UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

SUMMARIES OF TECHNICAL REPORTS, VOLUME XV

Prepared by Participants in

NATIONAL EARTHQUAKE HAZARDS REDUCTION PROGRAM

January 1983

OPEN-FILE REPORT 83-90

Menlo Park, California

1983

INSTRUCTIONS FOR PREPARATION OF SUMMARY REPORTS

1. Use 8 1/2" x 11" paper for both text and figures.

2. Leave at least 1" wide margins at top, sides and bottom.

3. Type headings at top of first page. Headings should include:

    a. Project title

    b. Contract, grant or project number

    c. Name of Principal Investigator(s)

    d. Name and address of institution

    e. Telephone number(s) of Principal Investigator(s)

4. Original copies of text and figures are required. No xerox copies.

5. Type figure captions on the same page as the figure.

6. Only type on one side of the paper.

7. Type all text single spaced.

8. Do not use staples.

9. All figures must be in black and white. No color figures (color, weak or grey lines will not photo-reproduce).

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Compiled by

Muriel L. Jacobson

Thelma R. Rodriguez

Wanda H. Seiders

The research results described in the following summaries were submitted by the investigators on November 15, 1982 and cover the 6-month period from April 1, 1982 through September 30, 1982. 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:

Earthquake Hazards and Risk Assessment (H)
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Earthquake Prediction (P)
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Global Seismology (G)
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Denver, Colorado 80225

Induced Seismicity (IS)
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Open File Report No. 83-90

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

Page

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 hypocenters on regional tectonics and seismic risk.

Results

David W. Gordon has continued analysis of over 240 instrumentally recorded Central U.S. earthquakes that he has relocated:

1. The accuracy of the results have been tested by comparing the calculated coordinates of events that have independently known positions with the corresponding known hypocenters. Twenty events, including 10 regionally recorded explosions, were available to check the accuracy of the revised epicenters. In 18 of 20 cases, the 95% confidence ellipse of the revised epicenter covered the independently known epicenter. To test the reliability of the recomputed focal depths, the results obtained in this study were compared to 34 events with known or independently estimated focal depths. Although most of the focal depths computed in this study are not estimated to be precise to within 10 km, they are consistent with the independent focal depths within the estimated precision of the solutions.

2. Comparison of the revised epicenters with previously accepted locations indicates that about 25% of the new epicenters differ from the old locations by 0.2° or more in lat or long. Nearly all of the old locations of this group are not covered by the 95% confidence ellipses associated with the new epicenters. In many instances, specific reasons for the differences between the old and new epicenters can be deduced. The two most common reasons for these differences are: (a) the epicenters of events through the early 1960's were often based primarily on intensity data, and (b) locations originally computed with a minimum number of observations sometimes changed appreciably when new data were added to the solution. Mislocations due to traveltime bias are also apparent among the previously accepted epicenters.

3. In the New Madrid zone, the revised epicenters show better agreement than do the old epicenters with seismicity patterns defined by recently recorded microearthquakes. In the vicinity of Marked Tree, Arkansas, the revised epicenters suggest a seismic trend transverse to the main axial trend of the New Madrid zone.

4. At least 80% of the relocated epicenters in the mid-continent region with $m_{bLg} \geq 4.5$ correlate with ancient plate tectonic elements, such as continental rifts, aulacogen's, transform faults, and suture zones.

Reports

Gordon, D. W., 1982, Recomputation of earthquake locations in the central United States, Abstracts of the 54th annual meeting, Eastern Section of the Seismological Society of America.

Choy, G. L., Boatwright, John, Dewey, J. W., and Sipkin, S. A., ________, A teleseismic analysis of the New Brunswick earthquake of January 9, 1982, submitted to J. Geophys. Res.

Engdahl, E. R., Dewey, J. W., Fujita, Kazuya, ________, Earthquake location in island arcs, Phys. Earth Planet Interiors, (in press).

Montero P., W., Dewey, J. W. 1982, Shallow-focus seismicity, composite focal mechanism, and tectonics of the Valle Central of Costa Rica, Bull. Seism. Soc. Am. 72, p 1611-1626.

Seismic Data Library

9930-01501

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This is a non-research project and its main objective is to provide access of seismic data to the seismological community. This Seismic Data Library was started by Jack Pfluke at the Earthquake Mechanism Laboratory before they joined the Geological Survey. Over the past ten years, we have built up one of the world's largest collections of seimograms (almost all on microfilms) and related materials.

Major holding of seismograms are:

(1) WWNSS film chips and fiches (1963-present) -- about 4,000,000 seismograms.
(2) USGS local network develocorder films (1966-1979) -- equivalent to about 1,500,000 seismograms.
(3) Historical seismograms (1903-present) -- about 300,000 seismograms so far.

The historical seismograms were made through an international effort in filming "old" seismograms (anything prior to 1963). The goal is to build up a library of a few million seismograms containing all available records from 30 or so key stations around the world, and selected seismograms for some 2,500 selected earthquakes. Key stations selected for U.S. are:

College, Alaska	(1935-63)
Denver, Colorado	(1909-45)
Honolulu, Hawaii	(1903-21, 1933-63)
Mt. Hamilton, Calif.	(1911-63)
Pasadena, Calif.	(1923-63) -- being filmed now
Tucson, Arizona	(1910-63)
Vieques/San Juan	(1903-63)

In addition, we have also filmed several other U.S. stations for selected events. Filming seismograms in other countries has just begun. A camera has been set up in China, and another one is on its way to USSR. However, it will be a few more years later before we will have any significant amount of seismograms from other countries.

We have also an extensive collection of station bulletins and related materials. In particular, we have filmed all the available phase cards from Caltech (1927-69).

National Earthquake Catalog

9920-02648

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Investigations

1. Collected, verified and corrected earthquake event lists for the catalog.

2. Developed and tested a calibrated method of relative and joint magnitude determinations.

3. Completed collection of phase data for Southern California earthquakes with $M \geq 5$.

Results

During this reporting period Carol Thomasson corrected 15,000 event listings in four VAX 11/780 source files of Alaskan earthquakes. Several thousand unverifiable listings in the CGS file were replaced with data published in the CGS Seismological Bulletin for 1944-1950 and 1954-1966. Sparse data for 2500 previously uncompiled Alaskan earthquakes were entered in new files and a considerable amount of intensity data were added to the original source files. Multiple verification procedures identified nearly all correction and data entry errors.

The primary event-list data base for New England, New Jersey, New York and Pennsylvania was assembled by adding regional network bulletin data to the published state files of Stover and others. The data base contains 1440 earthquakes (through 1980), but does not include locally recorded microearthquakes for which only origin times were listed in the bulletins.

Seismograms from the WWSSN station GOL were used by Taggart to estimate the magnitudes of 130 aftershocks ($1.5 \leq mbLg \leq 3.6$) relative to the independently determined magnitude (mbLg 4.0) of the largest aftershock of the 23 January 1966 Dulce, New Mexico, earthquake. Statistical data were obtained from joint magnitude determinations (JMD) of 18 aftershocks using six well distributed WWSSN stations (including GOL). The standard errors of the station corrections and the event magnitudes were < 0.2 units, which is comparable to the JMD standard errors from Nevada Test Site data reported by von Seggern. The estimation of relative magnitudes is rapid, accurate, and especially practical where network data is limited.

Karen Meagher completed collection of phase data from nearly 600 southern California earthquakes with $M \geq 5$. These data will be prepared for input to HYPO79, which will be used by W. H. K. Lee to relocate the hypocenters with appropriate velocity models. Meagher also has assembled and deleted redundancies from an extensive descriptive file of pre-instrumental earthquakes in California.

Areas Damaged by California Earthquakes, 1900-1949

Contract No. 14-08-0001-19934

Tousson R. Toppozada

and David L. Parke

California Division of Mines and Geology

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Summary:

The purpose of this investigation is to define the areas in California that were most damaged by earthquakes during the first half of the twentieth century. The earthquakes selected are those of magnitude 5.5 or greater that caused damage of Intensity VII Modified Mercalli or greater in California. From 1900 through 1949, 61 earthquakes meet these criteria. The areas shaken at Intensity V or greater were determined by interpreting the earthquake effects reported in the seismological literature, supplemented by newspaper reports from the damaged areas. Isoseismal maps showing the areal extent of the areas damaged are included for the 39 most damaging earthquakes in the Annual Technical Report. This provides the relative sizes of the earthquakes independently of the variations in seismographic instruments.

About 2,300 newspaper issues were searched, and one-third provided earthquake reports. A bibliography of the newspaper issues searched is included. Summaries of the reported effects that were used to determine values of intensity are also included.

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

14-08-0001-19173

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Bryan Grigsby
Daniel J. Olson
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Investigations

1. Completed USGS semi-annual technical report, "Surface and Subsurface Geology of the Santa Barbara-Goleta Metropolitan Area, Santa Barbara County, California, by Daniel J. Olson, to be submitted as a possible open-file report.

2. Completed first draft of a manuscript, "Early-Stage Thrust Faults and Deformational History in San Miguelito Oil Field, Ventura County, California," by Lu Hua-fu and Robert S. Yeats.

3. Collected additional data from the Rincon, Padre Canyon, and San Miguelito oil fields for further structural analysis of the late Quaternary Ventura anticline-thrust system.

Results

We have completed a map showing recency of faulting in the Santa Barbara-Goleta metropolitan area, shown here as Figure 1. The youngest bedrock is the Santa Barbara Formation (Qsb) of Pleistocene age. The Santa Barbara rests with angular unconformity on folded and faulted strata as young as the Pliocene Sisquoc Formation. It is deposited in a half-graben basin in which gently south-dipping Santa Barbara Formation is cut by south-dipping reverse faults, some of which (More Ranch, Mesa faults) have large separation and terminate the basin on the south (Figure 2). The Santa Barbara is overlain with angular unconformity by fanglomerate and by marine terrace deposits, one of which has an estimated amino-acid age of 40,000 years.

We mapped those faults which post-date fanglomerate or the 40,000 year terrace on the basis of (1) a faulted contact between bedrock and terrace, (2) a fault scarp, more or less dissected, in fanglomerate, or (3) steeply dipping fanglomerate. Critical localities are shown on the map where evidence is found for a young age of faulting.

Faults which pre-date the 40,000 year terrace and pre-date the Santa Barbara Formation are also shown. The evidence for faults which pose a seismic shaking and/or ground-rupture hazard is tabulated below:

Fault	Evidence for youthful activity
Cameros	Mainly and possibly entirely pre-Santa Barbara, but affects ground-water contours
Goleta	Same as Cameros
Modoc	Same as Cameros
More Ranch	Cuts 40,000-year terrace in sea cliffs at Elwood field; forms north-facing scarp; prominent 1929 air photo lineations 0.8 km NNW of Coal Oil Point
Lavigia	Monterey faulted against terrace deposits in trench northwest of Hope Ranch
Mesa	Steep, north-facing scarp; steeply dipping fanglomerate
Mission Ridge	Fault scarp in fanglomerate
San Jose	Deforms fanglomerate

Reports

Jackson, P. A., and Yeats, R. S., 1982, Structural evolution of Carpinteria basin, western Transverse Ranges, California: Am. Assoc. Petroleum Geologists Bull., v. 66, p. 805-829.

Yeats, R. S., in press, Large-scale Quaternary detachments in Ventura basin, southern California: Jour. Geophys. Research.

FIGURE I. RECENCY OF FAULTING IN THE SANTA BARBARA-GOLETA METROPOLITAN AREA.

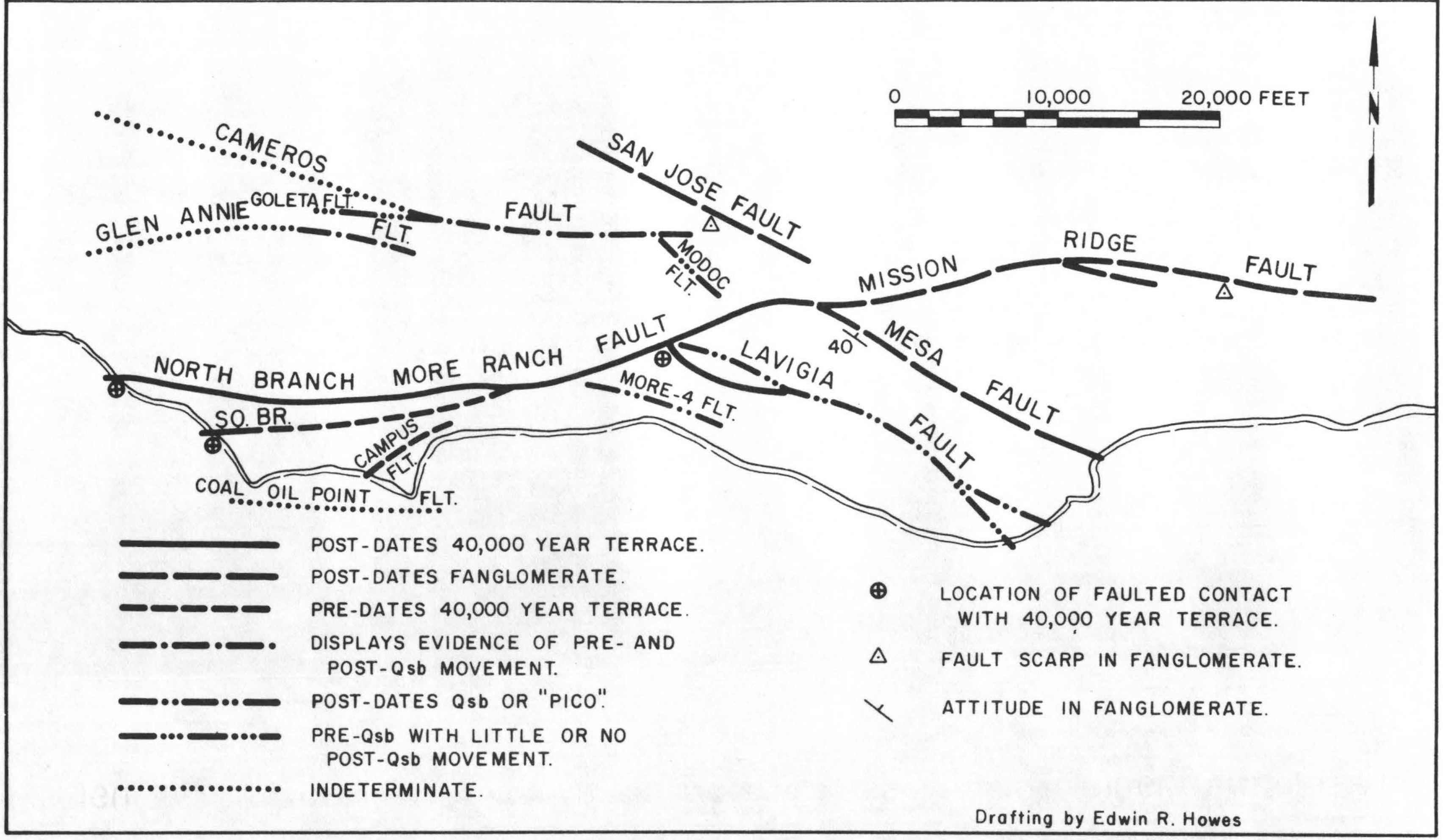
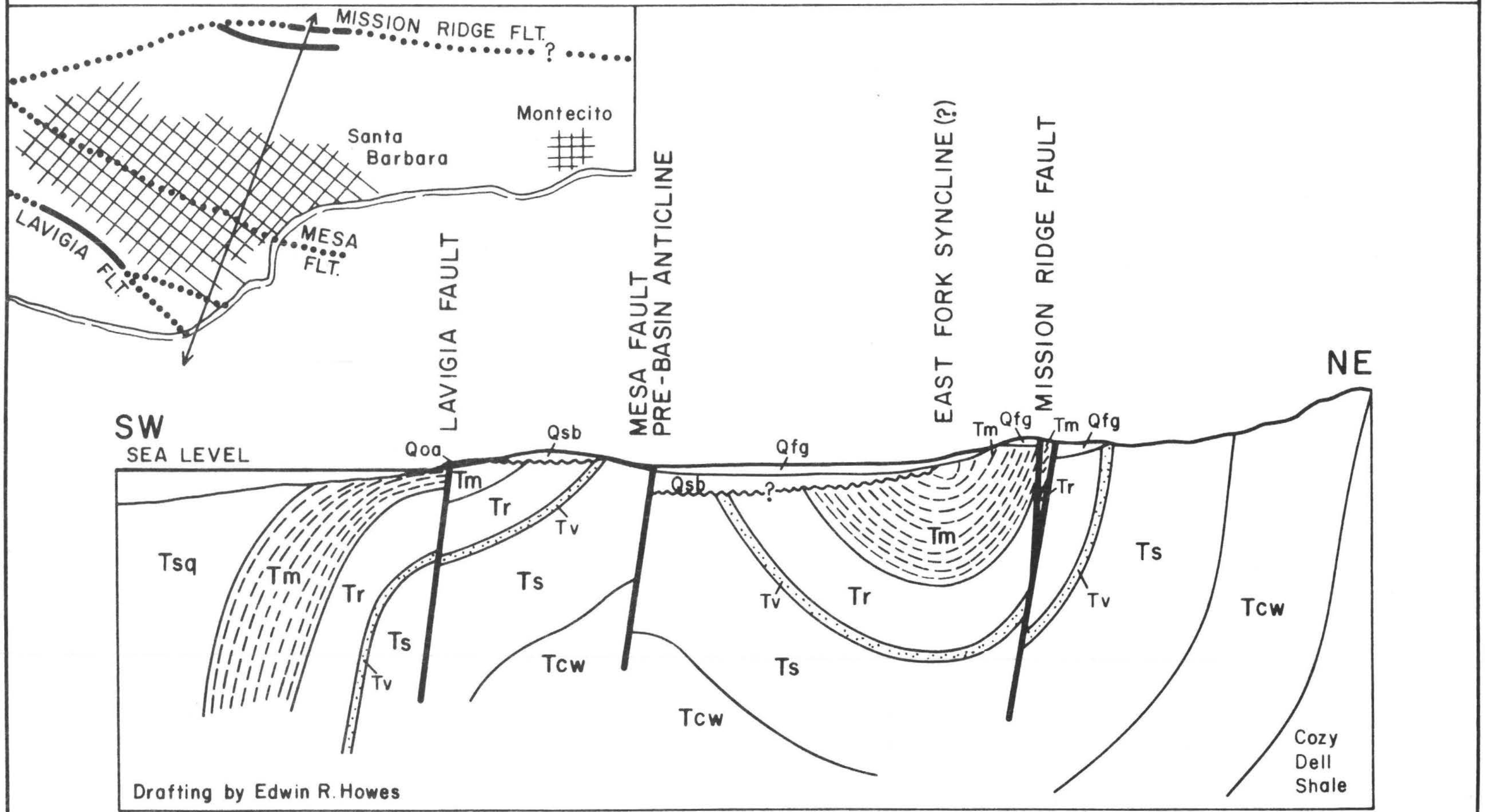


FIGURE 2. DIAGRAMMATIC CROSS SECTION ACROSS MISSION RIDGE AND SANTA BARBARA PLAIN (modified from Dibblee, 1966).



H1

Regional and National Seismic Hazard and Risk Assessment

9950-01207

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Investigations

1. Continuing assessment of sensitivity studies of regional probabilistic ground motion values to changes in the following input parameters:

A. Finite fault rupture models

1) Fault rupture length
2) Multiple fault spacings and rupture length variability
3) Site-to-source rupture aspect for homogeneous rupture regions

B. Various published ground motion attenuation models.

C. Parameters of magnitude-frequency relationships as a function of catalogue completeness and fitting technique.

2. Analysis of seismic source zones in the Eastern United States for mapping long return-period earthquake ground motion hazard.

3. Analysis of 1980 census data for estimation of economic loss from potential earthquake activity in selected cities in the western and midwestern United States.

4. Refinement of probabilistic seismic liquefaction intensity maps for southern California for three different return periods. The calculation used a liquefaction intensity attenuation devised by Youd (9950-01629).

5. Continuing review of intensity data for damaging earthquakes in the Mississippi Valley connection with a FEMA supported disaster preparedness study in the Midwest. A maximum Modified Mercalli intensity map is being constructed for the Mississippi Valley.

Results

1. Text and maps showing probabilistic estimates of maximum acceleration and velocity in rock in the contiguous United States have been completed (O.F. 82-1033) and supporting sensitivity studies to various input parameters are discussen and illustrated in the text.

Documentation of finite fault rupture models (O.F. 82-292) and a revised probabilistic ground motion computer program (O.F. 82-293) have been completed and serve as supplementary texts to O.F. 82-1033 by having more detailed information concerning the fault rupture model.

Refinement of text and figures describing sensitivities to fault rupture models has been completed and submitted for journal publicaton.

2. A text that summarizes a series of meetings convened to provide the project with a consensus viewpoint on new information and other factors that were considered in defining seismic source zones of O.F. 82-1033, is through technical review and very near completion of technical editing as a U.S. Geological Survey Circular. Regionalization of the Basin and Range Province according to age of fault displacements has been completed (O.F. 82-742).

Seismic source zones in the eastern United States for estimating ground motion values having low annual probabilities of exceedance are currently being analyzed.

3. A series of maps with accompanying text have been completed for the Basin and Range Province showing historical seismicity, strain-release, and probabilistic ground motion values. The report is in technical review.

4. Progress has been made in developing utility programs for operating on large files of earthquake and census information (O.F. 82-929) for earthquake loss studies.

5. Reevaluation of intensity data for the 1872 Washington earthquake has been completed and emphasis of study has shifted to historical seismicity in the central United States. Intensity data for the 1843, Arkansas earthquake and the 1895, Missouri earthquake are currently being reevaluated. Histories of shaking (Modified Mercalli Intensities) are being compiled on a county basis throughout a large portion of the central United States in conjunction with the FEMA supported disaster preparedness study in the Midwest.

Reports

Algermissen, S. T., Perkins, D. M., Thenhaus, P. C., Hanson, S. L., and Bender, B. L., 1982, Probabilistic estimates of maximum acceleration and velocity in rock in the contiguous United States: U.S. Geological Survey Open-File Report 82-1033, 99 p., 6 pls., scale 1:7,500,000.

Askew, B., 1982, Transformation of mapped data to grid systems with applications to earthquake data: U. S. Geological Survey Open-File report 82-929, 47 p.

Bender, B., 1982, Flowchart: A computer program for plotting flowcharts: U.S. Geological Survey Open-File report 82-999, 20 p.

Bender, B., 1982, Sensitivity analysis for seismic risk using a fault-rupture model: U.S. Geological Survey Open-File report 82-294, 74 p.

Bender, B., and Perkins, D. M., 1982, Seisrisk II: A computer program for seismic hazard estimation: U.S. Geological Survey Open-File report 82-293, 103 p.

Hopper, M. G., Algermissen, S. T., Perkins, D. M., Brockman, S. R., Arnold, E. P., 1982, [Abstract], The earthquake of December 14, 1872, in the Pacific Northwest: Seismological Society of America, 1982 Annual Meeting April 19-21, Anaheim, California.

Thenhaus, P. C., Algermissen, S. T., and Perkins, D. M., 1982, [abstract], A new seismic source zone map for the conterminous United States: Geological Society of America Abstracts with Programs, v. 15, no. 7, p. 630.

Thenhaus, P. C., and Wentworth, C. M., 1982, Map showing zones of similar ages of surface faulting and estimated maximum earthquake size in the Basin and Range Province and selected adjacent areas: U.S. Geological Survey Open-File report 82-742, 18 p., 1 plate, scale 1:2,500,000.

Seismic Wave Attenuation in Conterminous United States

9950-01205

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Results

1. Data analysis of 72 events recorded by the New England short-period network for L_g-waves have been completed. The matrix formulation (Dwyer, Herrmann and Nuttli, 1981) have been used to determine the attenuation of L_g-waves at 1 sec. Our results for γ, are lower than those of Chiburis and others. A report is in the process of being written on this topic.

2. A report entitled "An Algorithm to Compute a Multiple Volterra Rectangular Dislocation: Strike-slip, Dip-slip, Normal- and Reverse-faulting Cases," by A. F. Espinosa, S. McKay, Chalermkiat Tongtaow, and R. Yeatts is in the process of being written.

3. Two foreign scientists completed their training under this program: Ms. L. Casaverde, an Organization of American States Fellow recipient from Lima, Peru, South America, received an intense program training in Seismic Data Analysis Techniques. The other scientist Ms. C. Fernandes, an International Atomic Energy Agency Fellow from Brazil, received similar training plus the usage of digitizing and plotting procedures.

4. A report on L_g-wave attenuation in conterminous USA is in the process of being written.

5. A. F. Espinosa was invited as a visiting professor to the First International Course in Geophysics sponsored by the International Center of Theoretical Physics, Trieste, Italy; the Universite Pierre et Marie Curie, Paris, France; and the International Center of Physics, Bogota, Colombia, held in Bogota, Colombia. Participants from Central and South American countries attended this course.

6. An Open-file Report on L_g-wave data tabulation has been finished entitled "L_g-wave Data-Base Tabulation Recorded on the: I. LRSM Stations in the Conterminous United States, II. New England Stations," by A. F. Espinosa and J. Michael.

Strong-Motion Interpretations for Structural Engineering

9910-02759

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Investigations

The direction of these research efforts is oriented towards obtaining information concerning the strong-motion response of engineering structures. Although the goal of these studies is to improve the current understanding of fundamental problems in earthquake engineering, the scarcity of sufficient strong-motion records has impeded that effort. Consequently, these investigations have concentrated in the area of strong-motion data acquisition from engineering structures.

Results

Continuing studies in the area of instrumentation of earth dams are being conducted. In particular, guidelines pertaining to the implementation, cost, and maintenance of strong-motion and other instrumentation at dam sites are being developed.

A specific earth dam (Leroy Anderson Dam) has been identified as being suitable for instrumentation according to the guidelines reported herein. Coordination with the various agencies involved is being established. A preliminary strong-motion instrumentation scheme for the dam site has been developed. An evaluation of the suitability of downhole instrumentation at the dam is also being conducted.

Analysis of existing strong-motion data obtained from structures is continuing. The response records from Long Valley Dam during the May 1980 Mammoth Lakes Earthquakes are under investigation.

Additional engineering structures are being analyzed for planned strong-motion instrumentation. Various building projects in the San Francisco Bay region have been selected for both free-field and structure strong-motion instrumentation. Preliminary design schemes for the instrumentation of these projects are being formulated.

Reports

Matthiesen, R. B., and Porcella, R. L., 1982, Strong-Motion Data Recorded in the United States during the 1979 Imperial Valley Earthquakes: U.S. Geological Survey Professional Paper 1254.

Fedock, J. J., 1982, Strong-Motion Instrumentation of Earth Dams: U.S. Geological Survey Open-File Report 82-469.

Investigation of Seismic Wave Propagation for Determination of Crustal Structure

9950-01896

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Investigations

1. Continued to collaborate with Kaye Shedlock in the processing of the Mississippi River high resolution seismic reflection survey.

2. Collected and processed Mini-SOSIE high-resolution seismic reflection data across known surface lineations in the Mississippi embayment. The purpose was to determine if these features are controlled by subsurface movements or by the dynamics of the Mississippi River.

3. Collected and processed Mini-SOSIE high-resolution seismic reflection data across known scarps in Utah. The purpose of the survey was to determine if the fault scarps are of a non-tectonic origin or of recent tectonic movement such as a deep-seated fault.

Results

1. About 2/3 of the Mississippi River survey is processed and interpretations are beginning.

2. Preliminary processing was compiled on eight lines of the Mini-SOSIE data which was collected in the Mississippi embayment. Dave Russ was able to make a selection for trenching based upon the data.

3. Mini-SOSIE high-resolution data was collected.
    1. Across the Drum Mountain scarp system.
    2. Across the fault scarp near Clear Lake, Utah.
    3. Across the fault scarp near Scipio, Utah.
    4. Two lines were run across a fault lake scarp near Kaysville, Utah.

Reports

Shedlock, Kaye M., and Harding, Samuel T., 1982, Mississippi River seismic survey: Geophysical Research Letters, v. 9, no. 11, p. .

Data Processing, Golden

9940-02088

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Investigations

1. The purpose of this project is to provide the day to day management and 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, a PDP 11/70, three PDP 11/03's and a PDP 11/23, a VAX/780 and a PDP 11/34. Total memory is 6.4 Mbytes and disk space will be approximately 2.2 G bytes. Peripherals include three plotters, eight 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. Users may access any of the systems through a Gandalf terminal switch. Operating systems used are RSX11 (11/40 and 11/34), Unix (11/70), RT11 (11/03) and VMS (VAX).

The three major systems are to be shared by the Branch of Global Seismicity, Branch of Earthquake Tectonics and Risk, and the Branch of Ground Motion & Faulting.

Results

Computation performed is primarily related to the Global Seismology and Hazards programs; however, work is also done for the Induced Seismicity and Prediction programs as well as for DARPA, ACDA, and AFTAC among others.

In Global Seismology, the data center is central to nearly every project. The monitoring and reporting of seismic events by the National Earthquake Information Service is 100% supported by the center. Their products are, of course, a primary data source for international seismic research and have implications for hazard assessment and prediction research as well as nuclear test ban treaties. Digital time series analysis of Global Digital Seismograph Network data is also 100% supported by the data center. This data is used to augment NEIS activities as well as for research into routine estimation of earthquake source parameters. The data center is also intimately related to the automatic detection of events recorded by telemetered U.S. stations and the cataloging of U.S. seismicty, both under development.

In Earthquake Tectonic and Risk, the data center supports research in assessing seismic risk and the construction of national risk maps. It also provides capability for digitizing analog chart recordings and maps as well as analog tape. Also, most if not all of the research computing related to the hazards program will be spupported by the data center.

In Ground Motion and Faulting, the data center supports equipment for on-line digital monitoring of Nevada seismicity. Also it provides capability for processing seismic data recorded on field analog and digital cassette tape in various formats. Under development is a portable microprocessor based system to be used by the field investigations group to do preliminary analysis and editing of temporary local networks.

Reports

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

Neotectonic Synthesis of U.S.

9540-02191

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Investigations

1. Central California deep-crustal reflection profiling: 240 miles of existing reflection profiles were selected and purchased, an RFP for 70 miles of new profiling was issued, and a contractor was selected for the new work.

a. Northern Sacramento Valley - 100 miles of 5-second primacord data were purchased from Seisdata Corp. These lines extend across the northern Sacramento Valley between Willows and Red Bluff and abut Cretaceous outcrop on the west.

b. Southern San Joaquin Valley - 120 miles of 6-second Vibroseis data across the southern Coast Ranges and San Joaquin Valley from Moro Bay to crystalline basement east of Delano were purchased from Western Geophysical Co. The central 60 miles are being reprocessed to recover an additional 6 seconds of record.

c. Northern San Joaquin Valley - A contract has been signed with Geophysical Systems Corp. to collect and process 78 miles of 15-second, 100-fold Vibroseis data and 30 miles of 4-fold dynamite data along a line extending east from the crest of the Diablo Range north of Pacheco Pass through Chowchilla. Field acquisition is planned for late 1982.

2. Work continued (Menges) on late Cenozoic tectonic history of Arizona.

3. Work continued (Mayer) on estimation of age of fault offset from scarp morphology, and a major report on relative ages of fault scarps using regression and discriminant analysis is largely completed.

4. A temporary 6-station seismic net with a station spacing of about 10 km was operated over a 25 x 65 km area west of the Hurricane fault in southernmost Utah for 6 weeks in June-July, 1982 (Sbar and Johnson) to investigate the transition from Plateau to Basin and Range Provinces. Against a background of 0.5 to 1 event per day, a large swarm of about 40 events was recorded south of Enterprise and lesser swarm activity was detected elsewhere on a number of occasions. Locations to ± 1 km and a number of fault plane solutions will be possible from the data.

Results

1. Mark Zoback's realization that deep data can be recovered from shallower Vibroseis profiles where the sweep is long and upward across the frequency range has proved valuable. Western Geophysical's line SJ-6, originally

recorded to 6 seconds, has been reprocessed under contract to 12 seconds. Numerous deep events are evident, although they are continuous only over short distances and are interrupted by large areas of noise.

2. Within the Salinian granitic block at about 35°30' N lat. abundant short and discontinuous subhorizontal reflections occur throughout the crust and stronger reflections appear at about 4.7 and 9.2 seconds (two-way). Assuming a velocity increasing from 6.0 km/sec near the basement surface to 6.5 at 8 seconds, these stronger reflections occur at depths of 10 3/4 and 28 1/4 km. The deeper one must be the base of the crust; the midcrustal reflector is of unknown origin, but raises again the question of Salinian granitic terrane thrust over some underlying (Franciscan ?) mass.

3. The San Andreas fault is not evident at all in the 12-second record, at least in its present, preliminary state of processing.

4. Discontinuous reflections are evident between 6 and 7 seconds beneath the southern tip on the Diablo Range (McClure Valley) that are aligned (in time) with the west-dipping basement surface beneath the Cretaceous-Cenozoic section to the east of Kittleman Hills (South Dome). This relationship, together with evidence of detachment between the Cenozoic folds and deeper strata, suggests that the crystalline rock and unconformity on which the Valley sediments were deposited has been thrust westward at least 10 km beneath the Coast Ranges.

5. Scarp-profile studies in Arizona (Menges) indicate numerous faults having offsets in the range 5-20 thousand years. These are scattered along the whole length of the seismic zone that extends northwestward across the state. The shortest return times (perhaps 10^4 yrs) and longest fault histories occur in the northwest; elsewhere recurrence intervals are longer (perhaps 10^5 yrs) and faults tend to lack pre-late Quaternary activity.

Reports

Mayer, Larry, and Wentworth, Carl M., 1982, Geomorphologic differences east and west of the Stafford fault system, Northeastern Virginia (abs.): Geological Society of America, 1983 southeast section meeting (in press).

Nakata, J. K., Wentworth, C. M., and Machette, M. N., 1982, Quaternary fault map of the Basin and Range and Rio Grande Rift provinces, western United States: U.S. Geological Survey Open-File Report 82-579, map scale 1:2,500,000.

Thenhaus, P. C., and Wentworth, C. M., 1982, Map showing zones of similar ages of surface faulting and estimated maximum earthquake size in the Basin and Range province and selected adjacent areas: U.S. Geological Survey Open-File Report 82-742, map scale 1:2,500,000.

Yeats, R. S., 1982, Large-scale Quaternary detachments in Ventura Basin, southern California: Journal of Geophysical Research (in press).

Seismic Hazards of the Hilo 7 1/2' Quadrangle

9550-02430

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Investigations

Geologic mapping and ^{14}C dating of lava flows in the Hilo quadrangle is nearing completion.

Results

More than three quarters of the geology of the Hilo 7 1/2' quadrangle has been mapped at a scale of 1:24,000. Of the 25 Mauna Loa flows identified thus far, one is historic, the 1880-81 flow, and twelve have been dated by ^{14}C techniques. The flows range in age from 100 years to 24,000 years.

All of the Mauna Kea flows within the quadrangle are overlain by a thick section of ash. A Mauna Loa flow on top of the ash has been dated at 14,300 years; hence the Mauna Kea flows are older than this date.

Two flows from Kilauea Volcano have been identified but no charcoal has been found beneath either. In reconnaissance mapping by Holcomb (1980), these flows are considered to be between 350 to 500 years old. A slurry of mud and rocks is being deposited on the Kilauea flows to convert the land to agricultural use. This modification will make the mapping of a contact between the units very difficult.

Reports

Buchanan-Banks, J. M., and Lockwood, J. P., 1982, Geologic map of the Alenaio-Waipahoehoe Stream drainage area, Hilo, Hawaii: U. S. Geological Survey Open-File Report 82-655, scale 1:24,000.

Earthquake Effects, Tomales Bay Sediment

9830-02890

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Investigations

Geophysical surveys were continued in Tomales Bay, California, augmenting the reconnaisance lines run earlier in the year, and were also conducted in Bodega Bay between Tomales Point and Bodega head. Approximately 58 nautical miles of high resolution seismic reflection profiles and side scanning sonar lines were collected in Tomales Bay, bringing the total of geophysical lines in Tomales Bay to about 80 nautical miles (fig. 1). In addition approximately 51 nautical miles of high-resolution seismic reflection and side scanning sonar profiles were run in Bodega Bay (fig. 2). Sixty-one cores were also collected during the summer (fig. 3) in the continuing effort to locate stratified bay sediment which might bear the imprint of earlier earthquakes in the area. Three underwater profiles were run using scuba on the western side of Tomales Bay to assess the effectiveness of waves at redistributing the sediment.

Results

Wherever stratified sediment appears in the seismic reflection profiles, possible faults appear, manifested by the abrupt appearance of internal reflectors, or by their offset. Some of the apparent breaks in the geophysical records are associated with scarps on the seafloor. Preliminary analysis of the breaks suggests that recent offset on the San Andreas fault occurs in a zone of discontinuous fractures. Some of the fractures associated with the 1906 earthquake can be identified by their tie to the observed break on their shorelines of Tomales and Bodega Bay. A map delineating probable recent fractures in the two Bays is under preparation.

Cores of the sediment taken in Tomales Bay during the summer confirm that very little stratification exists within modern bay sediment. Other than in the tidal channels in the north end of the bay, where strong tidal flow actively reworks the sand, or very close to the western shore of the bay, where waves redistribute the sand locally on a small scale, the abundant infauna totally bioturbate most of the deposits within the bay. Layered deposits produced by the January 1982 floor remained discernible in cores taken 6 months later. The fact that the sediment displayed only those layers deposited in this recent flood suggests that even these strata are unlikely to be preserved for more than a few years. The general absence of stratification greatly limits the possibility of identifying the effects of previous earthquakes, such as that of 1906, within Tomales Bay sediment.

