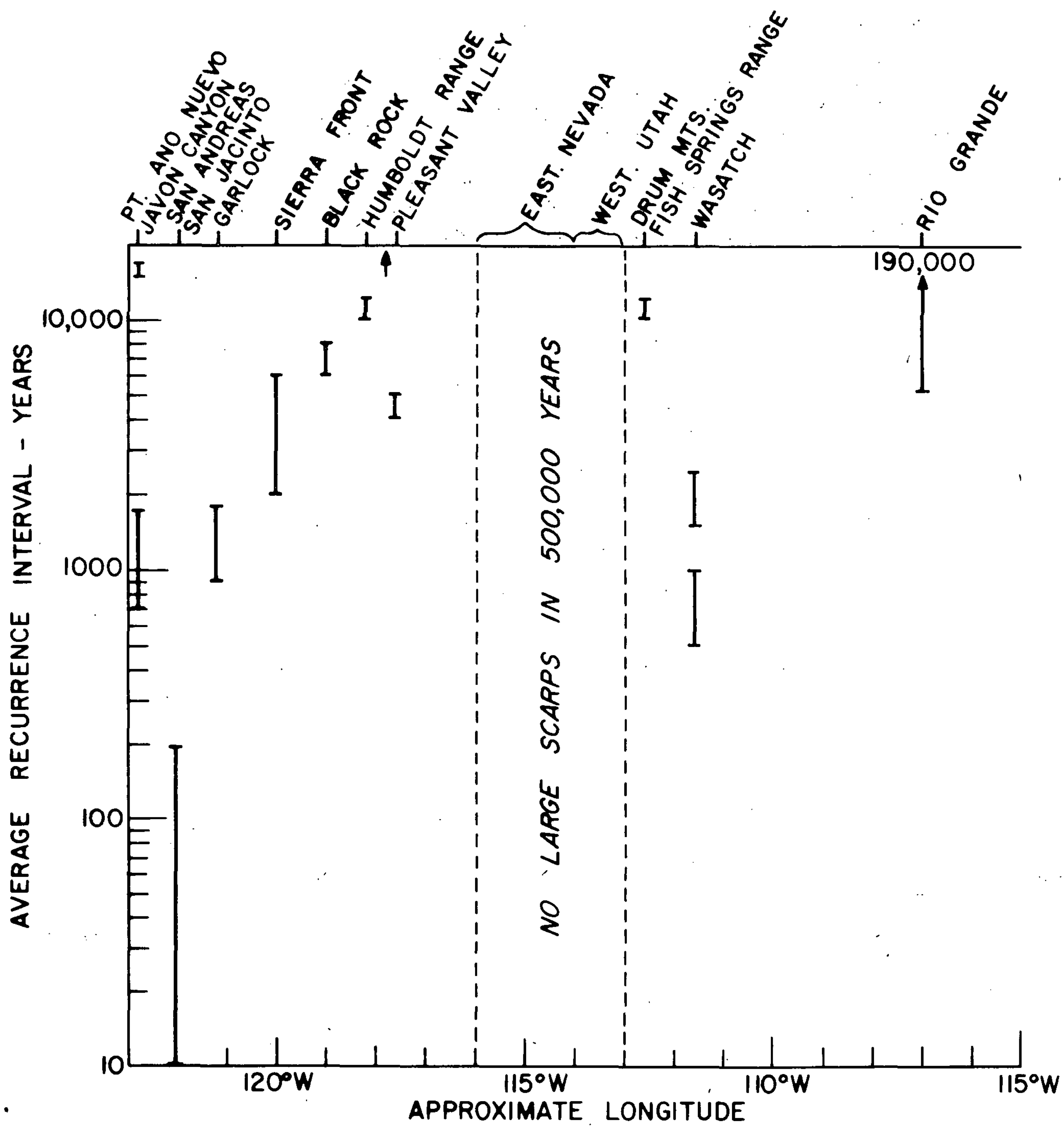
PT. ANO NUEVO
JAVON CANYON
SAN ANDREAS
SAN JACINTO
GARLOCK
SIERRA FRONT
BLACK ROCK
HUMBOLDT RANGE
PLEASANT VALLEY
EAST. NEVADA
WEST. UTAH
DRUM MTS.
FISH SPRINGS RANGE
WASATCH
RIO GRANDE
190,000
NO LARGE SCARPS IN 500,000 YEARS
AVERAGE RECURRENCE INTERVAL - YEARS
10,000
1000
100
10
120°W
115°W
110°W
115°W
APPROXIMATE LONGITUDE

Figure 1

Instrument Development and Geotechnical Studies

9940-02089

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Investigations

1. The development of techniques for the improvement of field data acquisition specifically in the application of triggered digital recording systems to aftershock studies.

2. Methods for improving the generation, recording and interpretation of shear waves for deep downhole surveys.

Results

1. The deployment of the triggered digital recording systems to study the "aftershocks" of the Mammoth Lake earthquake sequence of May-June 1980 added to our experience and assisted in the formulation of a draft earthquake response plan. The draft plan was circulated to personnel likely to be involved in the program of recording "aftershocks" to solicit their opinions toward improving the "plan".

Our experience with the triggered recording systems has detected some instrumentation problems which have been corrected. The manufacturer was urged to complete the design of a programmable timing system. The prototype was evaluated by Gene Sembera and suggestions for improvement were relayed to the manufacturer. The programmed timing option will allow the use of the recorders in refraction experiments where the high seismic noise level would cause tape to run out before the desired signal could be recorded. Additionally the recorders may be programmed to cause all recorders to start operation in the triggered mode at a preset time.

A master clock was constructed for our use by R. McClearn. This will allow closer control of the recorder clocks when good radio time signals are unobtainable.

2. The experience in logging the deep borehole near Gilroy encouraged us to try to improve the sensor and cable handling techniques. Toward that end a winch suited to the multiple cable is under construction.

Subsurface Geology of Potentially Active Faults in the Coastal Region between Goleta and Ventura, California

14-08-0001-17730

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Investigations

1. Completed the surface geologic map of the onshore and offshore Carpinteria basin for submission as an open-file report.

2. Continued construction of subsurface cross-sections in the Carpinteria basin and preparation of structure contour maps of the top Vaqueros, the base Pleistocene (Santa Barbara-Casitas), and the Rincon Creek, Carpinteria, and main and north branches of the Red Mountain fault from Rincon Point westward.

3. Continued field work and data collection in the Santa Barbara and Goleta basins.

Results

Northeast of Punta Gorda, the Red Mountain fault consists of three branches, all of which appear to cut the 45 ka terrace (Punta Gorda terrace of Lajoie and others, 1979). Two of these branches extend offshore beyond Rincon Point. At Rincon Point, the north branch questionably brings Sisquoc (earliest Pliocene) into contact with Repetto (early Pliocene), and the more southerly branch, called here the main branch, brings Repetto in contact with Pico (late Pliocene). Farther west, the main branch is traced offshore an additional 10.5 km to an area south of Montecito where dart-sample control and seismic control are not sufficient to map the fault. The fault brings strongly uplifted Miocene strata of the Summerland Offshore anticline and oil field into contact with the Pico Formation on the south. Stratigraphic separation on this fault decreases westward, and the fault steepens in dip westward also. Another branch of the Red Mountain fault mapped by Hoyt (1976) immediately north of the Rincon-Dos Cuadras anticline is not confirmed by our data.

The Pleistocene Carpinteria basin consists of alluvial fan deposits of the Casitas Formation grading southward and downward to shallow marine Santa Barbara Formation; the sequence is wedge-shaped, thickening southward. The Pleistocene sequence rests with angular unconformity on strata as old as Oligocene Sespe Formation; the Pico and Repetto are absent and were probably never deposited there. Most of the homoclinal south dip of the south flank of the Santa Ynes Range was acquired prior to the deposition of the Santa Barbara and Casitas. The sequence is cut off abruptly by a series of south-dipping reverse faults including the Rincon Creek (the largest and most important), Carpinteria, Holloway, and Shepard Mesa faults. These faults formed after Santa Barbara and Casitas deposition. The Rincon Creek fault forms a north-facing scarp on the sea floor and on the raised terrace east of the town of Carpinteria; the Holloway and Shepard Mesa faults also have topographic expression. The Rincon Creek fault cuts the Vaqueros Formation in the Summerland Offshore oil field.

The Javon Canyon fault of Sarna-Wojcicki and others (1979) is traced offshore for at least 3 km; middle Pico on the south is faulted against upper Pico on the north.

Subsurface Geology of the San Gabriel, Holser, and Simi-Santa Rosa Faults, Transverse Ranges, California

14-08-0001-19138

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Investigations

1. Completed surface geologic map of Castaic region of the San Gabriel fault for submission as an open-file report.

2. Constructed cross-sections through the Saugus oil field area of the San Gabriel fault between the completed study areas of Castaic and Newhall.

3. Continued construction of cross-sections of the Simi fault in Simi Valley and a surface geologic map of the eastern half of the Simi fault from Tierra Rejada east across the Simi Valley to the Simi Hills.

Results

1. The complex fold and fault structures of the Castaic area of the San Gabriel fault (SGF) can be divided into three stages, only the youngest of which should be considered as active and potentially hazardous. Stage I structures (Figure 1) are of late Oligocene-early Miocene(?) age and pre-date the Mint Canyon and Modelo Formations. These include most of the ENE-trending structures involving the Vázquez north of the Soledad basin, and also the Canton fault of Crowell (1954). The Canton fault, possibly an ancestral SGF, juxtaposes Palomas gneiss on the east against Whitaker granodiorite on the west; a possible equivalent of the Palomas gneiss west of the fault is exposed in the Alamo Mountain area northwest of the Castaic area. Although Crowell (1954) suggested that the Canton fault cuts the lower part of the Modelo Formation, the upper Modelo overlies the fault trace unconformably.

Stage II structures (Figure 2) post-date most of the right-lateral displacement on the SGF. The Pliocene Pico Formation wedges out northeastward, and the 700-foot Pico isopach shows only about 6350 feet (1935 m) displacement on the SGF; 6200 feet (1890 m) is the right-lateral horizontal component (Figure 3). If 0.5 km right slip occurred on the SGF after deposition of the Plio-Pleistocene Saugus Formation, as suggested by Weber (1979), about 1.4 km right slip occurred prior to deposition of the Saugus. The Ridge Basin Syncline (RBS of Figure 2) and related structures described by Crowell, including the Violin Breccia, pre-date Saugus deposition.

Stage III structures (Figure 4) post-date the Saugus and should be considered as possibly active. These include the SGF itself, which offsets Quaternary alluvium and landslide material (Weber, 1979), several folds in the Saugus, and the Hasley reverse fault (HF of Figure 4). The Hasley fault dips south about 55° at the surface and 70° at depth; it may be analogous to the larger Holser fault south of the area.

2. The Simi fault is mapped from Oxnard Plain east across the Simi Valley. The fault has reverse separation with the south side down. A zone of faults extends from the Simi Valley east into the Simi Hills where it bends east-southeast into the Northridge Hills fault, which also has reverse separation with the south side down. It was earlier suggested that the Simi and the Northridge Hills faults were part of a single, continuous zone of faulting because both these faults display topography suggesting late Quaternary movement. However, east of the Simi Valley, in a zone at least 5 km long, the fault has the north side down, and there is no geomorphic evidence suggesting late Quaternary movement. Possibly this segment of the fault is related to the Frew and Brugher faults to the northeast. Both these faults have the north side down; both cut the Pliocene Pico Formation, and both are overlain unconformably by the Saugus. If this interpretation is correct, the late Quaternary Simi fault terminates in the hills northeast of the Simi Valley, and the Simi and Northridge Hills fault do not connect at the surface.

Reports

Stitt, L. T., 1980, Geology of the Ventura and Soledad basins in the vicinity of Castaic, Los Angeles County, California: Corvallis, Oregon State University MS thesis and semi-annual technical report to U. S. Geological Survey, 124 p., 11 fig., 24 plates.

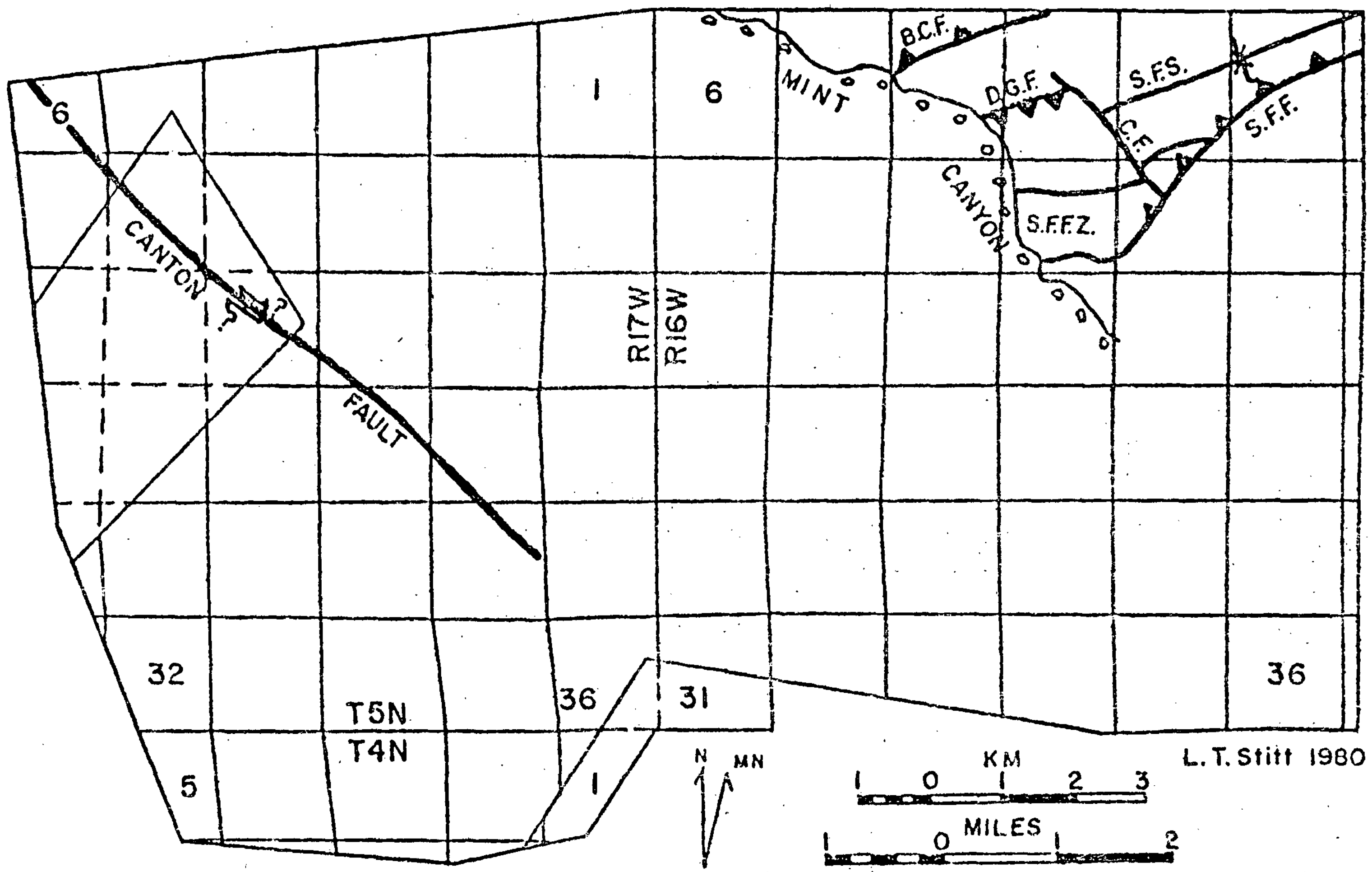

FIGURE 1: Post-Vasquez, Pre-Mint Canyon Structures (Late Oligocene - Early Miocene ?).

STAGE I

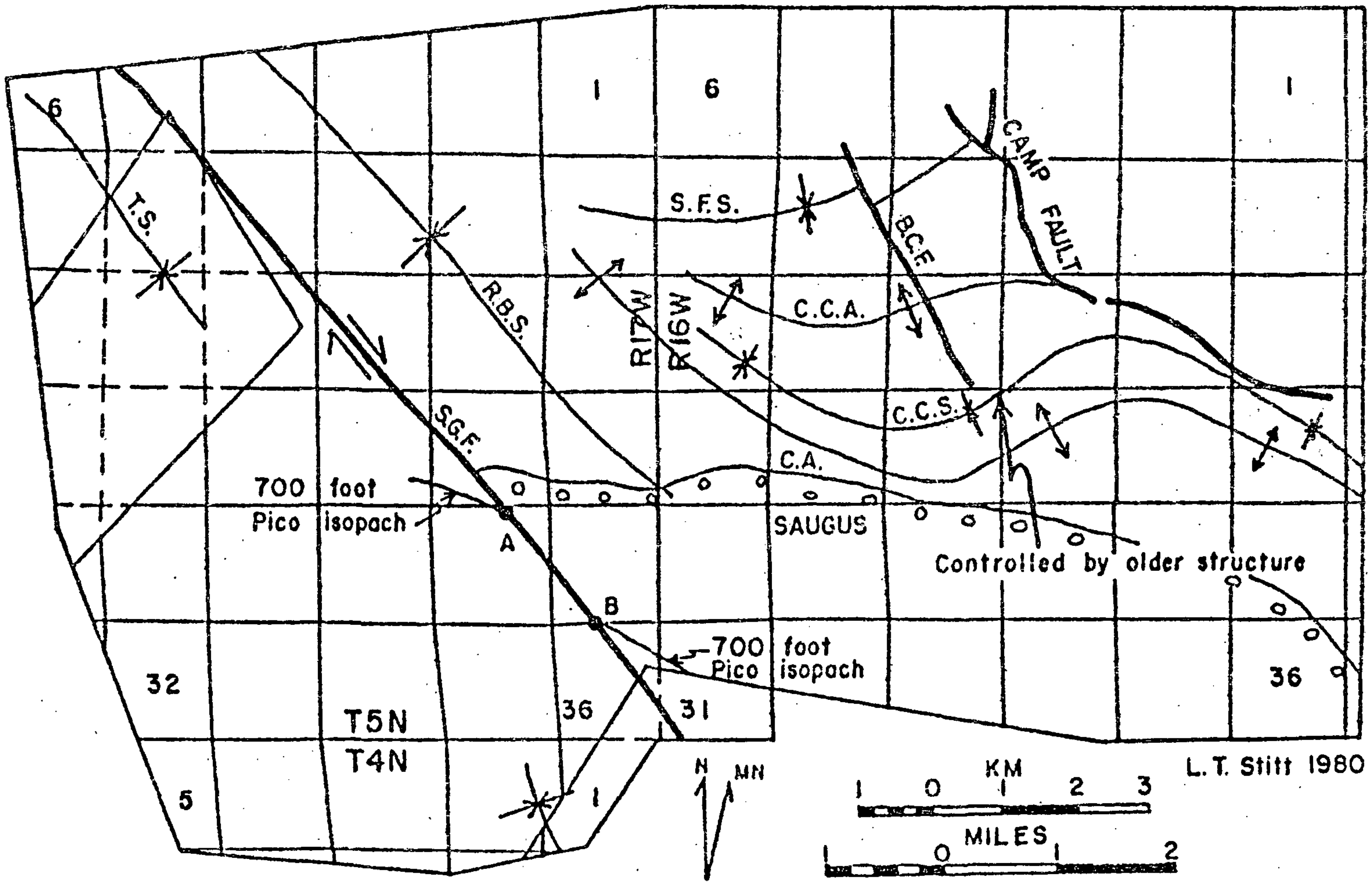

FIGURE 2. Post-Mint Canyon, Pre-Saugus Structures (Late Miocene – Late Pliocene).

STAGE II

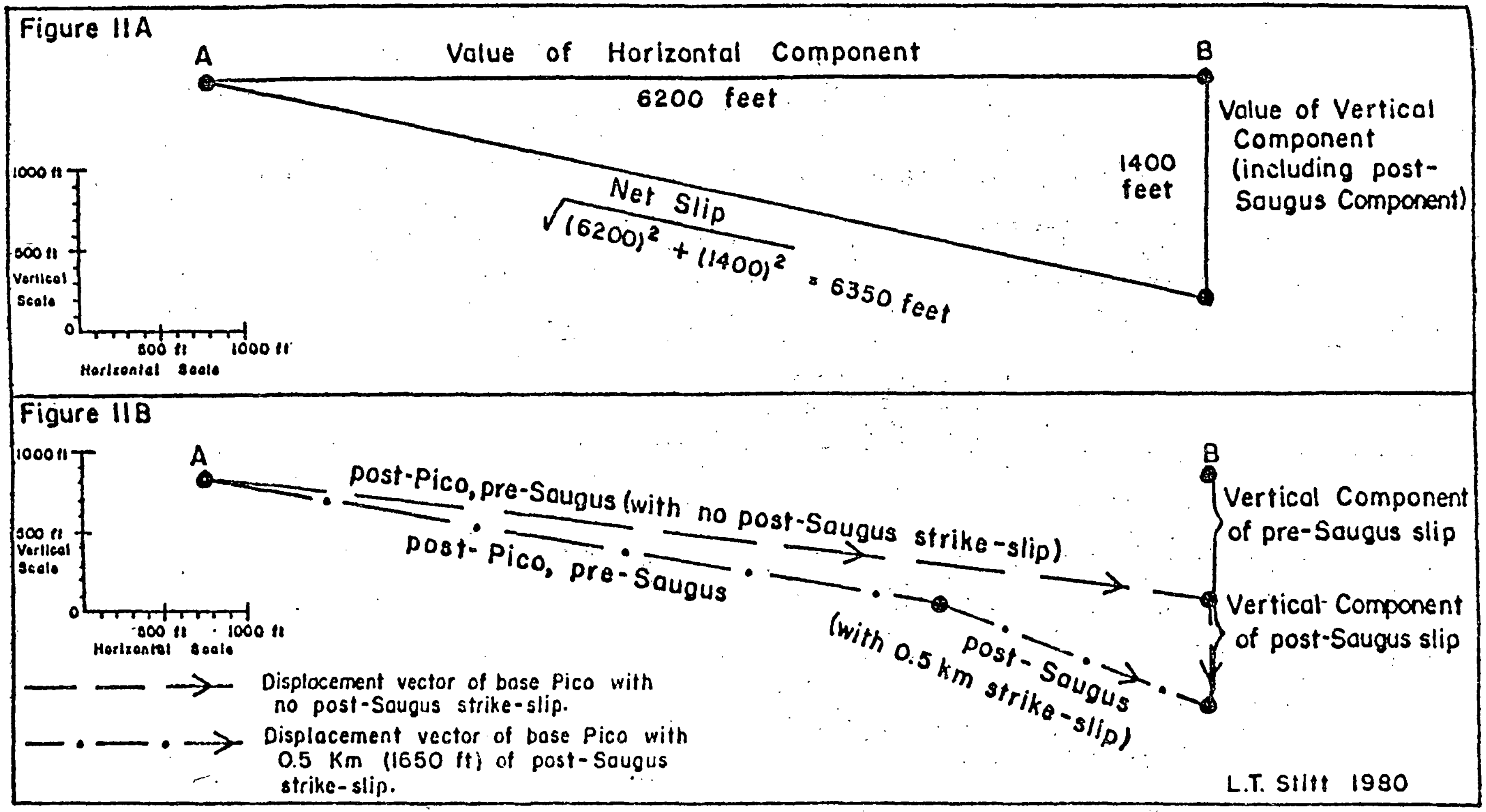

FIGURE 3A: Diagram parallel to the San Gabriel fault showing offset of the 700 foot isopach and the base of the Pico Formation. Points A and B located on Figure 2

FIGURE 3B: Diagram parallel to the San Gabriel fault showing two possible displacement vectors of the base of the Pico Formation (700 foot isopach). One vector assumes no post-Saugus strike-slip. The other vector assumes 0.5 Km (1650 feet) of post-Saugus strike-slip as suggested by Weber (1979).

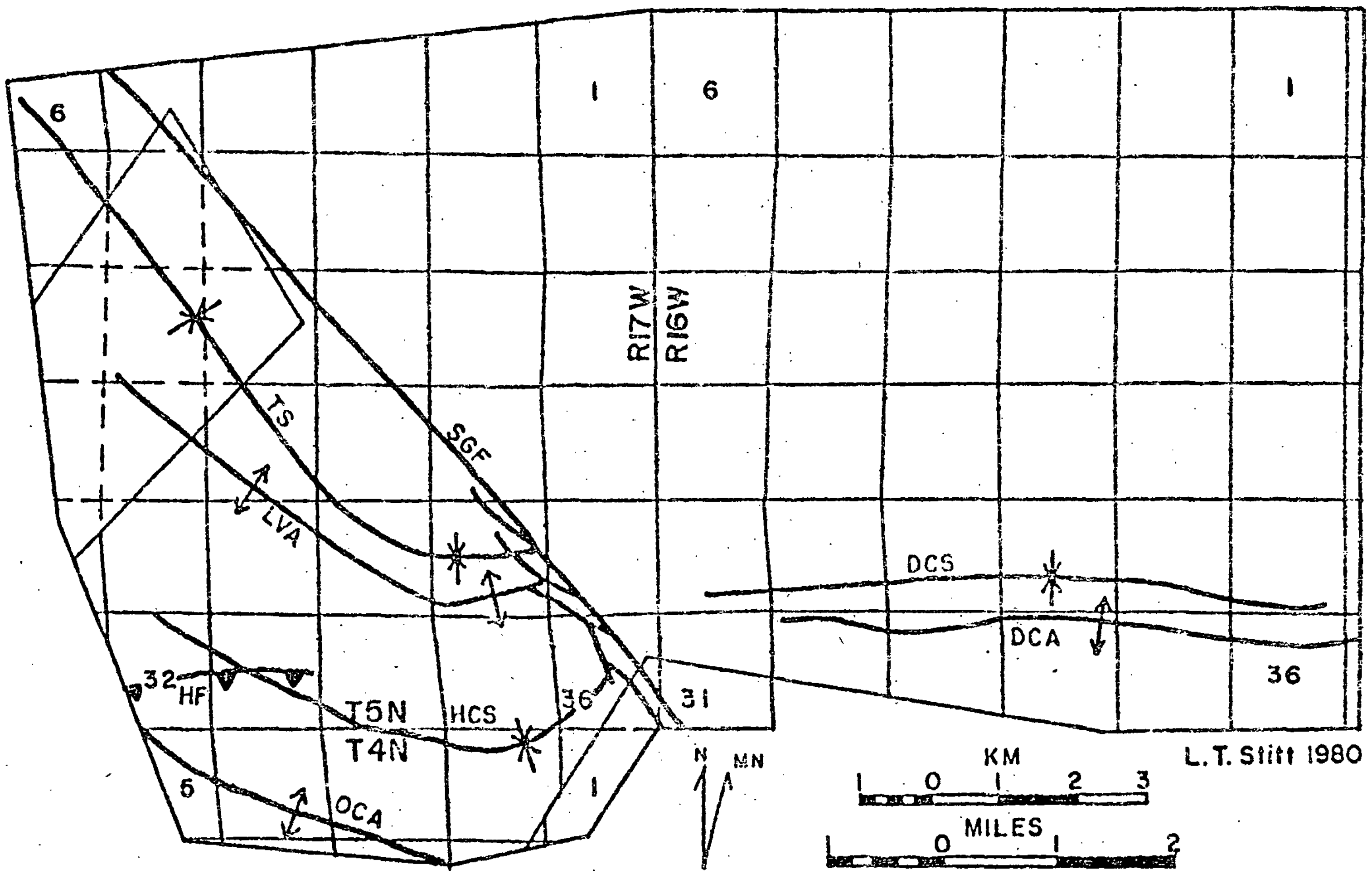

FIGURE 4: Post-Saugus Structures.

STAGE III

Physical Constraints on Source of Ground Motion

9940-01915

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Investigations

1. Dynamic stochastic fault modeling.

2. Strong motion record processing.

3. San Onofre site review.

Results

1. The major portion of a paper on dynamic random fault motion was completed this summer. The basic assumption is that, due to random geometric irregularities of the fault surface at all length scales, the slip velocity function in an earthquake has random fluctuations with no characteristic length or time scale. Its high-frequency spectrum is a power law. The spectral exponents of slip velocity and of shear traction are the same in time, but are different in space, due to quasistatic stress concentrations. The high-frequency spectral exponent of ground motion is the same in the far field and on the fault surface itself.

2. Work is continuing on revision of the strong motion data analysis system.

3. Joe Andrews attended another meeting with the Nuclear Regulatory Commission and consultants for Southern California Edison on the seismic safety of San Onofre Nuclear Generating Station Units 2 and 3.

3-D Near-field Modeling and Strong Motion Predictions in a Layered Medium

9940-02674

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Investigations

1. Analysis of the near-source accelerograms from the October 15, 1979, Imperial Valley, California, earthquake is continuing.

2. Examinations of the earthquake source mechanism is based on a forward solution using numerical methods to generate synthetic seismograms and on the formal inverse problem of interpreting the data.

3. Collecting, archiving and analyzing aftershocks from the May 26, 1980, Mammoth Lakes, California, earthquake sequence has neared completion.

Results

1. Using a velocity profile of the Imperial Valley based on the USGS refraction data of Mooney, Fuis, Healy, ..., we infer that the observed, large vertical phases can result from caustics formed by the large gradient in the P-wave structure in the upper 5 km. P-waves that reflect from the free surface have a turning point in the upper 5 km. Consequently, the resulting triplication in the travel time curve implies large amplitudes over a limited distance range.

2. In collaboration with Dr. Steve Hartzell of California Institute of Technology we examined how the fault's finiteness can affect near-source records. Spatially-varying slip, spatially-varying radiation coefficients and the rupture velocity strongly influence the azimuthal amplitudes and waveforms af near-source recordings. Looking at the deHoop-Knopoff representation theorem as a linear relationship between the observed data and slip on a fault, it is possible, in theory, to use the well-developed inverse theory formalism to deduce important parameters regarding the earthquake mechanism.

3. Over 1500 aftershocks of the 1980 Mammoth Lakes earthquake sequence were recorded on 3-component, digital seismometers and accelerometers. These events included 202 with local magnitude $3.0 \leq M_L \leq 3.9$; 22 with $4.0 \leq M_L \leq 4.9$; 3 with $5.0 \leq M_L \leq 5.1$ and one $M_L = 6.3$. One hundred fifty events were recorded on 3 or more stations and subsequently located. Epicentral locations show no well defined trend. A composite fault plane

solution of the best recorded events indicate either left-lateral strike-slip on a steeply dipping plane striking N.10°E. or right-lateral on the conjugate plane. Open-file reports detailing the data and the preliminary analysis are almost complete.

Reports

Spudich, P., 1980, The deHoop-Knopoff representation theorem as a linear inverse problem: Geophysical Research Letters, v. 7, p. 717-720.

National Strong Motion Data Center

9940-02085

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Investigations

The National Strong Motion Data Center provides investigators with a convenient, state-of-the-art tool for studies of earthquake sources, wave propagation, ground response, and strong motion. Projects hosted include field investigations of major earthquakes, routine processing for permanent installations, and studies of synthetic earthquakes. Incoming field data is transferred to on-line disk storage from several digital playback units (through parallel and serial interfaces), from in-house digitizers (through cards or IBM-compatible floppy disks), and from outside sources (on 9-track magnetic tape). Using familiar, industry standard Fortran techniques, real and synthetic data are analyzed, printed on terminals and line-printers, or displayed on Tektronix graphics terminals and Versatec or CalComp plotters.

Results

The National Strong Motion Data Center consists of a Digital Equipment Corp. PDP-11/70 minicomputer and associated peripherals running under the vendor supplied real-time operating system, RSX-11M. Center personnel are responsible for the maintenance of the system and preparation of applications software for the processing of strong motion records.

1. Hardware: Eight more terminal lines were added, allowing the connection of three additional terminals to the system. The Center is now able to support up to eleven simultaneous users: two at graphics terminals, six at editing terminals, one at the system console, and two on dial-up lines. An additional graphics terminal and two editing terminals are planned for expansion in FY81.

The additional terminal lines and the use of Fortran IV-Plus Virtual arrays required the addition of 128K words of core memory, bringing the system total to 256K words (approximately 192K words available for user programs).

A second RM03 disk drive (67M bytes) was added (with a dual port capability for possible simultaneous connection to another machine at a later date). This increased the permanent on-line storage from 67M bytes to 134M bytes. In addition, an order was placed for two CDC 9766 disks and controller (256M bytes each) to replace the aging RP04 disk drive and its set of mountable earthquake data packs.

2. Application Software: The following programs were either developed or modified to run on the PDP-11/70:

MULLER -- A flat- or spherical-earth travel-time calculation.
RAYAMP -- An extension of RAYTRC to include ray-theory amplitudes.
BUBA -- Generates complete far-field P-, SV-, and surface-wave seismograms for explosive or double-couple sources at an arbitrary depth in a layered half-space.
TRACES -- Automated plotting of multiple DR100 files.
MOMENT -- Computes estimates of moments, source radius, and stress drop.
ASEMB -- PDP-8 cross assembler for GEOS field recorder.
SIM8 -- PDP-8 simulator for GEOS field recorder.
CRAMIT -- RS-232 down-line program loader for GEOS field recorder.
EPROM -- RS-232 EPROM burner for GEOS field recorder.

Fast, Fortran-callable disk I/O routines were developed for use with the evolving data-base files.

A preliminary version of the new plotting library and post-processor was released.

3. System Software: The following commands were written:

STTY -- Set/show multiple terminal characteristics.
PFX -- Parity fixer to make a memory region with parity errors unusable.

The following system modifications were made:

DEVices command -- Display the names of publicly mounted volumes to all users.
Terminal driver -- Discard all unsolicited input if a slaved line has no task attached to it (required for the on-line CalComp plotter): properly deallocate the special terminator tables used in the GEOS support programs.
System status display (RMDEMO) -- Correctly display tasks in and out of memory, and system UP time.
K-series support routines -- Allow the DR11K sampling program to stop the digital input sweep without requiring another interrupt.
Command interpreter -- Command line passing in the RUN command; passing of syntactially incorrect MCR commands to the catchall task (...CA.); suppression of the default system prompt (">") when ...CA. exits.

Several new software components were added to the Center, including the OMSI Pascal compiler (V1.2), and a keypad editor for VT100 and VT52-style terminals (KED and K52).

Support for the standard Fortran compiler was terminated since the latest version of the Fortran IV-Plus compiler now contains all its features.

The RSX-11M-PLUS operating system and DECnet V3 were ordered and preparations made for their installation (Versatec and terminal driver modifications, elimination of separate XL: serial line driver, conditionalization of privileged code, inclusion of the console driver CO:, modifications to new versions of system commands).

4. Data: A suite of accelerograms and seismograms were obtained for over 1500 events following two $M_L \sim 6$ events at Mammoth Lakes, California on May 25, 1980. Twelve digital event triggered recorders were deployed for about one month and produced recordings of 22 events with $4 < M_L \leq 4.9$ and 3 events with $M_L > 5.0$.

Precise source parameters are being calculated for about 14 of the largest aftershocks of the Oroville, California earthquake (August 1, 1975). These parameters include stress drop, source radius, energy, and inhomogeneity. Similar work continues for the Imperial Valley earthquake of October 15, 1979 ($M_S = 6.8$).

5. Miscellaneous: Special reports were prepared at the request of the President's Science Advisor for evaluation of disaster preparedness planning.

<u>Reports</u>

None

EARTHQUAKE HAZARD EVALUATION

OF THE GREATER HELENA AREA, MONTANA

Contract No. 14-08-0001-19135

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INVESTIGATIONS

Detailed mapping of Tertiary and Quaternary deposits at a scale of 1:12,000 within the seismically active Helena Valley, site of the state capitol, is intended to provide: 1) a modern data base for identifying and locating all active or potentially active faults and to evaluate their potential for generating damaging earthquakes; 2) knowledge of the distribution and properties of foundation materials where strong ground motion may create a substantial hazard from liquefaction or rapid loss in strength, and 3) a delineation of areas of potential slope instability in the event of a strong local earthquake.

RESULTS

During the first six months of this research project, personnel have completed a search and compilation of the geological and geophysical literature for the project area, and a review and evaluation of logs from all water well and engineering borings available in the Helena Valley. Morning and afternoon low-sun-angle photography at a scale of 1:12,000 has been completed for the project area and comprises the mapping base. Eighty percent of the field mapping, which emphasizes lithostratigraphy and the time history of faulting, is complete.

The Helena Valley and surrounding foothills are underlain by siltite, quartzite, and calcareous siltstone of the Precambrian Belt Supergroup; fine-grained fluviatile (in part lacustrine?), arkosic silt, gravelly silt, and volcaniclastic sandstone and conglomerate of late Tertiary age; and a thin sequence of pediment gravel and moderately sorted, uncemented alluvial plain deposits of middle Quaternary to Holocene age. The Tertiary and Quaternary deposits lie within a fault-bounded structural and topographic basin that first began to take its present form during the middle to late Tertiary and has continued to form through vertical movement and down warping to the present. The Helena Valley fault zone is a narrow, linear belt of down-to-the-southwest faults that forms the northeast valley margin. This zone, less than 100 meters wide and over 35 kilometers long, is marked by very straight scarps of middle Quaternary to Holocene(?) age that range in height from less than 1 meter up to 10 meters. The Prickly Pear fault zone, which forms the somewhat irregular southwest margin of the valley, is a diffuse band of northwest-trending, down-to-the-northeast normal faults approximately 2 kilometers wide and 20 to 30 kilometers long, that passes beneath the city of Helena. Last movement on most of these fault traces appears to be early to middle Quaternary, but at least one fault in the Prickly Pear zone is of late Quaternary to early Holocene age.

The numerous fault traces mapped along the northeast, southwest, and north-central flanks of the valley transect middle to late Quaternary pediment and alluvial plain deposits and are viewed as potentially active. No historic movement has been observed on any of these faults, although several occur in areas of present day microearthquake activity. The Quaternary faults mapped as part of this project are associated with major basin boundaries that have existed since at least Miocene(?) time, and as such record continuing and generally consistent movement histories over approximately the last 20 million years.

Ground Motion Prediction at Selected Strong Motion Sites

9940-01168

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Investigations

1. Site studies at strong motion stations in the Imperial Valley.

2. Analysis of shallow refraction profiles and downhole P and S velocity surveys in the Chalome, Gilroy and Taft areas to provide information for interpreting and modeling strong motion data.

3. Comparison of peak ground acceleration from recent earthquakes with regression curves based on older data.

Results

1. Cone penetrometer surveys to depths of 50-150 feet have been completed at 14 sites and 250 foot holes for velocity surveys have been completed at seven sites with electric logs, gamma logs, and geologic logs.

2. A paper has been completed analyzing the effect of Quaternary alluvium on ground motion in the Coyote Lake earthquake.

3. A paper is in press (BSSA, December 1980) in which the peak accelerations from several recent earthquakes are compared to predictions based on regression analysis of older data. The comparison is excellent in distance ranges for which the regression analysis is relevant.

Publications

1. Joyner, W. and Boore, D. M., 1980, A stochastic source model for synthetic strong-motion seismograms: Proceedings, 7th World Conference on Earthquake Engineering, v. 1, p. 1-8.

2. Boore, D. M., 1980, On the attenuation of peak velocity: Proceedings, 7th World Conference on Earthquake Engineering, v. 2, p. 577-584.

3. Boore, D. M., 1980, Comments for the Panel on Strong Ground Motion: Proceedings, 7th World Conference on Earthquake Engineering.

4. Boore, D. M., 1980, Strong-motion recordings as accelerograms: Proceedings, Research Conference on Earthquake Engineering, Skopje, Yugoslavia, p. 81-95.

5. Boore, D. M., Joyner, W. B., Oliver, A. A. III, and Page, R. A., 1980, Peak acceleration, velocity, and displacement from strong-motion records: Bulletin of the Seismological Society of America, v. 70, p. 305-321.

6. Hudson, J. and Boore, D. M., 1980, Comments on "Scattered surface waves from a surface obstacle" by J. A. Hudson: Geophysical Journal of the Royal Astronomical Society, v. 60, p. 123-127.

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Abstracts

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Global Aftershock Project (GAP) Portable Arrays

9940-02689

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Investigations

The Global Accelerograph Project had an excellent beginning. Prior to the beginning of the fiscal year, a detailed plan was drafted within the Branches of Ground Motion and Faulting and Seismic Engineering and coordinated within the Office of Earthquake Studies. The plan was introduced to State Department representatives of the Office of Cooperative Science and Technology Programs at a special meeting. The plan was favorably received and suggested changes incorporated into a final revision.

Results

The objective of the Global Accelerograph Project is to obtain critical near-source ground motion data from large earthquakes and aftershocks. Data would be obtained from permanent and temporary arrays in foreign countries. The plan includes a comprehensive list of countries around the world likely to experience earthquakes and aftershocks of the magnitude we need for our research.

Following the State Department meeting work began on the selection of the first countries to be approached for introduction of the project. Ten countries were selected with consideration given to both technical and political factors. The airgram was sent through the Office of International Geology (OIG) for internal USGS coordination and through the State Department to the 10 selected embassies around the world. The airgram contained the project plan, introduced the project to the addressee countries and requested their expression of interest in participation in the project. The airgram also included the names of physical scientists and engineers who have served as USGS contacts in strong motion research through the years. We suggested that the embassy use those names as appropriate for a starting point to introduce the project into the in-country political/scientific structure. Enthusiastic response to the airgram was received informally at the Seventh World Conference on Earthquake Engineering in Turkey in September, 1980.

In efforts related to but separate from this project, the principal investigators, in cooperation with colleagues at Caltech and USC, prepared and submitted a proposal for the installation of strong motion instrumentation in the Peoples Republic of China. This proposal has been funded by the National Science Foundation, and progress is being made in instrument selection and array design.

D. M. Boore, A. Lindh, and W. Joyner submitted a proposal to the strong motion program of the California Division of Mines and Geology for the installation of a dense network of accelerographs along the San Andreas fault near Parkfield, California. This proposal was accepted and the above named investigators are advising the state in the deployment of the array. Some 40 new strong motion accelerographs will be installed over a 3 to 4 year period, beginning in the spring of 1981.

Future Plans

Future plans call for following through with the release of the airgram, initiating agreements with those countries who respond favorably and initiating the procurement of instrumentation.

Dynamic Soil Behavior

9550-01630

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Investigations

1. Developed computer programs to study the effect of using different nonlinear soil models on computed seismic response of soil deposits.

2. Developed computer programs to study the effect of modulus degradation of soils on computed seismic response of soil deposits.

3. Continued laboratory investigation of one- and three-dimensional properties of San Francisco bay mud.

Results

1. Results from three-dimensional cyclic testing of San Francisco bay mud suggested that the principal stresses and principal strains are not proportional. This may have serious implications on the application of the classical theory of plasticity to soil mechanics problems and warrant further examination of the current two- and three-dimensional formulations of dynamic analysis.

2. Analyses of laboratory data from torsional testing of San Francisco bay mud showed that, when the effects of shearing strain rate and number of cycles of loading are taken into account, consistent results can be obtained between the torsional simple shear and resonant column modes of testing.

3. Preliminary results from site response computations using different soil models indicated that response values based on the Pyke model were least conservative and the response values based on the Masing-Michigan model were most conservative.

Reports

Chen, A. T. F., 1980, The torsional pendulum test for soils -- a theoretical investigation: Report No. USGS-GD-80-003, NTIS No. PB80-154-115, 37 pages.

Isenhower, W. M., 1980, Torsional simple shear/resonsant column properties of San Francisco bay mud: M.S. thesis, Department of Civil Engineering, University of Texas, Austin, TX, 307 pages.

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Interpretation of Historical Earthquakes in Arizona

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The Arizona Bureau of Geology and Mineral Technology is researching the historical seismicity of Arizona in cooperation with the Department of Geosciences, University of Arizona. Compilation of data from original sources, such as newspapers, diaries, correspondence and contemporary manuscripts is essentially complete. Accounts of the largest historical earthquake (mag. 7¼ from moment) on May 3, 1887 in northern Sonora, have been analyzed and prepared for publication. Nearly 200 earthquakes, exclusive of those events near Lake Mead, Arizona (over 300), have been documented. Interpretation of data for these earthquakes is in progress to revise former epicenter locations and intensities or magnitudes which were based on less reliable information. An epicenter map and earthquake catalog are in preparation.

Based on distribution of Quaternary faulting and seismicity, tentative conclusions regarding the existence of at least four active seismic zones in Arizona (Figure 1) have been drawn: 1) the SW corner of the state near Yuma, where San Andreas fault system activity frequently affects Arizona communities; 2) the NW corner near Lake Mead, where reservoir-induced seismicity and possible tectonic activity associated with Nevada structural trends exists; 3) diffuse zone of epicenters in the NW quarter following the boundary between the Colorado Plateau and Southern Basin and Range Province, tectonic causes unknown; and 4) the SE corner, including the 1887 epicentral vicinity in northern Sonora, tectonic causes unknown. Possible connection of zones 3 and 4 from a seismic risk standpoint must be considered further, by means of detailed geomorphic and geophysical studies in both zones, as well as in the intervening zone of low historical seismicity.

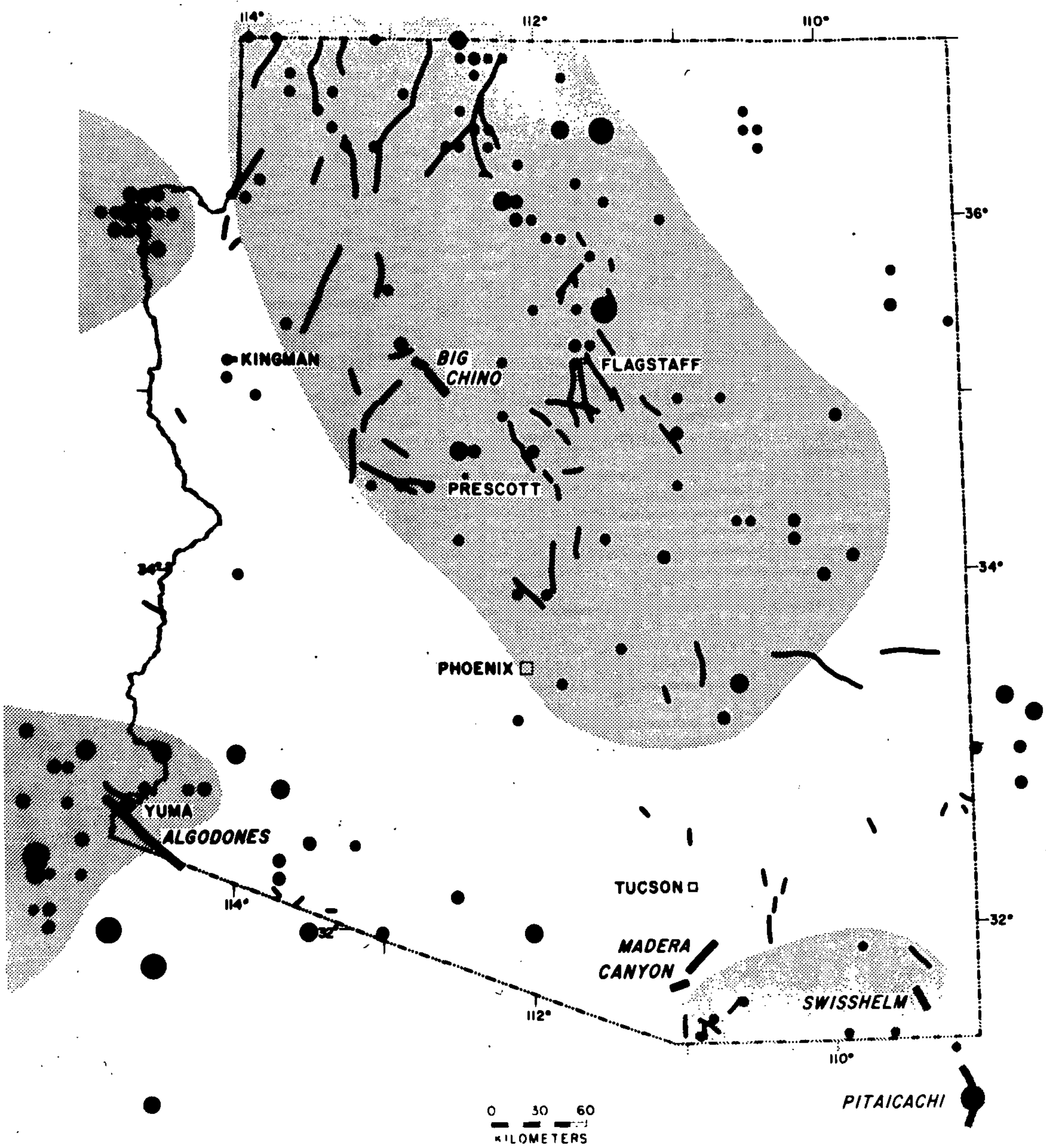

Figure 1. Preliminary epicenter map and seismic zones of Arizona.

Possible Quaternary faults - (from Howard and others, 1978 and Bull, pers. comm.)

Epicenters

Strong Ground Motion Data Analysis

9940-02676

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Investigations

1. Five 3-component digital seismographs were deployed at the Monticello Reservoir, S. C. in 1979 to determine source parameters and focal mechanisms of reservoir-induced earthquakes for comparison with measurements of in situ stress in the same area.

2. Ground motion data of earthquakes and mine tremors, measured from accelerograms recorded at small hypocentral distances, were analyzed in terms of several models of faulting to determine the effects of factors such as seismic moment, stress drop, instrument bandwidth and source inhomogeneity.

3. A comprehensive and flexible computer software package is being developed for processing and analyzing accelerograms of earthquakes recorded at multiple stations within the near-epicentral region. The output includes estimates of source properties such as moment, static stress drop, rupture velocity, source complexity, and dynamic stress drop.

4. Limitations on the class of permissable earthquake source models have been investigated by analyzing contrasts between the compressional and shear waveforms in both the frequency and time domains.

Results

1. Source parameters were determined for 10 events in the vicinity of the Monticello Reservoir and the stress drops for these shocks, ranging in depth from 0.5 to 1.4 km, were compared to in situ stresses measured by Zoback using the hydrofrac technique over a similar depth range. Nine of the events which had seismic moments ranging from 2 to 14 x 10^{18} dyne-cm had stress drops of the order of 1 bar, which is only a small fraction of the in situ stresses of 20 to 40 bars. The large event with a seismic moment of 7 x 10^{20} had a stress drop of approximately 17 bars, which is comparable to the in situ shear-stress level. Interestingly, the in situ data indicate that the state of stress varies with depth from a thrust-fault regime at the shallowest levels to a strike-slip or normal-fault

regime at depths below several hundred meters, whereas the earthquake focal mechanisms are all of the thrust-fault type.

2. Measurements of peak ground velocity, $\underline{v}$ and acceleration $\underline{a}$ for earthquakes and mine tremors, with local magnitudes ranging from -0.8 to 6.4 were analyzed in terms of a model of inhomogeneous faulting. The fault model involves the failure of a circular asperity of radius r_i surrounded by a previously faulted annular region of outer radius r_0. For $r_0/r_i >> 1$ both $\underline{v}$ and $\underline{a}$ are associated primarily with the failure of the asperity but also depend on the large-scale source parameters. Specifically,

$$\underline{v} = (\beta \Delta\tau r_0/\mu R)\ (0.10\ r_0/r_i + 0.15)$$

and

$$\underline{a} = (\Delta\tau/\rho R)\ [0.30\ (r_0/r_i)^2 + 0.45],$$

where β is the shear wave velocity, $\Delta\tau$ is the overall stress drop, μ is the modulus of rigidity and ρ is density. The terms involving r_0/r_i correspond to the high-frequency radiation associated with the failure of the asperity, and the other terms indicate peak parameters due to the broad-scale readjustment. r_0/r_i is normally within the range of 1 to 10.

3. In its present stage of development, the strong ground motion data analysis package provides a convenient means of estimating the usual seismic source parameters as well as less conventional source variables such as dynamic stress drop, radiated energy, source rupture geometry, rupture complexity, source coherence, and ambient faulting stress. These analytical tools are currently being applied to the strong ground motion data set of the 1975 Oroville, California sequence.

4. The common observation that the P waveforms are enriched in high-frequency motion relative to the S waveforms of the same earthquake has been investigated in considerable detail. Generally, this appears to be an effect related to source processes and cannot be explained in terms of wave propagation factors such as anelastic attenuation. This finding has important implications regarding the class of possible source models. For example, the "corner frequency shift" is compatible with neither the point-source nor the Haskell-type dislocation models.

Reports

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Analysis of Natural Seismicity at Anza, California

9940-02731

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Investigations

The purpose of this experiment is to provide a set of precise source parameters such as fault plane orientation, moment, source radius, stress drop and direction of rupture propagation for all events above a minimum magnitude ($M_L \sim 2$) along the San Jacinto fault near Anza, California. A digital-telemetered seismic array is being installed in the Anza-Coyote Canyon seismic gap to gather high-dynamic range data from an array of ten sites each of which has a set of three orthogonal velocity transducers. The source parameters as well as the time series data will be used to 1) determine if there are any premonitory changes in seismically observable quantities preceding small and moderate-sized events ($2 \leq M_L \leq 4\ 1/2$); (2) increase understanding of source mechanisms and high frequency ground motion over a wide frequency band; (3) study relationship between earthquake activity and fault geometry and crustal deformation as measured geodetically and with a variety of geophysical instrumentation at Pinon Flat observatory.

This is a cooperative project with Jim Brune and Jon Berger at UCSD.

Results

Procuring, installing, and testing the equipment associated with the digital array has been the main activity during the past six months. A Digital Equipment Corporation PDP 11/34 minicomputer has been delivered to UCSD to collect the digital data from a microwave receiver that links the seismograph array at Anza with UCSD. Development is now proceeding on the real-time programming necessary for receiving and collecting data at a rate of about 10,000 words/sec.

Investigations of Seismic Wave Propagation for Determination of Crustal Structure

9950-01896

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Investigations

The reflection seismic profile from work done around the New Madrid seismic zone gave indication of the existence of uplifts interpreted as laccoliths or sills. Acoustic modeling techniques along with finite differences were employed to test the reasonableness of this interpretation.

Results

Acoustical techniques were used to determine if physical models of intrusive masses and structure could produce geologic configurations similar to those observed on the reflection profiles. In particular, the modeling was done to test the interpretation that the localized uplifts are underlain by igneous bodies that, due to relatively small contrasts in density and velocity between the igneous bodies and host sedimentary rocks, are not well defined on seismic reflection profiles. Results of this investigation show that the modeled structure mimics that seen on the reflection profiles quite closely. Margins of igneous bodies, especially those beneath the bodies, are not well resolved. Compressional reflections and diffractions from faults have a similar appearance on the reflection profiles and synthetic cross sections.

In order to compare the acoustical method with the finite difference method, a comparison was made using a high velocity lens imbedded in a lower velocity material and a reflecting higher velocity interface below the lens. This model is shown in figure 1. Figure 2 is the result of the standard industrial acoustical reflection profile of this model. This gives relatively simple results. The reflection of the bottom of the lens is distorted upward, and the reflection below the lens is also distorted. Also there is a reduction in reflection strength below the lens. Figure 3 shows the horizontal and vertical time histories of half the lens from a vertical polarized source using the finite difference method. This shows the same reflection patterns along with all the scattered waves, making a much more complex picture. Figure 4 is the same lens but a horizontal polarized source. The comparison shows that there is a large amount of information lost using the simpler model.

Reports

Boore, David M., Harmsen, Stephen C., and Harding, S. T., Wave scattering from a step change in surface topography. Submitted to Seismological Society of America Bulletin.

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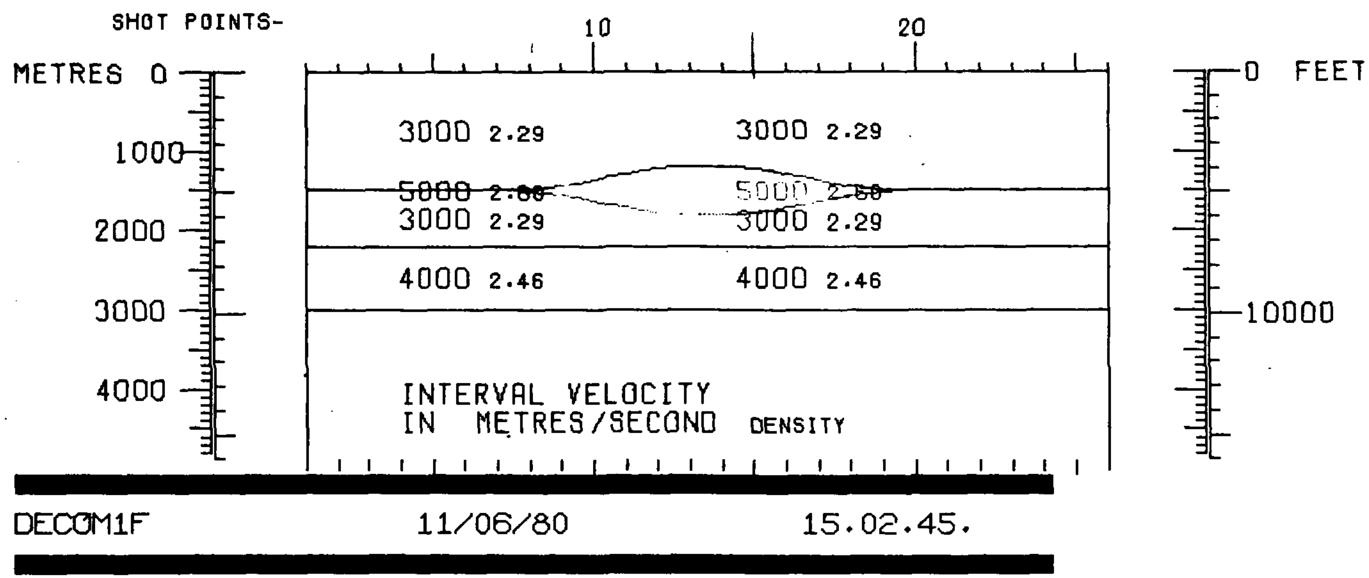

Figure 1.--Model of high velocity lens used in comparison between the acoustical modeling and finite difference modeling.

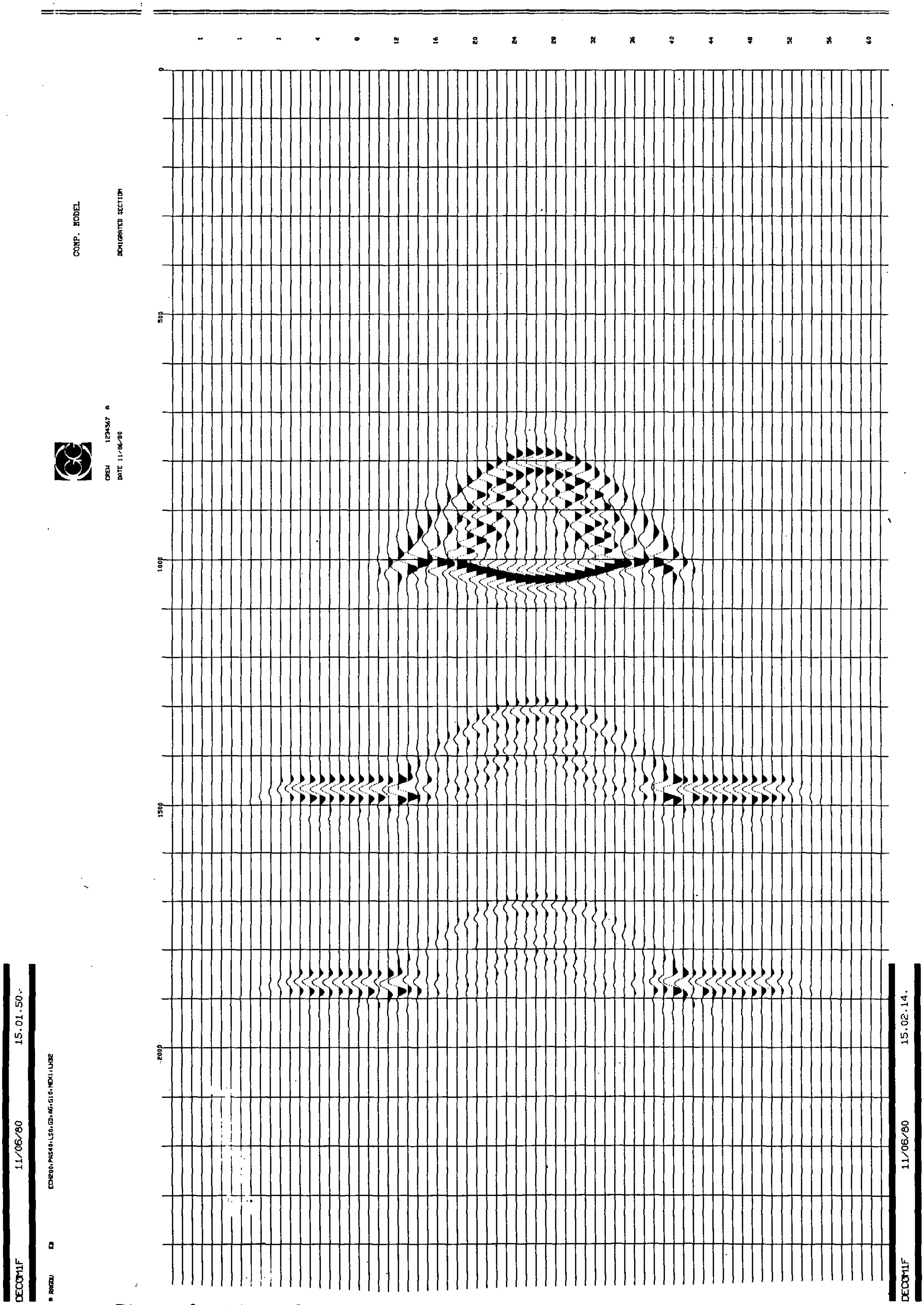

Figure 2.--The reflection profile of the model shown in figure 1 using acoustical modeling techniques.