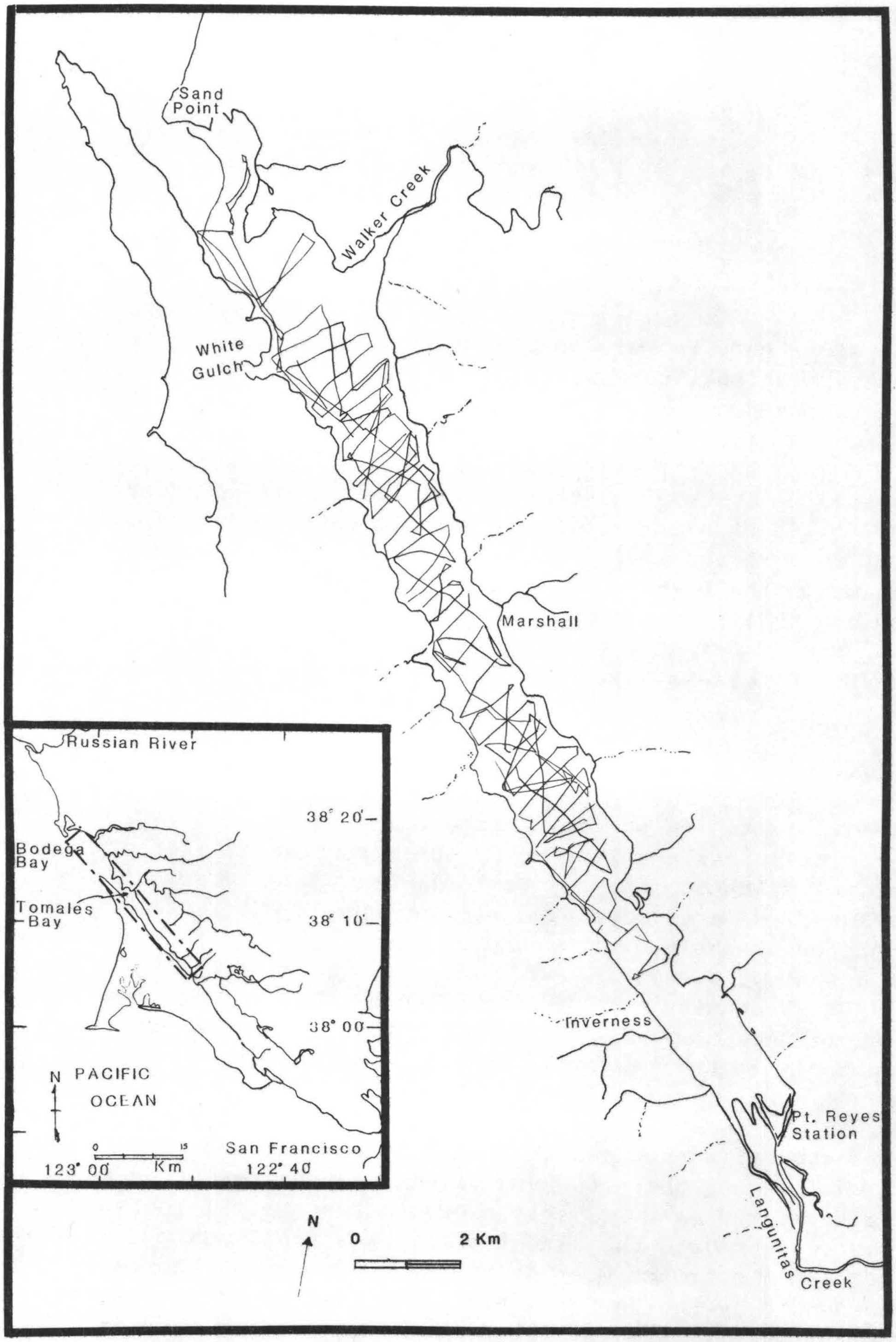

Figure 1. Geophysical tracks (high resolution seismic and side-scanning sonar profiles) in Tomales Bay. Insert shows location of Tomales and Bodega Bay.

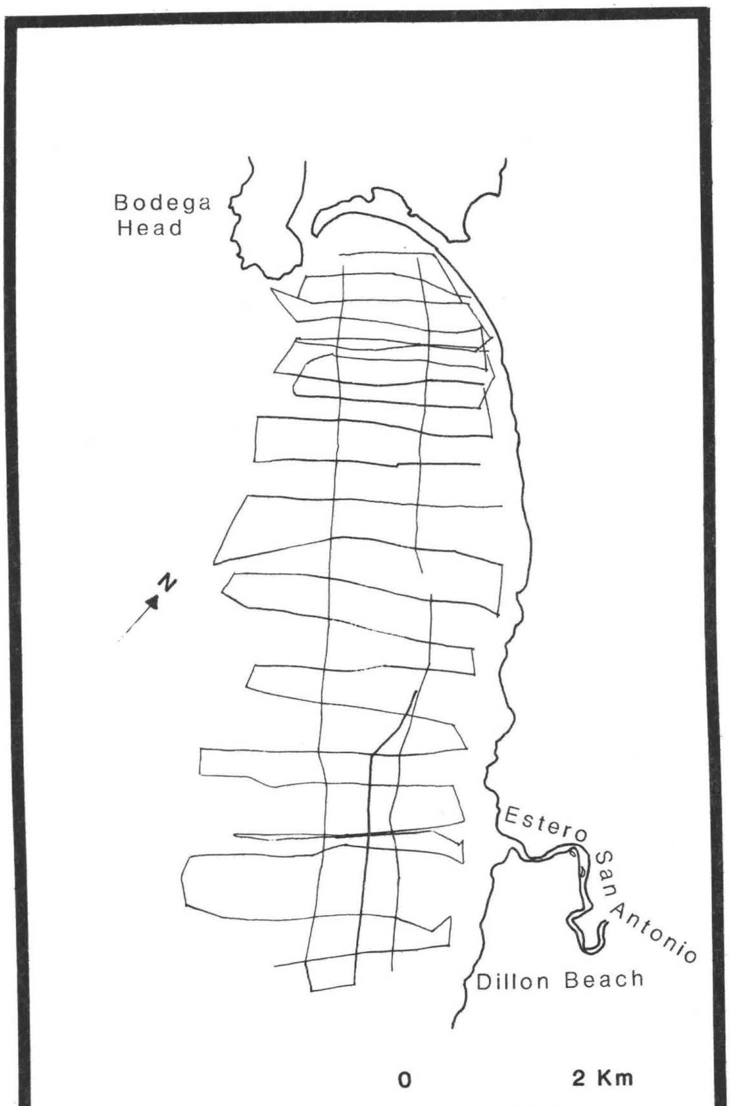

Figure 2. Geophysical tracklines across the San Andreas rift zone in Bodega Bay.

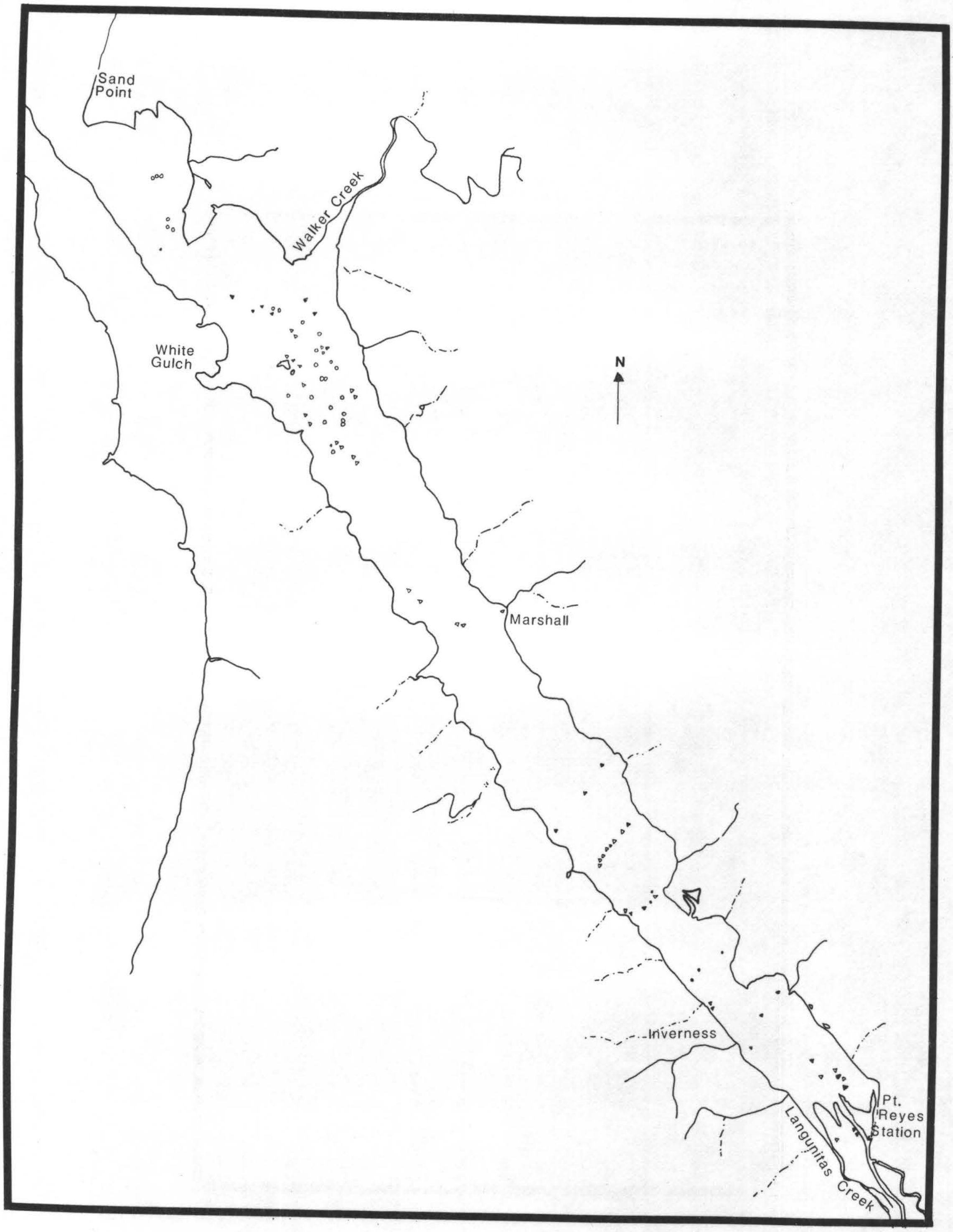

Figure 3. Location of cores taken in Tomales Bay.

NEOTECTONICS OF THE SAN FRANCISCO BAY REGION, CALIFORNIA

9540-01950

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Investigations

1. A search for recently active faults in the northeastern and southwestern San Francisco Bay area was reopened following discovery of several previously unrecognized, potentially active faults in those areas.

2. A map synthesis (scale 1:250,000) of the principal recently active faults in the San Francisco Bay area (encompassing the entire central California Coast Ranges and offshore continental borderland between latitude 36°15' N. and 39°00' N., and longitude 120°45' W. and 124°00'W) was prepared with D. S. McCulloch (Branch of Pacific-Arctic Geology, Menlo Park).

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3. Map synthesis (scale 1:250,000) of the principal recently active faults and earthquakes (1969-1980) in the San Francisco Bay area and surrounding Coast Ranges of central California--which is being prepared in cooperation with W. L. Ellsworth and L. N. Shijo (Project #9930-02103, Seismic Studies of Fault Mechanics, Menlo Park)--was corrected and revised.

4. A cooperative investigation of the landslides that were initiated in the San Francisco Bay area during an exceptionally intense rainstorm on January 3-4, 1982, was continued.

Results

1. Several heretofore unknown, recently active faults were recognized by Herd in the northeastern and southwestern San Francisco Bay area in an aerial-photographic search for evidence of later Quaternary faulting.

   a. A nearly continuous, north- to northwest-trending line of recently active reverse faults (west-side down) was discovered within the easternmost flank of the northeastern California Coast Ranges. The line of faults can be traced northward from Lagoon Valley (latitute 38°20' N.) through the mountains to at least latitude 39°10'N. The line of faults locally runs along the west side of Vaca Valley and Capay Valley, and everywhere closely follows the stratigraphic contact separating the Cretaceous Great Valley Sequence rocks of the interior Coast Ranges from the Tertiary and Quaternary rocks at the west side of the Sacramento Valley. The line of faults appears to be predominately bedding-plane in character, seemingly identical in strike and dip (?) with beds of the Great Valley Sequence. The fault offsets gravels of Pliocene and Pleistocene age (and erosional surfaces of probable mid-Pleistocene age) in west-facing escarpments that are locally tens of meters in height. Late Pleistocene terraces, however, do not appear broken by the faults.

b. A number of secondary reverse faults of mid- to late-Pleistocene age were discovered east of the above described line of reverse faults, within the Pliocene- and Pleistocene-age gravels at the west side of the Sacramento Valley. These north- to northwest-trending faults basically parallel the main line of reverse faults, similarly offsetting the gravels in west-facing escarpments. Most of these secondary reverse faults occur on the flanks of Bald Mountain northwest of Esparto. They include the Sweitzer fault, a reverse fault that had been mapped several decades ago on the west flank of Bald Mountain.

c. An east-trending thrust fault was discovered near Monterey, locally paralleling California Highway 68. The thrust fault, dips to the south, and can be traced eastward several kilometers to at least El Toro Creek. The thrust fault bounds the north side of an east-trending ridge that is underlain by folded Tertiary rocks; locally, beds are overturned at the fault. The fault appears to be continuous with a thrust fault recently discovered by W. Dupre' in the suburbs east of Monterey. There, the thrust fault offsets a marine terrace of mid- to late-Pleistocene age in a north-facing cliff.

2. Traces of recently active faults on the central California continental borderland (mapped by D. S. McCulloch and others in oceanographic cruises conducted during the last several years) have been compiled together with traces of recently active faults in the adjoining central Coast Ranges (mapped by Herd and others). The map compilation (scale 1:250,000) provides a new synthesis of the many recently active faults that have been discovered both onshore and offshore in the San Francisco Bay area, as well as new mapping of previously identified, recently active faults. The offshore mapping reveals the San Gregorio fault to be a line of *en echelon* fault segments not unlike that pattern of faulting now recognized along the Maacama and Green Valley faults. The San Gregorio fault joins the San Andreas fault west of San Francisco in a complex intersection of branching, discontinuous fault breaks.

Ground Response Along the Wasatch Front

9940-01919

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Investigations

1. The objective is to improve fundamental knowledge about how the ground response along the Wasatch front correlates with the local and regional geology. Data have been acquired in the Salt Lake City, Ogden, Provo, urban areas along the Wasatch front as well as in two other urban areas, Logan Cedar City, which provide a comparison. If possible, a field experiment is planned to explain an area of anomalously low ground responses in the Ogden area.

2. Compresional and shear velocities were measured at approximately 1/3 of the sites under investigation in the Wasatch area. The remaining sites and specific geologies will be investigated in the coming year.

3. A surface to subsurface ground motion investigation was made at a potential nuclear waste repository site.

Results

1. The maximum contrast in ground motion response values across the period band width of 0.2 to 6.0 seconds in Cedar City relative to an adjacent site underlain by rock is 4.0. A 43 meter length refraction survey made at the sites tested for site response in Cedar City did not record refraction arrivals from the underlaying bedrock and did not indicate any large velocity contrasts. The average Vp1 is 380 to 500 m/sec, Vs1 is 240 to 360 m/s and Vp2 is 710 to 1220 m/s Vs2 is 440 m/s to 960 m/s.

2. The surface-subsurface ground motion study at Calico Hills was finalized. The results generally indicate that the subsurface motions have frquency characteristics similar to the surface motions and the subsurface motions have a velocity spectral ammplitude that is less then the surface velocity spectral amplitude by a factor of 1.5.

3. The Wasatch seismic data report was finalized. The data is somewhat comparable to the seismic data reports from the San Francisco and Los Angeles areas.

Reports

1. King, K. W., 1982, Ground response in the Cedar City, Utah area [abs.]: Seismological Society of America, Feb. 1, 1982.

2. King, K. W., 1982, A study of surface and subsurface ground motion at Calico Hills, Nevada Test Site (directors approval Oct. 22, 1982).

3. King, K. W., Hays, W. W., McDermott, P. J., 1982 Wasatch front urban area seismic response data report (in final review.)

Alaska Seismic Studies

9940-01162

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Investigations

1. Beginning in October 1982, the scope of seismic monitoring in southern coastal Alaska was reduced in order to concentrate very limited funds on the areas of prime concern. Monitoring has been discontinued in southern Cook Inlet with the removal of six stations from Develocorder film; reduced in Prince William Sound and near Valdez with removal of four stations from film; discontinued between Yakutat Bay and Sitka with removal of stations at Juneau and Sitka from film; and terminated north of the Wrangell Mountains with closure of the station at Alcan. The remaining USGS network of 46 stations is focused on four areas of interest:

a) Yakatut Bay to Prince William Sound, centered on the Yakataga seismic gap.

b) Anchorage and the surrounding region of rapid growth and development.

c) The active Cook Inlet volcanoes-Iliamna, Redoubt and Spurr. Two of three stations near Mt. Spurr are funded by the State of Alaska as part of their geothermal program.

d) The region of the proposed Bradley Lake hydroelectric project on the Kenai Peninsula. This area is monitored by five stations with funds from the Army Corps of Engineers.

2. There are 42 strong motion instruments operated in Alaska by the USGS, including 13 between Icy Bay and Cordova in the area of the Yakataga seismic gap. Fourteen of these instruments are co-located with telemetered high-gain stations and are interconnected so that absolute time can be obtained on the strong motion record. Maintenance of the remaining instruments is shared between this project and the Seismic Engineering Branch.

3. Four Sprengnether DR-100 digital event recorders were deployed near Mt. Spurr volcano from August 8 to August 11, 1982 in an effort to learn more about the numerous nearby events that produce emergent low-frequency (2-4 Hz) signals. Due to inadequate weather protection, the instruments did not operate correctly and very few events are recorded on more than one instrument. It is still hoped, however, that analysis of the data obtained will provide some insight into the source of the local events.

Results

1. During the past six months, data processing has remained on schedule and preliminary earthquake locations have been obtained for March through August 1982 (Figure 1). Except for May, the monthly average of located events was 414. A total of 895 events were located for May due to a particularly energetic aftershock sequence following a shallow magnitude 5.1 (5.0 m_b, NEIS) shock that occurred May 2 near Icy Bay within the aftershock zone of the 1979 St. Elias earthquake. The aftershock activity from the May 2 earthquake continued for several days and was confined to an area with dimensions of about 5 by 10 km. On May 3, a magnitude 4.4 (5.0 m_b, NEIS) shock occurred southeast of the May 2 event, and initiated a less prominent aftershock sequence adjacent to but spatially distinct from the aftershock zone of the May 2 event. During June and July of 1980 a third sequence of activity occurred adjacent to the northeast boundary of the May 1982 activity within an area with dimensions less than about 10 km. These observations of non-overlapping aftershock zones with similar dimensions suggests that the spatial occurrence of these earthquakes is being controlled by asperities or fracture barriers with dimensions on the order of 5 to 10 km.

Other significant events which occurred during the past six months include a magnitude 4.5 (4.8 m_b, NEIS) shock 20 km east of Anchorage on May 5. This event was located at 43 km depth, which would place it within the Benioff Zone. The lack of any significant aftershock activity for this subcrustal event, in contrast to the prominent aftershock sequences observed for shallow events near Icy Bay, is consistent with the observations of Page (1968). This event was felt with MM intensity V at Anchorage and triggered ten strong motion recorders at seven sites (G. Brady, personal communication, 1982).

The regional pattern of seismicity for March through August 1982 is generally similar to that observed over the past few years. Except for the unusually high level of activity in the St. Elias aftershock zone during May, no significant changes were recognized in the spatial and temporal patterns of seismicity in and near the Yakataga seismic gap.

2. Earthquakes located within 100 km of Anchorage during 1972-82 were reviewed, utilizing local seismograph stations. The seismicity pattern is dominated by events within the Pacific plate that define a Benioff zone about 15 km thick dipping toward N. 75^{o} W. Below Anchorage the Benioff zone activity ranges in depth from 30 to 55 km. The dip of the Benioff zone increases smoothly from 5^{o} 100 km ESE. of Anchorage through 12^{o} below Anchorage, to 40^{o} 100 km to the WNW. Focal mechanisms were determined for nine Benioff zone events. These mechanisms can be divided into three types: two were thrust mechanisms compatible with underthrusting of the Pacific plate in a WNW. to NW. direction on a shallow-dipping plane; two had tension axes alined approximately downdip, and nearly horizontal pressure axes oriented NE.-SW.; and the remainder, which included the May 5 event, had nearly horizontal tension axes oriented E.-W. to SE.-NW. and steeply dipping pressure axes.

At depths between about 90 to 140 km the Benioff zone activity appears to define two parallel planes separated by about 12 km. This feature persists even for carefully selected and relocated events. It is not yet clear whether this structure represents a double Benioff zone, as reported for some other areas, or is fine structure within a single Benioff zone. Whereas double Benioff zones are characterized by a systematic variation in the orientation of focal mechanisms between the upper and lower zones, no clear evidence of this type has been found for the Benioff zone northwest of Anchorage.

Seismicity within the North American plate is generally limited to depths shallower than 20 km. The rate of shallow seismicity is approximately 15 times lower and the distribution is more scattered than within the Benioff zone. The pattern of shallow seismicity is dominated by: a diffuse NNE.-striking zone of events bounded approximately by upward projections of the 20- and 50-km depth contours of the upper surface of the Benioff zone; a band of activity along the volcanic axis; a cluster of events 50 km NE. of Mount Spurr; three clusters 90 km NNE. of Anchorage; and a cluster near the intersection of the Turnagain Arm with the Eagle River fault.

3. Continued study of shallow seismicity along the Cook Inlet volcanic axis from Mt. Spurr to Mt. Iliamna for the period October 1980 through May 1982 reveals that nearly all the shocks occur at depths between 5 and 20 km with two notable exceptions. First, most of the earthquakes located within 5 to 10 km of the active volcanoes--Spurr, Redoubt, and Iliamna have depths less than 5 km. Second, focal depths in a pronounced cluster of shocks about 15 km south of Spurr range from the surface to about 10 km. This concentration of activity lies in the vicinity of the proposed Chakachamna Hydroelectric Project and raises the possibility that faulting and highly fractured rock could be encountered in tunneling between Lake Chakachamna and the MacArthur River.

4. Five strong motion records were obtained for five different earthquakes that occurred near Icy Bay and Yakutat Bay, east of the Yakataga seismic gap, between September 1981 and August 1982. Preliminary results obtained from these records, all of which were triggered by S-wave motion, are summarized below:

Date	Origin Time (UT)	Magnitude M_{coda}	m_b(NEIS)	Depth (km)	Recording Station	Epicentral Distance (km)	Max. Horiz. Acc (g)
09/11/81	05:02	3.6	4.0	7	BCP	12	0.06
09/17/81	00:18	3.3	3.8	9	BCP	11	0.05
05/03/82	10:14	4.4	5.0	6	GYO	27	0.02
08/07/82	08:37	4.1	4.6	1	BCP	28	0.04
08/25/82	15:05	4.2	4.7	12	BCP	18	0.10

The four peak horizontal accelerations recorded at BCP are typical of values measured at comparable distances from other western U.S. earthquakes; whereas the one peak value from GYO lies more than one-standard deviation below the mean.

References

Page, R., 1968, Focal depths of aftershocks: Journal of Geophysical Research, v. 73, p. 3897-3903.

Reports

Fogleman, K. A., Stephens, C. D., Lahr, J. C., Rogers, J. A., Helton, S. M., Cancilla, R. S., Tam, R., Freiberg, J. A., and Melnick, J. P., 1982, Catalog of earthquakes in southern Alaska, April-June 1980, U. S. Geological Survey Open-File Report 82-___.

Fogleman, K. A., Stephens, C. D., Lahr, J. C., Rogers, J. A., Cancilla, R. S., Tam, R., Helton, S. M., Freiberg, J. A., and Melnick, J. P., 1982, Catalog of earthquakes in southern Alaska, July-September 1980, U. S. Geological Survey Open-File Report 82-___.

Lahr, J. C. and Stephens, C. D., 1982, Seismic activity in the vicinity of Anchorage, Alaska, 1972-1982 [abs.]: 33rd Alaska Science Conference, September 16 - 18, 1982, Fairbanks, Alaska.

Page, R. A., Waller, J. A., and Stephens, C. D., 1982, Recent seismicity around Spurr, Redoubt, and Iliamna volcanoes, southern Alaska [abs.]: American Association of Advancement of Science-Arctic Division, 33rd Alaska Science Conference, September 16-18, 1982, Fairbanks, Alaska.

Stephens, C. D., Lahr, J. C., and Page, R. A., 1982, Recent microseismicity along the eastern Gulf of Alaska and its relation to the Yakataga seismic gap [abs.]: 33rd Alaska Sciences Conference, September 16-18, 1982, Fairbanks, Alaska.

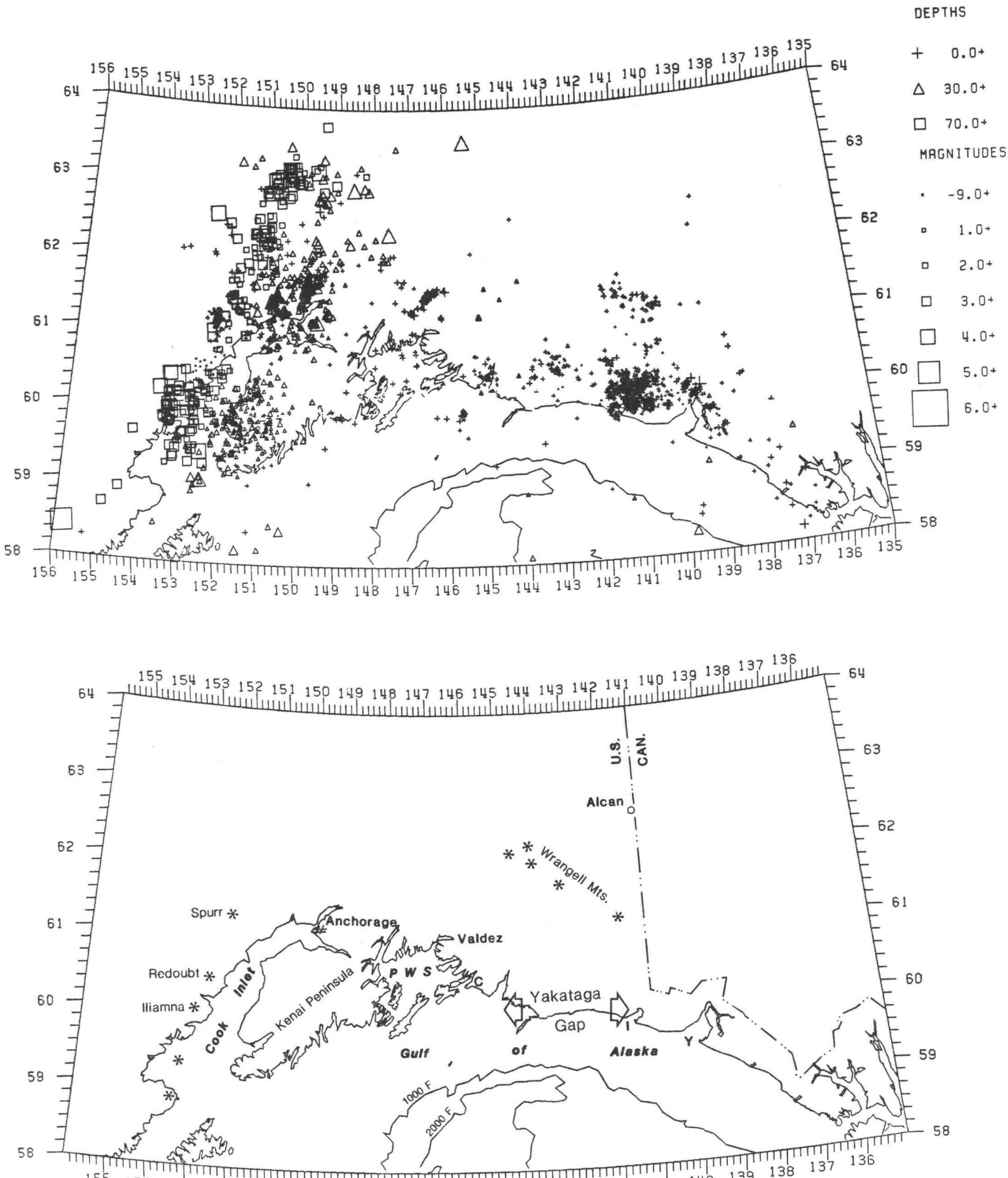

Figure 1 (*upper*) Seismicity in southern Alaska from March through August 1982, and (*lower*) location map for the same region. Abbreviations in lower map are: PWS--Prince William Sound; C--Cordova; I--Icy Bay; Y--Yakutat Bay.

Application of Private Site-Specific Data to Regional Evaluation of Earthquake and Faulting Potential in Southern California

Contract No. 14-08-0001-20513

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Investigations

Comprehensive reports evaluating seismic conditions at nuclear power (NP) plant sites, and engineering geology reports prepared to satisfy the Alquist-Priolo Special Studies Zones Act (AP) along major faults in southern California, are being reviewed; an annotated bibliography of these reports is in preparation. The AP reports are usually fairly brief and cover limited areas within individual fault zones, whereas the NP reports are more comprehensive and cover relatively large areas around individual sites and deal more with regional geology and tectonics. Detailed studies of seismic conditions extend to active features within 100 miles of the San Onofre and Diablo Canyon nuclear power plants and proposed Bolsa Island, San Joaquin, Sundesert and Vidal sites (Fig. 1). AP reports include detailed trench logs across the following active faults in southern California: San Andreas, San Jacinto, San Fernando, Newport-Inglewood, Whittier-Elsinore, Garlock and White Wolf (Fig. 1).

Results

An annotated bibliography of AP reports on file at Riverside County is complete; all reports on the Elsinore and San Jacinto faults have been reviewed. Figure 2 shows an example of reports listed in the bibliography. The reports are identified by county file number and, where available, by the California Division of Mines and Geology (CDMG) file number (Lo and Moreno, 1980); the date and title of the report, and name of geologist or consulting firm who prepared the report, are also given. The locations of areas studied are plotted on maps with the symbols shown on the left column of Figure 2; these symbols summarize the results of the investigation. A number "1" with an asterisk outside the circle means that physiographic evidence of faulting is present. The numbers inside the circle represent ages of earth materials exposed in the trenches: 1 - Holocene, <10,000 years old (recent alluvium); 2 - upper Pleistocene, 10,000 to 500,000 years old (older alluvium and alluvial terrace deposits); 3 - lower Pleistocene, 500,000 to 3,000,000 years old; 4 - pre-Pleistocene, >3,000,000 years old. For Riverside County report 45 (Fig. 2), the symbol indicates physiographic evidence of faulting (1*) and faulted older fan deposits (2) in the trench. The symbol for report 190-S indicates Holocene alluvium (1) faulted against Pauba Formation (2). The trenches for report 197 revealed faulted Temecula Formation (3) and possibly Pauba Formation (2?) overlain by unfaulted Holocene alluvium (1). The symbol for report 202 indicates no evidence of faulting in Holocene alluvium (1) across the fault and no older units penetrated by the test trenches. The trench for report 231 was located southwest of the fault in unfaulted bedrock (4).

The preparation of an annotated bibliography of reports for the selected six nuclear power plant sites has proceeded in two phases: (1) Locating documents for each site, identifying and listing reports and maps, and establishing a priority of reports to summarize. (2) Summarizing each report and copying particularly relevant and informative maps. The number of reports varies from about 20 to 50 for each NP site; the reports describe the regional and site stratigraphy and structure, seismic history, foundation conditions and ground-motion characteristics. Phase 1 has been completed for all sites. Phase 2 is about half finished on the Diablo Canyon and San Onofre sites and will begin shortly on the remaining sites. A third and fourth phase will proceed more or less concurrently with Phase 2 and will consist, respectively, of preparation of index maps for each site and a brief description of the salient tectonic aspects of each site.

References

CDMG (1980c,d,e,g) State of California Special Studies Zones 7½ minute quadrangles: c - Corona South; d - Murrieta; e - Alberhill; g - Lake Mathews.

Envicom, 1976, Riverside County Seismic Safety Element.

Hart, E. W., 1980, Fault-rupture hazard zones in California: Calif. Div. Mines and Geol., Spec. Publ. 42, 25 p.

Kennedy, M. P., 1977, Recency and character of faulting along the Elsinore fault zone in southern Riverside County, California: Calif. Div. Mines and Geol., Spec. Report 131, 12 p.

Lo, W. Y. C. and J. G. Moreno, 1980, State of California index to geologic reports for sites within Special Studies Zones: Calif. Div. Mines and Geol., Open-File Report No. OFR 77-6SF, revised August 1980.

Weber, F. H., Jr., 1977, Seismic hazards related to geologic factors, Elsinore and Chino fault zones, northwestern Riverside County, California: Calif. Div. Mines and Geol., Open-File Report No. 77-4LA, 96 p.

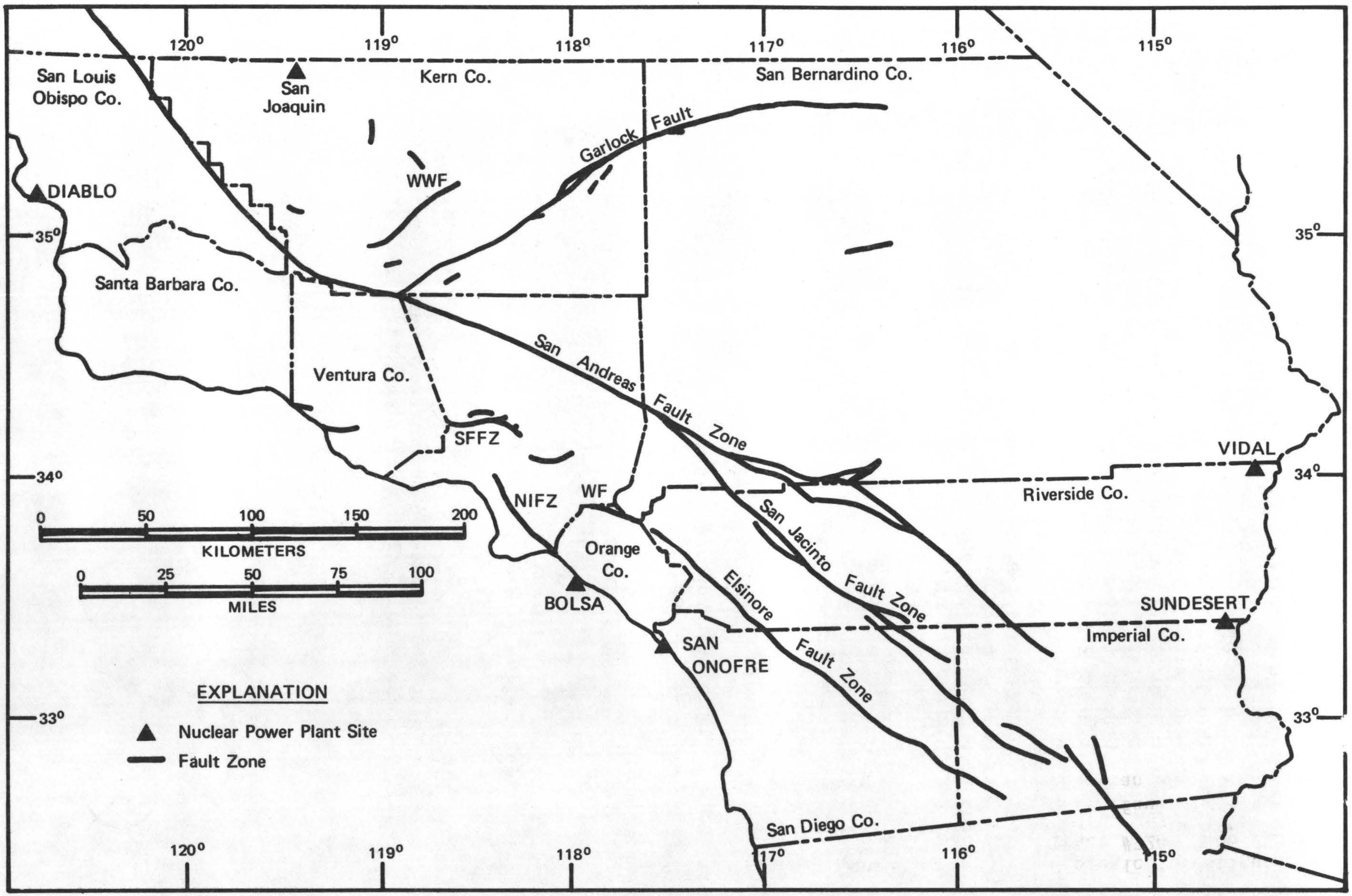


Fig. 1 - Map of southern California showing principal faults covered by Alquist-Priolo Special Studies Zones (Hart, 1980) and nuclear power plant sites. Abbreviations: NIFZ - Newport-Inglewood fault zone; SFFZ - San Fernando fault zone; WF - Whittier fault; WWF - White Wolf fault.

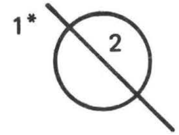
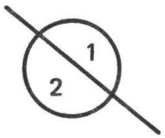
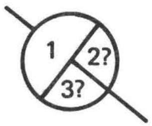
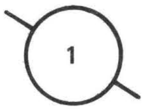
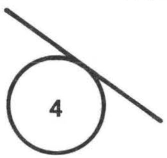
County (City) of Jurisdiction	County (City) File Number	CDMG AP File Number	7½ Minute Quadrangle(s)	Date of Report(s) (Mo/da/yr)	Investigating Firm or Geologist	Title of Report
Riverside	45		Corona South, Lake Mathews	2/13/76	Pioneer Consultants	Geologic investigation, Tract #7240, Job #2316-001
			Trenches to a depth of 12 feet across strands of Glen Ivy North fault (Weber, 1977; CDMG, 1980cg). Fault gouge and slickensides reported in older fan deposits (Qof, Weber, 1977). "Rift valley" (30 ft deep, 100 ft wide); water line in vicinity of Hunt Road requires annual repair; may be caused by continuous creep; parallel cracks in asphalt of Lawson Road.			
Riverside	190-S		Murrieta	3/7/78	F. Beach Leighton and Associates	Geologic seismic investigation, Tract #3587 and property southwest of intersection of Rancho California and Ynez Roads, Job #678043-01
			Trenches, 5-8 feet deep, across Wildomar fault (Kennedy, 1977; CDMG, 1980d). Alluvium faulted against Pauba Formation (Qal and Qps, Kennedy, 1977).			
Riverside	197		Murrieta	12/14/79	James P. McGoldrick, Con. Eng.	Geologic and seismic investigation, PM #13648, Murrieta, CA
			Seven trenches, maximum depth 15 feet, northeast and across Wildomar fault (Kennedy, 1977; CDMG, 1980d). Trench 1: well-developed, iron-stained reverse fault plane offsetting Temecula (?) and possibly Pauba (?) Formations (Qt and Qp, Kennedy, 1977). No faulting in overlying alluvium (Qal, Kennedy, 1977).			
Riverside	202	1232	Murrieta	1/19/79	Pioneer Consultants	Geotechnical evaluation, PM #14933, Job #1208-156,157,158,159
			Two trenches, 12-15 feet deep, across strands of Willard fault (Envicom, 1976). No faulting in alluvium (Qal, Kennedy, 1977).			
Riverside	231		Alberhill	11/80	Richard D. Merker	A geological fault location survey (on tentative PM 16615 and including portion of tentative PM 15778)
			"Shallow trench" southwest of Glen Ivy North fault (Weber, 1977; CDMG, 1980e). No fault in extremely deformed and gouged metamorphosed shale bedrock (Jb, Weber, 1977).			

Fig. 2 - Examples of entries in annotated bibliography of engineering geology reports prepared to satisfy Alquist-Priolo Special Studies Zones Act in Riverside County. See text for explanation of symbols on left used to summarize results of investigation.

Applications of Mathematical Modeling

9540-03301

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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 of selected parts of California and adjacent states.

2. Accelerated our investigations of the historic deformational history of southwestern Arizona and southeastern California in order to better define the boundary between tectonic activity and inactivity recognized in the late Quaternary geologic record.

3. Continued our studies of the magnitude of the residual refraction error in geodetic leveling. These studies are based on an examination of the existing geodetic record and designed to systematically search for correlations between those parameters that are thought to control the accumalation of this error and apparent tilt.