P WAVE SOURCE

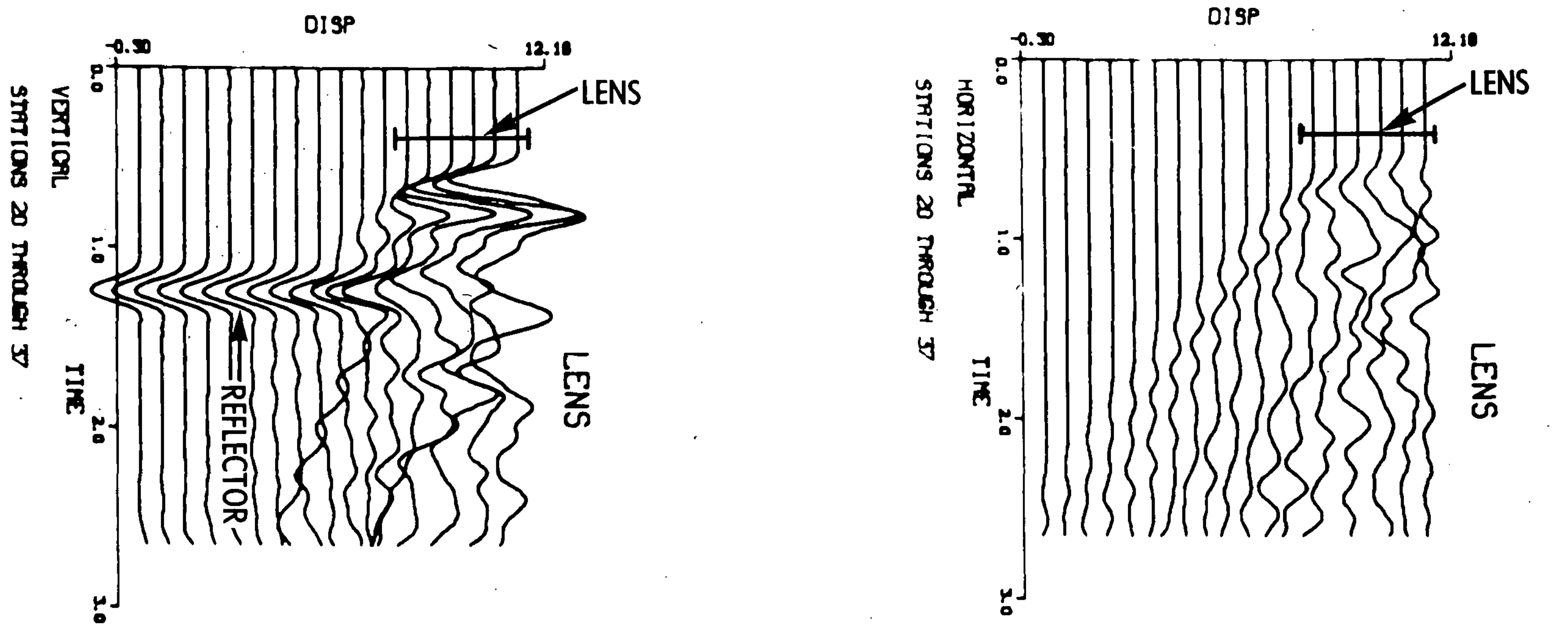

Figure 3.--Finite difference model using model shown in figure 1 with

S-WAVE SOURCE

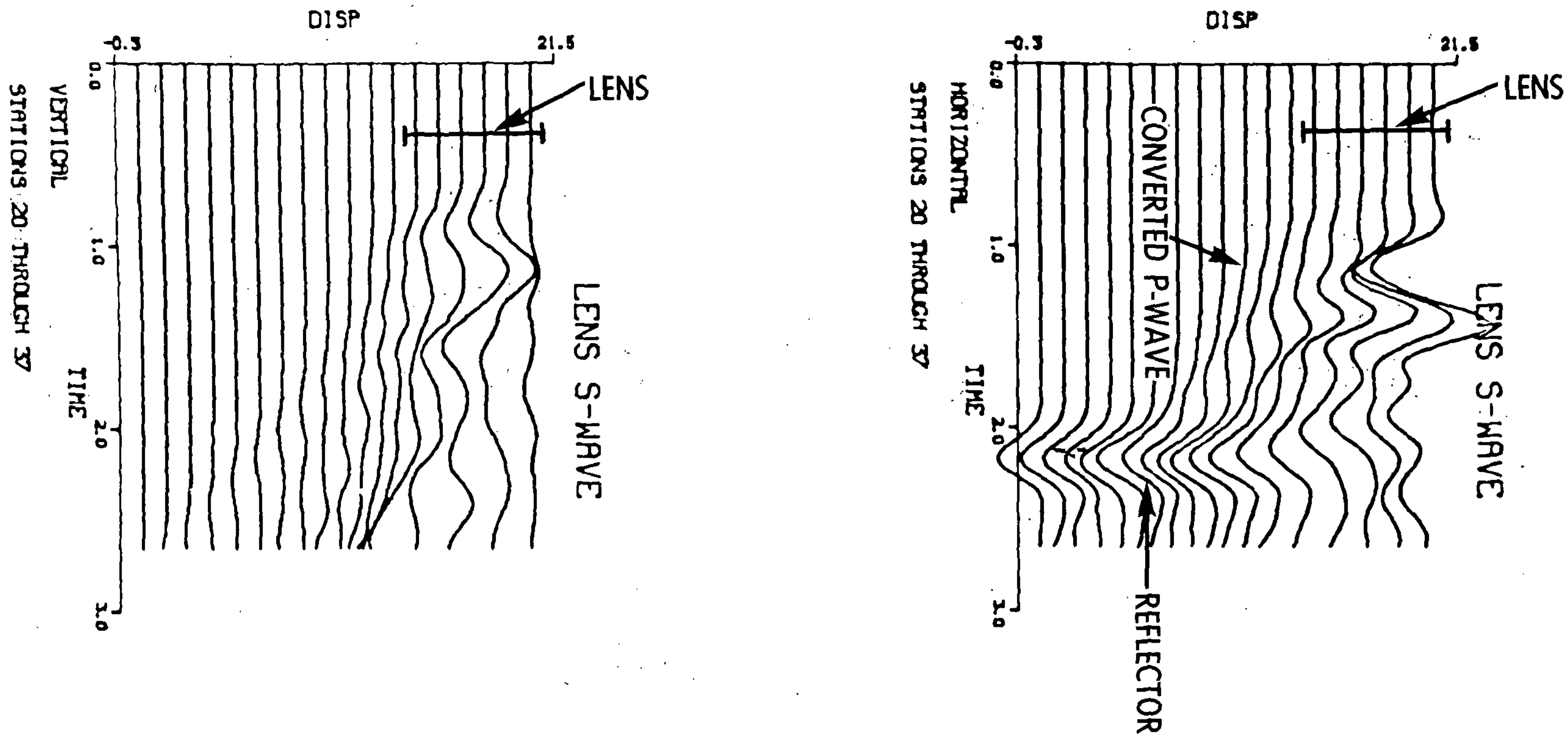

Figure 4.--Finite difference model using model shown in figure 1 with an S-wave source .1/2 of lens shown.

Stochastic Source Models for Synthetic Strong Motion Seismograms

9940-01913

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Investigations

1. Development of methods utilizing stochastic source models for the generation of seismologically realistic time histories of earthquake ground motion and mean Fourier spectra.

2. Analysis of strong motion data.

Results

Preliminary attenuation curves for peak horizontal acceleration and velocity incorporating recent close-in data were developed for the NSC-OST assessment of earthquake hazards in California.

Application of Earthquake Mechanism Studies to Prediction of Long-Period Ground Motion and Related Problems

Contract No. 14-0001-18321

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This report summary covers the six-month period from April 1, 1980 to September 30, 1980.

Investigations

1. Study of Body Waves of Great Earthquakes.

The complexity of the faulting process of an earthquake has dominating effects on the nature of strong ground motions resulting from it. Unfortunately, very little is known about the nature of complexity, particularly of very large earthquakes. We investigated the body waves from very large earthquakes in an attempt to understand the nature of complexity.

2. Development of an Analysis Method of Complex Events.

There is no standard method with which we can interpret complex events in terms of the seismic moment and the stress drop of the constituent events of a multiple shock. We develop a method which deconvolves observed seismograms into a series of discrete events.

Results

1. Study of Body Waves of Great Earthquakes.

Three of the largest earthquakes in this century are: Kurile Is., $M_w = 8.5$, Alaska, $M_w = 9.2$, 1964, and Rat Is., $M_w = 8.7$, 1965. These events were recorded by the WWSSN network with the 30-100 long period instruments. The body waves of these large events are compared to those of the Niigata earthquake, a "standard magnitude 8" event. As the body waves for these great earthquakes are off scale at nearly all of the stations in the teleseismic range (Δ = 30 to 80 deg.), seismograms recorded in the core shadow zone are used. The results can be best summarized by Figure 1 where two seismograms from each event, representative of the distance range, are plotted together. One striking feature of Figure 1 is that the Alaskan earthquake has a substantially larger body wave amplitude than the other earthquakes. The long period seismic moment of the Alaskan event is a factor of: 6.6 larger than the Rat Is. event, 12 larger than the Kurile Is. event, and 273 larger than the Niigata event. The total source process time for the larger events is several minutes long. For the Niigata event, there is basically a single pulse. An important feature that we wish to emphasize is the broad pulse width of the Alaskan earthquake. The first arrival in the Alaskan records has a pulse width of $\sim$ 30 sec. This broad pulse requires a ramp-type time function of at least 30 sec duration, and assuming a symmetric trapezoidal time function, the total time function would be greater than 60 sec in length. Thus, this pulse requires a time constant greater than 30 sec, and using a rupture velocity of 3.5 km/sec we conclude that the source length scale is greater than 100 km, and possibly 200 km. For comparison, the total time function duration of the Niigata event is less than 20 sec, and this corresponds to a source length scale of $\sim$ 30 km. Notice that the dominant periods of the Kurile Is. and Rat Is. events are intermediate to those of the Alaskan and Niigata events.

We conclude that the source region of the initial break in the Alaskan earthquake has a length scale greater than 100 km, and that the following multiple events had a similar length scale. This length scale is substantially larger than that for Niigata earthquake, which indicates that a great earthquake is not just a sequence of magnitude 8 events. The dominant periods of the Kurile Is. and Rat Is. events suggest that their characteristic length scales are between the Alaskan and Niigata values. Thus, it appears that a larger asperity length scale is associated with the largest earthquakes.

2. Development of an Analysis Method of Complex Events.

We assume that all the constituent events of a multiple shock have identical geometrical parameters, the strike, dip, and rake angles. We use the parameters determined from the first-motion data. The only unknown is the source time function. We further assume that the far-field source time function can be decomposed into unit ramp functions with an identical rise time τ.

Let s(t) be the synthetic wavelet for the unit ramp function, and m_i and t_i be the magnitude and the onset time of the i-th ramp function. Then the synthetic waveform is given by:

$$S(t) = \sum_{i=1}^{N} s(t-t_i)m_i \qquad (1)$$

where N is the total number of the ramp function. The values of m_i and t_i are determined by minimizing the estimation error defined by:

$$E = \int [\chi(t) - S(t)]^2 \, dt \tag{2}$$

where $\chi(t)$ is the observed wave form.

First we take a ramp function with the amplitude m_1 and the onset time t_1 for $S(t)$, and minimize E. The onset time t_1 is obtained by maximizing $|r_{s\chi}(t_1)|$, and the amplitude m_1 is determined by:

$$m_1 = r_{s\chi}(t_1)/r_s(0) \tag{3}$$

where $r_{s\chi}(t)$ is the cross-covariance of $s(t)$ with $\chi(t)$ and $r_s(t)$ is the auto-covariance of $s(t)$. Next, we subtract $m_1 s(t-t_1)$ from $\chi(t)$, and apply the same procedure to $\chi(t) - m_1 s(t-t_1)$ to obtain the second ramp function (m_2, t_2). The procedure is repeated until the residual or the estimation error defined by (2) does not change significantly any longer.

We applied this method to the 1976 Guatemala earthquake and the 1976 Turkey earthquake, to obtain the seismic moment and the stress drop of the constituent events.

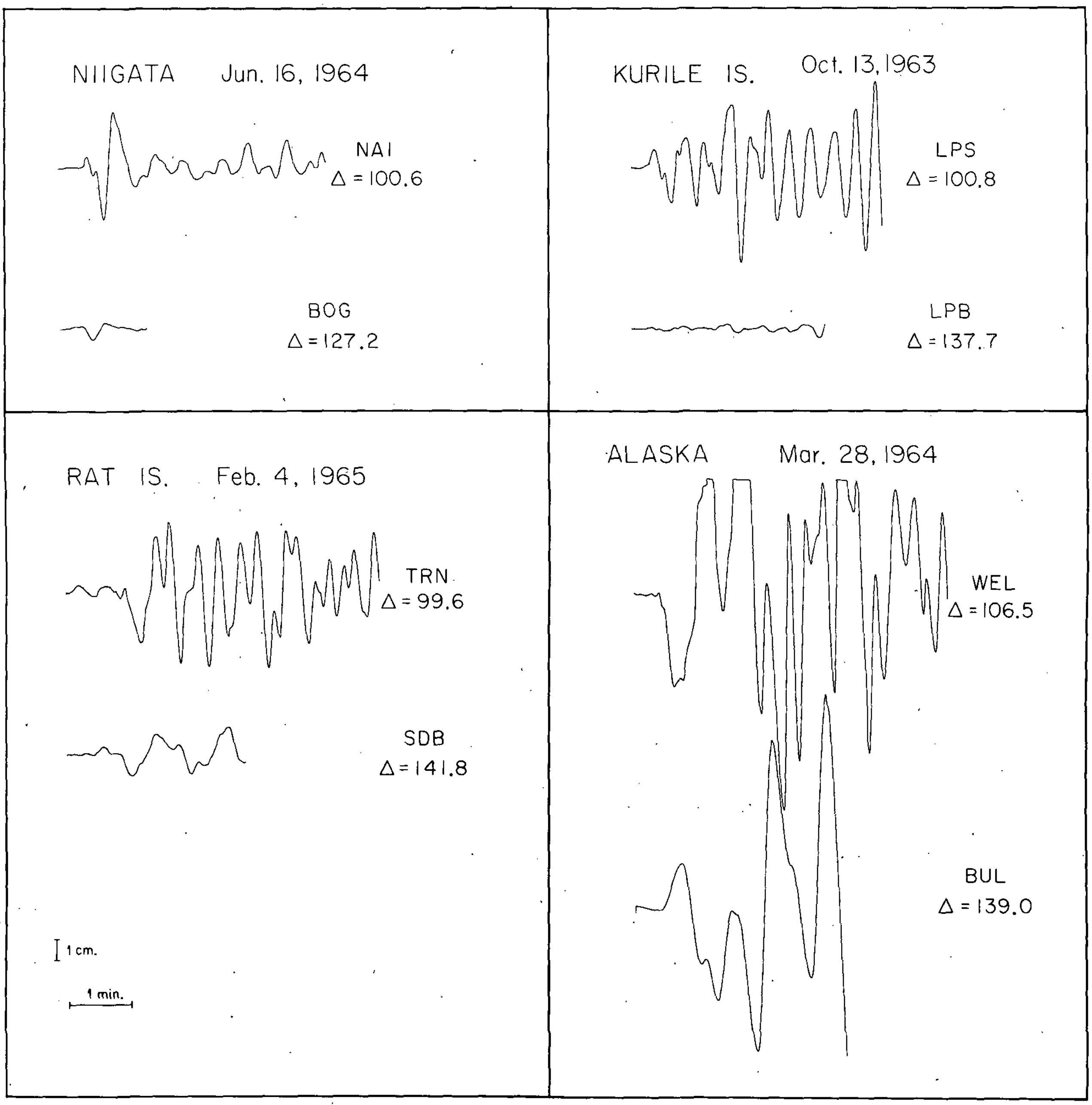

Figure 1

Comparison of P waves from four large earthquakes. All the records are normalized to standard magnification (x1500). Note the difference in the complexity, amplitude and dominant period.

Calculation of Strong Ground Motion and Local Field-Far Relationships for the April 29, 1965, Puget Sound, Washington, Earthquake

14-08-0001-18235

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Investigations

Work related to this contract has concentrated in producing viable source models for the April 1965 Puget Sound earthquake and viable earth structure models for Puget Sound and nearby areas to study the effects of strong ground motion wave propagation. Several different yet related topics have been addressed in this study. These are:

1. Construction of both deterministic and empirical source models for the 1965 Puget Sound earthquake based on teleseismic body wave data;

2. Investigation of crustal and upper mantle structure under specific sites in the Pacific Northwest;

3. Calculation of strong ground motions using these source and structure models with comparison to existing strong motion data recorded from the 1965 event.

Results

1. An attempt was made to model observed strong motion velocities and displacements from the April 29, 1965, magnitude 6.5 Puget Sound earthquake. Several different plane layered crustal models were assumed based on previous seismic refraction measurements. Source parameters for the 1965 event were taken from a previous study of teleseismic body waves. Teleseismic P waves recorded at Tumwater, Washington, near the Olympia strong motion site, were examined to place constraints on allowable interface contrasts and to determine whether lateral heterogeniety is a major factor affecting wave propagation. Because of the 60 km source depth and close epicentral distances for the strong motion sites, it proved adequate to approximate ground displacements and velocities by assuming an impinging P or S plane wave under the various crustal models and using a propagator matrix technique to compute the response. Amplitudes were scaled using the generalized ray theory result for direct P, SV, and Sh waves from a point dislocation. Although strong motion models qualitatively showed many of the characteristics of near-vertical wave propagation in layered structures, the observed amplitude behavior of individual stations was quite complex. Data from Tacoma and Seattle sites, close to the epicenter, attained lower velocities and acceleration compared to Olympia which was three times as far. The amplitude behavior is consistent with higher attenuation under Tacoma and Seattle although this is not strictly required.

The short-period P data recorded at Tumwater showed evidence of large velocity contrast interfaces under the station, from large P to S conversions, consistent with those assumed in the crustal models. Comparison of both horizontal components for several teleseisms also indicated that dipping structure or other lateral heterogeniety is important for Olympia structure. Thus, it is likely that strong motion amplitudes and waveshapes are also controlled by scattering mechanisms to a large degree. Irrespective of these wave propagation problems, the largest single factor which has affected the level of strong ground motions in Puget Sound is the large source depth of past earthquakes. Using a simple geometrical spreading argument it is shown that if the 1965 event was only at 10 km distance from Olympia instead of 100 km, all other effects being equal, then greater than 1g accelerations would have been recorded. Thus, estimates of seismic hazard based on a direct interpretation of the strong motion data of the 1965 and 1949 events will be erroneously biased towards less hazard if there is potential for shallow faulting in the Puget Depression. This work has been prepared for publication in the Bulletin.

2. Long-period teleseismic P waves recorded at VIC (Victoria, British Columbia) and COR (Corvallis, Oregon) show anomalously large Ps conversions and later arriving P-to-S reverberations not observed from typical continental crustal sections or from previously proposed structures for these stations determined from refraction surveys. The timing and large amplitude of the Ps phase, relative to direct P, suggests a high velocity-contrast interface at 45 to 50 km depth under VIC and COR forming the base of a distinct low velocity zone. This interface is proposed to be the oceanic Moho which is being subducted under North America. Off azimuth Ps recorded at COR is consistent with a 20^{o} eastward dip for the interface. Horizontal particle motion at both sites show evidence for lateral heterogeniety in local crustal structure. The distinct low velocity zone and its negative velocity gradient with depth has important consequences for refraction interpretation in the region. In principle, this type of structure suggests a solution for the Vancouver Island crustal thickness problem. This work has been prepared for publication in the Journal of Geophysical Research.

STRONG MOTION INTERPRETATIONS FOR STRUCTURAL ENGINEERING

9910-02759

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457-2881 (FTS)

Investigations

1. Evaluate the current seismic design zones in the light of recorded seismic response of buildings and propose criteria for seismic design zonation.

2. Compare ambient periods of vibration of modern buildings to those of buildings built in the 30's and 40's and with the simplified formulas currently used in seismic design of buildings.

3. Develop procedures for including nonlinear structural response and nonlinear soil-structure interaction effects into routine response spectrum calculations.

Results

1. A preliminary evaluation of the current seismic design zones in the Uniform Building Code has been discussed with committees of the Structural Engineers Association of California. Further discussion is taking place regarding the basic philosophy of seismic design of buildings, current design practice as it reflects the stated philosophy, modifications to current design practice, and improved criteria for seismic design zonation.

2. Preliminary ambient vibration surveys have been made on two buildings to evaluate available equipment and develop specifications for the type of equipment that is required to conduct ambient vibraton surveys of a range of representative types of buildings.

3. Preliminary studies utilizing a simple model that includes both nonlinear structural response and nonlinear soil-structure interaction have proven to be both encouraging and discouraging. Encouraging in that many of the general effects that are observed in records of building response can be simulated with the simple model. Discouraging in that the trial and error approach that was used made it quite evident that intuitive estimates of the model parameters are insufficient to produce results that compare with the recorded response

reasonably well. But encouraging in that they fulfilled the objective of all computation: "THE PURPOSE OF COMPUTING IS INSIGHT NOT NUMBERS" (Hamming, 1962). The focus of the study has shifted to an assessment of the current "systems-identification" procedures for the evaluation of structural response including soil-structure interaction.

Earthquake Maps for Developing Areas

San Francisco Bay Area

Contract No. 14-08-0001-19108

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INTRODUCTION

In this project, ABAG is extending the computer-based earthquake hazard mapping capability developed in an earlier contract (which focused on the San Mateo County area) to selected areas of significant development pressure. Specific applications for this mapping capability are being extended and refined. The results are being made available in forms useful to a variety of people working for and with local governments in the San Francisco Bay Area.

PROJECT COMPONENTS

1. Selection of a target area.

2. Development of map files.

3. Manipulation of map files.

4. Various applications for these files.

5. Communication of the information.

DISCUSSION OF RESEARCH PROGRESS

1. Target Area Selection

Although many of the basic data map files and hazard map files previously developed were for the entire nine county Bay Area, several were developed only for or only in detail for San Mateo County. The first task in this project was to choose study areas of significant development pressure. The study areas chosen are fifteen 7-1/2 minute quadranges in Petaluma and its vicinity and the ridgelands areas of the East Bay hills.

2. File Development

Three basic data map files are being extended to or refined in those fifteen quadrangles either by digitizing maps or by obtaining existing machine readable data sets. These files include:

- o geologic materials
- o existing landslides
- o digital elevation models

3. File Manipulation

These upgraded basic data map files are to be used to produce more refined hazard maps for those fifteen quadrangles.

- o More detailed ground shaking intensity files will be produced, including a maximum ground shaking intensity map and several risk of ground shaking damage maps.
- o The geology, landslide, and topography information, as well as information on vegetation and precipitation, will be examined to create a method of extending both the rainfall-induced and earthquake-induced landslide susceptibility mapping beyond San Mateo County.

4. Application of Files

These upgraded hazard maps, as well as hazard maps of liquefaction susceptibility, fault surface rupture, and tsunami and dam failure inundation, are being used in sample applications:

- o as maps for local general plans
- o to refine and extend ABAG's ability to develop an automated regional environmental assessment document to serve as a background report for local Environmental Impact Reports (EIRs)
- o to compile composite maps of earthquake hazards for the fifteen quadrangles being studied
- o to assess the vulnerability of existing and projected land uses and population to damage from a major earthquake.

5. Communication of the Information

Much effort is being made to ensure that this information is effectively communicated and disseminated to a variety of professionals working for and with local governments in the San Francisco Bay Area.

- o A series of ten working papers developed previously to document the mapping capabilities is being extended to include the documentation of this contract.
- o Tools are being developed to aid in presentations.
- o Talks are being given at professional societies.
- o Meetings are being conducted with local staff.
- o Descriptions of ABAG's mapping capabilities are being provided to various newsletters and magazines.
- o A procedure for producing these products is being integrated into ABAG's administrative structure.
- o The working papers on ground shaking intensity mapping have been integrated into a report for possible publication by USGS.

EARTHQUAKE HAZARD MAPS STEAMBOAT AND VISTA 7 1/2-MINUTE QUADRANGLES, NEVADA

14-08-0001-19116

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Goals

The objective of this study is to develop earthquake hazard maps for two 7 1/2-minute quadrangles in western Nevada. Previous geologic mapping supported by U.S. Geological Survey Contract No. 14-08-0001-17774 provides the base for determining the distribution and general physical characteristics of the unconsolidated Quaternary units and the location and relative age of the faults which offset these units.

Investigations

1. Geotechnical data have been collected and evaluated for both the Steamboat and Vista 7 1/2-minute quadrangles. Data on the bulk density of the unconsolidated deposits were obtained from the files of the Nevada Bureau of Mines and Geology and consulting engineering firms's foundation studies and site reports. Blow count data were collected when available. Data on standard penetration rates were correlated with bulk density values.

2. Depth to groundwater maps were produced for both quadrangles. These data were compiled from depth to water recorded in geotechnical borings and non-pumping wells.

3. Shear-wave velocity measurements have been performed at 15 sites on 8 separate and distinct geologic units in the Steamboat quadrangle and 24 sites on 7 geologic units in the Vista quadrangle.

4. Soil conservation maps have been used in determining the age of soils based on development. These age relationships are used to determine the age of last movement of faults.

Results

Results of the data collection phase of the investigation have provided information on the bulk density of the geologic units. Data on bulk density and standard penetration tests were collected from 323 geotechnical borings and/or test pits in the two quadrangles. Eighty-seven separate density determinations provided data on 5 different geologic units in the Steamboat quadrangle. Geotechnical data are more abundant in the developed portions of the Vista quadrangle. Bulk density data were derived from 232 determinations at 54 locations. These data provide average density values for six unconsolidated Quaternary deposits, which comprise the basin fill of the Truckee Meadows and Spanish Springs Valley.

A summary of the bulk density data collected from both quadrangles is presented in Table 1.

TABLE 1. Bulk Density Data

Steamboat Quadrangle	No. of Measurements	Range pcf	Average pcf
Fluvial-lacustrine deposits (Qfl)	25	52-94	81
Alluvial fan deposits (Qf)	57	81-120	97
Outwash deposits (Qdm)	31	94-124	110
Alluvium of Truckee Meadows (Qa)	3	92-122	103
Alluvial deposits in Virginia Range (Qal)	2	94-104	99
Vista Quadrangle			
Fluvial-lacustrine deposits (Qfl)	109	78-95	85
Alluvium of Truckee Meadows (Qa)	98	85-110	100
Older alluvial fan deposits (Qfo)	8	87-114	102
Outwash deposits (Qto)	42	88-132	105
Outwash deposits (Qdo)	1	-	109
Older alluvium (Qao)	2	113-114	114

Data on standard penetration tests were collected to verify and augment the bulk density data. Blow count data were available from 5 locations on 2 geologic units in the Steamboat quadrangle. In the Vista quadrangle standard penetration tests have been performed on 5 geologic units which make up the basin fill. A total of 508 determinations were made in 67 borings in the Vista quadrangle. Table 2 summarizes the standard penetration test data for the 2 quadrangles.

TABLE 2. Standard Penetration Test Data

Steamboat Quadrangle	No. of Measurements	Range BPF*	Average BPF*
Fluvial-lacustrine deposits (Qfl)	90	11-15	13
Alluvial fan deposits (Qf)	5	-	40
Vista Quadrangle			
Fluvial-lacustrine deposits (Qfl)	223	8-32	14
Alluvium of Truckee Meadows (Qa)	214	15-31	21
Older alluvial fan deposits (Qfo)	21	5-67	31
Outwash deposits (Qto)	42	22-66	44
Outwash deposits (Qdo)	8	27-56	42

*Blows per foot

Depth to groundwater maps were prepared for each quadrangle based on information obtained from geotechnical borings and regional groundwater investigations. The maps derived indicate that approximately 60% of the Truckee Meadows has depths to groundwater of less than 10 feet. An anomalous contour of depth greater than 10 feet to groundwater occurs in the north-central portion of the Truckee Meadows east of Sparks. This anomalous area is caused by pumping in a gravel pit. The draw-down to maintain a dewatered condition in the gravels so that they can be excavated is great enough to affect a 4.5 square mile area. The contour indicating 30 feet to water conforms to the bedrock alluvial fan contact throughout most of the Truckee Meadows and Spanish Springs Valley. An older fan complex at the southern portion of the Steamboat quadrangle has depths to water in excess of 30 feet.

Seismic velocity measurements are being interpreted at the present time. The results of these measurements will be combined with the bulk density data to provide a systematic rating of the suspected response of the geologic units to seismic shaking.

Examination of the soils maps of the two quadrangles accompanied by field inspection will continue during the remaining six months of the contract period.

GROUND MOTION PREDICTION AND EASTERN U. S. EARTHQUAKE MONITORING

14-08-0001-17739

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INVESTIGATIONS

1. Develop a method of using small earthquakes to predict the near source ground motion of a large earthquake.

2. The establishment of stations in northern and western New York.

RESULTS

1. The theoretical basis of an "Impulse Response method" of ground motion prediction has been developed. The ground motion caused by a large earthquake can be viewed as a convolution of the impulse responses with an appropriate source time-space function. An excellent data set of 1971 San Fernando aftershocks at several sites, including one site where the main shock was also recorded, is being analyzed to test the feasibility of this method.

2. Three digital forced-balanced accelerometer stations have been established in the area around Massena, N.Y.; one at the bottom of the Long Sault Dam, one in Nicholville and one near Potsdam. Another station is established in Alexander, N.Y., near the 1939 Attica epicenter. Through six months of testing and fine tuning, we have chosen the triggering parameters that will allow us to record magnitude 2.3 earthquake up to a distance range of 10 kilometers in these areas. The full scale of the three component instruments is 1g.

3. A field program in California after the August 6, 1979 Gilroy earthquake (5.9) has proved that the digital triggered accelerographs can record events reliably and clearly. At the La Canada station, we have recorded all the $M_L>2$ events within a distance range of 25km in the period we operated the station (no earthquake with $M_L>2$ occurred beyond the distance range of 25km).

EVALUATION OF LIQUEFACTION SUSCEPTIBILITY IN THE SAN DIEGO, CALIFORNIA URBAN AREA

14-08-0001-19110

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Investigations

The liquefaction susceptibility of deposits in the San Diego urban area is being assessed based on the distribution of geologic materials, the geologic and engineering characteristics of these materials, and the depth to ground water. Geologic maps and cross sections are being prepared showing the ages and mode of deposition of various deposits in the San Diego area. Logs of borings made for numerous projects in the San Diego area are being examined to aid in this mapping. Data from the borings on ground water levels and the engineering characteristics of the deposits, including penetration resistances (blow counts) and grain size and plasticity characteristics, are being compiled and analyzed. Criteria and rating schemes are being developed to rate the susceptibility to liquefaction of the various deposits.

Results

Preliminary geologic maps have been prepared using seventeen City of San Diego base maps at a (reduced) scale of 1 inch to 1600 feet. A number of cross sections have been prepared to aid in the mapping and to illustrate the vertical extent of the deposits. Emphasis in the mapping has been on Holocene deposits, including hydraulically placed fill, fluvial, deltaic and estuarine deposits, because of the anticipated relatively high liquefaction susceptibility of these deposits. Late Pleistocene sediments have also been mapped according to mode of deposition. Early Pleistocene and older formational deposits have been mapped as undifferentiated because of their anticipated very low susceptibility to liquefaction. Data from approximately 2000 borings have been compiled but have not yet been analyzed in detail.

Criteria and rating schemes for liquefaction susceptibility that are based on both geological classifications and engineering data are being utilized. The rating scheme based on geological age and mode of deposition is from the correlations described by Youd and Hoose (1977) and Youd and Perkins (1977). The rating scheme based on engineering data, principally the standard penetration resistance (blow count), and depth to ground water uses the correlation developed by Seed (1979).

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Soil Micromorphology and Faulting

14-08-0001-18320

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Investigations

1. Thin sections have been prepared, and micromorphological interpretations made, of a paleosol associated with the La Jencia fault, near Magdalena, New Mexico.

2. We have shown that the orientation of soil pores within a faulted soil is different than the orientation of soil pores in the normal (not faulted) soil of the area. These conclusions were made by visual evaluation of rose diagrams of soil pores. Such visual observations may be subject to human error or bias. Statistical parameters developed by those interested in particle morphology (Beddow and Melog, 1980) may be useful in describing soil pore orientation or distribution.

3. Soils and associated faulted soils were sampled at two sites. An "active or potentially active" fault and faulted soils in the Ojai Valley near Oak View, California (Keller, 1979), and faults, surface soil and faulted paleosols at the Kern Rock Company gravel quary, about 20 miles south of Bakersfield, California, were sampled. Samples from these sites are now being processed for micromorphological investigations.

Results

1. The micromorphology of the IIBt of the unfaulted paleosol at the La Jencia site shows a high degree of pedality. Porosity was moderately interconnected metavughs in a porphyroskelic or vosepic fabric (Plate 1). Bedded ferriargilans are found in voids. These features are characteristic of stable pedological conditions acting over a long time. Samples from within the zones of movement showed no pedality to very weak pedality. Soil breccia consisted primarily of skeletal grains with occasional fragmic or fragmoidic fabric (Plates 2 and 3). Within the zone of movement both altered structures inherited from the paleosol and post faulting soil development were identified.

2. Two methods for quantitatively assessing pore distribution have been developed. The first technique is based on a "von Mises" or "circular normal" distribution. Significance is determined by a "t test." The second technique

involves using a Fourier series to describe a rose diagram and evaluating the coefficients of the Fourier series. Both techniques are now being used to evaluate pore distributions. However, we feel that both methods must undergo extensive testing before they can be used in a routine manner.

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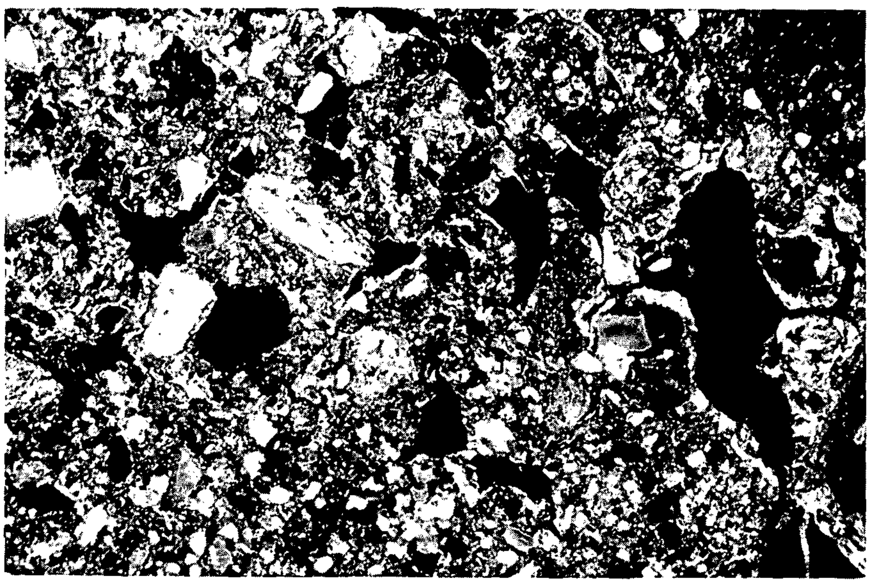

Plate 1. Well developed pedality of the IIBt horizon of the unfaulted paleosol. Crossed nicols. (X35).

Plate 2. Skeletal grains with agricutans (at arrows) in fault zone. Plain polarized light. (X70).

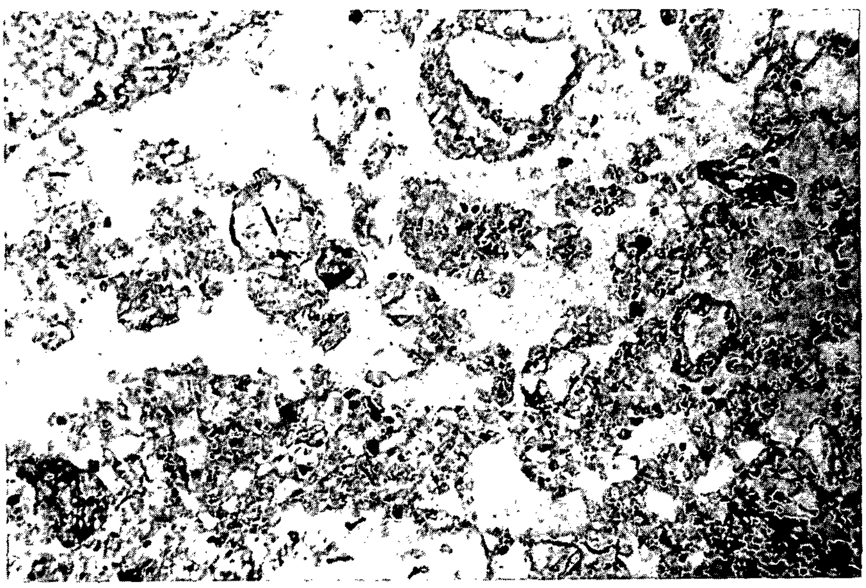

Plate 3. Weak pedality within the fault zone. Plain polarized light. (X35).

Soil Micromorphology and Faulting

14-08-0001-18320

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Investigations

Undisturbed samples were collected from soils across the La Jencia, near Magdalena, New Mexico. In a previous report (Summaries of Technical Reports, Vol. IX, p. 96) the effect of faulting on soil pores at this site was discussed. Thin sections were prepared and the effect of faulting on micromorphological structures is now under investigation.

Results

Figure 1 shows the soils and La Jencia fault. Samples A, B, C, D, F, H and K were from the Bt horizon of the Pleistocene soil. Samples E and I were from soil breccia within the fault zones.

Argillans, cutans or clay-skins composed of clay minerals may be indicators of the intensity of soil development. Those samples from the Bt horizon contained well developed grain, channel, plane and void argillans. Many pores and voids (Figure 2, top) were filled with argillans with large areas of continuous orientation. Samples E and I, from areas that represented projections of the Bt horizon into the fault zone, contained very few argillans (Figure 2, bottom), or other micromorphological evidence of soil development.

The soil at this site developed prior to movement of the fault. Faulting resulted in the near complete destruction of argillans, and other evidence of pedological movement in the zone of movement of the fault.

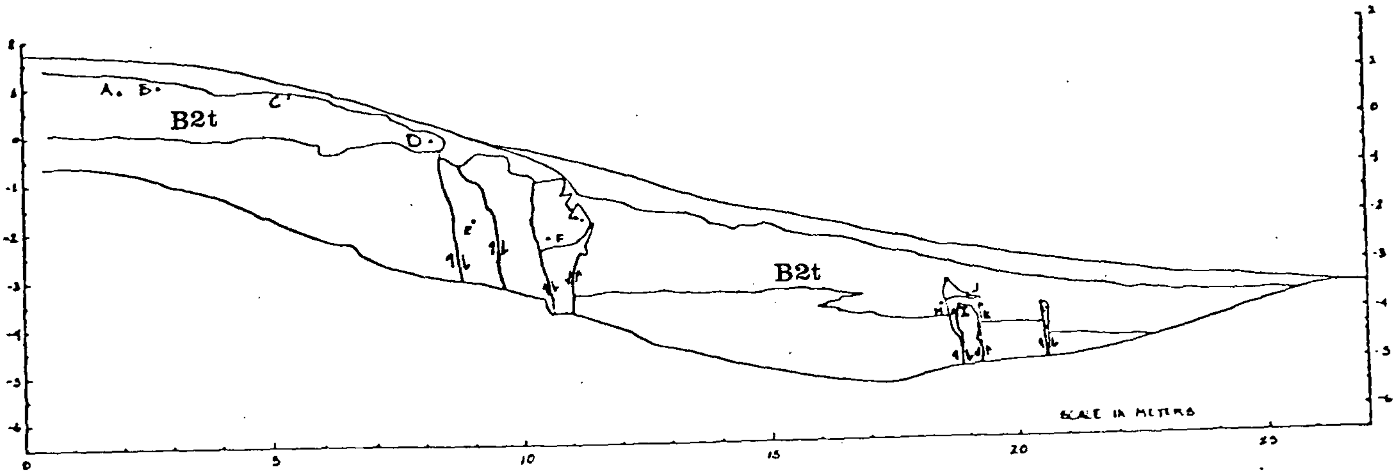
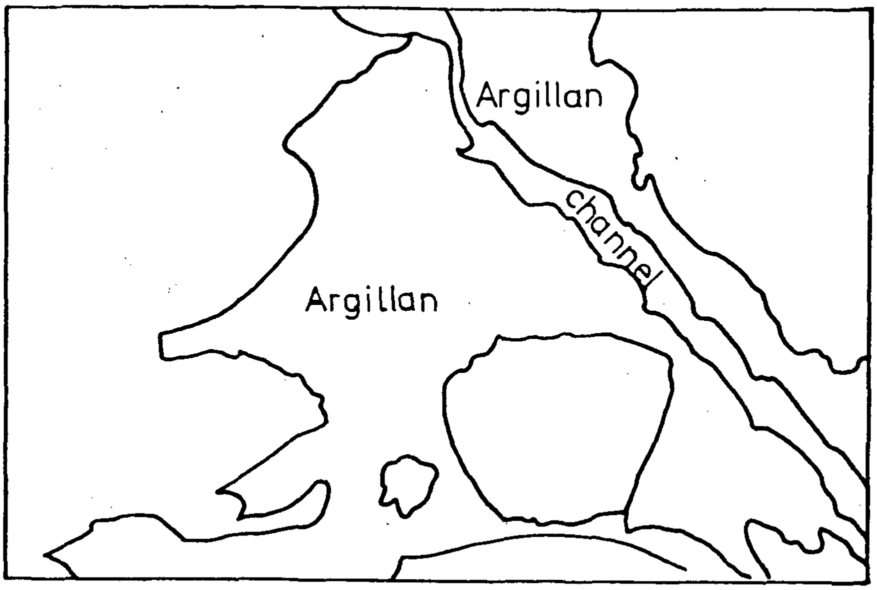
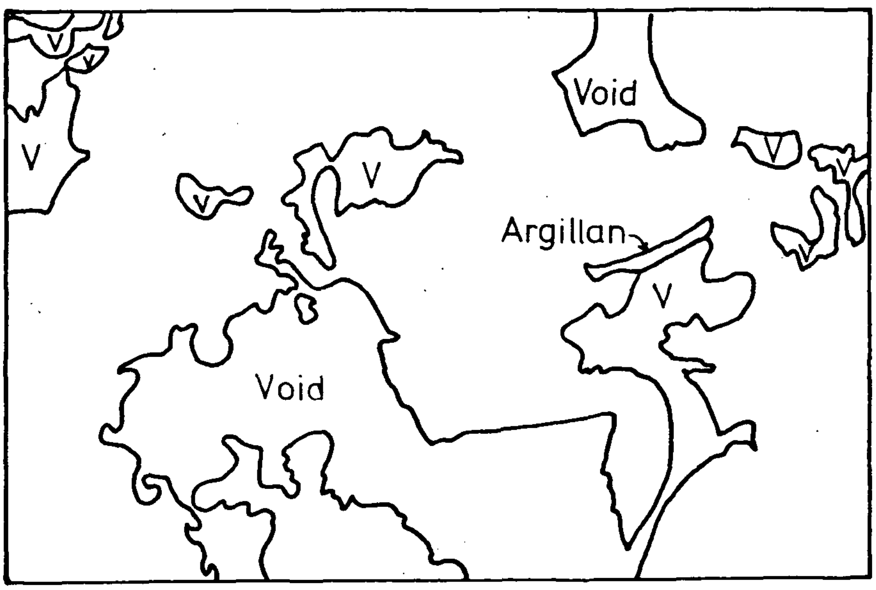


Figure 1. Soil sampling sites and La Jencia fault.


Argillan
channel
Argillan


V
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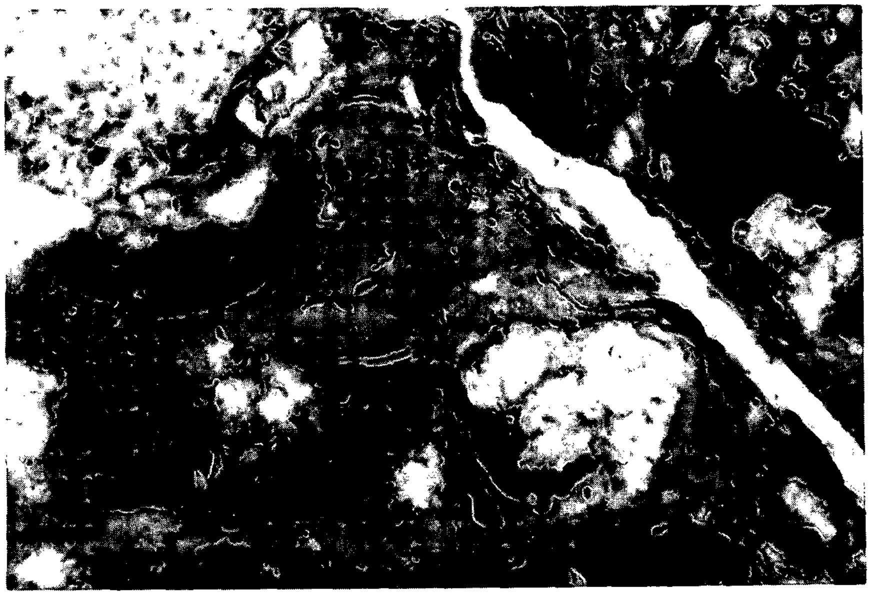

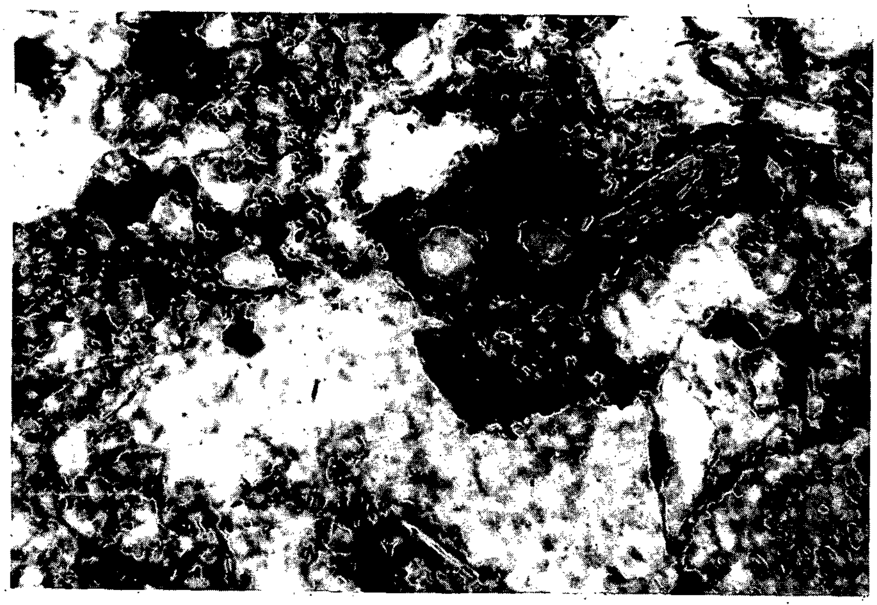

Figure 2. Top, Void argillans, sample C. Bottom, Typical voids and argillan, sample I. Top and bottom X150, plain light.

"Development of Techniques for Evaluating Seismic Hazards of Creeping Landslides and Old Dams"

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This investigation was launched to improve geological exploration tools pertinent to study of old dams and existing landslides because these features present threats to populated areas and to property in the event of a major earthquake. In the case of old dams, of which there are many hundreds to be evaluated in California alone, methods are required to evaluate the strength and deformability of fractured abutment and foundation bedrock. Since such work must usually be done from boreholes, new borehole techniques for mapping and evaluating rock fractures were investigated. In regard to existing, creeping landslides, methods for distinguishing active from inactive old slides were sought using self-recording creep meters set along lines at the surface. Neither area of investigation can be said to be complete and work continues. However, some improvements in the state of the art have been realized.

The testing of rock in boreholes by dilatomers is not new. Various dilatometer devices are reviewed in the final report. An important improvement is permitted by the development of steel reinforced rubber packers. These allow an increase in maximum working pressures of several times over the previous best devices. Interpretation of data (dilatometer pressure versus diameter expansion) necessitates assumptions about the spacing, orientation, and character of the network of fractures in the bedrock. For this purpose, we investigated various types of impression taking instruments. At first it was thought that the impression and dilatometer test could be made with a single operation with one instrument. This proved to be too optimistic as the design requirements for impression taking and deformability measurement are competing and mutually exclusive. However, it is possible to combine both functions in two instruments riding on the same drill string.

Initial experiments were conducted with an impression packer made at Imperial College based upon a design by David Hinds. This instrument uses cheap paraffin film as the impression medium. The film is pressed against the wall of the borehole by plates that are forced apart by the expansion of a packer. The instrument needs further improvement in various aspects, as reported; but it is able to provide the data required on orientation, and relative importance of fractures in the wall rock intersecting the core. A borehole camera or television could do the same but is much more costly, and would not operate in holes filled with dirty water or mud. As an indication of the usefulness of the impression record, it was possible in one test to show that several fractures that had been logged as having been induced during drilling were in fact structural features of the rock mass. In other tests, open, hydraulically conducting fractures were mapped while closed, non-conductive fractures were missed by the impression taking instrument.

For creep studies, a method was developed using a linear variable differential transformer (LVDT) attached to anchored invar wire. The wire was stretched between posts as much as 140 feet apart in stable and in clearly unstable hillsides. One end of the traverse was placed on stable ground wherever possible. After much study to develop procedures for correcting thermal, and other unwanted system effects, it was found that creep records could be used to distinguish stable from unstable hillslopes. Apparently creep rates on stable slopes were always less than $1. \times 10^{-4}$ inches per hour. Maximum rates recorded on unstable terrain were 3.6×10^{-3} inches per hour. Creep is not actually continuous but episodic. Slides "walk" downhill.

Seismic-Induced Ground Failure

9550-01452

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Investigations

1. Digital recording strong motion systems were emplaced near the sites of landslides from the May 25-27 (M = 6.1, 6.2, 6.2) earthquake sequence at Mammoth Lakes to monitor threshold ground motions necessary to generate rock falls.

Digital recorders were also used in conjunction with an electric piezometer to attempt to record the pore pressure response of saturated sands that liquefied in the Mammoth Lakes earthquakes. The goal was to test the instrument in a real situation, to compare the signature of the pore pressure record to that of the ground motion, and to measure what pressure levels and shaking durations begin to cause liquefaction should the aftershocks be strong enough.

2. A reconnaissance of landslides from the Mammoth Lakes earthquakes was undertaken with Dave Keefer to record their distribution and to investigate its dependence on topography, geology, and regional or local structure.

3. A geotechnical investigation was undertaken with Dave Keefer on three lateral spread failures northeast of Mammoth Lakes. Cone Penetration and Standard Penetration tests were used at 2 sites along the Owen's River about 18 km northeast of Mammoth Lakes and at Little Antelope Valley 10 km to the northeast. The studies were focussed on examining and determining the properties of the sediments within and adjacent to the failures and on which layer or layers were the most susceptible to seismic-induced failure.

Results

1. Strong-motion instruments deployed in the Mammoth Lakes area recorded hundreds of aftershocks. Both ground-motion and dynamic pore-water pressures during aftershocks were recorded at the site of a liquefaction-induced lateral spread failure on the shore of Convict Lake. Eight records of pore-water pressure response to aftershocks show that, for small events (well below the threshold of motion causing liquefaction), the pressure pulse responds to both the P and S waves and maintains frequencies close to that of

the recorded strong motion. To our knowledge these pore-pressure records represent the first such records obtained in a natural free-field site and establish the capability to measure pore-water pressure response of actual liquefaction in future earthquakes.

2. Several thousand rock falls and rock slides occurred in the Sierra Nevada in an area of approximately 512 km^2 centered about 32.2 km southeast of Mammoth Lakes. Many rock falls and rock slides formed avalanches of mixed rock and snow and developed prominent flow features. Some of these avalanches appeared to be greater than 50,000 m^3 in volume. Most of these failures were in Paleozoic metamorphic rocks; landslide concentrations were much lower in the adjacent granitic rocks of the Sierra Nevada batholith.

In McGee Creek Canyon, large rocks and morainal boulders were dislodged by shaking. One such rock, measuring 4.0 m in diameter, destroyed numerous trees and a gasoline-tank platform as it passed within 10 m of a house. Many other boulders were loosened from steep glacial moraines near the surface rupture of the Hilton Creek Fault. Several car-sized boulders shifted 1 m during the shaking and now balance precariously approximately a hundred meters above Lower McGee Creek campground.

Liquefaction phenomena were also widespread near Mammoth Lakes. Two prominent sites of lateral spreading cracks extended along the flood plain of the Owen's River for approximately 0.8 km. Displacement across the largest cracks was as much as 1.0 m horizontal and 1.5 m vertical. Similar liquefaction-induced failures occurred at Little Antelope Valley and along Little Hot Creek. At Little Hot Creek, about an acre of an active thermal area liquefied and spread about 10 m toward the creek exposing additional small fumaroles and areas of hot fine silt.

3. A geotechnical investigation of 2 lateral spread failures along the floodplain margins of the Owen's River northeast of Mammoth Lakes shows that liquefaction had taken place within near-surface fine to medium grained sands of no more than two meters depth. Although shallow, these layers accommodated up to 3 m of lateral displacement which resulted in total destruction of irrigation canals and gates along a 0.5 km stretch at one of the failure sites.

A similar investigation of a lateral spread failure at Little Antelope Valley, 10 km northeast of Mammoth Lakes, revealed several sensitive silts and clays as well as a surficial sand of high liquefaction susceptibility. The data and samples are presently being analyzed to determine the most probable sediment layer or layers that were responsible for the failure.

Ground Failures Caused by Historic Earthquakes

9550-02161

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Investigations

1. Data on ground failures were compiled from 10 historic earthquakes. Data have now been compiled from 51 earthquakes since the beginning of the project.

2. Post-earthquake reconnaissance was conducted (with Ed Harp) in the Mammoth Lakes, California area following the earthquakes of 25 and 27 May 1980.

3. Drilling and associated studies were carried out (with Ed Harp) at two sites of lateral spreading on the Owens River floodplain and at one site in the Little Antelope Valley.

Results

1. Data on types and geologic environments of ground failure continue to follow the same trends reported in Keefer and others (1978) and Keefer (1979). The more recent compilations, however, suggest that significant numbers of landslides and related ground failures occur at shaking intensities as low as MMI V1.

2. The Mammoth Lakes earthquakes of 25 and 27 May (M = 6.1, 6.2, 6.2) caused rock falls, rock slides, rock and snow avalanches, lateral spreads and instances of settlement and ground cracking in the epicentral region. Hundreds or thousands of rock falls, rock slides, and avalanches of mixed rock and snow occurred on steep, high slopes in an area of 500 km^2 south of Mammoth Lakes in the eastern Sierra Nevada. Some rock falls occurred as far from the epicenters as the Arch Rock entrance station to Yosemite National Park, a distance of approximately 80 km. Numerous large boulders were dislodged from glacial moraines south of Mammoth Lakes. Lateral spreads and instances of settlement and cracking effected artificial fills and Quaternary sediments in the Mammoth Lakes area, in the Little Antelope Valley, along Little Hot Creek, and on the floodplain of the Owens River. One of the lateral spreads, along Little Hot Creek, occurred in material surrounding an active thermal spring.

3. Drilling at two sites on the Owens River floodplain revealed that lateral spreading failures occurred in shallow layers of liquefied sand. The failure site at Little Antelope Valley contained both layers of liquefiable sand and of sensitive clayey

silt.

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Interactions Between Ground Motion and Ground Failure

9550-01628

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Investigations

1. Evaluated the mechanical stability of the debris flow blocking the Toutle River, Washington, from the 18 May 1980 eruption of Mt. St. Helens.

2. Conducted a geologic and geotechnical reconnaissance to gather data for a seismic slope stability map of the Hilo, Hawaii Quadrangle.

Results

1. During the eruption of 18 May 1980, a massive (3×10^9 yd^3) landslide off the north face of Mt. St. Helens flowed into Spirit Lake and the upper drainage of the North Fork of the Toutle River. The debris flow raised the level of Spirit Lake 200 feet and filled the Toutle valley with a layer of debris up to 550 feet thick which extended 14 miles downstream. The landslide and the subsequent eruption created a very destructive flood of water, ash, and mud down the Toutle, Cowlitz and finally the Columbia Rivers. After the flood subsided on 19 May, a question was raised about the mechanical stability of the debris flow and the possibility that the blockage of the Toutle River might suddenly breach, allowing further flooding. A preliminary investigation of this potential hazard was conducted by R. C. Wilson and T. L. Youd, during the period 19 May - 23 May (see reports). Three potential modes of failure were investigated: 1) overtopping by impounded waters and resultant erosional failure, 2) slope failure of blockage, possibly under seismic loading, and 3) failure by subsurface erosion (piping). From helicopter reconnaissance, it was found that approximately 200 feet of "freeboard" existed between the new level of Spirit Lake and the lowest point on the crest of the debris flow. Further, the level of Spirit Lake was falling slowly (2-3 ft/day), rather than rising, making overtopping unlikely before the 1981 Spring thaw. Topographic profiles made from point elevations from the helicopter altimeter and from "eyeball" surveys indicted that the overall slope of the debris flow was only some 4%. Large-scale slope failures by either gravitational or seismic loading is unlikely on such gentle slopes, even in unconsolidated materials. R. C. Wilson calculated a factor of safety against

static slope failure of at least 6.0 and a critical acceleration of at least 20% g, requiring a major earthquake ($M \geq 6.5$) for significant displacement (> 5 cm.). Failure by pipping was considered unlikely because of the relatively low hydraulic gradient (1400'/45,000' = 3%), and the observation that the material was well graded and consisted mainly of boulder-sized blocks in a fine-grained matrix. T. L. Youd calculated a factor-of-safety against piping failure of at least 3.6, also a large margin of safety. We concluded, therefore, that the Toutle River debris flow blockage was reasonably stable (under conditions existing on 23 May) and that large scale breaching and flooding was unlikely. However, we also recommended continuing monitoring of the situation, particularly during the next spring thaw.

2. A field trip was made to Hilo, Hawaii, in order to conduct a geologic reconnaissance (with J. Buchanan-Banks) and geotechnical investigations (with G. Wieczorek). Data from these investigations will be used in preparing a seismic slope stability map of the Hilo Quadrangle. The Hilo map will be prepared using the techniques previously developed for the seismic slope stability map of San Mateo, California (Wieczorek and Wilson, in review). J. Buchanan-Banks is preparing engineering geology and seismic hazards maps of the Hilo Quadrangle for another Earthquake Hazards project. The geotechnical investigations included hand-auger borings through the Quaternary ash at two sites west of Hilo: 1) the spillway of the Wailuku-Alenaio canal, and 2) the north flank of the Puu Hono cinder cone. These sites were selected to represent two distinct age-units of the Quaternary ash. The older unit, at site 1), is > 14,000 years old; the younger (site 2) is between 4000 and 9,000 years old, based on C^{14} dating of charcoals overlying and underlying lava flows (Buchanan-Banks, pers. comm.). Samples were collected from the borings for water content measurements and laboratory strength tests. In-situ shear strength measurements were also made with a vane shear to determine the sensitivity of the ash deposits (sensitivity = peak strength/residual strength). At site 1, water contents of up to 392% were measured in a layer with a sensitivity of 6.8. As expected, the older ash had higher water contents and sensitivities than the younger ash deposit, probably due to increased weathering. Only the older ash deposits are sensitive enough to pose a substantial risk of earthquake-induced flow landslides. A local example of such a failure, was the disastrous landslide at Wood Valley, Hawaii, from the April 2, 1868 earthquake, which flowed several kilometers and killed 31 people. Our reconnaissance included a trip to Wood Valley where we were successful in re-locating the 1868 landslide using historic descriptions. We sampled the flow deposit from an exposure in Makakupu Gulch. The Wood Valley flow landslide deposit was found to be geotechnically similar to the older Quaternary ash deposits in the Hilo area.

Reports

Youd, T. L., and Wilson, R. C., 1980, Stability of Toutle River blockage: Mt. St. Helens hazards investigations: U.S. Geological Survey Open-File Report 80-898, 14 p.

Experimental Mapping of Liquefaction Potential

9550-01629

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Investigations

1. Began revising distance versus magnitude criteria for occurrences of liquefaction to reflect attenuation of liquefaction effects with distance from the seismic energy source.

2. Continued compilation of liquefaction potential maps for San Mateo County, California, and San Juan, Puerto Rico, metropolitan areas.

3. Evaluated earthquake damage to buildings caused by permanent ground displacements generated either by secondary ground failure or by faulting.

4. With Raymond C. Wilson, investigated the stability of the debris blockage in the North Fork of the Toutle River, Washington, following the May 18, 1980, eruption of Mt. St. Helens.

Results

1. A review of foundation and building damage caused by permanent, earthquake-generated, ground displacements indicates that the threshold differential displacement for causing structural damage to buildings has ranged from obout 5 cm (2 in) to 30 cm (12 in) depending on the sense of displacement and the type of foundation. The amount of displacement across a narrow zone producing severe or irreparable damage to buildings has ranged from about 30 cm (12 in) to 60 cm (24 in) again depending on the sense of displacement and type of foundation.

2. An evaluation was made with Raymond C. Wilson of the static and seismic stability of a large (2.5 million m^3) landslide and volcanic ash deposit that was emplaced in the North Fork of the Toutle River north of Mount St. Helens during the eruption of that volcano on May 18, 1980. The evaluation was based on a field reconnaissance in which no indications of pending failure were observed, and an engineering analysis which indicated that the debris mass is stable against slope failure or piping. These results were used to remove a hazard warning to residents down

stream whose properties and lives might have been endangered had the debris blockage given way and released a flood of water from Spirit Lake, a lake impounded by the blockage.

Reports

Youd, T.L. 1980, Ground failure displacement and earthquake damage to buildings: Civil Engineering and Nuclear Power, Am. Soc. of Civil Engineers, v. 2, p. 7-6-1 to 7-6-26.

Youd, T.L., and Wilson, R.C., 1980, Stability of Toutle River Blockage: Mt. St. Helens Hazards Investigations: U.S. Geological Survey Open File Report 80-898, 14 p.

TITLE: Seismic Damage Assessment for High-Rise Buildings

CONTRACT NO.: 14-08-0001-19111

PRINCIPAL INVESTIGATOR: Roger E. Scholl

CONTRACTOR: URS/John A. Blume & Associates, Engineers
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URS/John A. Blume & Associates, Engineers, is conducting a three-year research program, now in its third year, to consider how procedures for predicting dollar losses for high-rise structures damaged by earthquakes can be improved. The problem is addressed by the identification, evaluation, and correlation of ground motion data and structural parameters. Ground motion data bases, analytical techniques, and known motion-damage relationships which have already been developed for high-rise buildings and for other classes of structures were identified early in the investigation; they are to be refined and extended so that reliable quantitative seismic risk evaluations can be made.

The research effort consists of three one-year phases composed of five major tasks, as follows:

Task I	Data Collection
Task II	Building categorization and calculation of theoretical motion-damage relationships
Task III	Estimation of engineering intensity from seismological intensity data
Task IV	Evaluation of empirical motion-damage relationships
Task V	Correlation of theoretical and empirical motion-damage relationships

Task I was mostly completed during the first year (1978-1979). Tasks II and III were initiated during the first year and are scheduled to be completed during the third year. Task IV was initiated during the current year and will be completed along with Task V in the third year.

Task I

The objective of the investigation was to collect information to establish a data base of world-wide seismic response and damage information for high-rise buildings. Only earthquakes that had affected high-rise structures were selected for study.

Five different forms were developed to systematically record pertinent data from the following regions: North America, Latin America, Europe and the Mediterranean; and the western Pacific, which includes Japan and New Zealand. Form 1 provides general earthquake data; Form 2, motion and damage data; Form 3, site information; Form 4, building categorization; and Form 5, detailed site and building information, such as soil-test boring logs or design calculations. Data that were collected for the continuation of the study include strong-ground-motion parameters, soil characteristics, estimated damage, design parameters, building categorization, and geographical location. For selected areas, seismological data, information on constuction codes and practices, and other general data was also collected. A computerized data base system HIRISE was established using the information collected on the forms. The data base facilitates access and retrieval of data in any order or arrangement desired, thus simplifying the correlation procedure.

Initially, the study focused on collecting data for specific buildings, primarily those damaged during each earthquake. Information on the characteristics of each building and on the damage it had sustained was stored in data base HIRISE. When the data base was established, space was left to accommodate additional information that is necessary for reconstruction of a realistic damage scenario -- such as statistical data on the undamaged buildings in each area -- and data on overall seismicity, distribution of soil types, density of high-rise buildings, and intensity distribution for each earthquakes, all needed to construct a profile for each area.

During the second year of study, the data base was reviewed and updated. Subsequent efforts focused on the completion of a profile for each urban area under investigation. For this task, soil maps, street maps, aerial photographs, and intensity maps of the various areas were used to establish grids dividing each city into sections with similar soil and motion intensity characteristics.

Task II

The task of building categorization has been completed. The following categories were established on the basis of structural systems: foundation systems, vertical-load-support systems, lateral-load resisting systems, and floor systems. Lateral-load-resisting systems are the most important for seismic resistance. Structural and architectural materials were also considered, since architectural materials, although not specifically designed to do so, contribute in varying degrees to lateral-load resistance and therefore are important for damage evaluation. Architectural materials' contribution to seismic resistance depends not only on the types of materials used, but also on the framing characteristics of building systems. Building configuration was included because irregularity in plan and elevation may result in torsional response or have other secondary effects. Torsional response may also occur because of ecentric location of either the building masses or the lateral-load-resisting elements. Each of these items was recorded on Form 4.

Using the damage information available from the data base HIRISE, detailed analyses of three buildings (Bank of California, and the two Holiday Inn buildings in Los Angeles), and previously published analysis of the same buildings, theoretically based motion-damage relationships are being developed. These relationships will permit prediction of damage levels for various types of buildings for given ground motion spectra.

Task III

Records of strong ground motion have not been obtained for many important earthquakes; only seismological intensity data are available for most earthquakes. Thus, there are numerous reports of damage for which no quantiative measure of ground motion exists. By developing general relationships between seismological intensity and engineering intensity, additional quantitative ground motion information can be developed for establishing motion-damage relationships for high-rise buildings. Engineering intensity provides a quantitative measure of ground shaking that can easily be related to structure response, and hence, to damage.

In Task III work is currently in progress to relate seismological intensity to engineering intensity. Results of studies based on previously published data from the 1971 San Fernando, California earthquake have been compiled and evaluated. An extensive data base of 281 3-channel strong motion records from earthquakes throughout the world has been formed. This data base is being used to develop relationships between seismological and engineering intensities. The effects of epicentral distance, earthquake magnitude and local geology on these relationships will also be studied.

Task IV

Damage matrices relating Engineering Intensity values and damage factors for a number of building categories will be developed using the damage information available from the data base HIRISE and the seismological-engineering intensity correlations. Initial building categories for which damage matrices will be developed will include various combinations of lateral load resisting structural systems and structural materials, such as moment resisting reinforced concrete frame, braced steel frames, reinforced concrete shear wall, etc. Each category will be subclassified according to building heights. Further subcategorization based on architectural components and occupancy will be considered if available data are sufficient to justify the development of damage matrices for these subcategories. Also, empirical relationships for predicting Damage Ratios, defined as the ratio of the number of buildings damaged to the total number of buildings within a given area, for given earthquakes will be developed using the data from the data base HIRISE. Procedures to utilize the developed damage matrices and the other empirical relationships in predicting building losses from future earthquakes will also be described.

Reports

URS/John A. Blume & Associates, Engineers, *Seismic Damage Assessment for High-Rise Buildings; Semiannual Technical Report: October 1978*, San Francisco, 1978.

_____, *Seismic Damage Assessment for High-Rise Buildings; Annual Technical Report: April 1979*, San Francisco, 1979.

_____, *Seismic Damage Assessment for High-Rise Buildings; Semiannual Technical Report: October 1979*, San Francisco, 1979.

_____, *Seismic Damage Assessment for High-Rise Buildings; Annual Technical Report: August 1980*, San Francisco, 1980.

Microprocessor-Based Seismic Processing

9970-02119

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Investigations

The earthquake picker algorithm developed earlier has been adapted for use in a multiprocessing environment in which each microprocessor monitors 8 seismic lines. Up to 32 processors (256 seismic lines) report to another microprocessor which acts as a supervisor for the pickers. This supervisor accepts reports of probable seismic events, cross-references them, and sorts out which reports should be grouped together as representing one earthquake. In performing this task, the supervisor makes use of station location information and calculates a preliminary location for the event. Output from the supervisor consists of station arrival information in standard phase card format for use by any of the usual USGS locator programs such as HYPOINVERSE or HYPO71. Output is via an RS-232 link which can go to a recording device such as a card punch or line printer; or it may go directly to a computer for on-line location.

Results

The first "production model" of the Multiprocessing Event Detector for the USGS Seismic Array (MEDUSA) is in operation with 120 stations. It is designed for 256 stations and is being expanded toward this figure as more circuit cards are checked out and installed.

Paul Reasenberg has compared the results of several months' operation of the 80-station prototype with corresponding "hand picks" from Calnet operations. His results indicate that the MEDUSA results are superior, both in sensitivity to small earthquakes and in timing of p-phase arrivals, to the hand picks from film.

Digital Signal Processing of Seismic Data

9930-02101

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Investigations

P waves from M_L 5 earthquakes on the San Andreas fault near Parkfield, Calif. are compared to investigate time and/or space variations in the stress field in the focal region of larger impending shocks.

Results

Wood-Anderson seismograms recorded at Mount Hamilton (MHC, 185 km, 327°), Santa Barbara (SBC, 180 km, 158°), and Tinemaha (TIN, 240 km, 56°) provide data for comparing P-wave spectra for two immediate (17 min) foreshocks, one early (55 hr) foreshock, two aftershocks, and two "isolated" Parkfield earthquakes. All are M_L 5.0 shocks with epicenters within 7 km of the common epicenter of the 1934 and 1966 Parkfield main shocks. The set of events is well suited for testing the hypothesis that foreshocks are high-stress drop sources. Calculated stress drops are controlled by source directivity at azimuths aligned with the fault break (at MHC and SBC). P-wave radiation from the three foreshocks is focused along one fault trace azimuth, suggesting that foreshock sources are characterized by pronounced unilateral rupture expansion. At TIN, broadside to the fault where directivity has minimum effect on calculated relative stress drop, the two immediate foreshocks are higher stress-drop sources. The early foreshock is a low-to-average stress drop source, indicating the possibility that stress concentration is a rapidly occurring phenomenon in rupture nucleation. Alternatively, the stress field is highly variable on the scale of 2-3 km in the focal region of an impending earthquake with a rupture length of 20-30 km.

Reports

Bakun, W. H., 1980, Seismic activity on the southern Calaveras fault in central California: Seismological Society of America Bulletin, v. 70, no. 4, p. 1181-1197.

Bakun, W. H., Bufe, C. G., and Stewart, R. M., 1980, Do P- and S-wave corner frequencies measure different source parameters?: U.S. Geological Survey Open-File Report 80-602, 11 p.

Bakun, W. H., and McEvilly, T. V., 198 , P-wave spectra for M_L 5 foreshocks, aftershocks, and isolated earthquakes near Parkfield, California: Seismological Society of America Bulletin (in press).

Seismic Source Mechanism Studies In The Anza-Coyote Canyon Seismic Gap

14-08-0001-18397

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During the contract period to date, design of the Anza seismic array hardware has been underway. A contract has been let for the prototype digital field stations and multiplexing relay station for delivery in the fall.

The design of the overall seismic telemetry system is illustrated in Figure 1. The system may be divided into the following components: 1) the remote seismic stations (up to 15), 2) the relay station receivers and interface equipment, 3) the microwave link including antenna systems, 4) the coaxial cable system, and 5) the demultiplexing and computer interface system.

The remote seismic station. A typical noise level at a quiet site over the band 1 to 10^2 Hz is 10^{-18} $m^2s^{-1}((m/sec)^2/Hz)$. Using a seismometer with a motor constant 10^2 v $m^{-1}s$ that has a flat response across the band, the equivalent input noise voltage at the amplifier input would be 10^{-14} v^2s or 1 μv rms over a 100 Hz bandwidth. This will set the input noise level of the front end amplifiers. There will be three seismic channels with such amplifiers whose gain is adjustable over 42 dB in four steps. Filters have a two pole low pass with a corner at 8 msec. The analog data are multiplexed and digitized with a 16 bit A/D which provides a dynamic range of 96 dB. A word defining one seismic channel (SC) is constructed with 16 bits of data, a parity bit and 2 bits of channel address; a total of 19 bits. Three of these are multiplexed along with some status bits and framing bits for a total of approximately 75 bits/scan. The combined bit stream is the input to a 158 mHz FM transmitter which feeds a multi-element Yagi antenna.

Relay station. The signals from the remote seismic stations will all be received on Toro Peak, an 8700 ft. peak on Santa Rosa Mountain, which has a clear path to the Anza area, PFO and to San Diego.

A bit stream from a local seismic station is received along with the VHF radio signals from the other remote stations. Each of these asynchronous serial bit streams is converted into parallel words one frame (or scan) wide and latched. Each station's scan (75 bits) is sampled in sequence and re-converted into a serial bit stream that now contains the whole array's scan multiplexed. Typically the bit rate for a six station array sampled every 4 ms will be 112.5 KBPS (kilo bits per second). Clearly the design should accommodate data rates at least twice this fast.

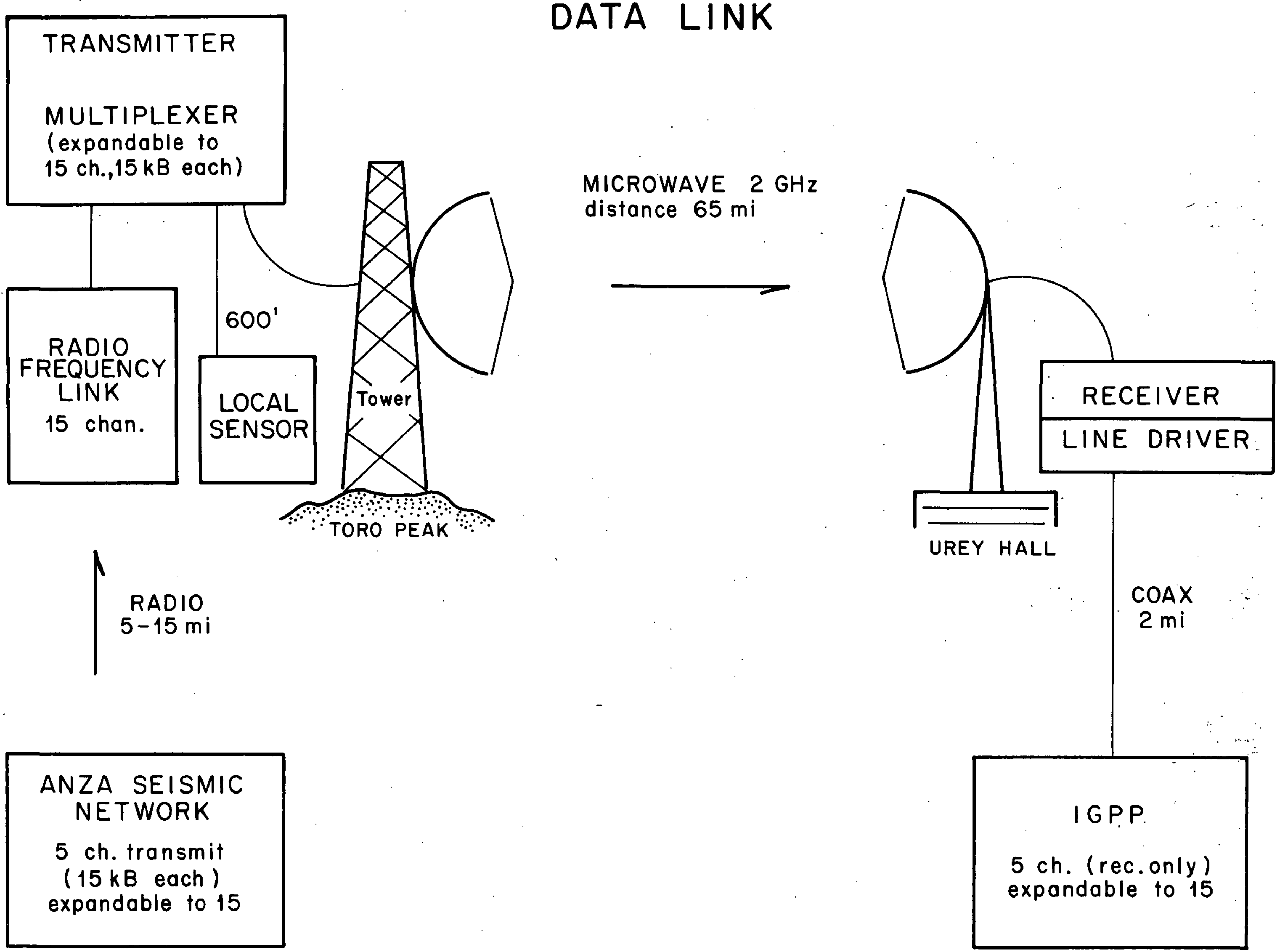
Microwave link, coaxial cable and demultiplexing. The bit stream, with parity and framing bits augmented, is encoded before being input to the microwave link. The purpose of this encoding is primarily to shift the spectrum of the bit stream to make it more amenable to transmitting on the FM microwave link. The form of this signal must be suitable for direct input into the microwave equipment, which will be either the Motorola Starpoint 2 GHz or the Farinon Model LR1-2 2 GHz equipment.

The encoded bit stream is input directly to a 2 GHz microwave frequency modulated transmitter. A 5 watt transmitter feeding an 8 ft. dish antenna will provide a 40 dB fade margin over the 104 km path to UCSD. This means that the data reliability over this link should be in excess of 99.9 percent. At UCSD, a second 8 ft. dish feeds the microwave receiver where, after demodulation and amplification, the signal is fed onto a coaxial cable link to the labs at IGPP.

At IGPP, the signal from the microwave is amplified and decoded to recover the original bit stream from the relay station. This serial bit stream is then synchronized by framing bits and converted into a sequential pattern of 16 bit data words and their associated channel addresses.

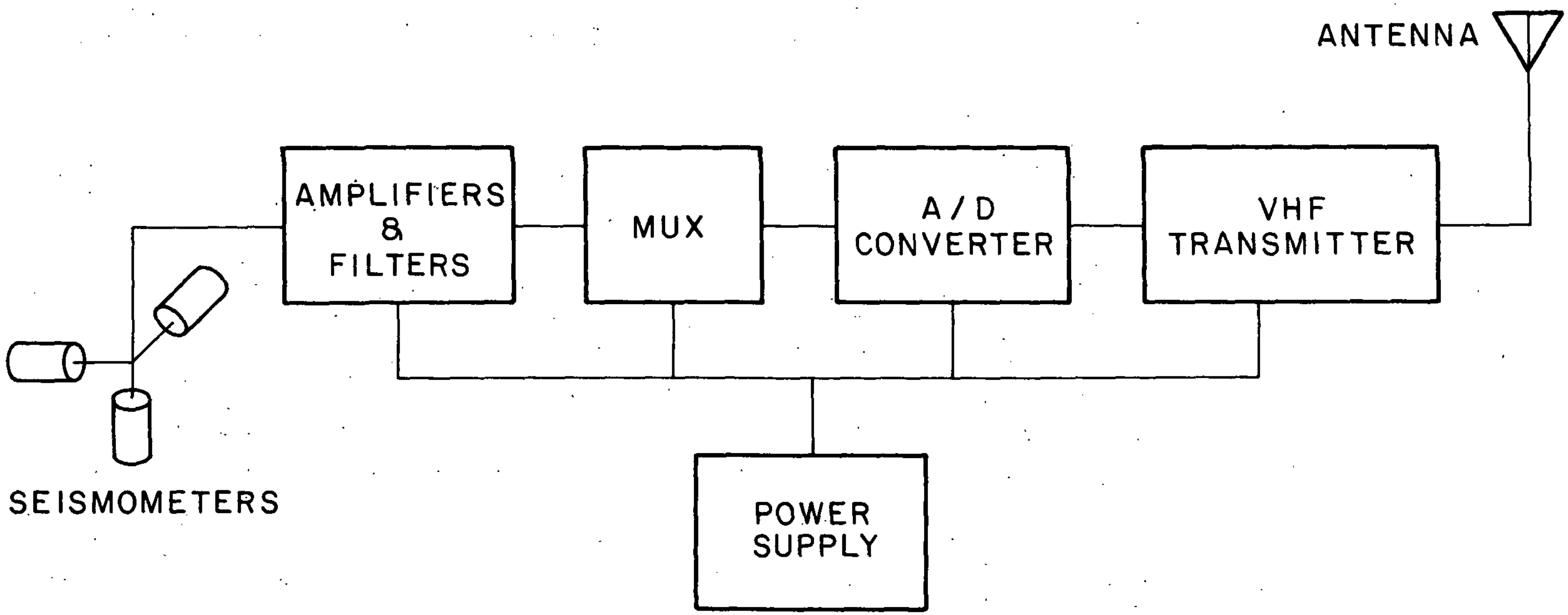
Between the synchronizer and serial to parallel converter and the main data logging computer (PDP 11/34), a microcomputer will act as a data buffer. Its job will be to handle interrupts from the synchronizer, transferring data from it into memory upon demand and associating a time with each sample. The micro will demultiplex the data, building buffer loads of each channel's data for subsequent DMA transfer to the PDP 11/34.

ANZA DIGITAL SEISMIC DATA LINK



Pl.a

REMOTE STATION



Pl.a

Seismic Studies for Earthquake Prediction

9930-01727

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Investigations

The objectives of this project are to develop, by seismological techniques, an understanding of earthquake mechanics and the physical properties of fault zones leading to the prediction of potentially damaging earthquakes. Zones of preparation for future earthquakes will be identified, where possible. Such long range predictions are useful in designing experiments to detect precursors. Other project goals are foreshock recognition and an understanding of why some earthquakes have foreshocks and/or aftershocks and others do not.

1. Study of the San Pablo Bay-Suisin Bay seismicity gap was initiated. Thirty-seven of the largest earthquakes in 1970-1978 were selected from the Calnet catalog for determination of focal mechanisms.

2. Source parameters of aftershocks and regional P- and S-wave attenuation were studied using data from a digital event recorder deployed in the epicentral area of the May-July 1978 earthquake sequence in the Langhada-Volvi Lakes area, Greece.

3. Analysis of the Willits, California aftershock study continued, with major effort devoted to refining the earthquake locations.

Results

1. On the south side of the San Pablo Bay-Suisin Bay seismicity gap three concentrations of earthquakes occur. Activity occurs on the Hayward fault zone and on a fault between the Calaveras fault to the south and the Green Valley fault to the north. Four of the selected quakes occurred on January 8, 1977 between the Briones Reservoir and Orinda, initiating a short-lived earthquake swarm. A more diffuse occurrence of earthquakes starts about 15 km north of Mt. Diablo and extends across the Sacramento River to the north. Most of the focal mechanisms show NNW trending, right-lateral, strike-slip motion, but a few events show normal fault motion.

2. Magnitudes of 17 digitally-recorded aftershocks that occurred in June and July 1978 in the Langahda-Volvi Lakes area, Greece fell within a narrow range of 2-3. Corner frequencies also fell within a narrow

range. Stress drops are low and apparently independent of magnitude Measurements of Q_p and Q_s fell in an average range. However, Q_s was generally found to be almost twice Q_p, suggesting that the aftershock area is not extremely hot and is dominated by partial water saturation.

3. The frequency-magnitude distribution of the Willits, California aftershocks shows a quite normal b-value of about 1.0 above magnitude 1.4.

Reports

Bufe, C. G., and Toppozada, T. R., 1981, Recent California earthquakes and persistent seismic quiescence: submitted to Science.

Maley, C. G , Bufe, C. G., Yerkes, R. F., Carver D L., and Henrisey, R., 1980, The May-July 1978 earthquake sequence near Thessaloniki, Greece: U.S. Geological Survey Open File Report 80 937, 36 p.

Remote Monitoring of Source Parameters for Seismic Precursors

9920-02383

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Investigations

1. Evaluation of digitally recorded broad-band teleseismic data for the study of the earthquake mechanism. The high-dynamic range, digitally recording instruments of the GDSN provide a broad-band capability that has not yet been utilized in source studies. We developed techniques that exploited the frequency band between several Hz to tens of seconds to extract source parameters and to describe the rupture process of earthquakes.

2. Monitoring changes in source parameters before large earthquakes using teleseismic data. The rupture characteristics of 4 large (m_b > 5.5) shocks that encircled the eventual rupture zone of the Miyagi-Oki earthquake of 12 June 1978 over a period of two years were studied using the digital data from the GDSN.

Results

1. Evaluation of digitally recorded broad-band teleseismic data for the study of the earthquake mechanism. The extended band-width of information, especially in the 'intermediate' frequency band, is particularly valuable for studies of frequency dependent attenuation and permits quantifying directivity effects associated with seismic sources. We were able to determine the complete rupture histories for two deep earthquakes including constraints on the dynamic and static stress drops, the rupture velocity and the rupture complexity.

2. Monitoring changes in source parameters before large earthquakes using teleseismic data. Having shown the appropriateness of the broad-band digital data for detailed teleseismic source studies, the method of analysis was extended to study the rupture characteristics of several large shallow earthquakes that preceded and encircled the seismic gap which was later ruptured by the Miyagi-Oki earthquake. Preliminary indications are that dynamic stress drop, rupture duration, complexity and direction of rupture propagation changed systematically with time.

Reports

Choy, G. L. and J. Boatwright (1980). The rupture characteristics of two deep earthquakes inferred from broad-band GDSN data, Bull. Seism. Soc. Am. (submitted).

Teleseismic Search for Earthquake Precursors

9920-02142

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Investigations

C. Mendoza and J. W. Dewey have studied prior seismicity and aftershocks of the Colombian earthquake of December 12, 1979 ($M_s \cong 8$) with the purpose of testing hypotheses on patterns of teleseismic seismicity that may be used to help predict large subduction zone earthquakes. Prior earthquakes and aftershocks of the Colombian earthquake occurring in the period from 1964 through December, 1979, with magnitude (m_b) 4.8 and above, were located by the method of joint hypocenter determination. The Colombian earthquake is of interest because it filled a previously identified seismic gap (Kelleher, Jour. Geophys. Res. 1972). The gap filled by the 1979 earthquake was that portion of the focal region of the great earthquake of January 31, 1906, that had not ruptured again in lesser, but still great earthquakes on May 14, 1942, and January 19, 1958.

Results

Most aftershocks occurring from December 12, 1979 through December 31, 1979 fall into two linear intersecting zones. A zone of 250 km length, width about 25 km, strikes N45°E, parallel to the Colombian Trench and about 50 km inland from the trench axis. The second zone, also about 25 km in width, strikes N20°W and extends 130 km inland from the trench axis. Focal depths of the shocks are consistent with their occurring on or near the interface between the Nazca plate and the overriding South American plate. The main shock hypocenter is more than 30 kilometers from either of the principal aftershock zones; only one of the relocated aftershocks occurred near the main shock hypocenter. Seismicity prior to the earthquake may be viewed as only partly consistent with a pattern recognized by Kelleher and Savino (Jour. Geophys. Res., 1975) before other great thrust fault earthquakes: prior seismicity was concentrated near several edges of the 1979 fault rupture as that rupture was to be defined by the 1979 aftershock sequence, but the region within 50 kilometers of the main shock hypocenter experienced no recorded prior seismicity of $m_b \geq 4.8$ in the years 1964-1979. It is noteworthy that the 1979 main shock epicenter lay in a zone of intense aftershock activity of the earthquake of January 19, 1958. It is possible that this part of the 1958 aftershock sequence was, in effect, the "prior seismicity" near the 1979 mainshock hypocenter that we have failed to find in 1964-1979.

The 1958 aftershock activity that occurred near the 1979 hypocenter may have marked the beginning of the failure process that was to culminate in the 1979 earthquake.

Central California Network Processing

9930-01160

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Investigations

Signals from 300 stations of the multipurpose central California Seismic Network are telemetered continuously to the central laboratory facility in Menlo Park where they are recorded, reduced, and analyzed to determine the origin times, magnitudes, and hypocenters of the earthquakes that occur in or near the network. Data on these events are presented in the form of lists, computer tape and mass data files, maps, and cross sections to summarize the seismic history of the region and to provide the basic data for further research in seismicity, earthquake hazards, and earthquake mechanics and prediction. A magnetic tape library of "dubbed" unprocessed records of the network for significant local earthquakes and teleseism is prepared to facilitate further detailed studies of crust and upper mantle structure and physical properties, and of the mechanics of earthquake sources.

Results

Summary catalogs of earthquakes located by the network from 1969 through 1976 have been published. Preliminary results for the years 1977 through Sept. 1980 are accessible in various forms, and work on completing and publishing the summary catalogs for these years has high priority.

Routine analysis of the network data has been transferred from the MULTICS system to the PDP 11/70 computer under the UNIX system. Processing procedures have been revised and described in detail to insure a more uniform treatment of the data and to reduce the amount of hand work required.

Reports

Eaton, Jerry, Lester, Rick, and Cockerham, Rob, 1980, Cal Net procedures for processing phase data and determining hypocenters of local earthquakes with UNIX. U.S Geological Survey Open File Report 80-131 p.

Eaton, J. P., 1980, Response arrays and sensitivity coefficients for standard configurations of the USGS short-period telemetered seismic system: U.S. Geological Survey Open-File Report 80-316, 33 p.

California Seismic Network Development

9970-90007

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Investigations

Current microearthquake networks in northern and southern California were developed selectively along particularly active sections of the San Andreas fault or in regions where outside funding dictated. The result is a heterogeneous patchwork of stations that does not provide uniform coverage of the entire San Andreas fault system. The current effort is to augment the California seismic network to permit uniform network coverage at moderate station density of the entire region from Mexico to Cape Mendocino and from the Pacific Ocean to the western edge of the Basin and Range Province. The goal is to attain a network suitable for uniform automatic processing with a magnitude threshold of about M 1.5 throughout the San Andreas fault system.

A comprehensive record of earthquakes throughout the San Andreas fault system and an accessible library of seismograms they produce constitute the most essential observational bases for earthquake prediction and research into the processes that generate earthquakes in California. Given the limited time and possibly limited number of "significant" earthquakes prior to the next great earthquake along the San Andreas fault system, it is imperative that the network be augmented to provide a comprehensive record of earthquakes throughout the region as rapidly as possible.

Results

The original augmentation plan called for 100 additional stations in northern and central California and 80 additional stations in southern California. Equipment for a total of 150 sites has been purchased and/or fabricated. At the present time (end of second project year), sites for about 75 stations in northern and central California and 75 stations in southern California have been obtained, and about 50 new stations are operating or are ready for operation (awaiting phone service) in each of the two regions. Work left for the third year consists of two parts: 1) complete installation of 25 permitted stations in each of the two regions; and 2) continue to press the phone company to provide promised phone lines to put the new stations into service.

Seismic Studies of Fault Mechanics

9930-02103

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Investigations

1. The seismicity of the Livermore Valley, California, region has been the focus of much of our research effort during this time period. Following the M_L 5.8 Livermore Valley earthquake of January 24, 1980, we have systematically reanalyzed the available microearthquake data to establish the regional tectonic framework and investigate the relationship between the microearthquake background and the active faults.

2. Responsibility for completion of open-file reports on the seismicity of central California for the year 1977 was transfered to this project during this time period. All existing data collected by the Calnet group covering this time period is being reanalyzed and brought to accepted levels of completeness and accuracy.

3. The earthquake history of the San Francisco Bay region has been reexamined in light of two recent strong earthquakes and a new catalog of 19th century seismicity compiled by T. R. Toppozada and co-workers.

4. The crustal velocity structure of the Parkfield, California region has been examined in detail using both explosion and earthquake travel-time data.

Results

1. Seismicity of the Livermore Valley, California, region for the 11-year period from 1969 through 1979 reveals a complex pattern of seismic strain energy release that is locally concentrated along geologically youthful faults but is also dispersed in regions that have no known active faults. A systematic evaluation of the relationship between the seismicity for this period and mapped faults leads to the classification of the Calaveras-Sunol, Concord, Greenville, Hayward and Mission faults as active faults. The Las Positas and Pleasanton faults are identified as probably active faults. The Livermore fault and the segment of the Williams fault located to the south of the Las Positas and Verona faults are classified as possibly active. Earthquake focal mechanism solutions for events near Vallecitos Valley demonstrate that this region is a zone of active thrust faulting. Available seismological data indicate that some of these thrust faulting events are in probable association with the Verona fault. Surprisingly few of the relocated epicenters could be associated with the Greenville fault prior to the M 5.8 earthquake that occurred on it on January 24, 1980. The segment of the Calaveras-Sunol fault lying north of its junction with the

Mission fault and south of Danville is similarly poorly defined by the seismicity. This segment of the Calaveras-Sunol fault is believed to have produced a strong earthquake in 1861.

2. Reanalysis of microearthquake data from the central California network for 1977 is now underway. The earthquake catalog for the first half of the year is now virtually complete and will be put into the open-file in the near future. Work on the second half of the year is progressing slowly but steadily.

3. The hypothesis that plate margin seismicity follows a cyclic pattern that is controlled by great earthquakes on the plate boundary, as advanced by the work of Fedotov and Mogi, is compatible with the historic record of seismicity in central and northern California. The three main stages of the cycle, quiescence following the earthquake followed by an increased level of activity that leads to the next major event and its fore- and aftershocks, can be identified along the portion of the plate boundary that broke in the 1906 earthquake. The timing of the next great earthquake cannot be forecast with precision at present, although it appears to be decades away. The recent occurrence of the two strongest earthquakes in the region since at least 1911, coupled with the reemergence of $M \geq 5$ earthquakes since 1955, after an extended period of quiescence following 1906, lead us to conclude that the region is entering the active stage of the cycle in which events as large as M 6, to perhaps M 7, can be expected. The conditional probability of such events appears to be higher now than at any time since 1906, and it may be as great as 0.1/a.

4. A new analysis of explosion and earthquake traveltime data from the Parkfield region has succeeded in placing the earthquake epicenters on the San Andreas fault and in unifying all available traveltime data in a single simple crustal model. There appears to be little difference in the gross velocity structure of the crust between opposite sides of the fault between Parkfield and Cholame, California. However, north of Parkfield there is a major change in velocity structure that clearly correlates with the presence of Franciscan basement in that region. Two-dimensional models of the velocity structure in the Parkfield-Cholame region do not strongly support the existence of a low-velocity fault zone that is seen elsewhere along the San Andreas fault.

Reports

Cockerham, R. S., Lester, F. W., and Ellsworth, W. L., 1980, A preliminary report on the Livermore Valley earthquake sequence January 24-February 26, 1980: U.S. Geological Survey Open-File Report 80-714, 54 p.

Ellsworth, W. L., and Marks, S. M., 1980, Seismicity of the Livermore Valley, California region 1969-1979: U.S. Geological Survey Open-File Report 80-515, 42 p.

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Reasenberg, P., Ellsworth, W., and Walter, A., 1980, Teleseismic evidence for a low-velocity body under the Coso geothermal area: Journal of Geophysical Research, v. 85, p. 2471-2483.

Thurber, C. H., and Ellsworth, W. L., 1980, Rapid solution of ray tracing problems in heterogeneous media: Seismological Society of America Bulletin, v. 70, p. 1137-1148.

Garm Source Mechanism Studies

9930-02100

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Investigations

U.S. participation in this joint US-USSR program was curtailed due to lack of travel funds.

Several projects undertaken to improve network operations included ordering 20 solar panels for remote station operations, investigation of numerous designs for a low-power DC-to-DC converter to power J600 and J400 series seismic amplifiers from solar panels, and modification of the Sangamo Sabre III analog tape recorder to prevent catastrophic tape skew.

A single supply shipment to Garm, USSR included six improved data discriminators for greater seismic channel isolation.

Results

An earthquake location program for use with a hand-held calculator was developed for use in situations where other programs are shut down by power outages. The HP41C program uses Geiger's method on p-phase arrivals from 4 to 10 stations over a half space.

Reports

Pelton, J. R., and Fischer, F. G., 1980, An earthquake catalog and velocity model for the USGS Peter the First Range seismic array, Tadjikistan, USSR: U.S. Geological Survey Open-File Report 80-840, 28 p.

Central California Network Operations

9970-01891

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Investigations

Maintenance and recording of 344 seismic, 34 tiltmeter, 16 magnetometer, 7 strainmeter, and 33 creepmeter sites located in northern and central California, Oregon, and Yellowstone National Park. The area covered is approximately 101,000 square miles.

Results

1. The Stanwick Corporation under Contract 14 08-0001-1945 is responsible for the maintenance of seismic, tiltmeter, magnetometer, creepmeter, and strainmeter field sites; inside maintenance of low frequency digital equipment; installation of new seismic stations, and final testing of J402 VCO/amps.

2. The Stanwick team consisting of ten members has far exceeded maintenance goals set by the reference contract (95% operational). Maintenance delays greater than 48 hours were attributable to weather, transportation, or access problems.

3. Field tests, using solar energy equipment to power batteries, are under way at eight separate sites. The equipment being tested is a Solarex Corporation 435H panel and a Gould AP-80 lead calcium battery. Anticipated longevity of the solar-powered operation could provide an inpact on cost effectiveness.

4. New seismic stations
   Installation of
   1 single component station in Livermore, Calif.
   1 single component, 1 multicomponent station at The Geysers
   1 single component at Parkfield, Calif.
   18 single components in Oregon
   2 single components in Walker Pass area.

5. New Phone Lines
   1 transmit line to Oregon

6. All on-line discriminators have been tested, repaired and calibrated for proper bandpass, deviation, and noise parameters.

7. Installed a visual seismic display in Ridgefield, Wash. for U.S. Forest Service to monitor Mt. St. Helens volcano.

Central American Seismic Studies

9930-01163

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Investigations

1. Monitoring of a previously reported long-term earthquake swarm in the Cerro Cruz Quemaoa area of southeastern Guatemala continued through May 1980. This swarm has provided more than 42,000 earthquakes larger than magnitude 0.7 since August 1979. The largest event was a magnitude 5.0 earthquake on October 9, 1979 that destroyed 140 adobe dwellings and damaged several hundred more. The earthquake swarm is located in a section of the Central American volcanic chain that has been inactive since the late Tertiary. Such earthquake swarms are typical of seismicity near active volcanoes, but a history of similar swarms every 20 to 50 years strongly suggests that a volcanic eruption is unlikely.

2. Focal mechanisms of shallow earthquakes along the volcanic chain in Nicaragua were determined to better understand the shallow tectonic processes in the vicinity of active volcanoes.

3. The close monitoring of seismic activity in the vicinity of a seismic quiescent zone on the shallow underthrust area of the subduction zone near the Pacific coast of Nicaragua is continuing.

Results

1. New results from a composite focal mechanism indicate the earthquake swarm in southeastern Guatemala originates along a normal fault that strikes N 10° W. Additional seismic activity trends N 45° W from the northern end of this fault and may join the Jalpatagua fault, a major fault striking N 60° W parallel to the volcanic chain.

2. Composite focal mechanisms of several of the larger earthquakes along the volcanic chain of Nicaragua indicate strike-slip faulting with either N 25° E left-lateral motion, consistent with fault movement during the 1972 Managua, Nicaragua earthquake, or N 65° W right-lateral motion, parallel to the strike of the volcanic line. The north-south maximum horizontal-stress axis indicated by these data is consistent with Quaternary geologic features but inconsistent with a maximum compressive-stress axis of N 30° E expected from the direction of plate convergence.

Reports

White, R. A., and Harlow, D. H., 1980, Preliminary catalog of seismicity from south-central Guatemala - July 1 through December 31, 1976: U.S. Geological Survey Open-File Report 80-83, 37 p.

Harlow, D. H., and White, R. A., 1980, Preliminary catalog of seismicity prior to the Guatemala earthquake of February 4, 1976 from the area between Guatemala City and Lake Atitlan - March 1975-February 4, 1976: U.S. Geological Survey Open-File Report 80-60, 127 p.

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White, R. A., Harlow, D. H., and Sanchez, E., 1980, A 9-month-long earthquake swarm in southeastern Guatemala (abs.): EOS, American Geophysical Union Transactions, in press.

Southern California Cooperative Seismic Network

9930-01174

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Investigation

1. Routine processing using stations of the southern California cooperative seismic network were continued for the period April, 1980 through September, 1980. Routine processing includes timing of phases using the interactive CEDAR analysis system, event location, preliminary and final catalog production. A new interractive timing and analysis system was implemented on a PDP-11/70 providing a five-fold increase in throughput. Seismicity during the past period was exceptionally high including 3 events exceeding magnitude 6.0 near Mammoth Lakes (25 May, 6.5 and 6.0; 27 May, 6.3) followed by an event of magnitude 6.1 near Victoria Estacion in Northern Baja, Mexico on 9 June. For a detailed discussion of the results of this investigation refer to C.R. Allen, Southern California seismic arrays, 14-08-0001-16719.

2. In Situ timing of blasts at Eagle Mountain mine was continued.

3. We responded to the 25 May, 1980 earthquake near Mammoth Lakes by deploying three field teams to the epicentral area within the first 24 hours. Two teams deployed a network of high-gain, smoked paper recorders, continuing operation for several days until more permanent instrumentation (5-day recorders) could be installed. The third team, in close cooperation with personnel from the U.S.G.S., U.S.C., and Caltech, deployed a network of 11 strong-motion accelerometers (7 Kinemetrics SMA1's and 4 Sprengnether DR100's). Six of these provided important records for the M_L = 6.3 event on 27 May, 1980. The closest instrument was located at Convict Lake and registered a peak horizontal acceleration of .75 g. More than 150 accelerograms were recovered from the sequence over several weeks of operation.

4. We continued development of an informal system to recognize dramatic hydrologic phenomena in southern California. We have requested 500 water companies in southern California to notify us in the event of any ground water conditions which they feel are unusual. This program is being expanded to include the oil and gas industry.

5. Computer codes have been developed which allow us to deterministically compute both nearfield and teleseismic motions which result from a specified dislocation on a finite fault in a layered space. These techniques are presently being used to study motions produced by the 9 Feb. 1971 San Fernando earthquake. The goal is to discover models of faulting time history which are consistent with as many different types of data as possible.

6. A refraction study of the western Mojave Desert was carried out consisting of two profiles (record sections) 25 km long and at right angles to each other as well as a partially reversed profile 25 km long. Nine shots were fired at 7 shotpoints with an average yield of 2000 lbs. with 281 occupied recording locations.

Results

1. Pn residual contour maps for 8 events (e.g. figure 1) have been studied to determine structural anomalies within southern California. Interpretations of these maps suggest the following results: 1) a regional Moho velocity of about 7.8 km/sec; 2) a 3 to 8 km crustal "root" below the area of the San Bernardino Mountains; 3) the existence of a topographic ridge on the Moho in the eastern Mohave Desert trending north-northeast to north-northwest; 4) crustal thinning in the Imperial Valley region with a fairly abrupt shallowing of the mantle beneath the southern half of the Salton Sea; 5) relatively fast crustal velocities in the western Santa Monica Mountains and the Perris Plains area; and 6) a relatively slow crustal velocity near the Temblor Ranges.

2. The on-line system being developed jointly by the U.S.G.S. and the University of Washington on the PDP 11/34 computer systems has been expanded to accomodate a network of 128 stations (single component) with digitization rates exceeding 80 hz. This appears to represent a physical limit for the present hardware. Plans for FY81 call for the increase in station load to a total of 256 channels using new A/D equipment.

3. An interactive routine analysis system similar to that in use in southern California since 1976 (CEDAR) was successfully implemented at the University of Washington for the rapid analysis of data from St. Helen's. This system is running on a PDP-11/70 computer under the UNIX operating system.

4. We have found evidence that the 9 February 1971 San Fernando earthquake may have been a double event on two separate, subparallel thrust faults. We postulate that the first event occurred at depth

on a steeply-dipping fault which is often called the Veteran's fault. The top and bottom of the postulated rupture are 5 and 15 km, respectively. We postulate that a second event occurred about 4 seconds later on another steeply-dipping thrust fault known as the San Fernando fault. It appears that rupture on this second fault began at depth of 6 km and ruptured upwards to the free surface. This model explains both strong-motion records and teleseismic P and S waveforms better than previous models consisting of either a single fault plane or a plane with a dip which shallows with depth.

5. Results from our seismic refraction survey of the Imperial Valley region of California in 1979 indicate the following. (1) Unmetamorphosed sediment occupies a trough centered on the seismogenic belt in the Imperial Valley. (2) Apparently two types of basement are present: crystalline basement under West Mesa and the mountains on either side of the Salton Trough (P-wave velocity, 5.9-6.0 km/s), and metasedimentary basement under the Imperial Valley. The total thickness of sedimentary and metasedimentary material in the Imperial Valley is 10 to 16 km. (3) A subbasement (P-wave velocity, 7.2, km/s) is present under the metasedimentary rocks in the Imperial Valley. This layer, probably composed of diabase and gabbro, compensates gravitationally for the relatively light sedimentary section above.

<u>Reports</u>

Lamanuzzi, V.D., 1980, Relative Pn travel-time residuals for stations in southern California: U.S.C. M.S. thesis, 117p.

Johnson, C.E., D.P. Hill, 1980, Seismicity of the Imperial Valley, California: part of U.S.G.S. Profession Paper (in press).

Heaton, T.H., 1980, The 1971 San Fernando earthquake; a double event?: (abs) EOS, (in press).

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Corbett, E.J. and C.E. Johnson, 1980, Evidence for mid-crustal horizontal shearing in the western Transverse Ranges, California: (abs) <u>EOS</u> (in press).

Fuis, G.S., Displacement on the Superstition Hills fault triggered by the Imperial Valley earthquake <u>n</u> the Imperial Valley earthquake of October 15, 1979: U.S.G.S. Professional Paper (in press).

Fuis, G.S., Mooney, W.D., Healey, J.H., McMechan, G.A., Lutter. W.J., Crustal structure of the Imperial Valley region <u>n</u> the Imperial Valley earthquake of October 15, 1979: U.S.G.S. Professional Paper (in press).

Fuis, G.S. Mooney, W.D., Healy, J.H., McMechan, G.A. Lutter, W.J., A Seismic refraction survey of the Imperial Valley region, California: (in review; to be submitted to JGR).

Fuis, G.S., Mooney, W.D., Healy, J.H., McMechan, G.A., Lutter, W.J., Seismic refraction studies of the Imperial Valley region - profile models, a travel-time contour map, and a gravity model: U.S.G.S. Open-file report (in review)

Fuis, G.S. Johnson, C.E., Richter, J.J., Preliminary catalogue of earthquakes in northern Imperial Valley, California - April 1978 through June 1978: U.S.G.S. Open-file report 80-1167, 19 pages.

Fuis, G.S. Mooney, W.D., Lutter, W.J., McMechan, G.A. Healy J.H., 1980, Modeling detailed seismic refraction profiles, Imperial Valley, California: (abs) Earthquake Notes, SSA Vol. 50, Page 53.

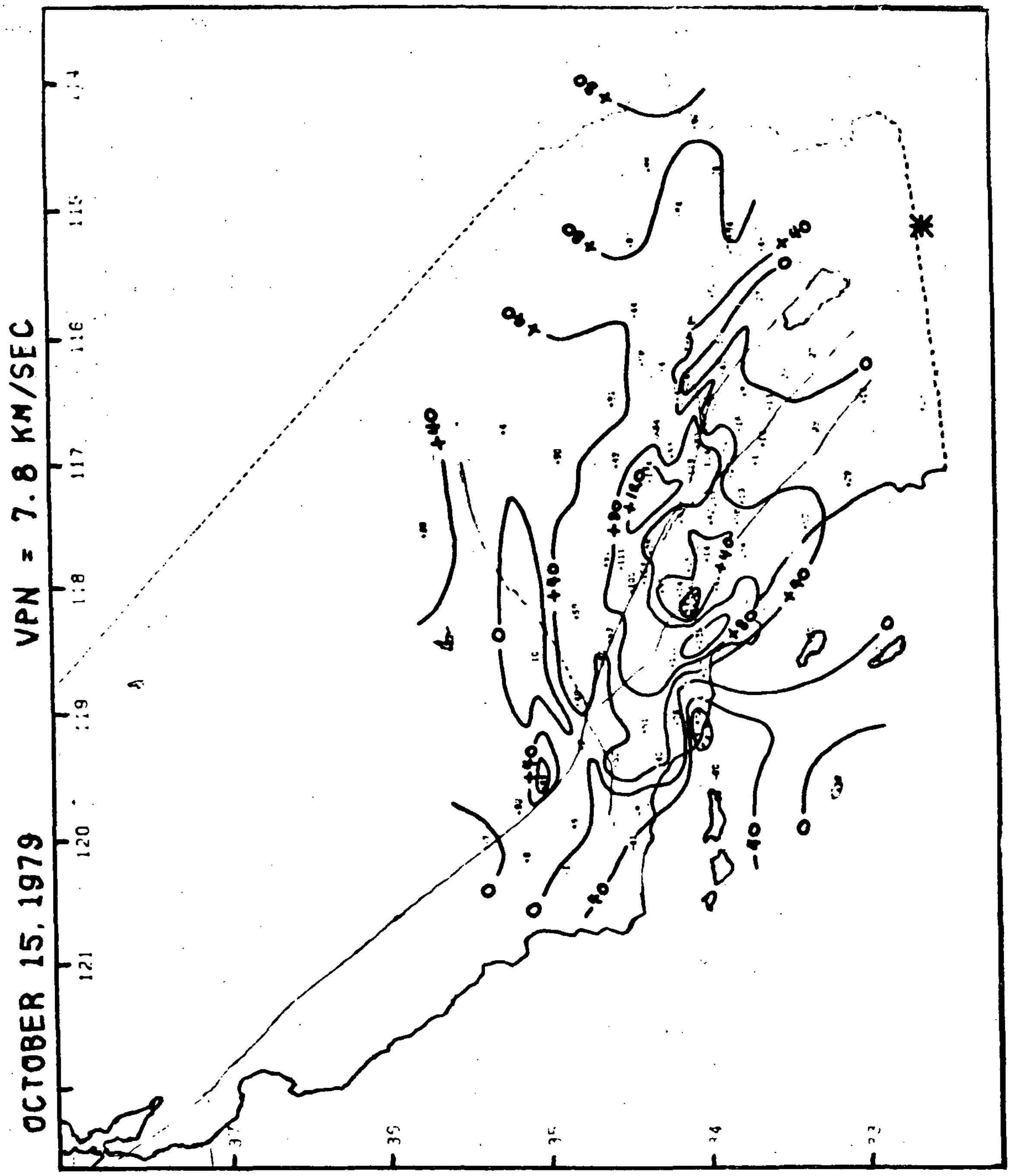

Figure 1. Contour plot on Pn residuals (positive is late) for the Imperial Valley earthquake (M_L = 6.6) of 15 October, 1979. Contour interval is 0.40 seconds. The residuals were determined with a theoretical mantle velocity of 7.8 km/sec. The epicenter is shown by an asterisk.

Seismicity Studies for Earthquake Prediction in Southern California Using a Mobile Seismographic Array

14-08-0001-18322

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1. P-wave velocity monitoring

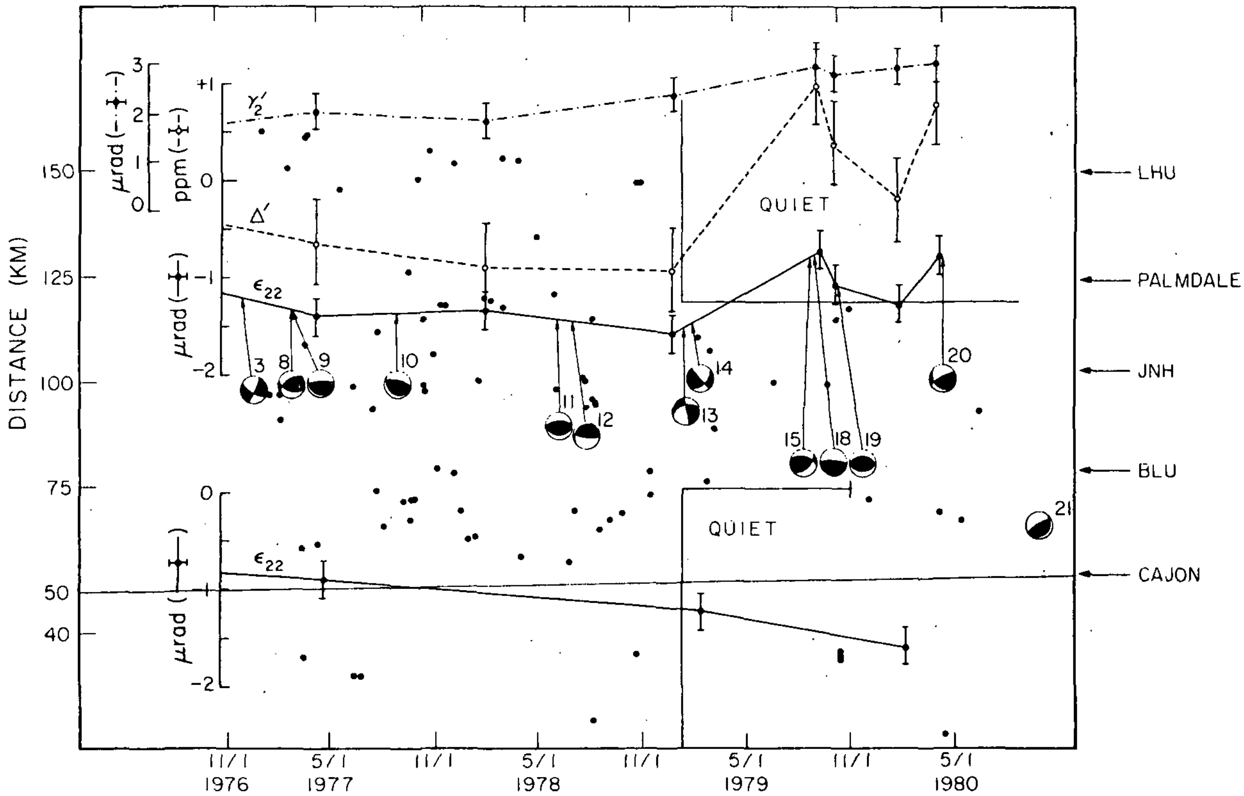
Since 1973, Caltech has been monitoring large quarry blasts which occur in southern California. During the period from 1 October 1979 to 30 September 1980, monitoring of quarry blasts at Mojave, Gorman, Victorville and Corona was continued.

2. Micro-earthquake surveys for southern California

A 100 km section of the southern San Andreas fault between the Salton Sea and Desert Hot Springs was the focus of an intensive micro-earthquake field survey, using a mobile array of eight seismographic trailers, between February and August 1979. This southernmost portion of the San Andreas has not undergone any significant rupture in historic time as documented by instrumental recordings and historic accounts. The results of our intensive micro-earthquake study in the Coachella Valley support the consideration of this region as a seismically unique portion of the San Andreas fault, characterized by low rates of earthquake occurrence at the present time, and a tendency to reflect the nature of large earthquake activity in bordoring areas. Activity along the San Andreas fault through the Coachella Valley is very low compared to other regions for which micro-earthquake activity levels are known. Of particular interest is the fact that even with mobile seismographic trailer stations augmenting the permanent network coverage, we do not see activity along the San Andreas. Earthquake activity in the Coachella Valley exhibits very marked patterns of occurrence. Events tend to be aligned along east-west trending features to the north and east of the San Andreas; essentially no activity is observed to the southwest of the San Andreas; and earthquakes commonly occur in "clusters" of closely related events which occur as very local features along the east-west lineations.

Micro-earthquake activity along the "Big-Bend" section of the San Andreas fault near Palmdale has been examined since the first quarter of 1980. Results of a study of focal mechanisms from the Juniper Hills, California region suggest a relationship to temporal changes in N-S strain observed at the U.S.G.S. Trilateration Network at Palmdale, California for the time periods of 1977-1980. The temporal changes of fault mechanism from strike-slip to thrust which has been observed for the swarm sequence at Juniper Hills (and back to strike slip for this sequence) and the August-October 1979 mainshock-aftershock sequence, which occurred about 25 km to the ESE, may also be related to these strain changes (see Figure 1)

The high quality and large quantity of data contained in the southern California catalogue (Hileman et al., 1973 and subsequent editions) demonstrate that in at least one seismically active area for which an extensive 50 year data set is available, 7 out of 11 aftershock sequences or 64 percent of those for earthquakes of $M_L > 6.0$ contained large, late occurring events of $M_L > 5.0$. Therefore we consider that in southern California, the occurrence of large, late aftershocks are significant throughout the region. It follows that such shocks can be identified as particularly likely in these local areas which have previously exhibited such patterns, e.g., the Imperial Valley, the southern San Jacinto fault, and northern Mexico. For this reason, several areas in southern California merit special consideration at this time with regard to expected aftershocks including the aftershock regions of the 15 October 1979 ($M_L = 6.6$) earthquake. Seismic activity immediately following the mainshock was relatively high at the ends of the aftershock zone, indicative of stress redistribution during the main event (Johnson and Hutton, 1980). Further evidence of the effect of the mainshock at large distance, was Kerry Sieh's (1980)identification of "sympathetic slip" along the portion of the San Andreas which we had been studying. This slip was found just north of the northern end of 15 October 1979 aftershock activity and occurred in the same region that had seen slip following the 1968 Borrego Mountain earthquake. This indication of stress redistribution caused us to once again investigate micro-earthquake activity in this portion of the San Andreas. For a one-week period following the mainshock, we re-occupied five temporary sites on both sides of the San Andreas using Sprengnether MEQ800 smoked paper recorders. Observed activity was high but at a rate not unusual for this area. Specifically on the 3rd and 4th days of our occupation of these sites, a large localized cluster of activity occurred along an east-west lineation known as Porcupine Wash. Although this activity occurred just after the Mexicali event, it does not appear to represent a change from normal activity, since clusters are quite common along the east-west lineations in this region and five others had been observed during our earlier study.



DISTANCE (KM)
150
125
100
75
50
40
μrad
ppm
+1
0
-1
-2
γ_2'
Δ'
ϵ_{22}
QUIET
3
8
9
10
11
12
13
14
15
18
19
20
21
LHU
PALMDALE
JNH
BLU
CAJON
11/1
1976
5/1
1977
5/1
1978
5/1
1979
5/1
1980

Figure 1

Data Processing Center Operations

9970-01499

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Investigations

This project has general housekeeping, maintenance and management authority over the Earthquake Prediction Data Processing Center. Its specific responsibilities include:

1) day-to-day operation and performance quality assurance of 5 network tape recorders,

2) day to day management, operation, maintenance, and performance quality assurance of 2 analog tape playback stations,

3) day-to-day management, operation, maintenance, and performance quality assurance of the USGS telemetered seismic network event library tape-dubbing facility (for California, Alaska, Hawaii, Oregon, and Yellowstone National Park), and

4) projection of usage of critical supplies, replacement parts, etc., maintenance of accurate inventories of supplies and parts on hand, and reordering of these items on a schedule that insures uninterrupted operation of the Data Processing Center.

Results

Procedures and staff for fulfilling its assigned responsibilities have been developed, and the Data Processing Center is operating smoothly and serving a large variety of scientific user projects.

Seismic Data Library of WWSSN Seismograms

9930-01501

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This is a nonresearch project, and its main objective is to keep the WWSSN seismograms up to date and properly filed. Everything is now up to date.

Worldwide Earthquake Research Database

9930-02104

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Investigations

The main goal of this project is to provide up to date information which will facilitate research on earthquakes. Two major topics now under investigation are:

1. Establishment of a seismogram library of significant earthquakes, especially those before 1963.

2. Organization and maintenance of a bibliographic data base and retrieval system on current earthquake literature.

Results

Seismogram library: Under contract from this project, the National Geophysical and Solar-Terrestrial Data Center, NOAA, has built a portable photocopying system for filming historical seismograms. Seismograms from key U.S. stations are now being filmed. Please see Glover (1980) for current activities.

Bibliographic database and retrieval system: The Current Earthquake Literature (CEL) database has been maintained and kept up to date. Annual and bimonthly indexes are being distributed on schedule

Reports

Glover, D. P., 1980, Historical seismogram filming project: Second Progress Report: U.S. National Oceanic and Atmospheric Administration, Environmental Data and Information Service, World Data Center A for Solid Earth Geophysics, Report SE-24, 63 p.

Gunn, M., and others. Index to Current Earthquake Literature (bimonthly issues).

Microearthquake Data Analysis

9930-01173

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Investigations

1. The primary focus of this project is the development of state-of-the-art computation methods for analysis of data from microearthquake networks.

2. The principal effort during the past six months has been devoted to a) completing the review paper "Principles and applications of microearthquake networks" by W. H. K. Lee and S. W. Stewart, and b) organizing a workshop on the Coyote Lake earthquake of August 6, 1979.

Results

1. The review paper "Principles and applications of microearthquake networks" by Lee and Stewart was completed (450 manuscript pages). It will appear in the Advances in Geophysics Series, published by the Academic Press, New York, in 1981.

2. In July, some 70 scientists from 16 U.S. and foreign institutions participated in a one-month-long workshop on the Coyote Lake earthquake. An integrated seismic study, headed by K. Aki of M.I.T., is underway to systematically investigate the Coyote Lake earthquake sequence. A detailed survey of the crustal structure beneath Coyote Lake area has been planned (headed by Walter Mooney of USGS), and a short explosion profile across the Gilroy-Hollister valley has been made. In addition to these two multiperson investigations, several other individual studies on various aspects of the Coyote Lake earthquake are underway.

Minicomputer Systems Development

9970-02118

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Investigations

The major goal of this project is to assist the Office of Earthquake Studies in efficiently processing data by means of minicomputer hardware/software.

A minicomputer-based seismic data processing system has been developed to process local earthquakes from the USGS central California network's analog tape recording system. The goal of the system is to provide preliminary hypocenters and associated waveform data on a routine basis.

The system is designed to process events involving hundreds of seismic stations. To accomplish this, it creates a dubbed analog library tape from five 14-track, on-line analog tapes. Information is recorded on those tapes in Frequency Division Multiplexing format (FDM) which allows up to 112 stations per tape.

The data flow within the system is controlled by an operator who, with the help of computer-updated files, invokes the appropriate processor as the events pass through the system. The current processing status of all events is accounted for from the time of the request until the event has been either copied onto a digital archive tape or processing has been discontinued.

The events are detected initially either by manually scanning microfilm or by an independent on-line earthquake detection system which produces request cards for the first stage of the system. The processing consists of reading the request cards, creating the dub library tape, selecting the analog channels to be processed, digitizing and displaying those channels, interactively picking first arrivals and other seismic parameters, locating the hypocenters, and creating a digital archive tape.

Results

Processing continues to be done by various groups and individuals. Several revisions and repairs have been made to the software since the last report period.

The most extensive revision involved the replacement of EVCON12, EVDIG12, and DMUX2 with NPCON, NPDIG, and DMUX3. The main purpose of this change was to allow the processing of events which have dubs from Network tapes D and E. Because of memory limitations, it was necessary to redesign the data structure, hence the necessity of rewriting the demultiplex routine. Another feature of NPCON is its ability to run unattended, being driven by a file of event ID's.

Crustal Inhomogeneity in Seismically Active Areas

9930-02231

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Investigations

1. Development of an online, realtime earthquake waveform data-acquisition system for the Central California Microearthquake Network is continuing in collaboration with Peter Ward. The system will use the PDP 11/34 as the digitizing and temporary data-storage medium, and will write the earthquake waveforms to magnetic tape, or transfer them directly to a larger computer for further analysis. The "trigger" to denote that an earthquake is in progress, and that the waveforms should be saved, will be provided by Rex Allen's microprocessor-based realtime earthquake-detection and timing system.

2. Preparation of the review paper, and updating the literature and references dealing with microearthquake networks, by W. H. K. Lee and S. W. Stewart was completed.

Results

1. Additional hardware for the PDP 11/34 computer has been ordered. This includes a 512 channel analog-to-digital converter and multiplexer system, and a dual-ported high-capacity disc system. The operating system will be built around the UNIX Real-Time System as originated and described by Dave James. I have begun studying the UNIX operating system software and the "C" programming language in order to get the appropriate software going on the PDP 11/34 as soon as possible.

2. The 450-page review paper "Principles and Applications of Microearthquake Networks" by W. H. K. Lee and S. W. Stewart was completed and sent to the editor of the Advances in Geophysics series, volume 23.

Reports

None.

Seismicity and Earthquake Prediction Studies in Turkey

14-08-0001-16887

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Investigation

In our project on seismicity and earthquake prediction we have been analyzing seismicity patterns for long range prediction of large earthquakes. In this study we have attempted to use swarms of weak earthquakes as a precursor to large earthquakes. This technique was originally proposed by Keilis-Borok and applied to different regions of the world. For a prediction to occur a swarm had to occur no more than 6 years before the large earthquake. A swarm is defined as "spatial clustering of earthquakes at a time when the seismicity of the region is above average" excluding aftershock sequences.

Results

In order to test the original technique and modification to it the seismicity of Turkey from 1914 through 1975 was used. This region was chosen because it has been the location of a series of major earthquakes during this century and has well-defined seismic zones. In order to better understand our results, a system of hypotheses with measures of success and a probabilistic model was developed. The two measures of success are percentage of large earthquakes predicted and the percentage of swarms that predicted large earthquakes. The method was applied separately to earthquakes in the North Anatolian Fault Zone, in whole and in segments, and to earthquakes in western Turkey.

Our best results are shown in Figure 1. For the North Anatolian Fault Zone we achieved prediction of 8 of 11 earthquakes of $M \geq 7$ with 81.6% confidence and had 15 of 21 swarms predict earthquakes for 88.4% confidence. In southwestern Turkey, 10 of 11 earthquakes of $M \geq 7$ were predicted with 99% confidence and 15 of 18 swarms predicted these earthquakes for 86.3% confidence. If these results are not the result of data fitting they represent successful prediction. The major problems encountered were the incompleteness of seismicity catalogs and the use of many arbitrary parameters.