Results

1. Presented two unscheduled papers at the International Association of Geodesy meeting in Tokyo showing: (1) that even in the absence of any leveling along the supposedly refraction-prone survey route between Sangus and Palmdale our reconstuction of the southern California uplifts would remain virtually unchanged; and (2) that the so-called Sangus-Palmdale field experiment is contaminated by error(s) unrelated to refractions, and, hence, that the results of this experiment provide a questionable basis for either modeling or confirming models of unequal refraction error.

Reports

Castle, R. O., and Elliott, M. R., 1982, The sea slope problem revisited: Journal of Geophpical Research, v. 87, p. 6989-7024.

Gilmore, T. D., and Castle, R. O., A proposed tectonic contribution to the preservation of the divide between the Salton basin and the Gulf of California: (approved by Director; submitted to Geology).

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 currently is on: (a) generation of liquefaction susceptibility and liquefaction opportunity maps; and (b) the three-dimensional distribution of the valley fill and its lithologic, lithofacies, and pedogenic character.

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) identification of Quaternary units to establish Quaternary depositional patterns and the relative ages of fault displacement along fault strands within the Banning Fault system; and (c) interpreting inter-relationships between the Banning Fault system and the South Branch of the San Andreas Fault.

Results

1. Our regional study of seismic ground response has focused on the acquisition of subsurface geologic data. For six weeks in July and August, 1982, Scott E. Carson and Curtis M. Obi visited municipal and county agencies in the upper Santa Ana River Valley area to compile geotechnical data for the shallow subsurface that are available in the public domain. These data consist chiefly of lithologic logs, shear-strength determinations, and grain-size data derived from test borings and shallow excavations prepared by engineering and geoscience consultants during foundation investigations that are required for building permits and subdivision applications. Additional subsurface data were obtained from the California Department of Transportation, from the San Bernardino County Flood Control District, and from the U.S. Army Corps of Engineers.

The data pool derived from these sources consists of over 3,000 geotechnical site investigations from throughout the upper Santa Ana River Valley region. The locations of these sites are being plotted on 1:48,000-scale base-stable maps. We presently are evaluating the quality, consistency, and suitability of these geotechnical data for their applicability to ground-response studies and to studies of Quaternary stratigraphy. Although the data are variable in quality, we are optimistic about their potential application to our ongoing regional evaluation of liquefaction potential. For larger commercial properties, geotechnical data usually extend 40 to 60 ft subsurface, and usually include standard penetrometer data. For smaller commercial properties and for subdivisions, test borings and excavations range from 12 to 40 ft subsurface, and occasionally include standard penetrometer data. Geotechnical data obtained from Caltrans, San Bernardino County Flood Control District, and the U. S. Army Corps of Engineers extend as deep as 100 ft subsurface, and include standard penetrometer data and (or) other types of penetrometer-resistance data.

Preliminary evaluation suggests that some subsurface data are too generalized or too shallow to be of much value for evaluation of liquefaction potential. However, many of the site investigations have produced lithologic data, grain-size data, and penetrometer data that can be correlated between local sites and that can be related to the stratigraphy we have observed in natural exposures and road cuts.

Areas in the upper Santa Ana River valley area that are underlain by young alluvial deposits and that have ground water shallower than 50 ft below land surface (Carson and Matti, 1982) are areas that are most susceptible to liquefaction-related ground failure. Fortunately, these areas have a high density of geotechnical site investigations. When these geotechnical data are integrated with our unpublished mapping of Quaternary surficical materials and with data derived from our in-house drilling program planned for FY 1983, we will be able to provide a regional evaluation of liquefaction potential comparable to the evaluation provided for the San Fernando Valley by Youd, Tinsley, and Perkins (1978).

2. We are continuing our neotectonic studies of the Banning fault zone in San Gorgonio Pass, where Leslie D. McFadden, Jonathan C. Matti, and John C. Tinsley have conducted reconnaissance studies of pedogenic soils developed on alluvial terraces that are cut by thrust- and reverse-fault strands of the Banning-B fault system. Two ideas are evolving from these tectonic and pedogenic studies: (1) As with Quaternary faulting within the Cucamonga fault zone, reverse and thrust faulting on the Banning-B system has recurred intermittently throughout late Quaternary time as evidenced by progressively higher fault scarps in progressively older alluvial deposits. We are working toward an estimate of faulting recurrence on the Banning-B system. (2) North of San Gorgonio Pass, from Beaumont on the west to Cabazon on the east, foothills of the San Bernardino Mountains that are underlain by crystalline rocks and by Tertiary sedimentary rocks form a dissected ramp-like surface that has rolling hill-and-valley geomorphology. This dissected lowland surface rises gradually northward to the main physiographic mass of the high San Bernardino Mountains. Throughout much of its extent, the dissected lowland surface is covered by relict Pleistocene alluvial-fan deposits that have soil profiles containing well-developed argillic-B horizons. We interpret the ramp-like surface as a former piedmont foreland for the main physiographic mass of the San Bernardino Mountains. During early Pleistocene time, this piedmont foreland locally was buried by aggrading alluvial fans that headed to the north in the rising San Bernardino Mountains. During late Pleistocene and Holocene time, the former piedmont foreland has become coupled tectonically to the main San Bernardino Mountains as a result of reverse and thrust faulting along strands of the Banning-B system. Uplift of the former piedmont foreland along these reverse and thrust faults has led to dissection of the piedmont and to its incorporation within the high San Bernardino Mountains. Ongoing neotectonic, pedogenic, and geomorphic studies in the southeastern San Bernardino Mountains and in San Gorgonio Pass will clarify

the timing and origin of Quaternary Transverse-Range type tectonism on the Banning-B system, and will clarify the relationship between reverse and thrust faulting on this system and right-lateral faulting on the South Branch of the San Andreas fault.

Reports

Carson, Scott E., and Matti, Jonathan C., 1982, Contour map of minimum depth of Ground Water, upper Santa Ana River Valley, California, 1973-1979: U.S Geological Survey Open-file Report 82-1128.

McFadden, Leslie D., Matti, Jonathan C., and Tinsley, John C., Implications of soil-geomorphic studies for latest Cenozoic landscape development in the San Bernardino Mountains, Southern California: 1983 Proceedings of the American Association of Geographers, Annual Meeting, Denver, Colorado. Submitted 9/30/82.

Seismicity and Earthquake Source Properties in the Yakataga Seismic Gap, Alaska

9940-03005

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Investigations

1. M. C. Astrue continued effort to fill gaps in the existing data base for earthquakes in and around the Yakataga seismic gap recorded by the USGS southern Alaska regional seismograph network prior to the February 1979 St. Elias earthquake.

2. In cooperation with George Zandt at the University of Utah, J. R. Pelton continued investigation of crust and upper mantle velocity structure beneath southern coastal Alaska by inverting arrival times of teleseismic P-waves recorded by the southern Alaska network.

3. J. R. Pelton began estimating the focal depths of moderate-sized earthquakes in and around the Yakataga gap by modeling long-period teleseismic P-waveforms.

4. R. A. Page, M. H. Hassler and C. D. Stephens precisely delineated the spatial distribution of aftershocks occurring near the center of the aftershock zone of the 1979 St. Elias earthquake on the eastern edge of the Yakataga gap.

Results

1. Earthquakes from November and early December 1976 were scaled and located using the four-film digitizing table and interactive microcomputer. The quarterly earthquake catalog for April-June 1978 was distributed. Completion of the catalog for July-September 1978 was delayed by having to move computer programs from one computer to another. Shocks from early December 1976 through September 1977 remain to be located to complete the microearthquake record in the seismic gap area for the interval from the installation of the regional network in 1974 through the 1979 St. Elias earthquake.

An operator's manual for the four-film digitizing system has been prepared for publication as an open-file report.

2. P-wave travel times were measured for 53 teleseisms recorded by the USGS southern Alaska seismograph network, extending from Yakutat Bay in the east to the Cook Inlet volcanoes in the west. A total of 1570 residuals were calculated and inverted for a block model of 3-D velocity structure.

In the crustal layer (0-40 km) large negative velocity (slow) anomalies coincide with the Cook Inlet lowlands, and the Gulf of Alaska Tertiary province from Kayak Island to Icy Bay. Positive (fast) anomalies mark the Cook Inlet volcanic chain, the SE half of Kenai Peninsula, Prince William Sound, and the Yakutat Bay region. These velocity variations appear to reflect changes in crustal composition.

In the upper mantle (3 layers from 40-440 km), west of about 147^{o}W longitude, velocity anomalies define linear features that persist to the bottom of the model. The velocity anomalies have a NE-SW trend that changes farther north to a N-S grain and can be related to the subduction of the Pacific Plate. East of this line, the upper mantle is relatively homogeneous indicating that if the Pacific Plate is subducting beneath this area, as some have proposed, then the plate does not penetrate deeply into the upper mantle; however, the presence of low-velocity pockets (40-140 km deep) beneath the Wrangell Mountains and the Yakutat Bay area might be indicative of some sort of convective instability related to past or present subduction.

3. Modeling of long-period far-field P-waveforms from seven earthquakes ($5.8 \leq m_b \leq 6.5$) in south-central and southeastern coastal Alaska was carried out using the procedure of Kanamori and Stewart (<u>Physics of the Earth and Planetary Interiors</u>, 11, 312-313, 1976). This procedure assumes a point double-couple source with a trapezoidal moment rate function, and includes the effects of the direct P, pP, and sP phases. Data available for each earthquake included the fault plane solution (various authors) and the ISC epicenter and focal depth. Preliminary results indicate: (1) focal depth is the most signficant factor in determining the position of peaks and troughs in the first 40 seconds of the long-period P-waveform, but trapezoidal rise time is also a factor; (2) waveforms to be modeled should be chosen from stations located away from the nodal planes of the radiation pattern on the focal sphere; (3) focal depths necessary to achieve optimum waveform fits (by eye) are in many cases different from the published ISC focal depths. The preliminary data set of seven earthquakes is not sufficient to bring out any systematic regional differences between ISC focal depths and those deduced from waveform modeling. In general, the waveform focal depths, which are for larger earthquakes between 1964 and 1973, appear to be consistent with depths of recent small earthquakes determined from local data recorded by the regional seismograph network. Future plans include modeling of additional earthquakes from coastal Alaska, and possible development of "characteristic" P-waveforms for different regions and focal depths that could be used routinely for estimating precise depths by visual inspection of long-period seismograms of southern Alaskan earthquakes.

4. Tectonic models proposed for the region of the Yakataga seismic gap are very general, relating the dominant thrusting inferred from fault plane solutions for large earthquakes to large-scale plate motions. Because of limitations in the available data, existing tectonic models lack details. For example, distances between adjacent stations in the regional seismograph network are typically 30-50 km, and thus routinely located hypocenters do not afford the resolution needed to delineate the shallow thrust faults along which much of the deformation in the region is assumed to occur.

To obtain precise information on the geometry of faulting the gap region, a unique set of aftershock data from the St. Elias earthquake (M_s 7.1) of

February 1979 have been analyzed. A few months after the main shock, a temporary array (dimensions 4-7 km) of four three-component seismographs was deployed near the center of the St. Elias aftershock zone. Hypocenters have been determined for about 70 shocks recorded between July 26 and August 15 by both the temporary array and the regional seismograph network. All well-located aftershocks occurring within a 24-km diameter circle centered on the array at 60°13'N, 140°52'W lie in the depth range 10-15 km. Within the resoultion of the data, the hypocenters define a single horizontal or gently dipping (less than 5°) planar zone less than 1 or 2 km thick, which is inferred to be the principal surface on which slip occurred during the main shock. Possible error in the velocity model used in locating the shocks probably introduces no more than 1 or 2 km of bias in the calculated depths.

Observations of travel times from shocks within the temporary array to surrounding stations of the regional network indicate the presence of a major lateral variation in crustal velocity in the Icy Bay-St. Elias region. Over the distance range 75-150 km, travel times are significantlly less to stations on the Yakutat block to the southeast than to stations to the west and northwest. This finding is consistent with the results from the 3-D velocity inversion of teleseismic travel times reported above in item 2.

Reports

Page, R. A., Hassler, M. H., Stephens, C. D., and Criley, E. E., 1982, Focal depths of aftershocks of the St. Elias, Alaska, earthquake [abs.]: EOS, Transactions, American Geophysical Union, v. 63, in press.

Pelton, J. R., and Page, R. A., 1982, Focal depth estimates from long-period P-waveform modeling of selected Alaskan teleseisms [abs.]: EOS, Transactions, American Geophysical Union, v. 63, in press.

Zandt, G., and Pelton, J. R., 1982, Three-dimensional crust-upper mantle velocity structure of southern Alaska [abs.]: EOS, Transactions, American Geophysical Union, v. 63, in press.

Geologic Earthquake Hazards in Alaska
9310-01026

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Investigations

The long-term goal of this project is to study and evaluate risk in Alaska from tectonic displacements, seismic shaking, and secondary geologic effects.

1. An evaluation was made of the tectonic deformation related to the 1899 Yakutat Bay earthquakes as well as the earthquake recurrence interval in Yakutat Bay (with Wayne Thatcher and Meyer Rubin).

2. Continued study of the extent and nature of pre-1964 earthquake vertical tectonic movements in the area of coseismic uplift within Prince William Sound and eastward to Kayak Island (with Meyer Rubin).

3. Working on the neotectonic map of Alaska and active fault data file (with Susan Hunt).

Results

1. Geologic studies in the Yakutat Bay region indicate that (a) the emergent shorelines along Yakutat Bay define a broad upwarp roughly 50 km by 30 km that is primarily related to slip on both the east-west-trending Esker Creek thrust fault and the concealed northwest-trending Yakutat Bay thrust fault; (b) there was no significant tectonic submergence of shorelines; (c) the apparent interval since the last comparable uplift event, as determined by radiocarbon dating of shells from a terrace deposit, is 380±70 years; (d) assuming average relative plate motion of about 6 cm/yr, net slip in 1899 was on the order of 22.8 m ± 4.2 m at 350° azimuth. These data, together with seismic moment data, suggest that deformation at Yakutat Bay in 1899 was mainly related to slip on faults having approximately the following parameters:

Fault	Strike	Dip	Total Slip	Dip Slip	Vertical Slip
Esker Ck.	90°	40° N.	22.8 m	22.5 m	15.0 m
Yakutat Bay	320°	30° NE.	22.8 m	11.0 m	5.5 m

2. In the region affected by coseismic uplift during the 1964 Alaska earthquake, there is clear evidence of widespread, gradual pre-seismic submergence of shorelines. Previously available radiocarbon dates from drowned shorelines indicated that in the Prince William Sound region tectonic submergence prevailed for at least 930 years prior to the 1964 earthquake (Plafker, 1969, p. I57, I60-I62). New data, from the area of maximum 1964 uplift, indicate that the duration of pre-seismic submergence at Montague Island in Prince William Sound was at least 1140±70 years with an average submergence rate close to 6 mm/yr (fig. 1). Data on pre-seismic submergence

provide independent support for the conclusion, based on dating of marine terraces at Middleton Island, that the last earthquake that involved tectonic deformation comparable to the 1964 event occurred approximately 1350±200 years ago (Plafker and Rubin, 1978).

3. Work on the active fault data file for Alaska approximately 70 percent complete and the neotectonic map is 50 percent complete.

References Cited

Plafker, George, 1969, Tectonics of the March 27, 1964 Alaska earthquake: U.S. Geological Survey Professional Paper 543-I, 74 p.

Plafker, George, and Rubin, Meyer, 1978, Uplift history and earthquake recurrence as deduced from marine terraces on Middleton Island, Alaska, in Proceedings of Conference VI, Methodology for identifying seismic gaps and soon-to-break gaps: U.S. Geological Survey Open-File Report 78-943, p. 687-721.

Reports

Decker, John, and Plafker, George, 1981, Correlation of rocks in the Tarr Inlet suture zone with the Kelp Bay Group, in Coonrad, W. L., U.S. Geological Survey in Alaska: Accomplishments during 1980: U.S. Geological Survey Circular 844, p. 119-123.

Hudson, Travis, Dixon, Kirk, and Plafker, George, 1981, Regional uplift in southeastern Alaska, in Coonrad, W. L., ed., The United States Geological Survey in Alaska: Accomplishments during 1980: U.S. Geological Survey Circular 844, p. 132-135.

Hudson, Travis, Plafker, George, and Dixon, Kirk, 1981, Horizontal offset history of the Chatham Strait fault, in Coonrad, W. L., ed., The United States Geological Survey in Alaska: Accomplishments during 1980: U.S. Geological Survey Circular 844, p. 128-132.

Plafker, George, and Bruns, T. R., 1982, Late Cenozoic subduction--rather than accretion--at the eastern end of the Aleutian arc: Geological Society of America, Abstracts with programs, v. 14, no. 7, p. 569.

Plafker, George, Bruns, T. R., Winkler, G. R., and Tysdal, R. G., 1982, Cross section of the eastern Aleutian arc, from Mount Spurr to the Aleutian Trench near Middleton Island, Alaska: Geological Society of America Map and Chart Series MC-28P.

Plafker, George, Hudson, Travis, Rubin, Meyer, and Dixon, K. L., 1981, Holocene marine terraces and uplift history in the Yakataga seismic gap near Icy Cape, Alaska, in Coonrad, W. L., ed., The United States Geological Survey in Alaska: Accomplishments during 1980: U.S. Geological Survey Circular 844, p. 111-115.

Rubin, Meyer, Plafker, George, and Hudson, Travis, 1982, Earthquake recurrence intervals from radiocarbon dating of marine terraces in the Yakataga seismic gap area, Alaska [Abs.]: Proc. of the 11th International Radiocarbon Conference, June 1982, Seattle, Washington, p. 51.

Seismic Zonation Studies in Los Angeles

9940-01730

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Investigations

1) Clustering of stations based on their geologic parameters.

2) Computation of mean site response in 3 period bands for each cluster.

3) Construction of mean site response maps in 3 period bands for 2 test regions in Los Angeles Basin.

4) Preparation of manuscript for professional paper on Los Angeles Basin entitled "Prediction of Site Response Employing Geologic Site Parameters in Three Period Bands of Engineering Significance."

In an effort to improve understanding of the controlling factors in site response, we reduced the site transfer functions to a manageable set of numbers by computing mean site transfer functions over ten period bands. A large body of geotechnical data describing site conditions underlying each station was also assembled. Data were chosen that have either been reported to have some relation to site response in the past or that, on the basis of simple physical models, are expected to control shear velocity and the resonance characteristics in the site transfer function. Thus, parameters such as % silt-clay, % saturation, and depth-to-water table have been reported previously to influence site response, while shear velocity (or void ratio which strongly influences shear modulus), Holocene thickness, Quaternary thickness, and depth-to-cementation are all parameters that might be used directly in a theoretical model to compute a site transfer function. Most of these kinds of data are obtainable from geologic maps, well logs, and city files containing engineering boreholes for construction projects. The data, therefore, would be of great value if quantifiably related to site response.

In developing an empirical method a great deal of experimentation was conducted using cluster analysis and discriminate analysis of cluster trials to try and identify groups of sites whose geologic properties are most nearly alike. Although these methods are not strictly applicable to data in which the functional relationships between dependent and independent variable is non-linear, such as with these data, it is possible to approximately linearize the problem by codefying some variables with properly choosen cluster parameter break points. The clustering variables chosen are those having the largest influence on response in a given period band, and the break points chosen for a given variable are the result of examination of the physical dependencies between response and geology. Once a set of clusters is formed, the mean response for each generic site type in the various period bands can be computed.

Figure 1 shows a plot of short-period cluster number at the bottom with median cluster properties, their ranges, and 90% confidence intervals plotted vertically above each cluster number. For example, cluster 4A includes sites with depth to basement greater than 0.5 km, Holocene thickness greater than 20 m, void ratios averaging 0.67, and short period response of about 3.6. Note that mean response, the top scale in the figure, varies from factors of 1 for the crystalline rock cluster to about 2 for the lowest alluvium cluster to 6.5 for the highest alluvium cluster. The figure shows that we settled on two clusters for rock and 8 clusters for alluvium. This result is a compromise between the many clusters that would be required to preserve all the complexity in the STF's as a function of geology, and the requirement that enough data reside in each cluster to estimate its mean response. However, even with only ten clusters, as shown, a useful result is obtained. That is, if we consider a factor of 2 in mean spectral level to approximately equal one MM intensity unit increment, then these clusters predict the true site response to within a fraction of one MM intensity unit 90% of the time. The response predicted by these clusters also preserve the important features of the physics of the problem. For instance, as void ratio increases from 0.5 to 0.65 to 0.8, mean response increases in rough proportion. Or for the same void ratio increasing the Holocene thickness to the critical value (see the last semi-annual report) increases response. Cluster 2A has a significantly higher response than 1A because 2A contains sites that are essentially thin alluvium sites overlying crystalline rather than sedimentary rock, and the resulting large velocity contrast induces large amplitudes.

For the long-period data (figure 2) 3 rock clusters and 8 alluvium clusters were used. The principal feature of this figure is that as depth to basement and Quaternary thickness increase the long-period response increases from about 1 to 5. Notice that as DTB increases beyond 6 km the long-period response begins to decrease. This effect is likely due to material attenuation in both the alluvium section and the sedimentary rock section. The effect is predicted for SH body waves by the theoretical results, which are not shown here.

These results were used to construct the three response maps shown in figure 3. The long-period map (figure 3) shows low response characterizes areas underlain by rock and thin alluvial deposits and highest levels of response in areas where the basin depth ranges between 4 and 6 km. Slightly lower levels of response are observed in the deepest parts of the basin (10 km). Geographically, the lowest response is in the Santa Monica Mountains and Verdugo Mountain areas. Response increases to the northwest (San Fernando Valley) and South (La Basin). In the southwestern part of the map, the response is relatively low where basement is about 3 km subsurface along the Newport-Inglewood structural zone. The short-period response map (figure 3) was prepared from a series of overlays on which each geologic parameter was delineated. The area illustrated is the central third of the area shown in the long-period response map. The map strongly resembles a surficial geologic map: the lowest response occurs in areas underlain by crystalline and sedimentary rock, and the highest response in regions where thickness of Holocene sediments are critical (11-20 m) and where void ratio values are high.

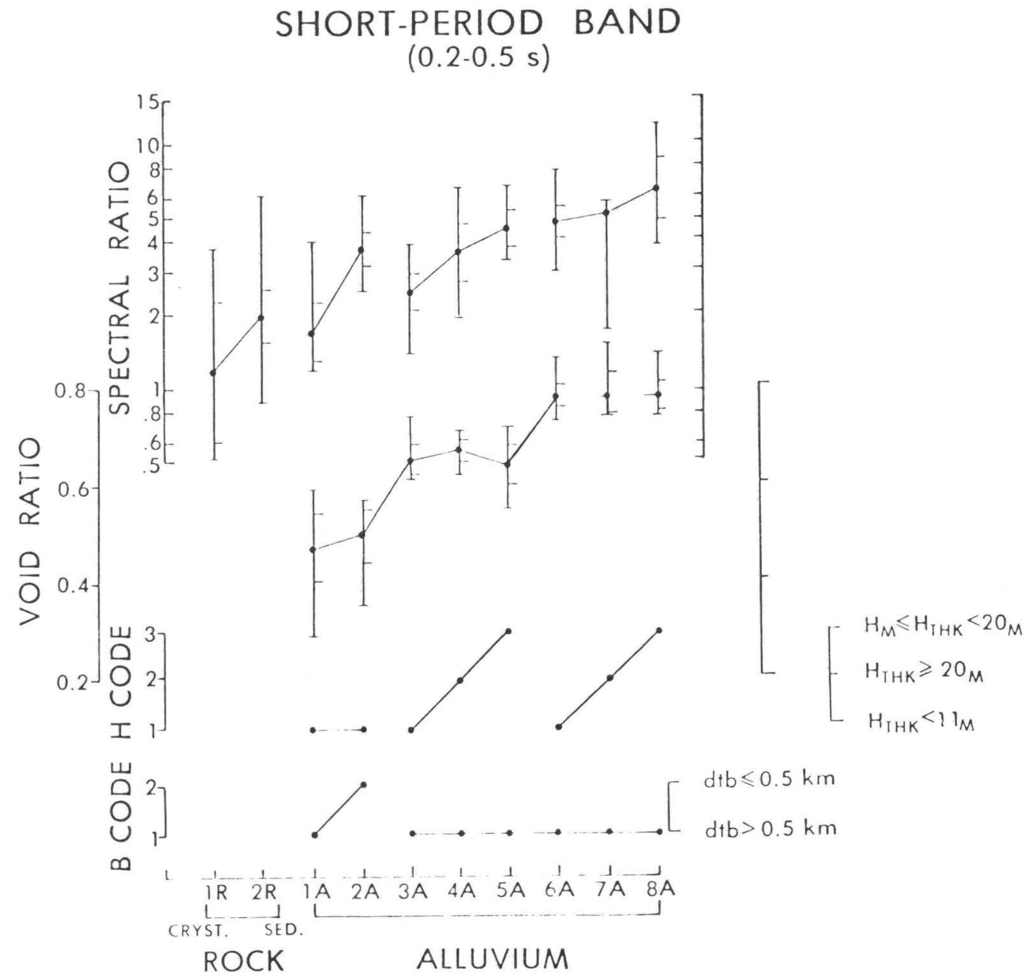

FIGURE 1.--Short-period clusters 1R thru 3A. The vertical bars indicate the variable range, the side tics indicate the 90% confidence intervals on each variable, and the solid dots indicate the median value of each variable.

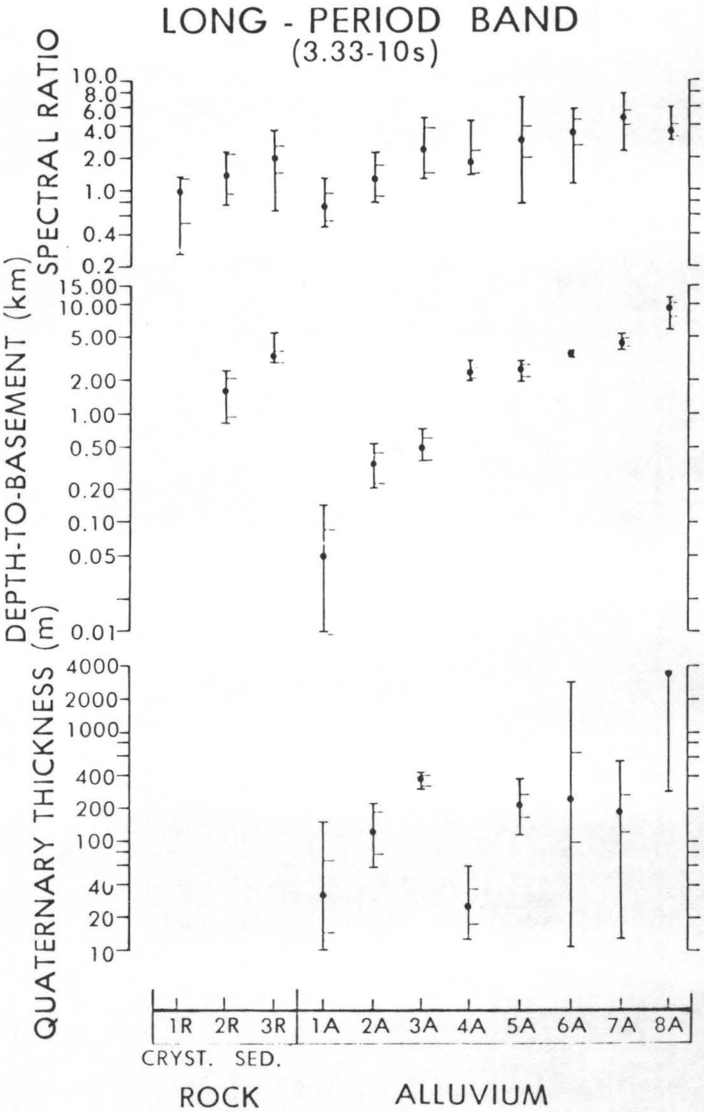

FIGURE 2.--Long-period clusters 1R thru 8A. The vertical bars indicate the variable range, the side tics indicate the 90% confidence intervals on each variable, and the solid dots indicate the median value of each variable.

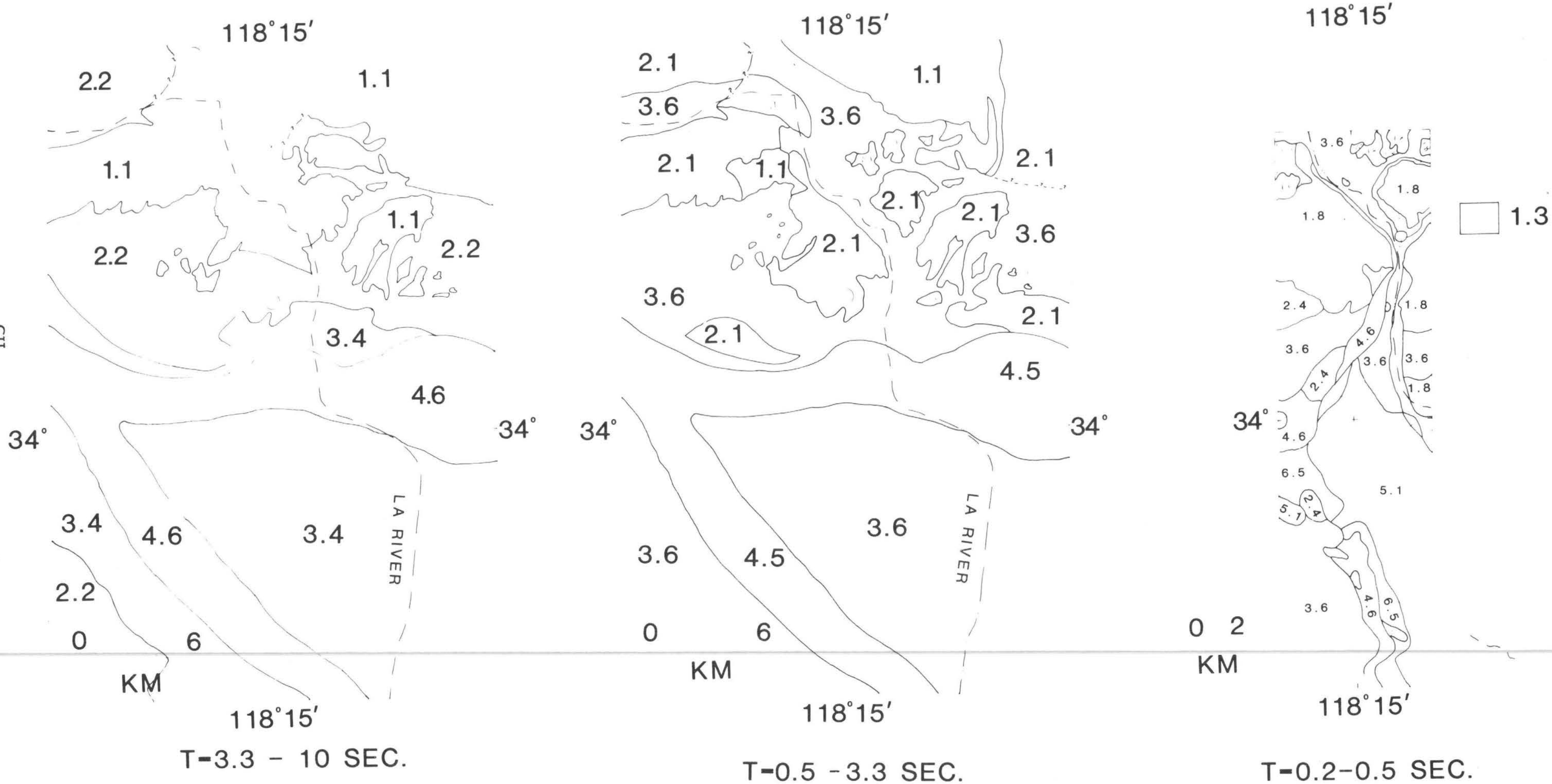

FIGURE 3.--Preliminary response maps in three period bands based on geologic data and the mean cluster response. The short-period, intermediate-period, and long-period maps are 0.2-0.5s, 0.5-3.3s, and 3.3-10s, respectively.

Earthquake Research in the Western Great Basin

Contracts 14-08-0001-17237 and 14-08-0001-21248

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Investigations

This project supports continued operation of a seismic network in the western Great Basin, and research to: (1) refine earthquake hazard assessment along the Sierra Nevada frontal fault zone; (2) complete a comprehensive investigation of premonitory seismicity patterns preceding the 1980 Mammoth Lakes earthquakes; (3) study seismicity associated with possible magma injection in Long Valley caldera during the recent Mammoth Lakes earthquake sequence; (4) analyze stress changes associated with observed systematic changes in focal mechanism with depth in the Great Basin; (5) evaluate the contribution that high-quality digital broadband seismic stations can make to improve research in the western Great Basin.

Results

1. Mammoth Lakes Sequence

Intensive microearthquake swarms that have the appearance of spasmodic tremor have been observed in the southwest part of Long Valley caldera, near Mammoth Lakes, California. This type of activity, possibly associated with magma injection, began six weeks after the occurrence, on 25-27 May 1980, of four ML 6+ earthquakes, and has continued sporadically to the present time. On 25 May 1982, the U. S. Geological Survey issued a Notice of Potential Volcanic Hazard for eastern California, citing uplift of the resurgent dome, observation of spasmodic tremor at a site near Mammoth Lakes, movement of earthquakes toward the surface at the same site, and formation of new fumaroles as reasons for issuing the Notice. To date, at least eight bursts of spasmodic tremor have been observed, the last occurring on 7-8 May 1982. Over the last two years, events in the swarm area have moved progressively to the north; depth of the activity has also changed, but not in a strictly progressive sense: minimum depth for events in the swarm area prior to 1981 was 7 km, while numerous events have had depth less than 5 km since then. In the most recent swarm on 7-8 May 1982, many events had relatively low-frequency P- and S-waves that were too emergent for analysis -- characteristics of the so-called "B-type" earthquakes in volcanic regions. In recent months the level of seismic activity in the Mammoth Lakes area has gradually decreased, and swarms with the appearance of spasmodic tremor have not been observed for seven months at the time of this writing.

The Mammoth Lakes earthquake sequence and associated volcanic activity are part of a broader increase in tectonic activity in a 15,000-sq. km. region surrounding the "White Mountains Seismic Gap," the area between the north end of the 1872 Owens Valley rupture zone and the south end of the

1932 Cedar Mountains zone. Since 4 October 1978, 47 earthquakes with ML 4.0-5.3 have occurred in the following zones: NE-trending zone between Mono Lake, California and Luning, Nevada; NE side of Fish Lake Valley, Nevada; and in the area around Bishop, California. Another 104 shocks with ML 4.0-6.3 have occurred in the Mammoth Lakes area. In comparison, only 19 events with ML 4.0 or greater were observed in this region during the previous nine years. Taken together with the observation of a two-year period of quiescence and an eight-year period of reduced b-value for this region, the relatively high level of seismicity from 1978 to the present indicates that the potential for a major earthquake in the White Mountains Gap may be relatively high.

2. Change in Focal Mechanisms with Depth

Focal mechanisms for 130 earthquakes in western Nevada and the eastern Sierra Nevada indicate a systematic change, from strike-slip movement for shallow events to oblique and normal slip for deeper events. The change in mechanism begins at depth of about 6 km, while normal faulting is found only for earthquakes deeper than about 9 km. The change in mechanism may be related to increasing overburden pressure with depth, resulting in rotation of the maximum compressive stress (P-axis) from horizontal at shallow depth to vertical at larger depth. Based on published stress measurements at shallow depth in the crust, together with our observation of different focal mechanisms at 5 and 10 km, we made a rough estimate of the individual principal stresses at both depths. Assuming hydrostatic pressure to depth of at least 10 km, we calculate the minimum, intermediate and maximum compressive stresses at 5 km to be about 750-1,000, 1,300 and 1,750-2,000 bars, respectively; at 10 km depth the minimum and maximum stresses are estimated at about 1,300 and 2,700 bars.

The systematic change in mechanism with depth may also explain discrepant mechanisms reported by different workers for strong earthquakes of the Mammoth Lakes series. For example, short-period seismograms from stations in Nevada and California indicate that the first ML 6 shock at 16h 33m on 25 May 1980 began at relatively shallow depth as a strike-slip event; however, analysis of long-period data (Wallace et al, 1982) requires a significant component of normal faulting for the integrated motion in the earthquake, which may be explained by the rupture propagating to greater depth. The combination of right- and left-lateral shear on nearly vertical fractures striking respectively WNW and NNE suggests that shallow earthquakes of the Mammoth Lakes sequence may be associated with the formation of clusters of magma-filled dikes, in agreement with a model proposed by Hill (1977) to explain earthquake swarms in volcanic regions.

3. Dixie Valley Study

A ten-station seismic network was operated in and around the Dixie Valley area from January 1980 to November 1981. Analysis of the network data indicates that seismicity in the Dixie Valley-Fairview Peak area is almost exclusively confined to the rupture zone of large earthquakes that occurred there in 1954. The few microearthquakes that occurred in northern Dixie Valley had focal depth of 7.2 km or less, compared to mean focal depth of 11.3 km for events in the 1954 rupture zone to the south. Focal mechanisms for larger events in the area studied are consistent with regional extension in a WNW-ESE direction, as found by a number of previous investigators.

The possibility of a large earthquake in northern Dixie Valley, as suggested by Wallace (1978) is supported by the observation of very low seismicity in the area north of Dixie Meadows (so-called "Stillwater Seismic Gap"), and by the observation of a decrease in b-value starting in the mid-1970's and continuing to the present time. On the other hand some of the evidence argues against an impending large shock in this area: Earthquakes in northern Dixie Valley are very shallow, and could even be associated with listric faulting in a shallow crustal section overlying a zone in which deformation does not involve brittle fracturing. In northern Dixie Valley and other areas characterized by high heat flow, maximum magnitude of earthquakes may be limited due to the weakening of crustal rocks by fracturing in the vicinity of intrusive bodies, or by the effects of stress corrosion and leaching due to geothermal fluids.

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Earthquake Hazard and Prediction Research in the Wasatch Front--Southern Intermountain Seismic Belt 14-08-0001-19257 April 1 to September 30, 1982

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Investigations

1. Subsurface geometry of major normal fault zones based on high-resolution seismic reflection data and correlation with seismicity..

2. Subsurface geometry of major normal fault zones--and correlation of seismicity with fine structure--based on earthquake field studies.

3. Geodetic measurements of horizontal strain across the Wasatch Front near Salt Lake City, Utah.

4. Mechanical model for the interrelationship of seismicity, strain patterns, and tectonic deformation in the northern Wasatch Front area.

5. Geologic and earthquake estimates of moment rates, strain rates, and contemporary deformation of the Great Basin.

6. Digital seismic-data analysis.

7. Instrumental calibration program and developmental work towards digital telemetry stations.

8. University of Utah network operations and seismicity for the period: April 1-September 30, 1982.

Results 1. Within intraplate extensional domains, such as the Great Basin, a direct correlation between epicenters and surface faults is generally not observed. To examine this problem several hundred kilometers of seismic reflection data in Utah have been examined to evaluate the geometry and location of faulting and its spatial relationship to seismicity. Data have been made available by the oil industry for the Wasatch Front and other areas of the eastern Great Basin. Interpretations of the reflection data reveal several important features that relate to the style and mode of Cenozoic deformation: (1) normal-faulting related to back-slip along Cretaceous and Early Cenozoic low-

*Final Technical Report includes contributions also from D. Doser, D. Julander, M. McKee, E. McPherson, G. Randall, and M. Swing.

angle thrust planes in the northern Wasatch Front area; (2) low- to high-angle normal faulting and concomitant asymmetric basin formation along the Wasatch Front; (3) several low-angle normal faults that bound the western sides of range fronts in central and western Utah; and (4) wide-spread, low-angle reflections beneath the eastern Great Basin at shallow crustal depths that can be interpreted as a basal detachment that dips westerly from depths of ~3 km on the east to ~10 km on the west. Where welldefined reflections from the interpreted detachent underlie major range fronts in western Utah they do not appear to be displaced, implying that the higher-angle normal faults terminate or flatten at shallow depths. Reflection interpretation of Early through Late Tertiary basin-sediments indicates that significant Basin-Range type extension has been accommodated on low-angle faults that were initiated in Early Cenozoic time.

2. Results of extensive portable-network field studies in central Utah-- an area of important historic seismicity characterized by complex subsurface structure--provide new insights into the correlation of diffuse seismicity with geologic structure in the Utah region. After special efforts to model upper-crustal structure, refine spatial precision of earthquake foci, and unravel single-event focal mechanisms, we find: (1) a predominance of seismic slip on fault segments with moderate to high-angle dip, (2) clustered seismicity commonly on secondary (including transverse)faults--rather than on first-order, valley-bounding faults, and (3) spatially discontinuous seismicity above and below a level that correlates with an inferred upper crustal, near-horizontal detachment (~6 km deep) beneath the Sevier Valley and flanking mountain blocks near Richfield. In the vicinity of the southern Wasatch fault, we inadvertently "captured" episodes of swarm seismicity ($M_L \leqq 2.0$) induced by the injection of fluid at 5 km depth into an oil-exploration well located within a dense temporary network. We're pursuing correlation of the earthquake data with the injection/pressurization history of the exploration well and implications for stress state.

3. Using a new compilation of modern seismic network data for the western U.S. (~14,000 earthquakes of >M3) and a compilation of data on Late Cenozoic faulting (>300 data points) we have calculated seismic and geologic moment rates. These data provide estimates of contemporary (historic seismicity) and Quaternary (geologic) strain rates and moment release rates. When modeled with various fault geometries, they allow a determination of contemporary and Quaternary deformation patterns. East-west extension due to seismicity (elastic release) occurs non-uniformly across the Great Basin, from 0 to 3.9 mm/yr, with maximum values across the central Nevada seismic zone and along the southern Intermountain seismic belt. Quaternary, east-west extension also varies laterally across the Great Basin with rates of 0 to 1 mm/yr--remarkably similar to that inferred by the active seismicity. These data are consistent with a model of contemporary extension of the eastern Great Basin and oblique slip along the Sierra Nevada front and the Mojave desert. An early stage of extension in the Great Basin appears to have occurred in Early to Middle Cenozoic time associated with low-angle faults. Historic seismicity appears to release elastic strain in a complexly faulted and folded, elastic upper-lithosphere that is only 9-10 km thick.

4. Background seismicity in northern Utah is characterized by generally diffuse, yet locally clustered, epicentral patterns. Also, major normal faults with surface expression, such as the Wasatch and East Cache faults, currently are unusually aseismic, despite geological evidence of repeated, large normal displacements.

Focal mechanisms and geodetic data indicate a spatially complicated strain field with 90° changes in P and T axes over short distances of several kilometers. The enigmatic Ogden strain reversal can be modeled as due to aseismic movement of a Wasatch Mountain block along a low-angle normal fault beneath the mountain range. Geological evidence supports an interpretation that the low-angle fault could be the down-dip portion of a back-valley listric normal fault whose surface trace lies along the eastern Morgan Valley east of Ogden. The upper crust of this region appears to respond in a complicated, irregular manner to regional tectonic extension, controlled to a major extend by pre-existing heterogeneities in the crust. Thus, rapid changes in strain fields can be attributed to the different local responses of partially-coupled crustal blocks to regional stress and the ensuing "jostling" and settling of these blocks. This type of "block tectonics" is very similar to that proposed by Hill (1982) for California and Nevada, except here the extensional aspects are dominant.

5. Estimates of horizontal strain rates in the vicinity of Salt Lake City, Utah, were derived from triangulation-trilateration data observed by the National Ocean Survey/National Geodetic Survey (NOS/NGS) between 1962 and 1974. The data span a 70 km N-S extent of the Wasatch fault zone in central Utah. Around and south of Salt Lake City these data produce an estimate of 79°±14° for the direction of maximum extensional strain in an area of E-W extension across the fault zone. To the north of the city, however, the estimated direction of maximum extensional strain is 149°±11°, almost orthogonal to the direction expected from geologic evidence. Nevertheless, the northern NOS/NGS estimate is consistent with an azimuth of 163°± 10° derived from the 1972-1978 U.S. Geological Survey (USGS) trilateration data. These USGS data are sufficiently precise to demonstrate that the Ogden region experiences essentially E-W compression, opposite to that expected for E-W extension on the Wasatch fault. Fault plane solutions derived from earthquake studies further document the spatial variability of the regional strain field orientation throughout northern Utah. Discrete fault segments, tens of kilometers in length and separately activated, provide a possible mechanism for the observed spatial variability. This mechanism suggests that the contemporary strain field may be ephemeral. Another possibility is that the strain accumulation may shift E-W from one N-S fault zone to another. This effect may concentrate the stress potential at the ends of the active segments.

6. As part of a coherent program to develop software for extracting information from our digital seismic network. We have recently developed and/or implemented routines for: calculating double couple radiation fields, estimating moment tensors from digitized seismograms, calculating source-spectra estimates employing corrections for radiation-pattern and attenuation effects, estimating local attenuation from spectral ratios, calculating pseudo-Wood-Anderson seismograms from available calibrated digital data, calculating synthetic seismograms with a variety of techniques for forward crustal modeling studies, and digitizing existing analog seismograms to permit digital analysis of historical earthquakes of interest.

7. Complete frequency response measurements have been made in the laboratory on representative samples of all components in current use in the University of Utah seismic network. All components proved to be well behaved linear devices as anticipated, so the response of any particular seismograph system can now be predicted by summing the responses of its component devices. As a follow-up, we decided to initiate *in situ* field calibrations using discrete-

frequency sine wave inputs to the seismometer calibration coils--with the plan of later changing the input signal to one that can be digitally analyzed to provide continuous amplitude and phase response curves. A remote computer trigger system was developed and tested that now is used by a field crew to trigger the computer at any time for recording a calibration sequence. Calibration of stations using the simple discrete- frequency method is presently continuing. Programs for analyzing the calibration data, digitally recorded on our 11/34 computer, have been developed and used to calculate a measured total-system frequency response for specific telemetry stations. Developmental work towards conversion of a small subset of stations to broadband digital telemetry has focused on building a system around an established microcomputer. The NSC800 system from National Semiconductor was chosen from several available systems because of the capabilities of its new processor and its potential for low-power battery operation.

8. During the six month period April 1 - September 30, 1982, 312 earthquakes were located within the Utah region. The largest event was a magnitude (M_L) 4.0 earthquake in central Utah near Richfield on May 24, 1982. This earthquake caused minor local damage (maximum M.M. intensity of VI) and was widely felt near Richfield. Aftershock field studies (10 portable seismographs, eight-days duration, 250 hypocenters) were carried out by the University of Utah. Other felt earthquakes during the report period included: (1) a shock of M_L 2.7 on August 29, 1982, 20 km northeast of Salt Lake City, where it was felt in the east-bench area, and (2) a shock of M_L 3.3 on August 23, 1982, felt at Cedar City and located about 20 km to its south.

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Quaternary Framework for Earthquake Studies
Los Angeles, California

9540-01611

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Investigations

1. Continued loading geotechnical data into the USGS computer from the Pasadena, Burbank, and Van Nuys 7.5' quadrangles (M. Nicholson, J. Tinsley).

2. Continued 1/24,000 geomorphic/photogeologic/soil stratigraphic mapping of the surficial geology in the Los Angeles area (J. Tinsley).

3. Continued analyzing relations among geologic map units and potential indicators of ground response, such as shear wave velocity, void ratio, granulometry and geologic age. Revised ground motion geotechnical data base. (J. Tinsley, A. M. Rogers, J. F. Gibbs, T. Fumol, D. Ponti, and R. Borcherdt).

4. Constructed maps (1:125,000) of a part of the L. A. Basin centered at 34°00'N. 118°15'W. showing predicted ground response in three period bands: T = 0.2-0.5 seconds, T = 0.5-3.3 seconds, T = 3.3-10 seconds. The methodology incorporats empirical studies of geologic and geotechnical parameters to characterize the latest Cenozoic deposits in the Los Angeles region. The ground motion was generated by nuclear tests at the Nevada Test Site and was recorded at 98 sites across the Los Angeles basin. Comparisons of the alluvium -to- crystalline-rock spectral ratios provide calibration for the estimates of ground response. Testing of the technique continues.

5. Continued appraising regional liquefaction potential in the Los Angeles area. (J. C. Tinsley, T. L. Youd, and D. M. Perkins). Sediment most likely to contain materials susceptible to liquefaction is that deposited during the past few hundred years (latest Holocene) and, to a lesser degree, that deposited during the past 10,000 years (earlier Holocene). Latest Holocene deposits are readily distinguished from the earlier Holocene deposits by historical accounts of flood deposition and by buried inceptisols and entisols. Pleistocene deposits typically have pedogenic soils that have a textural B horizon. Designations of high, moderate, and low susceptibility reflect the age of, depth to, and penetrometer resistance of the water-saturated sediment.

The regional distribution of these geologic conditions indicates that the areas most likely to undergo liquefaction during future earthquakes lie in parts of the flood plains of the Los Angeles, Santa Ana, and San Gabriel Rivers and their principal tributaries; in flood-control basins and groundwater-percolation complexes; in coastal dune and beach areas; and in "shoestring sand" deposits in the western San Fernando Valley. Eight decades of pumping of the ground-water basins has lowered water tables and reduced the extent of susceptible areas. In addition, variations in rainfall and changing management practices profoundly affect the liquefaction hazard. Due to wet winters since 1978, ground water levels in certain areas are approaching historical highs and artesian conditions noted there in the early 1900's are recurring. Development of the ground water resource and the resultant lowering of water levels by pumping simultaneously reduced the liquefaction hazard to a minimum. To the extent that water levels return to historical high levels, the greater will be the areas susceptible to liquefaction.

6. Continued revising a paper entitled, "Simulated calcic-horizon development in alluvial soils" (senior author: Dr. L. D. McFadden, Dept of Geology, University of New Mexico, Albuquerque, N. M., 87131. Paper has received technical review and will be submitted to TRU review in November, 1982.

Results

1. Data base compilation is 50% complete in the Van Nuys and Burbank quadrangles.

2. Surficial geologic mapping is 90% complete.

3. Thickness of a geologic unit is an important parameter, in addition to shear wave velocity, void ratio, and granulometry, that must be considered in evaluating ground response. When thickness is considered, over 90% of the ground motion sites in the short period band can be grouped consistently according to geotechnical parameters (J. Tinsley and A. M. Rogers).

4. The 1:125,000-scale regional microzonation mapping delineates the following alluvium:bedrock median spectral amplification ratios within the three spectral bands. The maps reflect relations among the geotechnical parameters as noted in (3) above.

Unit	Period= 0.2 - 0.5 sec	Period= 0.5 - 3.3	Period= 3.3 - 10 sec
1.	1.3	1.1	1.1
2.	1.8	2.1	2.2
3.	2.4	3.6	3.4
4.	3.6	4.5	4.6
5.	4.6	---	---
6.	5.1	---	---
7.	6.5	---	---

Reports

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USGS/Alaska Division of Geological & Geophysical Surveys Cooperative Earthquake Hazards Project: Geotechnical Mapping and Testing Programs, Upper Cook Inlet, Alaska

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Investigations

The Upper Cook Inlet area of south-central Alaska, which includes the Anchorage and Matanuska-Susitna Municipalities, is the most populous area of the state and sustained considerable damage and loss of life as a result of the 1964 Prince William Sound Earthquake. Much of the resultant destruction was attributed to massive ground failure of Quaternary soils. Subsequent to the investigations conducted in the years immediately following that major event, very little research has been conducted on earthquake hazards in the region. The present study involves (1) detailed determination of present-day susceptibility for ground failure in response to a seismic event, (2) characterization and mapping of soil units exhibiting failure potential modes, and (3) establishing an engineering soils data bank of geotechnical borehole logs and associated test results for the Upper Cook Inlet Region.

Results

(1) The Bootlegger Cove Formation, which underlies much of Anchorage, has been found to consist of eight discrete geologic facies which vary in their engineering characteristics based upon differing geologic histories and modern ambient conditions. I have been able to characterize these engineering geologic facies in terms of both static and dynamic behavior. The Quaternary geology of the Government Hill area (north Anchorage) and south Anchorage have now been mapped in three-dimensions at a scale of 1:10,000 to a depth of 50 m below sea level, and incorporate the engineering parametric characterization of the facies of the formation. Geologic cross-sections and derivative maps showing facies distributions, formational structure, and thicknesses have been produced. The Government Hill mapping project has resulted in two manuscripts in press with the USGS. The south Anchorage mapping project has generated two manuscripts presently in press with the Alaska Geological and Geophysical Survey. A third mapping project in downtown Anchorage will be initiated during FY 83.

(2) State-of-the-art dynamic testing on the Bootlegger Cove Formation has been seriously lacking since the early efforts immediately after the 1964 earthquake. I have initiated a series of testing programs at two high-rise building sites in downtown Anchorage. The studies focus on the Bootlegger Cove Formation and include: (a) a series of deep geotechnical stratigraphic boreholes, (b) a laboratory program of static engineering tests on core samples, (c) resonant column tests, (d) cyclic triaxial tests, and (e) cyclic simple shear tests. Independent runs of the SHAKE program were made before and after the dynamic testing. Multiple publications are forthcoming.

(3) During April, 1982, the Electric Cone Penetration Testing System (Ertec CPT) was brought to Alaska and utilized at selected sites in the vicinity of the 1964 Turnagain Heights, "L" Street, and 4th Avenue landslides. The CPT data has been processed to (a) further characterize the pre-defined Bootlegger Cove Formation facies, (b) calibrate the CPT data with existing SPT data, geotechnical logs, and static laboratory testing results, and (c) enhance geologic mapping. Alaska Geological and Geophysical Survey publications will be written prior to June, 1982.

(4) Bedrock and surficial geologic mapping has been intitiated at 1:25,000 scale along the west front of the Chugach Mountains. One aspect of that mapping has been to identify active faults along the trend of the Border Ranges Fault System. Two high angle normal fault scarps, believed to be splays of that system have been mapped traversing both McHugh Complex (Jurassic/Cretaceous) bedrock and late Quaternary glacial/periglacial surficial deposits. The bedrock geologic maps of three quads along the west Chugach Mountain Front are nearly complete; the surficial geology will be finished during FY 83.

(5) The engineering soils data bank for Anchorage and vicinity has now been on line for three years and is continuously being updated with new borehole and testing information provided by municipal, state, and federal agencies, and by industry. Presently the information for several thousand sites has been catalogued and is being stored in the original report format, but these data will eventually be transferred to a computer-based retrieval system. The data are used as an integral part of the three-dimensional geologic mapping discussed above.

Geothermal Seismo-tectonic Studies

9930-02097

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Investigations

1. St. Helens seismic zone (SHZ) studies. Seismicity along the SHZ continues to be concentrated in the Elk Lake area. Earthquakes with magnitudes greater than 1.5 are being analyzed in an effort to detect changes in seismicity in the Elk Lake area that could be related to a forthcoming moderate earthquake. Parameters being monitored include the orientation of the P and T axes, the distribution of earthquakes, and the b-value.

2. Olympic Peninsula-Washington Coast Range seismicity and velocity structure studies. The Olympic Peninsula subnet of the University of Washington statewide network continues to record low rates of both subcrustal and crustal seismicity. Focal mechanisms for small magnitude (2+) earthquakes on the Olympic Peninsula continue to be routinely calculated. Crustal structure studies on the Olympic Peninsula have advanced to the stage of ray-tracing and synthetic seismograms in an effort to better resolve velocity models.

3. A teleseismic P-delay study, initiated in 1981, has been completed. Teleseismic residuals were used to constrain the geometry of the subducting Juan de Fuca plate beneath the North American plate. Simple residual analysis, ray tracing, and 3-D inversion methods have been employed.

4. Puget Sound/Western Washington seismicity studies. Seismicity since 1954 has been examined prior to three periods of increased seismic energy release in western Washington in a search for recognizable precursor patterns. Earthquake catalogs since 1970 have been used in a study to attempt to define potentially active faults in the crust of Puget Sound that could generate moderate earthquakes (magnitudes 5-6.5) similar to those recorded in southwest Washington in 1981 (Elk Lake, magnitude 5.5; Goat Rocks, magnitude 5.0).

Results

1. No significant changes in seismicity have occurred in the Elk Lake area during this report period. Focal mechanisms continue to be show nearly pure strike-slip faulting, on fault planes striking a few degrees west of north.

2. Earthquake catalogs were searched for possible precursor activity before the three largest Puget Sound earthquakes since 1964 (Bellingham, 1964, magnitude 4.8; Seattle, 1965, magnitude 6.5; Kitsap, 1978, magnitude 4.6). We have searched for seismic precursors in the form of: 1) immediate foreshock

activity; 2) increases in seismicity in epicentral regions months and years prior to larger earthquakes; 3) changes in regional seismicity months and years before larger earthquakes; and 4) quiescence at small magnitude levels in epicentral regions (a Mogi gap of the second kind). Prior to 1970 our search was confined to precursory earthquakes with M>3.5-4.0. After 1970 the search could be conducted at the M>2.0 level and often at even smaller magnitudes. No definitive and distinctive seismic precursors were found for these three events.

We have discovered a 2500 km^2 zone of quiescence in the NE portion of the Puget basin (Figure 1). This area has been aseismic at the $M \geq 2.5$ level since 1974. It has probably been an area of low seismicity at the $M \geq 3.5$ level since 1960. A large part of the north zone's boundary can be associated with either mapped faults or structures inferred from gravity data. The northern zone of quiescence has a companion zone in the SE Puget basin, that has an area of 3000 km^2 (Figure 1). This southern zone has been aseismic at the $M \geq 2.5$ level since 1976. The implications of these two quiescent zones for the location and time of future large earthquakes in the Puget basin are uncertain.

The most important seismogenic structure that has been identified in the Puget basin lies in the southern Kitsap peninsula (Figure 1). A M_c=4.6 earthquake and aftershock sequence occurred along part of this structure in 1978. A narrow, 35 km long NNW striking zone of earthquakes, which includes the 1978 sequence, has been active at the M>0 level since the early 1970's. Preliminary results indicate that earthquake focal mechanisms in the northern and southern parts of the zone are significantly different. The implications of this zone for earthquake hazards has not been determined.

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Michaelson, C. A., 1982, Crust and upper mantle structure from teleseismic P-wave residuals (abs): EOS, Transactions of the American Geophysical Union, v. 63, 379.

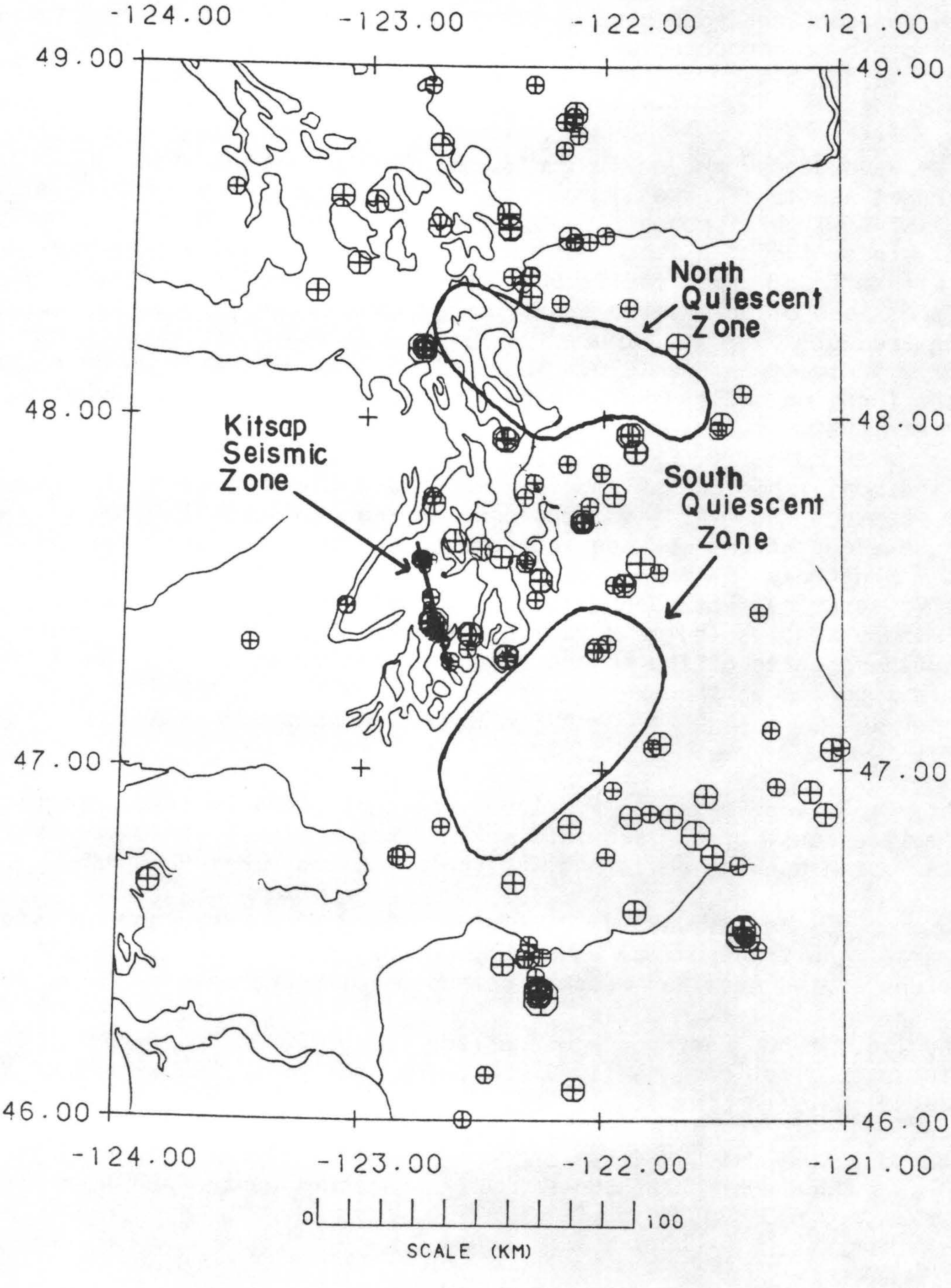

Figure 1: Earthquakes in western Washington located between 1974 and 1982. Earthquakes are scaled by magnitude, with three symbol sizes: smallest- less than 3.0, medium- between 3.1 and 4.0, largest- greater than 4.0.

Earthquake Hazards Studies, Metropolitan Los Angeles-Western Transverse Ranges Region

9540-02907

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Investigations and results

1. Historic earthquake data (W. H. K. Lee). The Archives Institute of California Institute of Technology has filmed and transmitted to the U.S. Geological Survey approximately 400,000 "phase" cards containing all data from routine processing of southern California earthquakes since the mid 1920s. In addition, all existing seismograms from all stations (except Pasadena) since the beginning of the Seismological Laboratory through 1933 have been filmed and transmitted. All seismograms from the Pasadena station are being filmed under a cooperative project. During the filming project the Archives Institute recovered a series of Richter notebooks that contain a wealth of unpublished data, pertaining especially to the 1933 Long Beach earthquake on the Newport-Inglewood zone. We have extracted phase data for some 200 shocks of the sequence, but many problems of timing and picking phases remain to be resolved.

2. Late Cenozoic ashes (Sarna-Wojcicki).

a. Bishop ash bed identified in deep-ocean sediments of the Pacific Ocean.

We have identified the Bishop ash bed from core samples obtained from deep-ocean (D.S.D.P.) hole 470, in the Pacific Ocean near Guadalupe Island, 300km west of Baja California (fig. 1). The glass composition of this ash, determined by electron-microprobe analysis (EMA), is identical within the error of analysis to that of the Bishop ash bed (table 1). However, several Quaternary ash beds erupted from the Long Valley-Glass Mountain volcanic complex east to the central Sierra Nevada are very similar in chemical composition to the Bishop ash bed, and thus cannot be distinguished on the basis of EMA along.

The ash bed in hole 470, however, (1) has the diagnostic chemical signature of ash layers erupted from the Long Valley-Glass Mountain complex, (2) is thus over 1000 km away from its source area (fig. 1), and (3) is 10 cm thick in the D.S.D.P. core, thus indicating that it was produced by a very massive eruption. The Bishop ash is generally the thickest and most widespread ash bed erupted from the Long Valley-Glass Mountain complex (Fig. 1., triangle). Furthermore, the ash bed in hole 470 is situated in the upper part of the Quaternary section, as indicated by independent biostratigraphy. If we arbitrarily assign the widely-accepted 1.8 MA (million year) age to the Quaternary/ Pliocene (Q/P) boundary independently identified in the bore hole on the basis of nannofossils, and if we assume a constant sedimentation rate at site 470, we calculate an age of 0.71 MA for this ash bed--an age very close to the isotopically-determined 0.73 MA age of the Bishop ash bed (Dalrymple, 1980). Conversly, if we apply the 0.73 MA age to the ash bed in hole 470, we obtain an age of 1.85 MA for the biostratigraphically-designated Q/P boundary.

The ash in hole 470 represents the southernmost documented locality of the Bishop ash bed. Identification of this and other ash beds in deep-ocean cores (see Sarna-Wojcicki, this volume) permits correlation of deep-ocean biostratigraphic zones with provincial on-land marine and continental faunal chronologies and magnetostratigraphy. (We gratefully acknowledge the assistance of the D.S.D.P. Program of Scripps Institute of Oceanography and the National Science Foundation for donation of core samples).

b. Bishop ash in the Saugus Formation, Newhall area, southern Calif.

Our analyses of glass samples from two ash exposures in the Saugus Formation near Newhall, Calif., identify them as the Bishop ash bed. Samples collected by Jerry Treiman (C.D.M.G.), and Shaul Levy (O.S.U.), were analysed by EMA (table 1) and energy-dispersive X-ray fluorescence spectrometry. Magnetostratigraphic work by Levy indicates that the ash is normally magnetized and overlies a magnetic reversal about 150-200 m stratigraphically lower in the section, supporting the identification (all major Quaternary ash beds erupted from the Long Valley-Glass Mountain complex are reversly magnetized except for the Bishop ash bed). Identification of this ash bed in the Saugus Formation demonstrates the time-equivalence of the continental Saugus and the marine Santa Barbara Formation situated further to the west. The correlation also provides an important age and stratigraphic horizon that provides an age constraint on the deformation of the Saugus Formation in the Newhall area.

c. Magnetostratigraphy and a putative Huckleberry Ridge ash bed in Balcom Canyon, southwestern Calif.

Magnetostratigraphic work by J. C. Liddicoat (Lamont-Doherty Geological Observatory, in cooperation with our project) has resulted in the identification of a magnetically normal-polarized stratigraphic interval beneath the Bailey ash bed (1.2 MA), in the Pico Formation near Santa Paula. This normal interval coincides stratigraphically with the Q/P boundary, as identified by J. Ingle (Stanford Univ.) on the basis of foraminiferal zones, and thus probably represents the Olduvai event. We have found a volcanic ash bed near the base of the Pico Formation further down in the section in Balcom Canyon that we tentatively identify as the Huckleberry Ridge ash bed on the basis of EMA analysis and shard morphology. This ash is somewhat lower in the section than the position of the Q/P boundary as inferred from biostratigraphy. We are doing further analyses on this ash bed to determine whether it has been correctly identified, or whether the foraminiferal zones are somewhat time transgressive.

3. Fault and epicenter maps (Yerkes). Completed initial classification and compilation of Quaternary/Holocene fault map at 1:250,000, including results of all cooperative trenching/dating investigations through 1981. Monitoring

continues. Obtained print at 1:250,000 of 1970-1981 epicenters of earthquakes $M_L \geq 1$ as recorded by CIT for the Los Angeles region.

4. V_p sections, Los Angeles basin (Yerkes). Completed structure sections at 1:250,000 of inferred V_p across Los Angeles basin as derived from 3-D density-gravity model of T. H. McCulloh.

5. Lompoc earthquake (Yerkes). Completed and submitted for outside publication a journal report on the April 1981 reverse fault and microearthquake near Lompoc (see Yerkes and others in GSA Abs. with Programs, vol. 13-7, p. 586, for abstract).

6. Los Angeles region earthquake hazards (Yerkes). Completed through technical review a chapter on geologic and seismologic setting for a multi-disciplinary Professional Paper report on earthquake hazards of the Los Angeles eegion (J. I. Ziony, editor).

Reports

Sarna-Wojcicki, A. M., Bowman, H. R., Meyer, C. E., Russell, P. C., Asaro, Frank, Michael, Helen, Rowe, J. J., Jr., Baedecker, P. A., and McCoy, Gail: Chemical analyses, correlations, and ages of late Cenozoic tephra units of east-central southern California. (For U.S. Geol. Survey Prof. Paper. Approved).

Morrison, S. D., and Sarna-Wojcicki, A. M., 1981, Time-equivalent bay and outer-shelf facies of the Neogene Humboldt Basin, Calif., and correlation to the north Pacific microfossil zones of D.S.D.P. 173: Proceedings of the International Workshop on Pacific Neogene Biostratigraphy, 6th International Working Group Meeting, Nov. 25-29, 1981, Osaka, Japan. Osaka Museum of Natural History, p. 130-131.

Liddicoat, J. C., 1982, Paleomagnetism of the Pliocene-Pleistocene Pico Formation in Balcom Canyon, Ventura Basin, California: Geol. Soc. of America, Abstracts with Programs, v. 14, no. 7, p. 546-547.

Yerkes, R. F., Ellsworth, W. L., and Tinsley, J. C., New reverse faulting and crustal unloading, northwest Transverse Ranges, California approved and submitted to Geology.

Table 1. Electron-microprobe (EMA) analysis of volcanic glass of the Bishop ash bed. Analyses are recalculated to 100 percent, water-free basis. C. E. Meyer, U.S.G.S., analyst.

Sample	SiO_2	Al_2O_3	Fe_2O_3	M_gO	MnO	CaO	BaO	TiO_2	Na_2O	K_2O	Cl
1.	77.60	12.45	0.84	0.05	0.03	0.48	0.02	0.08	3.67	4.72	0.06
2.	77.81	12.22	0.79	0.04	0.04	0.47	0.02	0.05	3.72	4.80	ND
3.	77.25	12.89	0.78	0.04	0.02	0.46	0.00	0.07	3.71	4.77	ND
4.	77.15	12.83	0.78	0.04	0.01	0.45	0.01	0.07	3.81	4.77	0.09
5.	77.37	12.82	0.76	0.03	0.04	0.41	0.02	0.05	3.76	4.66	0.07
6.	77.71	12.54	0.74	0.03	0.04	0.40	0.00	0.06	3.80	4.60	0.08
7.	77.47	12.74	0.76	0.03	0.03	0.48	0.00	0.06	3.56	4.83	0.05

1. Ash bed in D.S.D.P. hole 470 west of Baja California (see fig. 1).
2. Ash bed in Santa Barbara Formation, Ventura, southwest Calif.
3. Ash bed in Saugus Formation, southern Calif., coll. by Jerry Treiman (C.D.M.G.).
4. Ash bed in Saugus Formation, southern Calif., coll. by Shaul Levy (O.S.U.).
5. Ash bed in beds of Pleistocene Lake Tecopa, southeastern Calif.
6. Air-fall ash bed at base of ash-flow Bishop Tuff, 10 km.north of Bishop east-central Calif.
7. Ash bed of reworked, fine ash at Friant, central Calif.

Figure 1.

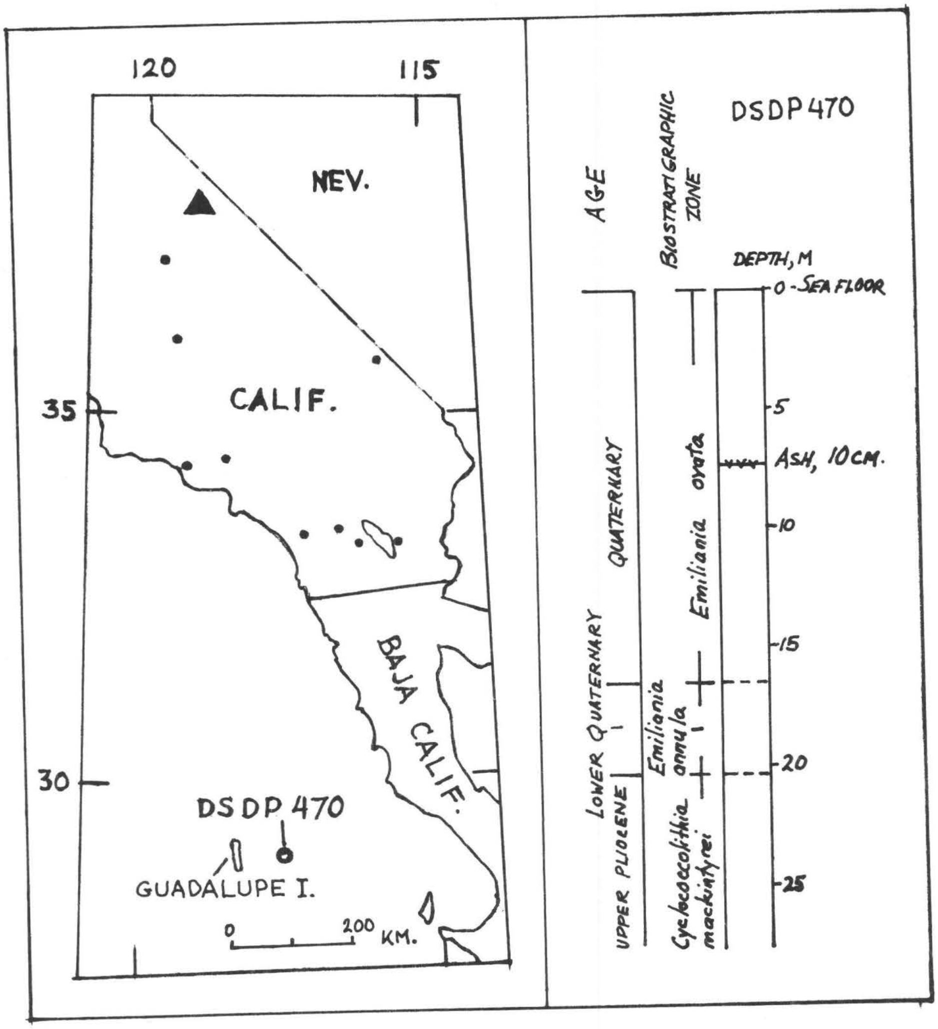

Figure 1. Left side: Open circle - location of D.S.D.P. hole 470; closed circles - locations of exposures of the Bishop ash bed in southern California triangle - Long Valley - Glass Mountain volcanic complex from which Bishop ash was erupted. Right side - biostratigraphic zonation in D.S.D.P. hole 470.

Earthquake Hazards
Puget Sound, Washington

9540-02197

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Investigations

Historically, foci of large earthquakes in Puget Sound occurred at depths between 50 and 70 km, and resultant damage has been attributed to amplified ground shaking and ground failure (liquifaction phenomena and landsliding). Little, if any, evidence for ground rupture along faults at the land surface has been documented from past well-located earthquakes. Therefore the major investigations of this project have concentrated on:

1. Delineating and characterizing the major Quaternary stratigraphic units in the central Puget Lowland.

2. Developing an understanding of the seismotectonic setting of Puget Sound and the major tectonic forces responsible for earthquakes in the region.

3. Searching for evidence of recent differential vertical motion across major aeromagnetic and gravity discontinuities (interpretated as faults) running through the Puget Lowland.

Specific studies undertaken during this past year include completion of 1:24,000 scale mapping of surficial deposits in the Uncas, Center, Mt. Walker, Bothell, Edmonds East, Kirkland, Snohomish, Everett, and Maltby quadrangles. Synthesis and compilation of these data onto the Seattle 1:100,000 base map has begun. In addition, logs from nearly 200 geotechnical boreholes in the Seattle 1:100,000 map area have been examined in order to characterize the physical properties (grain size, water content, bulk density, penetration resistance, cohesion) that might be useful in studies of seismic ground shaking or liquifaction potential; this has been done for each mappable Quaternary unit.

Results

1. Thickness variations of individual Quaternary units and topography developed on the top of the Tertiary bedrock surface are large. More than 1000 meters of relief exists on the Tertiary bedrock surface in parts of the Seattle 1:100,000 quadrangle. In addition, as much as 200 meters of relief was sculpted into the Quaternary sediments of Puget Sound during the last invasion of continental ice into the region. The resulting succession of unconsolidated glacial and alluvial facies nested inside semi-consolidated older Pleistocene glacial and nonglacial units, often along sloping to near-

vertical contacts, makes horizontal layer models of seismic ground response difficult to apply in many parts of Puget Sound.

2. Mappable Quaternary units can be grouped by similarities in physical properties into a few broad categories that are useful for ground response or liquifaction potential evaluation. Units with the highest water content, and lowest penetration resistance, bulk densities, and cohesions are muddy to sandy Holocene alluvium and fill, late-Wisconsin recessional lacustrine sand and silt, and some advance outwash sand of the last glaciation. Units with intermediate properties include coarse-grained sand and gravel of both recessional and advance stages of the last glaciation, sand and silt of nonglacial intervals that preceeded the last glaciation, and some coarse-grained Holocene alluvium. Lodgement till of the last glaciation, and till and associated outwash deposits of previous glaciations generally show low water contents and high bulk densities and resistances to penetration. These values are near or in excess of values observed for older Tertiary sedimentary and volcanic rocks.

3. Radiocarbon ages of 3260±80 YBP (USGS-7) and 1350±55 YBP (M7484) on shells from uplifted marine terrace deposits at Blakely Harbor and Alki Point, respectively, suggest at least 3 meters of differential vertical motion across the large east-west trending gravity gradient (interpreted as a fault in Gower and Yount, in press) passing from Eagle Harbor through southern Seattle. These marine terrace deposits are restricted to the south side of the gravity gradient. The terrace is cut into Oligocene marine siltstone and sandstone in the Blakely Harbor area, and previously it was thought that the lack of a terrace north of Blakely Harbor could be explained by the inability of Quaternary sediments to maintain a wave-cut terrace, thus restricting the feature to areas underlain by bedrock. The dated locale approximately 1 km south of Alki Point is cut into Quaternary nonglacial fluvial sand and silt that underlie deposits of the last glaciation. Thus, it appears that bedrock presence is not necessary to preserve the terrace, and that the restriction of the feature to the region south of the Seattle-Bremerton Fault may be the result of differential vertical uplift, rather than an artifact of preservation.

Reference

Gower, H. D. and Yount, J.C., in press, Seismotectonic Map of the Puget Sound Region, Washington: U.S. Geological Survey Miscellaneous Investigations Map, Scale 1:250,000.