Publications

Michael, A.J. and M.N. Toksöz, Earthquakes swarms as a long-range precursor to large earthquakes in Turkey, Geophys. J. R. Astr. Soc., submitted, 1980.

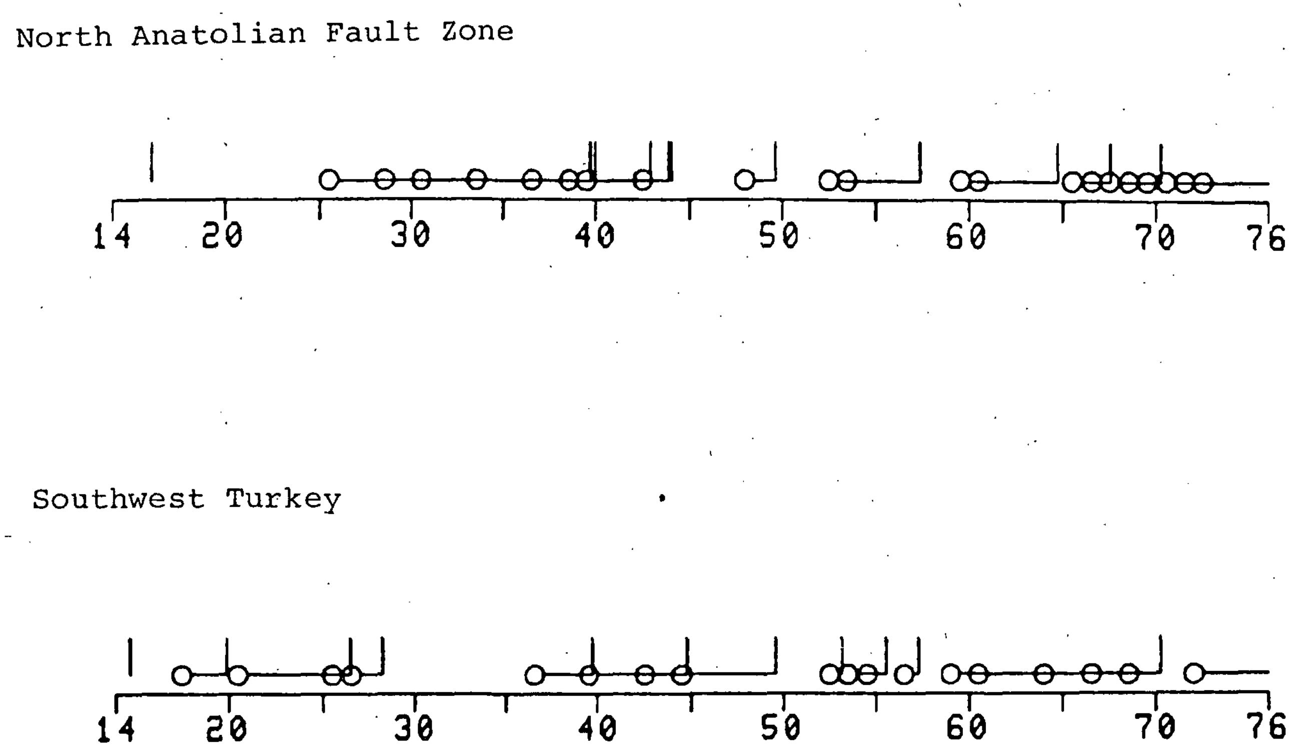

Figure 1. Each timeline covers the time interval considered (1914-1975 inclusive) and shows the occurrence of earthquakes $M \geq 7$ (vertical line), swarms (circles), and periods of alarm (horizontal lines) for a run.

ADEQUATE AND TIMELY DATA PROCESSING

9930-02392

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Investigations

Work continued on assembling a tool-oriented computer environment aimed at facilitating the exchange of data and programs and aimed at reducing the programming labor involved in analyzing data in the Earthquake Hazards Reduction Program. The environment is built around the concept of tools where thousands of general-purpose tools are available to analyze different types of data. Users are encouraged to add new tools to the collection or improve the old tools. The tools can be linked together easily using compiled languages such as FORTRAN, or using an interactive language called Geolab. A relational data base and advanced plotting system are integrated into the environment.

Results

1. Version I of the software was delivered to 12 seismologic groups on April 23, 1980 and is described in the last report.

2. 200 sets of an eight-volume manual set including nearly 1800 pages each were distributed in late September 1980. The manuals document the tools, Geolab, database, and plotting in their preliminary forms. The manuals also contain documentation of the operating system and its tools compiled from many different sources. The manuals are printed using phototypesetting techniques on the Versatek printer-plotter.

3. A new version of the database is being developed to run significantly faster and to be fully integrated with a new version of Geolab. The basic storage and retrieval algorithms are completed and in use. The high-level search capabilities have been integrated into Geolab in the form of "table" variables. Generalized input and output routines are being developed.

4. An automatic Geolab interface routine, glif, has been written that writes interface programs to connect any tool to Geolab. The user simply specifies what variables will be passed from and to Geolab, what the subroutine call is and any restrictions desired for variable types. Glif then does all the work and the user simply enters Geolab and calls the new tool.

5. The International Mathematical and Statistical Library has been integrated into the environment. This commercial library contains over 500 routines.

6. The 11/70 minicomputer in Menlo Park now handles 15 to 20 simultaneous users and typically provides 180 user login hours per day.

7. Willie Lee's hypo80 program for locating earthquakes has been extensively reorganized, rewritten, and tested to make it strongly tool-oriented and to make it fit better on small machines.

8. The 11/70 has been receiving data continuously and in real-time from Rex Allen's p-picking microprocessors. Locations are done daily. Shortly, locations will also be done in real-time.

9. Routine analysis of earthquake phases and locations for the central California net are now being done on the 11/70. All Creep data are being analyzed on the 11/70 and tilt and magnetic data will soon all be analyzed on this system.

10. Detailed plans were made and equipment ordered for routine on-line digitization of up to 512 channels of seismic data in central California.

11. Tools were provided by many users during this period including:

    a. General seismology and surface wave programs by Bob Herrmann at St. Louis University.

    b. Seismic data collection routines for the 11/34 by Alex Bittenbinder and Steve Malone of the University of Washington and Carl Johnson of Caltech.

    c. Seismic phase picking program by Carl Johnson at Caltech.

    d. Mathematical, virtual array, and plotting routines from CIRES.

    e. Programs to read Global Digital Seismograph Network Data from the Network Day Types by Ray Buland and others at the USGS in Golden.

    f. Analysis programs for seismic data from Lincoln Laboratories.

12. It is fervently hoped that we will all find ways to better work together and share our programming efforts to get more earthquake-related data processed quicker and with less duplication of effort. Sharing takes a little more effort up front but has been proven to save energy in the long run.

U.S.G.S. Contract No. 14-08-0001-18388

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The Mark III Field System computer was installed and used successfully in July 1980 with the transportable Mark III terminal at the radio telescope in Effelsberg, West Germany; the experiment, conducted with four other telescopes, was completed on 28 July and data processing has begun. Processing of the data obtained in the November 1979 experiment that involves the transportable terminal is continuing, but final values of station coordinates are not yet available. We are still investigating the origin of systematic trends in the post-fit residuals from these data.

Southern California Repeat Gravity Studies

9730-01034

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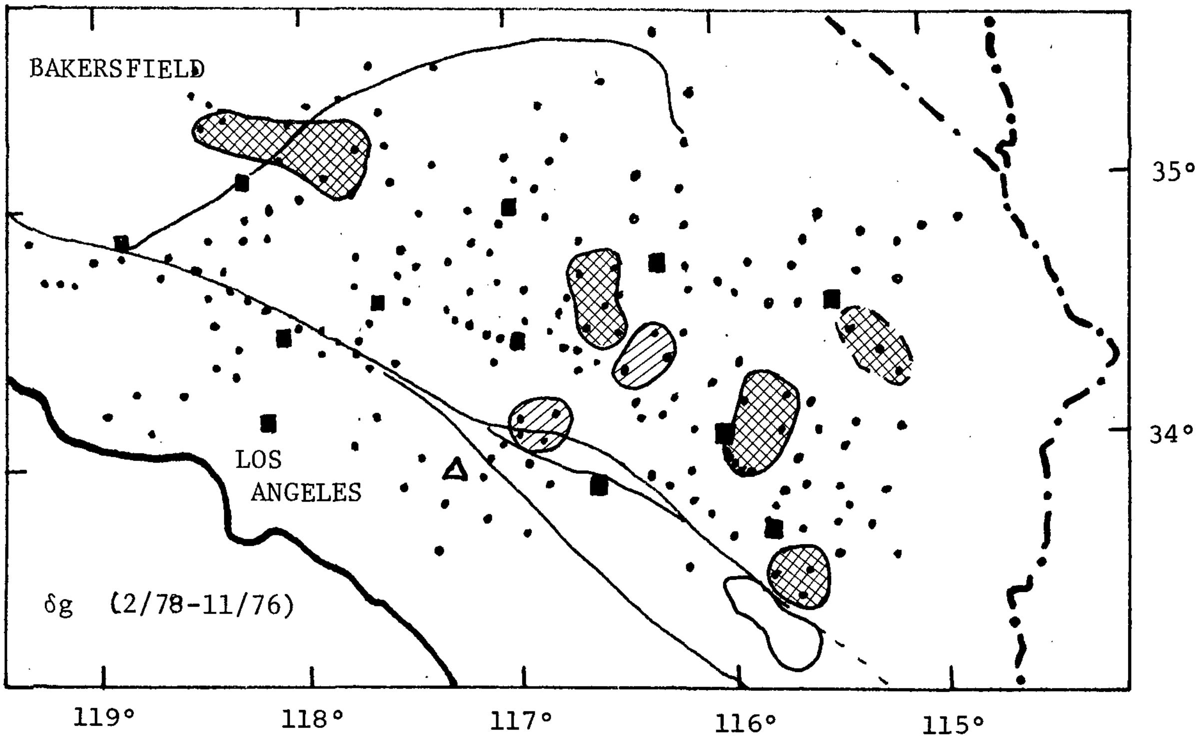
Investigations

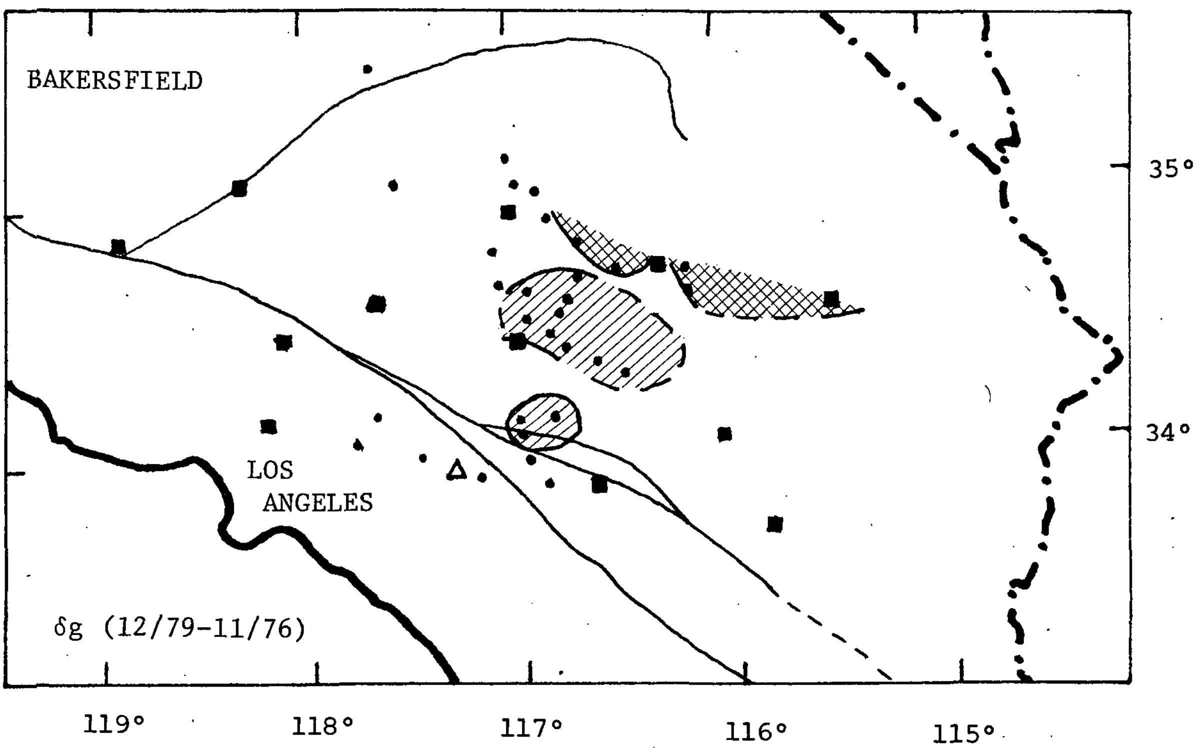
Parts of the southern California high-precision gravity network, established during the fall of 1976, were remeasured during May 1980. This survey constituted the fifth partial reoccupation during the past 3.5 years. As in previous surveys, 12 stations of the secondary reference station network scattered over an area of 45,000 km^2 were remeasured. The rest of the time was spent remeasuring sites in the vicinity of Lucerne Valley, Homestead Valley, Barstow and Lavic.

Results

Comparison of results from the initial survey and that conducted during the spring of 1978 revealed an area of anomalous gravity change (assuming gravity at the primary reference station at Riverside was invariant) in the central Mojave Desert. The feature had the form of an area of gravity decrease (~ - 30 μGal over about 500 km^2) centered over Homestead Valley (34.3°N, 116.4°W) flanked on the northwest by an area of gravity increase (figure 1). The magnitude of the gravity increase was about 20-30 μGal over an area of roughly 700 km^2. Three subsequent surveys of the region (January-March 1979, December 1979 and May 1980) showed that during this period the area of gravity decrease systematically grew in size mainly by expansion to the north and northwest (figure 1, bottom). By May 1980 gravity had decreased over an area of more than 3000 km^2. The magnitude of the gravity decrease also grew systematically during this period and reached its largest value (-60 μGal) at one of the sites where it was first detected in 1978. The survey results also suggest that as the area of gravity decrease expanded to the north and northwest, the area of gravity increase that existed there in 1978 moved to the north and northwest. However, the data distribution is not adequate to define the exact position and size of this feature through time.

The cause of the anomalous gravity change is not known but because the observation stations are located on crystalline bedrock outcrops, gravity changes at them due to changes in the distribution of groundwater presumably are small. Level surveys into the area are planned for the fall of 1980 to determine whether elevation changes accompanied the anomalous gravity change.





Measured gravity changes in southern California for two intervals. The dots and solid squares indicate gravity control. The open triangle is the primary reference station at Riverside. Contours enclose regions where three or more adjacent stations showed changes larger than 15 μGal. Areas of gravity increase are shown by cross hatched patterns and areas of gravity decrease are shown by diagonal pattern.

Geodetic Strain Monitoring

9960-02156

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Investigations

1. A portable two color laser geodimeter (Terrameter) was ordered in 1978 for the purpose of high resolution trilateration surveys in selected areas of the San Andreas fault system.

2. Postseismic deformation was measured using an electronic distance measuring instrument in the region around the northern third of the observed surface rupture of the October 1979 Imperial Valley earthquake.

3. Three Sacks Evertson volumetric strainmeters, which were installed at the ends of boreholes drilled into the sidewall of an experimental tunnel at a depth of 3 km in the ERPM gold mine near Johannesburg, recorded strain changes associated with mine tremors extending the mine excavation, and temperature changes in the rock. Strain changes occurring before, during, and after well-located tremors were measured and the results were compared to theoretical expectations.

Results

1. The Terrameter, ordered in 1978, was put through a second series of acceptance tests in July 1980; the first series, described in the previous report, were run in February and March, at which time it was found that the instrument had serious problems. In brief, during the second period of testing we found that, although some of the essential problems had been solved, the Terrameter was nevertheless performing substantially below its specified standards. During a 28-hour test during which neither the instrument nor the retroreflector was moved, the measured line length of about 3 km was found to vary over a range of nearly 5 parts per million a factor of 50 greater than the specified precision. Following these tests the instrument was shipped back to the factory for further work.

   When it became clear that there might be a protracted delay in the final delivery of the Terrameter, we negotiated an arrangement with Dr. L. E. Slater, of the University of Colorado, involving moving the two-color distance measuring instrument that has been in operation in Hollister, California, since 1975 to a site near Pearblossom, California. In the meantime an observatory has been prepared on the crest of the Holcomb Ridge just to the ESE of Pearblossom and on the NE side of the San Andreas fault, opposite the Devils Punchbowl formation. The University of Colorado instrument is currently being installed and the intent is to make daily or bi-daily measurements of line lengths to about 12 benchmarks distributed radially around the observatory for much of the remainder of 1980; the line lengths are in the range of 3 to 9 km.

2. Analysis of repeated line length measurements, over a geodetic network of 54 baselines, during the 120 day period following the Imperial Valley shock, has largely been completed. The behavior of fault slip and strain accumulation as a function of time was reported previously. In the more recent analyses it was found that for the 120 day period from late October 1979 until mid-February 1980, the entire network shows a pattern of simple shear strain accumulation at a rate of 0.03 ± 0.01 μstrain/day; for right-lateral shear the direction of maximum strain accumulation is $N27^{o}E \pm 12^{o}$. Considering some subregions of the network separately, the subregion in the northeast quadrant, on the southern margin of the Mesquite Lake basin, showed N-S extension at an average rate of 0.07 ± 0.01 μstrain/day. On the west side of the fault there was no significant strain accumulation at a level of two standard deviations of 0.03 μstrain/day.

   The geodetic data were also interpreted in terms of a dislocation model that allows a non-uniform distribution of slip. Both linear programming and least squares techniques were used to fit models of slip on both the Imperial and Brawley faults to the data. Both methods indicate that slip on the Imperial fault below 2 to 3 km was not large enough to make a statistically significant contribution to the observed deformation. furthermore, slip on the Brawley fault was not resolvable as the network did not extend across that fault.

3. Analysis of short term (less than a day) strain changes, measured by the Sacks-Evertson strainmeters and recorded using a multi-channel dot recorder, was completed as well as the report describing these results. The strain data were also recorded on magnetic tape, which provided better time resolution and a somewhat more complete data set. These data will be analyzed in the future as time permits.

Reports

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RECENT VERTICAL MOVEMENTS OF THE CRUST IN THE WESTERN UNITED STATES: REDUCTION AND ANALYSIS OF LEVELING DATA AND ITS INTERPRETATION IN LIGHT OF RELATED SEISMOLOGICAL AND GEOLOGICAL INFORMATION

14-08-0001-17625

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Background

Vertical crustal movement information has been derived from releveling data collected by the National Geodetic Survey (NGS) in the western U.S. Our objective is to determine to what extent this data base can contribute to our understanding of geodynamic phenomena with emphasis on earthquake prediction and seismic hazard evaluation. After critically examining the crustal movement information from a geodetic perspective, the leveling results are interpreted in view of other relevant geophysical and geological data.

Recent Accomplishments

Neotectonic Deformation, Near Surface Movements and Systematic Errors in U.S. Releveling Measurements: Implications for Earthquake Prediction

Analyses of U.S. releveling measurements indicate that derivative crustal movement estimates may reflect tectonic deformation, near-surface movements, and/or systematic errors. Discriminating the contributions of these factors is especially crucial for unambiguous geodetic detection of possible precursory seismic deformations. While reliable leveling measurements of co-seismic and post-seismic movements are well documented for some of the larger (M > 6) dip-slip earthquakes, leveling evidence for pre-seismic motion is generally sparse and often ambiguous. Subtle earthquake-related motions may be masked by both aseismic movements and systematic errors. For example, deep magma injection and surficial groundwater withdrawal are two mechanisms which have been documented to cause surface movements which have been misidentified as seismic-related. Of more concern, perhaps, are systematic measurement errors. Topography dependent errors are an exceptionally troublesome type, perhaps affecting as much as 20% of U.S. leveling. However, other varieties of systematic error also contribute to the uncertainty. Discrepancies between leveling and tide gauge data and within nets of leveling alone suggest large, long baseline accumulations of error. In many cases, aseismic and erroneous contributions cannot be unequivocally determined *ex post facto*. However, a comprehensive examination of the NGS crustal movement data base, representing a large sampling of the entire U.S. Level Net, provides perspective and criteria needed to begin to recognize movement directly related to earthquake activity.

Perhaps, the most extensive set of measurements relevant to the earthquake prediction problem exists in southern California, where much attention has recently been focussed. Reevaluation of some of these leveling observations indicates that while some appear to reflect tectonic deformation, others are suspect because of indications of systematic errors and/or near surface, non-tectonic movements. Specifically, possible preseismic movements reported for the 1971 San Fernando earthquake in the vicinity of the earthquake fault as well as approximately 30 km northwest of the epicenter may be due to systematic errors. Movements near the San Gabriel fault, initially ascribed to the Palmdale Bulge and more recently to preseismic effects of the 1971 San Fernando earthquake apparently reflect near-surface sediment compaction due to water table fluctuations. The configuration of the "Palmdale Bulge" itself will, at the very least require revision in light of improved understanding of those factors which can influence releveling measurements. However, since certain spurious effects may be isolated, the southern California releveling data remain an important source of information on contemporary tectonic activity. For example, possible tilting southwest of Palmdale between 1961 and 1964 is not easily related to systematic errors or near-surface movements and thus may represent tectonic deformation. Whether this tilt anomaly was due to preseismic effects of the San Fernando earthquake or a mechanically separate tectonic event is presently being investigated.

Recent Publications

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Crustal Strain

9960-01187

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Investigations

Analysis of strain accumulation in central and southern California was the principal subject of investigation, although some analysis of networks elsewhere in western United States was undertaken. A detailed search of Geodolite measurements was made to detect possible earthquake precursors with negative results.

Results

1. Frequent surveys of seven trilateration networks in southern California over the interval 1973-1980 suggest that a regional change in strain accumulation may have occurred in 1978-1979. Prior to 1978 the strain accumulation was predominantly a uniaxial north-south compression whereas since that time there has been a diminished rate of north-south compression and an increased rate of east-west extension. The onset of this change appears to occur first in the networks farthest south. The changes occur without any unusual seismicity within the networks, but the overall seismicity in southern California had been unusually low for the three years prior to the onset of the change and has been unusually high since. The average principal strain rates for the seven networks in the 1973-1980 interval are 0.17 μstrain/a north-south contraction and 0.08 μstrain/a east-west extension. Although the observed change in strain accumulation could be related to unidentified systematic error in the measuring system, a careful review of the measurements and comparisons with three other measuring systems reveal no appreciable cumulative systematic error.

2. Analysis of a network of 60 lines crossing the San Andreas, Hayward, and Calaveras faults in the vicinity of San Francisco Bay, measured between 1970 and 1980, has revealed details about the accommodation of relative plate motion in this area. The most striking result is that the deformation is not uniformly distributed across the area. In the east bay along the Hayward and Calaveras faults all motion appears to take place as slip directly on the fault with no accumulation of strain in the adjacent crust. On both the Calaveras and the Hayward faults the

rate obtained for the 1970 to 1980 period agrees with geologic rates spanning a few million years and with creep rates spanning a few decades. The Hayward fault slip rate is 6±1 mm/yr. The Calaveras fault slip rate is 6±1 mm/yr with perhaps half of this slip distributed across a zone a few kilometers wide, probably as inelastic deformation of weak near-surface material. The absence of strain accumulation in the east bay is surprising since the Hayward and Calaveras faults have been the site of large earthquakes in the past. Along the San Francisco peninsula the situation is quite different. No detectable slip occurs (less than 1 mm/yr) at the surface, but appreciable strain is accumulating. Near fault strain rates are 0.6±0.1 μstrain/a. The relative motion rate across the whole region is 34±1 mm/yr. The slip rate at depth in the vicinity of the San Andreas fault is thus inferred to be 21±1 mm/yr. A block located east of the Calaveras fault and south of the Las Positas fault is rotating clockwise at a rate of 0.3±0.1 μrad/yr with very little internal deformation.

3. The Bishop (M_L = 5.8, October 4, 1978) and the Mammoth Lakes (M_L = 6.0, 6.3, and 6.0, May 25 and 27), California, earthquakes occurred on the edge of a trilateration network (45 km aperture) used by the U.S. Geological Survey to monitor strain accumulation in northern Owens Valley. The network was surveyed in 1972, 1973, 1976, July 1979, and September 1980. Although the Bishop earthquake occurred at a depth of 15 km directly beneath one of the stations in the network, the 1976-1979 deformation was not significantly different from that in 1973-1976. The Mammoth Lakes earthquakes, on the other hand, produced displacements as great as 60 mm at distances of 30 km from the epicenter. The 1979-1980 deformation suggests extension perpendicular to the range-front faults along the Sierra scarp, whereas preliminary nodal plane solutions for the Mammoth Lakes earthquakes seem to require left-lateral slip on vertical faults striking northward. The deformation of the network through July 1979 was quite regular with no suggestion of an anomaly preceding the Mammoth Lakes earthquakes up to that time.

4. A 1980 Geodolite resurvey of a 1913 third-order triangulation network in the Shumagin Island seismic gap, Alaska, shows no significant shear strain accumulation (4.5 μradian standard deviation) in the 67-year interval between surveys. A two-dimensional dislocation model of the seismic gap predicts an accumulation of 12.5 μradians in that interval. A new Geodolite network was established in the Yakataga seismic gap, Alaska. Part of the network coincides with a 1959 EDM traverse loop (aperture 35 km). Comparison of the 1959 and 1979-1980 surveys indicates that the western edge of the Yakataga network has been displaced 3.4 m S40°E with respect to the eastern edge. We attribute this

deformation primarily to the 1964 Alaska earthquake, the effects of which apparently penetrated into what is now known as the Yakataga gap. A comparison of 5 lengths common to the 1979 and 1980 surveys shows maximum contraction of 0.5 ± 0.3 μstrain/yr at $N42^{\circ} \pm 12^{\circ}E$ and maximum extension of 0.9 ± 0.5 μstrain/yr.

Reports

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Paleogeodetics

9960-01488

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Investigations

Analysis and interpretation of repeated geodetic survey measurements relevant to earthquake-related deformation processes operative at or near major plate boundaries. Principal recent activities have been:

1. A review of the uses of geodetic measurements in problems related to earthquake hazard assessment and prediction research.

2. An analysis and interpretation of trilateration measurements made in the spring of 1978 across the Montagua fault, site of the M=7.5 1976 Guatemala earthquake.

Results

1. Repeated geodetic surveys provide data relevant to earthquake hazard assessment and precursor monitoring and supply constraints on the mechanisms of stress build-up and relief in the crust and upper mantle. The detection of steady deformation indicates a seismic hazard, the degree of which depends upon the rate of deformation and the time elapsed since a previous large earthquake. If the coseismic strain drop is known the measured deformation rate can be used to estimate earthquake recurrence interval. On a regional scale, monitoring for precursory deformation is practical only if resurvey intervals are about one year or greater. On a local scale, observations can be almost continuous. Significant experience with the first type of monitoring and limited experience with the second has uncovered several possible precursors but no unambiguous ones. Reported anomalies have amplitudes of $\sim 10^{-6}$ in strain or tilt. Using careful observing procedures, attainable precision is $\sim 2 \times 10^{-7}$. Resolving ambiguities is thus impeded not primarily by measurement imprecision, but rather by unexplained episodic movements such as aseismic uplift in southern California that are not obvious precursors. The plate tectonic setting and Quaternary deformation history provide clues to the origins of such aseismic movement. Deformation modeling is useful in assessing the significance of suspected precursory deformation, in deciphering

observed movement patterns, and in constraining the mechanical properties of the lower lithosphere and uppermost asthenosphere, where precursory movements may originate (W. Thatcher).

2. A 15-station geodetic control network extending 10 km north and 40 km south of the Motagua fault in Guatemala was reobserved after the February 4, 1976 M = 7.5 earthquake. The initial first-order triangulation was observed in two parts: the Guatemala-Honduras border arc completed in 1935 and the Motagua Valley arc completed in 1953. The trilateration survey was done in February - March 1978. The changes between the combined 1935-53 survey and the 1978 trilateration survey were used to determine co-seismic fault slip assuming a simple dislocation model. The model was divided into three successively deeper sections. The inversion predicts average left-lateral slip of nearly 1 m near the surface, increasing to 2 m in the 5- to 15-km section and becoming undetermined at greater depths. The surface slip is similar to that measured by Plafker (1976), and the increased slip at depth is consistent with the afterslip observed by Bucknam *et al.* (1978). The seismic moment predicted by the 0- to 15-km displacements over the 250-km-long fault break is 2.2 $\pm$ 0.5 x 10^{27} dyne-cm and agrees with independent estimates obtained from long-period seismic surface-waves by Kanamori and Stewart (1978) (M. Lisowski and W. Thatcher).

Reports

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Precursory Strain/Seismic Anomaly Studies on a Strike-Slip Fault System

9930-02393

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Investigations

Approximately twenty years of seismic data are being analyzed to test seismicity as an earthquake prediction tool. Intense seismicity and the central location of our study area within a dense seismometer network operated by the Hawaiian Volcano Observatory provides ideal conditions for an earthquake prediction study supplemented by strain studies. To understand the tectonics of this region, our current goals are to obtain improved hypocenter locations (for all events) based on a number of crustal models and to determine focal mechanism parameters for all large magnitude events. Computer programs and data analysis techniques are being developed at the Univerrsity of Washington to analyze and present this voluminous data set. Early efforts will focus on events associated with a body-wave magnitude 5.5 event that occurred on November 30, 1974 on the Kaoiki fault system. Field evidence suggests that extensive surface fractures in a 0.5 x 2.0 km region are related to this earthquake and its aftershocks. An additional goal of the project is to complete a fracture map that is consistent with the seismic data.

Results

A. Seismic

Approximately 1000 copies of earthquake film records and hard copies of digitized seismic events have been collected for a focal mechanism study of the Kaoiki region and the south flank of Kilauea. These events are part of a group of 5000 events that have been relocated using two different crustal models. First-motion plots have been completed for larger magnitude events from 1972-1979. The 1979 results indicate more than one type of faulting is taking place in the Kaoiki study area. In addition to right-lateral strike-slip faulting, low-angle normal or thrust faulting appears to be also taking place in the Kaoiki area.

To meet our project goals, the effect of structure models has been studied. A paper, coauthored with Robert Crosson of the University of Washington and pointing out the effect of structure models on focal mechanisms, has been submitted for technical review. The report discusses focal mechanisms related to the November 29, 1975 Kalapena earthquake.

In a followup study of the Kalapena earthquake, focal mechanisms for 200 Kilauea south-flank earthquakes with body wave magnitudes greater than 3.3 have been determined. Consistent with the results of our paper is the invariance of what we consider to be the slip directions for individual events. The slip directions of focal mechanism solutions are also consistent with the results of strain studies on the south flank of Kilauea. The work on the south flank events gives us some knowledge of station reversals that are important to reliable focal mechanism solutions for the Kaoiki study area. The same computer graphics programs developed for the south flank study are being used to present results of the Kaoiki fault zone study. A focal mechanism catalog for large magnitude events is in the planning stage.

B. Deformation

A preliminary 1:900 scale map of surface fractures in the region of study has been completed. Mapped features will be transferred to orthophotos for a final distortion-free map. The en echelon nature of the fractures and displacements are consistent with right-lateral strike-slip focal mechanism solutions of large magnitude Kaoiki earthquakes. Level lines and EDM arrays have not been reoccupied since initial measurements during the summer of 1979, hence there are no results to present for this report.

Tests of the Kinemetric's platform-type tiltmeters are encouraging. Two tiltmeters, one located in the Mauna Loa seismic vault and the other located in the Uwekahuna seismic vault, tracked water-tube type tiltmeters. In addition, during a March 1980 summit deflation of Kilauea, the platform tiltmeter at Uwekahuna tracked a 1-meter-base Ideal-Aerosmith mercury tiltmeter to within a few tenths of a microradian during the deflation event. Preliminary results suggest vault installations to be far superior to any borehole installation.

Reports

Endo, E. T., Nakata, J. S., and Crosson, R. S., 1979, Focal mechanisms of crustal and mantle earthquakes beneath the island of Hawaii (abs.): Symposium on intraplate volcanism and submarine volcanism, p. 160.

Support of the Southern California Geophysical Data and Analysis Center

14-08-0001-18330

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Goals

1. To support the data collection and processing activities of the CEDAR (Caltech Earthquake Detection And Recording) system and CROSS (Caltech Remote Observatory Support System).

Results

1. CEDAR

CEDAR operations, originally developed and supported by this contract and its predecessors (contracts # 14-08-0001-16629,17642), is now an element of the joint USGS-Caltech SCARLET system (Southern California Array for Research on Local Earthquakes and Teleseisms). As such its product is a component of the results produced by the contract "Southern California Seismic Arrays", contract # 14-08-0001-16719. The result of this effort will be reported on for the latter contract (16719).

2. CROSS

This contract supplies continuing operational support for CROSS developed under the predecessor contracts (given above). During this reporting period, three sites have been abondoned (Buck Canyon - Clark, Valyermo - Clark, Valyermo - Lamar/Merifield), two are temporarily out of service (Bouquet Resevoir - Teng, Caltech Campus - Ahrens), and one site added (Riverside - Teng). They are as follows:

SITE LOCATION	# CHAN. IN USE	TYPE of MEASUREMENTS	PRINCIPAL INVESTIGATOR	NOTES
Anza	1	water well	Lamar/Merifield	
Bouquet Reservoir	1	Gravimeter	L. Teng	1
Hollister	8	tellurics	T. Madden	
Kresge Lab.	6	tilt,gravimeter	J. Whitcomb	
Palmdale	8	tellurics	T. Madden	
Riverside	3	radon	L. Teng	
Caltech campus	6	tilt	T. Ahrens	1

Notes: (1) Currently out of service at the discretion of the Principal Investigator.

The data at these sites is collected once a day via the telephone telemetry polling procedure and is being accumulated as a data base on the Caltech Seismo. Lab. PRIME computing system. The data is available externally via a modem port on the computer system but the current method of data delivery for non-Caltech investigators is by use of magnetic tape.

Instrument Development and Quality Control

9970-01726

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Investigations

This project supports other projects in the Office of Earthquake Studies by designing and developing new instrumentation and by evaluating and improving existing equipment.

Results

This group has taken over the development of GEOS microprocessor event recorder which was initiated under a contract with ARGO Systems, Inc. A microprocessor development system has been set up using the Ground Motion PDP 11/70 minicomputer. The hardware design of the GEOS system has been improved and finalized. The software for the system has been extensively modified and is approaching completion. Procurement of the majority of the components necessary to build 25 GEOS recording and 5 playback units has been initiated. Work is continuing on development of production hardware (i.e., printed circuit boards, cases, etc.).

A new timing system for the Calnet Playback Center has improved its fail-safe capabilities and timing accuracy. A hardware interface to allow 5-day tape recordings to be digitized on the Eclipse B computer has been completed along with preliminary documentation. Tape ID decoding has been implemented on several playback machines. Hardware and software for automatic discriminator checking on the Eclipse B system are now operational.

Six precision portable clocks for use with portable seismic recorders have been completed and are in use. A highly portable, low-power counter for field maintenance was developed and several have been built. A new voltage-controlled oscillator (VCO) intended for retransmission of seismic data received at telemetry recording sites was developed. Fifty have been constructed and another 100 are under construction.

Alignment and repair of 220 telemetry radio transmitters and receivers was completed as well as calibration of over 300 seismometers. Construction of 200 discriminators is continuing.

This group has provided maintenance support of the Seismic Cassette Recorder (SCR) system during field programs and in the office. Research and development on a radio-controlled trigger for this system is continuing. This group has also begun development for improvement of the system for digital telemetry of low-frequency geophysical data.

The Parkfield Prediction Experiment

9930-02098

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Investigations

The U.S. Geological Survey has undertaken a detailed earthquake prediction effort near Parkfield, California, on the San Andreas fault midway between San Francisco and Los Angeles. This area has been the site of four very similar M 5½ earthquakes in this century, the most recent in 1966. It is located at a junction between locked and creeping sections of the San Andreas at the north end of the great 1857 earthquake.

Since 1966 a variety of geophysical measurements have been made in this area by Caltech, the State of California (Division of Mines and Geology) and the USGS. Analysis of this data has led us to the following conclusions: 1) The 1966 earthquake (and by inference, the earlier events as well) occurred on a slip patch approximately 5 km wide and 20 km long centered at a depth of 5 km beneath the town of Parkfield, Calif. Displacement during the earthquake averaged about 50 cm. 2) To the north of this 20 km long zone, the surface slip rate for 1970-80 is 25 mm/yr but less than 10 mm/yr to the south. 3) Similarly, the microseismicity rate is 15 eq/yr ($M > 1\ 3/4$) to the north but only 5 eq/yr to the south. 4) The microseismicity which does occur adjacent to the 1966 rupture is clustered on the periphery, much as the aftershocks were. This activity is somewhat deeper and has a lower b-value (0.8) than seismicity in the north which has a b-value of 1.2. 5) Analysis of the geodetic data indicates that between 1970-80 the 1966 slip patch slipped on the average between 0 and 15 mm/yr, while the adjacent portions of the fault, to the north and below 10 km, slipped at about 30 mm/yr.

We assume that the next Parkfield earthquake will involve this slip patch "catching up" with the adjacent portions of the fault. We hope that prior to the final failure some accelerated deformation will occur, and our efforts at this time are directed to detecting this deformation.

Results

1. Installed enough additional seismic stations so that good locations are now obtained for all events of M 1 and larger. As of January 1980 we are also making least-squares estimates of the moment tensor for all events located, and hope to soon add stress drop and radiated energy to the list of parameters routinely measured.

2. Installed several additional creep meters and alignment arrays. The average distance between sites is now less than 5 km.

3. Established (or remeasured) 40 km of first-order level lines in the area. One km portions of these lines will be measured frequently (2-3 times/yr) as tilt arrays, the entire array will be measured every few years.

4. Added additional monuments to existing geodetic nets to create a dense intermediate scale array. This will be measured two to three times per year in hopes of better resolving the slip distribution along the fault in space and time, and possibly learning something about the slip distribution with depth.

5. In cooperation with Selwyn Sacks and Alan Linde of the Carnegie Institute we have installed two Sacks-Everson dilatometers at a depth of 700' into the Mesozoic gabbro at Gold Hill. We also operate a number of surface strain and tiltmeters in the area, but what is known of their noise spectrum is not encouraging at periods greater than a few days. One tiltmeter site near Gold Hill appears to have produced some good data during periods of dry weather in 1979, and we plan to install several instruments very close together at this site in hopes of further clarifying the situation.

6. We are currently monitoring the seismicity and creep data on a real time basis (lag < 48 hrs). For the last 18 months the seismicity rate in the region to the north of the 1966 slip patch has been about one-half that observed since 1975, and in the last 9 months large variations in creep rates have been noted at two sites. Similar changes were last observed prior to a M 5 event that occurred in 1975 and may have preceded the 1966 earthquake. It is unclear as of mid-March whether these changes are premonitory to a large earthquake.

Field Experiment Operations

9970-01170

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Investigations

This project performs a broad range of management, maintenance, field operation, and record-keeping tasks in support of seismology and tectonophysics networks and field experiments. Seismic field systems that it maintains in a state of readiness and deploys and operates in the field (in cooperation with user projects) include:

a. 5-day recorder portable seismic systems
b. Smoked paper-recorder portable seismic systems
c. Seismic refraction trucks
d. "Cassette" seismic refraction trucks
e. Portable digital event recorders

This project is responsible for obtaining the required permits from private landowners and public agencies for installation and operation of network sensors and for the conduct of a variety of field experiments including seismic refraction profiling, aftershock recording, teleseism P-delay studies, volcano monitoring, etc.

This project also has the responsibility for managing all radio telemetry frequency authorizations for the Office of Earthquake Studies and its contractors.

Results

Network augmentation. All preliminary field work and orders have been completed on the California network augmentation. Installation will proceed as telephone circuits are completed.

Seismic refraction. Project personnel carried out the permitting of shot holes in Southern Illinois, Geyers area in Northern California, Santa Clara Valley, and the Palmdale area in Southern California. Seismic reflection and refraction experiments were conducted near Palmdale consisting of twelve shots at seven shot points.

Portable networks. Of the six 5-day recorders being operated near Mt. St. Helens, Washington two were lost during the explosive eruption of May 18, 1980 and the others were replaced with permanent telemetry equipment. Fourteen 5-day recorders were operated around Mt. Lassen, California from July 20 to October 1, 1980.

UNIVERSITY OF CALIFORNIA, LOS ANGELES

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Institute of Geophysics and Planetary Physics
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Contract #14-08-0001-17686

Can Animals Predict Earthquakes?
A Search for Correlations Between Changes in the Activity Patterns of Captive Fossorial Rodents and Subsequent Seismic Events

Robert G. Lindberg, Principal Investigator
Durward D. Skiles, Co-Principal Investigator
Page Hayden, Research Associate

This project is an experimental investigation of the possibility that certain animals may behave in unusual ways immediately prior to nearby earthquakes. Specific objectives of the study are:

1. to establish animal monitoring facilities within seismically active regions;
2. to continuously monitor (a) the daily and long term activity of small rodents under controlled conditions of light and temperature and (b) the daily and seasonal activity of small rodents in artificial burrow systems buried in the ground and exposed to the natural environment;
3. to determine whether any correlations exist between changes or anomalies in the activity of these animals and subsequent seismic events;
4. to record baseline patterns of animal activity in the absence of seismic events: and to determine whether correlations exist between changes or anomalies in the activity patterns and changes in non-earthquake related environmental parameters such as temperature, rainfall, humidity, insolation, barometric pressure, and atmospheric electrostatic fields.

Towards these ends, we are continuously monitoring the activity of a small number of individuals of a few species of captive burrowing rodents. At a facility located on the Big Morongo Wildlife Reserve in San Bernardino County, California, we have the capability of monitoring 20 animals housed individually in running wheel cages in an indoor, temperature controlled room, and 11 animals housed individually in fabricated burrow systems located out of doors. We also have installed a second burrow system facility in Stone Canyon, San Benito County, California. The latter facility has the capability of monitoring 10 rodents.

At the indoor facility on the Morongo Reserve we have been using kangaroo rats (Dipodomys merriami) and pocket mice (Perognathus fallax), and at the outdoor facility we have recently been monitoring six little pocket mice (Perognathus longimembris), four kangaroo rats, and one large pocket mouse (Perognathus fallax). These species are native to the area, and all individuals were trapped on or near the Reserve. At Stone Canyon, we are monitoring six P. longimembris and four of a larger species of pocket mouse (P. californicus) which is native to the region.

Data from Morongo Valley neither support nor detract from the possibility that animals can anticipate seismic events. This was primarily due to low seismic activity during the reporting period. The data do emphasize the need to monitor a variety of environmental parameters to place anomolous behavior in proper perspective. Increased animal activity prior to earthquakes has been observed at Morongo Valley, but was coincident with both weather changes and derived foreshock patterns.

During the reporting period 11 earthquakes of magnitude 2.5 to 3.5 and one swarm comprising 10 events of magnitude 2.3 to 4.0 occurred within 20km of the Stone Canyon study site.

At least six of the twelve events were preceded or accompanied by what could be contrived as activity anomalies (5 cases of increased activity, 1 case of decreased activity) by most, but not all, individual animals. Two cases were not preceded or accompanied by anomalies and the remainder were ambiguous owing either to insufficient data or close proximity in time to an earlier earthquake which was correlated with an anomaly. However, the apparent anomalies which were correlated with earthquakes were neither particularly dramatic nor particularly significant statistically.

Thus, the Stone Canyon data do not provide strong support for the premise that animals behave anomalously prior to earthquakes. Neither, however, do they support the opposite premise. The earthquakes recorded near Stone Canyon were invariably small and we have no basis for assuming that significant activity anomalies might not be observed in conjunction with moderate or large earthquakes. In fact, the possibly positive, though limited, responses noted in several cases indicate that the data are not entirely ambiguous but lend tentative support to the notion that some animals may behave unusually prior to some earthquakes. We believe this provides ample justification for continuing the study with the hope of improving out statistics and intercepting larger earthquakes.

Biological Premonitors of Earthquakes:
A Validation Study

14-08-0001-19112

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The goal of this project is to test the long-held, popular belief that many types of animals behave unusually just before earthquakes, presumably in response to one or more precursors. To this end, a network of volunteer observers of animal behavior has been set up in selected seismic regions of California. The key feature of the reporting protocol adopted is that each volunteer is asked to report on a "hot line" all observed instances of unusual animal behavior. Only reports received before an earthquake are considered to be positive evidence in support of the hypothesis under test.

During the first six months of 1980 the number of observers grew from 1200 to 1473. Most of them are concentrated in southern Humboldt County; the San Francisco Bay area, north to Santa Rosa and south to Santa Cruz and Hollister; the northern Los Angeles area, particularly around San Fernando; and the San Diego area. During this time there were 128 earthquakes in California with a preliminary magnitude of at least 4.0, 17 of which had a magnitude of at least 5.0. A total of 1192 hot line reports were received.

Graphical display of the 1980 data revealed that none of the earthquakes of $M \geq 4.0$ fell well within the observer network but five on the fringes of the network appeared visually to be preceded by a relatively larger number of reports than the baseline report level. A computer-programmed statistical model and analysis procedure created for quantitatively correlating earthquakes and observer reports was applied to these five candidates. No significant correlations were found.

An in-depth analysis of reporting behavior preceding the most likely candidate, the 24 January 1980 Livermore earthquake (M = 5.5) indicated that the lack of significance was not due to lack of opportunity by volunteers to observe their animals. A survey questionnaire, mailed to 260 observers residing within approximately 100 km of the epicenter, revealed that 95% of the 195 (75%) observers who responded were around their animals during the two-week period preceding this earthquake.

Most routine network operations are automated, including maintenance of records of the performance of each observer, the mailing of additional logs, praise and delinquency notices, and the preparation of weekly and monthly management and statistical reports. A cadre of non-observer volunteers in the Menlo Park area handle other non-automatable functions.

Creep and Strain Studies in Southern California

Contract No. 14-08-0001-16718

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This semi-annual summary report covers the six-month period from 1 April 1980 to 30 September 1980. The contract's purpose is to maintain and monitor strainmeters, creepmeters, tiltmeters, and alignment arrays across or in proximity to active faults in the Southern California region. Primary emphasis focuses on the Imperial and Brawley faults in the Imperial Valley.

IMPERIAL VALLEY

Aftercreep phenomena related to the 15 October 1979 Imperial Valley earthquake still dominate the motion along the Imperial fault. Figure 1 demonstrates the creep pattern observed prior to the earthquake while figure 2 shows the pattern following the event, suggesting that aftercreep will continue to predominate for several years.

During the reporting period the alignment array at Highway 80 was surveyed 3 times and shows continuing motion. The 4 creepmeters on the Imperial and Brawley faults were each serviced 2 or 3 times. The creepmeters at Ross road and Heber road, located in the region of large coseismic displacements associated with the 15 October 1979 earthquake, have recorded continuing creep occurring exclusively in discrete creep events. The average rate of slip for the reporting period is 0.5 to 0.6 cm/month. The Ross road creepmeter, which was damaged, but not permanently disabled by the large earthquake displacements, was dug up and reinstalled in May. The other creepmeters seem to have adequately survived and continue to be maintained as usual.

The Anderholt and Worthington road nail files were each visited 3 times during the reporting period. Each indicated continuing displacements shown plotted versus logarithmic time in figure 2. The average creep rate over the reporting period was 0.63 cm/month at Anderholt and 0.47 cm/month at Worthington. In additon a third nail file has been installed at Ross road and is now regularly resurveyed.

The tiltmeters, deployed in a 1 mile linear array, continued their disappointing performance. All four of them were removed in August 1980 with the intention of redeploying some of them at other sites, in better configurations for servicing, and recording at much lower gain.

The creepmeters at North Shore, on the San Andreas fault, and Superstition Hills, on the Superstition Hills fault, were each serviced twice, but showed no motion during the reporting period. However, between 30 January and 20 March 1980 0.5 cm motion accumulated on the Superstition Hills instrument and was associated with cracking in the pavement along the fault trace nearby.

OTHER INVESTIGATIONS

During the reporting period the following alignment arrays were each resurveyed once: ANZA, on the San Jacinto fault, and CAMERON, CHRISTMAS CANYON, and RAND, on the Garlock fault. None of them showed significant motion since the previous surveys, which were done 6 months to 2 years earlier.

Manuscript in press:

Cohn, S.N., C.R. Allen, R. Gilman, N.R. Goulty, Creep on the Imperial and Brawley faults preceding and following the 1979 Imperial Valley, California earthquake: U.S.G.S. Professional Paper.

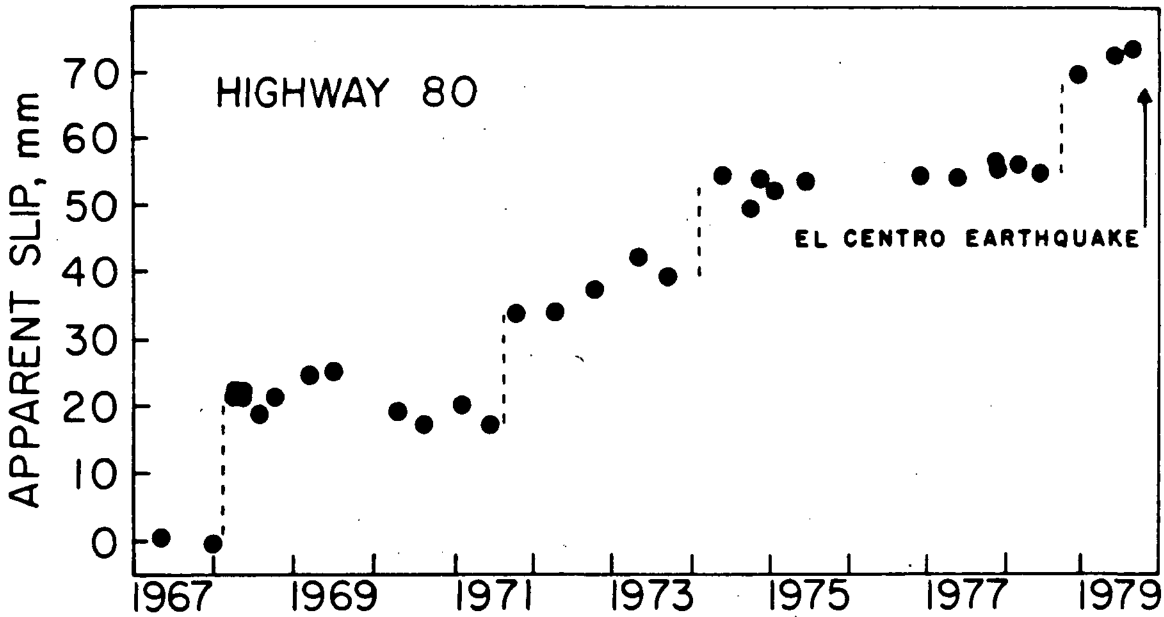

Figure 1. Plot of creep events observed between 1967 and 1969 at the Highway 80 alignment array.

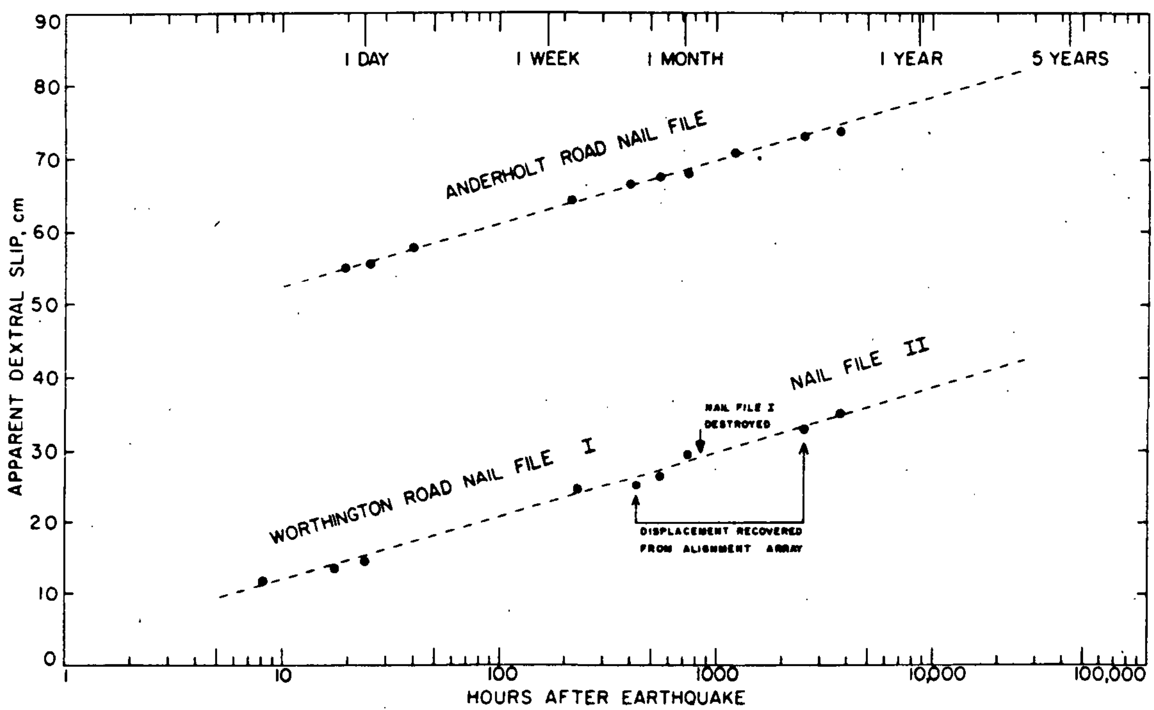

Figure 2. Displacement on the Anderholt road and Worthington road nail files as a function of $Log_{10}(t)$. The dashed lines represent $Disp[cm]=44+8.5Log_{10}(t[hr])$ and $Disp[cm]=3+8.7Log_{10}(t[hr])$ for Anderholt and Worthington roads respectively.

Crustal Deformation Observatory
Part D - Data Logging Facilities
14-08-0001-18365

Jonathan Berger
submitted by Frank Wyatt

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This contract is providing support to facilitate researchers participating in the ongoing *Crustal Deformation Observatory* at Pinyon Flat, California. Art Sylvester from the University of California, Santa Barbara has installed benchmarks at the observatory, which have been re-levelled twice. Participants from Lamont-Doherty Geological Observatory, University of Cambridge, and the University of California, San Diego have begun the installation of parallel long baseline tiltmeters.

Current Developments

1. A total of five tiltmeter vaults have been constructed for housing the electronic components.

2. Complete power and signal wiring has been installed at the end vaults.

3. The working space at the site has been augmented by the addition of a second 50' trailer. This trailer will serve to house the various recording instruments and provide living quarters for visiting researchers.

4. A 14 channel cassette data logger has been fabricated for recording low frequency signals.

5. Four slow speed chart recorders are available for monitoring up to 16 signals.

6. Technical assistance for all researchers at Piñon Flat Observatory has been readily available.

Future Plans

1. In order to minimize future efforts in maintaining instrumentation at the observatory, we have decided to standardize all signal cable drivers and receivers. This equipment will be designed and fabricated by UCSD personnel.

2. The anticipated completion date for the first three long baseline tiltmeters is September, 1980.

3. Larry Slater, C.I.R.E.S., is planning to install a two-fluid tiltmeter along the common tiltmeter baseline about December, 1980.

4. Installation of three Sacks-Evertson borehole strainmeters is expected to take place in April 1981.

Studies of the Seismic and Crustal Deformation Patterns of an Active Fault: Piñon Flat Observatory

14-08-0001-18398

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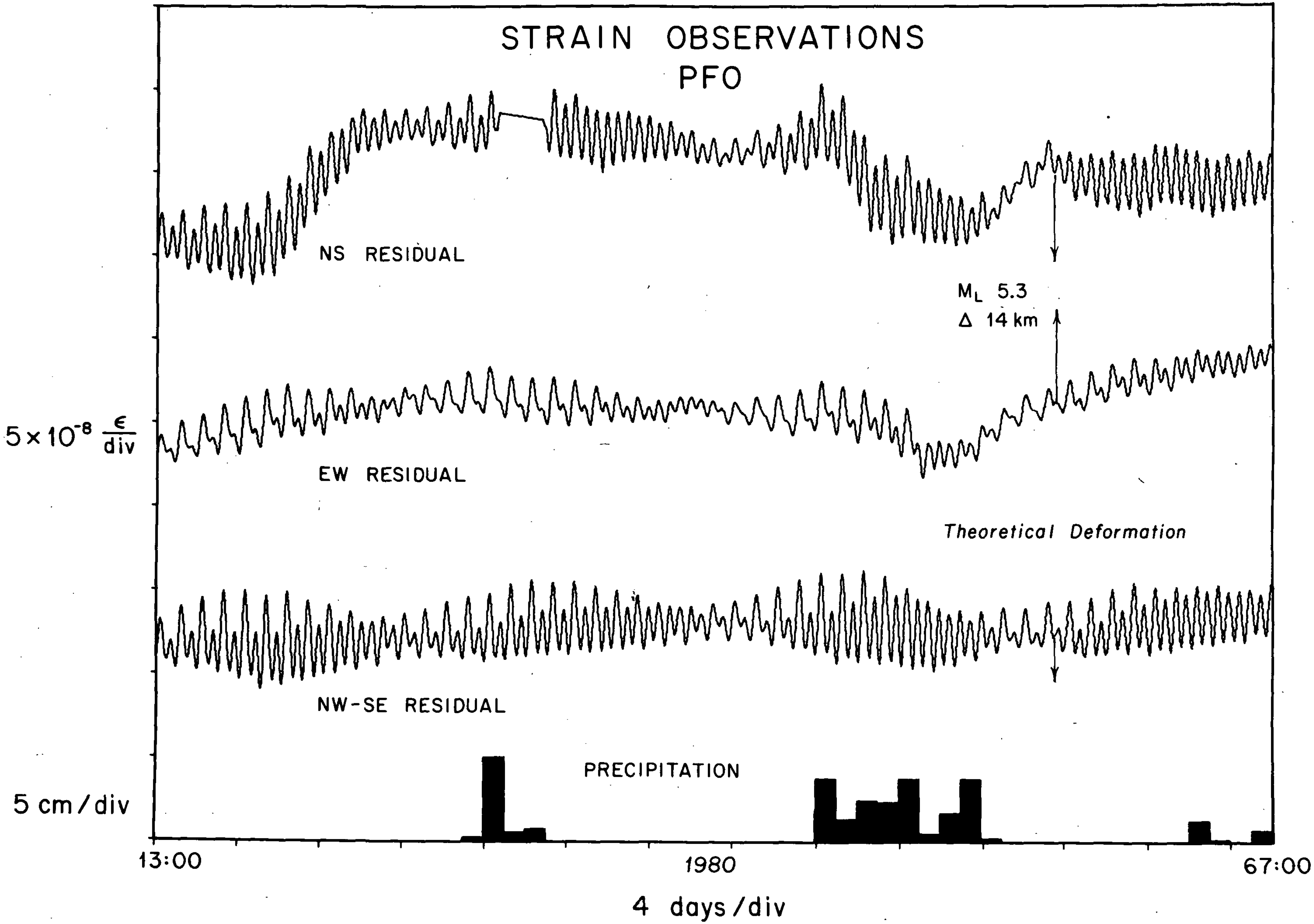
Measurements of crustal deformations are being actively monitored at Piñon Flat Geophysical Observatory (PFO). Geodetic techniques and measurements at the observatory place an upper limit of a few parts in $10^{-7}\varepsilon$ per year of average secular deformation in the region. This rate is currently near the limit of resolution of the various measuring techniques employed. We have found that the limiting factor in the laser strainmeters, the fluid tiltmeter and a number of other deformation monitoring devices is associated with end point or benchmark instabilities. These instabilities appear to be the result of local surface deformations induced by changing meteorlogical conditions. Strain excursions on the order of $5 \times 10^{-7}\varepsilon$, with periods of a few months, are associated with the larger rainfalls. Many of the other instruments at the observatory produce their largest signals during these times. Elimination of this noise by purely analytic techniques is difficult because the response of the surface to these sources is not well understood.

We are attempting to isolate the true tectonic deformations from the locally induced surface deformations by, essentially, making measurements at depth. The depth we have selected as a stable reference is 20-25 meters below the surface. Refraction studies and drill tailings indicate that the material at PFO becomes significantly more competent at about 20 meters in depth.

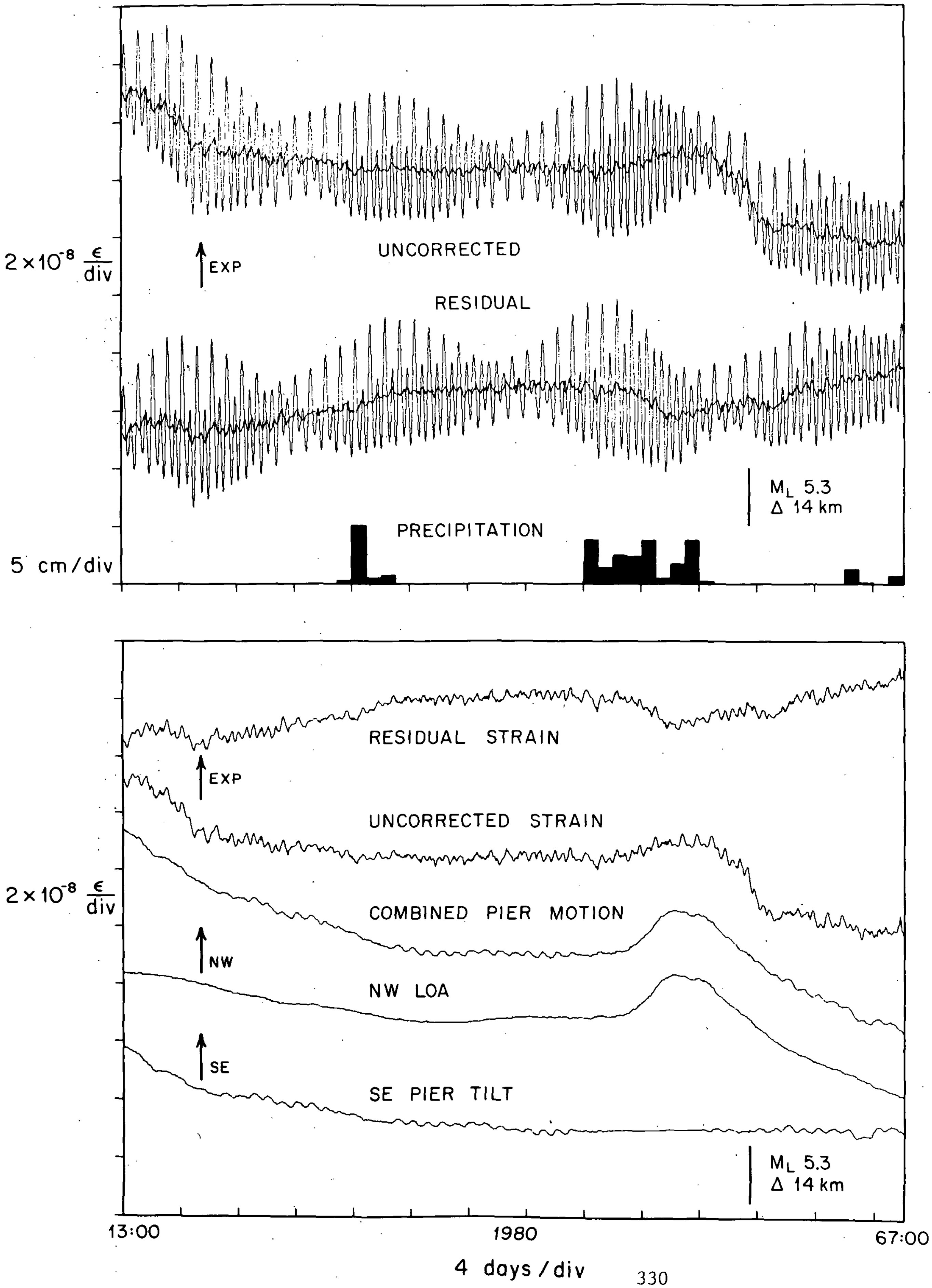
This past winter we experienced a period of exceptionally heavy rainfall at PFO, which was followed by a $M_L = 5.3$ event at an epicentral distance of 14 km. Figure 1 presents a record of the corrected strain records and the precipitation for this period. The theoretical static deformation due to the displacement at the fault is indicated by the arrows. The observed strain offsets have been removed. Unfortunately the high acceleration which occurred at the time of the earthquake caused the end monuments to displace. The instrument least perturbed by the rainfall was the NW-SE strainmeter. At one end of this instrument we have employed our "optical anchor." This instrument monitors the horizontal displacement of a surface monument relative to a point at depth, in this case 25 m. Figure 2 presents the various signals that were used to produce the residual NW strain from the uncorrected strain. Clearly the large perturbation in the uncorrected strain record was due to a displacement of the NW monument as recorded by the optical anchor (labeled NW LOA).