Reports not previously listed

Yount, J. C., in press, Earthquake Hazards of the Puget Sound Region: Proceedings of Conference XIV of U.S. Geological Survey Earthquake Hazards Reduction Program, U.S. Geological Survey Open-File Report.

Minard, J. P. , 1980, Distribution and description of the geologic units in the Snohomish quadrangle, Washington: U.S. Geological Survey Open-File Report 80-2013, Scale 1:24,000.

Minard, J. P., 1981, Distribution and description of the geologic units in the Maltby quandrangle, Snohomish and King Counties, Washington: U.S. Geological Survey, Open-File Report 81-100, Scale 1:24,000.

Minard, J. P., 1981, Distribution and description of the geologic units in the Bothell quadrangle, Snohomish and King Counties, Washington: U.S. Geological Survey Open-File Report 81-106, Scale 1:24,000.

Minard, J. P., 1981, Distribution and description of the geologic units in the Everett quadrangle, Snohomish County, Washington: U.S. Geological Survey Open-File Report 81-248, Scale 1:24,000.

Minard, J. P., 1982, Distribution and description of the geologic units in the Mukilteo quadrangle, Snohomish County, Washington: U.S. Geological Survey Miscellaneous Field Investigations Map, MF 1438, Scale 1:24,000.

Regional Syntheses of Earthquake Hazards in Southern California

9940-03012

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Investigations

1. Analysis of the geologic and seismologic character of late Quaternary faults of the Los Angeles region, as determined from published and unpublished sources and from limited field investigations, continued. Our emphasis is on obtaining: (a) quantitative data on offsets of deposits or geomorphic features younger than about 700,000 years in order to provide a reasonably uniform basis for estimating rates of geologically-recent slip along individual faults, and (b) geologic constraints on the recurrence of large earthquakes. The long-term objectives are to estimate the relative activity of these faults, and, where possible, their earthquake and surface faulting potential.

2. Coordination of the preparation of a professional paper on the earthquake hazards of the Los Angeles region continued. This comprehensive report will summarize the current methods and conclusions of USGS investigators concerning the major earthquake-hazard factors for the region.

Results

1. A report summarizing our current understanding of the fault hazards of the region has been submitted for technical review. Detailed information on the geometry, style and amount of offset during late Quaternary time, and associated seismicity is presented for 96 faults of the region that have been active during the past 700,000 years; the sparse geologic evidence on recurrence of large earthquakes along individual faults is summarized; and constraints on the size of future events to be expected along these faults are discussed.

2. Approximately half of the 15 chapter contributions to the proposed professional paper on the Los Angeles region are in technical review, and the remainder are expected to be submitted by February, 1983. Results of these studies pertinent to methods for mapping of fault-, shaking-, and ground-failure hazards were summarized at the Third International Earthquake Microzonation Conference.

Reports

U. S. Geological Survey Staff (Ziony, J. I., coordinator), 1982, Seismic zonation of the Los Angeles region - a progress report: Proceedings of the Third International Earthquake Microzonation Conference, June 28 - July 1, 1982, Seattle, Washington, Vol. 1, p. 157-172.

Tectonic Tilt Measurements Using Lake Levels

9950-02396
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Investigations

1. Completed an analysis of NGS and USGS level lines in the Salt Lake City to Brigham City, Utah, area run since 1950. The extent of possible survey error in the data is being evaluated. Procedures for future releveling of the Weber Canyon line across the Wasatch Fault zone are being studied.

2. Lake-level measurements were made on Great Salt Lake and on Utah Lake, Utah. New recording sites were established and documented in September by Kirk Vincent.

3. Lake-level measurements were made on Kenai, Skilak, Tustamena, and Harlequin Lakes, southern Alaska in August. Several 1964 reference bench marks were recovered on Tustamena Lake that were under water during a previous search in 1979.

Results

1. Comparisons of 1953 and 1967 NGS level surveys on railroad routes along the Wasatch Mountains front between Salt Lake City and Ogden, show elevation changes of at least 80 mm that can be interpreted as movement on Wasatch Fault Zone. Similar results are obtained from a comparison of 1958 NGS with 1974 USGS leveling across the Wasatch Fault Zone in Weber Canyon near Ogden. Elevation change shows as surface tilt of 6 to 30 microradians within a 12-km-wide zone centered on the fault zone. The possibility of refraction and rod-calibration error as a cause of these apparent elevation changes is being considered for this data set and also for future releveling. Magnitude of the surface tilt and the coincident results from two independent surveys argue that these may be real tectonic movement along a strained normal-fault zone.

2. Recovery of 1964 bench marks on Tustamena Lake, Alaska, show that about 200 mm of down-to-the-southeast tilt occurred across Tustamena Lake on the Kenai Peninsula since the 1964 earthquake and before 1979. This is similar to the result reported by Wood (1981) for Kenai Lake. These measurements suggest that the post-seismic movement reported by Brown and others (1977) extended over much of the Kenai Peninsula.

From 1979 to 1982, apparent tilt is less than 35 mm across Kenai and Tustamena Lakes and probably within the noise level of the measurements. This year's survey showed an apparent elevation change of about 70 mm (down to the south) across Skilak Lake that occurred between 1979 and 1982.

An investigation of Holocene Neotectonic Deformation in the Charleston, S.C., Region, Compared to Areas to the North and to the South

Contract No. 14-08-001-20515

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Investigations

1. Regional Cretaceous and Tertiary stratigraphic studies compiling data developed in seven theses and dissertations of limited areas have revealed a discontinuity on structure contour and isopach maps in the Charleston region.

Results

1. Displacement of unconformity surfaces is noted on seven contour maps along a line extending N 45° W from Charleston in Charleston and Dorchester Counties.

2. Isopach maps constructed of intervals between the unconformities indicate faulting was active in Median Eocene time. Faulting may have occurred earlier, but deep data is insufficient for proof. Growth faulting on the order of 100 feet displacement is shown for Base Lutetian-Base Priabonian. The fault appears hinged to the northwest, and is downthrown on its southwest side. Displacement appears greatest in western Charleston and Dorchester Counties, and curiously is not supported in Charleston Medical Center nor adjacent Mount Pleasant holes.

3. Recognition of this discontinuity introduced a change in our Holocene investigation area during the summer of 1982 to attempt to refine our results, within the Charleston Study Area (figure 1).

Reports

1. Colquhoun, D.J., Woollen, I.D., Van Nieuwenhuise, D.S., Padgett, G.G., Oldham, R.W., Howell, P.D., Bishop, J.W., and Boylan, D.C., 1982, Tectonic framework development and initial glacio-eustatic sea level change east Georgia embayment, U.S.A., Abstracts with Programs, 1982, Geological Society of America Annual Meeting, vol. 14, no. 7, p. 466.

2. Boylan, D., Thunnell, R., and Colquhoun, D., 1982, Stratigraphy, water depth, erosional unconformities and time of emplacement of the South Carolina Coastal Plain, Charleston to Hilton Head Island, in program NE-SE Sections, Geological Society of America Meetings, Washington, S.C.

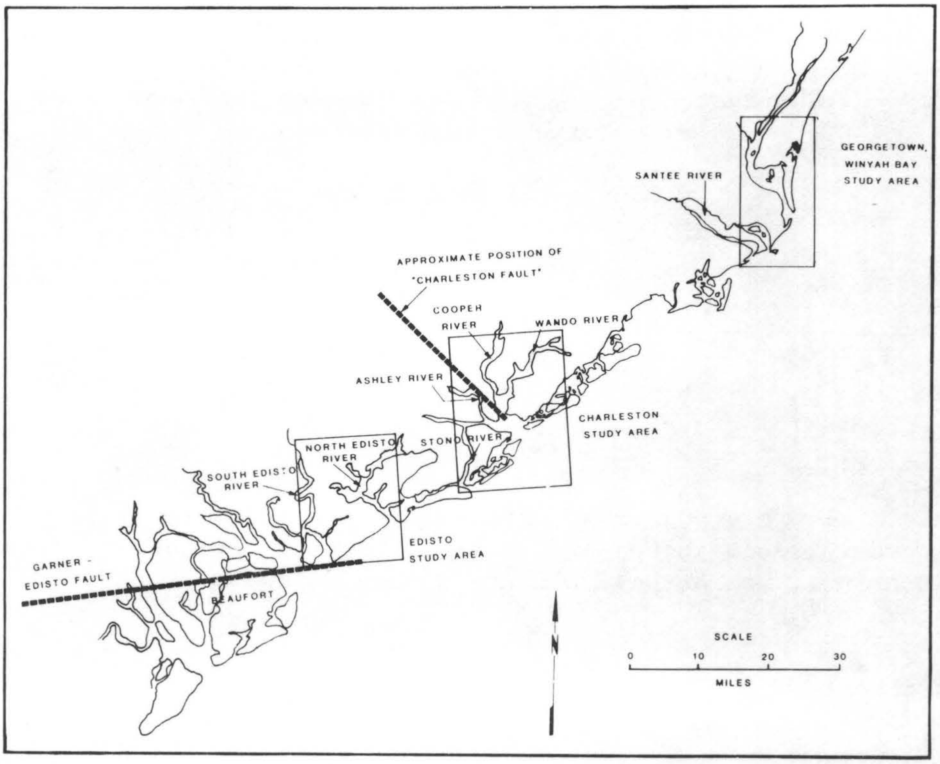

Figure one: Location map of study areas, showing discontinuities observed in subsurface.

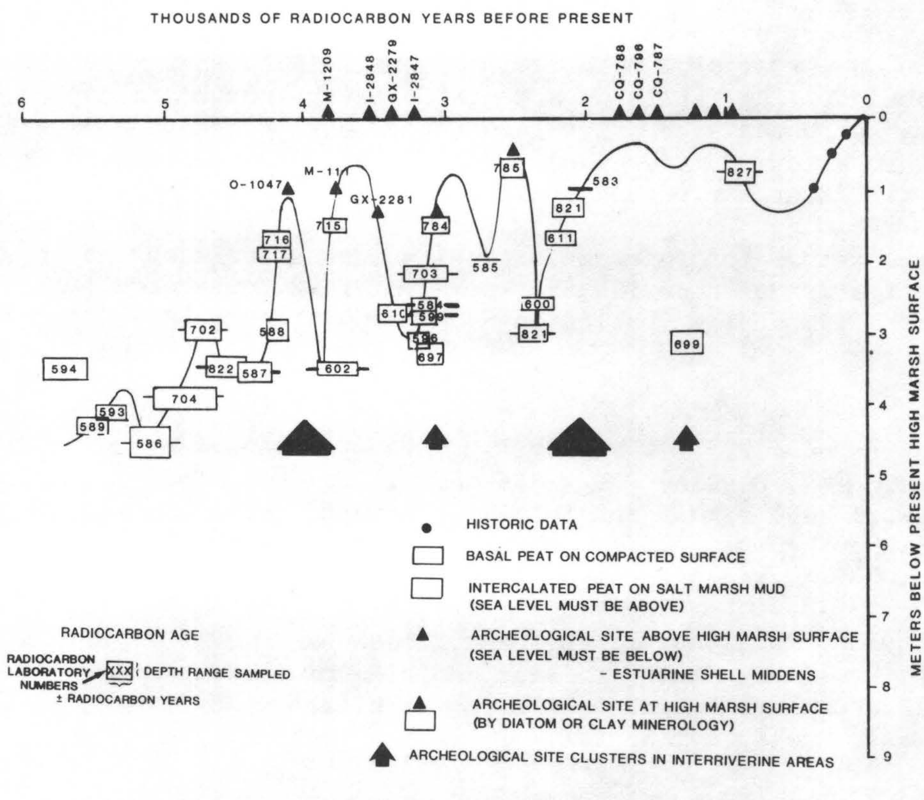

Figure two: Composite sea level change curve for South Carolina Coastal Zone

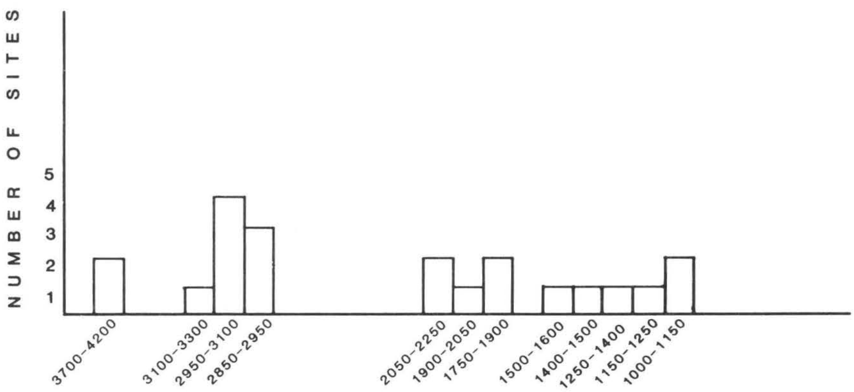

Figure three: Interriverine site clusters in the Cooper River Estuary

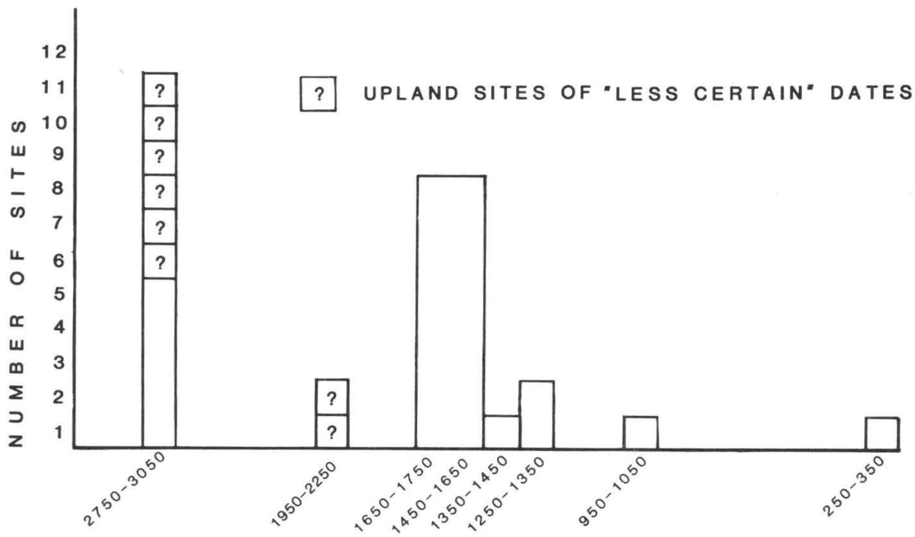

Figure four: Interrriverine site clusters in the Winyah Bay area.

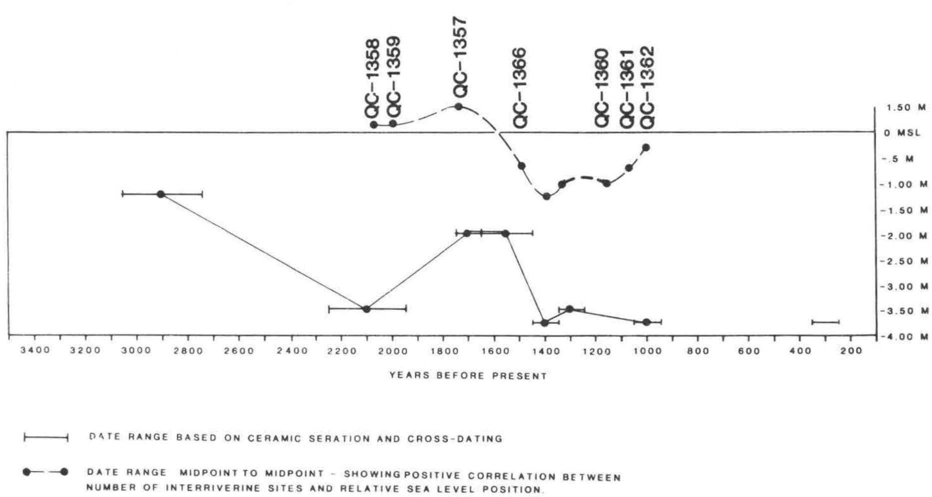

Figure five: Summary of Winyah Bay data relative to sea level change/

Investigations

2. Holocene stratigraphic and archeologic studies proceeded in the Winyah Bay Area (40 miles northeast of Charleston); in the Cooper River Valley (at Charleston) and in the North and South Edisto River Estuaries (30 miles southwest of Charleston) in order to draw up sea level change curves in each region for comparison in the time interval 0-6000 radiocarbon years before present. The stratigraphic studies included coring in marshes to provide records from the present high marsh surface to the Pleistocene-Tertiary. Intertidal peats as opposed to salt marsh clays were collected, analyzed for diatoms and pollen, and submitted for C_{14} dating at fresh-salt water boundary transitions in cores, to indicate previous high marsh surfaces. The archeologic studies included 1) interrivering sites and 2) coastal-estuarine middens to indicate limiting high marsh elevations and trend of sea level change. In addition midden stratigraphy was investigated to indicate successive midden submergence by higher sea levels during the Holocene.

In the Winyah Bay area 22 cores were taken and logged. From these, intertidal basal peats were identified by pollen and diatom analysis. We await C_{14} dating on four of these. Seven archeologic C_{14} datings have been received from midden materials related to marsh stratigraphy. A large number of interriverine sites have been investigated.

In the Cooper River Valley (Charleston) 15 cores were taken and logged in addition to our previous published investigations. Four additional intertidal basal peats are being C_{14} dated to add to our published dates in this area.

In the Edisto River Estuaries 39 cores were taken and logged. From these we await dating on seven intertidal basal peats. Nine middens were examined and five C_{14} dates are in process.

In order to refine our measurements with respect to the discontinuity reported in 1, we have begun studies in the Ashley River Valley (Charleston) where three cores were taken and logged. No intertidal basal peats were confirmed by diatom and pollen analysis. We are commencing investigations in the Stono and Wando River Valleys.

Results

1. Archeologic and Holocene stratigraphic studies in the Winyah Bay region of the Coastal Zone have indicated additional sea level change data for the radiocarbon year interval 2000-0 B.P. Sea level drops near 500 and again near 1200 years B.P. are noted, with rises occurring between. This result has been confirmed by other studies to the south, near Beaufort by other workers, in South Carolina. (figure 2)

2. Interrivering site clusters near Georgetown are noted for the intervals 2750-3050, 1950-2250, 1250-1750, 950-1050 and 250-350 radiocarbon years B.P. (through ceramic seriation). The first three of these are nearly identical with similar clusters noted in the Cooper River Valley near Charleston S.C.,

where they were assigned to times of rising sea level in marsh stratigraphic studies (Brooks et al 1978). The Georgetown observations differ from the Charleston observations in that 1) more clusters are apparent near Georgetown and these occur at times of rising sea level as indicated in the Beaufort data (1 above), and 2) the number of sites identified in the 1250-1750, 950-1050 and 250-350 clusters at Georgetown are significantly more than have been measured in the Cooper River Valley near Charleston. Near Charleston Brooks et al 1978 noted the number in interriverine sites seemed to correlate with the relative change of sea level occurring during the cluster intervals. The greater the change in sea level, the greater the number of interriverine sites. (figures 3 & 4)

Our present observations in Georgetown and in Charleston would indicate therefore that sea level changes in the Cooper River Valley (Charleston) were not as severe in the Charleston area, than as at Georgetown, from 1750 radiocarbon years B.P. until the present. The trace of the fault induced from the studies noted in Investigation 1 (above) together with the displacement noted on that discontinuity (upthrown on the northeast side) would support elevation of the Cooper River Valley observation area, a reduction in relative sea level changes during this portion of the Holocene, and a consequent decrease in the number of clusters and the number of sites within clusters noted for Charleston as compared with Georgetown. It would indicate displacement first noted in the Lutetian continuing in the Holocene from 1750 radiocarbon years before the present, and possibly, from present archeologic data sporadically in time.

Reports

1. Colquhoun, D., Brooks, M., and Michie, J., Evidence for little Ice Age sea level change in the southeastern U.S. accepted for program, XI Congress, International Union for Quaternary Research Moscow, U.S.S.R. August 1982.

2. Colquhoun, D.J., Brooks, M.J., Michie, J., Abbott, W.B., Stapor, F.W., Newman, W.H., and Pardi R.R., 1981, Location of archaeological sites with respect to sea level in the southeastern United States in Florilegium Florinis Dedicatum. Striae, vol. 14, pp. 144-150.

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 and seismic zoning of the eastern United States continued. Particular attention is being given to thickness of the seismogenic layer and its relation to seismicity.

2. Construction of additional average elevation maps using various averaging schemes was initiated. These maps will supplement GP-933, which has well received in several quarters.

3. Examination of some characteristics of the New Brunswick earthquake of January 9, 1982 was undertaken, the results were presented at the SSA meeting in Anaheim.

Results

1. A final draft of a Bouguer gravity anomaly map of Pennsylvania 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 has now been printed and distributed, as GP-933. Additional maps using different averaging schemes are under construction.

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, particularly in the vicinity of the Adirondack Mountains.

4. A continuing study of thermal convection in water-filled holes has begun to reveal some information on the nature of the fluid motions. This information may be useful in interpreting temperature-time data in terms of crustal strain. It may also be useful in assessing the accuracy of other in-hole measurements that are sensitive to small fluid motions. An opportunity arose to examine the phenomena in some holes of intermediate diameter (~4 in.) over a wide range in gradient (0-1000^{o}c/km).

5. Comparison of precision temperature logs made in a deep (2 km, 165°C) geothermal well (East Mesa 31-1) in 1977(2), 1978(2), and 1982(1) exhibit little sensible change above the slotted interval (~1.6 km). Changes in the slotted interval may partly reflect fluid motion along faults induced by the nearby Imperial Valley earthquake of October 15, 1979. Small changes slightly above the slotted interval probably resulted from slumping of the hole wall into uncement parts of the annulus between hole and casing. An important point is that small differences between temperture logs obtained at different times in deep high temperature regimes can be interpreted in terms of physical changes provided proper attention is given to instrumentation and calibration. The point is further illustrated in the study made in a deep hole near Desert Peak, Nevada under more extreme conditions (reference below).

6. A brief period of time was spent helping to evaluate one aspect of a 200 million dollar sewage diversion project near Rochester, NY based on new data acquired by others as compared with that we had acquired a decade ago (reference below).

Reports

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Shear Wave Velocity Models Near New Madrid, Inferred from USGS Refraction Data

14-08-0001-20527

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Goals

Infer shallow shear wave structure and shear wave anelastic attenuation from high frequency surface waves recorded at short distances as part of the 1980 USGS Mississippi Embament refraction project.

Investigations

Two USGS refraction profiles have been examined. Data have been analyzed using multiple filter analysis and p-tau stacks. In addition a pseudo Monte Carlo technique has been used to match observed waveforms by adding surface wave modes together.

Results

Preliminary results are not yet available due to the nature of the sediments, e.g. little dispersion. Modeling indicates that the precise nature of both the shear wave velocity and anelastic attenuation are required to model the data. A 77 page report on a suite of computer programs for f-k and p-tau methods of synthesizing seismograms has been prepared.

Earthquake Hazard Studies in Northeastern United States

USGS-14-08-0001-19750

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Investigations

During the past decade Lamont-Doherty Geological Observatory (LDGO) has been operating a network of short period seismic stations in the states of New York, New Jersey, and Vermont. The present configuration of this network consists of 38 stations and two SMA-1 strong-motion accelerographs. Two stations are currently three-component sites, and we plan to convert two additional stations to three-component sites. Data for local earthquakes and quarry blasts recorded by this network and other networks in New England and adjacent Canada are analyzed to study the earthquake hazard, the seismicity, the relationship of earhquakes to geologic structures, the state of stress, and the crustal and upper mantle velocity structure in the northeastern United States and adjacent Canada. The results of studies of the network data are helping to enhance our knowledge of seismic phenomena and earthquake hazard in the Northeast.

Results

During the first quarter of this year our efforts were primarily directed towards preliminary studies of a number of relatively large earthquakes that recently occurred in the Northeast. These studies involved preliminary hypocentral locations, aftershock monitoring, and intensity surveys for the following events:

(1) Long Island Sound - 21 October 1981;
16:49:07.1 UT; 41.1N, 72.6W; $m_b \approx 3.5$

(2) New Brunswick, Canada - 9 January 1982;
12:53:52 UT; 47.0N, 66.5W; $m_b \approx 5.7$

(3) New Hampshire - 18 January 1982;
00:14:43.2 UT; 43.5N, 71.6W; $m_b \approx 4.8$

We have completed our study of earthquake magnitudes and seismicity in the New York City metropolitan area. Various magnitude scales have been analyzed to determine an accurate measure of the size of earthquakes in this region. A signal-duration magnitude scale is found to be the most useful magnitude scale for the events studied, and other magnitude scales are used to compare signal-duration measured from the local network data with m_b and M_L. During this period of operation of dense microearthquake networks in the New York City region (1970-present) the largest earthquake in the study area occurred near Cheesequake, New Jersey on January 30, 1979. The magnitude of this event (m_b) is estimated to be approximately 3.0. A seismicity map of the larger events suggests that earthquakes in the New York City metropolitan area are primarily concentrated in geologic structures that surround the Newark (Triassic-Jurassic) basin.

Determination of the crustal and upper mantle velocity structure is a prerequisite for accurate earthquake locations and meaningful interpretation of the seismic data. For much of New York State and areas adjacent to it, such information was either non-existent or very limited in scope prior to the installation of local seismic networks. Thus far, tentative crustal and upper mantle velocities have been deduced from P and S wave travel time studies in parts of New York State. The resulting preliminary velocity models are used in our earthquake location procedures. Our more recent investigations of relative residuals of P-waves from distant earthquakes and nuclear explosions indicate that residuals vary from -0.3 to +0.6 sec. The pattern of residuals is found to be constant to within 0.15 sec in broad subregions, but to vary markedly between subregions. Since the transition zones between subregions are no more than 50 to 100 km wide, most differences in velocity appear to be situated in the upper 100 km. This result appears to conflict with the limited amount of existing refraction data which indicate that very little of the differences in travel time can be associated with the crust or uppermost mantle.

Reports

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Earthquake Hazards in the New York City Region: Deployment of a Portable Network of Digitally Recording Seismographs

USGS-13-08-0001-20552

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Investigations

Recent Lamont-Doherty studies of seismicity in the New York City metropolitan area suggest that earthquakes in this region occur in geologic structures that surround the Newark basin. Although significant attention has been paid to seismic activity associated with the Ramapo fault zone, other geologic structures that surround the Newark basin appear to also have had significant earthquake activity during the decade of microearthquake recording in this region. Our proposal emphasized seismic activity near the southwest extensions of the Ramapo fault zone. Our research since the writing of the proposal suggests that earthquake activity is also quite significant to the east of the Ramapo fault zone in the Manhattan prong and Atlantic Coastal Plain provinces. Our revised program of research emphasizes investigations of earth structure and seismicity associated with geologic structures that lie to the east of the Ramapo fault zone in an attempt to determine whether these regions are capable of generating large earthquakes.

Results

Significant changes in the scope of work and schedule for this contract have been necessary because of late receipt of equipment and inadequate hardware and software for the research projects discussed in our proposal. The current configuration of stations differs from that originally proposed for two reasons. First, the maximum pre-event memory that we will be able to program in the PDP 11/03 system is only about 7 sec. This limits the diameter of the array to be less than about 70 km if event detection is to be successfully employed. Second, the cost of telephone lines has increased significantly since the writing of the original proposal, which also limits the diameter of the array.

The current configuration of the portable network increases station coverage in the Manhattan prong and Coastal Plain provinces. Three vertical component stations are operating and a fourth station is expected to be installed. All four stations are eventually expected to be 3-component sites, which will provide a complete 3-dimensional record of ground motion.

The software for the PDP 11/03 was not adequate for our purposes for a number of reasons. For example, the pre-event memory is, at present, only about 2 sec long, and the tape format, at present, does not have end-of-file markers at the end of each event recorded. Without such end-of-file markers it becomes difficult and very time consuming to search for seismograms recorded on the tape. We have hired

Phill Gross, who developed the software for this system at Pennsylvania State University, to correct these problems and to finish developing the software to make the portable network more useful.

Reports

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Central and Eastern U.S. Tectonics

9730-03399

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Investigations

1. The principal activity of the report period has been in final analysis of the data gathered in earlier stages of the project, including preparation of reports. Simpson and Kane prepared first drafts of reports on crustal studies and seismicity of the eastern United States that were submitted to the Branch. Hildenbrand continued the study of basement features of the midcontinent region using magnetic data.

Results

1. Kane concludes that much of the crustal structure underlying the appalachian orogen may be made up of rift systems that were developed as part of the continental shelves of the proto-Atlantic. These systems were brought together in the continental collision (Europe-Africa, North America) that happened in Paleozoic time. A strong regional gradient is interpreted as marking the suture zone of the collision. Seismicity northeastward from Virginia is concentrated along the proposed suture zone and particularly near its offsets. The gradient offsets may be expressions of transform faults in the plate southeast of the suture zone. Secondary features of both the gravity and magnetic fields such as discordant trends of secondary anomalies, and disruptions in major anomaly trends are interpreted as evidence of a transverse structural zone extending from central Virginia to south-central Tennessee. Correlation of the zone with the northwest edge of the southern Appalachian allochthon and with the northwest margin of the major Appalachian gravity low suggests that the zone may be related to the northwest boundary of a depression of the crust caused by the load of the allochthon. A zone of seismicity is located along and south of the zone. A transform fault is interpreted to extend southeast from the suture zone through the vicinity of Charleston, SC although the azimuth of the transform is not well constrained.

2. Simpson concludes that the new compilations of gravity and terrain data suggest the presence of a plexus of interconnecting Precambrian structures that may explain the seismic zone extending from the Gulf of St. Lawrence to the Mississippi embayment. He suggests that the seismicity may be localized by structural elements within the zone whose trends are at a significantly large angle to the regional E-W to NE-SW compressive stress field.

3. Hildenbrand compiled various types of filtered magnetic-anomaly maps to enhance lithologic and structural boundaries in the midcontinent region. First and second vertical derivative filters were applied to the data to resolve or sharpen anomalies of small areal extent. Directional filters proved useful in identifying trends in magnetic basement. Lithologic variations were enhanced by draping tha data at a constant elevation above the

Precambrian (magnetic) basement. A map of the ratio of magnetization contrast to density contrast was developed from the magnetic and gravity data. This latter map exhibits many anomaly patterns that should prove useful in identifying regions characterized by particular rock types.

Reports

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Quaternary Stratigraphy and Bedrock Structural Framework of Giles County, Virginia

9510-02463

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Investigations

1. A bedrock map of Giles County and adjacent areas was compiled at a scale of 1:125,000. The map includes the currently active Giles County Seismogenic Zone as identified and defined by G. A. Bollinger and R. C. Wheeler.

2. Reports on surficial deposits in Giles County were prepared for publication by Hugh Mills and submitted for review.

Results

1. Analysis of bedrock structure has revealed no definite surface effect that can be related to the Giles County Seismogenic Zone. However, a topographic trend lies parallel to and 10 kilometers to the southeast of a vertical projection of a part of the zone. No connection can be demonstrated as yet; the parallelism is either a coincidence or the result of very subtle control which is not recognizable in the bedrock compilation. Similarity of the trend of the seismogenic zone to that of Central Appalachian structures suggests a possible relationship, which would indicate an age of at least Late Paleozoic for the zone. Implications for the evolution of Appalachian Foreland deformation are under study.

2. No evidence of neotectonic activity has been discovered in the investigation of surficial deposits. No examples of faults or of soft-sediment structures such as sand blows or liquefaction features were found. Terrace distribution can be explained by variations in climate during the Pleistocene, but cannot as yet be interpreted to suggest vertical displacement. Mapping of terrace deposits and analyses of colluvial deposits on mountain slopes provide a record that may be used to support the assignment of neotectonic effects in this area when such processes are better understood.

Reports

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Active Seismology in Fault Zones

9930-02102

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Investigations

1. Collection and preliminary analysis of seismic refraction data in several locations in the Great Valley of California and adjacent Coast Ranges and Sierran foothills (A. Walter and W. Mooney).

2. Collaboration with C. Wentworth and others in the purchase and processing of existing seismic reflection data in the Great Valley and contracting for new data (A. Walter, W. Mooney, and W. Kohler).

3. Development of traveltime and time-term maps of the Imperial Valley region of southern California (W. Kohler and G. Fuis).

4. Continued analysis of a seismic refraction profile in the Mojave Desert region of California (G. Fuis and A. Walter).

5. Collaboration with D. Howell and others in construction of Continent-Ocean Transect C-3, from southern California to New Mexico (G. Fuis).

Results

1. Refraction data was collected in the Great Valley between Stockton and Fresno, California, along five reversed profiles. Three of the profiles are subparallel to the Valley axis and are located on the west side, at the center, and on the east side of the Valley. Two transverse profiles extend from the Diablo Range to the Sierra Nevada and are located near the latitudes of Tracy and Los Banos, California. Along each profile, 100 seismic cassette recorders were deployed at spacings of 1.0 to 1.5 km and shots were fired at shotpoints located near the endpoints and centers of the profiles. The collected traveltime data will be used to construct a crustal velocity model for the Great Valley between the Coast Ranges and the Sierra Nevada. This model will better delineate the feature producing the aeromagnetic and gravity highs in the Great Valley. Refraction data was also collected along two end-to-end 120-km long profiles extending from Morro Bay, on the California coast, across the southern Great Valley to the Sierra Nevada east of Delano,

California. For each of these profiles, the 100 cassette recorders were deployed at 1 to 1.2 km intervals and shots were fired at four shotpoints spaced 20 to 50 km apart.

2. Vibroseis reflection data was purchased from Western Geophysical along the route of our seismic refraction profiles from Morro Bay to the Sierra Nevada. The refraction data are being analyzed to provide velocity-depth functions that can be used to reprocess the reflection data. Geophysical Systems Corporation has been contracted to collect vibroseis reflection data along our refraction profile through Los Banos, California. The line is east-west and 120 km long. The reflection records will have a two-way time dimension of 15 seconds in order to study the deeper parts of the crust.

3. A contour map of reduced traveltimes from our most widely recorded shotpoint in the Imperial Valley region of California (Fuis and others, 1983, U.S.G.S. Professional Paper 1254, Ch. 3) reveals in plan view the trend of a number of large buried scarps in the Imperial Valley region and also reveals something of the subsurface nature of the known geothermal resource areas. Traveltimes from several other widely recorded shotpoints in the Imperial Valley region have now been contoured in a similar fashion. The new contour maps confirm many observations made from the first map but also reveal new features. All of the traveltime data were next integrated to produce a time-term map, which in principle eliminates distortions of features seen on traveltime maps and can be converted to a sediment isopach map. Striking features seen on this map include the following: 1) A complex buried scarp along the west side of the Imperial Valley. This feature, seen on the earlier traveltime maps, trends roughly north-south; it appears to be terraced and also segmented. The Superstition Hills fault and Superstition Mountain fault bound one segment and northwest-striking buried faults(?) farther south appear to bound other segments. 2) A prominent scarp is also seen northeast of the Salton Sea and appears to be a continuation of the modern mountain front beneath the sediments. (We had surmised earlier than such a scarp existed about 10 km farther southwest,along the San Andreas fault.) 3) Geothermal areas are reflected on the maps as areas of relatively low time-terms. These areas have varied shape and relief on the map. The Salton geothermal area has the strongest relief and is the largest areally. In conjunction with this investigation a computer program was written for machine contouring of data points. We have experimented extensively with the program in order to establish optimum grid spacing and distance weighting functions.

4. Ocean-continent transect C-3, constructed for the U.S. Geodynamics Committee's Transect Program, extends from offshore southern California, across southern California and Arizona to central New Mexico.

The transect consists of: 1) a one-degree- (110-km-) wide, 1:500,000 geologic strip map, 2) two 1:500,000, ve 1:1 geologic cross sections, one colored by age, the other by lithotectonic "kindred", 3) gravity, magnetic, heat flow, and seismic-velocity profiles, and 4) ancillary diagrams explaining the progressive tectonic development of the region. The major tectonic provinces crossed by the transect include, from west to east, the southern California borderland, the Transverse Ranges, the Peninsular Ranges, the Salton Trough, the southern Basin and Range, the northern Sierra Madre Occidental, and the Rio Grande Rift provinces.

Reports

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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 New Jersey to zones of seismicity in and around the Newark Basin.

2. Core drilling in the vicinity of the Ramapo fault.

3. Detailed gravity modeling of the northern end of the Newark Basin.

4. Tectonic framework of Mesozoic rift basins in southern New England and relationship to current seismicity.

Results

1. Bedrock mapping of the West Point quadrangle, N.Y., was completed in August by H. Helenek and Ratcliffe. Our results reveal abundant development of Mesozoic(?) horst and graben tectonics within Proterozoic Y basement of the Hudson Highlands. Locally the course of the Hudson River (N,NNW) is controlled by closely spaced brittle fracturing associated with "dog legs" in the general northeast trending fault patterns. A major zone of Mesozoic(?) right oblique-normal or strike slip fault, the Beacon-Lagrangeville fault marks the northwest border of the Hudson Highlands from Cornwall, N.Y., and extends northeastward to Stissing Mountain. From Cornwall southeastward, this fault appears to be continuous with the southeastern border of the Green Pond syncline in New Jersey and with the Flemington fault of New Jersey. The strike length of this Mesozoic(?) fault is about 200 km. The 150 km segment southwest of Lagrangeville is spatially associated with seismic activity; the northern part is aseismic. Reconnaissance mapping by Ratcliffe in the Lower Hudson River Valley suggests the other zones of brittle faulting comparable strike length are present east of Poughkeepsie as far north as Kingston, N.Y. A large area of the Hudson River valley area appears to have been affected by Mesozoic faulting.

2. Core drilling of 480 feet of sediments on margin of the Newark Basin shows that limestone fanglomerate unconformably overlies Cambrian and Ordovician marble along the east-west margin of the basin at Stony Point. Basal sediments of the Newark Basin here contain abundant locally derived detritus from immediately north of the basin as well as clasts of brecciated dolostone that were contributed from a border fault that was active during sedimentation. These results rule out a fault contact at the north end of the basin and require that Paleozoic rocks immediately north of the basin were beveled prior to Triassic deposition.

3. Three hundred and six gravity stations in a grid pattern were surveyed and established in the northern part of the Newark Basin by Wendy Rosov and Ken Kodoma of Lehigh University. These data points have been integrated with earlier traverses of Marty Kane and Robert Kucks. Data reduction (elevation, latitude, and terrain corrections) have been completed for all 406 stations. Preliminary geologic models utilizing available core data and density determination have been formulated for modeling of two dimensional gravity profiles across the Newark Basin.

4. Analyses of fault and fold patterns within Triassic-Jurassic sediments of the Newark Basin and of fault-movement-plans outside the basin suggest that the Newark Basin formed through syndepositional right-oblique normal faulting. This pattern is consistent with formation of the basin as a right slip pull-apart basin rather than by listric normal faulting in a simple extensional regime. If this model is correctly applied to the Newark Basin then faults bounding the basin (Ramapo-Flemington faults) are not shallow dipping listric faults at the hypocentral depth of 10-15 km beneath the Ramapo seismic zone.

Reports

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MISSISSIPPI VALLEY SEISMOTECTONICS

9950-01504
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Investigations

1. An integrated geological and geophysical investigation to search for Quaternary surface faults and to determine rates of recurrence of large earthquakes in northeastern Arkansas is in progress. The study area is situated in the Mississippi Valley and lies along the NE-SW trending zone of microearthquakes that parallels the axis of the Reelfoot rift. The study consists of four separate and sequential tasks:

    1) Aerial photo interpretation

    2) Field mapping of suspected faults and liquefaction features

    3) Minie-Sosie reflection seismology--high resolution seismic reflection profiling across suspected faults

    4) Exploratory trenching of suspected faults and liquefaction features.

2. Processing and interpretation of seismic reflection data recorded by the R/V Neecho on the Mississippi River was continued.

3. Mapping was begun in northeast China of the Tanlu fault system, a major right-lateral strike-slip fault that may be similar to large faults in the New Madrid region of the United States. The mapping was a cooperative venture with R. V. Sharp.

4. A geodetic level-line program to investigate recent vertical ground deformation in the Mississippi Embayment was continued.

Results

1. A detailed analysis of 15' topographic quadrangles and multiple scales of black and white aerial photography resulted in the identification of more than 30 features in northeastern Arkansas that were inferred to be possible surface faults. Many of the features were associated with, or in close proximity to, circular and linear sand blows. Based upon careful ground examination and mapping, the number of potential faults that were felt to be worthy of further examination was reduced to 12. High resolution Minie-Sosie reflection profiles were run over 10 of the 12 features. Though none of the lines displayed clear and unequivocal evidence of surface faulting, shallow subsurface faults were evident on a number of the lines. Shallow exploratory trenches were dug across 2 of the lines that had showed near-surface faults. No faults were detected

in the trenches. There was abundant evidence, however, of earthquake-generated sand fissures, paleo-soil deformation, and sand cones produced by the explosive force of the sand-extrusion process. Carbonaceous material collected from the trench walls is being radiometrically dated to determine the age of these liquefaction features. Additional trenches are planned across other nearby possible faults.

2. Processing of the Mississippi River boat reflection data is about 2/3 complete. The processed profiles, matching line drawings with interpreted stratigraphy and structure, and brief texts are being published as a series of Miscellaneous-Field Maps.

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Earthquake Hazard Studies in Southeast Missouri

14-08-0001-19751

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Goals

1. Monitor seismic activity in the New Madrid Seismic Zone, using data from a 35 station regional seismic array.

2. Conduct research on eastern United States seismic sources using array and supplemental data.

Investigations

1. The project consists of monitoring data from a network of 26 USGS and 8 NRC seismograph stations located in the central Mississippi Valley. These will be augmented by 8 additional USGS and 8 additional NRC stations in the near future. In addition telemetered data from eight Tennessee Earthquake Information Center stations in the southern part of the New Madrid Seismic Zone will be recorded digitally. The seismic data are recorded on 16mm film and on a PDP 11/34 digital computer. Since the initial deployment of seismograph stations in July, 1974 1718 earthquakes have been located through the end of June, 1982. The locations of these are shown in Figure 1. Operation, analysis and publication of quarterly bulletins are an ongoing task. Cooperative arrangements with other organizations have been made in order to make the quarterly published Central Mississippi Valley Seismic Bulletin as complete as possible.

2. The implementation of advanced analysis tools on the PDP 11/70 is progressing. Following a modification of our hypocenter program by the University of Washington, we are modifying ours again to take into account their improvements as well as to make use of information on gain changes of our network stations. During this period, considerable effort went into making the USGS Southern Great Basin software more efficient and compatible with our own. The device independent plot filters running under UNIX* were made much more usable. Central to this was the implementation of an interface between FORTRAN Calcomp compatible calls and the plot filters. A frame command was implemented as well as clipping when the plot call exceeds the physical plotting area.

*UNIX is a Trademark of Bell Laboratories.

3. Mr. E. Haug, NRC effort project engineer, has made great strides in enabling the PDP 11/70 to perform real time seismic trace digitization when operating under the UNIX operating system. A real time seismic data acquisition system for the PDP 11/70 written by Herriot et al (1982) has been installed and is being tested. We are now ready to compare various algorithms for event detection.

Results

1. During the first six months of 1982, 113 earthquakes have been located, including 17 events with $m_{bLg} > 3.0$.

2. Major research results are listed in the papers below. Operational results include upgrading of field instrumentation packages and inclusion of teleseism readings in the Quarterly Bulletins. The use of a New Madrid refraction earth model given by Mooney et al, makes most earthquakes locate at depths 4.5 km deep in the embayment, i.e, in the crust and not in the sedimentary section.

Publications

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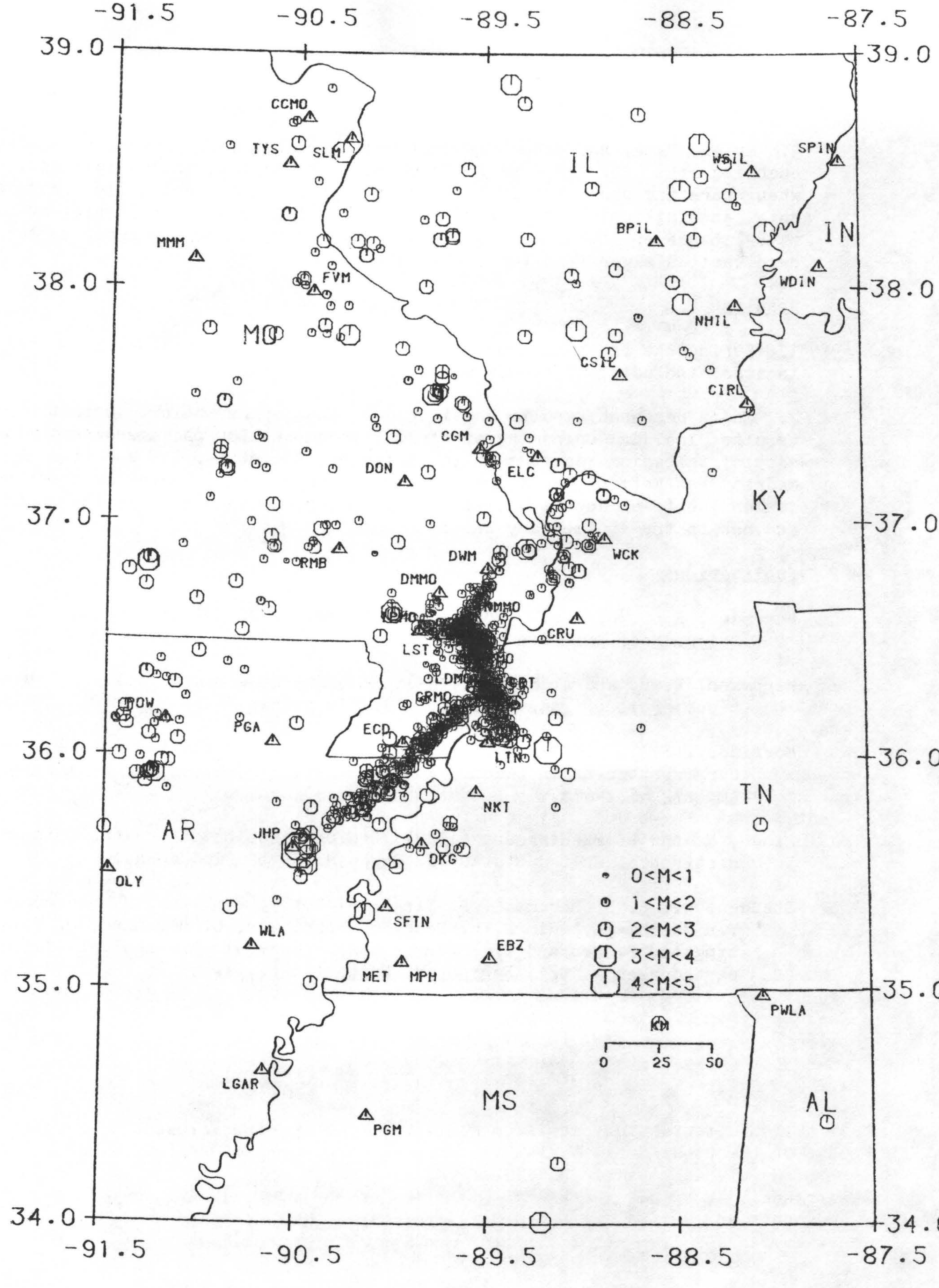

REPORTING PERIOD 01 JUL 1974 TO 30 JUN 1982
LEGEND . ▲ STATION ⊙ EPICENTER

Glacial Lake Passaic

9510-02724

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Investigations

Detailed mapping of the surficial geology of the Pompton Plains 7.5′ quadrangle and part of the Paterson 7.5′ quadrangle was completed in FY ′82 by G. J. Larson, assisted by J. M. Burnhard. Glacial Lake Passaic stratigraphy and associated deposits of the Late Wiconsinan terminal moraine were integrated with upland moraine deposits to the west, near Boonton, N.J., and deposits in the Watchung uplands to the east near Paterson. Continued surface mapping in the Great Swamp basin and in the vicnity of Bernhardville completed 40% of the mapping in the Chatham quadrangle. Shallow seismic profiles of the Great Swamp basin were analyzed and tied to other subsurface data.

Results

1. Mapping of deltaic and lake bottom deposits confirmed the ice-marginal position of two compound deltas, each containing a higher Moggy Hollow-stage and a lower Great Notch-stage delta plain, at Preakness and at Pequannock. The amount of postglacial tilt of the Moggy Hollow-stage water plain, upward to the north-northeast about 0.65 m/km, is consistent with tilt indicated by surface altitudes of the younger Great Notch-stage deltas and the altitude of Great Notch. Thus, crustal rebound probably began after ice retreat from the basin and draining of the lake.

2. Detailed mapping of a surface fluvial sand unit which conformably overlies varved clay in the vicinity of Green Village at the northern edge of the Great Swamp basin, has shown that the sand thickens to more than 3 m at its northern end. Here, the sand contains large pebbles and has been deeply incised by subsequent erosion. Erosional channels that cut through the sand and into underlying varved clays are filled with swamp deposits, including peat. The sand is tentatively interpreted as a post-lake alluvial fan that was deposited prior to glacial crustal rebound. Organic sediments that fill the erosional channels, which probably were cut during or after rebound, may yield a minimum age for the beginning of crustal tilting.

3. Seismic refraction data from a 2,400-foot-long line across the eastern edge of the Great Swamp basin, collected in a cooperative effort with F. P. Haeni, WRD, Hartford, WRD personnel from Trenton, and New Jersey State personnel, show less than 50 ft of relief on the bedrock surface. These lines and other and seismic borehole data indicate that no deep buried channel exists beneath the varved clay and sand units of the basin.

Source Characteristics of Eastern and Central United States Earthquakes from a Broad Band Digital Array

Contract 14-08-0001-20522
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SUMMARY

The purpose of this research is to estimate the source characteristics of selected earthquakes in eastern and central United States and adjacent areas in Canada, primarily, from analyses of signals recorded by the Catskill Seismic Array (CSA). CSA is a tripartite array of digital, three-component broad-band instruments, unique in eastern United States, that was located near the Catskill Mountains about midway between New York City and Albany and operated by Rondout Associates, Incorporated under contract from the Air Force Office of Scientific Research from September 6, 1980 to November 18, 1981.

A number of appropriate earthquakes have been selected for detailed study and initial analytical procedures such as frequency filtering, spectral estimation, and correlation of signals and noise across array elements have been applied to a few events. Some representative results from four earthquakes provide an indication of the quality of the data available: New Madrid, Missouri, $\Delta = 13.1^{o}$, m_b = 3.8-3.9; Rhode Island, $\Delta = 2.2^{o}$, m_b = 2.7; New Brunswick, $\Delta = 7.3^{o}$, m_b = 3.6; Keewatin, N.W.T., $\Delta = 25.6^{o}$, m_b = 4.5.

Computer programs and procedures for further analyses such as polarization filtering, beam-forming, and frequency-wave number (phase velocity) analysis are being established for use during the remainder of the project.

STUDY OF EARTHQUAKE RECURRENCE INTERVALS ON THE WASATCH FAULT ZONE, UTAH

14-08-0001-20618

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Investigations

Data on Holocene slip rates and the recurrence of surface faulting events have been obtained at locations along the Wasatch fault zone (north of Brigham City, Kaysville, Little Cottonwood Canyon, Hobble Creek and North Creek) and along the East Cache fault zone near Logan (Swan and others, 1980, 1981; Hanson and others, 1981; Woodward-Clyde Consultants, 1982). These data will be integrated with present investigations to assess the recurrence of surface faulting earthquakes for the entire fault zone.

1. Field studies are being conducted to obtain geomorphic and structural data along suspected transition zones between fault segments.

2. Preliminary age-dates on eight new charcoal samples have been obtained by Dr. Allen Tucker (Department of Physics, San Jose State University) using the accelerator mass spectrometry laboratory at the University of Arizona.

3. Mapping of the amount of cumulative tectonic displacement and the geometry of post-Bonneville and post-Provo fault scarps was completed along the East Cache fault.

Results

1. At least four major fault segments that exhibit different geologic and geomorphic characteristics have been identified along the Wasatch fault zone (Figure 1). Several sites have been selected for test pits south of Spanish Fork that will be useful for characterizing differences in the timing of the most recent surface faulting event on the North Creek and Hobble Creek segments.

2. The preliminary radiocarbon dates on the eight new samples collected along the series of short discontinuous fault scarps south of Nephi are presented in Table 1. These dates and additional dates on samples that have been submitted for analysis permit comparison with the timing of the most

recent faulting event at North Creek. The preliminary age dates are compatible with the geomorphic evidence that suggests these scarps formed at the same time as the most recent event at North Creek (post 1110 ± 60 ^{14}C yr B.P. and probably within the past 300 to 500 years) (Hanson and others, 1981; Schwartz and others, 1982)

3. Two surface faulting events that post-date recession of Lake Bonneville below the Bonneville shoreline (elevation 1564 m) 14,000 to 15,000 years ago have been identified along the East Cache fault near Logan, Utah. The earlier event occurred before the lake receded below the Provo level (elevation 1464 m) about 13,500 years ago. Scarps produced by the most recent event, which occurred post 13,500 years ago, are completely buried by Holocene alluvial fans along much of the fault trace suggesting a middle to early Holocene age. At the mouth of Logan Canyon the most recent event produced a 3-m high scarp and an associated graben across the Provo terrace. The vertical tectonic displacement across the graben is 1.4 m.

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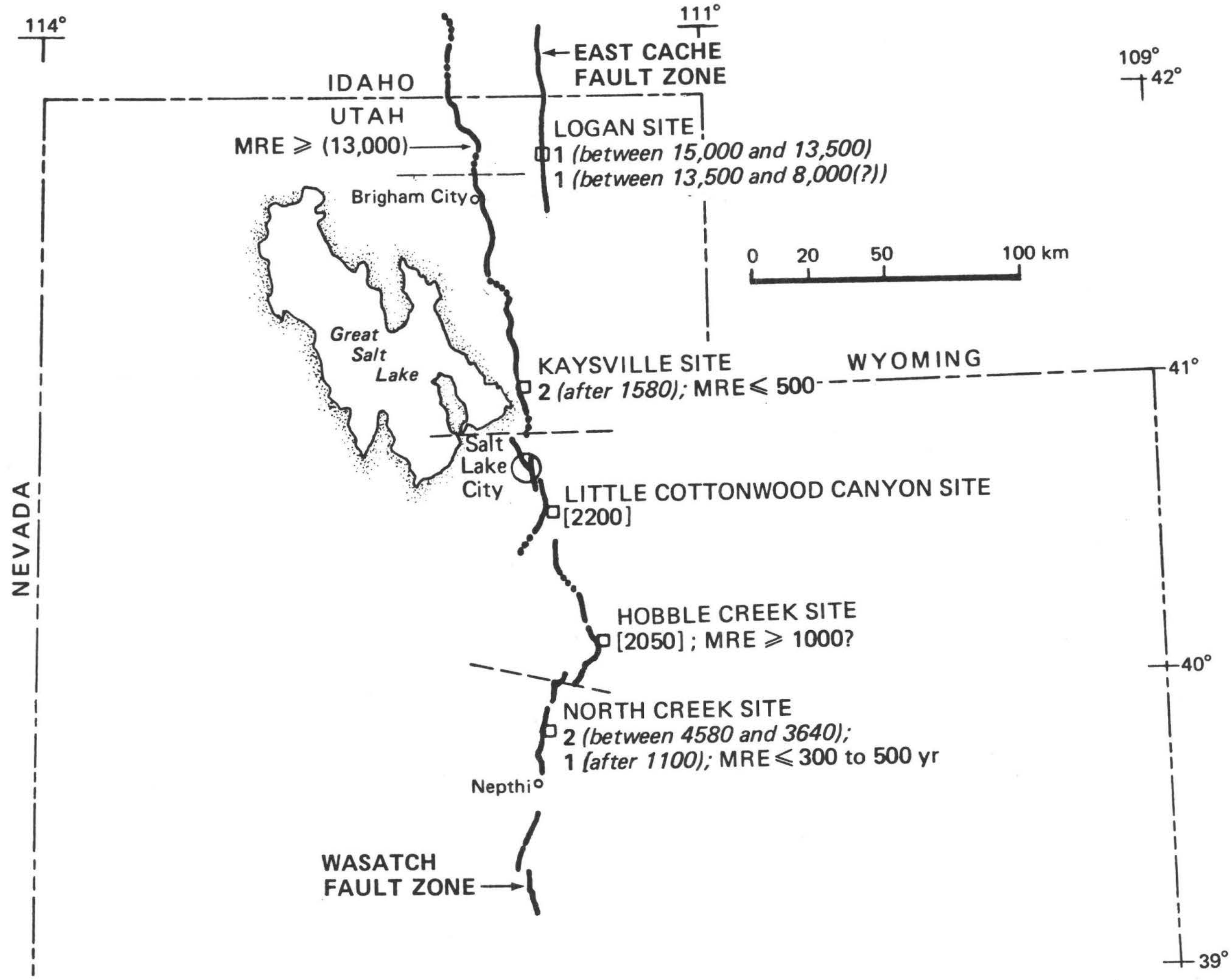

EXPLANATION

2 (after 1580): Number of events during or after radiocarbon dated (14C yr B.P.) datum

[2200]: Average recurrence in years

MRE ≤ 300: Estimated age (yr B.P.) of most recent event

— — — — Major segment boundary (?)

(Data based on Hanson and others, 1981; Swan and others, 1980, 1981; Woodward-Clyde Consultants, 1982)

Figure 1 — SUMMARY OF RECURRENCE DATA AT SELECTED SITES ALONG THE WASATCH AND EAST CACHE FAULT ZONES

TABLE 1

PRELIMINARY AGE-DATES
SOUTHERN WASATCH FAULT ZONE

Sample No.	Age-Date (14 C yr B.P.)	Location	Comments
1-81-1	7200 ± 1200	Pole Creek NE¼, SW¼, Sec 22, T11S, R1E Santaquin 15' quadrangle	Detrital charcoal from faulted alluvium upstream from main fault scarp; depth ~2.5 m
1-81-2	7200 ± 600	Pole Creek	Same as above; depth ~4 to 5 m
1-81-4	3040 ± 250	Deep Creek C, Sec 18, T15S, R1E Nephi 15' quadrangle	Detrital charcoal from faulted alluvium
1-81-5	1570 ± 650	Deep Creek	Same as above, sample collected ~1.8 m above sample 1-81-4
1-81-7	800 ± 400	Deep Creek	Detrital charcoal from unfaulted alluvial fan that extends across the easternmost fault scrap; this date may provide a minimum limiting age for the most recent surface faulting event
1-81-9A	1750 ± 350	Pigeon Creek SW¼, SW¼, Sec 28, T14S, R1E Nephi 15' Quadrangle	Detrital charcoal from faulted alluvium, depth 1.18 m
1-81-9C	2100 ± 800	Pigeon Creek	Same as above, depth 0.8 m
1-81-10	2000 ± 750	Crystal Springs Ranch Road SE¼, NE¼, Sec 15, T16S, R1W Skinner Peaks 7½' Quadrangle	Detrital charcoal from below strath terrace inset in faulted alluvial fill

Structural Framework of Eastern United States Seismic Zones

9950-02653

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Investigations

The overall project goal is to help provide a geologic basis for hazard evaluation in the East. The justification for a geologic basis is that the record of seismicity is too sparse to characterize hazard by itself. The strategy is to identify types of structures or structural associations that are seismogenic, and to map their areas of occurrence.

Work continued to use new and existing data and understanding of Appalachian structures and tectonics, to identify and map the types of faults most probably responsible for seismicity in and near Giles County, southwestern Virginia. Work also expanded to apply results to other areas in the East. Efforts were coordinated with faculty at Virginia Polytechnic Institute and State University (especially G. A. Bollinger), other USGS projects, and other pertinent investigators in state surveys, universities, and elsewhere. Work included, in decreasing order of time spent:

1. Compilation and interpretation of a map of known continental rifts in the central and southeastern U.S., to test the suggested association between damaging seismicity and rifts. See Results 1, 2, 3, and 4.

2. Descriptions of seismicity in and near Giles County, Virginia, and geological evaluations of the most probable types of causative faults, have been published as an Open-File Report. The OFR is being edited for publication as a Professional Paper, probably in late calendar 1983. A summary report has been accepted for publication by Science. See Reports 1 and 2.

3. Analysis of stratigraphic data to seek evidence of Devonian tectonism at the Allegheny Front in Maryland, West Virginia, and Virginia. A manuscript of 55 pages is in review for a Festschrift honoring W. Lowry, and a supporting Open-File Report of 43 pages is also in review.

4. Initial planning of a multi-sheet seismotectonic map of the East. The intent is to examine and test spatial associations of geologic, geophysical, and other factors that are thought to contribute to damaging eastern seismicity, and to identify complexes of factors that are necessary and sufficient for seismicity. Each map sheet will show one or more factors. All sheets will be at a scale and projection that allow them to be overlain on existing or planned geologic and tectonic maps.

Results

1. A compilation of known continental rifts of the central and southeastern U.S. shows that as much as one third of the present continental crust may be underlain by rifts of Keweenawan, early Paleozoic, and Mesozoic ages. Some aborted their openings, to remain as graben systems in continental crust. Others continued to open, to become systems of normal faults embedded in passive continental margins of the Iapetus and Atlantic Oceans. No one type of data can map or distinguish rifts of the three ages reliably, because they differ in geological and geophysical characteristics. This is well illustrated in central Kentucky, where Keweenawan and Paleozoic rifts cross. The older rift is recognizable by Bouguer gravity highs and flanking lows, and by short wavelength, high amplitude magnetic anomalies, both produced by its mafic filling. The Paleozoic rift has little or no expression in either potential field because it is filled with nonmagnetic clastic and carbonate rocks of roughly the same density as the surrounding basement.

2. In the three most seismically active areas in the central and southeastern U.S., dense local networks have established spatial patterns of seismicity that are clear enough to test geological interpretations. In each area, the seismogenic faults most probably originated or were reactivated as portions of rifts: (1) an early Paleozoic graben system that extends from the Mississippi embayment at least through western Pennsylvania and includes the seismicity near New Madrid, Missouri, (2) an early Paleozoic passive margin that extends the length of the Appalachians and includes Giles County, Virginia, and (3) the early Mesozoic passive margin of the Atlantic Ocean that includes Charleston, South Carolina. A subjective list of the nine most active areas in southeastern North America, including the three just named, includes eight that fall in aborted rifts and successfully rifted terrains of all three ages, and one area that falls far from known rifts or rifted terrains. If there were no association between rifts and seismicity, three of the nine areas should fall in the rifts or rifted terrains. For eight to do so is significant at 0.001. Thus the association appears worthy of further investigation, and may apply over much larger areas than hitherto thought. JHD relocations of instrumental earthquakes by D. Gordon and J. Dewey (Project 9920-01901) show a strikingly high proportion of the new locations falling in rifts or rifted terrains. However some segments of rifts are not known to be active, and some seismicity occurs outside rifts, so that other factors must also be involved in the production of damaging seismicity.

3. A large eastward rise in the Bouguer gravity field runs the length of the Appalachians, and reaches amplitudes as large as 150 mgal. At least south of Vermont, it is widely interpreted as the southeastern edge of relatively intact North American continental crust, left from the rifting that gave rise to the Iapetus Ocean. Thus the gravity rise approximates the southeastern edge of the realm of expected Iapetan normal faults, which are embedded in a passive margin of early Paleozoic age. The gravity rise also approximates the line along which accreted terranes collected from the southeast throughout the Paleozoic. Today, the rise forms the northwestern boundary of the realm of Mesozoic rifted terrains, including the Mesozoic graben and the passive margin of the Atlantic Ocean. Thus Mesozoic extension occurred only in or immediately adjacent to accreted terrains, which therefore may comprise weaker crust. Those observations and inferences allow the speculation that the passive margin of the Iapetus Ocean localized that of the Atlantic Ocean.

4. The preceding results and speculation are being presented in talks at the meeting of the Eastern Section of the Seismological Society of America, and in symposia on Appalachian rifts and on neotectonics at the meetings of the Northeastern and Southeastern Sections of the Geological Society of America. A manuscript is in review for submission to the Bulletin of the Geological Society of America.

Reports

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Neotectonics of the North Frontal Fault System of the San Bernardino Mountains, Southern California

Contract No. 14-08-0001-19754

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Investigations

1. We are engaged in geologic mapping of the north frontal fault system of the San Bernardino Mountains between Silverwood Lake and Ruby Canyon. Our goal is to (a) establish a better constrained uplift history for the San Bernardino Mountains, (b) elucidate the nature and modes of deformation acting on the northern range front, (c) estimate Holocene rates of deformation along the northern range front and (d) estimate, if possible, recurrence intervals and vertical/lateral offsets for the frontal fault system. We have finished detailed mapping of the range front from Silverwood Lake to White Mountain. In this report we will present the results of our detailed mapping between Arrastre Canyon and White Mountain. The area between Silverwood Lake and Arrastre Canyon was discussed in detail in our first and second Summary Reports.

Results

1. Well-sorted fluvial sand and gravel exposed along a prominant linear ridge (Milpas ridge) at Milpas Road in the Juniper Riviera area can be traced almost continuously from Ocotillo ridge in the Marianas area to the west. These deposits constitute the bulk of the material exposed in the walls of Arrastre Canyon, and underlie most of the Juniper Riviera, Marianas area at a shallow depth. The Milpas and Ocotillo ridge deposits can be traced along the Bowen Ranch Road to Juniper flats via remnants of an old alluvial fill, defining a mid-Pleistocene(?) drainage system that was tributary to the ancestral Mojave River and fed by the Arrastre Canyon basin.

The area east of Milpas Road is characterized by segmented alluvial fans containing distinctive clast lithologies attributable to small range-front drainage basins. As older segments of the fans were abandoned through fan head trenching, younger segments emerged down-fan and buried the pre-existing bajada. Three fan segments can be distinguished in most drainages east of High Road (sec 31, R1W T4N).

A change in the character and expression of alluvial deposits at High Road accompanies the transition from Rattlesnake Mountain pluton source terrane to more resistant hornblende-quartz-monzonite and metasedimentary lithologies. This change in source lithology is responsible for an increase in range-front relief, decrease in drainage basin size, increase in supply of soil forming elements and increase in resistance of fan material to breakdown and erosion.

Each drainage east of High Road has three alluvial surface levels. The fact that these three surfaces exist in all major drainages suggests that they record regional tectonic or climatic events, and can therefore be correlated from one basin to another. If climatic in origin, these episodes may correlate with similar pulses of fan building in the Ord Mountains and Silverwood Lake areas.

2. Preliminary paleomagnetic measurements made from 39 samples collected from the Harold Formation, Shoemaker Gravel and Old Alluvium in the Cajon Pass area show that the Brunhes/Matuyama polarity reversal boundary (700,000 y.B.P.) occurs within the upper Harold Formation or lower Shoemaker Gravels. Both chemical and thermal demagnetization show a good clustering of normal vectors for samples from the Old Alluvium and upper Shoemaker Gravels. Samples from the lower Harold Formation show a good clustering of reversed paleomagnetic vectors, including reversed NRM's. Further demag steps will be necessary to resolve the precise horizon where the reversal takes place. We are currently extending this time-line to the range-front study area.

3. A pervasive system of NE-trending faults form lineaments on the upland erosion surface south of Lovelace and Grapevine Canyons. Within this system, an ENE-trending set of faults are consistently cut by members of a NNE-trending set. One of the NNE-trending faults clearly offsets a bedrock antiform about 1 km in a right-lateral sense, and lesser right-lateral offsets can be observed on other members of this group. Several members of this fault system are truncated by the range-front fault zone.

A low-angle fault zone can be traced almost continuously from Grapevine Canyon to near White Mountain. Since it is buried by alluvial deposits and cut by later high-angle faulting, it is probably mid-Pleistocene or older. The relief of the range front follows the trace of the thrust, supporting the theory put forward by Peter Sadler (1982) that uplift of the northern range front was largely accomplished on early Pleistocene thrust faults.

The reverse fault system along the north side of Ocotillo Ridge in the Marianas area continues east across the fan-head trench of Arrastre Canyon and bounds the north side of Milpas Ridge (secs 16,17, R2W T4N). Scarce bedding attitudes in the mid-Pleistocene(?) deposits of Ocotillo and Milpas Ridges define a tight, asymmetric anticline running parallel to, and just south of, the fault system. A continuous zone of markedly steeper slope on the north side of the ridge, interpreted as a degraded scarp, can be traced into younger alluvial-fan and debris-flow deposits just east of Milpas Ridge (SE1/4, sec 16, R2W T4N). The reverse fault system turns southeastward and merges with EW-trending structures southwest of Sky Hi Ranch (sec 25, R2W T4N).

A group of NE-trending faults that join the range front at Arrastre Canyon are an apparent continuation of a prominant NNE-trending lineament that we have interpreted as an extension of the Cleghorn fault (Summary #2; Dibblee, 1966; MacColl, 1964). One such fault clearly cuts mid-Pleistocene(?) Milpas/Ocotillo Ridge deposits exposed in a roadcut on the Bowen Ranch Road just east of Juniper Flats. Deflection of drainage paths and alluvial ponding are consistent with <0.5 km left-lateral motion with a subordinate east-block-down component. Disruption of geomorphic drainage patterns suggests that this motion postdates incision of the Arrastre Canyon erosion surface. Preservation of minor beheaded drainages would seem to require some motion since the late-Pleistocene. Exposures do not permit us to establish a connection between this fault and the reverse fault system at Milpas Ridge.

Another branch of the NE-trending system joins the range front between Arrastre and Lovelace Canyons. Although displacement of the old erosion surface conveys a general sense of NW-block-down motion, offsets are complex in detail. The linear ridge between Hill 4369 and Hill 4896 (secs 32,33, R2W T4N) is flat on top suggesting that the erosion surface has been forced up in a horse within the fault zone. A NW-trending antiformal structure in the basement rocks requires a cumulative right-lateral offset of about 1 km across the fault zone. Symmetry of this basement structure rules out any sizeable dip-slip component of motion. Between Lovelace Canyon and High Road the NE-trending fault system joins the frontal reverse fault system in a highly complex zone of deformation. Basement rocks show chloritization, shearing and brecciation characteristic of near-surface cataclasis.

Southeast of High Road (sec 31, R1W T4N) range-front structure converges to form a single NW-trending, high-angle fault zone. Alluvial fans containing distinctive suites of clasts suggest about 0.5 km of right-lateral offset has occurred along this structure since the time of fan deposition. Several streams show evidence of right-lateral offset leading to capture by an adjacent drainage (sec 5, R1W T3N; sec 31, R1W T4N). Shutter ridges (sec 31, R1W T4N) are underlain by alluvial fan material which has been warped up on the north side of the fault and offset right-laterally; vertical offset has been negligible.

4. There is no clear-cut evidence for Holocene activity on the north frontal fault system of the San Bernardino Mountains between Arrastre Canyon and Silver Canyon. The cones of small Holocene(?) alluvial fans show no evidence of having been broken or displaced along scarps in the Ocotillo Ridge, Milpas Ridge and High Road areas. The possibility that young alluvial surfaces have been warped cannot be ruled out.

East of High Road a 1-meter-high, south-facing scarp was found in the youngest abandoned fan surface (NW1/4, SE1/4, sec 31, R1W T4N). This surface, though relatively undisturbed, is incised to 20 meters and has a strong soil developed on it. It is doubtful that this soil could have been formed in the Holocene.

It will not be possible to estimate uplift or offset rates for the area covered in this report until some age control can be established. Our paleomagnetic sampling effort coupled with study of soils seem to offer the best prospects.

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Regional and Local Hazards Mapping in the Eastern Great Basin

9950-01738

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Investigations

1. Evaluate the anomalously high strain rate and anomalous strain signature northeast of Cedar City, Utah.

2. Continue map compilation and report preparation of fault scarps in the Elko 1^o x 2^o quadrangle, Nevada.

3. Interpret a seismic reflection profile across the Wasatch fault zone, central Utah.

4. Excavate and map a trench across one of the Holocene-age fault scarps in the Drum Mountains fault scarp system, Utah.

Results

1. The data base pertaining to the anomalously high strain rate in the Braffits Creek area, 10 km NE of Cedar City has been expanded to include: A. data that document historic movement at three localities where faults are crossed by fences, B. fault-slip data from 185 fault and fracture surfaces at 32 localities, and C. stratigraphic and structural data that provide critical new insight into the nature and history of deformation in the area. Together with previously available geomorphic, geodetic, isotopic, and geologic data, the new data provide a basis for estimating prehistoric and historic strain rates as well as the sense of stress in the area.

Geodetic data indicate an average rate of change in position of five monuments within the 4 km-wide trilateration network of about 0.6 cm/km/yr ranging to as great as almost 1 cm/km/yr. The manner in which these shifts are distributed and the kinds of structures on which they are accomodated over the 0.65 to 2.0 km that separate station pairs is not known. In the eastern part of the network where exposures are excellent there are many exposed faults between any two station pairs that, collectively or individually, could have accomodated the strain. Offset of 1000 year old radiocarbon-dated strata indicates an approximate 1cm/yr rate of slip on one fault, and deformation at fence crossings indicates a comparable rate over the past 100 years or so on another fault. These roughly comparable geodetically, culturally, and geologically determined strain rates (representing periods of about 1000, 100, and 4 years) are more than an order of magnitude greater than the 0.4 mm/yr uplift rate on the nearby Hurricane fault averaged over the past 1 million years. They are inferred to be characteristic only of the portion of the Hurricane Cliffs in and around the Braffits Creek area. Data from the Braffits Creek area indicate highly complex deformation that includes important components of vertical and horizontal historic and prehistoric movements. A series of en-echelon trenches and ridges along a north-trending fault represents geomorphic evidence of a dextral component of horizontal slip on that fault. Slip lines on many fault and fracture surfaces of diverse trend indicate major components of horizontal slip as do the orientations of some drag folds adjacent to those faults. Horizontal striae represent the last motion on many well-exposed faults. Shifts in the positions of surveyed monuments over a period of 4 years document important components of horizontal displacements. The displacements appear to be restricted to the area bridged by the network. That is, there is no significant postion shift between two fixed-position monuments located in Parowan Valley at the base of the Hurricane Cliffs and the most distant monument located atop the cliffs at the edge of the Markagunt Plateau. All five stations between these three stations show a significant shift to the south--the largest is 3.9 cm. There is abundant geomorphic evidence of late Quaternary vertical displacements in the form of fault scarps and numerous closed basins. Slip lines on several fault and fracture surfaces indicate major vertical components of slip. The distance between one of the network monuments and an auxillary monument located in a closed depression within the area covered by the network increased by 18 cm in 4 years. This extreme distance increase is probably associated with a strong component of differential vertical displacement of the two stations. Slip lines on similarly oriented faults at some exposures record highly diverse slip directions, and on some individual faults there is evidence of two slip episodes of highly diverse orientation. Collectively these geomorphic, geologic, and geodetic observations indicate very complex deformation. A preliminary effort to extract a stress tensor from fault-slip data yields a poorly constrained least principal stress oriented approximately north-south. The deformation is aseismic at current monitoring thresholds.

2. The fault scarp map and accompanying report for the Elko 1^{o} x 2^{o} quadrangle is about 80% complete.

3. A 30-km-long 24-fold seismic reflection profile has been obtained across the late Cenozoic Wasatch fault zone (WFZ). In the vicinity of the profile, the WFZ lies near the eastern limit of major Mesozoic thrusting. The seismic data and detailed gravity data were acquired to investigate the subsurface geometry of the WFZ and to examine the relationships between it and the earlier thrusts. Despite complex surface structure, including steeply dipping to overturned beds, abundant horizontal and subhorizontal reflectors are observed on the seismic profile. These reflectors may be thrust-related but they cannot be correlated across the WFZ. One thrust-related (?) reflector appears to shoal as the WFZ is approached from the west. The possibility exists that abrupt shoaling of early thrusts created a zone of structural weakness along which the WFZ was subsequently localized. The seismic profiles provide no evidence to suggest that displacements on the WFZ represent a younger, opposite sense of motion on older thrust or reverse faults. Two aspects of the reflection data suggest a relatively planar, high angle geometry (as opposed to a listric and/or low-angle geometry) for the deeper structure of the WFZ: 1) truncation of reflectors near the fault zone to

depths of ~10 km. 2) synclinal structure of the sediments within the basin bounded by the fault, i.e., beds dip away from the fault zone, and reverse drag and/or antithetic faulting characteristically associated with listric normal faulting is not observed. Microearthquake studies in the region support this interpretation, indicating seismic strain release on relatively steeply dipping (~ 33^{o}-90^{o}) planes (W. J. Arabasz, 1982, written communication).

4. Data from a 17 m-long, 3 m-deep trench and adjacent natural exposures of one of the scarps in the Drum Mt. fault scarp system show that the scarp is the product of a single surface faulting event. Stratigraphic correlations across the 1.5 m-wide fault zone indicate a total vertical stratigraphic offset of 3.71 m; this compares with a surface offset of 2.66 m determined from nearby scarp profile measurements. The difference between stratigraphic and surface offset is attributed to post-faulting deflation and alluviation which tend to decrease the original surface offset with time. A natural exposure of the fault scarp shows the buried lower part of the free-face and the stratigraphy of the adjacent post-faulting colluvium. A comparison of measurements from the free-face with the total stratigraphic offset of 3.71 m suggests that between 36 and 45 percent of the original free-face has been preserved by burial. Unfortunately, no age-datable material was found. Preliminary comparison between the amount of pedogenic carbonate that has accumulated in the post-faulting colluvium and the amount that has accumulated on the ralatively stable ground surface of the upthrown block suggests that the faulting is mid to early Holocene in age.

Reports

Zoback, M. L., 1982, Interpretation of a seismic reflection profile across the Wasatch fault zone, central Utah: [Abs.] Trans. American Geophysical Union, in press.

Surface Faulting Studies

9940-02677

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Investigations

The investigations were focused on the study of statistical data related to surface faulting, in collaboration with J. J. Lienkaemper and R. K. Mark.