A primary purpose of the observatory is to provide a reference station where other researchers can come to evaluate different techniques in a well instrumented area. A project currently underway (USGS 14-08-0001-18365) involves deployment of four 530 meter fluid tiltmeters on parallel baselines by researchers from other institutions as well as UCSD. Each of these researchers is employing different techniques for measuring surface tilt. Comparisons between these measurements should serve to improve the resolution of tectonic signals of interest. A greater understanding of surface deformation due to environmental and site effects should also be possible. This information would be important to all experimenters using surface monuments to monitor crustal deformations.


STRAIN OBSERVATIONS
PFO
NS RESIDUAL
M_L 5.3
Δ 14 km
$5 \times 10^{-8} \frac{\epsilon}{div}$
EW RESIDUAL
Theoretical Deformation
NW-SE RESIDUAL
PRECIPITATION
5 cm/div
13:00
1980
67:00
4 days/div

F7.a

NORTHWEST - SOUTHEAST STRAINMETER
PFO



Motagua Fault, Guatemala, Afterslip Study

9950-02395

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Investigations

1. Completed development and construction of a prototype creepmeter in conjunction with Harold Clark and Robert Young of the Albuquerque Seismological Laboratory.

2. Periodic resurvey of 4 alinement arrays across the Motagua fault, Guatemala by Instituto Geografico Nacional and reduction of the data.

Results

1. To allow long-term monitoring of continuing afterslip on the Motagua fault, a prototype of an easily installed creepmeter capable of running unattended for long periods of time has been developed. Rather than sensing change in distance between endpoints on opposite sides of strike slip fault by means of a taut wire, the prototype installation measures the angular rotation of a bar supported on opposite sides of the fault and oriented perpendicular to the fault. The rotation is measured by a transducer giving a digital signal recorded on cassette tape. The instrument will resolve 0.5 mm of slip parallel to the fault with data recorded once each minute for 3 months on 1 tape. It is easily installed and not sensitive to thermal fluctuations since angle, not distance between endpoints, is measured. The instrument will be field tested at a site in California where there is an existing creepmeter and alinement array.

2. Following the 4 February 1976 Guatemala earthquake, continuing displacement (afterslip) was observed at a number of sites along the Motagua fault. The most complete record is from the area where the fault trace crosses Highway CA-10, near the town of Zacapa. The first measurement of slip at that site was made by Plafker and others (1976) four days after the earthquake who found 60 cm of left-lateral slip. Subsequent measurements are reported by Bucknam and others (1978) for the two years following the earthquake (610 days) who found the slip had increased to 91 cm. By 19 July 1980, the total slip had increased to 97.3 cm. In May of 1978, with the cooperation and logistic support of Instituto Geografico Nacional of Guatemala, surveying alinement arrays were installed across the fault at four localities (Bucknam, 1978) to allow long-term measurement of afterslip with a high degree of precision (better than $\pm$ 0.5 mm). Afterslip occurring since May of 1978 is summarized below.

Summary of Afterslip Measurements Based on
Theodolite Surveys of Alinement Arrays,
Motagua Fault, Guatemala
(Measurements in mm)

Days after Earthquake

Site	834	843	844	1106	1107	1115	1370	1371	1372	1626	1627	1628
Gualan		0.0		22.6				35.6				48.4
Zacapa			0.0	20.7			32.8				54.6	
Marmol	0.0				24.1			31.0				49.6
Palencia	0.0	monuments destroyed				0.0			15.2	19.6		

Note: Values for the Palencia site below the dashed line are out of step with other sites due to destruction of original monuments by agricultural activities.

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A MULTI-PURPOSE CRUSTAL STRAIN OBSERVATORY, DALTON TUNNEL COMPLEX, SAN GABRIEL MOUNTAINS

Contract No. 14-08-0001-18339

UNIVERSITY OF SOUTHERN CALIFORNIA
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SUMMARY

Two pair of Bilham-King carbon fiber strainmeters are presently operating in southern California. One pair (parallel; east-west orientation; 80 ft. and 60 ft. long located in a shallow mine just north of Bouquet Reservoir) has been operational since December 1978. The second pair (an orthogonal NW-NE pair, 105 and 195 ft. long, respectively, in the Dalton Observatory north of Glendora) were set up in mid-June 1980.

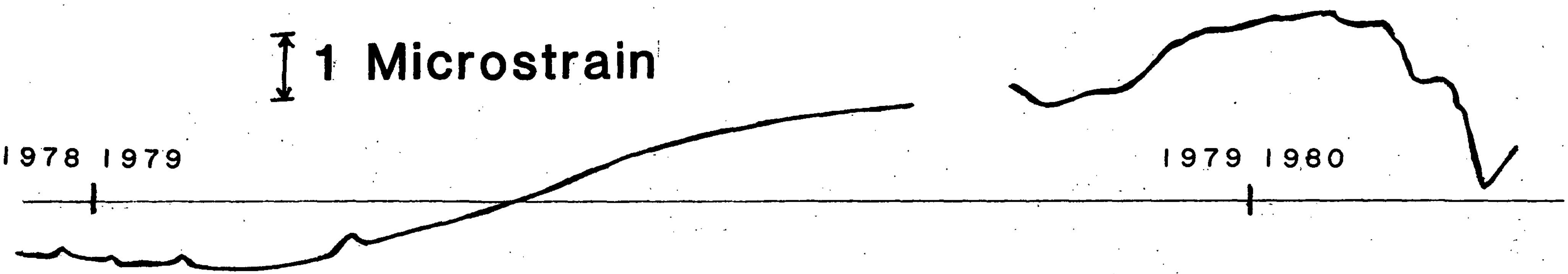
A. Bouquet Strainmeters

BQS1 experienced an episode of E-W tension in the period covered by the trilateration anomaly of Savage et al. Figure 1 shows the BQS1 data from late 1979 through March 1980. Unprocessed records for June and July, 1980, show the extensional recovery of March 1980 to be continuing.

B. Dalton Strainmeters

Dalton Tunnel was equipped with massive concrete piers anchored to the tunnel walls by numerous ribs of 3/4" re-inforcing steel epoxied to the rock to depths of 18". The two strainmeter mounts were fixed to the piers with stainless steel anchors and epoxied in place. The instruments have shown no tendency to drift after the first week.

Because Dalton Tunnel is still being regularly visited by persons installing instrumentation, we have not processed the long-term records. The new Hebrides earthquake excited a sizable response in the NE (195 ft.) instrument (Figure 2) but not the NW (105 ft.) instrument. Since the relative azimuth of source and receiver is NE, the preferential excitation on the NE instrument may reflect strong Rayleigh wave energy and weak Love wave energy along the azimuth.

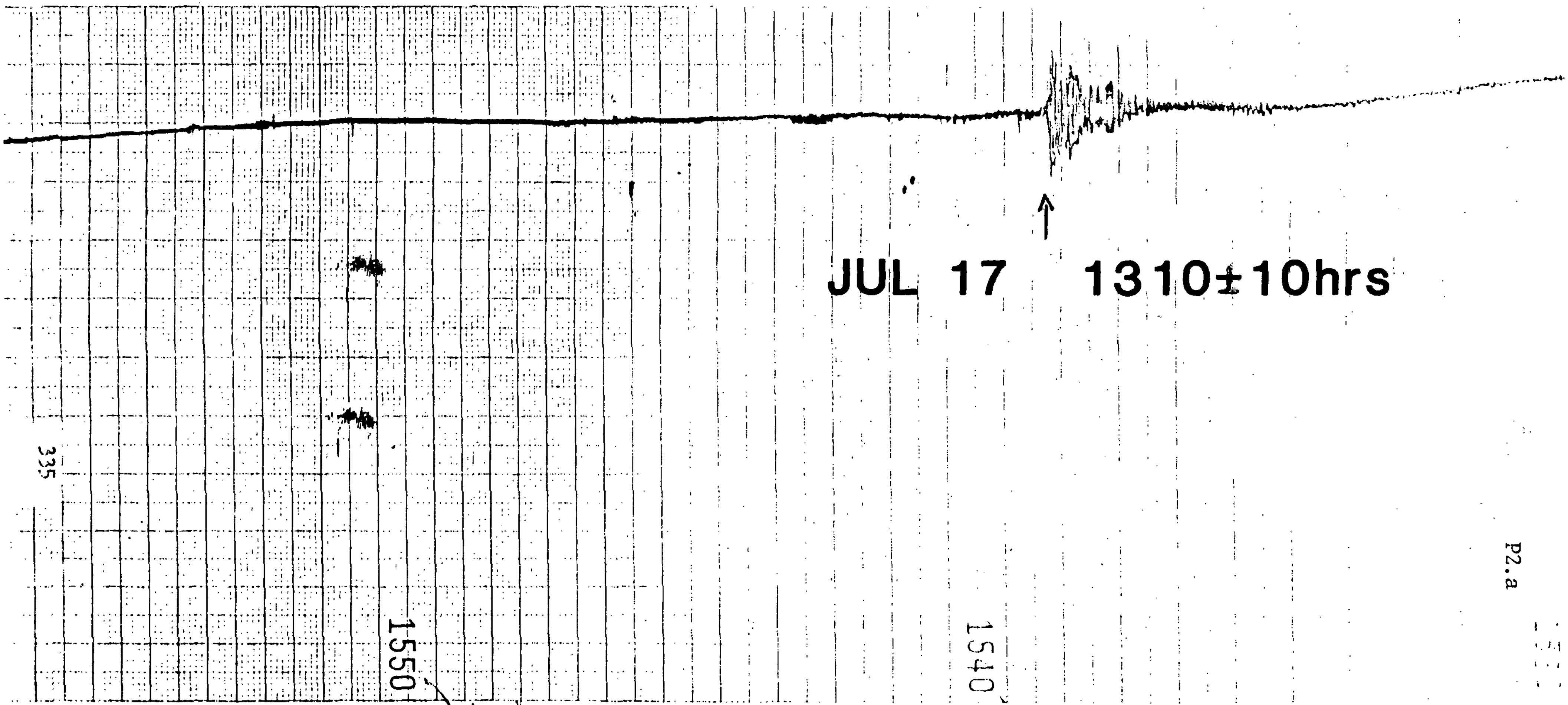


BOUQUET RESERVOIR STRAINMETER

Figure 1

Figure 2

NEW HEBRIDES EARTHQUAKE



P2.a

Tilt, Strain, and Magnetic Measurements

9960-02114

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Investigations

1. As part of the U.S.-China Cooperative Exchange Program two combination geodetic and magnetic arrays were installed and measured across active segments of the Red River fault system in Yunnan Province. Seismic activity in this region is high and rapid uplift of 50 mm per year has been reported. Initial magnetic measurements were made also in arrays on the Da Chang and Ba-Bo Chang faults in the Beijing area.

2. Magnetometers and tiltmeters were installed on Mt. St. Helens eight days prior to its most catastrophic eruption this century. Records from the one surviving magnetometer and the few surviving tiltmeters are presently being analyzed. Subsequent to this eruption, three new telemetered magnetometers and a differential micro-barograph have been installed.

3. Drill holes for the Carnegie deep hole volume strainmeters in the Mojave Desert are now in the final stages of completion due to the participation and cooperation of many different people. Installation is expected to be complete by November.

4. Determination of the accuracy and precision of the USGS magnetometer array is now almost complete following testing at magnetically quiet and tectonically stable sites in Colorado.

5. A deep-hole differential strainmeter has now been designed and constructed. Stability testing will be carried out in the Presidio Vault.

6. Noise reduction techniques are being applied to differential magnetometer data from the USGS magnetometer array.

Results

1. Three recording proton magnetometers with 0.25 nT sensitivity were installed on Mt. St. Helens, ten days before its most catastrophic eruption in the last 1000 years. Two units were lost in this eruption. The third, located about 5 km to the west of the main crater, has sampled continuously to the present at a rate of 0.1

min^{-1}. When referenced to synchronized data in California or Victoria, Canada, no transients of more than 2 ± 2 nT occurred during the eruption. An offset of 9 ± 2 nT occurred during the eruption. More than half of the offset may be due to the removal of about one cubic kilometer of the mountain and a similar amount could have resulted from elastic strain release. Subsequent large eruptions on May 25 and June 12 were preceded by transients of more than 50 nT occurring several days beforehand. These appear, however, to be due to extraordinary external field disturbances that, by coincidence, preceded these eruptions. Simple volcanomagnetic models, consistent with the observed deformation data, indicate transient anomalies at this location of not more than 20 nT.

2. An analysis of synchronized total magnetic field measurements throughout California indicates that localized anomalies with amplitudes of more than one nT occur at both ends of the creeping zone of the San Andreas fault in central California, the junction of the San Jacinto and San Andreas faults, and the region near the Mission Creek-Morongo Valley faults. A search for general regional differences between the mean data obtained from southern California sites and that from central California sites indicates that, after correction of the data from normal secular variation during the period 1974-1980, no mean field difference greater than 2 nT has occurred during this time in spite of the different tectonic regimes of these two areas. The secular variation rates were determined by least squares line fitting and ranged from 45 nT/yr near San Francisco to 55 nT/yr near the Salton Sea. The best fitting plane to these data has the form $0.043X - 2.22Y + 123.18 - Z = 0$ where X is the decimal longitude, Y is the decimal latitude, and Z is the secular variation per year. This corresponds to a maximum spatial gradient of 1.5 ± 0.5 nT/100 km/yr.

3. The variations in daily averages of 37 different field records between pairs of magnetometers in the U.S.G.S. array have been analyzed for evidence of localized magnetic variation that might relate to stress changes on the San Andreas and Calaveras faults. Fluctuations in the differences that can be attributed to magnetospheric and ionospheric activity are seen in 19 of the 37 and have been removed using a linear combination of the component fields from Boulder Magnetic Observatory. The optimal coefficients are found for each pair, using multi-channel (Wiener) predictive filtering. In a few cases for which the coefficients are large, application of coefficients determined from high frequency fluctuations, has the effect of correcting the long term drifts in the differences to fit the secular variation trend for central and southern California. The effect is so large for one pair, that on correction the drift changes polarity. Temperature effects are seen in three cases and can be removed using the

prediction filtering, but in general such effects are undetectable in the daily averages. The cleaned difference fields which result from removing fluctuations corresponding to ionospheric and magnetospheric activity (and temperature, where applicable) reveal the presence of localized magnetic variations unexplained by these effects. Excursions before the Busch fault earthquake of 1974 have been identified in the records of the two magnetometers closest to the epicenter, but the records from the magnetometer in the vicinity of the Coyote earthquake of 1979 do not show a similar precursive variation. The spatial and temporal coherence of the remaining magnetic excursions is currently under investigation.

4. Five electronic tiltmeters were installed around Mt. St. Helens during April and early May of 1980 over a range of radial distances which varied from three to fifteen kilometers from the center of the volcano. Since the beginning of its operation in mid-April, the instrument located four kilometers northeast of Mt. St. Helens indicated a general inflationary trend corresponding to roughly one to two microradians per day. This instrument and the one located to the east were both destroyed during the beginning of the large eruption on May 18. The three tiltmeters located to the south of the volcano continued to operate with changes of a few microradians recorded by the closest surviving instrument situated five kilometers south of the volcano. As indicated by this one instrument, the region around Mt. St. Helens continued to slowly inflate after May 18 at a rate of roughly one microradian per day until mid-June, at which time this inflationary trend apparently stopped. This change in the tilt pattern approximately corresponds in time to the appearance of the first dome. Two additional electronic tiltmeters were added in late June to the network surounding Mt. St. Helens. Since July, these new stations together with the previously existing instruments have indicated an overall subsidence of the region around the volcano amounting to five to ten microradians at a radial distance of five kilometers.

5. The wedge shaped Darran Mountains in Fiordland, New Zealand, extend from 40 km to within 10 km of the Alpine fault. Since their emplacement (~150 m.y.B.P.) the fault has displaced by nearly 500 km in a right lateral sense, and at least 10 km of uplift has occurred on the Southern Alps to the north. Arcuate ophiolite belts and apparent bending of schist belts to the northeast imply distortion on scales of hundreads of kilometers. Paleomagnetic field directions across the Darran mountains indicate that, within the measurement errors, no apparent shear rotation has occurred, and only a minor tilting, of the block down to the southeast, is necessary to obtain agreement with the well determined Mesozoic/Jurassic geomagnetic pole. Both a.f. and thermal demagnetization experiments show these magnetization

directions to be stable and free from substantial secondary overprinting. The mean paleomagnetic field direction for all sites is D = 136°, I = -64.7°, α_{95} = 9.4°.

These results can be most simply explained by invoking a concentration of shear deformation in a presently contorted gneiss zone between the Darran mountains and the Alpine fault. In this zone magnetization directions are more chaotic and are not apparently related to present or past poles. The apparent absence of horizontal rotation of Fiordland implied by these data and other data further to the east may provide some constraints on fault. In particular, indications of viscous flow near the fault and the lack of apparent deformation of the Darran Block suggest that the Alpine fault zone is weak, and this is most easily achieved if the normal stress on the fault is low.

6. Seven weeks prior to the M=5.1 Thanksgiving Day earthquake of November 28, 1974, an anomalous magnetic variation was observed at one of the magnetometers of the USGS array which lasted for about three weeks (Smith and Johnston, 1976). Recently developed methods of reducing noise on magnetic records reveal that anomalous magnetic changes occurred at about the same time at three of the six stations analyzed. Such changes have not been seen either previously or subsequently. The largest variation occurred at the two stations closest to the earthquake, but a change also occurs at a station 44 km to the south.

7. The epicenter of the Coyote Lake earthquake (M_L=5.9±0.2) of August 6, 1979, is located within an array of recording magnetometers which has been in operation since 1974. The nearest instrument, COY, was within 5 km of the epicenter. It was installed in October 1978 and is located on sedimentary rock, although volcanic and ultramafic rocks with magnetizations of up to 1 A/m outcrop 2 km to the west. A second recording magnetometer was operated for 18 days, beginning 4 days after the main event, to record the latter stages of the aftershock activity. Although longer-term magnetic field variations were recorded at station COY early in 1979 relative to other sites in the area, no anomalous changes within the two months prior to the earthquake were observed outside the present measurement uncertainty of 0.8 nT for hourly average differences. During the late aftershock stage, no magnetic field change greater than 0.25 nT occurred for more than a day. We conclude that, in contrast to the 2-nT change observed before a previous M=5.2 earthquake near Hollister, California, no demonstrable preseismic, coseismic, or postseismic tectonomagnetic effect was detected. A reasonable seismomagnetic model of the earthquake indicated that station COY was poorly located to detect stress-generated magnetic perturbations from this earthquake. Using a magnetization distribution indicated by modeling the aeromagnetic data over the

area, we have calculated that homogeneous shear stress changes of about 5 MPa or greater would have been necessary to produce any observable effect at COY. This change in stress is precluded by geodetic data from over the area. However, COY is ideally situated for detection of electrokinetically generated magnetic anomalies. This initial null observation indicates that the assumptions used in the calculation of electrokinetic effects have, in this case, not been satisfied.

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Fault Zone Tectonics

9960-01188

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Investigations

1. Maintained and upgraded creepmeter array in California.

2. Moved archived creep data to PDP 11/70 computer and wrote software for data reduction, manipulation, and plotting.

3. Searched for distinctive fault creep prior to earthquakes.

Results

1. A new wire creepmeter (instrument XHR1) was installed on the San Andreas fault south of San Juan Bautista to run concurrently with the older rod instrument HRS3. The rod instrument SJN1, just north of San Juan Bautista, was replaced with a new rod instrument. Telemetry was added to three of the creepmeters near Parkfield, California. Instrument XWR1 near Palmdale, California, was reinstalled after being vandalized. Currently 42 extension creepmeters operate; 25 of the 42 have on-site strip chart recorders; and 20 of the 25 are telemetered to Menlo Park.

2. Fault creep data from all 42 USGS creepmeter sites on the San Andreas, Hayward, and Calaveras faults have been updated (through September 1980) and stored in digital form (1 sample/day). Software for manipulating the data and producing creep-time plots has been written and is now operational.

3. Some of the most striking anomalies of the creep data that have been noted during this period include the following deviations from the apparent long term creep rate:

   a. A pronounced decrease in rate at SHR1 (Calaveras fault 10 km NW of Hollister) beginning in 1975 and recovering about the time of the August 6, 1979, Coyote Lake earthquake.

   b. A decrease in rate at XSJ2 (San Andreas fault near San Juan Bautista) from 9 mm/yr to 3.5 mm/yr beginning in early 1976 and continuing to the present.

c. A gradual increase in rate at HWR1 (Hayward fault, City of Hayward) from 4 mm/yr to 6 mm/yr beginning in 1976.

d. A significant decrease in rate at CRR1 (San Andreas fault near Parkfield) from 10 mm/yr to nearly 0 mm/yr since 1977. This is the first lag of its kind at CRR1, which has kept at a remarkably steady rate since 1969.

Theoretical Mechanics of Earthquake Precursors

9960-02115

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Investigations

1. Constructed and performed parametric studies on two-dimensional models of faults in the Hollister, California, area. The models simulate the elastic (and geometric) interaction of faults and predict, in particular, the effects of localized earthquake slip on nearby creep and geodetic measurements. If the models are consistent with past seismicity, fault creep, and geodetic data, the models will be used to estimate parameters of future earthquakes.

2. Studied theoretical models of one-dimensional and two-dimensional faults, incorporating fault zone constitutive laws inferred from laboratory measurements of frictional sliding.

3. Continued development of a simple method for using repeated geodetic measurements to estimate nearness of earthquake instability.

Results

1. Model simulations were made to help clarify the relations among seismicity, fault creep, the orientation of fault strands, and the regional principal stresses. In the model, fault strength obeys a pressure dependent law, which is assumed to have the form of a constant coefficient of friction. Observed moderate earthquakes are included in the simulations by imposing abrupt drops in frictional strength. A close fit of observed creep with calculated slip suggests that most changes in creep rate (persisting for more than 3 months) are caused by moderate earthquakes lying within 10-20 km, even when the creepmeter and earthquake are on different faults. That is, separate fault segments interact. In particular, the model predicts periods of anomalously low creep rate before most earthquakes as a direct result of earlier earthquakes elsewhere in the fault system. Because a constant coefficient of friction is assumed, the results, so far, do not predict the actual earthquake instability. Strain- and velocity-dependent fault laws, which will lead to instability, are being incorporated.

2. These model simulations were made to explore the effect of laboratory-inferred friction laws on the sliding behavior of in situ-scale faults. The fault zone "frictional" strength is characterized by two competing effects: an instantaneous dependence of fault strength on velocity (strength increases with velocity); and also an inverse dependence of strength on velocity that takes full effect only after a finite amount of slip d has occurred. The models predict recurring rapid slip events followed by periods of strain accumulation. Slow stable (creep) events are favored by low pressure, large elastic stiffness, and large d, and vice-versa for unstable events. 2-D simulations in a plate, with increasing pressure with depth, show a pronounced damping of slip perturbations at shallow depths ranging downward to steady oscillations and downward further to unstable growth of perturbations. Comparison of results with creep events on the San Andreas fault suggests that surface creep events must be confined to approximately the upper 1-2 km of the fault: deeper events would tend to be unstable.

3. In the method, a single scalar variable R is estimated from changes of geodetic measurements. In theory, R increases with time and reaches unity at earthquake instability. The equation for R is derived from an instability criterion (such as those used in strain softening instability models), conventional elastic dislocation solutions, and a regional strain field. R requires a specified fault geometry but is independent of fault properties and magnitude of shear stress. The method has been applied to geodetic measurements near Palmdale, California.

Reports

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Experimental Tilt and Strain Instrumentation

9960-01801

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Investigations

1. The project investigators continued to operate tiltmeter and strainmeter arrays in central and southern California, totaling 54 sites, and a tiltmeter array in Alaska consisting of three doubly instrumented sites.

2. Shortly after the initial venting of Mt. St. Helens on March 27, 1980, Carl Mortensen initiated action to install tiltmeters on the mountain to monitor possible short-term deformation that might be associated with eruptions. In early April he went to the mountain to investigate possible tiltmeter sites and to help Arnold Okamura, of HVO, in the installation of five platform type tiltmeters. It was decided to observe the performance of the platform instruments and to delay installation of the borehole instruments until the melting of the snowpack. John Dvorak transferred to Vancouver to monitor and interpret the data. Two of Okamura's platform instruments, along with telemetry equipment from this project, were lost in the explosive eruption of May 18. In early June Mortensen, Iwatsubo, Myren, Murray, and Dvorak installed two borehole tiltmeters near the mountain using a modified technique to permit rapid rezeroing of the instruments. In August Gene Iwatsubo transferred to Vancouver to maintain the tilt and magnetic instrumentation.

3. Tom Murray continued to maintain and upgrade a system that uses sensitive pressure transducers to monitor the "tilt" of San Andreas Lake, near Belmont, California.

4. Doug Myren, with technical advice from John Van Schaack, took the lead role in evaluating, modifying, and testing the standard Kinemetrics' tiltmeter electronics for improved thermal immunity and stability. He and Doug Collins modified and tested twenty tiltmeter electronics for use in a "cluster" test, in extended-baselength installations and for the retrofit of existing field sites. The modifications typically decrease the thermal response of the electronics by a factor of 5 to 10 compared with unmodified but properly operating electronics.

5. A program has begun to exchange unmodified for modified electronics packages at tiltmeter sites. With only one week of data at one site available to date, a substantial improvement in performance has not been observed at that site. Since this simple test has little control, it is not possible to say whether the site is bad or whether the sensor is malfunctioning. It is planned to exchange electronics packages at most sites within the tiltmeter network to see whether substantial improvement in data quality can be realized.

Results

1. To determine the contribution of electronic thermal response to tilt records from shallow borehole sites with standard and modified electronics, a test was conducted in which one of each electronics in the same instrument pit was operated with a dummy resistance buried in the borehole where the sensor is normally positioned. Records from this test appear in Figure 1a. Presumably they reflect thermal electronic noise isolated from other sources of tilt noise or signal. The worst electronic drift was 0.07 μradian over a seven-day period; it occurred on the "x" component of the unmodified Kinemetrics. It is interesting to note that even the worst case of electronic drift cannot account for the large fluctuations that appear in some of the tilt records. It is also interesting that there is no indication of diurnal periodicity in the records from this test. Temperature tests of the strainmeters indicate that the dominant thermal contribution is from thermoelastic strain in the ground.

2. Figure 1b shows a comparison of 40 days of data from the prototype extended-baselength tiltmeter, which has a baselength of 10 m, with data from the adjacent short-baselength tiltmeter. These data serve to confirm the earlier results that the baselength extension substantially improves immunity to surface tilt noise, while introducing sightly larger thermal response. Temperature tests are being conducted to determine whether the greater thermal signal is due to increased conductivity around the sensor, thermal response of the mechanical parts of the installation, or differing ground response.

3. The Gold Hill (GOH) tiltmeter site near Parkfield was selected as the site for an experiment involving a closely spaced cluster of five modified and calibrated instruments. The GOH tiltmeter has produced some of the lowest-noise tilt data in the past and is considered to be one of the best tilt sites. Thus the good quality of the site for this experiment is taken as an a priori assumption, and as long as one instrument of the cluster of five produces data of the quality of the original GOH instrument, or better, the site-selection criteria are not in question. The test, then, is to determine whether detectable changes in tilt are

coherent among closely spaced instruments in shallow boreholes over periods that might be of interest in earthquake prediction--on the order of a week to a month. Figure 2 shows some of the first data from the five clustered instruments as well as concurrent data from GOH (Figure 2a, top two traces). Substantial improvement in data quality is evident. However, there is no apparent coherence over this six day period. It should soon become apparent whether this behavior represents a settling-in period or is the typical pattern of behavior for shallow-borehole, short-baseline tiltmeter installations at carefully selected sites. In the latter case a value for tilt noise will have been determined empirically for such sites and it should be possible to decide whether the tiltmeter experiment should proceed in its present form.

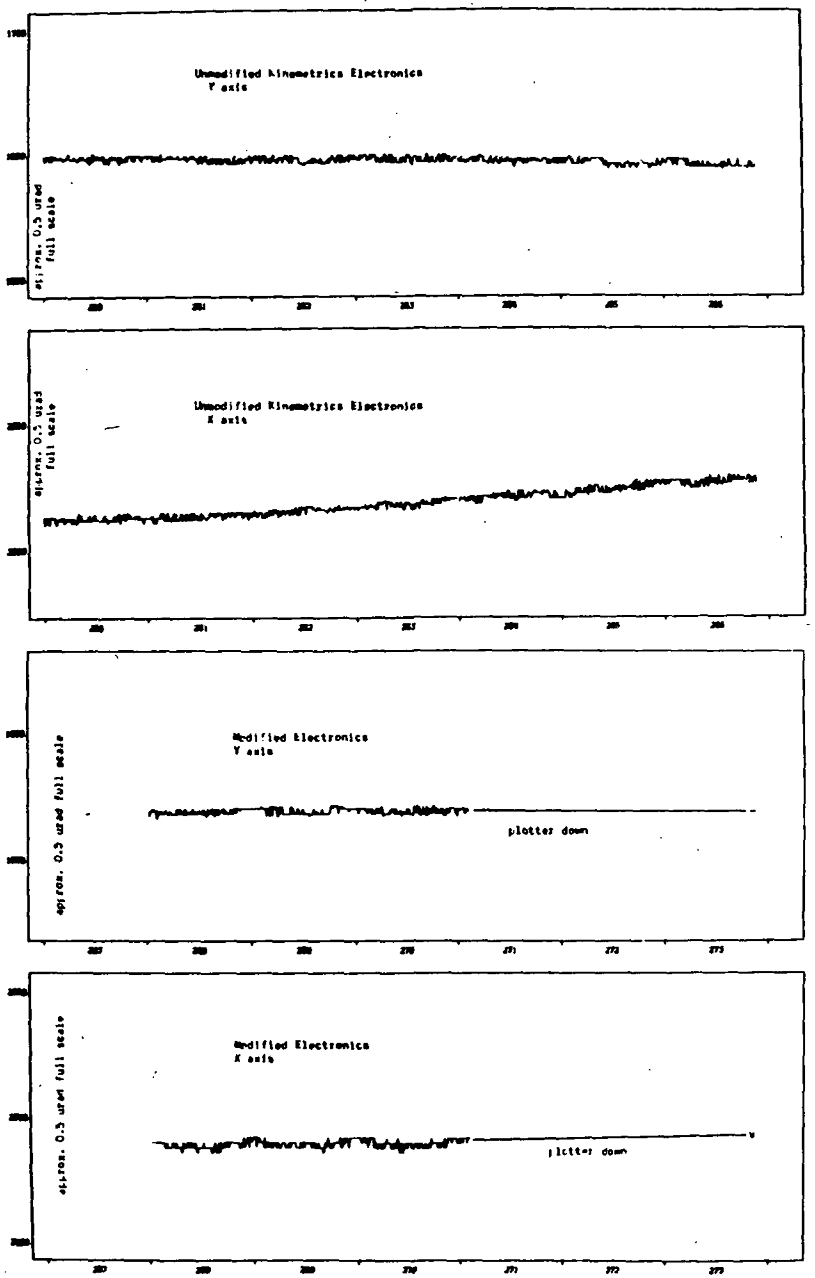

Fig 1a. Field temperature test using dummy resistance bridge in place of tilt sensor. Worst case drift is 0.07 urad in seven days for unmodified electronics, X axis.

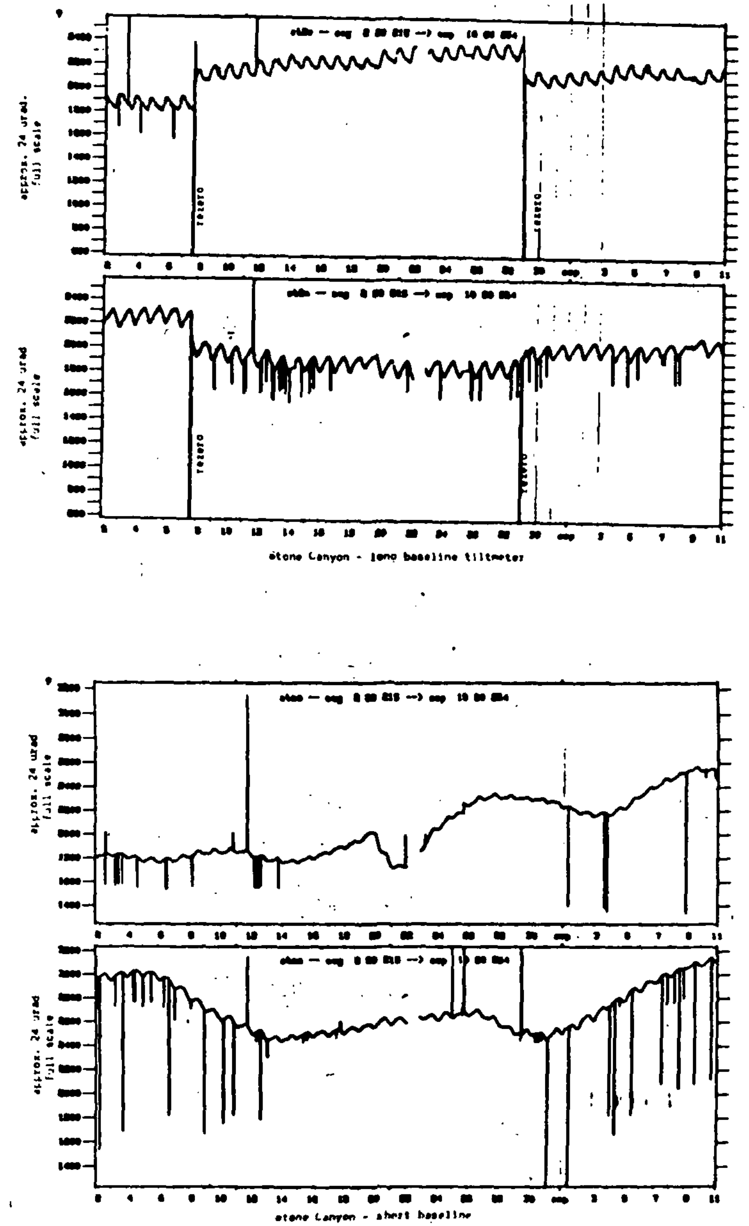

Fig 1b. Comparison of prototype extended base-length tiltmeter (top two traces) with short-base instrument (bottom two traces).

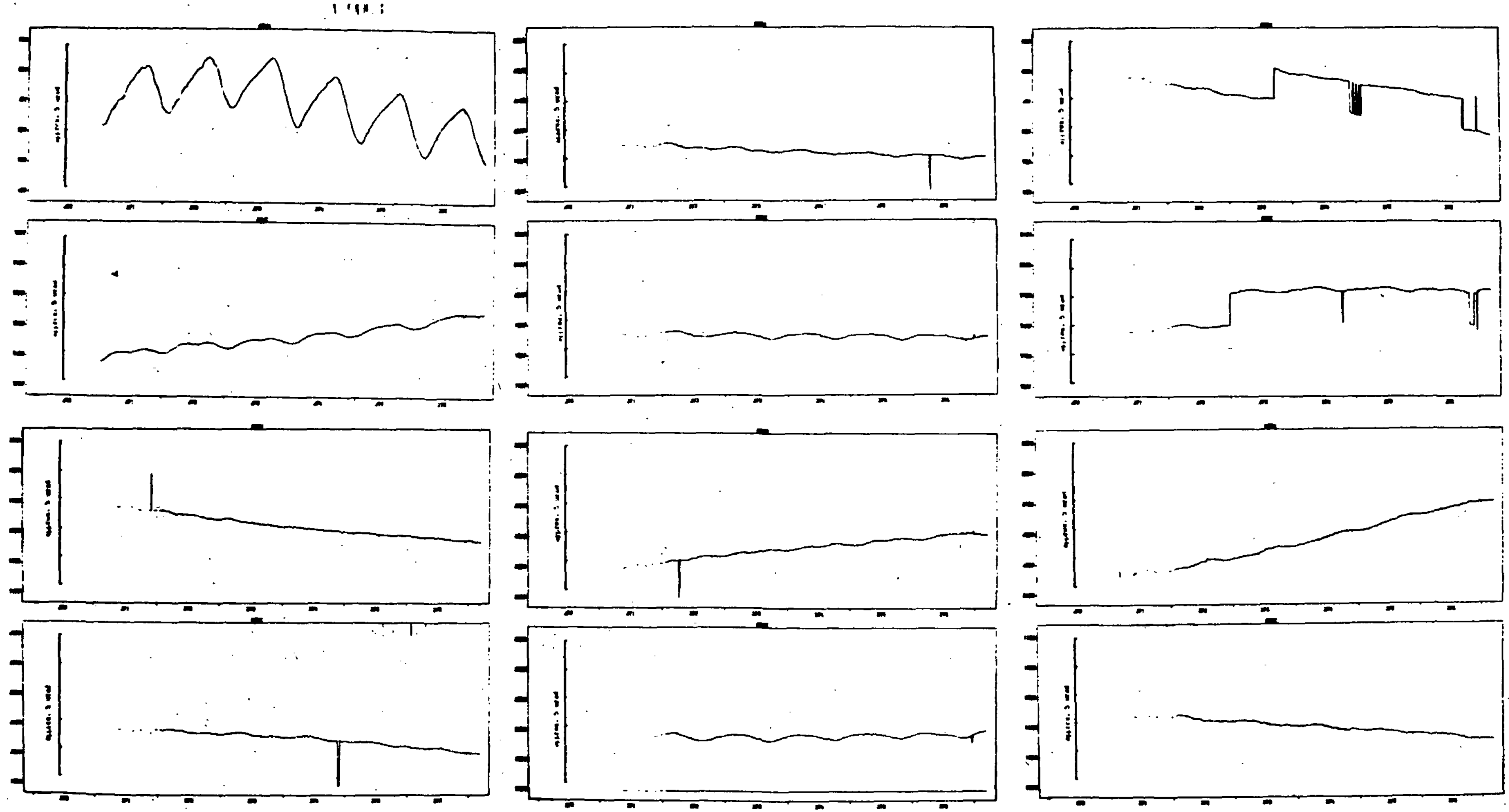

Fig.2a. Unmodified tiltmeter (top traces)
Modified tiltmeter A (bottom traces)

Fig.2b. Modified tiltmeter C (top traces)
Modified tiltmeter B (bottom traces)

Fig.2c. Modified tiltmeter D (top traces)
Modified tiltmeter E (bottom traces)

Dry Tilt and Nearfield Geodetic Investigations of Crustal Movements, Southern California

14-08-0001-17685

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Investigations

By means of telescopic spirit leveling (dry tilt) of small aperture triangular arrays, precision leveling of short lines across faults, and precision surveying of alignment arrays and trilateration networks, we have been monitoring the following physical phenomena within the southern California uplift and in other areas of potentially active crustal movement:

1. The regional pattern and timing of tilt, if any, and
2. The nature of strain accumulation and release, if any, across well-defined active and potentially active faults.

During 1979-80 we resurveyed 49 dry tilt arrays from 2 to 10 times each. Most of the arrays are located along the San Andreas fault zone from Frazier Park to Cajon Pass. Others are located along the frontal fault system of the San Gabriel Mountains. Twenty-four of the arrays have been in place nearly 4 years, and others have been added more recently.

We have established 19 short level lines across active faults in such diverse places as San Fernando, Death Valley, Palmdale, San Juan Bautista and Santa Barbara. Some of these lines were established 10 years ago and have accumulated as many as 14 resurveys. Two lines, one across the San Andreas fault near Valyermo, and one across the Llano fault 30 km east of Palmdale, were established in the present contract period.

Two leveled alignment arrays established four years ago across the San Andreas fault were resurveyed twice each in the past year.

Thirteen trilateration arrays have been established across several faults in southern California in the last three years. Only those across the Santa Cruz Island fault zone were surveyed in the past year.

Results

We have observed no local or regional tilt activity which we would regard as anomalous, and indeed there has been no earthquake activity in the study area which would be expected to have produced such activity. Thus, the anomalous tilts we observed in the Juniper Hills-Lake Hughes area in Winter and Spring of 1978 ceased in the late 1978 and 1979, just as the earthquake swarm activity there has also ceased along that segment of the San Andreas fault zone.

With one exception, resurveys of the short level lines have documented only non-tectonic effects related to thermoclasticity and subsidence related to withdrawal of groundwater for agricultural irrigation. Where the irrigation is fairly continuous and involved large withdrawal volumes that exceed recharge rates (San Juan Bautista, Duravan Ranch), the subsidence is episodic in detail but continuous in annual rate and direction. Where the withdrawal is of small volume and less than presumed recharge rates (Pallett Creek) the subsidence is small, 1 mm over a line length of 200 m, and recovers completely when the well is not pumped.

The exception is the Mesa Valley Farm leveled alignment array located across the most recently active trace of the San Andreas fault between Gorman and Frazier Park. Precise leveling shows that 3 mm differential vertical separation has taken place between July 1978 and August 1980. This is a stretch of the fault which is not known to have moved since at least 1911 if not 1857. The separation corresponds temporally with the stress changes observed by others across the San Andreas fault in southern California and may be the surficial strain manifestation of the stress changes.

REAL TIME MONITORING OF RADON AS AN EARTHQUAKE PRECURSOR IN ICELAND

Contract # 14-08-0001-17726

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REPORT SUMMARY

We report radon data collected from October 1979 to May 1980 from geothermal wells in Iceland. Discrete radon samples are being collected weekly from nine stations in the Southern Iceland Seismic Zone (SISZ) and two stations in the Northern Iceland-Tjornes Fracture Zone (TFZ) to determine the potential for earthquake prediction. We also monitor volume ratio of gas to water, wellhead temperature and chloride content of the water to enable us to constrain the possible mechanism involved in radon anomalies.

During the report period we observed one prominent radon anomaly at Hafralaekur and a second radon anomaly at Selfoss. The change at Hafralaekur preceded a (M=4.7) earthquake that occurred 60 km away. The less prominent Selfoss anomaly preceded a (M=2.01) earthquake that occurred at a 9 km distance. Two spreading episodes occurred on February 11 and March 16 at Krafla in northern Iceland. A prominent coepisodic increase in radon emission that is monitored in fumaroles on top of the magma chamber followed the March 16 spreading episode. The February 11 episode was a minor event and no large changes in radon emission were observed.

A quantitative description of our Flow Rate Model is presented. The model can be used to predict the changes of ground water flow velocity needed to sustain some of the observed radon anomalies.

INVESTIGATION OF RADON AND HELIUM AS POSSIBLE FLUID-PHASE PRECURSORS TO EARTHQUAKES

14-08-0001-18348

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This report includes new data on radon, helium, and other dissolved gases (N_2, Ar, CH_4) in thermal wells and springs along our Southern California network, for the period October, 1979, to September, 1980. Additionally, since this is an annual report, complete tables and graphs of data measured from 1975 to the present are included as appendices. Temperature and conductivity graphs are also shown for most sites.

Two sites, Arrowhead Hot Springs and Hot Mineral Well, at opposite ends of our S. California San Andreas network, have been of special interest during the past year. Arrowhead Hot Springs showed a large increase in radon and helium (plus all other gases) in early 1979, prior to the Big Bear earthquakes (M=4.8). This increase, probably precursory, has been extensively discussed in TR 11 and TR 12, in which it was shown that the observed increases represent an increase in the "deep" component of gases in a two-component mixture with atmospheric gases dissolving into the exposed hot-spring surface water. By mid-1980, the radon and helium levels at Arrowhead had returned to normal baseline levels where they have remained since then.

At the south end of the San Andreas, in the Salton Sea geothermal area, Hot Mineral Well and Bashford's Baths Well, two 60°C hot wells in continual use, both showed 37% increases in radon concentration relative to previous baselines, beginning in February of this year. These increases may have been precursory to three small (M=3.3, 3.0, 3.3) earthquakes on April 6 and 7, which occurred 25 km south of these wells, on the fault trace. These increases were observed only in radon; helium, nitrogen, and argon showed no effect. The time interval prior to the earthquake was 66 days in each case, somewhat longer than expected for such small seismic events. Two lower-temperature wells and Frink Spring, farther south and closer to the epicenter, showed no radon variations prior to the earthquakes.

Frink Spring has, however, undergone a steady increase in helium concentration since 1975, approximately 5% per year over a five-year period. This 25% increase in helium is not matched by increases in radon, nitrogen, or argon. Nor, as we show in this report, has there been any change in the He^3/He^4 isotopic ratio during this time. The effects in this spring, including very unusual N_2 and Ar concentrations, are quite complicated and are not yet understood. A significant component of mantle helium appears to be present, since the He^3/He^4 ratio is twice the atmospheric ratio and is probably higher than can be accounted for by tritium from nuclear weapons testing.

During May and June, H. Craig spent six weeks in China and Tibet, a visit occasioned by the Symposium on the Qinghai-Xizang (Tibet) Plateau organized by Academia Sinica, with a field trip across Tibet after the meeting. A preliminary plan for cooperative work in geochemical monitoring was laid out with the State Seismological Bureau in Peking, and several lectures on our work were given at the Bureau prior to the meeting.

In Tibet, H. and V. Craig returned to Lhasa after the field trip and carried out field work in the Yangbajin geothermal area to the north, collecting gases from hot springs and geothermal steam wells. This work was done with Dr. Cai Zuhuang of the SSB, who is collaborating in the Tibetan study. The most important result to date has been the finding that the Tibetan helium is entirely "crustal", i.e. radiogenic in origin, with no evidence of a mantle component. The He^3/He^4 ratio is, in fact, lower by a factor of 135 than the ratio in helium at Yellowstone Park (a mantle plume area)!

Joint work with the Peking SSB is continuing. Two Chinese scientists will visit our laboratory for one month during December, to study laboratory and field collection techniques. Then during early 1981, two of our group will work in the Yunnan geothermal area with SSB scientists, and carry out some further collections in the Peking area. A program for a very extensive study of crustal fluids throughout China is being developed as a joint long-term study involving helium, radon, other gases, stable isotopes, and chemistry, in a variety of tectonic regimes where significant earthquake hazards are present.

TECTONIC MONITORING OF THE SOLOMON ISLANDS AND NEW HEBRIDES ISLANDS REGION

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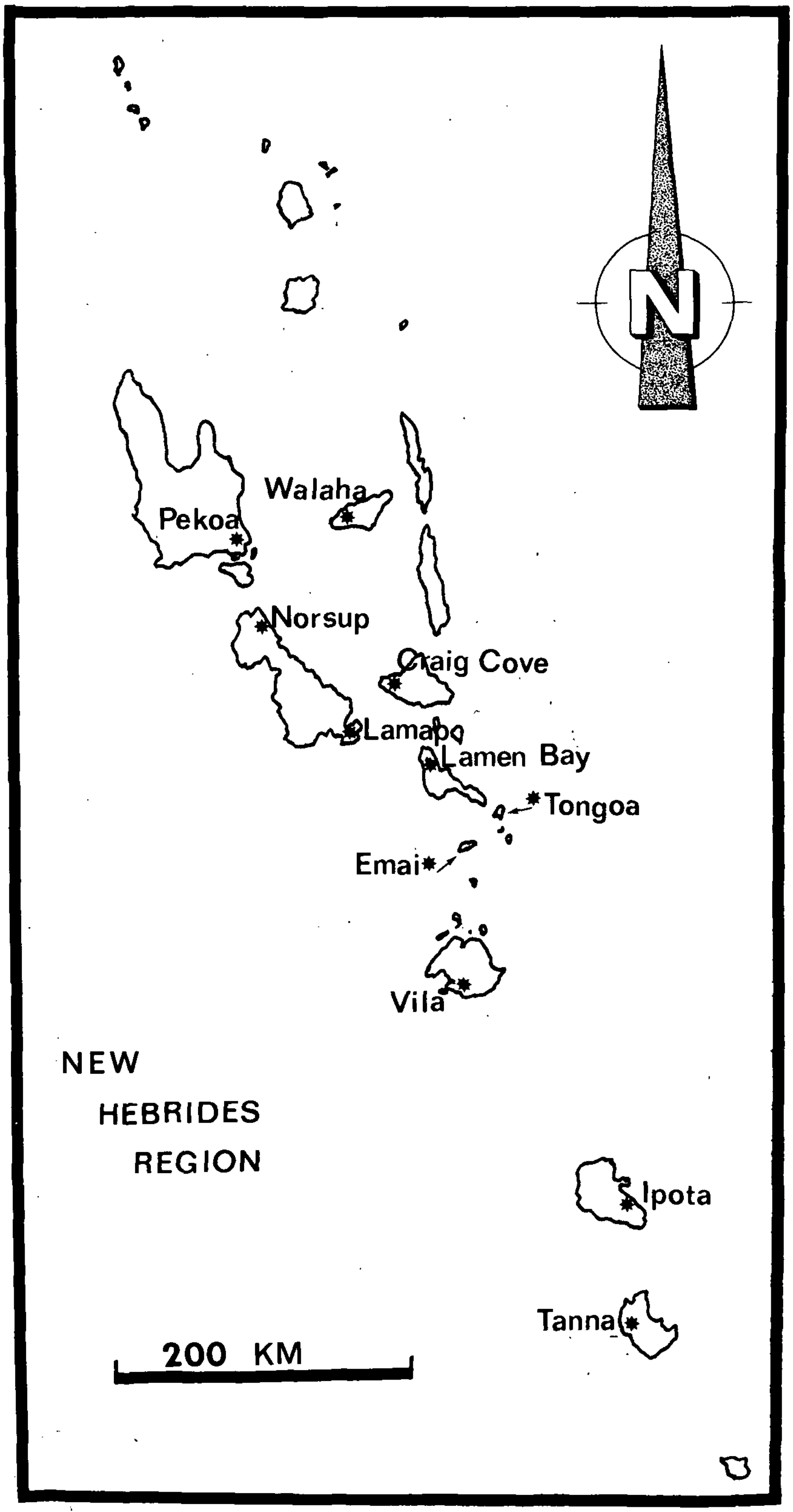
The major objective of this work is the capture of at least two events of magnitude greater than 7 with an array of magnetometers and strain meters in the Solomon and New Hebrides Islands Region. An array of eleven sites has been established in the New Hebrides. At each site magnetic field is measured with a proton precession magnetometer ($\frac{1}{4}\gamma$) every six minutes synchronously over the array. This data is multiplexed with station performance and some environmental parameters into a standard data collection platform for the GOES satellite. Transmissions occur every three hours at each site, and the data is returned ultimately to Menlo Park where it is transcribed to magnetic tape for return to Australia.

The present station package is relatively basic and is being used for evaluation of site characteristics. At the next maintenance visit each station will be upgraded in the light of this information to final standard and will then include microprocessor control, algorithms for on site improvement of the data set and reserve printer. Stations are designed for annual maintenance only, but make daily reports of status of on line and reserve power systems, including battery efficiency.

At this stage no data analysis beyond daily monitoring of basic station operations has been performed. Present effort is directed almost exclusively into development and fabrication of the final set of stations which will be installed late this calendar year. These stations will be distributed equally between the Solomon Islands and Eastern New Guinea.



STATION LOCATIONS

DEEPWELL MONITORING OF STRAIN-SENSITIVE PARAMETERS OVER THE SOUTHERN CALIFORNIA UPLIFT

14-08-0001-18383

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Douglas E. Hammond
Charles G. Sammis
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SUMMARY

High-frequency, wideband (20 Hz to 16 kHz) recording instruments for the detection of minute seismic emissions in borehole environments have been designed, developed, and deployed in three deep wells within seismically active regions. Two of these well sites are within a few km of the San Andreas fault near Palmdale, California; the third site is at the Monticello reservoir, South Carolina. Seismicity near the Monticello reservoir is induced by the recent impounding of water. The sensor is a highly-sensitive hydrophone emplaced at the bottom of the fluid-filled well. The surface recording package is an analog event recorder complete with event-detecting logic and digital delay circuit. In all three cases, numerous minute seismic emissions were detected with dominant spectral energy in the band 0.5 to 5 kHz and a peak at about 2 kHz. These events have durations on the order of 10 to 100 milliseconds and waveforms similar to a near-field earthquake greatly scaled down in size. Risking downward extrapolation of the duration time vs. magnitude relationship, these events may be assigned magnitudes in the range of -1 to -5; and as such we call them nanoearthquakes. From the high-frequency content and due to strong attenuation in the upper crust, these nanoearthquakes are probably occurring at distances less than one km from the sensor. If the laboratory results are applicable to field situations, the frequency of occurrence of nanoearthquakes may reflect the state of ambient stress, and their rate of occurrence may be useful in identifying the approximate time when a large earthquake is imminent.

Fault-Zone Water and Gas Monitoring

9960-01485

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Investigations

1. Radon in soil gas. Radon content of subsurface soil gas was continuously monitored by the Track Etch method in capped shallow holes at about 80 sites along several active faults between Santa Rosa and Cholame in central California, and at 35 sites in southern California (in cooperation with UCSD and UCSB). Radon has also been monitored since June 1980 at 44 new sites in Livermore and Parkfield areas with thermoluminescent dosimeters in cooperation with Westinghouse Research and Development Center.

2. Radon in groundwater. Radon content of groundwater was continuously monitored at two artesian wells in San Juan Bautista, California (in cooperation with University of Tokyo). Radon was also monitored in four other wells by the Track Etch method.

3. Water level. Water level was continuously recorded at eight wells in central California.

4. Water quality. Temperature, salinity, conductivity, and pH were periodically measured at eight wells and two springs in central California.

5. Water samples were collected from the above-mentioned wells and springs for chemical and isotopic analyses by two USGS groups (I. Barnes and J. R. O'Neil).

6. A weather station was maintained at Stone Canyon, California.

7. Soil-gas samples were periodically collected near eight radon-monitoring sites for helium measurement by G. M. Reimer of USGS in Denver, Colorado.

8. Mercury in soil gas. Mercury content of soil gas was monitored at nine radon-monitoring sites in the San Francisco Bay area (in cooperation with Arizona State University).

9. A preliminary field survey of the Mono Lake area was conducted for possible water and gas monitoring. One water well was instrumented in September 1980.

Results

1. Anomalous water-quality changes before a magnitude 4.8 earthquake. Salinity and conductivity of groundwater showed a large change (of about a factor of two) in the beginning of March 1980 in two wells near San Juan Bautista, California. A magnitude 4.8 earthquake occurred six weeks later on April 13 within several kilometers of the wells. Analyses of water samples taken from these wells showed corresponding changes in the ion content of Na^{+}, Ca^{++}, Mg^{++} and HCO_3, and in the isotope ratios of D/H and O^{18}/O^{16}. Such changes were probably not due to rainfall, because no comparable change was observed during the previous year. A possible large strain episode in the study area was recorded during December 1979 through March 1980 on a multiwavelength distance-measuring instrument, according to L. E. Slater. The strain changes may conceivably have created leaks in the relatively impermeable fault-gouge zones so that the groundwater on the opposite side of the fault may have induced into the wells and resulted in the observed changes in water quality and chemistry.

2. Anomalous water-level changes at Chabot Well in Oakland. Water level in this well increased by more than 1.5 meters during a one-day period on August 1, 1980, and returned to original level during the next 10 days. This anomaly was followed by a magnitude 3.9 earthquake on August 24 located about 30 km away near the aftershock area of the magnitude 5.5 Livermore earthquake of January 26. This anomaly is similar in shape and size to the one that occurred before the Livermore earthquake (mentioned in the preceding report). It occurred during a dry season and thus cannot be attributed to rainfall. This result suggests that the anomalous water-level changes are likely to be truly earthquake related.

Reports

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King, C.-Y., 1980, Episodic radon changes in subsurface soil gas along active faults and possible relation to earthquakes, J. Geophys. Res., 85, 3065-3078.

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O'Neil, J. R., and C.-Y. King, 1980, Deuterium anomalies in groundwater as precursors to seismic activity in California (abs.), EOS, Trans. Am. Geophys. Union, in press.

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High Sensitivity Monitoring of Resistivity and Self-Potential Variations in the Palmdale and Hollister Areas for Earthquake Prediction Studies

Contract No. 14-08-0001-16724

Principal Investigators: Theodore R. Madden and M. Nafi Toksöz

During this reporting period we installed a new type of electrode on both the Hollister and Palmdale arrays and we reworked all the old data. Some telephone line and electronic problems occurred, which have been corrected, but some of the data quality was effected.

The data reworking was instigated by an apparent trend in the Palmdale resistivity variations reported in the last semi-annual report and the discovery of an error in the dipole-channel relationship. The analyses that are involved are inversions without damping of data segment averages. The lack of damping is necessary to give us ties between data with different array balance settings and the results can be used as upper limits on the dipole apparent resistivity variations. Figure 2 shows the results of the analysis. The apparent trend we thought we saw on dipole B at Palmdale disappeared; this dipole is occasionally noisy due to a phone line problem but gives stable results when the noise is absent. In fact, the Palmdale array appears quiet (if we exclude the first segment) at a level of ±.2% over a nine month period. The Hollister array is even quieter except for dipoles B and F. These dipoles appear to show a change associated with the Coyote Lake event, but we cannot yet rule out the possibility of a seasonal effect.

The new electrodes that were installed are following the design concept used by Professor Frank Morrison's group at Berkeley. They are AgCL:KCL reference electrodes in a fluid bath and enclosed in an airtight container except for the porous ceramic at the bottom. If the seals are good, fluid loss only results from gas diffusion through the porous ceramic which is very slow. Our design needs improvements as the bonding process caused some of the ceramic pieces to crack, which resulted in fluid loss. Figure 3 shows self potential data from Hollister with the new electrodes. There are still some problems with electrode potential variations (and their measurement), but the self potential variations appear very quiet with the possible exception of the potential at B. The Palmdale array has cultural signals at Cs and Lc which lowers the data quality, but some variations may exist at Pearblossom.