Results

A large fraction of the work during this period consisted of developing and analyzing data on the statistical relations among earthquake magnitude, surface rupture length and surface fault displacement. Because of the problems pointed out by Bolt (1978, Geology, p. 233-235), the data base was reexamined to estimate measurement errors in the variables. Over 100 events have been reviewed; numerical estimates of errors in reported surface length, displacement, or both, could be made for about 50 of them.

To estimate the errors in surface wave magnitude for the group of about 50 events, which occurred over a period of about 75 years, a uniform method had to be developed. Determination of magnitude for nearly half of the events must rely heavily on the data compiled by Gutenberg and Richter in preparing their 1954 report "Seismicity of the Earth". In order to produce a set of magnitudes that were consistent with the Gutenberg and Richter values, various methods of obtaining "average" magnitudes had to be compared. To facilitate the comparison, J. J. Lienkaemper developed an interactive computer program that accepts various forms of amplitude data, computes the surface wave magnitude, and performs several statistical operations on the results.

The rupture lengths, surface displacements, magnitudes, and their associated measurement errors were statistically analyzed by R. K. Mark. The analyses suggest that the measurement errors of the three variables are small compared to the stochastic variation in the data. Under these conditions, it appears that regressions based on the York (1966, Canadian Jour. Phys., v. 44, p. 1079-1086) method, which yields a single regression line, may not be as appropriate as methods that yield two regression lines (y regressed on x and x regressed on y), as suggested by Mark (1977, Geology, v. 5, p. 464-466). Whether the measurement errors should be used in the regressions, and by what methods, is still under study.

Some regional differences in magnitude-surface rupture length correlations are apparent, no matter which of the several regression methods we use. A striking difference seems to exist between the U. S. attenuation regions k 1.5 and k 1.75 of Evernden, et al. (1981, USGS Professional Paper 1223); for a given rupture length, a larger M_s is indicated in the k 1.5 region than in the k 1.75 region. Differences are also apparent between Turkey and the western U.S.; this may partly result from the fact that most of the Turkish events are on a plate boundary.

The manuscript "Evaluation of Potential Surface Faulting and Other Tectonic Deformation" was revised after review by the USGS and by representatives of the Nuclear Regulatory Commission, Corps of Engineers, Bureau of Reclamation, NOAA, and Department of the Navy. The report, which is intended for eventual use as guidance for Federal agencies in evaluating faulting and other tectonic deformation, was released as USGS Open-File Report 82-732, and a camera-ready copy was provided to the Nuclear Regulatory Commission for distribution through their NUREG series.

A report titled "American National Standard--Criteria and Guidelines for Assessing Capability for Surface Faulting at Nuclear Power Plant Sites," has been published by the American Nuclear Society. The project chief was an active member of the working group that prepared the report.

Reports:

Bonilla, M. G., 1982, Evaluation of potential surface faulting and other tectonic deformation: U. S. Geological Survey Open-File Report 82-732.

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

Contract No. 14-08-0001-19841

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GOALS

This research program was intended to use the insights gained through our previous study of the Dogtown site to establish: 1) the style of offset and deformation of late Holocene sediments, 2) the amount of strike-slip displacement that has occurred during past seismic events, 3) the number of pre-1906 seismic events, and 4) the recurrence intervals for paleoearthquakes.

INVESTIGATIONS

In order to attain the objectives outlined above, an extensive surface and subsurface investigative program was developed and initiated. The surface investigation involved preparation of detailed planimetric maps showing the San Andreas fault, exploratory trenches and offset cultural and geomorphic features. The subsurface investigation involved excavation of deep, backhoe exploratory trenches which were subsequently shored, examined in detail and carefully logged. Trenches were excavated both perpendicular and parallel to the fault. In addition, samples of carbonaceous material were collected from key stratigraphic horizons. A representative suite of samples was selected for radiocarbon dating.

RESULTS

Our investigation indicates that the style of offset of late Holocene sediments at the Dogtown site is predominantly strike-slip. The diverse and complex stratigraphic relationships exposed during the subsurface investigation, however, did not afford us the unique opportunity to measure the amount of strike-slip displacement associated with paleoearthquakes recorded at the Dogtown site. Consequently, we have not been able to establish a late Holocene slip rate for this reach of the fault. Since abrupt lateral facies changes are characteristic of the Dogtown site, juxtaposition of dramatically dissimilar stratigraphic units across the fault are not by themselves convincing evidence for pre-1906 seismic events as had been previously interpreted (Hay, et al., 1981). In addition, rupture surfaces truncated by unconformities appear, in some instances, to be highly localized relationships, and therefore, not necessarily conclusive evidence for pre-1906 seismic events. Consequently, we appear to have "lost" two of the pre-1906 seismic events previously thought to be recorded. We are presently of the opinion that only four (4) seismic events (including the 1906 event) are recorded at the Dogtown site. Unfortunately, we have not received the latest radiocarbon age dates, and therefore, we cannot further refine our recurrence intervals for paleoearthquakes for this reach of the fault (Hay, et al., 1981).

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Trenching for Seismic Activity and ^{14}C Dates, the Hollywood and Santa Monica Faults, California

14-08-0001-20523

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Introduction

Relevant published and unpublished literature and 1920s vintage aerial photographs and old topographic maps along the two fault zones were reviewed and consulting and governmental geologists were contacted regarding recent geologic investigations near the suspected fault traces. A field check was then made of the prospective trench sites included in the original proposal and some additional sites chosen during the above study. A total of seven trenching sites were chosen; five on the Hollywood fault and two on the Santa Monica fault. Three sites included in the original proposal were dropped from consideration.

Results

Three sites on the Hollywood fault were examined. Site S-4, at Greystone Park, was a road cut excavated by hand. Evidence for faulting was exposed but involved only materials thought to be mid-Pleistocene and older in age. Site S-1, at Mulholland Memorial Fountain, was excavated by backhoe. No evidence for faulting was exposed. An unfaulted sand bed was exposed 2.4 m below the surface for the full 52 m of trench. Charcoal was collected near the top of this bed. A date from this layer may provide a minimum age for the last episode of faulting. Site S-2, at Wattles Park, was excavated by backhoe. The entire 52 m of trench consisted of massive colluvial sandy silt and silty sand with no indication of faulting.

Tectonics of Central and Northern California

9950-01290

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Investigations

1. Paleomagnetic study of Permian and younger strata of eastern Klamath terrane: collaboration with E. A. Mankinen and C. S. Gromme.

2. Tectonic accretion of terranes of northern California: collaboration with C. D. Blome.

3. Relations between seismicity and crustal outgassing of carbon dioxide: collaboration with Ivan Barnes.

Results

1. Additional core-drilling was done during the report period to round out our paleomagnetic study of the Redding section of the eastern Klamath terrane. Our earlier work was in the Permian to Jurassic volcanic and sedimentary strata exposed along the Hawkins and Nosoni Creek transects of the Redding section. Paleomagnetic measurements on cores taken from these and superjacent Cretaceous strata indicate (1) equal amounts of clockwise rotations greater than 100° relative to stable North America for the Permian and Triassic rocks, (2) clockwise rotation of about 50° for the Lower and Middle Jurassic rocks, and (3) little or no rotation of the Cretaceous rocks. Also, no significant latitudinal displacement of these rocks is indicated. These findings suggest that the eastern Klamath terrane began rotating in Late Triassic or Early Jurassic time and had virtually stopped rotating by Early Cretaceous time.

2. Much effort continues to be focused on the radiolarian-bearing cherts and tuffs of the accreted terranes of northern California because of their utility in dating the oceanic-facies rocks and for timing tectonic events. During the report period, the study of radiolarian chert also revealed a seeming enigma in regard to the provenance of certain old gravel deposits that were sampled by Irwin and B. L. Court in northwest Hyampom quadrangle. The gravels contain pebbles of red radiolarian chert. They are associated with high-level remnants of an old physiographic surface developed on Klamath bedrock near the western limit of the province and are 2000 feet or more higher than the present drainage base (South Fork of Trinity River). The age of the red chert is Late Jurassic (Tithonian) based on the radiolarians. Red chert containing Tithonian radiolarians is not found in bedrock terranes of the Klamath

Mountains province, but is found in other provinces associated with the Coast Range ophiolate and with the Franciscan assemblage. The concentration of red chert pebbles suggests a nearby source. However, the nearest known suitable source for the red chert pebbles is not only many kilometers distant, but also would seem to require a transport regime different from that of the present drainage. Efforts to date the gravel beds may provide information regarding rate of tectonic uplift of the region. We also sampled basal beds of Lower Cretaceous(?) Great Valley sequence near Beegum at the south end of the Klamath Mountains. These beds onlap the "Nevadan" and older Klamath terranes, and some contain radiolarians that may aid in determining a precise upper limit to the time of accretion.

3. A world map and report (WRI 78-39) relating zones of seismicity and carbon dioxide discharges was revised, and has been submitted for technical review.

Reports

Mankinen, E. A., Irwin, W. P., and Gromme, C. S., 1982, Tectonic rotation of the eastern Klamath Mountains terrane, California [abs.]: EOS (American Geophys. Union Trans.), San Francisco meeting, in press.

Irwin, W. P., Jones, D. L., and Blome, C. D., 1982, Map showing sampled radiolarian localities in the western Paleozoic and Triassic belt, Klamath Mountains, California: U.S. Geological Survey Miscellaneous Field Studies Map MF-1399, scale 1:250,000.

Soil Chronosequences as Instruments for Dating Holocene and Late Pleistocene Faulting, Western Transverse Ranges, California

14-08-0001-19781

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Investigations

1. Develop a soil chronosequence for use in dating late Pleistocene and Holocene tectonism in the Western Transverse Ranges.

2. Study the tectonic segmentation of late Pleistocene terraces of the Ventura River near Oak View, California.

3. Study the style of tectonic deformation associated with the San Cayetano Fault on the north flank of the Santa Clara River Valley and the upper Ojai Valley.

4. Study the uplift and deformation of late Pleistocene and Holocene river terraces over the Ventura Avenue anticline.

Results

1. A soil chronosequence useful in dating late Pleistocene and Holocene geomorphic surfaces has been developed. Table 1 summarizes the chronosequence which is based upon relative soil profile development, radiocarbon dates, and in limited, controlled circumstances, rates of faulting.

2. Four terraces of the Ventura River near Oak View, California apparently are tectonically segmented by flexural-slip faulting. The faults are: located in a zone of deformation south of the Arroyo Parida fault on the north limb of a large syncline; strike northeast to east, parallel or nearly parallel to bedding; dip southeast to south towards the axis of the syncline; have reversed displacement; and are marked by abrupt linear scarps up to several kilometers long and locally up to 100 meters high.

Evidence for the flexural-slip hypothesis include: fault blocks, produced by multiple vertical offsets, are tilted southeast away from the Ventura River towards the synclinal axis; tilting generally is greater on faults closer to the axis of the syncline; and the vertical slip rate for individual faults decreases to the west towards the nose of the syncline.

Estimated ages of the terraces were determined by radiocarbon dating and correlation of soils that have developed on terrace deposits and extrapolation of the rate of vertical displacement of the Arroyo Parida fault (which is not a flexural-slip fault) determine for younger dated terraces to older terraces. Resulting age estimates for the four main late Pleistocene terraces are: Qt_{5b} - 29,000 ybp, Qt_{6a} - 38,000 ybp, Qt_{6b} - 55,000 ybp, and Qt_{6c} - 90,000 ybp. These terraces and the major faults in the Oak View area are shown on Figure 1

Assuming that the estimated chronology is correct, then vertical slip rates for individual flexural-slip faults can also be estimated from vertical displacements measured from topographic maps. This information is summarized on Table 2. Vertical slip rates range from about 0.3 to 1.1 mm/yr, but may be quite variable depending upon the location relative to the axis and nose of the syncline to which the faults are confined.

The rate of downcutting of the Ventura River during the late Pleistocene, and presumably into the Holocene, has been nearly constant, suggesting that tectonic processes have been sufficiently active to mask possible climatic effects. The rate of downcutting of the Ventura River north of the zone of flexural-slip faulting is 0.9 mm/yr compared to 1.7 mm/yr in the deformation zone immediately to the south. This latter (and greater) rate is nearly equivalent to the cumulative rates of vertical slip of the faults, suggesting there is a rough balance between rates of uplift and downcutting of the fluvial system during tectonic deformation.

3. Late Pleistocene and Holocene alluvial fans and stream terraces are being deformed by active thrust faulting along the San Cayetano fault. Intense folding of the footwall has resulted in the overturning of the Plio-Pleistocene bedrock and tilting and faulting of late Pleistocene and Holocene alluvial fan deposits. Deformation on the hanging wall has resulted in back-tilting of late Pleistocene alluvial fan gravels near Santa Paula Creek. Multiple strands of the fault are typical along its entire length with as many as three imbrications at any one locality.

Estimated rates of faulting range from 3.6 to 8.4 mm/yr at the central part of the fault, decreasing to about 0.5 mm/yr towards its western terminus. The lower rate is based on presumed displacement of Holocene alluvial fan material. The higher rate is based on bedrock stratigraphic evidence; redbed clasts are included in the oldest fan deposits in Timber Canyon which were derived from a source on the hanging wall 1370 to 1680 m stratigraphically above the present level of bedrock erosion. More than one strand has been active during the late Pleistocene and Holocene time as demonstrated by faulted alluvium, but it cannot be shown whether or not the strands move synchronously. Faulted Holocene alluvium along with Holocene footwall deformation shows that deformation continues to the present time.

Folding rates for alluvial deposits on the footwall approach 1° per 10,000 years, and associated bedding plane faulting rates are about 0.5 to 1.5 mm/yr. Folding rates for the hanging wall have not yet been determined, but based on preliminary soils geomorphic work, they appear to be less and only locally of significance.

4. Late Pleistocene and Holocene river terraces in the Ventura River Basin are folded over the Ventura Avenue anticline. At least six mappable River terraces were cut by the Ventura River during the last 80,000 years. Soil chronosequence work, in conjunction with Carbon-14 age dating

yields rates of uplift and folding. Figure 3 shows terrace profiles along the Ventura River and their estimated deformation over the Ventura Avenue anticline. Table 3 summarizes the tectonic deformation of river terraces during the last 205,000 years. A significant observation is the fact that uplift rates have been decreasing through time. This is interpreted to result from the mechanics of folding rather than a decrease in the rate of crustal shortening during the last 200,000 years. That is, assuming that the rate of crustal shortening has been constant, then the rate of uplift due to folding will be much greater in the early stages of folding than later when the dips of the folds approach 45° or greater. Figure 4 shows the theoretical uplift curve for the Ventura Avenue anticline, given the assumption of constant convergence. Also plotted on this curve are the major river terraces that have been dated by radiocarbon or, in the case of the 80,000 year old terrace, correlative with a marine terrace dated by amino acid racemization.

Reports

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Table 1. MEASURES AND INDICES OF RELATIVE AGE OF FIFTEEN SOIL PROFILES

Geomorphic Surface		Brightest moist mixed color in B horizon			Clay[2] XB/XA	Clayfilm Index[3]	Estimated age in years before present (BP)
		Hue	Chroma	Color Index[1]			
Qt_1	Car body	AC profile, no B horizon			No B	0	10-20
Qt_2	Sespe	AC profile, no B horizon			No B	0	85-135[4]
Qt_3	Orcutt 0	10 YR	3	4	0.6	0	500-5000[5]
Qt_4	Orcutt 1	10 YR	4	5	1.3	3.0	8,000-12,000[6]
Qt_{5a}	Honor Farm	10 YR	4	5	ND	4.0	15,000-20,000[7]
Qt_{5a}	Shell 2	10 YR	3.5	4.5	ND	4.5	15,000-20,000[7]
Qt_{5b}	Orcutt 2	10 YR	4	5	1.1	6.0	25,000-30,000[6]
Qt_{5b}	Bankamericard	10 YR	4	5	ND	7.0	29,000[7]
Qt_{6a}	Oak View[10]	7.5 YR	5	7	1.4	7.25	38,000[8]
Qt_{6b}	Apricot	7.5 YR	6	8	1.5	5.5	~55,000[9]
Qt_{6c}	La Vista[10]	7.5 YR	7	9	1.6	7.0	~90,000[9]
Qt_7	Timber Canyon[4]	5 YR	6	9	ND	8.0	160,000-200,000[6,11]

[1]Color index is computed by adding chroma number to hue (of moist mixed sample), where 10 YR = 1, 7.5 YR = 2, 5 YR = 3. Indices from different profiles on same geomorphic surface are averaged. To determine color, a large air-dried bulk sample was passed through a 2 mm seive, then fractionated in a mechanical splitter, moistened, hand homogenized to a putty consistency and rolled to a sphere; the latter was then pulled into halves, and color noted from one freshly broken surface.

[2]Ratio of the mean percent of clay in B horizon to that in the A horizon (computed from particle size graphs (Keller et al., 1980).

[3]This undex is based on clay film information contained in the profile descriptions and is computed by adding the percent frequency of clay film occurrence to their thickness, as follows: Percent frequency, very few = 1, few = 2, common = 3, many = 4, continuous = 5; Thickness, thin = 1, moderately thick = 2, thick = 3. For example, in the B_{22t} horizon of La Vista 2 there are "... many to continuous (4.5) moderately thick and thick (2.5) clay films..." The index would be 7.0.

[4]This age is based on the inclusion of an abraded brick fragment in the C horizon of the Qt_2 soil at Sespe Creek. This type of red fired clay brick was introduced after the capture of California from Mexico in 1848. A photograph taken in 1898 shows the terrace already present.

[5]This age estimate is collectively based upon tree rings of a number of mature oaks growing upon the Orcutt 0 surface, the degree of soil profile development, and a C-14 date (see Timber Canyon 1 profile description) on charcoal collected from a presumed buried soil in the lower part of the Timber Canyon profile.

[6]Age estimate based in part upon relative amount of displacement on flexural-slip faults between older surfaces in Orcutt and Timber Canyons, and one C-14 date. Also based upon soil correlation to well dated soils along the Ventura River.

[7]Age based on C-14 dates from correlative terraces along the lower Ventura River.

[8]Based on two C-14 dates on charcoal collected at the base of the Oak View Terrace below Oliva 1.

[9]Age based upon relative amount of displacement on the Arroyo Parida fault.

[10]These measures were taken from the buried soil portion of the profile; only the buried soil portion of the profiles of Oliva 1 and La Vista 3 are correlated to the Qt_6 geomorphic surfaces.

[11]Older and more developed soils groupd with Qt_7 have been sampled and described. Thus, a 160,000 age estimate is a minimum for Qt_7 soils, but appears correct for Timber Canyon 4 as discussed above.

Table 2. Slip rates on flexural-slip faults and Arroyo Parida fault near Oak View, California

FAULTED GEOMORPHIC SURFACE

Fault	5b ~29,000 yrs.[1]			6a ~38,000 yrs.[1]			6b ~55,000 yrs.[2]			6c ~90,000 yrs.[2]		
	Dv[3]	Rv[4]	Rd[5]	Dv	Rv	Rd	Dv	Rv	Rd	Dv	Rv	Rd
Arroyo Parida[6]	11	0.4	0.4	14	0.4	0.4	20	0.4	0.4	34	0.4	0.4
Villanova[7]	9	0.3	0.4	11	0.3	0.4	ND	ND	ND	ND	ND	ND
La Vista[7]	11	0.4	0.5	15	0.4	0.6	41	0.8	1.1	98	1.1	1.5
Devil's Gulch[7]	ND	ND	ND	18	0.5	0.7	37	0.7	1.0	ND	ND	ND
Oak View[7]	ND	ND	ND	ND	ND	ND	19	0.3	0.5			

1 BASED ON RADIO CARBON DATES

2 ESTIMATED - BASED ON RATE OF DISPLACEMENT FOR ARROYO PARIDA FAULT (Q5b and Q6a).

3 Dv VERTICAL DISPLACEMENT (meters)

4 Rv VERTICAL SLIP RATE (mm/yr.)

5 Rd DIP SLIP RATE (mm/yr.)

6 FAULT THAT CUTS SECTION

7 FLEXURAL SLIP FAULT

Table 3. Summary of Tectonic Deformation of River Terraces Over Ventura Avenue Anticline

Surface Age	Sea Level (m)	Present Displacement Above Ventura River (m)	Degrees Tilting To Present	Uplift Rate to Present (mm/yr)
16K	-120	30.5 (±10)	-	5.6 ± 3.7
20K	-90	85.3 (±10)	-	6.5 ± 2.2
29K	-41	120 (±10)	1.8 (±.5)	4.9 ± 0.8
38K	-38	175 (±10)	-	5.1 ± 0.5
~80K	-13	625 (±100)	10.6 (± 1)	7.9 ± 0.1
~205K	0	2720 (±200)	45 (±)	13.3

Summation of tectonic deformation of river terraces in the lower Ventura River area. The ~205,000 year surface is San Pedro bedrock; all other surfaces are fluvial terraces.

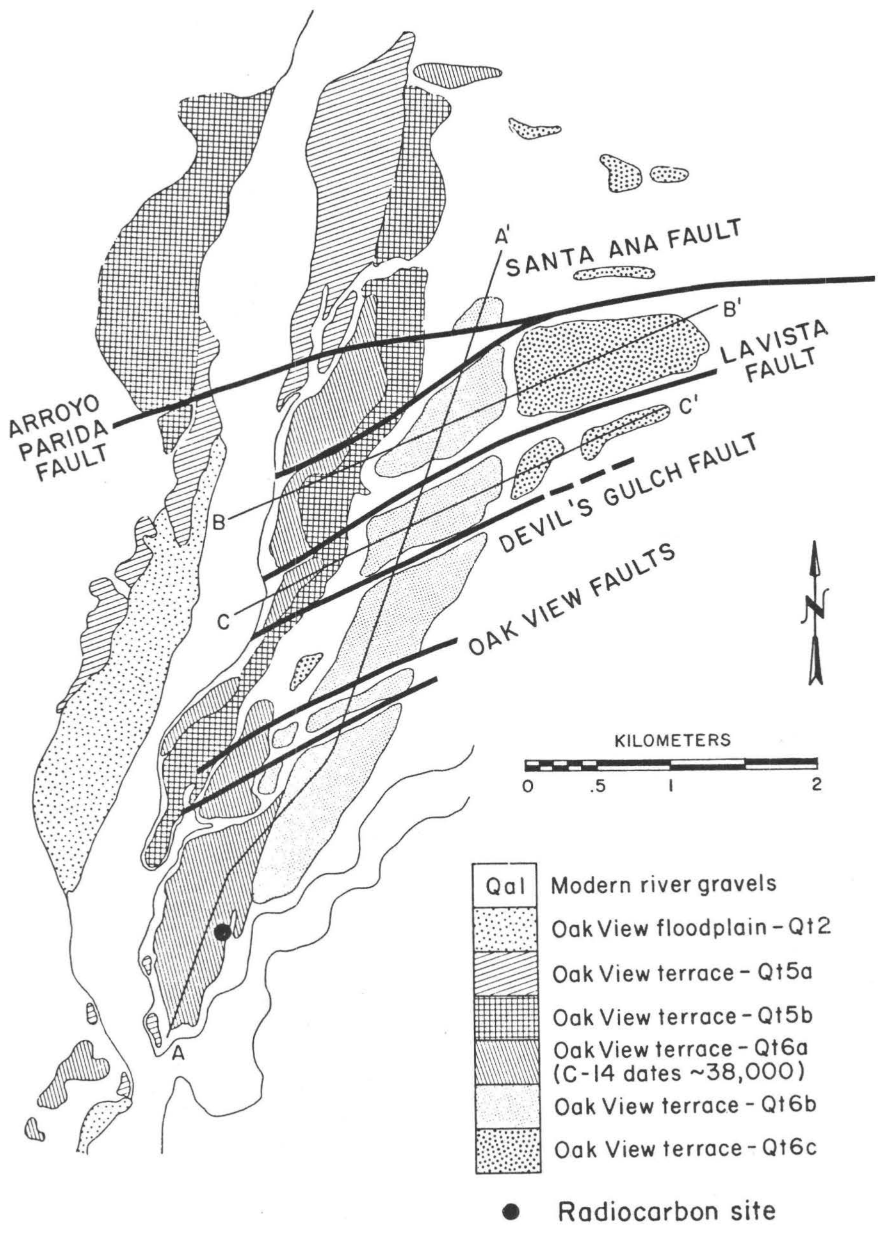

Figure 1. Quaternary units and faults of the Oak View area.

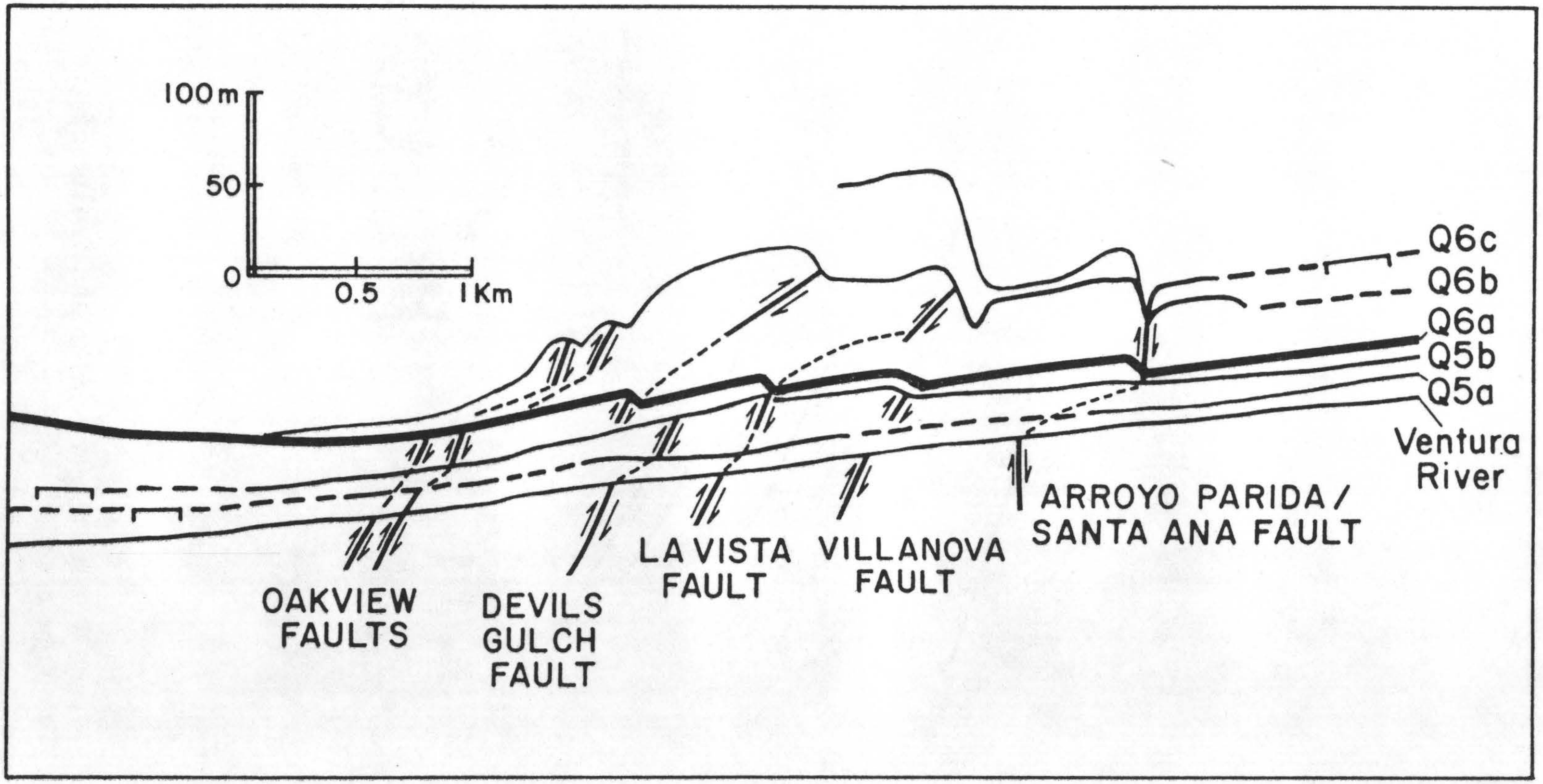

Figure 2. Terrace profiles near Oak View, California

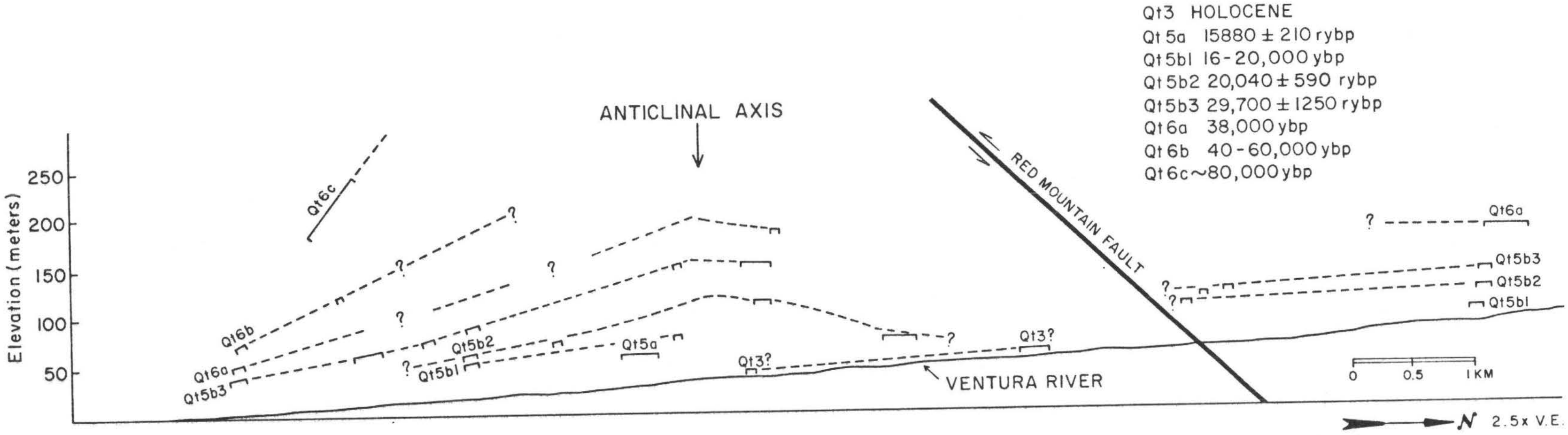

Figure 3. Terrace profiles over the Ventura Avenue Anticline.

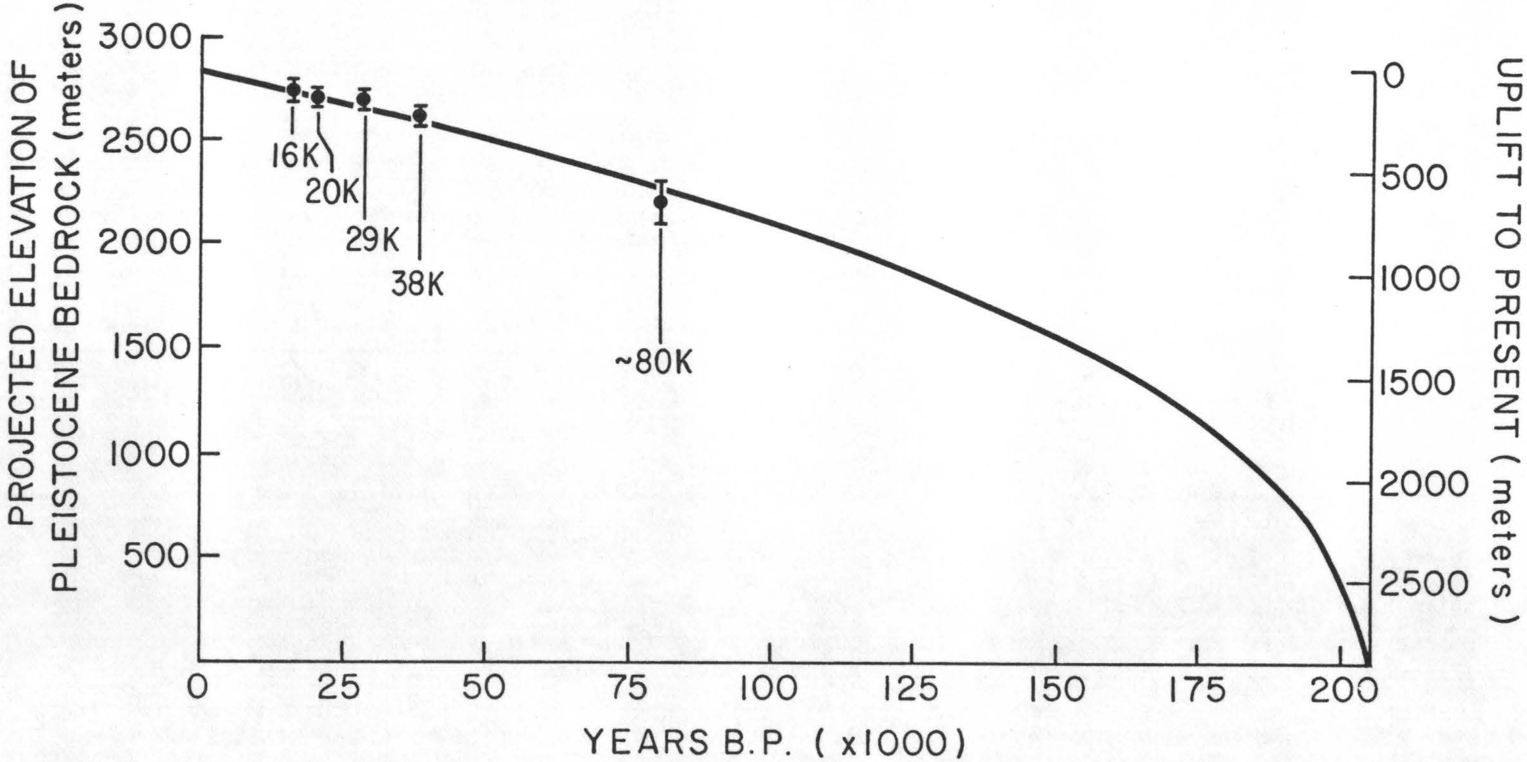

Figure 4. Theoretical uplift curve for the Ventura Avenue anticline. Dated river terraces are plotted on the curve and show uplift to present time.

Coastal Tectonics, Western U.S.

9940-01623

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Investigations

The objectives of this project are to determine patterns and rates of quaternary crustal deformation and ground response in the coastal area of he Western United States by mapping and dating marine terraces and associated marine and alluvial deposits, and evaluating geotechnical data on marine and alluvial deposits in deep sedimentary basins.

Results

1. S. Mathieson, P. Vaughan, and M. Vivrette obtained numerous well-logs from public and private agencies for a stratigraphic study of late Quaternary deposits in the Los Angeles basin under the leadership of D. Ponti. The primary objective of this study is to map the extent and deformation of marine sediments deposited during the last interglacial sea level highstand (85-125 ka BP). We hope to establish or constrain slip rates on the Newport-Inglewood and other faults in the basin. An initial goal will be to correlate marine deposits in the basin to emergent marine terraces at Pacific Palisades (cooperation with J. McGill), the Palos Verdes Peninsula and the San Joaquin Hills (cooperation with J. Vedder) using paleontological and amino-acid racemization data.

2. P. McCrory initiated a study of the neotectonics of the Mendocino triple junction in northern California. The objective of this study is to describe and date the Quaternary tectonic events in this seismically active area using stratigraphic basin analysis and geomorphic data.

3. S. Mathieson completed a study of the coastal erosion at Half Moon Bay, San Mateo County, California, where the tectonically deformed Half Moon Bay marine terrace is warped below sea level, thereby exposing unconsolidated terrace deposits to wave attack. Previous data indicated natural erosion rates (sea-cliff retreat) were about 0.3 m/yr. More accurate recent data indicate the natural rate was actually much longer. South of the Half Moon Bay breakwater (built in 1959) erosion rates have increased to as much as 2 m/yr.

4. K. Lajoie completed mapping of emergent Holocene marine terraces near Ventura in southern California and Cape Mendocino in northern California. The maximum tectonic uplift rate expressed by Sea Cliff terrace near Ventura is 5.3 m/ka. The maximum rate derived from the Ocean House terrace at Cape Mendocino is 2.8 m/ka and the maximum rate from the Big Flat terrace south of Cape Mendocino is 3.3 m/ka; typical uplift rates for most of coastal

California are 0.3 m/ka. The Big Flat terrace resulted from both tectonic uplift and rapid coastal accretion at the mouth of Big Flat Creek.

5. Paleomagnetic (J. Liddicoat) and trace-element (A. Sarna-Wojcicki) data correlate ash #15 in the Wilson Creek beds of Mono Basin in eastern California with the Carson Sink ash in the Sehoo Formation in Carson Sink, Nevada. This tephra layer, which was derived from the Mono Craters south of Mono Lake, is independently dated at 28 ka in both basins. Stratigraphic and geomorphic data indicate that Lake Russell in Mono Basin and Lake Lahonton in Nevada had similar fluctuation histories during late Pleistocene time. Both lakes stood at intermediate levels during the glacial maximum about 20-15 ka BP and rose to highstands about 13-12 ka BP. These data indicate the climate in the western Great Basin was cold and dry during glacial maximum times, but warmer and wetter (pluvial) at the end of the Pleistocene.

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PALEOMAGNETIC INVESTIGATION OF NEOGENE DEPOSITS IN THE EASTERN UNITED STATES WITH APPLICATION TO DATING TECTONIC DEFORMATION IN THE ATLANTIC COASTAL PLAIN AND RAMAPO SEISMIC ZONE

14-08-0001-19746

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Investigations

1. Processed 220 samples from cores of the Atlantic Margin Coring Project (AMCOR) for analysis by the USGS Branch of Paleontology and Stratigraphy for ostracodes and amino acid dating at the Lamont-Doherty Geological Observatory.

2. Sampled the Upper Cretaceous in USGS Core MRN-78 (374 m) from Conway, South Carolina, to assess the sediment for paleomagnetic analysis and to correlate the record to magnetostratigraphy in Clubhouse Crossroads Core-1 near Summerville, South Carolina.

3. Assisted in coring the outer Atlantic Coastal Plain near Nags Head, North Carolina, to refine the chronology in a USGS paleoclimate reference core.

4. Sampled the Chowan River Fm (Pliocene) in outcrop near Edenton, North Carolina, for comparison with polarity in the formation measured at a quarry near Portsmouth, Virginia.

Results

1. AMCOR cores 6009B (continental shelf) and 6021 (continental slope) (Hathaway, et al., 1979) contain a rich fauna that is being examined for amino acid dating by K. King (L-DGO). The D/L values will be keyed to paleoenvironmental data (ostracodes) to correlate the marine and onshore sedimentary record in the central Atlantic Coastal Plain.

2. The Upper Cretaceous of the lower Atlantic Coastal Plain was partially recovered near Conway, South Carolina, in USGS Core MRN-78 (wire-line: 374 m). Paleomagnetic samples from the Pee Dee Fm (Maestrichtian: 10.7-36.6 m), Black Creek Fm (Campanian: 36.6-175.3 m), and Middendorf/Cape Fear Fms (Cenomanian: 175.3-266.7 m) were preliminary to assess the sediment for paleomagnetic investigation in a follow-up and more complete core (>610 m) drilled in the summer 1982 near St. George, South Carolina. Only sediment in the Pee Dee Fm records reliable paleomagnetic polarity -- consecutive samples have similar inclination (positive) and relative declination (the core is not oriented in azimuth), and the normal polarity corresponds to that in much of the Maestrichtian of Clubhouse Crossroads Core-1 (CCC-1)

(Liddicoat, *et al.*, 1980) from Summerville, South Carolina. Data from the St. George core were to be compared with the paleomagnetic record in CCC-1 to improve the chronology of deposits in the southeastern Atlantic Coastal Plain.