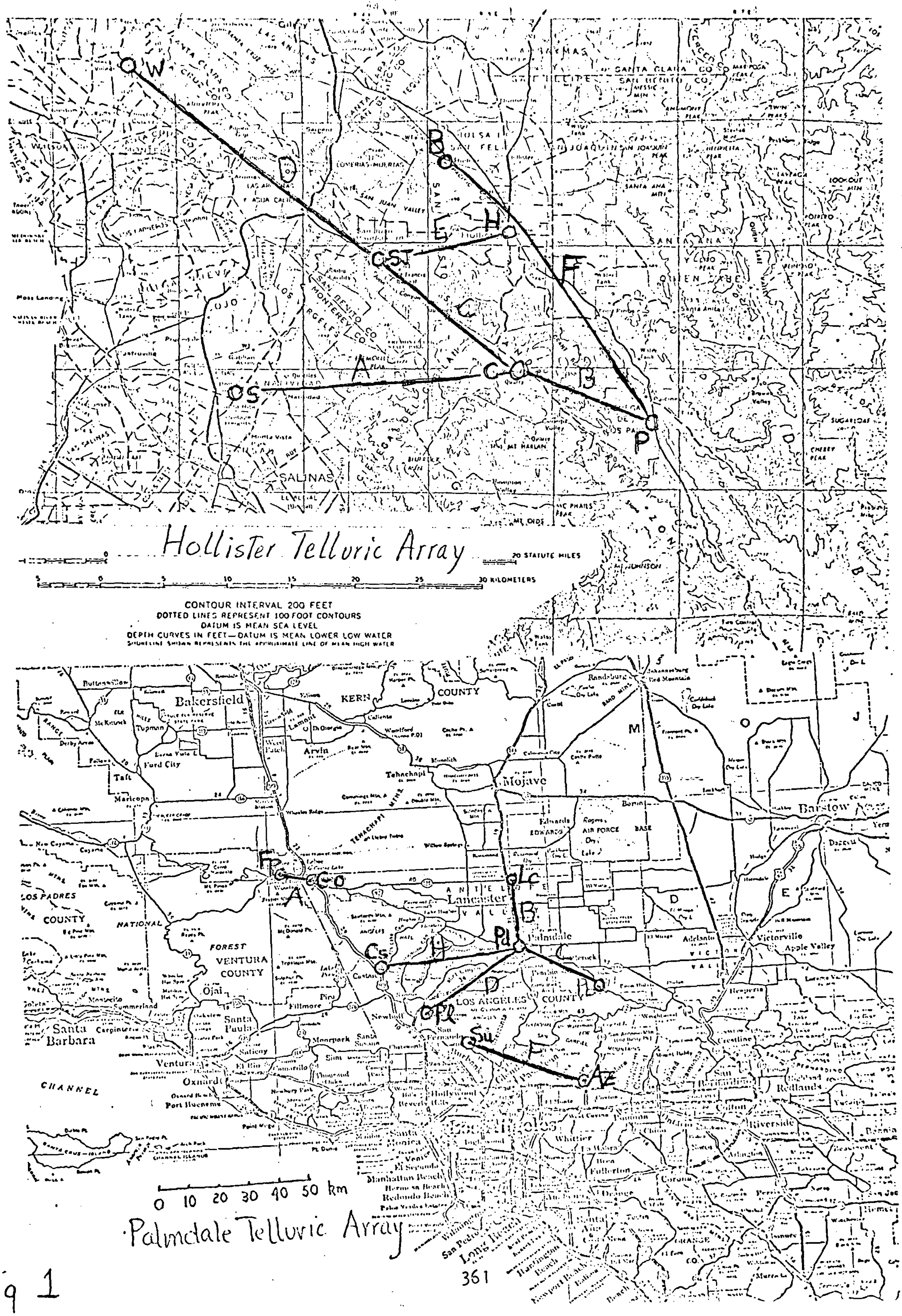
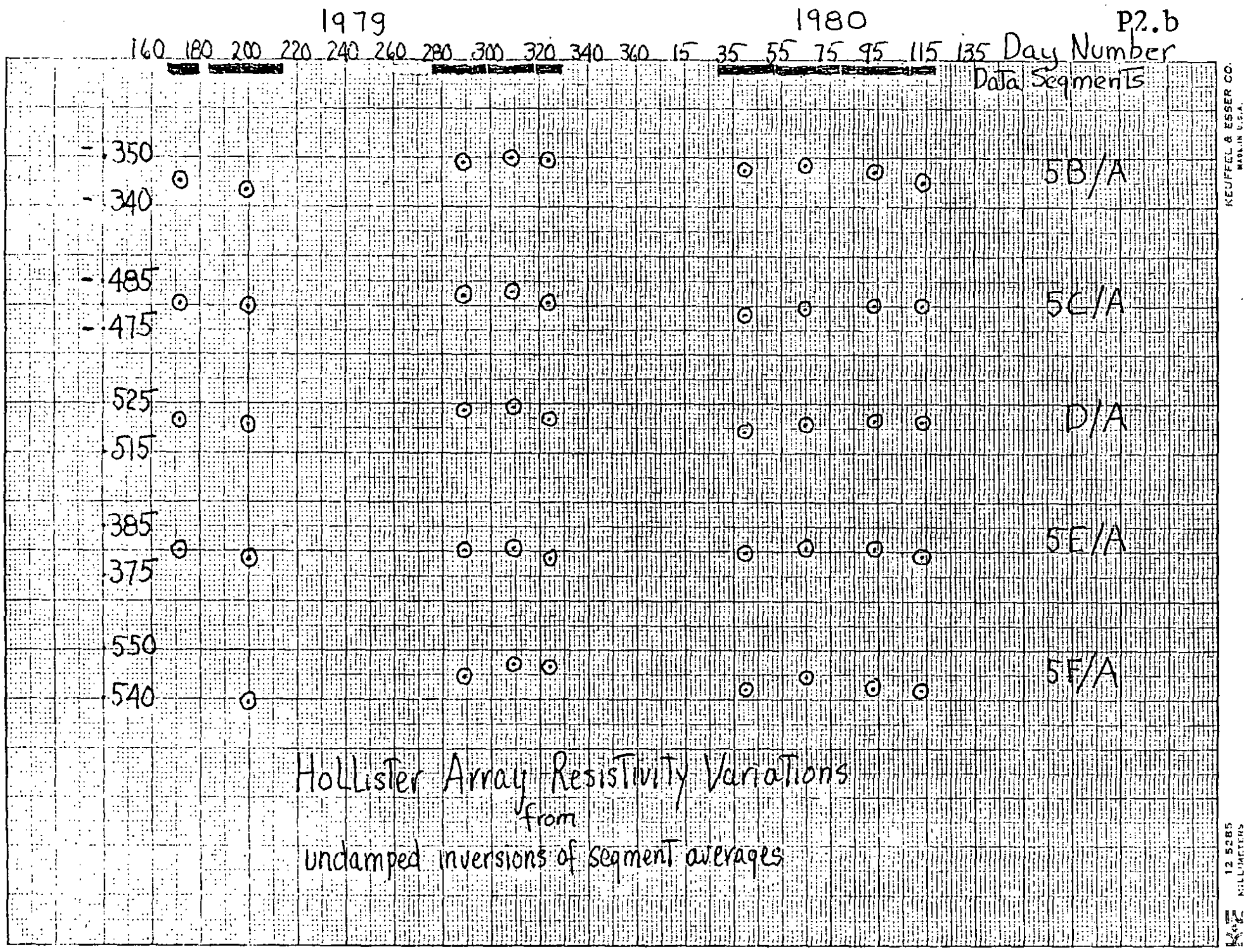

Hollister Telluric Array
20 STATUTE MILES
30 KILOMETERS
CONTOUR INTERVAL 200 FEET
DOTTED LINES REPRESENT 100 FOOT CONTOURS
DATUM IS MEAN SEA LEVEL
DEPTH CURVES IN FEET—DATUM IS MEAN LOWER LOW WATER
SHORELINE SHOWN REPRESENTS THE APPROXIMATE LINE OF MEAN HIGH WATER
W
D
BO
H
E
CST
F
C
A
OS
B
P
SALINAS
Bakersfield
KERN
COUNTY
Mojave
Barstow
Lancaster
Palmdale
Victorville
Fr
Co
Lc
Pd
Cs
Pl
Su
Az
VENTURA COUNTY
LOS ANGELES COUNTY
Santa Barbara
Oxnard
0 10 20 30 40 50 km
Palmdale Telluric Array

Fig 1

P2.b


1979
1980
160 180 200 220 240 260 280 300 320 340 360 15 35 55 75 95 115 135 Day Number
Data Segments
350
340
485
475
525
515
385
375
550
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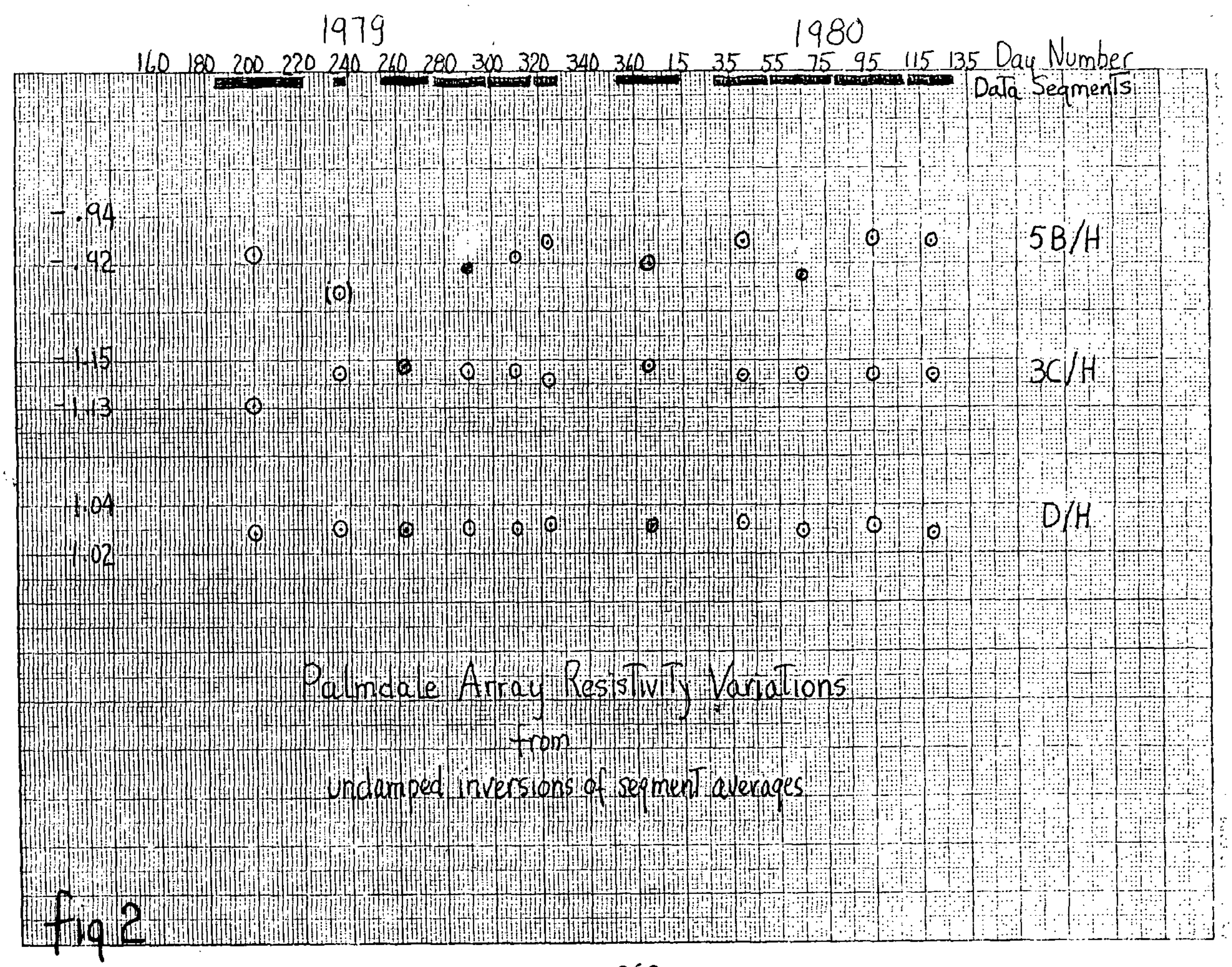
5B/A
5C/A
D/A
5E/A
5F/A
Hollister Array Resistivity Variations
from
undamped inversions of segment averages


1979
1980
160 180 200 220 240 260 280 300 320 340 360 15 35 55 75 95 115 135 Day Number
Data Segments
.94
.92
1.15
1.13
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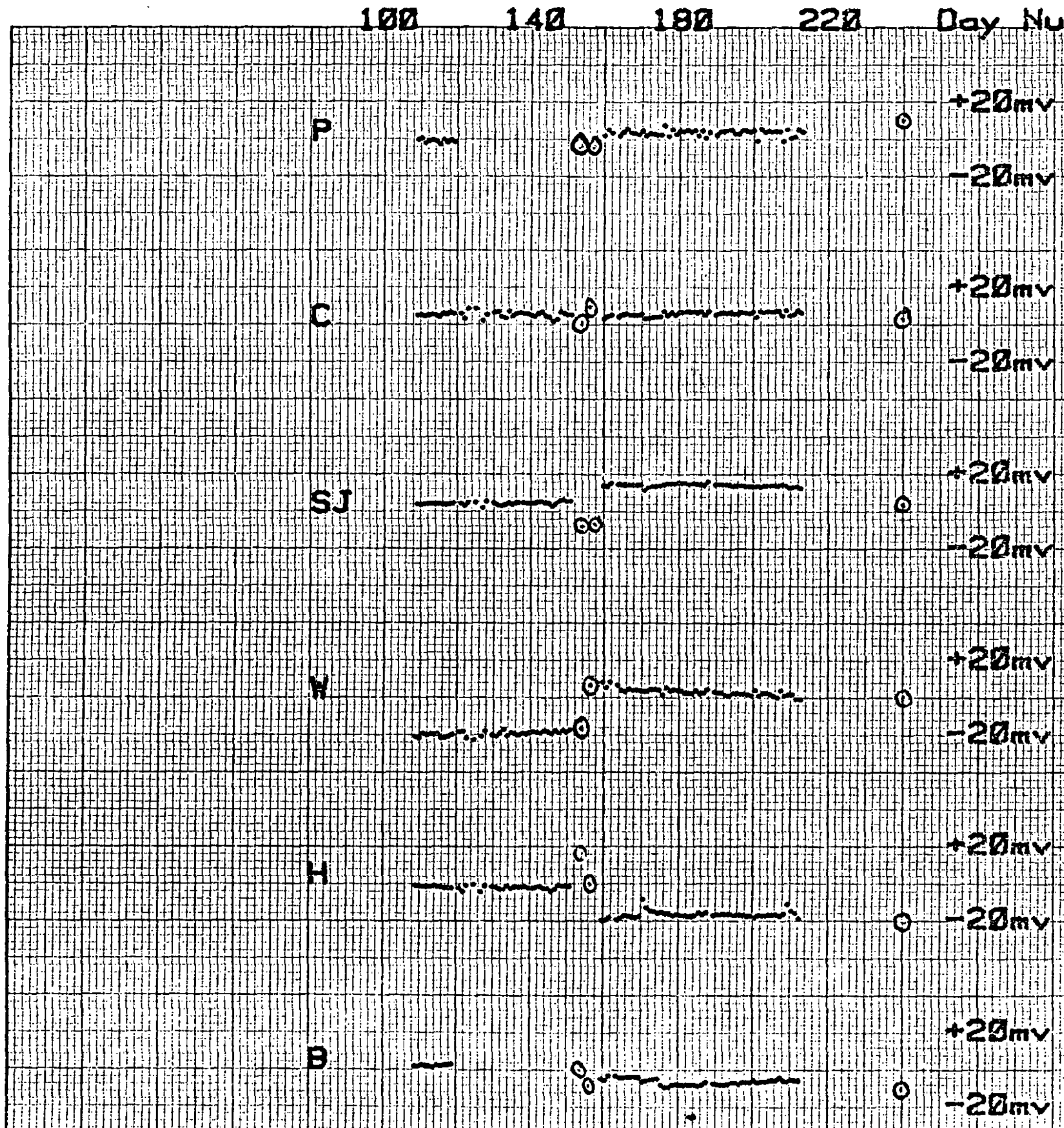
1.02
5B/H
3C/H
D/H
Palmdale Array Resistivity Variations
from
undamped inversions of segment averages

fig 2



○ electrode potential contribution (new electrodes day 155)

Fig 3 Self Potential Variations Hollister Array

P2.b

IN-SITU SEISMIC WAVE VELOCITY MONITORING

CONTRACT 14-08-0001-17645

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During this report period, repairs were completed to the vibrator donated last August by Western Geophysical Company. Faulty steering and brake systems on the vibrator truck were improved substantially, and two hydraulic cylinders on the vibrator itself failed and were repaired during final testing. Recording truck steering and suspension systems were overhauled during the same period.

Field work began in March. Tests in March and early April at the Cienega Winery monitoring area showed that the vibrator operated well on the special concrete and asphalt pads discussed in previous reports. Signal strength at high vibrator drive levels was several times larger than with the previous vibrator, but several more vibrator failures occurred, due to operation at high drive level. Tests showed that shaking at low drive levels reduced signal strength only marginally while reducing substantially the severity of shaking of system components. Application of this discovery will improve the vibrator maintenance situation.

Repeated measurements of down-hole travel-time using the vibrator source and a borehole geophone receiver indicate that measurement errors due to source instability will be less than ±0.1 msec (the standard deviation was 0.04 msec), a significant improvement over results obtained with the previous vibrator. Tests of source reproducibility are yet to be made. An experiment using a hammer source and the borehole geophone yielded a larger but still acceptable standard deviation of 0.1 msec. These stable borehole results using both sources indicate that corrections for near-surface travel-time changes can be measured with adequate precision to correct for much of the seasonal long-term variations which can mask evidence for changes at depth.

The first monitoring measurement with the new vibrator system was made using established source and receiver sites in the Cienega Winery area in early April. The resulting first arrival travel-time was within 2-3 msec of the values measured in the springs of 1979 and 1978, indicating that no substantial change has occurred at a resolution level of a few parts in 10^{-3}. Routine monitoring is now underway at the old winery sites and at several new sites in the Stone Canyon area.

Water-Level Monitoring Along San Andreas and San Jacinto Faults, Southern California, During Second Half of Fiscal Year 1980

14-08-0001-18358

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Investigations

Beginning in October 1976, a program of water-level monitoring of abandoned water wells was initiated in the Palmdale area with the purpose of identifying possible water-level changes premonitory to a major earthquake on the San Andreas fault. In October 1977, the program was extended southeastward along the rift zone to the Valyermo area. In November 1977, the monitoring of water wells along the San Jacinto fault was initiated with the expectation of experiencing a moderate size earthquake while monitoring was in progress. Currently over thirty wells are being monitored. Eleven wells are monitored continuously with Stevens Type F recorders or by TIMS units, as described below. The remaining wells are probed weekly, or in some cases semi-weekly or daily, by volunteers. We are endeavoring to improve the volunteer program by increasing the frequency of measurements and simplifying the procedure to minimize measurement errors.

Weekly water-level data are displayed on computer-generated hydrographs for each well. Rainfall and earthquakes are plotted on the graphs for direct comparison with water levels. The hydrographs are updated and reviewed weekly. Weekly hydrographs are also prepared from recorder charts on two wells maintained by W. R. Moyle, Jr., of the U.S. Geological Survey, Water Resources Division Office, Laguna Niguel, California.

During Fiscal Year 1981, additional geochemical parameters, including radon utilizing the track-etch techniques, temperature, salinity and conductivity, will be measured in ten selected wells at the time the water-level charts are changed. Additional TIMS installations are in preparation for wells in Valyermo and Borrego Springs.

Results

Remote Observatory Support Systems (TIMS) constructed by the Caltech Seismological Laboratory have been installed at wells in Palmdale and Anza to telemeter water-level data to Caltech. Both are functioning perfectly, and water-level measurements taken at one-minute intervals are received at Caltech twice each day.

Local seismic activity was recorded in water levels of the two wells in Borrego Springs with continuous water-level recorders. One well in particular showed peculiar high frequency water-level fluctuations during a period from 22 July to 21 August 1980 (Fig. 1), after which the record has appeared normal.

The solid lines in Figure 2 are the hydrographs for eight wells in the Palmdale-Valyermo area which show water-level changes since early 1979 different from what would have been predicted based on the previous history of water-level changes and seasonal rainfall. The dashed lines represent the hydrograph which would have been predicted. Shapiro et al (1980) have reported anomalous radon counts in two wells along the frontal fault system of the Transverse Ranges in southern California which occurred during the last half of 1979. The radon anomalies began a few months after initiation of the anomalous water-level changes illustrated on Figure 2, and both began at about the same time as the reported changes in strain pattern from compression to expansion along the San Andreas fault in the same area (Kerr, 1980; Shapiro et al, 1980). According to Shapiro et al (1980), the radon and other geophysical anomalies ended in early 1980. Thus, if the water-level anomalies are related to the other geophysical anomalies, the water levels illustrated on Figure 2 should have returned to "normal" in early 1980. This has definitely occurred in only two wells (5N/12W-4J2 and -4J4); two other wells have shown some return to normal (5N/12W-4H1 and 5N/10W-30L1). Levels in the other four wells have remained anomalous throughout the current reporting period.

Thus, while possibly anomalous water levels in some wells appear to be coincident with changes in the crustal strain pattern and other geophysical anomalies in late 1979, those in other wells do not. Moreover, a longer period of observation is required to determine whether the changes are indeed anomalous. They may result from a delayed response to seasonal rainfall following a long drought, or may be due to other variations in surface or subsurface flow. It is interesting that five of the eight wells with possibly anomalous water-level changes have been identified as good strain meters based on their response to earth tides. The response to earth tides of well 5N/12W-4J2 is unknown, and wells 5N/10W-30L1 and 4N/10W-10Q1 show poor response to earth tides. The six wells which show an unexpected rise in water level are located west of the earthquake swarm that occurred in 1976-1977 (McNally et al, 1978), whereas those which show water levels lower than would have been predicted are located east of the earthquake swarm.

References

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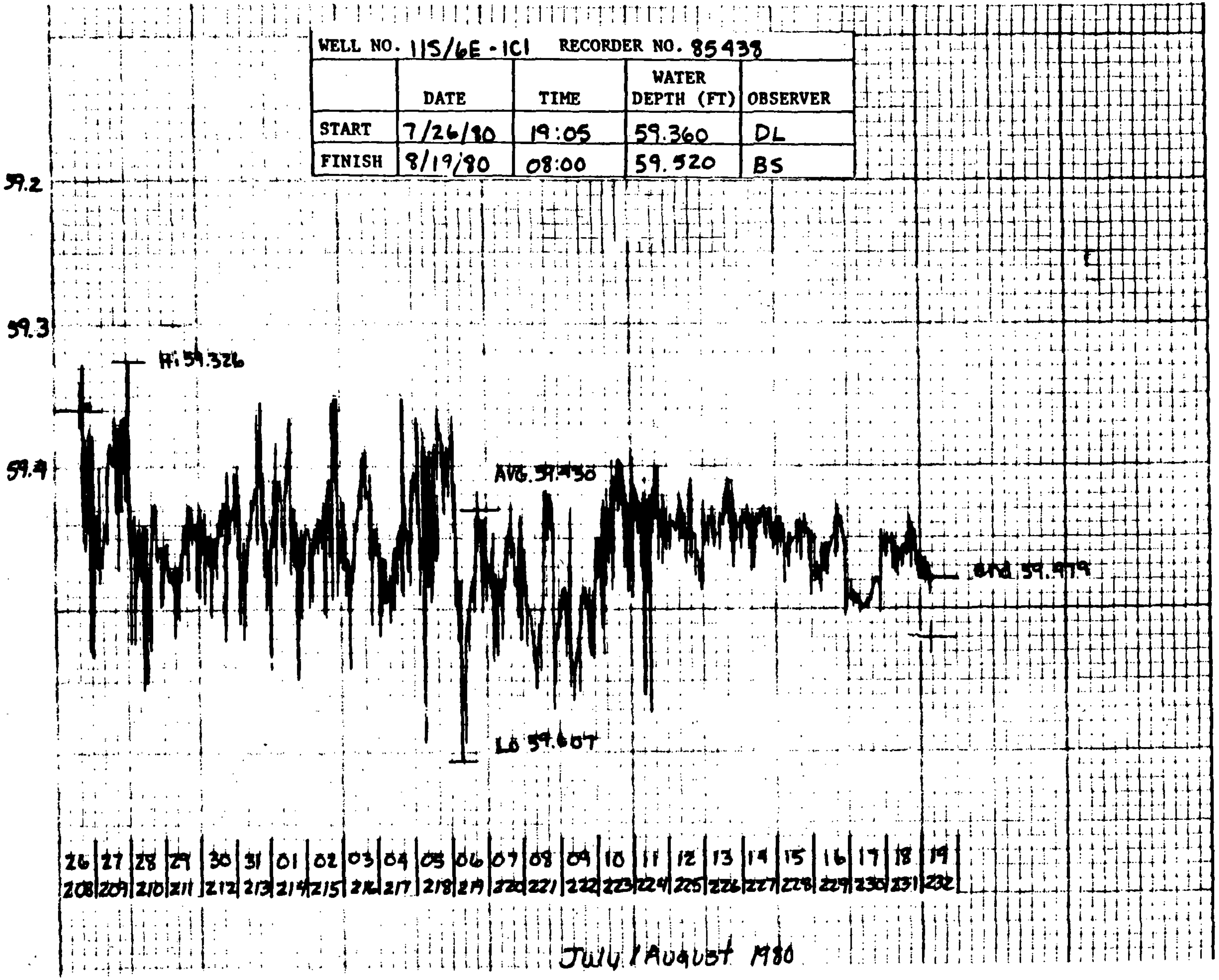

Fig. 1 - Stevens water-level recorder chart for well number 11S/6E-1C1, Borrego Valley, for period July 26-August 19, 1980.

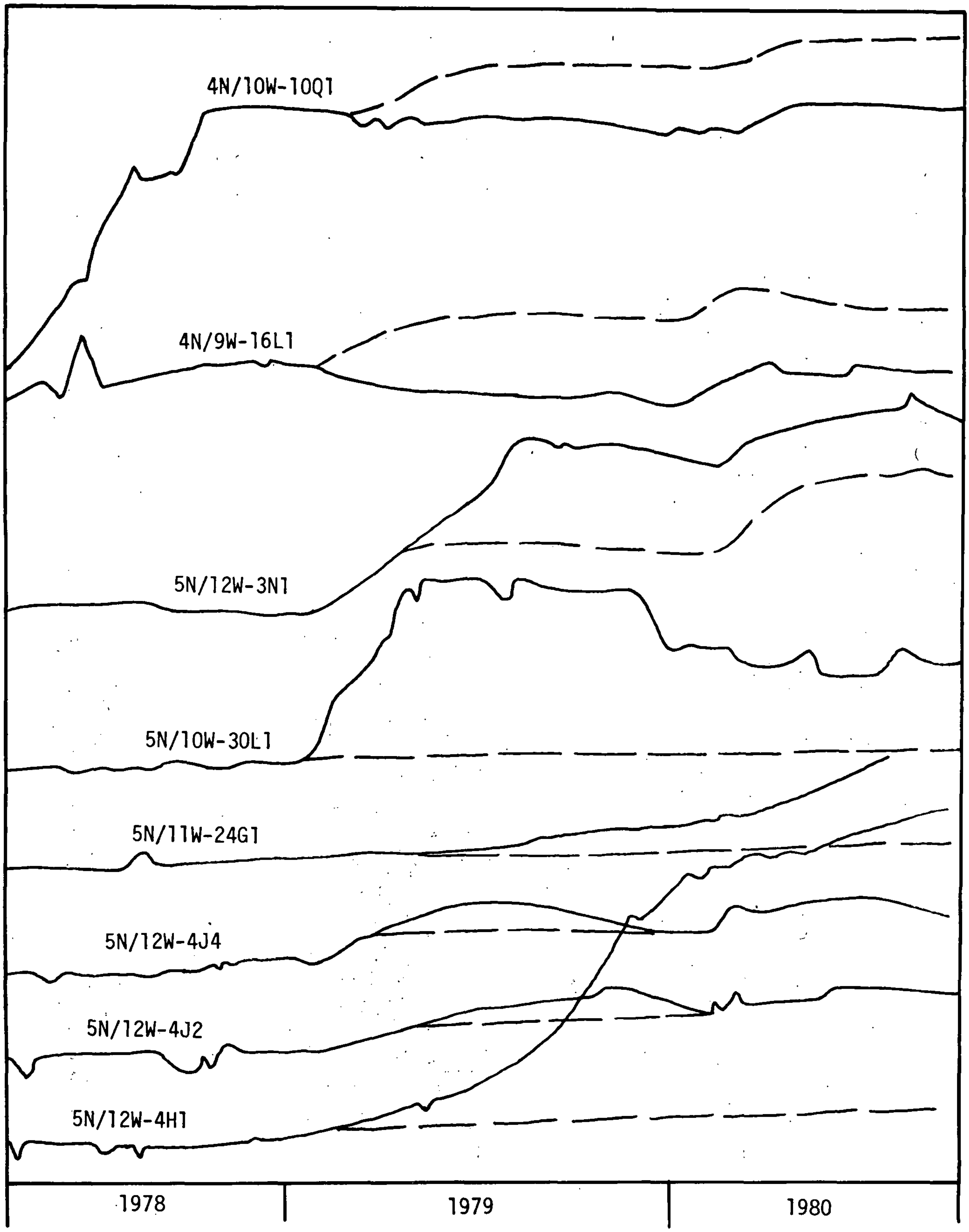

Fig. 2 - Comparison of actual (solid lines) and predicted (dashed lines) water-level changes in observation wells, Palmdale-Valyermo area.

CONTINUOUS MONITORING AND INTERPRETATION OF CRUSTAL VELOCITY CHANGES NEAR PALMDALE, CALIFORNIA

14-08-0001-16762

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SUMMARY

Between November 1978 and April 1980 seismic travel times from Bouquet Reservoir to two borehole sensors 13 km and 18 km to the northeast (Figure 1) were measured to an average precision of ± 3 msec ($\approx \frac{\Delta V}{V}$ = .1%) for the first arrival (P-wave) and to ± 6 msec for subsequent refraction and S-wave arrivals ($\frac{\Delta V}{V} \approx$ .2%). We observed no trending or prolonged travel time anomaly for a variety of sampling intervals (weeks to months) and sampling rates (hours to days). A total of 200 travel time determinations for each phase to each borehole were made during the 18 month study period. Of these the bulk occurred in month-long sampling periods, August 1979 (25 pts.), December 1979 (35 pts.), and January-February 1980 (100 pts.). The average P-wave (first arrival) travel times for these clusters are shown in Figure 2. Results for the P-wave and reflected P-wave over a shorter time interval (1 wk, January, 1980) are given in Figure 3.

P2.5
Figure 1

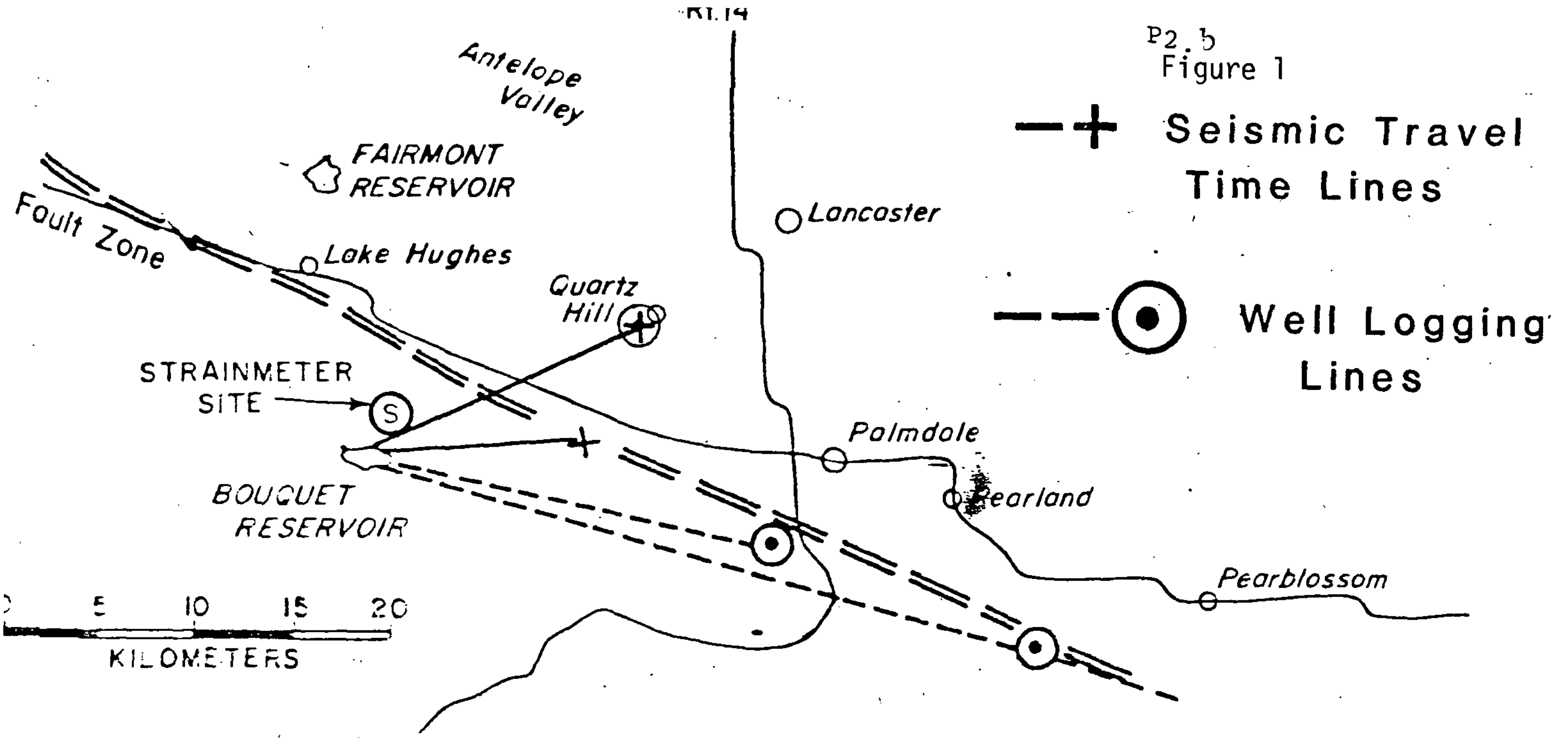


Figure 2

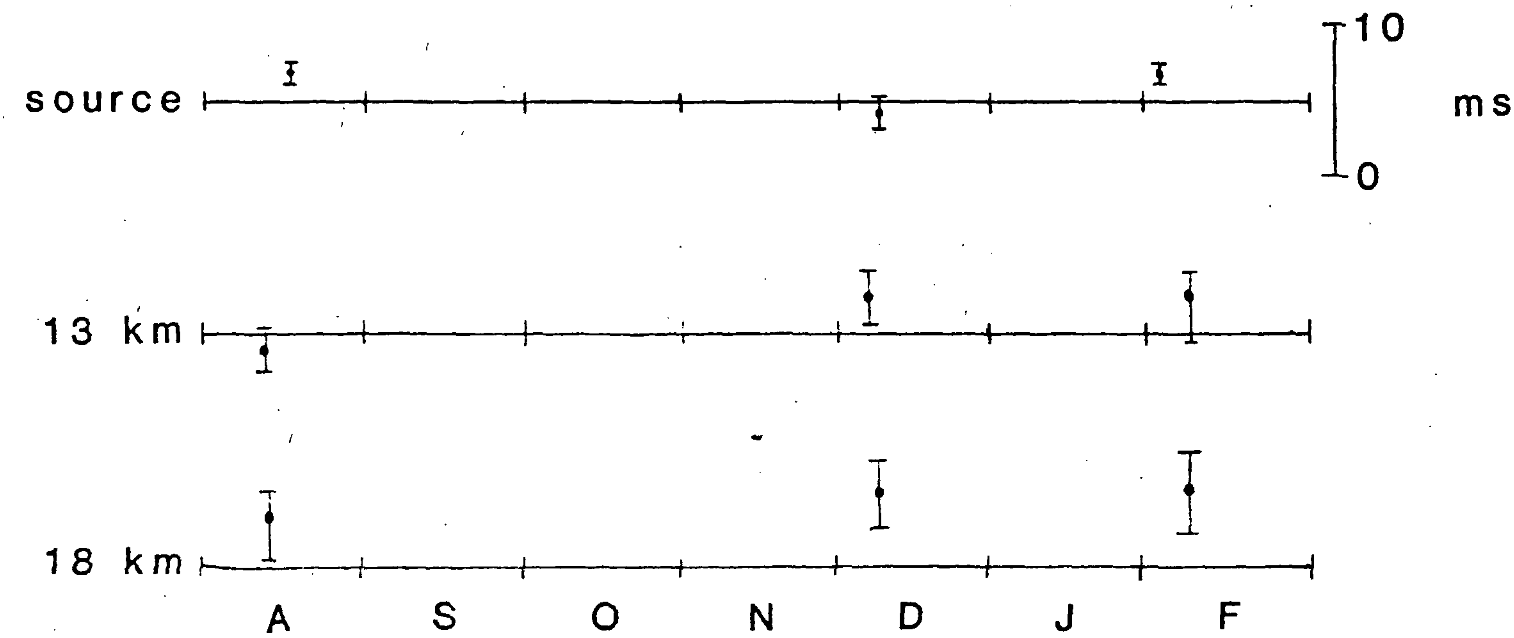
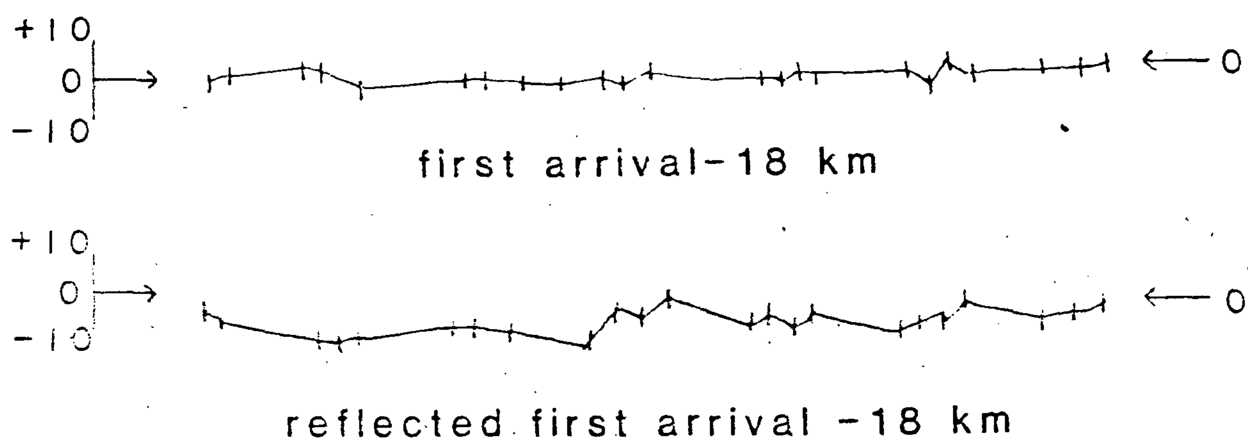


Figure 3



Helium Monitoring for Earthquake Prediction

9440-01376E

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Investigations

Seven additional soil-gas collecting stations have been added to the existing 10 stations along the San Andreas Fault. The network now extends from San Juan Bautista to San Benito, a distance of 55 kilometers. Sampling is still being carried out approximately weekly and the samples are returned to Denver, Colorado for analysis. In a few locations, probes will be inserted to a depth of 5 m to see if that may reduce the effects of seasonal variation exhibited with the current 2-m probes.

Results

1. More than one year's worth of data has been collected and a seasonal pattern was revealed. It followed the anticipated increase during the wet season and decline in the dry season.

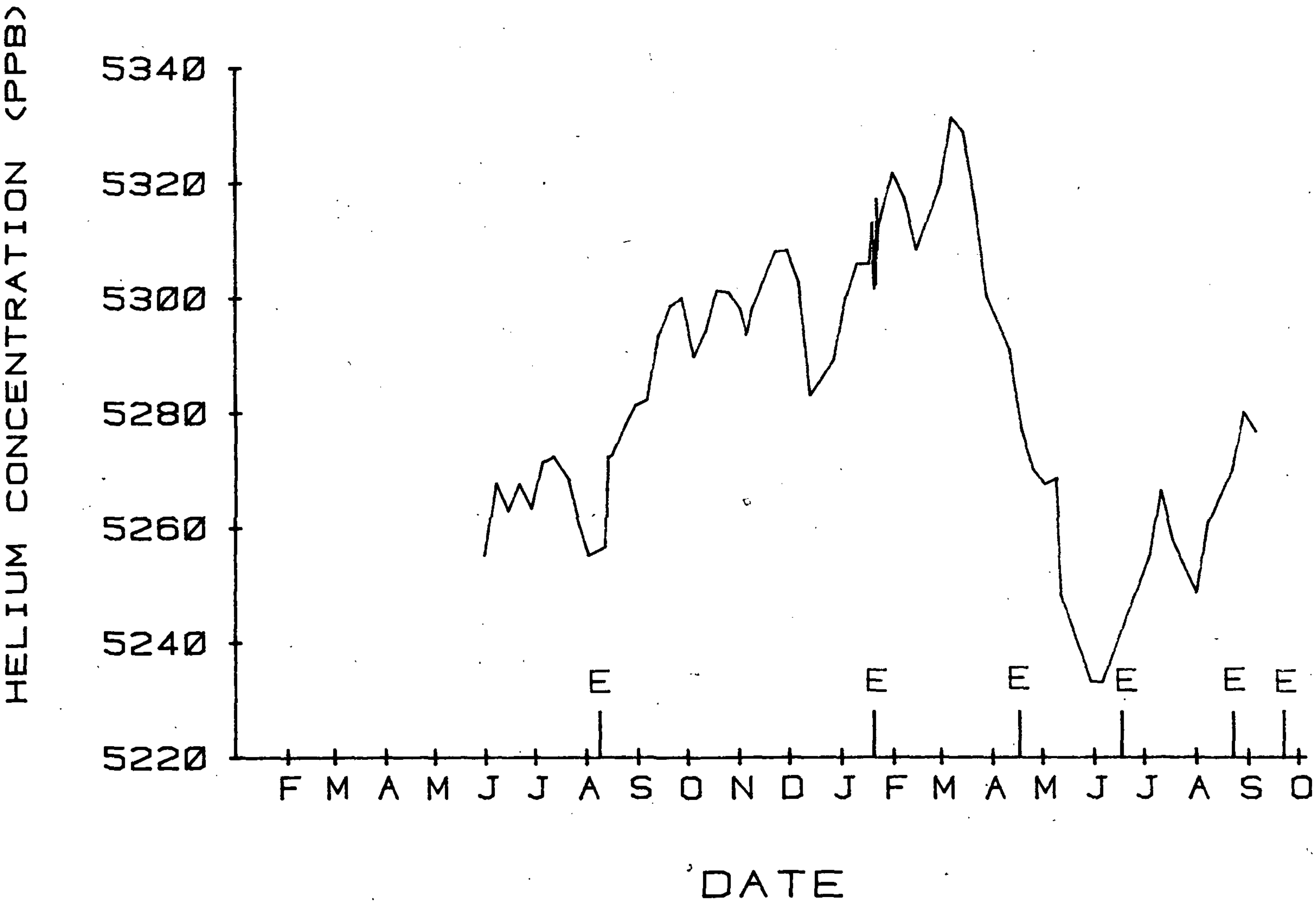
2. Several additional decreases in the helium concentration were observed to precede earthquakes of magnitude greater than 4 occurring April 13, 1980 near San Juan Bautista; June 18, 1980 near Watsonville; and August 24, 1980 near Berkely. The helium decreases related to the April 13 and June 18 earthquakes are attenuated by the superimposed seasonal decrease but may have contributed to the rapidity of that decrease. There does not appear to be any resolution of a helium decrease associated with the September 24 earthquake near Coalinga; we have analyzed samples that have been returned only through September 10, 1980.

3. Although we have no idea what the comparative relationship of the epicenter location is to our observed signal variations, we are currently selecting, arbitrarily, a radius of influence of 120 Km for comparison.

Reports

Reimer, G. M., 1979, Helium soil-gas variations associated with recent California earthquakes: Precursor or coincidence? (Approved by director for outside publication).

HELIUM CONCENTRATION IN SOIL-GAS NEAR HOLLISTER, CA
3-POINT MOVING AVERAGE FOR 10 STATIONS



P2.b

EARTHQUAKE PREDICTION RESEARCH IN TAIWAN

14-08-0001-16895

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SUMMARY

The purpose of this contract was to provide equipment to Taiwan to assist that country in establishing a program in earthquake prediction and hazards studies. Also, expert assistance was provided for Taiwan's establishment of a routine field program using the equipment.

In carrying out this objective, the following equipment was provided:

1) Two proton precession magnetometers

2) Two LaCoste-Romberg gravimeters

3) One H-P 3808 laser geodimeter

4) Three Kinemetrics PDR-2 field digital event recorders

5) One groundwater radon measuring system

The equipment has been set up in Taiwan under the direction of Dr. Ben Tsai, Director of the Taiwan Earthquake Institute.

COMPARISON OF RADON MONITORING TECHNIQUES, THE EFFECTS OF THERMOELASTIC STRAINS ON SUBSURFACE RADON, AND THE DEVELOPMENT OF A COMPUTER OPERATED RADON MONITORING NETWORK FOR EARTHQUAKE PREDICTION

14-08-0001-17734

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INVESTIGATIONS

During the first half of FY79, automated radon-thoron monitoring continued at five southern California stations (Stone Canyon Reservoir, Kresge, Santa Anita Canyon, Dalton Canyon, and Lytle Creek.) The data taking phase of the San Juan Bautista comparison experiment in which the Caltech automated radon-thoron monitor measured radon from the same well as two other types of continuous radon monitor was concluded near the end of this period. Heavy winter weather has delayed the deployment of the Pacoima radon-thoron monitor. During this period a number of improvements were made to the monitor hardware and software in order to permit the measurements of additional parameters such as borehole water depth and temperature, and to allow the radon-thoron monitor to control other instruments. In collaboration with Gulf Research, a portable gas chromatograph has been modified to operate under control of the Pacoima radon-thoron monitor. This will allow hydrogen and helium to be monitored from the Pacoima borehole as well as radon and thoron. Site selection field work has been carried out for three additional monitor sites which will be developed during the second half of FY80. A large-volume, high-resolution Ge(Li) detector has been calibrated absolutely for the non-destructive determination of uranium and thorium in rock samples from the field sites.

RESULTS

The large radon anomalies that were observed at the Kresge and Dalton Canyon sites during the second half of FY79 appear to have subsided to a considerable extent. These radon anomalies coincided with several other anomalous geophysical and geodetic data, and it now appears likely that these phenomena were caused by a regional strain event in southern California. The occurrence of the 6.6 M Imperial Valley earthquake and the general increase in seismicity in southern California during this period may have been related to the same strain event.

The intense winter rainstorms which created difficult operating conditions also provided an opportunity to examine the response of the radon-thoron monitoring system during major changes in hydrological conditions. Four of the five southern California units showed well-defined radon pulses in response to the heavy influx of groundwater. A sample of this data is shown in the figure.

REPORTS

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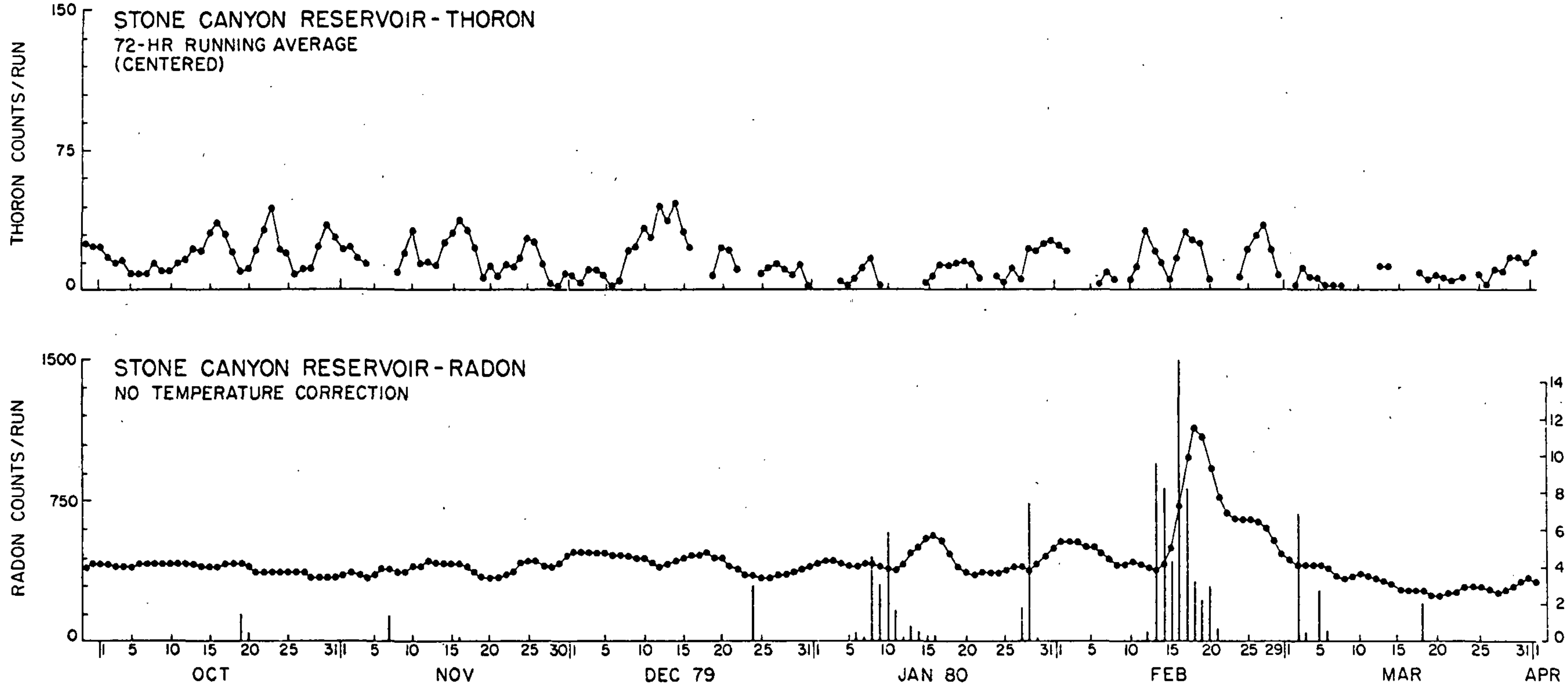
STONE CANYON RESERVOIR - THORON
72-HR RUNNING AVERAGE
(CENTERED)
THORON COUNTS/RUN
150
75
0
STONE CANYON RESERVOIR - RADON
NO TEMPERATURE CORRECTION
RADON COUNTS/RUN
1500
750
0
RAINFALL (cm)
14
12
10
8
6
4
2
0
OCT
NOV
DEC 79
JAN 80
FEB
MAR
APR

P2.5

MAGNETIC FIELD MONITORING OF TECTONIC STRESS IN SOUTHERN CALIFORNIA

Contract #14-08-0001-18335

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Investigations:

Magnetic total-field measurements are being taken at 42 field sites distributed across a large portion of southern California. This project, initiated in 1973, is conducted in an effort to monitor changes in tectonic stress beneath the sites. Field observations are taken along the San Andreas and San Jacinto fault zones from Quail Lake on the NW to Indio and the Anza Valley on the SE. A loop of 10 sites also extends around the eastern and northern flanks of the San Bernardino Mountains. Three complete surveys are carried out each year, and earthquake episodes are measured more frequently.

For these surveys, instruments are not placed permanently at the field sites, but buried, benchmark-like supports are utilized to relocate the magnetometer sensor from survey to survey. Readings are taken at two adjacent sites simultaneously over a 10-minute interval of time, and the mean values of the data sets are computed and differenced. The time variation of this differnce of means becomes, via the piezomagnetic effect, an indicator of tectonic stress change in the earth's crust beneath the site pair.

Three surveys were completed during the past year, one in December, 1979, one in April 1980, and one in July 1980.

Results:

The time period from July 1979 to December 1979 was one of minor stress change, with marginally significant anomalies identified along the San Andreas fault zone between Palmdale and Cajon Pass. All other areas covered by the array were changing very little and this was in marked contrast with the prior interval of time from April 1979 to July 1979.

For the time interval December 1979 to April 1980 there is indicated an increase in the rate of tectonomagnetic change - the strongest anomalies are at Palmdale and Cajon Pass, where rates of change of 6.7 and 6.3 quarter gammas per 30-day month were determined. These rates have been associated with earthquakes at Wrightwood, Landers and other places in the past.

For the time interval April 1980 to July 1980 there were nine anomalous areas identified. The Palmdale anomaly has shifted southward to the vicinity of San Fernando, and the Cajon Pass anomaly persists. Other anomalies are at or near Mojave, Three Points, City Creek, San Jacinto, Desert Hot Springs.

To the present time the project has identified magnetic anomalies associated with pre-earthquake effects (Wrightwood) and with post-earthquake effects (Landers). The procedure remains an inexpensive and effective way of monitoring a large portion of Southern . However, the data could benefit greating from enhancement techniques that would remove noise due to diurnal change.

Another survey will be completed in December 1980.

MECHANISMS OF FRACTURE AND FRICTION OF CRUSTAL ROCK IN SIMULATED GEOLOGIC ENVIRONMENTS

Contract No: 14-08-0001-18325

Principal Investigators: B. K. ATKINSON, N. J. PRICE

Additional Contributions by: S. M. DENNIS, P.G. MEREDITH, D. MACDONALD, and R.F. HOLLOWAY

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01-589-5111 X 1683, X 1690

Investigations

1. Construction of apparatus for high-temperature (up to 500°C) and high-pressure (up to 3 kbar) apparatus for fracture mechanics studies of critical stress intensity factors and subcritical (stress corrosion) crack growth in crustal rocks.

2. Fracture mechanics experiments and associated acoustic emission studies of stress corrosion crack growth in granites and basalts.

3. Study of thermal and stress cycling on fracture and acoustic emission properties of rock.

4. Experimental study of influence of pore water on sliding properties of faults in granites and basalts at conditions of temperature and pressure typical of the upper 15 km of the earth's crust.

5. Identification of active mechanisms of deformation in the above experiments and construction of fracture and friction deformation mechanism maps.

Results

1. We have constructed 3 new pieces of apparatus for fracture mechanics experiments. (a) double torsion environmental cell for deforming rock plates in vacuum or vapour environments to 500°C, (b) short rod apparatus for tests on cores at ambient humidity to 300°C, and (c) internally pressurized thick-walled cylinder apparatus for tests to 3 kbar and 500°C. All three pieces of

apparatus are designed to be used in measurements of crack propagation parameters for mode I deformation (tensile). Acoustic emission can be monitored simultaneously with other parameters relevant to the test.

2. Additional apparatus development has been done to enable the measurement of mode II (in-plane shear) crack propagation parameters. Two methods have been chosen: (a) one based on a double direct shear specimen for tests at ambient pressure, and (b) one based on a modification to the analysis of post-failure stress/displacement data from triaxial tests suggested by Rice (Proc. Int. School of Physics 'Enrico Fermi', LXXVIII, 1979).

3. Double torsion experiments to study stress corrosion and acoustic emission of Whin Sill dolerite gave the following results for n (stress corrosion index, $V = \alpha K_I^n$) n_E (event rate index, $dN_E/dt = \beta K_I^{n_E}$), and n_R (ring-down rate index, $dN_R/dt \cong \gamma K_I^{n_R}$). Crack velocity is V, stress intensity factor is K_I, α, β and γ are constants, N_R and N_E are number of ring-down counts and events, respectively, and t is time.

	Air, 20°C, 30%RH	H_2O, 20°C	H_2O, 75°C
n	31.2 (0.990)	29.0 (0.992)	28.4 (0.995)
n_E	31.1 (0.984)	29.1 (0.977)	
n_R	32.9 (0.981)	29.9 (0.973)	

Figures in brackets are correlation coefficients.

The activation enthalpy for crack propagation determined by two different methods gave the following results: 30.4±1.9 $kJ.mole^{-1}$ and 34 to 47.6 $kJ.mole^{-1}$. K_{Ic} for this dolerite was 3.28±0.1 $MN.m^{-3}/2$.

As we have found for other materials the rate of acoustic emission is a good guide to the crack velocity.

4. Short rod tests have been run on a variety of rock types at 20°C and ambient humidity to check out the validity of this test for rock and to get an idea of K_{Ic} values for materials on which no data existed before this study. Some results are given here. Where possible they are compared with results for double torsion experiments.

Material	K_{Ic} ($MN.m^{-3/2}$) SR	DT
Westerley granite	1.62±.08	1.74
Whin Sill dolerite	2.96±.19	3.28
Black gabbro	2.73±.40	2.88
Pink granite	1.53±.17	1.66
Icelandic Tholeiite	0.87±.06	
Serpentinized dunite	1.39±.38	
Arkansas novaculite	1.77±.25	1.34
Oughtibridge gannister	1.39±.27	
Penant sandstone	1.97±.06	
Tennessee sandstone	0.79±.05	0.45
Carrara marble	0.82±.04	0.64
Solnhofen limestone	1.09±.06	1.06

5. Acoustic emission was monitored from thermal and stress cycled Westerley granite. Also stress intensity factor /crack velocity diagrams were determined for heat treated granite.

On increasing the maximum temperature of heat treatment the microcrack density increases and K_{Ic} decreases. The most marked change in these properties occurs between 200°C and 300°C. During stress cycling the Kaiser effect is only observed up to a specific fraction of K_{Ic}, thereafter there is an anomalous increase in the acoustic emission that suggests the release of locked-in, residual strain energy. With increasing heat-treatment there is a reduction in the stress intensity factor required to obtain a given crack velocity.

6. Preliminary estimates of critical strain energy release rate in mode II deformation for granite are of the order $10^4 J.m^{-2}$.

7. A fracture mechanism map for quartz has been constructed. It may be inferred from this diagram that the propagation of pre-existing cracks by stress corrosion will be the most important mechanism of tensile failure in the upper 15-20 km of the earth's crust.

8. A study of the influence of pore water on the fracture and sliding friction strength of Westerley granite shows that at 20°C the presence of water has little effect. i.e. the so-called Rehbinder effects are not very important. The following results were obtained from stress relaxation experiments on dry and wet, intact and initially prefaulted specimens at 300°C and 400°C and under a pore water pressure of 200 bars or 1 kbar at a fixed effective

confining pressure of 1.5 kbar.

(a) Dry granite shows no reduction in sliding stress at strain rates down to $10^{-12}s^{-1}$.

(b) The sliding stress on wetting is reduced at strain rates below ca. $10^{-7}s^{-1}$, but not by as much as Tennessee sandstone or Mojave quartzite.

(c) Increasing pore fluid pressure at constant effective pressure substantially increases the rate of stress relaxation.

(d) Values of the stress exponent, n, where strain rate $\propto$ $(\text{stress})^n$ are as follows:

P_{H_2O}	n
200 bars	25
1000 bars	6

(e) The activation enthalpy for frictional sliding of wet specimens of Westerley granite from 300°C to 400°C, varied from 20 - 45 $kJ.mole^{-1}$.

These results do not support a model in which the rate of sliding of wet specimens is controlled by pressure solution. An alternative model based on stress corrosion has been developed which is a more satisfactory fit to these data.

Similar work is now under way on a Tholeiitic basalt. Additionally, textural studies of specimens deformed in constant strain rate mode to total strains of ca. 3-5% are being performed.

Reports

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Dennis, P.F. and ATKINSON, B.K. 1980. Flow and fracture deformation mechanism maps for quartz (in preparation)

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ATKINSON, B.K. 1980. How to take the shock out of earthquakes. The Guardian, 25 September.

Rock Mechanics

9960-01179

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Investigations

Laboratory experiments are being carried out to study the physical properties of rocks at elevated confining pressure, pore pressure, and temperature. The goal is to obtain data that will help us to determine what causes earthquakes and can we predict or control them.

Results

The permeability and strength of San Andreas fault gouge from the Cienega Valley was measured for confining pressures up to 2 kb. The gouge was almost entirely composed of clay minerals, predominantly montmorillonite and mixed layer clays. Permeability was found to be in the nanodarcy range for both hydrostatic and strained conditions. Permeability did not depend on accumulated strain or creep, but was sensitive to differential stress. The presence of water in the clay lowered the strength, even in the absence of excess pressures.

Rock samples taken from two outcrops, as well as rare cores from three well bores at the Geysers Geothermal Field were tested at temperatures and pressures similar to those found in the geothermal field. Both intact and 30° sawcut cylinders were deformed at confining pressures of 200 to 1000 bars, pore pressure of 30 bars, and temperatures of 150 and 250°C. Thin section and x-ray analysis revealed that some borehole samples had undergone extensive alteration and recrystallization. Constant strain rate tests of 10^{-4} and 10^{-6} per sec gave a coefficient of friction of 0.68. Due to the highly fractured nature of the rocks taken from the production zone, intact samples were rarely 50% stronger than the frictional strength. This result suggests that the Geysers reservoir can support shear stresses only as large as its frictional shear strength.

Two additional experiments were performed in which p-wave velocity (6.2 km/sec) was measured and acoustic emission and sliding on a sawcut were related to changes in pore pressure. b-values were computed from the acoustic emissions generated during fluid injection giving typical values of about 0.55. An unusually high b-value was observed during sudden injection of water into the sample (approximately 1.3) and may have been related to thermal cracking.

The changing permeability of Westerly granite in a temperature gradient, with confining and pore pressure, was measured over time. Permeability decreased in all cases, at a rate which increased at higher temperatures. Near 300°C, permeability dropped sharply within a few days to around 5% of the initial value regardless of the stress applied to the rock mass. The dissolution and redeposition of quartz and feldspar minerals within cracks and channelways was found to be the major cause of permeability reduction.

Reports

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Mechanics of Earthquake Faulting

9960-01182

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Investigations

1. Experimental and theoretical study of fault constitutive properties continued.

2. A study of fracture geometry and stress-strain relationships for rock cubes subjected to true three-dimensional strain conditions was completed.

3. Planning was initiated for an experimental study of fault energy dissipation mechanisms and fault heating. The experimental method is based upon measurements of stick-slip sliding parameters including duration of slip, displacements, stress/strain changes, and temperature transients. Work done in frictional heating during slick-slip will be obtained from the observations of temperature transients using calibrations obtained from a second set of experiments using heaters on the fault plane that are pulsed for the observed stick-slip duration.

4. Study of fault instabilities in the large biaxial experiment continued. Software tools and electronic instrumentation for spectral analysis of signals were developed.

Results

1. An electronically controlled system for varying the apparent stiffness of the small, 50 ton biaxial apparatus was designed and tested. The system is based on variable electronic mixing of displacement and load transducer outputs for high-speed servo-controlled feedback. In principle for simulated fault experiments, apparent machine stiffnesses from zero to infinity can be obtained. In practice, system response rates and signal noise limit actual stiffnesses. Tests have shown that stiffnesses as high as 100 bars/micron are practical. Experiments with this system confirm theoretical predictions that system stiffness is an important determinant of fault response during stable sliding. Previous work has established the strong control of stiffness for unstable slip.

2. Study of rocks in a three-dimensional strain field was completed. In the experiments, cubic samples of Berea Sandstone, Sierra-White granite, and Candoro limestone were loaded on their three pairs of faces by three independent, mutually perpendicular presses at room temperature. Two of the presses were servo-controlled, and applied constant strain rates throughout the experiment. Most samples displayed four sets of faults in orthorhombic symmetry. These faults formed in several yielding events that followed a stage of elastic deformation. In many experiments, the maximum and the intermediate compressive stresses interchanged orientations during the yielding events, whereas the corresponding strains were constant. The final stage of most experiments was characterized by pseudo-ductile flow due to slip along the faults. The dependence of the number of sets of faults and their orientations on the three dimensional strain field was explained by a strain theory of faulting. The theory predicts that fault orientations that require minimum stress difference to accommodate three dimensional strain are the most likely to form. A good agreement was found between the predicted and observed data.

Reports

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Prediction Monitoring and Evaluation

9920-02141

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Investigations

1. This project monitors and evaluates earthquake predictions from any source. Techniques have been established which can determine whether success in predicting earthquakes is due to skill or to chance. An extensive file of predictions now exists. Though predictions are no longer being evaluated, we continue to accumulate them both from non-scientists and scientists in the event the prediction of a particular event or predictions from a particular individual become an issue. Predictions are submitted to this office or extracted from a variety of publications which are monitored.

Results

1. Since this program is a continuing project which monitors published predictions, final results in the usual sense cannot be expected although interim reports have been published in the past. Analysis has shown that non-scientist predictions are of no value.

2. Because the project budget was not increased to cover the large increase in computer charges, any prediction scoring or evaluation and all program development has been impossible. Predictions received can only be dated and filed.

Reports

No reports were published during this period. None will be published in the future because computer evaluation cannot be done.

Experimental Rock Mechanics

9960-01180

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Investigations

1. Creep instabilities of silicates at high temperatures and pressures have been investigated and applications to strain localization along faults is considered.

2. Deformation microstructures in mantle xenoliths from the Tanchen-Lujiang fault zone of eastern China have been studied.

3. The effects of crystallographic orientation of compression direction on the creep of synthetic quartz crystal were explored.

4. The plasticity and plastic yield strengths of synthetic aluminum oxide single crystals were established.

Results

1. Strain softening and creep instabilities occur in many silicate rocks tested at high temperatures and pressures. The phenomenon is associated with the onset of recrystallization at grain boundaries. The basic physical mechanism responsible for the instability appears to be grain boundary sliding in the fine-grained aggregate along the original grain boundaries. The process removes many of the constraints imposed on individual original grains due to the requirement of strain continuity with their neighbors. Stress drops on the order of 50% are common in constant strain rate experiments. This indicates that if the instability occurs first at a local strain perturbation, the strain rate in this zone would be ten to 100 times faster than in the surrounding area deforming by normal dislocation processes. This could account for the extreme localization of strain found in mylonite zones along major faults (Kirby, 1980).

2. He Yong-nian, a geologist from the Institute of Geology of the Chinese State Seismological Bureau, has studied the deformation microstructures in the ultramafic xenoliths collected from basalts which issue from the Tanchen-Lujiang fault zone in eastern China. These rocks are thought to be samples of the fault zone within the upper mantle. Mr. He has found deformation microstructures which are characteristic of a high strain rate environment. We suggest that

these features are associated with the deep strain accommodation of fault movements associated with great earthquakes (He and Kirby, 1980).

3. Kirby and Linker (1980) have shown that the creep behavior of synthetic quartz crystals compressed in various crystallographic orientations may be classified as follows:

   A. Crystals compressed at about 45º to the [c] axis deform principally by easy glide on $(1\bar{2}10)$ and (1010) in the [c] direction and show a relative low sensitivity of creep rate to changes in temperature.

   B. Crystals compressed perpendicular to the [c] axis deform primarily by slip parallel to the [a] axes and show a much greater temperature effect on creep rate.

   C. Crystals compressed parallel to [c] deform at rates that are many orders of magnitude lower than groups A and B. No slip system has been rigorously identified but apparently these samples deform by slip in the [c± a] directions on various slip planes.

   Earlier, we put forward an explanation of the differences in creep behavior of samples in groups A and B in terms of the diffusion anistropy of water in quartz (Linker and Kirby, 1980). This model appears to account for differences among a wider range of orientations.

4. Jacques Castaing, a materials scientist from the C.N.R.S. laboratory at Bellevue, France, and I have made an experimental survey of the plasticity and yield strengths of aluminium oxide single crystals. This close-pack oxide, which can be considered a model material for the phases which occur in the lower mantle, has been plastically deformed over an extremely wide range of temperature (200 to 1800ºC). The form of the yield strength variation with temperature is not consistent with prevailing theory.

Reports

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Large Scale Rock Fracture Experiment
Contract No. 14-08-0001-18307

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We have carried out all the proposed objectives of our first year program. In particular, we have developed a system for capturing and storing transient acoustic emission waveforms. The system employs eight sensors and provides sufficient data for hypocenter and focal mechanism determinations for discrete acoustic emissions. These signals are stored in digital form on mini-floppy discs and are available for spectral analysis. An independent counting system provides the cumulative number of events and their rate of occurrence over a selectable measuring interval. These two componenets of the main system provide checks on each other, for example, when the counter indexes we can observe the waveform on the transient recorder and determine the counts per waveform and whether or not the count is a real event. Knowledge of the total number of events allows us to evaluate the adequacy of our waveform capturing capability.

During the course of our work we have developed a very effective noise discriminator whose output correlate one for one with a recorded event (Sondergeld, 1980).

We have used this equipment to study the acoustic emission activity associated with the cyclic uniaxial loading of Westerly granite (Sondergeld and Estey 1980a, b). With our enhanced "seismological" capabilities we have found that even at low volumetric strains acoustic emission events display a pronounced spatial and temporal clustering. Initial studies of elastic wave radiation patterns indicate that similar radiation patterns are generated for events which display the spatial and temporal clustering. These studies demonstrate our software capabilities for determining hypocenters and focal mechanisms for discrete AE events.

We visited Moscow and were witness to the capabilities and cooperation of our Russian colleagues in performing a large scale rock fracture experiment. Our preliminary measurements suggest: (1) there are no unsurmountable noise problems; (2) dominant frequency bandwidth appears to be from 50 to 300 KHz which would permit good resolution in hypocenters. (3) large fractures (10-15cm in length) are contained wholly with these large samples (50cm x 50cm x 70cm). This last point is most relevant to the natural situation where earthquakes are certainly terminated and provides us with the unique opportunity to study AE, strain, and electrical phenomena associated with this crack development and propagation.

Local Changes in the Gravity and Magnetic Fields Due to Tectonic Strain

14-08-0001-18212

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Investigations and Results

Surface displacements and tilts and local changes in the gravity and magnetic fields provide complementary sources of information about tectonic events at depth. I have been analyzing the changes in the gravity and magnetic fields due to tectonic strain using an elastic half-space as an earth model. I have four analyses in progress; these are:

(1) Derivation of the influence functions relating the change in the magnetic field at the earth's surface with a dislocation at depth in an elastic isotropic half-space. Magnetism is due to the earth's field, assumed uniform, acting on magnetic minerals uniformly distributed throughout the half-space.

(2) Derivation of the influence functions relating the change in gravity measured at the earth's surface to a change in the body force field. The earth is assumed to be a uniform elastic half-space.

(3) Derivation of the influence functions relating the change in gravity at the surface to a dislocation at depth in a half-space with a low-density surface layer but with uniform elastic properties.

(4) Calculation of the effective piezomagnetic behavior of sample having a mixture of magnetic and non-magnetic grains using a new approach.

In addition I spent one month at the Office of Earthquake Studies (Menlo Park, California) working with M.J.S. Johnston.

Reports

There have been no publications.

MEASUREMENT AND ANALYSIS OF THE NEAR SURFACE STRESS FIELD IN THE VICINITY OF ACTIVE FAULTS IN SOUTHERN CALIFORNIA

14-08-0001-17703

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The immediate objective of this research program is to determine if tectonic stress can be measured near active faults using near-surface *in situ* techniques. The method we use is a strain-relief technique developed by the U. S. Bureau of Mines. In actuality, strain is directly measured and stress is calculated from the strain and measured rock moduli.

Data were obtained in the field during summer 1979 and winter 1980. A total of forty individual stress measurements were made at four sites with the greatest depth being 10.5 m. Doorstopper *in situ* stress measurements (a different strain-relief technique) were previously made at two of the sites. Similar orientations were observed with both methods.

The most significant development this season is the marked difference in strain and therefore stress measured at one site from summer to winter. This site was the first site occupied during the summer and the first at which we used the Bureau of Mines technique. Technical problems prevented us from collecting as much data as desired. This site was tested again in January to obtain more data. To our surprise the strain values were very small and averaged about a factor of five less than the previous summer. We checked and double-checked the equipment, but everything was working fine. The observation certainly seems to be valid. As a further check the stress magnitudes observed during the summer were similar to those at a site 2 km away in the same rock type. We suspect thermally induced stress is the cause of this difference. The continuous recording stress meters in the area (Bruce Clark, personal communication, 1980) showed no significant change, so we did not think the stress change was tectonic.

Hooker and Duval (1971) investigated this phenomenon and noted that the effect of the seasonal temperature change should be significant near the surface and should diminish with depth to zero at about 8 m. Plots of the theoretical variation of temperature with depth for the summer and winter are attached. The dashed line is the calculated stress for an elastic half-space rigidly confined at its sides. The stars and squares are the average stress at the noted depths for one winter site and two summer sites. The tensile stresses shown in the winter would not be observed because of the presence of joints. In a perfectly homogeneous half-space the thermal stresses would be the same for both horizontal components, and could be easily eliminated from our data.

To understand the influence of fractures, consider a single set of joints that are parallel. If the rock expands the joints will close, relieving strain. This will yield a lower stress perpendicular to the joints than parallel. An *in situ* stress measurement between joints will thus produce a deviatoric stress. In the rocks sampled there are generally two to three joint sets. We expect the thermal expansion to produce a deviatoric stress that depends on the character and orientation of the joints. Other effects such as rock anisotropy may also be important in modifying thermal stress. The influence of residual and topographic stress have been either minimized or found not significant at these sites.

Future work is planned to more conclusively determine the effect of thermally induced stress. We want to know how deep we must go to avoid it and how joints and rock anisotropy modify it. This summer we will make measurements to depths of 30 m at each of two sites in different rock types. During the winter, we will drill parallel holes at both sites and compare the data. The stress values should converge below the thermally active zone.

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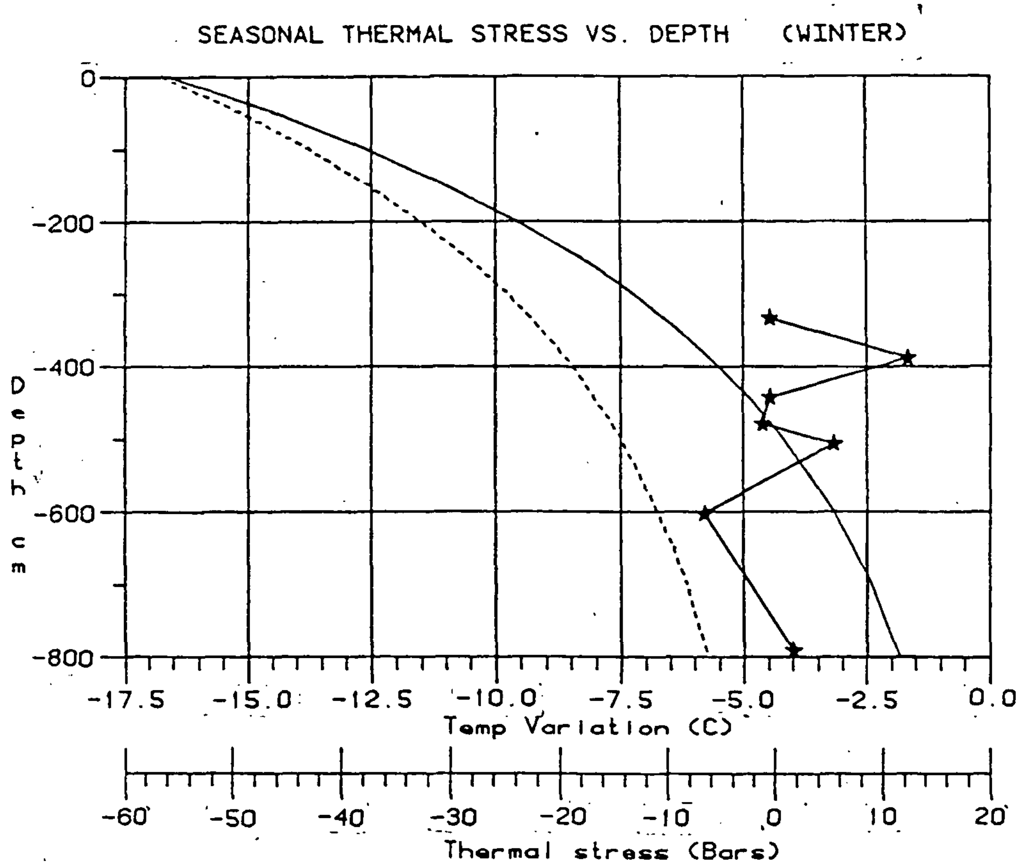
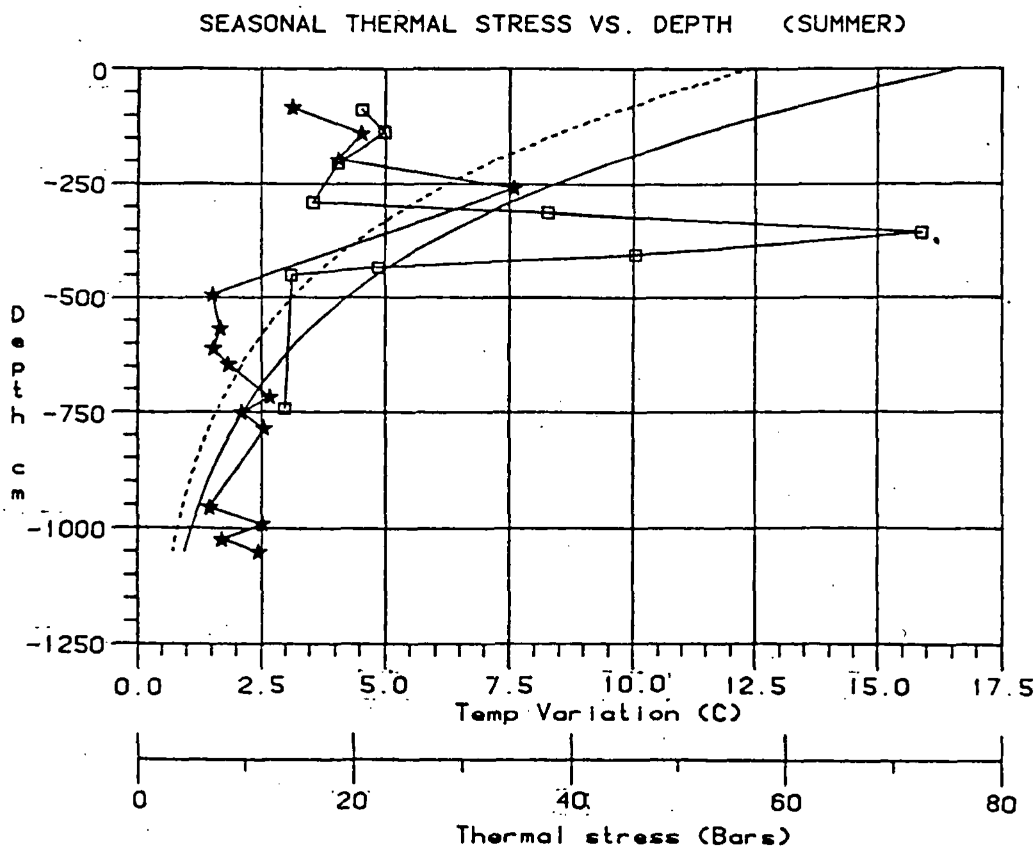

SEASONAL THERMAL STRESS VS. DEPTH (WINTER)
Depth cm
0
-200
-400
-600
-800
-17.5 -15.0 -12.5 -10.0 -7.5 -5.0 -2.5 0.0
Temp Variation (C)
-60 -50 -40 -30 -20 -10 0 10 20
Thermal stress (Bars)


SEASONAL THERMAL STRESS VS. DEPTH (SUMMER)
Depth cm
0
-250
-500
-750
-1000
-1250
0.0 2.5 5.0 7.5 10.0 12.5 15.0 17.5
Temp Variation (C)
0 20 40 60 80
Thermal stress (Bars)

Fault Zone Structures

9960-01725

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Investigations

A seismic refraction system of 100 portable seismographs was used to continue detailed studies of a wide range of earth structures in a few selected areas to provide critical data leading toward a predictive understanding of earthquakes and a close examination of potential nuclear waste disposal sites.

1. Two 25 km long reversed seismic refraction profiles, lying in a cross pattern, were recorded to study the structure of the western Mojave Desert north of the San Andreas fault to determine the degree of anisotropy with velocity structures in these rocks and to relate this anisotropy to stress. Another 75 km long, partially reversed profile was recorded across the San Andreas fault and the San Gabriel Mountains to San Bernardino. This study was conducted to map the distribution of the fractured layer along these profiles, to get accurate velocity measurements, to look for deep crustal reflections, and to gather data for planning future Vibroseis surveys of the area.

2. A seismic refraction study was designed to test the underlying structural features of the New Madrid Seismic Zone. A series of profiles were recorded along and across the rift, dense patterns of stations being deployed in several areas including that south of Reelfoot Lake, Tennessee, which has a relatively high level of seismic activity.

3. An investigation of the tectonic framework of Yucca Mountain was conducted at the Nevada Test Site using a modified seismic refraction technique across a proposed nuclear waste disposal site. It is necessary to determine the relationship between the seismic velocity and fracture density in order to predict long term tectonic stability. If the various factors determining seismic velocity can be identified and separated, the pattern of seismic delays can provide critical information about the distribution of fractures which could provide paths for ground water convection in and above the waste disposal system.

4. Continued interpretation of seismic refraction data from the epicentral region of the Coyote Lake earthquake of August 6, 1979. A reversed refraction profile was conducted in July 1980 across the valley south of Gilroy, California, and an unreversed profile was conducted in the Santa Cruz Mountains.

5. Continued analysis of data and publication of results from the 1979 seismic refraction survey of the Imperial Valley region, California. Based on an interpretation of the data, it is fairly certain that the structure of the region consists of a thick layer of sediments overlying an oceanic crust. A combination of geologic, seismic refraction and reflection, and gravity data give a result which shows a crustal layer with about a 7 km/s velocity underlying the valley at a depth of about 10 km and underlying adjacent continental crustal rocks at a depth of about 15 km.

6. Continued analysis of Saudi Arabia refraction data. Completion of travel-time interpretation, re-digitization of the data, and of new true-amplitude record sections. A summary of the major results and conclusions was presented at the Commission on Controlled Source Seismology meeting in Park City, Utah, in August 1980.

7. Continued analysis of seismic refraction data from the Livermore, California, area. The reversed refraction profile was recorded in the epicentral region of the Greenville fault earthquake of January 24, 1980. Additional profiles are being planned.

8. Continued analysis and interpretation of data from Mount Hood, Oregon. Paper in process of publication.

Results

1. An apparent anisotropy of the upper crustal rocks has been measured in the Mojave Desert south of Edward's Air Force Base. Both terms of the anisotropy function are prominent in the data and the observed magnitude and direction of the effect are consistent with measurements of tectonic stress in this region. Further analysis and interpretation of the data is being conducted.

2. Aeromagnetic and reflection data suggest that the main structural feature of the New Madrid Seismic Zone underlying the northern Mississippi embayment is a northeast striking rift about 20 km long and 80 km wide. Data is presently being prepared for analysis and a report is scheduled for the December 1980 AGU meeting in San Francisco.

3. Successful recordings of nuclear blasts at the Nevada Test Site revealed the deep structures in the vicinity of the proposed waste disposal site. Data preparation is in progress and an attempt is

being made to use all available data to correlate seismic velocity changes with fractures and develop a method to map major fracture zones at depth.

4. Analysis of the seismic refraction data from the Gilroy and Santa Cruz Mountains profiles reveals that the velocity structure of the Santa Clara Valley consists of three media with velocities of 2.26 km/s, 4.45 km/s, and 6.0 km/s. The first velocity is typical for unconsolidated sediments and the second probably arises from propagation in consolidated sediments. The velocity of 6.0 km/s at about 2 km depth beneath both the valley and the mountains raises a problem in the interpretation of the structure because previous profiles in the Diablo Range indicate that such a velocity is not reached until a depth of about 8 km. This suggests that the structure of the rocks west of the Calaveras fault differs significantly from those east of the fault.

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In-Situ Stress Measurement

9960-01184

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Investigations

1. A well about 1 km deep was drilled into crystalline rock about 4 km from the San Andreas fault in the Mojave Desert north of Pearblossom, California, to measure the state of stress, natural fracture distribution, bulk permeability, and sonic velocity as a function of depth. Natural fractures in the well were studied with an ultrasonic borehole televiewer and in-situ bulk permeability was measured by conducting "slug" transmissivity tests. Ultrasonic velocity measurements, a temperature log, and an inclinometer survey were completed in the hole.

2. Downhole experiments to study velocity and seismic attenuation, the latter as a function of frequency and depth, were successfully completed at the East Mesa Department of Energy Test Facility in the Imperial Valley, California. A temperature log was completed in one well and a vertical seismic profile, using an airgun source, in another well. These measurements were taken in a known area of hot rock to discover whether there are any measureable effects of high temperatures on velocity and attenuation.

3. We assisted in hydrofracture studies conducted by the University of Wisconsin in a 5000' deep hole drilled in granitic basement near Freeport, Illinois. Televiewer and velocity logs were performed in the hole, the principal objective being to correlate measurements of fracture density, velocity, and stress in continental shield areas to similar measurements in tectonically active regions.

4. A reservoir-induced seismicity study was conducted in the Monticello #2 well near Columbia, South Carolina. Hydrofrac measurements and televiewer and velocity logs were completed in order to determine the variation in stress with depth, as well as the probability of fracture density and orientation and velocity. Both the S- and P-waves and the aquifer pore pressure at various depths were measured.

Results

1. Hydraulic fracturing stress measurements taken in the Mojave well indicate that the maximum and minimum principal stresses respectively increase with depth from about 50 to 90 bars at 160 m to about 350 m and 190 bars at 750-850 m. Shear stress on planes parallel to the San Andreas fault also increases with depth and the local direction of maximum horizontal compression is about N20°-45°W from the local trend of the San Andreas. A near-surface zone of dense fracturing extends to a depth of about 130 m below which the fracture density slowly decreases with depth. Bulk permeability was found to be 1-10 millidarcies for the fractured crystalline rock but was not observed to decrease markedly with depth. Ultrasonic velocity measurements show an increase of P-wave velocity with depth and a general correlation is seen between this velocity and the magnitude of the horizontal principal stresses.

2. Data taken from the East Mesa well in the Imperial Valley suggest that high temperature effects on velocity and seismic attenuation are indeed measureable. Further data analysis is in progress and a paper is in preparation.

3. From the data taken from the well in Illinois, a correlation between seismic velocity and fracture density was established. The data is presently being analyzed and a paper is in preparation which incorporates data taken from the three Limekiln, California, wells. These wells were drilled during the fall of 1979 for velocity, stress, and fracture density measurements.

4. In-situ rock measurements taken in the Monticello #2 well, South Carolina, are in general agreement with seismologically determined hydrologic diffusivities, velocities, and stress regimes. A "slug" type transmissivity measurement taken in the well revealed bulk permeability values from about 1×10^{-5} to 2×10^{-3} darcies for intervals with average fracture spacings of about 4 to 1.5 m. The permeability in this well was observed to decrease rapidly with depth. The data is presently being analyzed; a paper is in preparation and an abstract is scheduled for the fall 1980 AGU meeting in San Francisco.

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Heat Flow and Tectonic Studies

9960-01176

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Investigations:

1. Energetics of the San Andreas fault zone. About 20 heat-flow holes have been drilled in the Salton Trough region of the San Andreas fault zone.

2. Regional heat flow and tectonics of the western United States. Analysis of regional data and the results of some site-specific geothermal evaluations continue.

3. Site-specific heat-flow studies relevant to geothermal energy and nuclear waste disposal. Field studies have been made in the northern Black Rock Desert, the California Cascades, Modoc Plateau, Lassen Known Geothermal Resources Area, the Nevada Test Site, and the Paradox Basin in eastern Utah. Supporting laboratory and interpretive studies are under way.

4. Additional temperature measurements have been made at 17 sites in the National Petroleum Reserve (Alaska).

Results:

1. Sonoran Desert. Preliminary determinations of heat flow indicate a thermal regime consistent with average Basin and Range conditions. We are attempting to reconcile this observation with suggestions of substantially different tectonic styles (which may have different thermal implications) between this region and the northern Great Basin.

2. Black Rock Desert, Nevada. An additional 12 holes provided confirmation and a northward extension of heat-flow data published by Sass, Zoback, and Galanis (Open-File 79-1467). The new control reinforces our earlier conclusions; namely, that the geothermal manifestations at the margins of the Black Rock Desert result from hydrothermal circulation within and/or beneath the basin sedimentary.

3. Thermal results from the Nevada Test Site. Data were obtained for the first time from granitic rocks (the Climax Stock) on the test site. No laboratory data are available, but the temperature gradients support our earlier interpretation of regional heat flow in the NE part of the test site. Results from Calico Hills suggest active hydrothermal transport. Fairly detailed albeit preliminary thermal measurements at a proposed nuclear waste repository in the Yucca Mountain area are consistent with a regional model of pervasive hydrologic recharge.

Centrifuge Modeling of Earthquakes: Air-Gun Seismic Velocity and Attenuation Measurements in the San Andreas Fault Zone

9960-02413

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Investigations

1. Effect of tidal stress on seismic wave velocity and amplitude in fractured granite.

2. Laboratory measurement of rock internal friction. For a detailed discussion of the results of this investigation refer to L. Peselnick, Rocks Under Geothermal Conditions, 9960-01490.

3. A rapid method to prepare brittle scaled crustal models suitable for centrifuge modeling of earthquakes.

Results

1. There have been reports in the literature of change in seismic velocity with semidiurnal periodicity (De Fazio _et al_., 1973; Reasenberg and Aki, 1974; Bungum _et al_., 1977). This semidiurnal variation of seismic velocity has been attributed to the opening and closing of thin cracks (aspect ratio 10^{-5}) in the rock mass by the tidal stress. The reported high stress sensitivity of velocity change ($(dV/dp)/V = 0.2$ bar^{-1}) indicates that seismic velocity and amplitude could be used to monitor the tectonic stress in the crust. To further investigate this semidiurnal variation in seismic velocity, we have collected seismic data over two 18 hour periods. The first period (September 22-September 23, 1980) coincides with a tidal stress maximum and the second period (September 30-October 1, 1980) coincides with a tidal stress minimum. The site of the experiment is a fractured granite mass located 2 km from the San Andreas fault (Limekiln Road, Hollister, CA). A Bolt Associates 40 cubic inch air gun fired in a mudpit was used as the seismic source. Two seismometers, separated by 600 m in a north-south direction to reduce the tidal diurnal stress components, were used to record the travel time difference. Two Sprengnether digital recorders with digitizing rate of 600 samples per second were used to record the seismic signals. The clocks of the two recorders were synchronized to

within 0.2 ms by a third reference clock before each shooting sequence. Each shooting sequence comprises ten to twenty shots approximately 1 minute apart. The time separation between successive shooting sequences is two hours. First arrivals of the air gun shots were clearly recorded. These records are now being analyzed for time and amplitude variations.

2. A method has been developed to rapidly prepare brittle scaled crustal models suitable for centrifuge modeling of earthquakes. This method uses reciprocating air cylinder as a ram to consolidate the silica-linseed oil mixture to a desired density, which, after cured in a microwave oven, can be used as various crustal blocks in a centrifuge earthquake fault model. Typical block size is 25 cm x 25 cm x 25 cm. The reciprocating air cylinder ensures uniformity of the stress in consolidating the modeling material. It also speeds up the process of model making.

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Laboratory and Field Investigations of Fault Gouge

14-08-0001-17677

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Investigations

The overall objective of this project is to investigate fault mechanics of gouge-host rock systems through controlled laboratory experiments and correlated field studies with the emphasis on understanding the operative physical principles that govern shallow-focus earthquakes. In this report we discuss the results of investigations into two areas: (1) field studies of natural fault zones and (2) laboratory studies of time-dependent friction behavior.

Results

Field studies of natural fault zones. Field studies are still in progress along the Palochic fault zone in Guatemala. A part of the zone which is actively creeping is being studied to characterize the physical properties. Correlation of the field data with the results of current laboratory studies will be used to infer mechanical processes. As the field work is still in progress final results will be delayed until a later time, but presently some tentative observations can be made. The original trace of the fault had one very large and several broad sinusoidal bends to it. As the fault displaced one block overrode the other, forming depositional basins. The rocks in the depositional basins have subsequently been faulted to form slivers which give the fault a braided form. The active displacement zone appears to get progressively narrower as slip progresses. This will produce higher shear strains. This model is similar to that proposed by Crowell for segments of the San Andreas and other faults. It also agrees with observations of experimental studies of simulated fault zones. Further petrofabric studies of samples should provide insights into the operative mechanical processes.

Laboratory studies of time-dependent friction behavior. During the latter part of this contract period we have directed our effort toward developing a physical basis for some of the complex phenomena observed in friction experiments from both our and other laboratories. A model is proposed which follows closely that of Dieterich (1978, 1979) and of Johnson (1980), but which, in addition, is strongly influenced by the earlier works of Rabinowicz (1957) and Kragelskii (1965). The model attempts to provide an explanation for the observed phenomena of (1) the strengthening of frictional surfaces with increasing time of contact (Dieterich, 1978; Teufel and Logan, 1978) and (2) the weakening of intact rocks with increasing time of deformation (Stesky et al., 1974). The model is then compared with the experimental data of this laboratory and other workers. The conclusions of this analysis are:

(1) A necessary but not sufficient condition for the occurrence of stick-slip in a frictional system is that the system must exhibit an inverse dependence of shearing resistance on shear strain rate or shear displacement rate, at the conditions under which it is being deformed.

(2) In order that the system may possess this characteristic, the strain rate sensitivity of the applied stress must be greater for deformation of asperities normal to the surface than for shear, by an amount which exceeds the reciprocal of the exponent in the geometric distribution function describing the variation of asperity heights across the surface.

(3) It might be expected that inverse strain-rate effects are more often associated with polished, than with rough, surfaces.

(4) Condition (2) (above) is most readily met when a positive gradient in the mechanical properties with depth exists, such that, for a given stress, the constitutive relation for creep of adhesive junctions leads to higher strain rates than that for creep of the bulk material, and the two relations are independent of each other.

(5) Inverse strain-rate effects lead to a microstructure that is characterized by discrete zones of relative displacement, and which is therefore highly heterogeneous. Evidence that a shear zone has deformed only by homogeneous flow, precludes the possibility that the zone may have undergone unstable frictional slip, and is therefore diagnostic of stable deformation. Conversely, regions of a fault that have deformed unstably should display heterogeneous deformation features, i.e., discrete slip zones within relatively undeformed material.

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EXTENDED REFLECTION SURVEY OF THE SAN ANDREAS FAULT ZONE, SAN BENITO COUNTY, CALIFORNIA

CONTRACT NO. 14-08-0001-16804

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An extensive reflection survey was conducted in 1978, crossing the San Andreas fault zone in San Benito County, California. Some 18 km of CDP coverage, up to 24-fold, was obtained in addition to in-line and lateral offsets of up to 16 km and 8 km, respectively, providing subsurface information of variable redundancy over a distance of 44 km along the profile (WSW-ENE) and in a 6 km-wide strip along the profile at the fault zone. The full data set with maps and sections was presented in the first Technical Report for the contract and is not reproduced here.

The purpose of the survey was 1) to extend across the fault a previous survey line wholly west of the fault showing good deep data, 2) to obtain velocity information in the contrasting granitic and Franciscan crustal plates and possibly the fault zone, investigating the possibility of a low velocity wedge extending from the seismically active (∿ 3-10 km depth) section of the fault zone several km laterally into the crustal blocks, 3) to provide sites for recording reflections with strategic paths in our program of travel-time monitoring, and 4) to provide preliminary information on the feasibility of a 3-dimensional seismic imaging for velocity and structure within the fault zone.

Data in the granitic crust show generally good reflections to the base of the crust, seen as a series of arrivals over nearly 10 km of transition. Along the entire CDP line there are apparent reflections to 3.0 sec travel-time, but within the Franciscan crustal block there appears to be a diffusion of energy as if by back scattering and attenuation, with very little return from the lower crust, in marked contrast to the granitic section to the west. The fault zone is characterized by high attenuation, some shallow coherent arrivals, and several apparent diffractions. The interval 4-6 sec appears generally non-reflective, possibly related to the depth (10 km +) of the onset of stable sliding in the fault zone.

Extensive lateral velocity gradients are seen, with a decrease of some 30% over about 5 km approaching the fault zone from the granitic side. Such gradients make difficult the tasks of stacking properly the multifold data and preclude the use of flat-layer algorithms for velocity estimation. This problem has been addressed during the no-cost extension period of the contract. Forward ray-tracing modeling of first arrivals and reflections provides a velocity distribution which satisfies the data under some constraints. The resulting model features a very low velocity fault zone and a strong lateral velocity gradient within the western fault block with a probable low-velocity wedge extending at least 5 km laterally from the fault zone in the depth range of 3-8 km, coinciding roughly with that of the seismicity.

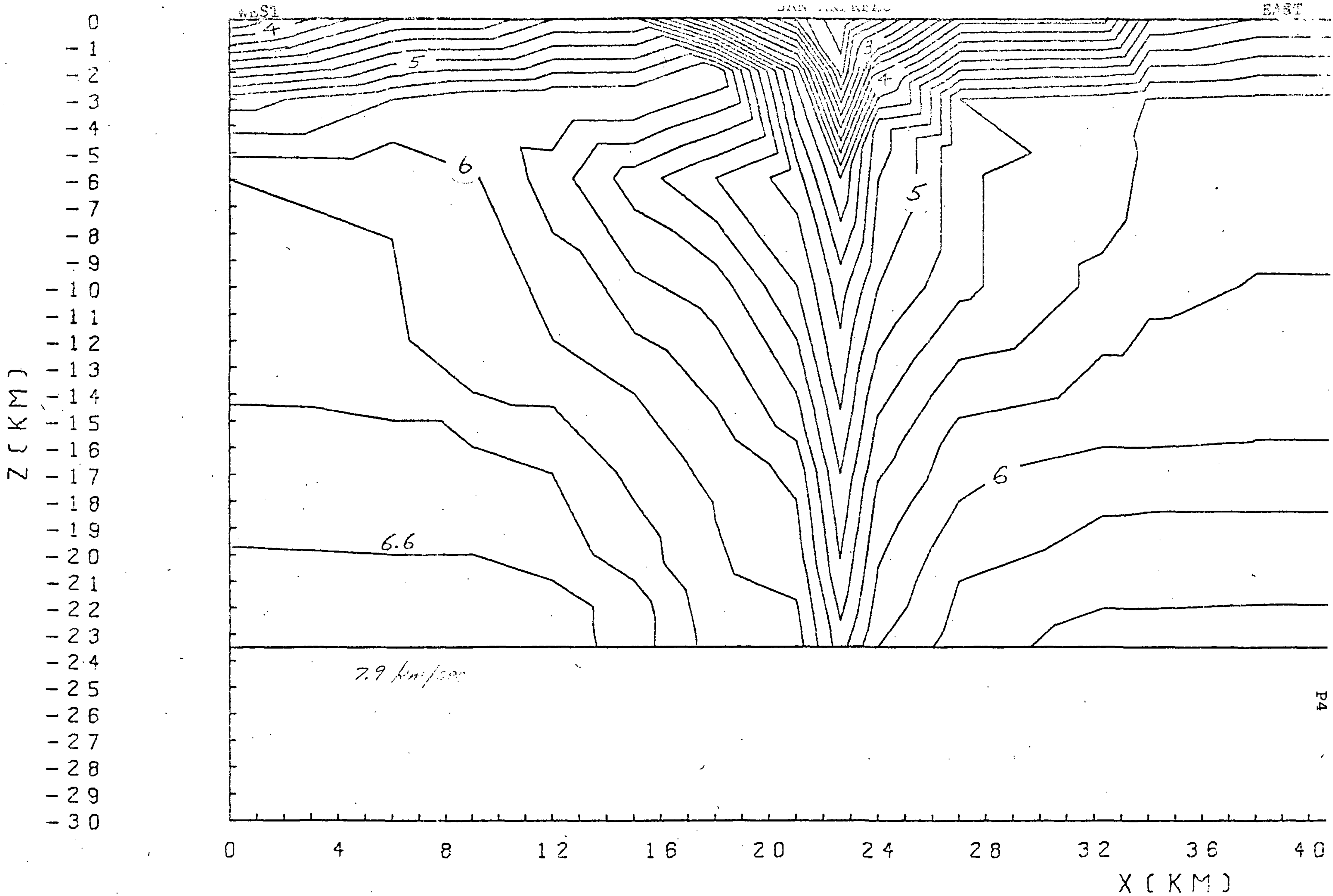

Figure 1. Equal velocity contours for a section across the San Andreas fault zone in central California.

P4

Deviatoric Stresses in the Earth's Crust and Uppermost Mantle

9960-02414

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Investigations

1. A final report was prepared for publication summarizing the results from a study of possible correlations between San Francisco Bay area seismicity and the fortnightly fluctuations in tidal amplitude.

2. Using total field magnetometer readings collected at the sea surface by the RV New Horizon in 1979, paleomagnetic poles were calculated for a series of six small seamounts on the northern Cocos plate. These apparent poles were then interpreted in terms of absolute plate motion of the northern Cocos plate during the last 10 m.y.

3. Published estimates of apparent flexural rigidity of the oceanic lithosphere show considerable departure from a simple theoretical curve relating plate thickness to the age of the lithosphere at the time of loading. Preliminary calculations indicate that much of this scatter can be reduced by correcting both the estimates of lithospheric age for thermal rejuvenation and the plate thicknesses for the dependence of plastic yield strength on total deviatoric stress.

Results

1. During the ten year period from 1969 to 1978 the strike-slip earthquakes with magnitude greater than 2 in the San Francisco Bay area occurred randomly with respect to the fortnightly tidal fluctuation. In addition, it appears unlikely that earthquakes with magnitude greater than 3 are triggered by favorable stress from the semidiurnal tide.

2. Paleodeclinations from the Cocos plate seamounts demonstrate that the plate rotated approximately 30° counterclockwise about a pole close to its northern boundary during the last 1 to 6 m.y. This conclusion supports an earlier plate motion model proposed by H. W. Menard based on topographic trends near Clipperton Island. Paleoinclinations agree with models of absolute plate motion in which the northern component of velocity for the Cocos plate is approximately 50 mm/yr.

3. The refinements used in calculating the relationship between elastic plate thickness for the oceanic lithosphere and thermal age of the lithosphere at the time of loading increase the estimate for the temperature at the base of the elastic lithosphere from the 300° to 600° range previously proposed. These corrections help to remove some discrepancies between laboratory-derived creep parameters and those deduced from geologic loading studies.

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Active Seismology in Fault Zones

9930-02102

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Investigations

1. Continued investigations of the P-wave velocity structure and tectonic framework of the Imperial Valley, southern California, based on the analysis of seismic refraction data collected in early 1979 (with G. S. Fuis and J. H. Healy).

2. Analysis of seismic refraction data from the Livermore, California region.

3. Interpretation of seismic refraction data from the epicentral region of the Coyote Lake earthquake of August 6, 1979 (with J. H. Luetgert).

4. Analysis of seismic refraction data collected in Saudi Arabia by the USGS during February 1978 (with J. H. Healy).

5. Continued development of efficient methods for the calculation of ray amplitudes and travel times in laterally inhomogeneous media (with G. A. McMechan and J. H. Luetgert).

6. Initiation of a seismic refraction investigation of The Geysers-Clear Lake geothermal region (with J. H. Healy, D. H. Oppenheimer and H. M. Iyer)

7. Analysis of seismic refraction/reflection data from the Mojave Desert, southern California (with G. S. Fuis and J. H. Healy).

8. Reinterpretation of seismic refraction data for both the Diablo and Gabilan Ranges (with Allan Walter).

9. Collection of seismic refraction data in the Mississippi embayment (with J. H. Healy, R. M. Hamilton, and Allan Walter).

Results

1. Major results of the study of the Imperial Valley are: (i) Unmetamorphosed sediment occupies a trough centered on the seismogenic belt in the Imperial Valley. (ii) Apparently two types of basement are present: crystalline basement under West Mesa and the mountains on either side of the Salton Trough (P-wave velocity 5.9-6.0 km/s), and metasedimentary basement under the Imperial Valley

(P-wave velocity, 5.65 km/s). The west boundary between these two basement types is a buried scarp on the west side of the Imperial Valley. The total thickness of sedimentary and metasedimentary material in the Imperial Valley is 10 to 16 km. (iii) A subbasement (P-wave velocity, 7.2 km/s) is present under the metasedimentary rocks in the Imperial Valley. This layer, probably composed of diabase and gabbro, compensates gravitationally for the relatively light sedimentary section above.

The plate tectonic model for this region can be elaborated from our studies. By drawing in our inferred boundary (or suture) between the two basement types, we can better identify idealized elements of this model with actual geologic structures. In particular, the San Jacinto and Elsinore faults appear to be analogous to fracture zones that are northwestward extensions of the Imperial and Cerro Prieto transform faults, respectively. This identification is not "clean" for the Elsinore fault. Departure from the idealized plate tectonic model may be due to interference of the North American continent, with its preexisting weaknesses.

2. Five explosions were fired at three separate shot points to provide reversed refraction profiles in the epicentral region of the Greenville fault earthquake of January 24, 1980. These data define a laterally inhomogeneous velocity structure; the major structure consists of 5.5 km of material with a velocity of ~3.8 km/s underlain by a material with a velocity of 5.7 km/s. These materials may be interpreted as the Great Valley Sequence and Franciscan Terrain, respectively. There is, locally, a sharp velocity discontinuity between these materials as evidenced by a prominent reflected phase. These models will be valuable in locating aftershocks of the Greenville fault earthquake and in modelling its source parameters.

3. In order to elucidate the velocity structure of the region, a reversed refraction profile was conducted in July 1980 across the Santa Clara Valley (near Gilroy, California) and an unreversed profile was conducted in the southern Santa Cruz Mountains. Analysis of these data reveal that the compressional wave seismic velocity structure of the Santa Clara Valley consists of three media with velocities of 2.26 km/s, 4.45 km/s and 6.0 km/s. The 2.26 km/s velocity is typical for unconsolidated sediments. The velocity of 4.45 km/s most likely arises from propatation in consolidated sediments. This velocity is typical of near-surface Franciscan rocks (Stewart and Peselnick, 1978; Stewart, 1968) but is atypical of Great Valley sequence rocks (Mooney, in preparation). From this it can be concluded with some certainty that the Santa Clara Valley is underlain by the Franciscan Formation which outcrops to the west.

   The identification of a medium with a velocity of 6.0 km/s at about 2 km depth beneath both the valley and the southern Santa Cruz Mountains raises a problem in the interpretation of the structure because previous profiles in the Franciscan Terrain of the Diablo

Range indicate that a velocity of 6.0 km/s is not reached until a depth of ∿8 km. This suggests that the structure of the Franciscan rocks west of the Calaveras fault differs significantly from those east of the fault in the Diablo Range.

4. The major features of the velocity structure of the Saudi Arabian Shield which emerge are. (i) The upper crust (22 km thick) of the shield has a near-surface velocity of 6.1 km/s and in most regions a positive velocity gradient of 0.01-0.02 km/s. (ii) The lower crust (19 km thick) of the shield is separated from the upper crust by a seismic discontinuity of 0.2-0.4 km/s. The average velocity of the lower crust is about 6.7 km/s. (iii) The M-discontinuity is probably a transition zone 2-5 km thick and occurs at a nearly constant depth of about 40 km. Upper mantle velocity is 8.0-8.1 km/s and there is evidence for fine structure in the upper mantle. (iv) The structure of the Red Sea-continent transition remains uncertain with the currently available data. It is clear that the M-discontinuity deepens from ∿12 km in the Red Sea to 40 km on the shield. It is possible that the Red Sea is underlain by a substantial low velocity zone at a depth of 20-35 km.

5. The major effort has been to make available on the USGS PDP 11/70 computer the ray-tracing and synthetic seismogram methods which were developed over the last year.

6. The objective of the project is to provide a clear picture of the upper crustal structure in an area of geothermal importance. There will be 100 vertical-component seismographs deployed at close spacing along a 70-km-long profile. Four shots will be fired along the profile, yielding split and reversed profiles. In addition, 30 three-component seismographs will be deployed in cross arrays to assist in the positive identification of reflections and shear waves. This data will be complimented by recordings from the USGS/DOE The Geysers-Clear Lake telemetered array of permanent seismograph stations.

   Every effort is being made to encourage the participation of interested state and Federal agencies, and universities in this project. Field work will take place in November 1980.

7 The Mojave data reveal a basement of velocity ∿6.1 km/s, overlain by a sediments and/or weathered zone of variable thickness (0.1-0.2 km) and velocity (3.5-5 km/s). The data are rich in surface waves and possibly contain deep reflections. Processing of the data to enhance these phases is in progress. Several faults have been identified on the basis of travel-time offsets

8. Laterally heterogeneous velocity structures for both the Diablo and Gabilan Ranges that were derived by analyzing seismic refraction data previously reported by Stewart (1968). A computerized two-dimensional ray-tracing method was used iteratively to make both

lateral and vertical changes in the velocity structure until agreement between the calculated and the observed phase arrivals was judged adequate.

For the Diablo Range, the gross velocity structure consists of a sedimentary layer of variable velocity and thickness overlying a crystaline basement consisting of four layers with uniform average velocities except for an anomalous lower-crustal velocity found near the southern end of the range

The velocity in the sediments ranges from 2.9 to 4.8 km/s the thickest section being located in the valley north of the range. The average velocities of the crystaline layers are 5.0 km/s, 5.6 km/s, 6.2 km/s, and 6.9 km/s.

The velocity model for the Gabilan Range also consists of a sedimentary layer and four basement layers. The average sediment velocities are greater north of the Gabilan Range (3.6-4.6 km/s) than south of the range (2.4-3.8 km/s). The basement layers have average velocities of 5.5 km/s, 6.1 km/s, 6.35 km/s, and 6.7 km/s.

9. Analysis has just begun on the data collected during September and October 1980. Thirty-four shots were fired at nine separate shot points. Reversed profiles were made within and outside the embayment. A detailed model of the crustal velocity structure will emerge from these data.

Reports

Mooney, W. D., 1980, A travel-time interpretation of the 1978 seismic refraction profiles in the Kingdom of Saudi Arabia (abs): Presented at the IUGG Commission on Controlled Source Seismology, Park City, Utah, August 1980

Mooney, W. D., 1980, Seismic modelling of laterally varying structures: A comparison of interpretations of the 1978 seismic refraction profiles in the Kingdoim of Saudi Arabia (abs.): EOS, American Geophysical Union Transactions (in press).

Mooney, W. D., and Luetgert, J. H., 1980, Seismic-refraction study of the Santa Clara Valley, west-central California (abs.): EOS, American Geophysical Union Transactions (in press).

Fuis, G. S., Mooney, W. D., Healy, J. H., Lutter, W. J., and McMechan, G. A., 1980, Seismic refraction results in the Imperial Valley region, California, and implications for plate tectonics (abs.): EOS, American Geophysical Union Transactions, (in press).

Rocks Under Geothermal Conditions

9960-01490

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Investigations

1. Development of direct stress-strain apparatus for determination of internal friction (Q^{-1}) of rock at seismic frequencies (0.1 to 1.0 Hz) and seismic strain amplitudes (10^{-8} to 10^{-6}).

2. Feasibility study for experimental determination of linear compressibility anisotropy of rocks at small strain amplitudes (10^{-7}).

Results

1. Several sources of experimental error in the determination of internal friction in the Young's modulus mode (Q^{-1}) were found to exist for small strain amplitude measurements (10^{-8} to 10^{-7}) at seismic frequencies. Most of the effort for this report period was used to identify the specific sources of these errors and to eliminate or reduce their effects. A sketch of the most recent version of the Q-apparatus is shown in Figure 1. Briefly, the rock sample R is placed in a central column consisting of a steel rod S, ball-bearing B, and piezoelectric transducer stack G, X, E, and I. A compressive prestress is applied by the platens LP and TP by adjusting the nuts N. Sinusoidal changes in stress (0.1 to 1.0 Hz) are superposed on the prestress by the piezoelectric transducer X. Longitudinal displacements in the central column are detected by capacitor plates C and C' secured to the central column. The internal friction is determined from the shape of the hysteresis loop formed by the outputs from channels A and B. (Refer to Peselnick et al., 1979, for additional details for similar Q-apparatus.)

   The rock R and the steel rod S were replaced with a single piece of high-Q steel for the purpose of determining sources of error. Several sources of apparatus loss were identified:

   a. Magnetic Interactions. When a solenoid was placed in series with the central column, large errors in Q were found to result from the interaction between the magnetic field of the solenoid and the iron parts of the apparatus. The solenoid was replaced with a piezoelectric (PZT) transducer X. The PZT transducer also solved the problem of temperature (and signal) variations produced by power dissipation in the solenoid.

b. Bending Modes. Non-uniform stress in the central column, which produces bending of the column, was found to result in an error in the measurement of Q. This error occurs because the phase of the bending deformation is not generally the same as for the longitudinal deformation. The bending mode was reduced by use of an optical system for observing interference fringes at the interface between the rod S and the optical flat F during adjustment of the prestress. Parallelism of the interference surfaces is a requirement for uniform stress. In addition, a stiffer frame was constructed to minimize non-axial modes of frame deformation.

c. Reference Plane Rotation Measurement of the displacements of the upper and lower electrodes, c and c', are referred to a reference plane represented by the dashed line in the rod S and housing H. We are presently investigating a possible source of error due to rotation of this reference plane. For example, non-homogeneity of the epoxy film securing the housing H to the steel rod S can result in an effective rotation of the reference plane and introduction of non-longitudinal modes to the output signals. Testing and modifications are in progress to eliminate this source of error.

2. Feasibility study for small strain compressibility and anisotropy measurements in rocks. The increase in Young's modulus with stress, elastic hysteresis, and anisotropy in rocks can often be attributed to the effects of cracks (Walsh, 1965; Brace, 1965). The investigation of linear compressibility of rocks at seismic strain amplitudes and as a function of direction would be complementary to the Q measurements. A design was completed for measuring the relative compressibility in six directions in a rock sample at strain amplitudes of about 10^{-7}.

References Cited

Brace, W. F., Some new measurements of linear compressibility of rocks, J. Geophys. Res., 70, 391-398, 1965.

Peselnick, L., H.-P. Liu, and K. R. Harper, Observations of details of hysteresis loops in Westerly granite, Geophys. Res. Lett., 6, 693-696, 1979.

Walsh, J. B., The effect of cracks on the compressibility of rock, J. Geophys. Res., 70, 381-389, 1965.

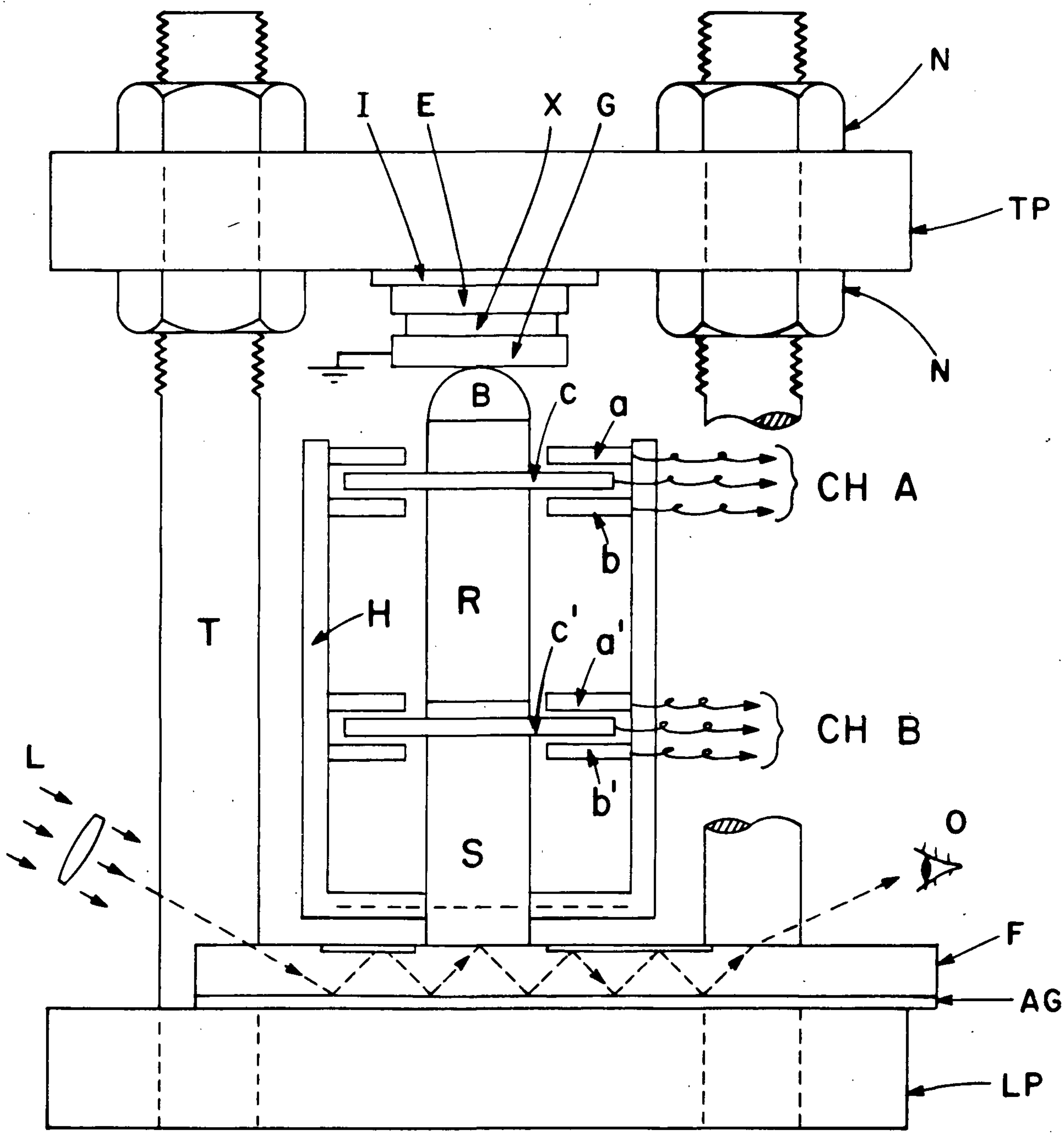

Figure 1. Sketch of Q-apparatus.

Mechanics of Geologic Structures Associated with Faulting

9960-02112

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Investigations

1. Field mapping and thin section investigation of faults and related structures in granitic rocks.

2. Field mapping and thin section investigation of hydrothermal extension fractures in granitic rocks.

3. Theoretical analysis of an array of propagating extensional cracks in an elastic material.

4. Experimental study of propagating extension cracks.

5. Theoretical analysis of pressure solution surfaces as anticracks.

Results

1. Several excellent exposures of fractures in granite have been mapped in detail, within the Mt. Abbot quadrangle (central Sierra Nevada). Fractures within a given area typically form a parallel, northeast trending set, with separations between fractures small compared to average fracture lengths. Individual fractures display left-lateral strike-slip offsets of 0-2 meters. It has been possible to demonstrate that the fractures initially formed as extensional cracks. Subsequent to this, the region was subjected to shear, and the resulting deformation concentrated on the pre-existing fractures. The shearing induced large inelastic deformations, both within the fracture-filling minerals and the host granodiorite. This process eventually led to the formation of narrow mylonite zones. Secondary fracturing also acted to link individual shear cracks together, forming fault zones of $\sim$1 meter in width with offsets of $\sim$10 meters. In addition, the left-lateral shear was accompanied by buckling of the granite into kink structures. The kinks are defined by the buckling of the fault surfaces, and may represent complementary right lateral strains of $\sim$40%.

Mapping and data collection have been completed. Examination of thin sections of cataclastically deformed granite and analysis of field data is continuing.

2. Joints were mapped in two outcrops, 2,400 m^2 and 13,000 m^2 in area, in the Mount Givens granodiorite, central Sierra Nevada, at scales of 1:100 and 1:250, respectively. The joints occur in one subparallel set trending north-south. Both maps are of sufficient detail to identify and accurately locate cracks as fine as 0.1 mm in width, and as short as 1 m in length. Within the map areas, there is no evidence of shear offset on the joints, even at the scale of individual crystals within the granodiorite. Crack openings range from 0.1 mm to 3.5 mm. Together, these observations constitute strong evidence that the joints formed in extension, not shear. The joints are mineralized with epidote and chlorite, with associated hydrothermal alteration of the wallrocks. There is no periodic spacing of joints· distances between nearest neighbors range from 10 cm to 30 m. Individual joints have lengths ranging from a few meters to nearly 100 m. In detail, each joint consists of parallel, echelon cracks, many of which are interconnected. Steps between cracks are typically less than 10 cm. In addition, many small parallel cracks are observed adjacent to the joints and near joint terminations. Inter-joint regions that appear unfractured contain centimeter-long cracks that may represent initial cracks that gave rise to the joints. Measurements of joint openings yield estimates of the strain accomodated by fracturing of 1 to 5 x 10^{-4}.

3. In crystalline rocks the presence of extensional fractures can control the bulk permeability and gross mechanical response of the rock. Both these effects are observed in the field studies discussed above. We are studying the behavior of a system of many cracks that grow concurrently in an elastic medium. The postulated initial conditions are that numerous, parallel cracks with length $\underline{c_0}$ are present in an elastic medium, subjected to steadily increasing remote displacements. The cracks begin growing when the crack extension force $\underline{G}$ reaches the value required for quasi-static crack growth $\underline{G_0}$. As the cracks extend, the applied strain is increasingly "accomodated," and the average stress in the medium decreases. A relation for $\underline{G}$ as a function of crack length $\underline{c}$ is obtained assuming that cracks are of the same length and that there is negligible interaction between them. $\underline{G}$ is found to increase from $\underline{G_0}$ to a maximum and then to decrease to $\underline{G_0}$. Thus, crack growth terminates in a stable configuration when a sufficient strain is accomodated. This allows calculation of the ratio of final to initial crack length $\underline{c_f}/\underline{c_0}$, from the crack density in the initial state. Conversly, $\underline{c_f}/\underline{c_0}$ can be calculated solely from the crack density in the final state. The average behavior is modified by

the elastic interaction between neighboring cracks. The function G(c) combined with empirical G - crack-tip velocity relations illustrates that crack-tip velocities increase as G increases to G_{max}, and then decrease to zero. Results indicate that joint formation occurs rapidly relative to the tectonic strain rate, but slowly relative to dynamic propagation. Predictions of the analysis are consistent with geometric data obtained from joints in the Sierra Nevada.

4. A series of experiments has been designed to test the theoretical results for growing crack arrays (3. above). The results will also be compared to observed fracture distributions in granites. Presently the necessary equipment is being assembled for the experiments.

5. Pressure solution is manifest in tectonic events and the vertical compaction of rock where the major amount of shortening is accomplished on discrete surfaces of solution. The location and pattern of these surfaces has been attributed to pre-existing structures (joints and clay-rich seams) that act as effective pathways for material transport. In contrast, we propose that solution surfaces originate at flaws or stress concentrations and propagate through rock as anticracks. If a thin lamina of material is removed from an elastic rock by pressure solution and the walls of the cavity are then pressed together to form a solution surface, the compressive stress is reduced on the surface and a stress concentration is established at the tips. The stress and displacement field is the same as that for a crack loaded in effective tension, except for a sign change; hence, we term the structure an anticrack. The large isotropic compressive stress along the crack plane favors local dissolution and in-plane propagation for an isolated anticrack. Propagation along the trajectory of isotropic compression is indicated for interacting anticracks. Solution surfaces will propagate until they interact with other surfaces to form a regular stable array corresponding to some bulk state of strain or strain-rate. The anticrack model is consistent with the observations of Stockdale (1922) of solution surfaces in vertically compacted limestone: (1) the surfaces are bounded in extent; (2) the dissolved thickness varies from a maximum at the center to zero at the tips: and (3) the maximum dissolved thickness is proportional to the length of the surface

Reports

Segall, P., and D. D. Pollard, 1980, Mechanics of discontinuous faults, J. Geophys. Res., 85, 4337-4350.

Rock Mechanical Investigation of Clay and Clayey Gouge at High Pressures and High Temperatures

14-08-0001-17747

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Investigations

The mechanical properties of preconsolidated clays as approximation for clayey gouge are studied at confining pressures of 1-4 kbar. Four types of clays have been studied, including montmorillonite, kaolinite, illite, and chlorite. The experiments were carried out under undrained, triaxial condition. The purpose of the investigation is to provide useful information for our understanding of the mechanisms of faulting which may in part be controlled by the properties of clayey gouge along the faults.

Results

At confining pressures equivalent to those at midcrust, different clays have the following common properties which differ significantly from those at low confining pressures: (1) the clays possess significant strength of several hundred bar; (2) the constitutive relations are marked by a ductile yielding and strain hardening, followed by a broad peak strength and a gradual decrease in strength at greater deformation; and (3) the change in volume during shearing is small. On the other hand, the behavior of montmorillonite differs from that of the other clays (kaolinite, illite, and chlorite) in the following ways: (1) its peak strength at a given confining pressure is about half of the strengths of the other clays; (2) its peak strength occurs at an axial strain of about 10%, while for illite and chlorite the peak strength occurs at an axial strain of 20-25% (for kaolinite, strain hardening continues even at 30% axial strain); and (3) the fracture surfaces of some montmorillonite samples deformed at relatively low confining pressures show features resembling those in natural fault gouge, whereas at high confining pressures, montmorillonite and the other clays remain unfractured at shortening up to 30-40%.

Reports

Wang, C. Y., Mao, N. H., and Wu, F. T., 1980, Mechanical properties of clays at high pressure, Jour. Geophys. Research, vol. 85, p. 1462-1468.

Golden Seismological Data Processing Center

9920-02496

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Investigations

While no investigations are done directly under this project, it provides hardware, software, and consulting support for nearly every project in the branches of Global Seismology, Earthquake Tectonics and Risk, and Ground Motion and Faulting, which are based in Golden, Colorado.

Results

The data processing center currently provides the following facilities and/or services:

1) digital time series analysis
2) small scale theoretical computations
3) analog to digital conversion of magnetic tapes
4) digital format/media conversion
5) real time data acquisition
6) digitizing table

Reports

Not applicable.

U. S. Seismic Network

9920-01899

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Investigations

U.S. Seismicity:
Continuously monitor U.S. seismicity using data recorded by the U.S. Seismic Network.

Worldwide Seismicity:
Data from the U.S. Seismic Network is used to obtain a preliminary location of significant earthquakes worldwide.

Results

As an operational program, the U.S. Seismic Network operated normally throughout the report period. Data was recorded continuously in real time at the NEIS main office in Golden, Colorado. At the present time, 72 channels of SPZ data are being recorded at Golden on Develocorder film. This includes 9 channels of Alaskan data telemetered to Golden via satellite from the Alaska Tsunami Warning Center, Palmer, Alaska. A representative number of SPZ channels are also recorded on Helicorders to give NEIS real time monitoring capability of the more active seismic areas of the U.S. In addition, 9 channels of LPZ data are recorded in real time on multiple pen Helicorders.

In September, 2 channels of real time NORSAR data from Norway were added to the network. The NORSAR data is transmitted via satellite to the Vela Seismological Center, Alexandria, Virginia, where two channels of data are retransmitted to Golden over an existing data line.

Data from the U.S. Seismic Network is interpreted by record analysts and the seismic readings are entered into the NEIS data base. The data is also used by NEIS standby personnel to monitor seismic activity in the U.S. and worldwide on a real time basis. At the present time, all earthquakes large enough to be recorded on several stations are worked up using the "Quick Quake" program to obtain a provisional solution as rapidly as possible. Finally, the data is used in such NEIS publications as the "Preliminary Determination of Epicenters" and the "Earthquake Data Report".

Development work is continuing on an event detector to monitor the U.S. Seismic Network in real time. Current plans are to use several PDP 11/03 micro computers to monitor the data and pass events on to a PDP 11/23 for further processing.

The goals of the U.S. Seismic Network are to upgrade the quantity and quality of the data received to make possible more rapid and accurate location of U.S. earthquakes and significant earthquakes worldwide.

DIGITAL NETWORK-DATA PROCESSING

9920-02217

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Investigations

1. Data processing for the Global Digital Seismograph Network. All of the digital data received from the global network is reviewed and checked for quality.

2. Network-Day Tape Program. All the digital data received at the ASL is assembled into network-day tapes which are archived and distributed.

3. Event detection software program for short-period digital data. Developed a software program to detect and re-record short-period events from continuous short-period data.

Results

1. Data processing for the Global Digital Seismograph Network. During the past six months, 279 digital tapes from the global network were edited, checked for quality, corrected when feasible, copied and archived in the Albuquerque Seismological Laboratory. Fifty-seven of these tapes were from two digitally recording WWSSN systems recently installed at Longmire, Washington, and Jamestown, California. Additional copies are regularly supplied to a number of the stations and other data users.

2. Network-Day Tape Program. The network-day tape project assembles the data from the entire digital network for a specific calendar day onto one magnetic tape. This tape includes all the necessary station parameter, calibration data, and time correction information for each station in the network. The first network-day tape was assembled in early April of this year and the first tape was for January 1, 1980. As of October 1, 1980, the network-day tapes were completed to August 15, 1980. Distribution of these tapes is being handled by the Environmental Data and Information Service, NOAA, in Boulder, Colorado.

3. Event detection software program for short-period digital data. The event detector algorithm has been coded and tested. These tests have been performed on short-period data for most of the SRO and ASRO stations. The results indicate that this program detects short-period events very well and introduces few false alarms even when the background changes by 12 to 18 dB.

Reports

Murdock, J. M., and Jaksha, L. H., 1980, Time-term solutions and corresponding data for the crustal structure of north-central New Mexico, USGS Open-File Report (approved for publication by the director, USGS).

Murdock, J. M., and Jaksha, L. H., 1980, The P-wave velocity of the uppermost mantle of the Rio Grande rift region of north-central New Mexico, (approved for Journal publication, by the director, USGS).

SEISMICITY OF THE RIO GRANDE RIFT

9920-01774

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Investigations and Results

1. A seismic refraction experiment was carried out in the San Juan Basin. Explosions originating at the Navajo, San Juan, and Jackpile mines were used as energy sources. Measurements were made at 16 sites along a line between Farmington and Laguna, New Mexico. The explosions were observed at the permanent seismic stations monitoring the basin as well. A preliminary analysis of the data suggests that the P-wave velocity in the basement rocks of the basin is near 6.1 km/s, the sedimentary section is several kilometers thick. The average P-wave velocity in the sedimentary rocks is near 3.5 km/s.

2. Microearthquake surveys using up to five temporary seismic stations over small (~400 km^2) areas were conducted near Grants and Standing Rock. No earthquakes large enough to be located were observed in either area. Each survey was of four days duration. Local explosions recorded on these networks will be used in a time-term study of the upper crust beneath the array.

3. A permanent seismic station was installed at Chaco Canyon National Monument in July. This station provides us with a control point near the center of the San Juan Basin. The National Park Service is interested in a long-term station at Chaco Canyon because of future coal mining operations planned for an area just north of the monument. Their primary concern is the effect of blasting in nearby coal mines on the archeological sites.

Reports

Jaksha, L. H., and Locke J., 1980, Seismicity near Albuquerque, New Mexico, 1976-1978, USGS Open-File Report (in review).

ALBUQUERQUE OBSERVATORY

9920-01260

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Investigations and Results

1. A preliminary analysis of the feasibility of a seismic refraction experiment between the White Sands Missile Range, New Mexico, and the coal mine at Kayenta, Arizona, was made. P-wave amplitudes from blasting at Kayenta were observed at some 20 sites in New Mexico at distance ranges up to 300 km. The S/N ratio of the p-waves appears satisfactory for the experiment. A 650 ton high explosive shot at White Sands Missile Range is tentatively scheduled for September 1981 by the Department of Defense.

2. The new observatory facility at the Albuquerque Seismological Laboratory is complete except for the standby power system. Further improvements await adequate funding.

3. Permission for us to use the Coyote Tower on Kirtland Air Force Base as a radio repeater site has been granted. When the repeater is installed, we will be able to eliminate the hard wire link between Albuquerque Seismological Laboratory and Manzano Tower.

4. All of the remote sites in New Mexico were visited for maintenance during the summer.

GLOBAL DIGITAL NETWORK OPERATIONS

9920-02398

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Investigations

The Global Network Operations continued to provide technical and operational support to the SRO/ASRO/HGLP observatories, which includes operating supplies, replacement parts, repair service, redesign of equipment, training and on-site maintenance, recalibration and installation. Maintenance is performed at locations as required but also each station is scheduled a visit by a technician every few months for preventative maintenance and training purposes.

The SRO systems at Ankara, Grafenberg, Bangui, Bogota, Guam, Chiang Mai, Taipei, Narrogin, Wellington, and the ASRO systems at Charters Towers and Matsushiro were maintained and recalibrated.

Installation of the DWWSSN system upgrade was completed at Longmire, Washington, and Jamestown, California. A replacement borehole seismometer was installed at Taipei, Taiwan.

A competitive procurement resulted in the award of a three-year contract to Raytheon Service Company. This contract provides senior and junior digital technicians for the maintenance of our global digital network and installation of upgrade DWWSSN systems. Actions were started in anticipation of a 1 October 1980 start date for the hiring of additional technicians to meet our requirements in the South Pole WWSSN station modifications and DWWSSN upgrade overseas. Generally, a smooth transition took place from the previous contractor.

A special proposal was provided to ARPA for participation in an international experiment to collect and analyze continuous SP data from the SRO, ASRO, and Longmire and Jamestown stations for 15 days beginning 1 October 1980. Four stations (ANMI, ANTO, BCAO, AND BOCO) will be modified to provide three components of short-period data. Letters were sent to all stations, except Kabul and Mashhad, asking if they would like to participate and, if so, what they would have to do. All stations, except Shillong, which has been inoperative, responded affirmatively.

Results

The network provides improved geographical coverage with highly sensitive short- and long-period seismic sensors with analog and digital magnetic tape recordings.

USGS AND COOPERATIVE OBSERVATORIES

9920-01261

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Investigations

Field activities consist of occasional visits to the seismic stations for the purpose of maintenance, calibration, or installation of new instrumentation. Stations are provided with advice on operation, maintenance, and calibration. Also all stations are provided with spare parts, operational supplies and replacement modules.

Results

These observatories contribute essential data to the NEIS, both routinely and on a rapid basis when required. The locations were selected to fill gaps in station locations and to provide better coverage for local events. All data are available for other seismologists when required.

WORLD-WIDE STANDARDIZED SEISMOGRAPH NETWORK (WWSSN)

9920-01201

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Investigations

1. The Global Network Operations continued to provide technical and operational support to the WWSSN observatories as funding and staffing permitted.

2. During this period, 247 WWSSN modules were repaired and 348 separate items were shipped to support the network. Thirty-seven stations were supplied with annual shipments of photographic supplies and emergency shipments were made to five stations.

3. In conjunction with another project, Nick Orsini visited the WWSSN stations at Bulawayo, Zimbabwe, Pretoria, South Africa, and Nairobi, Kenya.

Results

A continual flow of high quality seismic data from the network of 115 observatories for use by the seismological community.

Global Seismograph Network - Evaluation and Development

9920-02384

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Investigations

1. Technical aspects of the WWSSN were reviewed as part of the task to document the Global Seismograph Network. Accurate transfer functions were derived and used to evaluate the accuracy of empirical calibration techniques used in the WWSSN systems. Parameter stability and effects of drift, based on measurements taken at a large number of stations that had not been recalibrated for 10 years or more, also were analyzed.

2. The background noise at the SRO and ASRO stations in the period band from .1 to 100 seconds was investigated and the results have been published.

Results

1. Computed and empirically-derived calibration for the WWSSN short-period seismograph is in excellent agreement, although coupling does become a factor at magnifications above 50,000. There are systematic differences between computed and empirical calibration for the WWSSN long-period seismographs caused partly by the fact that the step response amplitude is not a lineai function of magnification. Assigned magnifications for the LP vertical components are 3% to 11% too high, depending on magnification, and assigned magnifications for the LP horizontal components are 10% to 15% too high. As one might expect, instrument parameters drift with time. Mean measured parameter values (for seismometer period, galvanometer period, and calibrator constant) did not vary by more than 2% from nominal values, and indicate that there are no systematic one-sided drift effects. However, standard deviations from the mean were quiet high: 5.5% for LP seismometer period, 6% for LP galvanometer period, 6% for SP seismometer period, 2.5% for SP galvanometer period, and 9% for SP calibrator constant. The mean error for the LP calibrator constant was + 4%. In many cases, the parameter drift affects only the calibration step function. Errors are introduced into the recorded seismogram when the station operator readjusts the step response to its prescribed amplitude. The step response amplitude should not be readjusted except during complete system calibration.

2. Noise spectra were computed for quiet periods from data recorded at the SRO and ASRO stations. As expected, short-period noise varied over a wide range as a function of station location but long-period noise was relatively constant at all sites. A composite low-noise curve was obtained by overlaying spectral plots from all stations and selecting low-noise points. The composite curve is probably a fair representation of noise levels that could be expected at isolated sites in quiet regions of the world.

Reports

Peterson, J., 1980, Preliminary observations of noise spectra at the SRO and ASRO stations, U.S. Geological Survey Open-File Report 80-992, 25 p.

Seismic Observatories

9920-01193

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Investigations

Recorded and provisionally interpreted seismological and geomagnetic data at observatories operated at Newport, Washington; Cayey, Puerto Rico; Adak, Alaska; and Guam. At Newport, Washington and Guam, 24-hour standby duty was maintained to provide input to the Tsunami Warning Service operated at Honolulu Observatory by NOAA. Also, Newport Observatory served as a part of the National Earthquake Information Service's, Early Earthquake Reporting Service during off duty hours by reporting information on felt and damaging earthquakes in the United States and on worldwide events of magnitude 6.5 or greater to government agencies, the news media, and the public.

Results

Continued to provide data on an immediate basis to the National Earthquake Information Service and the Tsunami Warning Service. Supported the Puerto Rico Project of the Branch of Earthquake Tectonics and Risk. Provided geomagnetic data to the Branch of Electromagnetism and Geomagnetism. Responded to requests from the public, interested scientists, state and federal agencies regarding geophysical data and phenomena.

The McMinnville Observatory, formerly known as the Cumberland Plateau Observatory (CPO) was discontinued as a manned operation in September 1975. As this Branch is no longer telemetering data from this site, the facility has become excess to our needs. Consequently, the complete CPO facility has been transferred to the Department of Energy who will use the site to conduct long term seismic experiments.

National Earthquake Information Service

9920-01194

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Investigations and Results

The weekly publication, Preliminary Determination of Epicenters, continues to be published on a weekly basis, averaging about 50 earthquakes. The PDE, Monthly Summaries and Earthquake Data Reports (EDRs) are being done on the Energy Enterprises DEC-20 computer. We continue to publish all earthquakes which have data available within 30 days of the earthquake. We have had a few improvements on rapid data flow from our foreign contributors, but in order to reach our goal of a 10-day PDE, we will need much faster reporting of seismic data from our contributors both foreign and domestic.

Those problems are still being worked on and slow but steady improvement is taking place. We continue to receive telegraphic data from the USSR on magnitude 6.5 or greater earthquakes; the latest was the 7.3 Algerian earthquake of October 10, 1980. Data from the PR China via the American Embassy in Beijing began being received in April; recently, permission to receive data from Southern China through the Canton consulate was granted and is expected to be initiated soon.

The catchup on the backlog of Monthly Listings of Earthquakes and Earthquake Data Reports (EDRs), which began in June of 1979, has been completed. To date, the Monthly Listing and EDR have been completed through May 1980 and are being printed and mailed.

The programs for entering seismic data on the BGS 11/70 computer were completed and are scheduled to be operational in the first month of FY 81. Programs for producing the NEIS publications on the 11/70 and ultimately the Golden VAX are now being coded and are scheduled for operations in FY 81.

We continue to provide services on recent earthquakes in response to the increasing demands from scientists and the general public.

Reports

Preliminary Determination of Epicenters (24 weekly publications--March 1980 to present--Numbers 11 through 35). Compliers: W. Leroy Irby, Reino Kangas, John Minsch, Waverly Person, Bruce Presgrave.

Monthly Listings of Earthquakes and Earthquake Data Reports (EDR) (8 publications--October 1979 through May 1980). Compilers: W. Leroy Irby, Reino Kangas, John Minsch, Russell Needham, Waverly Person, Bruce Presgrave, William Schmieder.

Goals

Provide more rapid and comprehensive hypocenter locations to the government and the scientific community using our in-house computers.

Provide more rapid notification of significant or damaging earthquakes to relief agencies, the press, the scientific community, and the general public.

Keep the Monthly Listings and Earthquake Data Reports up to date.

Seismic Review and Data Services

9920-01204

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Investigations and Results

The quality control, and technical review of 100,500 seismograms (560 station-months) generated by the World Wide Standardized Network (WWSSN) were carried out.

Station performance reports were sent to 30 Station Directors. These reports cover instrumental and station operations and include calibration accuracies, damping, timing precision, noise patterns and intensities, recording quality, seismogram backlog, label data, and any unusual problems. Overall standards remain high throughout the system. Timing data showed that 75% of the stations had an average daily error less than 50 milliseconds. The polarity problems remain at Georgetown (GEO), Stuttgart (STU), and at Bulawayo (BUL). Those at the El Salvador (LPS) station (SP horizontals) have not been instrumentally corrected, but have been corrected on the seismogram labels.

Analog records from the first upgraded WWSSN station to digital recordings made at Longmire (LON) were received for the month of April 1980. The mags remain at 100 K for the SP's and 1.5 K for the LP's with considerable improvement on the long periods by the elimination of the heavy trace drift that formerly dominated these seismograms.

The Kabul station is still sending its WWSSN and ASRO records. The situation with the Iranian stations remains unchanged.

A microfiche library of the WWSSN, SRO, ASRO and HGLP seismograms starting with July 1978 data has been set up. Included are some of the 35 mm Historical File films. Space is still a problem. Some of the files and viewing areas are in separate locations. The quality of the fiche copies has improved through better controls by the filming service, as well as adopting slower run times in the duplicating process. The microfiche resolution is, however, somewhat less than that of the same generation 70 mm.

United States Earthquakes

9920-01222

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Investigations

1. Forty-five earthquakes in 15 states were canvassed by a mail questionnaire for felt and damage data. A field investigation was made of the July 27, 1980, Kentucky earthquake. It was located at 38.17N, 83.91W, depth 8 km, magnitude 5.2 mb, 4.7 MS.

2. The United States earthquakes for the period April 1, 1980 to September 30, 1980 have been located and the hypocenters, magnitudes, and maximum intensities have been published in the Preliminary Determination of Epicenters.

3. The data for the seismicity maps for New Hampshire, Vermont, New York, New Jersey, Connecticut, Massachusetts, Rhode Island, and Delaware have been compiled.

Results

The maximum Modified Mercalli intensity assigned to the July 27, 1980, Kentucky earthquake is VII at Maysville; which is located about 50 km north of the epicenter on the Ohio River. The most predominant damage at Maysville was to chimneys which consisted of top layers of bricks shaken off, chimneys broken at the roof line, and in some cases the entire chimney fallen. Intensity VI was assigned to the epicentral area near Sharpsburg. This event was felt in all or parts of 15 states which covered an area of about 600,000 sq. km.

Reports

Stover, C. W., Minsch, J. H., Person, W. J., and Smith, P. K., 1980, Earthquakes in the United States, July-September 1978, Geological Survey Circular 819-C, p. 32.

Reagor, B. G., Stover, C. W., Minsch, J. H., and Hubiak, P., 1980, Earthquakes in the United States, October-December 1978, Geological Survey Circular 819-D, p. 31.

Stover, C. W., Reagor, B. G., and Algermissen, S. T., 1980, Seismicity Map of the state of Michigan: Miscellaneous Field Studies Map 1228.

Reagor, B. G., Stover, C. W., and Algermissen, S. T., 1980, Seismicity Map of the state of North Carolina: Miscellaneous Field Studies Map 1224.

Reagor, B. G., Stover, C. W., and Algermissen, S. T., 1980, Seismicity Map of the state of South Carolina: Miscellaneous Field Studies Map 1225.

Reagor, B. G., Stover, C. W., and Algermissen, S. T., 1980, Seismicity Map of the state of West Virginia: Miscellaneous Field Studies Map 1226.

Person, W. J., 1980, Earthquakes, September-October 1979: Earthquake Information Bulletin, v. 12, no. 2, p. 74-77.

Person, W. J., 1980, Earthquakes, November-December 1979: Earthquake Information Bulletin, v. 12, no. 3, p. 113-116.

Person, W. J., 1980, Seismological Notes, July-August 1978: Seismological Society of America Bulletin, v. 70, no. 2, p. 647-649.

Person, W. J., 1980, Seismological Notes, September-October 1978: Seismological Society of America Bulletin, v. 70, no. 3, p. 937-939.

Person, W. J., 1980, Seismological Notes, November-December 1978: Seismological Society of America Bulletin, v. 70, no. 4, p. 1421-1423.

Digital Data Analysis

9920-01788

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Investigations

1. Earthquake Magnitude Derived from Mantle Waves. Relate observed ground displacement due to long period (100-250s) Love and Rayleigh waves to earthquake moment using synthetic seismograms.

2. Efficient Generation of Regional Travel Times. Discover efficient computational methods which are at least as general as current table driven schemes and allow the easy use of many models.

3. Routine Seismic Source Parameter Determination. Use seismic body wave waveforms to determine the orientation and scale of the faulting generating the event on a routine basis.

4. Develop Seismic Time Series Analysis Software. Finish conversion of the MIT Lincoln Laboratory Seismic Display Package software. Begin development of machine independent Network Day Tape reading program.

5. Test Automatic Association Algorithm. Use synthetic seismic phase arrival information to test the NEIS automatic association of phases with earthquakes.

Results

1. Earthquake Magnitude Derived from Mantle Waves. Normal mode synthetic seismograms were used to develop scaling relations for various wave types, periods and faulting geometries. The technique was applied to GDSN data from the February 28, 1979 St. Elias earthquake resulting in a moment-magnitude (M_W) of 7.52, precise to .05 units.

2. Efficient Generation of Regional Travel Times. Two algorithms are being investigated for one dimensional velocity structure (in plane or spherical geometry). First, a linearizing transformation is used to enable efficient direct computation of travel time integrals. This method is slower, but more general than the second method. Second, a table driven scheme is used to compute $\tau(p)$, eliminating the multi-valuedness of $T(\Delta)$.

3. Routine Seismic Source Parameter Determination. Green's functions have been generated using full wave theory and WKBJ synthetic seismograms. Various methods of finding the constrained source moment tensor have been tested with synthetic data. Schemes for minimizing the effects of lateral variations are

being investigated.

4. Develop Seismic Time Series Analysis Software. The SDP is up and running and mostly documented. The Network Day tape programs are completed and being documented. A preliminary distribution has been performed.

5. Test Automatic Association Algorithm. The synthetic data was run through the regular NEIS production system. Although a number of errors in association were made, virtually all synthetic events were discovered and their hypocenters reasonably well constrained.

Reports

Buland, R. and Taggart, J., 1980, a mantle wave magnitude for the St. Elias Alaska earthquake of February 28, 1979, BSSA, in press.

Earth Structure and its Effects upon Seismic Wave Propagation

9920-01736

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Investigations

1. Body wave interactions with upper mantle structure. Generate synthetic seismograms for body waves that interact strongly with the upper mantle discontinuities by using spectral methods; investigate the constraints on upper mantle velocity and attenuation models that can be inferred from waveform information; compare the differences in theoretical seismograms generated by various methods and evaluate how these differences might affect the inference of upper mantle structure.

2. Shear wave polarization anomalies caused by lateral variations in Earth Structure. Investigate the perturbation of body wave polarization incurred by shear waves propagating through laterally inhomogeneous Earth structure; evaluate the extent of bias in investigations of earthquake mechanism if the perturbation is not corrected.

3. Interference among the Earth's free oscillations. Develop the theory and implement computer programs that relate the splitting of spectral peaks of normal modes to lateral heterogeneity in the Earth.

4. Evaluation of broad-band seismic data. Develop methods of processing digital data from the GDSN; evaluate source parameters and Earth structure from this new globally recorded digital data set.

Results

1. Body wave interactions with upper mantle structure. Earth models PEM-c and T7 predict distinct differences in displacement waveforms for P-waves that interact with the 400 and 670-km discontinuities; later arrivals such as interference head waves are important constraints on Earth models; minor differences in waveforms generated by full wave, reflectivity and Cagniard methods do not significantly affect the interpretation of observed waveform data.

2. Shear wave polarization anomalies caused by lateral variations in Earth structure. The polarization of seismic shear waves is perturbed in an easily predictable manner by lateral variations in the seismic wave speed in the Earth. If uncorrected for, it is a source of bias in investigations of the earthquake mechanism.

3. Interference among the Earth's free oscillations. The interference between two free oscillation spectral peaks yields a new peak of the same form. One consequence is that lateral variations in the Earth will introduce unavoidable scatter (though little bias) into measurements of anelastic attenuation.

4. Evaluation of broad-band seismic data. High quality broad-band deconvolved records of ground displacement and velocity can be constructed from the long- and short-period vertical channels of the GDSN instruments with a frequency band-width ranging from many Hz to tens of seconds. In generating synthetic pulse shapes to match the data in the 'intermediate' range of frequencies, constraints on the frequency dependence of attenuation in the Earth were found. The extended band-width of the deconvolved data showed significant directivity effects from which the complete rupture histories for two deep earthquakes were determined, including constraints on the dynamic and static stress drops, the rupture velocity and the rupture complexity.

Reports

Cormier, V.F., and G. L. Choy (1980). Theoretical body wave interactions with upper mantle structure, J. Geophys. Res. (in press).

Choy, G. L., and J. Boatwright (1980). The rupture characteristics of two deep earthquakes inferred from broadband GDSN data, Bull. Seism. Soc. Am. (submitted).

SYSTEMS ENGINEERING

9920-01262

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Investigations

1. Design, develop, and test microprocessor based seismic instrumentation.

2. Design, develop, procure, and test special electronic systems required by seismic facilities.

3. Design, develop, and test microprocessor/computer software programs for seismic instrumentation and seismic data recording systems.

Results

1. Extensive testing and evaluation of the WWSSN Digital Recording System at the Albuquerque Seismological Laboratory verified the system operation and program function before the initial systems were installed at Longmire, Washington, and Jamestown, California.

2. The original WWSSN Digital Recording System at Longmire, Washington, experienced intermittant operating problems which required a special visit by ASL Engineering to help correct the problem. The source of the intermittant operation was traced to faulty ribbon-wire assemblies. The end connectors were not pressed on properly during assembly. New cables were installed and different assembly methods are being implemented with the future cables.

3. As a result of the Longmire WWSSN Digital Recording System problems, it became obvious that a field portable digital tape read-back and verify system was needed. Two such systems have been built and are now in the checkout phase of testing. These new systems will allow the installing personnel to playback and plot the recorded digital data in an analog form. These units will also provide recorded time check and verification of the system timing in the field. These units will save days to weeks of time for the installing crews because they will be able to immediately check and verify the system operation instead of waiting for the test tape to be sent to Albuquerque for playback.

4. The Seismic Fault Monitor System for the Branch of Earthquake Tectonics and Risk has completed all operational and evaluation tests at the Albuquerque Seismological Laboratory. The Branch of Earthquake Tectonics and Risk plans on installing the unit in California for a brief test phase before final installation on a Central American fault. This system is a microprocessor based recording system which uses a precision shaft encoder to determine the direction and amount of fault movement. The fault movement is sensed by the shaft encoder mounted on one side of the fault and connected by a four to five meter rod across the fault to a fixed mount on the other side of the fault. A position reading is recorded every minute. Twelve hours of position data is stored in the microprocessor before the tape unit is turned on to record the data, then the tape unit is turned off to conserve power. This fault monitor system was designed to be solar powered and will operate unattended for 120 days. At the end of 120 days, the unit requires the magnetic tape cassett to be changed and the system clock corrected. This system was designed to be packaged in small carry-on units for air travel and can be installed rapidly in the field.

TSUNAMI NETWORK SUPPORT

9920-01263

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Investigations

1. Design, develop, and test microprocessor based TSUNAMI related seismic and tide systems.

2. Design, develop, and test GOES satellite related TSUNAMI data transmission techniques and instrumentation.

3. Design, develop, and test microprocessor/computer software programs for TSUNAMI instrumentation and TSUNAMI data retrieval systems.

Results

1. A standard short-period TS-4 Seismic System was modified for long period seismic signals. This unit was tested at the Guam Observatory for possible on-line use over the GOES satellite system. A GOES satellite transceiver unit with helical antenna was installed at Guam. The evaluation of this system is continuing at this time. Guam is located on the fringe of the Western GOES satellite and operation may not be reliable for TSUNAMI warning operation.

2. The four South American TT-4 tide systems are being designed and assembled at the Albuquerque Seismological Laboratory. Severe problems with the GOES radio transceiver units has forced delays in this program. At present, there is only one company making these GOES transceiver units and there are no other sources of these units. Some of the South American tide systems will be operating with the new pressure type tide meters and the remaining units will be the standard Bristol tide meters. These TT-4 tide systems will transmit tide data over the GOES satellite system upon command. These units will provide the Tsunami Warning System with approximately two minutes time duration from a South American tide station request until the data is available at the TSUNAMI Warning Centers.

Seismicity and Tectonics

9920-01206

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Investigations

1. Peru Seismicity and Tectonics. Determine the space-time patterns of aftershocks of the October 3, 1974 Peru Earthquake.

2. Mantle Structure Beneath the Rio Grande Rift. Use a 3-D, seismic ray tracing algorithm to invert a set of teleseismic P-wave delay data, with the objective of determining the maximum depth and degree of velocity anomaly in the upper mantle beneath the Rio Grande Rift.

3. February 28, 1979 St. Elias Earthquake. Use SRO digital data and WWSSN seismograms to determine the size and radiation pattern, in the surface wave and mantle wave spectrum, of this seismic gap earthquake.

Results

1. Peru Seismicity and Tectonics. The 1974 aftershock series occurred in two segments, separable spatially and each with distinctive focal mechanisms. Each aftershock segment contains one primary cluster of activity. The cluster in the parallel-to-coast, offshore segment lies between the locations of the October 3, 1974 main shock (M_S=7.8) and the November 9, 1974 primary aftershock (M_S=7.1) which is ∿ 30 km to the SSE of the main shock. The cluster in the perpendicular-to-coast segment lies at the zone of this segment's eastern terminus. The aftershock series is comprised of distinct space-time groups. The primary space-time phenomenon is that a given segment tends to be very active for a period of 2 - 2 1/2 days, while the other segment is essentially lacking in activity; then the situation reverses. When the offshore segment is active, there is a strong tendency for aftershocks to oscillate between the ends of the aftershock zone, but with occasional events occurring in the central cluster of this segment. When the perpendicular-to-coast segment is active, the primary activity is in that segment's cluster, with repeated jumps into the offshore cluster.

2. Mantle Structure Beneath the Rio Grande Rift. The upper mantle beneath the Rio Grande rift, and perhaps eastward as far as the Front Range, has a P-wave velocity that is 4 - 6% lower than that of the adjoining High Plains Province, down to a depth of 200 km ± 15 km. At a depth interval of 90-130 km beneath a 150 km length of the NE-trending Jemez shear zone (which includes

the Jemez volcanic field), there is a layer of concentrated low velocity material. Beneath the Socorro, NM area, at a depth interval of 40-80 km, there is a layer of relatively high velocity material.

3. February 28, 1979 St. Elias Earthquake. Ray Buland and James Taggart (1981) have developed a new analytical procedure for estimating the size of large earthquakes from mantle wave data. Surface and mantle waves from the St. Elias earthquake are investigated using standard time-domain techniques and a highly automated procedure for frequency-domain analysis. Mantle wave spectral densities at periods of 100, 150, 200 and 250 sec are determined from R_1 through R_5 and G_1 through G_6 recorded by ten stations of the Global Digital Seismograph Network using a method similar to one developed by Brune and Engen (1969) for 100 sec Love waves. For comparison, synthetic seismograms are generated by normal mode summation using two published fault plane solutions (Lahr and others, 1979; Hasegawa and others, 1980) and assuming a point source. The precise orientation of the St. Elias mechanism has a significant impact on the efficiency of mantle wave generation and hence on moment inference. Further, source finiteness effects, expressed as distortion of the radiation pattern and a disparity between moment estimates made using Love and Rayleigh waves, are clearly visible at all periods we examined. However, these effects decrease dramatically with increasing periods and are gratifyingly small by 250 sec allowing a moment estimate to be made. The following measurements of the size of the St. Elias earthquake are obtained:

20-sec Rayleigh waves (30 obs.)	M_S=7.08
20-sec Rayleigh waves (30 obs. azimuthally weighted)	M_S=7.23
Seismic moment (dyne-cm)	M_O=2.36x10^{27}
Moment Magnitude	M_W=7.52

Report

Buland, Ray, and James Taggart, 1981, A mantle wave magnitude for St. Elias, Alaska, Earthquake of February 28, 1979. Submitted to the Bull. Seismo. Soc. Amer.

Induced Seismic Cogdell Canyon Reef Oil Field

9950-02412

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Investigations

1. Following the m_b 4.7 earthquake of June 19, 1978, close to Snyder, Texas, an eight-station microearthquake network was installed. The subsequent earthquakes fall in or near the Cogdell Canyon Reef oil field. This oil field has been undergoing water flooding since 1956. The purpose of the project has been to determine, if possible, the relationship of the water flooding and earthquake occurrence.

Results

1. Since the network was installed in February 1979, there have been 20 earthquakes with coda length magnitudes, .3 to 3.5, and depth ranging from .95 km to 6.48 km. These are listed in table 1. Figure 1 is a plot of the earthquakes. Along with the earthquakes, this figure shows the general outline of the oil field and the producing portion of the oil field, including the portions which are undergoing water flooding. The oil field, when originally discovered in 1949, had a reservoir pressure of 3120 psi and dropped quickly to 1150 psi, making it necessary to begin a pressure maintenance program in 1956. The surface pressure for the water flooding has averaged 3000 psi. This represents a downhole pressure at the producing depth of 6800 ft below the surface of approximately 6000 psi. The exact value is unknown and depends on the mixture of brine to fresh water used at any particular time. This pressure is almost the value of the overburden and above the parting pressure determined in West Texas for this depth. The pressure of water injection has been maintained fairly constant throughout the history of the field, so comparison of pressures and earthquake production, such as those conducted in Rangely by Raleigh et al. (1972) cannot be done. The only correlation which shows any connection between water injection and earthquake occurrence is a comparison between barrels of water pumped into the field and the larger earthquakes reported in the area. This plot shows that a reduction of field permeability is seen prior to the larger earthquakes and an increase in permeability after the earthquakes. The reduction of water prior to the 1978 event exemplifies this process. As the field stress increases, cracks and channels within the field close and reduce the ability of the formation to accept fluids. When this stress is released by the earthquake, the permeability increases along with fluid acceptance. This also is illustrated following the 1978 event.

Reference

Raleigh, C. B., Healy, J. H., and Bredehoeft, J. D., 1972, Faulting and crustal stress at Rangely, Colorado: American Geophysical Union, Geophysical Monograph, v. 16, p. 275-284.

Table 1.

Date	Time	Lat	Long	Mag	Depth
5/06/79	16:2:52.33	32 N. 56.43	100 W. 53.65	0.9	2.63
5/19/79	12:37:24.67	32 N. 56.10	100 W. 54.14	0.8	1.76
5/24/79	0:16:39.07	32 N. 56.81	100 W. 53.45	1.1	1.85
5/26/79	0:47:52.14	32 N. 58.02	100 W. 52.92	0.6	1.54
6/10/79	0:18:14.55	32 N. 58.03	100 W. 53.20	0.3	1.55
6/12/79	10:9:57.47	32 N. 58.54	100 W. 51.74	0.7	1.29
7/05/79	1:4:59.19	32 N. 56.91	100 W. 53.56	3.5	1.96
7/07/79	11:47:39.97	32 N. 57.62	100 W. 53.82	0.0(?)	3.73
8/02/79	22:39:54.09	32 N. 57.78	100 W. 53.58	0.7	?
8/03/79	5:29:36.82	32 N. 57.58	100 W. 54.69	1.5	6.48
8/03/79	5:38:57.93	32 N. 56.89	100 W. 54.18	0.8	0.60
8/03/79	5:39:14.01	32 N. 58.84	100 W. 54.22	1.2	0.10
8/03/79	5:48:50.87	32 N. 58.21	100 W. 54.99	0.8	0.53
8/03/79	6:4:56.80	32 N. 56.24	100 W. 57.07	1.5	1.72
8/04/79	13:55:32.08	32 N. 58.14	100 W. 53.49	0.7	2.00
8/04/79	13:56:22.48	32 N. 57.06	100 W. 54.01	0.7	0.73
8/23/79	2:24:37.81	32 N. 58.27	100 W. 53.37	1.9	1.58
8/23/79	2:46:41.52	32 N. 58.13	100 W. 53.48	2.1	2.99
3/11/80	8:59:2.99	32 N. 58.27	100 W. 54.76	0.4	0.95
3/17/80	6:0:6.19	32 N. 57.35	100 W. 54.98	0.4	1.24

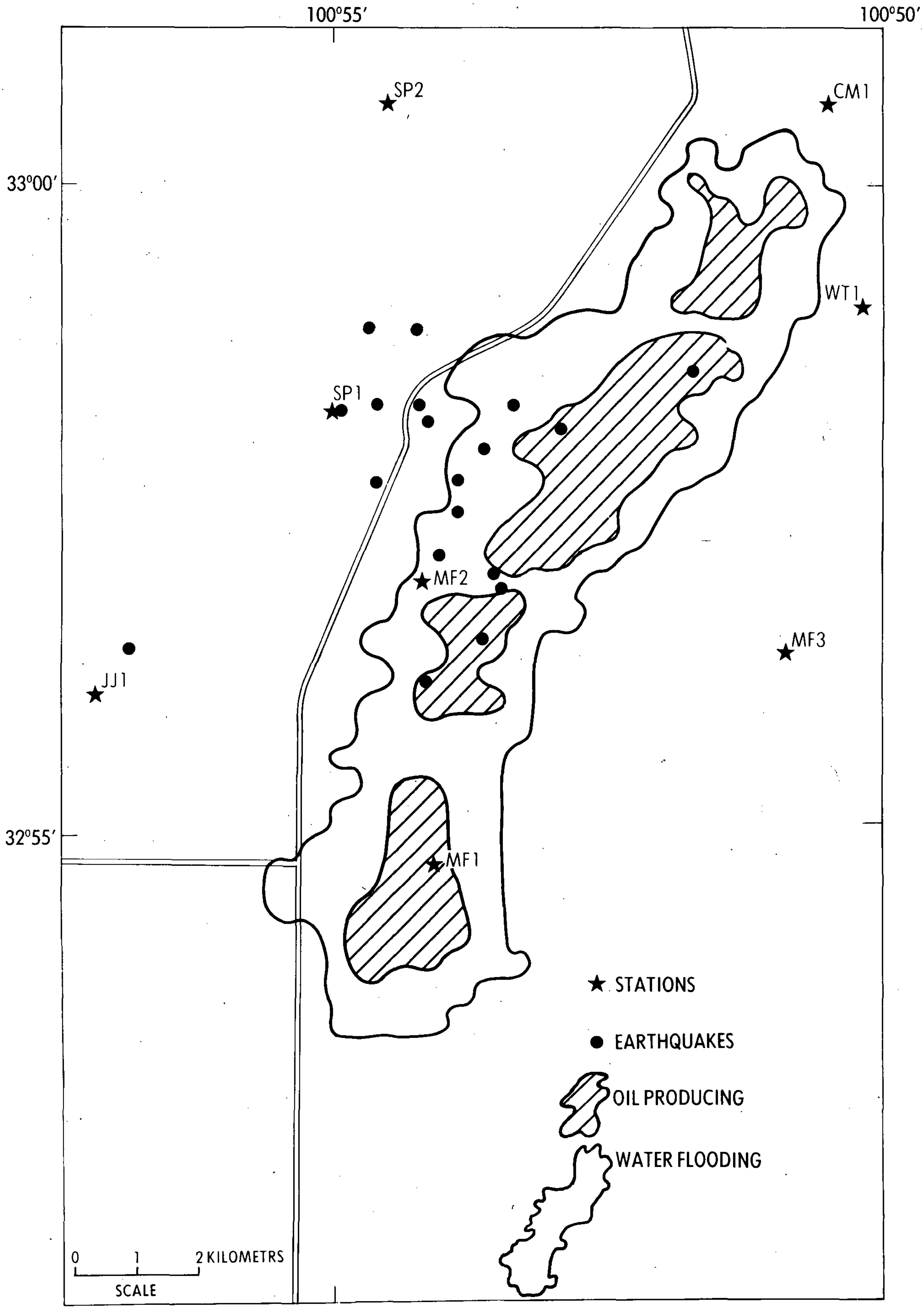

Figure 1.--Map showing earthquakes, extent of water flooding, oil production, and network station locations.

IS

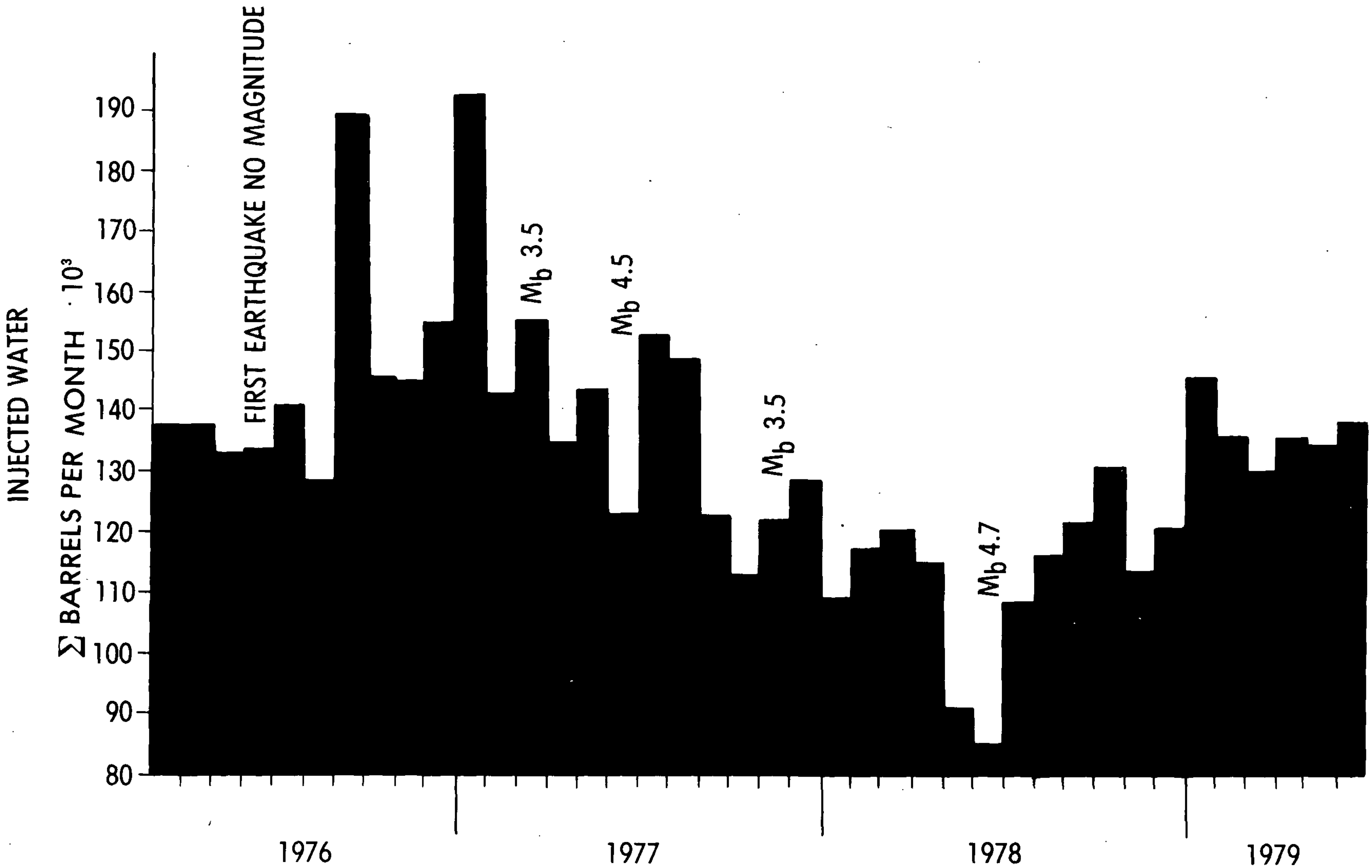

Figure 2.--Plot of monthly total of barrels of water injected and time of reported earthquakes.

Induced Seismicity and Earthquake Prediction Studies at the Koyna Reservoir, India

9930-02501

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This project, aimed at setting up 13 portable seismic stations in the Koyna Dam region of Maharashtra State, India, is still awaiting approval of the Government of India. When the required permission is forthcoming, work on installation of the network and data analysis will be started in collaboration with the National Geophysical Research Institute, Hyderabad, India, to precisely locate the hypocenters of earthquakes occurring in the region and relate their locations, numbers, magnitudes, fault-plane solutions, moments, migration patterns, etc. to the water-level fluctuations in the Koyna reservoir and other relevant factors. An attempt will also be made to develop earthquake prediction techniques for the region. The project is particularly timely at the moment as there seems to be a significant increase in seismic activity at Koyna compared to the past few years. Since September 2, 1980, three earthquakes with magnitudes (M_b) close to 5.0 have occurred in the region, accompanied by numerous aftershocks.

As part of this project, W. H. K. Lee's group has read, using a sophisticated data processing system, arrival times and amplitudes of Koyna earthquakes recorded by the WWSSN station POO (Poona) for the period 1976-77. The cataloging of the events will continue as long as the project remains active.

Seismological Field Investigations

9950-01539

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Investigations

Provide technical support to the Induced Seismicity Program for the operation, maintenance, recording, and playback of seismic data of a ten-station seismograph network installed around the Monticello, South Carolina reservoir. Purpose of the investigation is to study reservoir-induced earthquakes that result from water loading and unloading following reservoir impoundment. Pradeep Talwani at the University of South Carolina, Department of Geology, is the principal investigator.

Results

The initial four stations of the network were installed by the South Carolina Electric and Gas Company and began operation on November 29, 1977. Six additional stations were purchased and installed by the U.S. Geological Survey and became operational on July 1, 1978. All data are telemetered to the University of South Carolina at Columbia and recorded on analog magnetic tape. The seismic data are playedback and digitized at the USGS facility in Golden, Colorado, and then returned to the University of South Carolina for analysis and interpretation.

Brittle Tectonics and Reservoir-Induced Seismicity

9510-02389

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Investigations

1. Brittle fractures at the Richard Russell Reservoir dam site were studied in order to compare them to known Cenozoic fractures along the Coastal Plain Fall Line to the south. Detailed geologic mapping is being used to help determine the nature of the faulting in the vicinity of the reservoir and its possible relationship to the nearby Towaliga fault.

2. The tectonic relationships between the Cenozoic Warm Springs fault and the Towaliga fault in western Georgia were studied in an attempt to determine whether the Towaliga was significantly active in recent geologic time.

Results

1. Brittle faults at the Russell dam site have fracture textures similar to known Cenozoic faults (e.g. Belair fault zone, Augusta, GA). Unlike the Cenozoic faults, however, the brittle faults at the dam site are characterized by the development of secondary minerals such as chlorite and zeolites along the fractures. These minerals are also associated with brittle faults of late Paleozoic or early Mesozoic age near known Traissic-Jurassic basins. Similar fault materials from deep drill holes at the nearby Monticello Reservoir (South Carolina) are being studied for comparison.

2. The Towaliga fault at a variety of localities shows evidence of brittle deformation following the initial ductile phase of faulting. In places, evidence suggests several episodes of brittle deformation. However, the age of latest brittle faulting cannot yet be determined from exposures along the Savannah River.

3. The Warm Springs fault is a Cenozoic fault having a minimum vertical offset of 60 m (200 ft) since the late Paleocene. The nearby Towaliga fault may have been reactivated at the time of the Warm Springs faulting, helping to preserve Paleocene sediments in the Georgia Piedmont. Direct proof of Cenozoic offset along the Towaliga fault is not available at this time.

Reports

Prowell, D.C., 1980, Index of Cretaceous and Cenozoic faults in the eastern United States: U.S. Geological Survey MF Map 1269 with text.

Christopher, R.A., Prowell, D.C., Reinhardt, Juergen, and Markewich, H.W., 1980, The stratigraphic and structural significance of Paleocene pollen from Warm Springs, Georgia: Palynology, vol. 4.

Reinhardt, Juergen, Prowell, D.C., Christopher, R.A., and Markewich, H.W., 1980, Evidence of Cenozoic tectonics from an isolated sedimentary basin near Warm Springs, Georgia [abs.]: Geological Society of America Programs with Abstracts, v. 12, no. 7, p. 508.

Crustal Loading and Induced Seismicity
at the Yacambu Reservoir, Venezuela

14-08-0001-17644

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The Yacambu engineering project is a scheme to create a reservoir on the southern side of the Venezuelan Andes and to divert its contents through a gravity fed underground aqueduct a distance of 24 km to a second reservoir in the arid Quibor Valley to the north. The tunnel will pass through the 4 km wide Boconó fault zone at a depth of about 1 km. The Yacambu Reservoir will be sufficiently deep (160 m) for it to be considered a likely candidate to induce seismicity at the time of impoundment. We have devised a series of measurements to monitor surface deformation at the time of impoundment ranging from subsurface piezometric measurements to continuous measurements of strain and tilt in tunnels near the surface.

The Yacambu Reservoir is in a region of high seismicity and is an approximate two-dimensional feature that is simple to model using finite element technqiues. At the base of the reservoir an apparently inactive fault trends approximately parallel to the Bocono fault (15 km to N). In the finite element models we have developed for the reservoir, dam and surrounding areas, this fault is subjected to reduced normal stress upon impounding. The effect is partly due to the action of the water load and partly due to the hydrostatic containment by the dam structure and abutments to the south putting the floor of the reservoir into relative tension.

We have installed strainmeters in tunnels in the abutment and underwater strainmeter across the fault in the reservoir. Additional strainmeters and tiltmeters await the completion of suitable drainage tunnels in the abutment of the dam. Piezometers have been acquired for use in two deep boreholes that will be constructed by Venezuelan engineers specifically for the project. A series of geodetic measurements have been planned to extend the continuous observations near the dam to distances up to 5 km downstream. The region to the north is unsuitable for geodetic measurements.

In the past year, we have acquired strain data representative of the noise levels we must operate with at the time of impoundment. Strain rates of the order of 10^{-7}/week are presently monitored which are presumably the result of recent tunnel excavation. The same locations in two or three years time promise to provide data with reduced noise characteristics since the existing data were acquired amid considerable disturbance from mining activities.

Reservoir Induced Seismicity

9540-02199

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Investigations

We continued to update the computer data base of large dams and reservoirs which was created to permit a statistical study of reservoir-induced seismicity world wide. The data base now contains information for 1799 dams including year of completion, type of dam, foundation height, water depth, volume and dimensions of reservoir, induced seismicity, geographic coordinates, and rainfall for almost all dams. The completeness of information on reservoir filling, elevation, geology, and structure is variable from country to country and is being added by E. B. Newman.

The Statistical Package for the Social Sciences (SPSS), and MINITAB computer programs were used by R. K. Mark and E. B. Newman to calculate crosstabulation of various parameters with the occurrence of induced seismicity in an effort to weigh the relative importance of each parameter. This approach contrasts with our earlier efforts in which only maximum water depth and volume were analyzed. Of the 60 or so reported cases of reservoir induced seismicity, only 20 with earthquakes of Richter Magnitude 3 or greater had data judged to be sufficiently supportive of induced seismicity to warrant inclusion in the statistics. Compilation of data has been continuous, so an arbitrary cut-off was applied in order to compute statistical results.

Results

1. Water depth and volume still appear to be the most significant parameters correlated to reservoir induced seismicity (Fig. 1, table 1). It appears that induced seismicity begins to occur significantly (i.e., in >5% of the reservoirs) in the 60-90 m depth interval only for high volume reservoirs ($>10^{10} m^3$). For depths greater than 90 m, induced seismicity occurs significantly for lower volumes ($>10^9 m^3$). For depths greater than 150 m, induced seismicity apears to occur in about 20% of the reservoirs with an even wider range of volumes.

2. For deep reservoirs ($\geq$90m):
Although sample size limits analysis, the following results are observed:
a) Neither the presence of faults nor fault activity appear to be significant (tables 3 and 4). b) The presence of metamorphic rocks appears to be positively correlated with induced seismicity (Table 2). However we have looked at enough geologic parameters to expect that chance could make one parameter appear significant at the 5% level. c) Presence of other rock types (e.g., igneous, sedimentary) and rock ages do not appear to be significant at the 5% level.

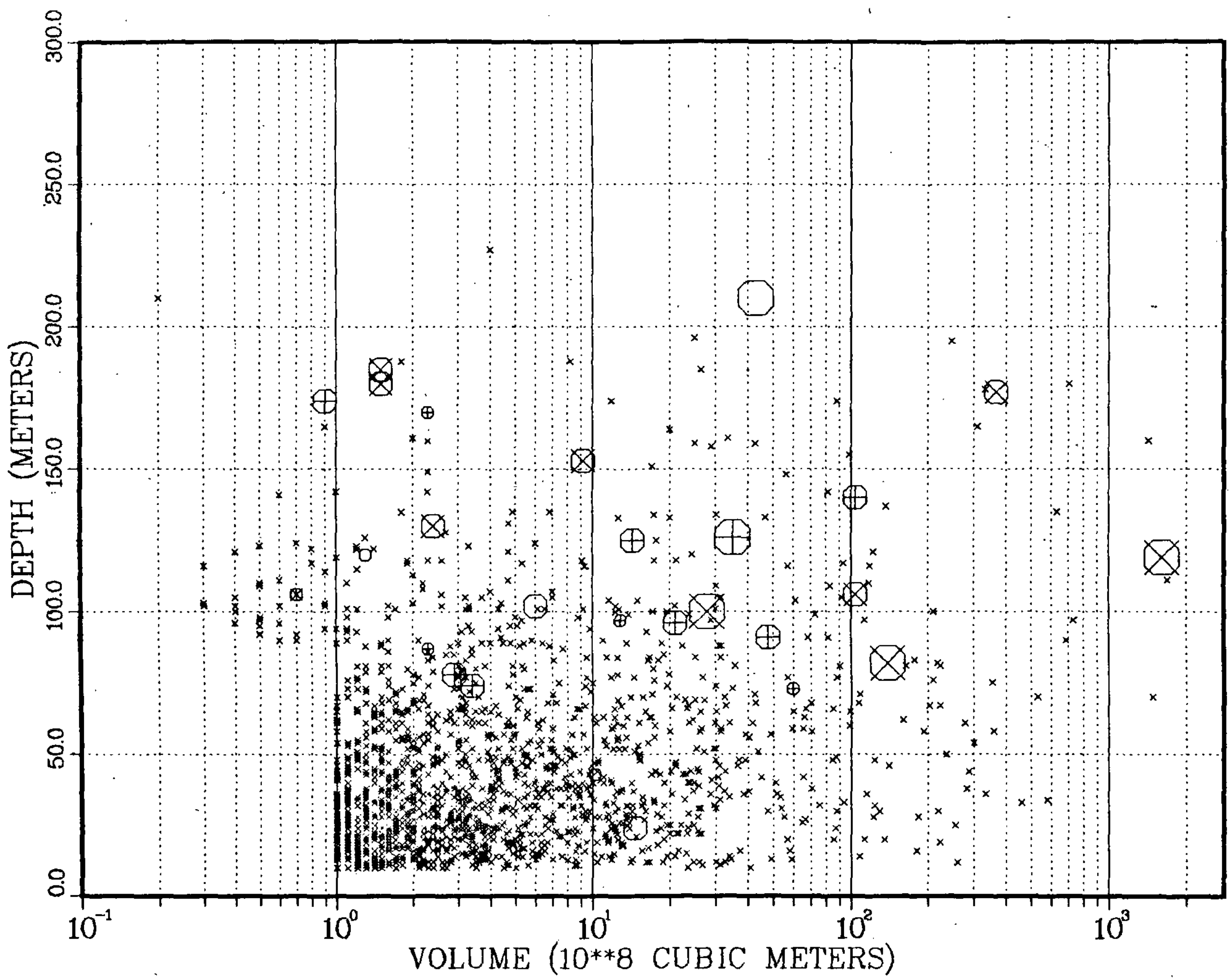

Figure 1. Water depth and volume of 1645 reservoirs completed prior to 1977. Reservoirs with water depth < 10 m or with depth <90 m and volume $< 10^8 m^3$ are excluded. Octagons indicate induced seismicity cases and size denotes maximum magnitude of seismic events. Small indicates magnitude <3, medium 3 to 5.5 and large ≥5.5. Symbol inside octagons denotes degree of assurance that the seismicity was reservoir induced. Open octagons indicate questionable cases, plus octagons indicate probable cases and X octagons indicate definite cases.

rows: reservoir depth in meters
columns: reservoir volume in 10**8 cubic meters

	.1-1	1-10	10-100	>100	all
10-60		909	214	24	1147
		0	1	0	1
		0.0%	0.5%	0.0%	0.1%
60-90		163	69	16	248
		2	0	1	3
		1.2%	0.0%	6.2%	1.2%
90-120	28	52	30	8	118
	0	1	3	2	6
	0.0%	1.9%	10.0%	25.0%	5.1%
120-150	7	16	10	4	37
	0	1	2	1	4
	0.0%	6.2%	20.0%	25.0%	10.8%
>150	3	9	12	6	30
	1	3	1	1	6
	33.3%	33.3%	8.3%	16.7%	20.0%
all	38	1149	335	58	1580
	1	7	7	5	20
	2.6%	0.6%	2.1%	8.6%	1.3%

Table 1. Crosstabulation of depth by volume. Cells contain a) total reservoir count, b) induced seismicity reservoir count (M>3), c) percentage b of a.

METAMORPHIC ROCKS

COUNT / ROW PERCENT / COLUMN PERCENT / TOTAL PERCENT		ABSENT 0	PRESENT 1	ROW TOTAL
RIS OTHERS	0	78	77	155
		50.3	49.7	92.3
		97.5	87.5	
		46.4	45.8	
ACCEPTED RIS CASES M>3	1	2	11	13
		15.4	84.6	7.7
		2.5	12.5	
		1.2	6.5	
COLUMN TOTAL		80	88	168
		47.6	52.4	100.0

CHI SQUARE = 5.87 (1 DEGREE OF FREEDOM). SIGNIFICANCE = 0.02

Table 2. Crosstabulation of induced seismicity by metamorphic rocks.

RIS	COUNT / ROW PERCENT / COLUMN PERCENT / TOTAL PERCENT	FAULTS: ABSENT 0	FAULTS: PRESENT 1	ROW TOTAL
OTHERS	0	7	79	86
		8.1	91.9	90.5
		87.5	90.8	
		7.4	83.2	
ACCEPTED RIS CASES M≥3	1	1	8	9
		11.1	88.9	9.5
		12.5	9.2	
		1.1	8.4	
	COLUMN TOTAL	8	87	95
		8.4	91.6	100.0

CHI SQUARE = 0.093 (1 DEGREE OF FREEDOM). SIGNIFICANCE = 0.76

Table 3. Crosstabulation of induced seismicity by faults.

RIS	COUNT / ROW PERCENT / COLUMN PERCENT / TOTAL PERCENT	ACTIVITY: INACTIVE 0	ACTIVITY: ACTIVE 1	ROW TOTAL
OTHERS	0	12	11	23
		52.2	47.8	85.2
		85.7	84.6	
		44.4	40.7	
ACCEPTED RIS CASES M≥3	1	2	2	4
		50.0	50.0	14.8
		14.3	15.4	
		7.4	7.4	
	COLUMN TOTAL	14	13	27
		51.9	48.1	100.0

CHI SQUARE = 0.006 (1 DEGREE OF FREEDOM). SIGNIFICANCE = 0.94

Table 4. Crosstabulation of induced seismicity by fault activity.

Earthquake Prediction Studies in South Carolina

Contract No. 14-08-0001-17670

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Continuous reservoir induced seismicity has been monitored at Lake Jocassee since October 1975 and at Monticello Reservoir since December 1977. In addition, at Lake Jocassee, the radon concentration in groundwater has been monitored for over 3 years, and the water level in an observation well for one year. These form part of a multifaceted approach to seek out precursory changes associated with the larger, $2.0 \leq M_L \leq 4.0$ events. The earthquake source region inferred from seismicity, changed from heterogeneous, brittle rocks (1/1976) to moderately heterogeneous (2/1977), to relatively uniform (8/1979). The seismic parameters studied include the spatial and temporal behavior of seismicity, changes in ts/tp and P/SV amplitude ratios, and tests of some statistical algorithms. A fair degree of success was achieved with these methods. The results of the data collected so far include the formulation of an empirical earthquake prediction model and successful prediction of two small events. Long period and short period changes were noted in the radon concentration in an observation spring. The water level in an observation well was also found to be associated with short term ($\sim$1 day) changes preceding the larger events. The amplitude of these anomalies was found to depend on the distance of the well from the hypocenter and on the magnitude of the earthquake. These observations suggested that a multifaceted approach is a useful one, and that the conclusions and models arrived at after monitoring small earthquakes in a small region can perhaps be extended to larger tectonic ones.

Induced Seismicity at Monticello Reservoir, South Carolina

9960-02668

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Investigations:

In-situ measurements of the state of stress, pore pressure and permeability, seismic velocity and natural fracture distribution in the second of two ~ 1 km-deep wells were completed and analysis of the data is in progress.

Results:

The in-situ measurements indicate that the earthquakes at Monticello Reservoir are resulting from subsurface pore changes triggering near-surface thrust-type fault motion on naturally existing joints and fractures in the rock. The stress measurements indicate that the state of high horizontal stresses capable of causing the thrust faulting persists only to a depth of about 300 m. Pore pressure measurements in both wells clearly demonstrate increased subsurface pore pressures due to impoundment and although the subsurface pore pressure change is only several bars, it is apparently sufficient to trigger the many small magnitude (< 3.0), very shallow (mostly less than 0.5 km), earthquakes which are observed. Permeability measurements in the well support the hypothesis that earthquake migration after impoundment is controlled by pore fluid diffusion.

The attached figure shows that fractures encountered in the wells have approximately the same orientation as the fault planes inferred from focal plane mechanisms (P. Talwani, written comm.). In the vicinity of well Monticello 1, there are two sets of focal plane mechanisms (labelled "M" and "Q") which agree fairly well with the orientation of the statistically significant concentration of fractures and joints observed in the well (at least 3 standard deviations greater then random). Near Monticello 2, a fault plane implied by the focal mechanism agrees very well with the borehole fracture and joint orientations. Thus, these data, the shallow depths of the events, the shallow depth to which the measured high horizontal stresses persist, the clustering of the events in small zones, and the varied nature of focal plane mechanisms all suggest that the source zones of the earthquakes are existing fractures and joints. If correct, this interpretation can be used to place bounds on the probable depth of the induced earthquakes and their probable maximum size.

Reports:

Zoback, M. D., In-situ study of the mechanism of reservoir triggered earthquakes in the southeastern United States, Proc. Conf. on Intra-Continental Earthquakes in Ohrid, Yugoslavia, in press.

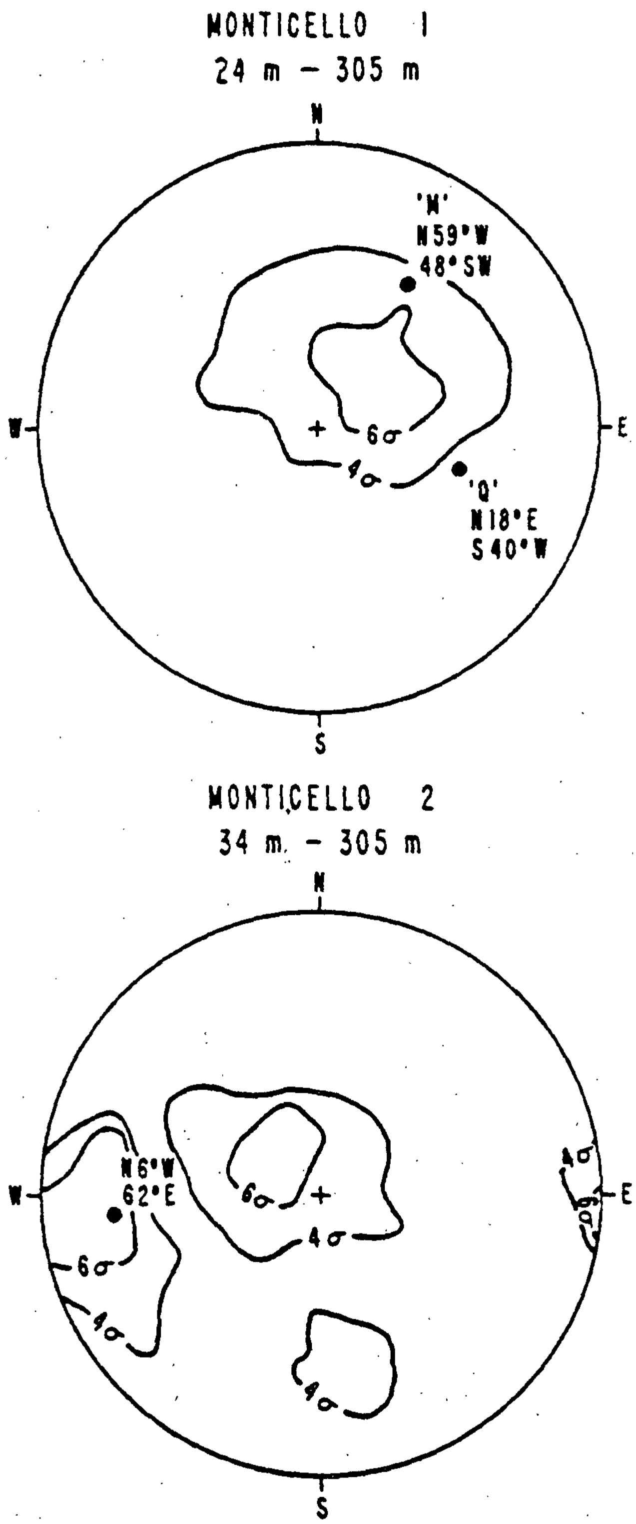

Figure 1 - Comparison of poles to fault planes indicated by composite focal plane mechanisms (P. Talwani, written comm.) and the poles to fractures and joints observed in the wells. The well data is presented as contours of the number of standard deviation (σ) from a random distribution. Pole concentrations greater than 3σ are statistically significant and shown in the figure.

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