3. The USGS Branch of Paleontology and Stratigraphy cored upper Pleistocene deposits in the Atlantic Coastal Plain near Nags Head, North Carolina. The lowermost horizon of stable paleomagnetic polarity (normal) occurs at 27 m and is interpreted to be Brunhes age (<0.73 myBP). The paleomagnetic data confirm the age assignment for the stratigraphy using fauna (ostracodes) and flora from an auger core drilled nearby in May 1981.

4. Sampled the Chowan River Fm in the bank of the Chowan River at Edenhouse Landing and Mt Gould Landing, North Carolina. Reversed paleomagnetic polarity at both sites matches that in the formation at a quarry near Portsmouth, Virginia. On the basis of stratigraphic position and fauna (mollusks)(Blackwelder, 1981), the Chowan River Fm is interpreted as Matuyama age (<2.48 myBP: late Pliocene).

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Soil Dating Techniques, Western Region

9540-02192

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Purpose: To establish data base for soil chronosequences and to conduct basic research on soils as correlation and dating tools for Quaternary surficial deposits in the western United States.

Strategy: Fourteen numerically dated soil chronosequences from varied climatic and geologic environments have been sampled (see previous report) and are being analysed to determine which soil properies are the most useful indicators of soil age and how rates of soil development vary in different environments.

Personnel: M. N. Machette, J. W. Harden, E. M. Taylor, M. C. Reheis, Glenn Dembroff, and R. M. Burke. On contract: M. J. Singer, A. J. Busacca, and Peter Janitzky (University of California at Davis); M. L. Gillam (University of Colorado at Boulder).

Investigations

1. Drafted preliminary outline for 14 individual chronosequences with description of regional geology, Quaternary stratigraphy, soil sites, and soil-forming factors. The chronosequences will be treated separately as sequential chapters in a Professional Paper. (Harden)

2. Transferred soil-description and laboratory data from Multics system to NBI word-processing equipment. Assembled data in table-format for microfische publication in Professional Paper series. (Taylor and Dembroff)

3. Completed analysis of samples from the Honcut and Ventura chronosequences; continued analysis of the Santa Cruz and Ano Nuevo chronosequences. (Janitzky, Singer, and Busacca)

4. Completed mapping, sampling, and some initial analyses for two soil chronosequences along the Animas River in Colorado and New Mexico. (Gillam)

5. Visited sites in the Merced River and Ventura chronosequences to ascertain whether these soils are suitable for ^{10}Be-dating by Milan Pavich. (Harden)

6. Field reconnaissance of Quaternary deformation at various points along the Garlock fault between Mohave and Death Valley, California. (Machette and Taylor)

7. Lead 1982 Rocky Mountain Friends of the Pleistocene Field Trip through central Utah (Machette). Presented papers at GSA's Cordilleran, Rocky Mountain, and National meetings (Gillam, Machette, Reheis, and Taylor)

Results

1. Recommended laboratory methods for chronosequence studies of different soil types, a draft manuscript by contract personnel at the University of California-Davis, is currently in project review. This soil manual, based on four years of testing of several chronosequences, discusses (1) pertinent problems and solutions for each method (including data from tests that were conducted by this project), (2) equipment, (3) laboratory techniques with emphasis on critical or sensitive aspects, (4) calculation methods, and (5) comparisons to other laboratory methods or applications to other types of studies.

   Topics include (1) field techniques, (2) sample preparation, (3) sonic dispersal, (4) total chemical analysis, (5) X-ray fluorescence with special recommendations for soils, (6) particle-size analyses, (7) clay mineralogy by two methods, (8) bulk density, (9) dithionite extractions of iron, aluminium, manganese, and silica, (10) oxalate extractions of iron and aluminium, (11) phosphorus fractionation, (12) cation exchange (capacity and cation type), (13) pH by 3 methods, (14) extractable acidity (total or titratable acidity), (15) organic carbon, (16) total nitrogen, (17) total gypsum, and (18) calcium and manganese carbonates. (Janitzky, Singer, Busacca, and Harden)

2. Soils along Rock Creek in south-central Montana indicate major differences in climate over the past 2 m.y. Mountain-front soils (cool-subhumid climate) show logarithmic rates of weathering in soil properties such as rubification, melanization, clay films, total texture, and gain of pedogenic clay (g/cm^2-column). Conversely, basin soils (cool-semiarid climate) on identical parent materials show progressive, linear changes in color (paling and lightening), total-texture, and gains in pedogenic $CaCO_3$ and silt (g/cm^2-column). Therefore, basin soils are responding mainly to inputs of eolian material, whereas mountain soils are responding to in-situ weathering. Thin sections of the calcic soils reveal multiple episodes of $CaCO_3$ precipitation and dissolution that are related to climatic change and lateral shifting of the pedocal-pedalfer boundary.

   Age control for the Rock Creek deposits is based on the 0.6-m.y.-old Lava Creek ash bed, correlation with the Yellowstone glacial sequence, and ages estimated from an assumed constant incision rate. Age control is further refined by correlation of the oldest terrace deposit (the Mesa) with a terrace deposit 50 km to the east that is overlain by the 1.9-m.y.-old Huckleberry Ridge ash bed. (Reheis)

3. Field studies of two soil chronosequences along the Animas River in southern Colorado and northern New Mexico indicate that comparison of chronosequences is complicated by variations in the lithology of polymictic terrace gravels and in the texture of overlying deposits (loess or sandy alluvium). Nevertheless, our studies show that in the subhumid northern region, argillic B horizons form rapidly due to relatively high effective moisture, weathering of red mudstone clasts (5-20%), and rapid influx of desert loess. Calcic horizons in all but the highest gravel deposit have the same stage of $CaCO_3$ morphology, which may reflect a balance between leaching and both Ca^{++} influx and primary carbonate (1-25% limestone clasts) in the soil.

   In the semiarid southern region, B horizons form relatively slow due to lower effective moisture, rarity of red mudstone clasts, and the coarser texture of some sands overlying the gravel. Limestone clasts are rare, but translocation of airborne carbonate results in progressive carbonate accumulation and formation of stage IV morphology in about 1 m.y. Gypsum and other soluble salts occur within the B, Cca, and K horizons of many arid soils in the southern region. (Gillam)

4. Reconnaissance studies suggest that Quaternary surficial deposits along the Garlock fault between the town of Mohave and China Lake Military Range record six or more climatically(?) stimulated episodes of sedimentation in local drainage basins. These deposits are characterized by soils which develop both argillic and calcic horizons; the soils range from profiles with ochric A and weakly leached C horizons in Holocene alluvium to profiles with thick, clayey Bt horizons and thick stage III to stage IV K horizons in middle? to early? Pleistocene alluvium. We are hopeful that, with detailed study, the age of these deposits can be determined from soil properties using the soil-profile index of Harden and quantitative assessments of secondary clay and calcium carbonate content. Because these deposits are laterally offset by the Garlock fault, we feel confident that detailed mapping and soil investigations could yield Quaternary slip rates along different segments of the Garlock fault. One could then compare these rates on both a spatial and temporal basis, and contrast them with the 60 km of total offset recently cited for the Garlock Fault. (Machette and Taylor)

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Quartz Crystallinity Index of Fault Gouge and Associated Protolith

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Investigations

The purpose of this investigation was to determine if the quartz crystallinity index of fault gouge can be used as a measure of the amount of shearing on the atomic scale. The method seems especially useful to identify faulted soil in excavations for critical structures which might be built. The quartz crystallinity index is a measure of the goodness of packing of ions in alpha quartz. The index is determined by standard x-ray diffraction equiptment. (Murata and Norman, 1976)

1. The effect of sample preparation had not been determined previously. The fault gouge is well comminuted but the protolith must be crushed to be compared to the soil.

2. The inherent analytical error in the determination of the quartz crystallinity index was not known.

3. The quartz crystallinity of quartz from fifty faults was determined to see what the inherent variability might be.

4. The quartz crystallinity of quartz from the above faults was compared to the quartz crystallinity of the quartz in the associated protolith.

Results

1. The effects of sample preparation on the quartz crystallinity index are statistically significant but very minor.

2. The analytical error in the measurement of quartz crystallinity is so great that it jeopardizes the interpretation of natural variations except in cases where the gouge had very much lower quartz crystallinity than the protolith.

3. We have discovered that the quartz crystallinity of clay sized grains is extremely sensitive to grain size. This explains the fact that our initial study of fault gouge showed such low indeces.

It is, therefore, necessary to separate the quartz grains by grain size, and compare grains which are fine silts.

4. Fault gouges tend to be deeply developed soils. In 40% of the gouges sampled there was not enough coarse quartz to determine the crystallinity index.

5. The quartz crystallinity index of many gouge zones is not statistically different from the associated protolithic indeces. This is especially true of very large old faults such as the well exposed outcrops of the San Andreas Fault at Fort Ross , Frasier Park, and the Garlock Fault at Gorman. The disordered layers formed by shearing are known to be much more reactive than normal well crystallized quartz(Dempster and Ritchie,1952).

6. The quartz crystallinity index of some small faults is markedly lower than the index of quartz in associated protolith. These are probably geologically young gouges.

The quartz crystallinity index technique is comparable to the more traditional signs of faulting used in the differentiation of fault gouge from soil filled rock joints. Slickensides, drag faults, offset landforms, offset soil horizons, mylonite, and quartz crystallinity index depression are often missing from fault zones, but the presence of any one of the above characteristics in a fracture filling is positive proof of faulting.

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Quaternary Dating and Neotectonics
9530-01559

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Investigations

1. Developed and tested a theoretical model of fault-scarp degradation with time based on the diffusion and continuity equations for hillslopes (S. M. Colman).

2. Completed compilation of two neotectonic maps for Colorado: (1) State map (1:1,000,000) showing late Cenozoic faults and other tectonic information, and (2) a map of the Rio Grande rift in Colorado (1:125,000) showing Quaternary faults, late Cenozoic deposits, scarp-morphology data, and other age information (S. M. Colman).

3. Organized and proposed to Academic Press a book consisting of papers on rates of weathering. The book has been accepted for publication and will be titled "Rates of chemical weathering of rocks and minerals" (S. M. Colman).

4. Completed final drafting, peel coats, and map pamphlet layout for the first of seven 1:250,000-scale MF maps showing Quaternary and Pliocene faults in the Rio Grande rift of New Mexico and west Texas (M. N. Machette).

5. Continued 1:1,000,000-scale compilation of Quaternary and Pliocene faults and volcanic rocks in the Rio Grande rift of New Mexico and west Texas. Map shows faults whose most recent activity are of Holocene, late Pleistocene, middle Pleistocene, and early Pleistocene-Pliocene age (M. N. Machette).

6. Conducted 3 day field trip through central Utah for the Rocky Mountain Cell of the Friends of the Pleistocene with William Scott and William McCoy (M. N. Machette and R. R. Shroba).

7. Continued synthesis of soils data for surficial deposits adjacent to the Wasatch fault and for surficial deposits buried by the last cycle of Lake Bonneville (the Little Valley cycle) (R. R. Shroba).

8. Analyzed soils data and preliminary uranium-trend age for a soil chronosequence near Allens Park, Colorado (R. R. Shroba).

9. Investigations of pumiceous ash found in loess and lake sediments of southeastern Idaho (K. L. Pierce).

10. Completed field work on chronology of glacial sequence in the Chehalis River drainage, Washington (K. L. Pierce and S. M. Colman).

11. Obtained, logged, and made arrangements for study of pollen, ostracods, diatoms from core from Grays Lake, Idaho. (K. L. Pierce)

Results

1. Testing of the theoretical model of fault-scarp degradation with time suggests that the model can be used to estimate unknown ages of single-event fault scarps. Scarps of known age are used to derive a rate contant and to calibrate that constant for different areas. Fault-scarp ages estimated from the model, using a rate constant derived from the known age of the Bonneville shoreline, compare favorably to independent age estimates for fault scarps in Utah, Colorado, and New Mexico (S. M. Colman, investigation no. 1).

2. The morphology of fault scarps in unconsolidated Quaternary deposits of the Rio Grande rift was used to estimate the recency of movement and the magnitude of displacement of about 50 prominent Quaternary faults. From this analysis, we identified faults with single, segmented, or compound movement of Holocene, late Pleistocene, or middle Pleistocene age. The following faults have Holocene displacement: the Sawatch and Sangre de Cristo fault zones in Colorado; the Coyote Springs, Socorro Canyon, La Jencia, Caballo, Cox Ranch, and Peloncillo faults in New Mexico; and the Van Horn and Mayfield faults in west Texas. Most basins of the rift contain or are flanked by late to middle Pleistocene faults. These faults and those with Holocene movement are oriented mainly north, 10-30^{o} eastward of Miocene structures that mark the initial development of the Rio Grande rift. Regional uplift, extension, and faulting apparently accelerated in the late Miocene to early Plicene, forming the modern rift topography. In comparison, extension rates since the middle Quaterary may have decreased, yet faults have formed over most areas of the rift. The timing and distribution of Quaternary faulting suggests that southward-widening expansion of the rift is continuing, possibly related to postulated rotation of the Colorado Plateau. The number of Quaternary faults and their cumulative across-rift displacement appear to increase from north to south in the rift. These faults form a slightly radiating pattern, open to the south, where the Holocene faults mark the active east and west rift margins. Fairly continuous faults with Holocene movement in southern Colorado may be related to the northward propagation of the rift's apex (M. N. Machette and S. M. Colman, investigations no. 2 and 5).

3. The numerical ages of the fine-grained surficial deposits of Holocene and late Pleistocene age, which are faulted along the Wasatch front, can be estimated by the amount of scondary calcium carbonate in the soil profile. Analyses indicate that the average rate of accumulation of secondary calcium carbonate for these soils is 0.5 $g/cm^2/10^3$ yr for the past 12,000 yr. This rate is compariable to that established for Holocene soils from southern New Mexico by M. N. Machette (R. R. Shroba, investigation no. 7).

4. Till near Allens Park, Colorado, which we consider to be of Bull Lake age on the basis of soils data and other relative-age criteria, has been dated by J. N. Rosholt using the uranium-trend method. Analyses of 10 samples from the relict soil in till indicate an age of 130,000 ± 40,000 yr. This age compares favorably with the obsidian-hydration age of 150,000 yr for the Bull Lake Till at West Yellowstone, Montana. The uranium-trend age also supports many of our previous stratigraphic correlations and soil-age estimates in the Rocky Mountains which have been based on descriptive and analytical soils data (R. R. Shroba, investigation no. 8).

5. In southeastern Idaho, the China Hat rhyolite dome is 61,000 ± 6,000 years old (G. B Dalyrmple, written commun., 1982). Thicknesses of glass hydration rims are very similar for tephra from China Hat, a pumice lapili tephra downwind from China Hat in the lower part of the upper loess unit, and a tephra from 16 m depth in a core from nearby Grays Lake. Studies in progress suggest the early Wisconsin age for the China Hat dome may be applied to dating the regional loess deposits and the paleoclimate record from Grays Lake (K. L. Pierce).

Reports

Colman, S. M., 1983, Map showing late Cenozoic tectonic features in Colorado: U.S. Geological Survey Miscellaneous Investigations Map, scale 1:1,000,000 (Branch approval).

Colman, S. M., McCalpin, J. P., Ostenaa, D. A., and Kirkham, R. M., 1983, Map showing upper Cenozoic rocks and deposits and Quaternary faults, Rio Grande rift, south-central Colorado: U.S. Geological Survey Miscellaneous Investigations Map, scale 1:125,000 (Branch approval).

Machette, M. N. 1982, Quaternary and Pliocene faults in the La Jencia and southern Albuquerque-Belen basins, New Mexico: Evidence of fault history from fault-scarp morphology and Quaternary geology, in Grambling, J. A., and Well, S. G., eds., Albuquerque County II: New Mexico Geological Society, 33rd Annual Field Conference, Guidebook, p. 161-169.

Machette, M. N., 1982, Guidebook to the late Cenozoic geology of the Beaver basin, south-central Utah: U.S. Geological Survey Open-File Report 82-850, 42 p.

Machette, M. N., and McGimsey, R. G., 1983, Quaternary and Pliocene faults in the Socorro and western part of the Fort Sumner 1^{o} x 2^{o} quadrangles, New Mexico: U.S. Geological Survey Miscellaneous Field Studies Map 1465-A, 1:250,000 scale (Directors approval).

Pierce, K. L., 1982, Pleistocene glaciation threshold, modern snowpack and Pleistocene glacier activity, transect across Western U.S.: Geological Society of America Annual Meeting, Abstracts with Programs, v. 14, no. 7, p. 558.

Pierce, K. L., 1982, History and dynamics of glaciation in the northern Yellowstone National Park area, in S. G. Reid and D. J. Foote, eds: Wyoming Geological Association, 33rd Annual Field Conference, Guidebook, p. 27-29.

Scott, W. E., Shroba, R. R., and McCoy, W. D., 1982, Guidebook for the 1982 Friends of the Pleistocene, Rocky Mountain Cell, Field trip to Little Valley and Jordan Valley, Utah: U.S. Geological Survey Open-File Report 82-845, 58 p.

NEOGENE MICROMAMMAL BIOCHRONOLOGIES

9590-02708

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Investigations

Between 1 April through 30 September 1982, work was continued on publication of the microtine rodent biochronology of the Northern Hemisphere and most publications and reports approved for publication related to this effort.

Initial study of Neotropical cricetine rodents was begun with the objective of developing time-sensitive tools that apply in areas south of the distribution of microtine rodents in the United States and Mexico.

Collection in the Rio Grande Trench of the earliest Sierra Ladrones Formation fauna at Truth or Consequences, New Mexico, was completed with excellent results. Reconnaissance of areas to the south to El Paso was conducted with the help of William Seager, New Mexico State University at Las Cruces. With the help of John Hawley and Bob Weber, New Mexico Bureau of Mines and Mineral Resources, Socorro, deposits to the north as far as the Albuquerque basin were briefly examined for fossil potential. Several promising areas were seen.

Continued field work in the ancient lake basin of the Plains of San Agustine with Vera Markgraf and Platt Bradbury resulted in much greater geologic and (non-vertebrate) paleontologic understanding, but further discouraged the thought that micromammal biochronologies will be of assistance to the project.

Reconnaissance of the Nevada Test Site for possible age control of late Tertiary and Quaternary deposits in this area was similarly discouraging. One age estimate was corrected and one bulk sample is currently being screened and picked with minimal results.

Results

In August the outline of Pleistocene History of Mammals of the World, as calibrated through micromammal biochronologies with climatic (^{18}O in the deep sea) and paleopolarity events, was presented to the Third International Theriological Congress in Finland.

Study of Central and South American cricetine rodents in the U.S. National Museum (two study visits) and preliminary comparison with known North American fossils has clearly demonstrated that many Neotropical cricetines have an earlier history in North America. The long-standing dogma has been that a few primitive forms dispersed to South America and there diversified, some returning to North America as advanced forms; to a large extent, this hypothesis is in error and acceptance of the dogma has greatly inhibited prior attempts to their classification, history, and biochronology. Their potential as chronologic tools is thereby seen as being much greater.

The oldest deposits in the southern Rio Grande Trench between the Socorro Basin and the Palomas Basin (near Truth or Consequences) appear to be about 4 Myr. old. Although older deposits are present to the north (Albuquerque Basin) and south (Mesilla or Las Cruces Basin), these are not represented in the intermediate area and thus the first integrated flow of the Rio Grande between Albuquerque and El Paso seems to be about this age. Flow has been continuous since then. More age control in this southern part of the trench will help reconstruct the tectonic history.

Related to the Rio Grande Trench, and sometimes considered a part of the structural unit, the San Agustine lake beds to the west of the Rio Grande Valley and 2,500 feet higher in elevation, have a much more complicated history that may have extended a million years earlier in time than previously supposed. Major periods of entrenchment along NE trending shear zones seem to be recorded in the lake and basin deposits which appear to overly fanglomerates at least 3 Myr. old on the basis of micromammals. However, attempts to find micromammals dating the stages of filling have not been fruitful.

Three days spent in review of the sediment fill in the basins of Nevada Test Site resulted in only two localities with any potential for micromammals. Both need additional attention, but large mammals from one have already indicated a revision in its age approximation.

Reports Published

May, S. R., and Repenning, C. A., 1982, New evidence for the age of the Old Woman Sandstone, Mojave Desert, California. Pages 93-96 in Geological Excursions in the Transverse Ranges, J. D. Cooper, compiler. Guidebook for the Geological Society of America Cordilleran Section Meeting, Anaheim, California, April, 1982.

May, S. R., and Repenning, C. A., 1982, New evidence for the age of the Mount Eden fauna, southern California. Jour. Vert. Paleontology 2(1):109-113, May, 1982.

Repenning, C. A., 1982, Pleistocene mammalian faunas: climate and evolution. Abstracts of Papers, Third International Theriological Congress, Helsinki, 15-20 Aug. 1982.

Repenning, C. A., and Fejfar, Oldrich, 1982, Evidence for earlier date of 'Ubeidiya, Israel, hominid site. Nature 299:344-347, Sept., 1982.

Reports in Press

Repenning, C. A. Biochronology of the microtine rodents of the United States. In M. O. Woodburne, ed., Cenozoic mammals: their temporal record, biostratigraphy and biochronology. Univ. California Press.

Repenning, C. A. Fauna exchanges between Siberia and North America. Schrift. Geolog. Wissenschaften, Berlin.

Repenning, C. A. New evidence for the age of the Gubik Formation, Alaskan North Slope. Quaternary Research.

Repenning, C. A. *Pitymys meadensis* Hibbard from the Valley of Mexico and the classification of North American species of *Pitymys* (Rodentia: Cricetidae). Jour. Vert. Paleontology 2(4), February, 1983.

Repenning, C. A. Pleistocene mammalian faunas: climate and evolution. Acta Zool. Fennica.

Basement Tectonic Framework Studies
Southern Sierra Nevada, California

9950-01291

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Investigations

1. Completion of reconnaissance geologic mapping and sampling of the basement rocks in a belt several kilometers wide on both sides of the Kern Canyon-Breckenridge-White Wolf fault zone north to 36°00'N. lat.

2. Geologic mapping and sampling of the granitic basement rocks of the Neenach volcanic area near Gorman.

3. Geologic mapping and sampling of a hornblende-rich plutonic terrane with small scraps of included ultramafic rocks near the White Wolf fault west of Caliente.

4. Continuing petrographic study of plutonic and metamorphic samples from the area near the Kern Canyon fault zone.

Results

1. Preliminary analysis of data from an area of hornblende-rich plutonic rocks and some gneiss and ultramafic scarps west of Caliente on the northwest side of the White Wolf fault suggests a striking basement contrast with tonalite that is exposed directly across the fault to the southeast. The hornblende-rich terrane can be tentatively correlated with gneissic and hornblende-rich rocks that are exposed near Comanche Point on the southeast side of the White Wolf fault. About 12 km of right-lateral offset is suggested by this correlation. Such an offset is comparable to offsets of basement rock units further to the north on the Kern Canyon fault. South of Walker Basin (where the Kern Canyon and Breckenridge faults are postulated to join) this is the only "matching pair" of basement units that has been seen along the entire length of the Breckenridge and White Wolf faults. Hopes for other matchups of basement rocks along the White Wolf fault are frustrated by alluvial cover of the fault along most of its strike length.

2. One of the more satisfying discoveries from the 1982 field work concerns the correlation across the Kern Canyon fault of mafic and ultramafic rocks near Bodfish with two bodies near Wofford Heights in the Lake Isabella area. Early cursory examination of these rocks suggested some significant lithology

differences and correlation was largely based on the presence of nearby granitic rocks that were correlative across the fault. The differences in rock types between the three areas were rationalized as "normal" differences for mafic and ultramafic terranes, but there was no real tie between the three areas. More detailed study of these dark rocks last summer led to the discovery of very unusual gabbros with mantled olivine crystals in all three outcrop areas. Furthermore, these gabbros tend to weather to distinctive spheroidal outcrops ("cannonballs"). The common bond of mantled olivine gabbro makes the mafic correlation across the Kern Canyon fault much more confident, even though differences still exist in the proportions of various mafic and ultramafic rocks between the three areas.

3. In 1977, samples of 12 plutonic rocks from the Salinian block, from Bodega Head on the north to the La Panza Range on the south, were analyzed by neutron activation methods, chiefly to determine their rare earth element content. Inexplicably, the analytical data were buried in my files and only accidently rediscovered in May 1982. In belatedly analyzing these data, it became apparent that there were possibly significant differences in europium anomalies between these samples and similarly analyzed samples from the southernmost Sierra Nevada.

In most granitic suites, europium anomalies are well developed in most felsic granitic samples, but less distinct or absent in less felsic rocks such as granodiorite or tonalite. In the samples from the southernmost Sierra Nevada, pronounced europium anomalies are present, not only in granite samples, but are common in granodiorite and present in some tonalite samples as well. Granitic samples from the central Sierra Nevada behave more "normally" and europium anomalies are generally confined to granite. In the samples from the Salinian block, on the other hand, not even all the granite samples have europium anomalies.

This contrast, which is admittedly based on preliminary and sparse data, can be interpreted to mean that the granitic rocks of the southernmost Sierra Nevada are "unusual" and have different fractionation and crystallization patterns relative to the more "normal" granitic rocks of the rest of the Sierra Nevada and the Salinian block. Alternatively, the data can be interpreted to suggest that the europium anomaly contrast between the southernmost Sierra Nevada and the Salinian block reflects not just a different fractionation history, but that the granitic rocks of the two regions are unrelated. The europium data could thus be used to argue against correlation between these two granitic terranes. With the present europium data, the argument against correlation is far from compelling, however and chemical data are needed between the central and southernmost Sierra Nevada to better evaluate these two possible interpretations (and probably other alternatives as well).

Reports

Ross, D. D., 1982, Results of instrumental activation analyses for selected plutonic samples from the Salinian block, California Coast Ranges: U.S. Geological Survey Open-File Report 82-935, 16 p.

Tephrochronology (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 and volcanism in California, Nevada, Oregon, and Washington, and to provide independent calibration for other age dating techniques. Neutron-activation, X-ray fluorescence, and electron microprobe analyses of separated volcanic glass and crystals, together with petrographic characteristics, 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 (with C. E. Meyer, J. L. Slate, J. R. Rivera, and Gail McCoy, BWRG).

Investigations

1) Continued tephrochronologic work in the following areas:
   a) Southern California (Ventura basin and South Mountain anticline, with K. R. Lajoie, BGM&F, R. F. Yerkes, BEG, and J. C. Liddicoat, Lamont-Doherty Geol. Observatory, N. Y.; Newhall area, with Gerry Treiman, CDM&G, and Shaul Levy, Oregon State Univ.; Los Angeles basin, with T. H. McCulloh, Mobil Oil; Anza-Borrego area, with George Miller, Imperial Valley College; Lake Tecopa area, with J. W. Hillhouse, BP&RS).

   b) Central California and western Nevada (San Joaquin Valley, with J. A. Bartow; Mono Basin, Carson Sink, and Pyramid Lake, with K. R. Lajoie, J. C. Liddicoat, and J. O. Davis, Desert Research Institute, Reno, Nev.).

   c) Northern California (Humboldt basin, with S. D. Morrison and K. R. Lajoie, BGM&F; northern Sacramento Valley, with D. S. Harwood and E. J. Helley, BWRG; Mohawk Valley, with S. A. Mathieson, BGM&F; Mount Lassen area, with M. A. Clynne, BFG&M).

   d) Central and eastern Washington (with Susan Shipley, B. F. Atwater, BWRG, R. B. Waitt, Cascade Volcano Observatory, and D. R. Mullineaux, BEG, Denver).

2). Completed through Director's approval report on chemical analyses, correlations, and ages of late Cenozoic tephra units of east-central and southern California (for U.S. Geol. Survey Prof. Paper, with 8 coauthors).

3). Completed through Director's approval report on hazards to nuclear reactors from volcanic ash erupted in the Pacific Northwest of the U. S. (MF 1435, with Susan Shipley, BWRG).

4). Continued study of erosion and redeposition of ash layer formed by the May 18, 1980, eruption of Mount St. Helens (study by Susan Shipley).

Results

1. We have identified the Mazama ash bed at several new localities in the Okanagan area of north-central Washington, on the basis of electron-microprobe (EMA) and energy-dispersive X-ray fluorescence (XES) analysis (work in cooperation with B.F. Atwater, BWEG). The Mazama ash was produced by a massive eruption from the Crater Lake, Ore., area about 6800-7000 yr. B.P., covering a large area of the northwestern U.S. The ash correlations are being used to provide age control in mapping late Pleistocene and Holocene deposits in this area.

2. The Carson Sink bed, an ash in the late Pleistocene Sehoo Formation of pluvial Lake Lahontan, Nevada, correlates well with Ash 15, an ash in late Pleistocene lake beds of the Wilson Creek Formation of pluvial Lake Russell, Mono basin, in east-central California (work in cooperation with K.R. Lajoie, J.C. Liddicoat, and J.O. Davis). The correlation is made on the basis of EMA and XES data (table 1), as well as petrographic characteristics.

In Mono basin, a magnetic excursion has been found previously to coincide with the stratigraphic position of Ash 15 at several sites. Association of this excursion with Ash 15 has lead Liddicoat to search, and find, the same excursion at the correlative locality in the Carson Sink area. The ash correlation, together with the magnetostratigraphic data and independent radiocarbon ages that date this ash bed at both the Mono basin and Carson Sink sites at about 28,000 yr. B.P., indicates that the pluvial Sehoo and Wilson Creek Formations are coeval.

3. An ash bed exposed at Summer Lake, in eastern Oregon (work in cooperation with J.O. Davis), and an ash obtained from a core sample at Fargher Bog, in southwest Washington (work in coop. with R.B. Waitt, Jr., Cascades Volcano Observatory) correlate with ash layer Cy, erupted from Mount St. Helens about 35,000 yr. B.P. (Mullineaux and Crandall, 1981), based on analyses of volcanic glass by XES and EMA. These samples, in turn, correlate with the Marble Bluff ash bed of J.O. Davis, found at several localities in the Lake Lahontan basin, in the basal part of the Sehoo Formation (Davis, 1978).

4. We tentatively identified an ash obtained from D.S.D.P. core hole 36, located 250 km west of the Gorda Ridge in the Pacific Ocean, as the Huckleberry Ridge ash bed (dated at 1.9 m.y. B.P., Christianson and Blank, 1972, Naeser and others, 1973), on the basis of EMA, glass shard morphology, and biostratigraphic data. Although the EMA and morphological data alone are not unequivocally diagnostic of this ash, its stratigraphic position near the

N21-N22 planktic foraminiferal boundary, considered by Ingle (1976) to coincide with the Quaternary/Pliocene (Q/P) boundary, tends to support this correlation. However, the Q/P boundary in hole 36, as based on biostratigraphic evidence, is placed below, rather than at, the stratigraphic level of the ash. Further analysis are currently under way to confirm the ash identification, and to determine whether its isotopic age is correct, or whether the position of the biostratigraphic Q/P datum is diffuse or time-transgressive.

The Huckleberry Ridge ash bed has been previously identified from marine beds of the Pico Formation in the Ventura area of southwestern California. If further confirmed, the hole 36 locality will be the fartherst documented westward extent of this ash. The Huckleberry Ridge ash was erupted from the Yellowstone area in northwestern Wyoming and eastern Idaho, and has been found as far as Kansas and Nebraska to the east. Presence of this ash in areas to the west is puzzling and argues for multiple eruptions or complex wind-distribution patterns with altitude during its eruption.

Reports

Sarna-Wojcicki, A. M., Bowman, H. R., Meyer, C. E., Russell, P. C., Asaro, Frank, Michael, Helen, Rowe, J. J., Jr., Baedecker, P. A., and McCoy, Gail, Chemical Analyses, correlations, and ages of late Cenozoic tephra units of east-central and southern California. (For U. G. Geol. Survey Prof. Paper. Approved).

Morrison, S. D., and Sarna-Wojcicki, A. M., 1981, Time-equivalent bay and outer-shelf facies of the Neogene Humboldt basin, Calif., and correlation to the north Pacific microfossil zones of D.S.D.P. 173: Proceedings of the International Workshop on Pacific Neogene Biostratigraphy, 6th International Working Group Meeting, Nov. 25-29, 1981, Osaka, Japan. Osaka Museum of Natural History, p. 130-131.

Liddicoat, J. C., 1982, Paleomagnetism of the Pliocene-Pleistocene Pico Formation in Balcom Canyon, Ventura Basin, California: Geol. Soc. of America, Abstracts with Programs, v. 14, no. 7, p. 546-547.

Table 1. Energy-dispersive X-ray fluorescence analysis of volcanic glass of ash erupted from Mono Craters, east-central California. Values given are normalized, integrated peak intensity ratios from spectral analysis. M. J. Woodward and J. L. Slate, analysts.

Sample	K	Ca_1	Ca_2	Ti	Mn	Fe_1	Fe_2	Rb	S	Y	Zr	Nb
1.	1243	354	51	83	192	5070	819	2140	704	883	1914	668
2.	1237	352	52	81	206	5040	817	2198	688	912	1762	673

Table 2. Electron microprobe analysis of volcanic glass of ash erupted from Mono craters, east-central California. Values given are in oxide weight percent except for chlorine, which is in atomic weight percent. Concentrations are recalculated to a water-free basis. C. E. Meyer, analyst.

	SiO_2	Al_2O_3	Fe_2O_3	MgO	MnO	CaO	BaO	TiO_2	Na_2O	K_2O	Cl
1.	76.75	12.88	0.95	0.04	0.03	0.68	0.05	0.07	3.80	4.75	0.06
2.	76.63	13.03	0.95	0.04	0.03	0.68	0.01	0.07	3.80	4.70	0.06

1 - Ash 15, Wilson Creek Formation, Mono basin, coll. by K. R. Lojoie.
2 - Carson Sink bed of Davis (1978), in Sehoo Fm., coll. by J. O. Davis.

Salton Trough Tectonics and Quaternary Faulting

9940-01292

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Investigations

1. Surficial record of late Quaternary movement on the Tanlu fault, Shandong Province, People's Republic of China.

2. Monitoring level changes of near-field monuments at four sites on the San Jacinto fault zone and one site on the San Andreas fault near the Salton Sea.

3. Continuation of mapping of southwestern boundary faults of the Salton Trough, California.

4. Continuation of study of faulting induced by ground water withdrawal in the Garlock fault zone in Fremont Valley, California (with E. Pampeyan and T. H. Holzer).

5. Measurement of small strain quadrilaterals placed across the active trace of the Garlock fault.

6. Analysis of late Quaternary slip rates along the eastern Sierra Nevada fault zone from Walker River to Owens Valley.

Results

1. Field investigation was resumed between September 15 to October 15, 1982. Results will be summarized in reports at a later date.

2. No significant changes in relative elevation of monuments across the Coyote Creek and Clark faults of the San Jacinto fault zone were detected in the report period. Apart from minor seasonal changes of relative elevations of stations in the North Shore line across the San Andreas fault, there has been a gradually accumulating E-W component of basinward tilt of about 22 microradians between November 1980 and October 1982 measured on that 0.58 km-long line.

3. Field investigation of normal faults that have brought sediments of the Salton Trough into fault contact with crystalline basement along the southwestern margin of the basin has been completed for the region between Palm Springs and Agua Caliente Hot Springs.

4. Prominent fissures and scarps along the main trace of the Garlock fault at the north edge of Fremont Valley mirror the fissures and scarps found in 1971 along the opposing en echelon main trace of the fault 5 km away at the south

edge of the valley. Maximum height of the newly discovered scarps is greater than 1 m near the abandoned settlement of Gypsite; about half of this displacement appears to be less than 10-20 years old. The faulting is aseismic and is clearly related to subsidence caused by removal of groundwater.

5. Fifteen quadrilaterals across the Garlock fault were taped and leveled with a precision of few millimeters in 1982. The quadrilaterals, about 20 m on a side, will permit documentation of future displacement, either from creep or at the time of earthquakes.

6. The major normal faults that bound the eastern Sierra Nevada from Bishop Creek in northern Owens Valley to West Walker River show large variations in both rate and location of late Quaternary displacement.

The range-front fault zone in this region includes 8 major en echelon faults from 10-30 km long that trend more northerly than the range. These faults are separated by 2-10 km of terrain that has evidently not been faulted in late Quaternary time, and with the exception of 2 faults west and southwaest of Mono Lake, they step left. Maximum late Quaternary displacement rates range from 0.5 to 2 mm/yr and necessarily decrease to zero at the ends of the faults.

Late Quaternary displacement rate at a given location appears to be constant for some faults (Hilton creek fault, parts of Round Valley fault), but variable for others. At Bloody Canyon, along the fault southwest of Mono Lake, moraines of the Mono Basin glaciation (>130,000 yr B.P.) are vertically offset 60 m, but younger moraines (Tahoe and Tioga glaciations) are not displaced. Three km to the south at Parker Creek this fault does not offset latest Pleistocene (Tioga) moraines, but does offsest older moraines. Three km farther south, the same fault shows no late Quaternary displacement. These observations indicate highly variable displacement rates with both time and position and also show that this fault may not rupture over its entire length during one earthquake.

Large variations in displacement rate along a fault and from one fault to another, together with possible changes in those rates with time, emphasize the need for caution in using a single displacement rate to characterize normal faults and normal fault zones.

Reports

Clark, M. M., in press, Remote sensing in assessments of seismic hazards: in Chapter 31, Geologic Applications, Manual of Remote Sensing, 2nd Ed.

Clark, M. M., 1982, Variations in late quaternary displacement along faults of the eastern Sierra Nevada, CA [abs.]: Program, AGU Chapman Conference on fault behavior and the earthquake generation process, Snowbird, Utah.

Aspects of the Holocene History and Behavior of the San Andreas Fault System

14-08-0001-19756

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INVESTIGATIONS

This contract supported continuing investigations of the Holocene behavior of the San Andreas fault system. The purpose of these studies has been to determine the long-term fault slip rates and the frequencies and spatial relationships of large earthquakes along the fault. Such information may lead to forecasts of the location, time, and size of future large earthquakes along the fault.

RESULTS

Data from several sites is beginning to enable a more detailed view of the long-term behavior of the San Andreas fault. Latest progress is outlined below:

1) Near Indio, final ^{14}C dates can now be plugged into the stratigraphic and structural context described in earlier reports. The latest large earthquake involving slip along the fault here apparently occurred more than 560 years ago (Sieh, 1981). Creep at a rate of $\sim$2 mm/yr may have been continuous for this time period.

2) At Ray Weldon's site near Cajon Pass, at least two and probably more large slip events have occurred within the past $\sim$700 years (Weldon and Sieh, 1981). These may represent two or more of the latest four events recognized at Pallett Creek, which is about 30 km to the northwest. Our best estimate for the Holocene slip rate here is now 25 mm/yr. Based upon these and data reported in previous years, the fault segment southeast of the San Bernardino Mountains appears to have a much longer recurrence interval than the fault to the northwest. The question of which segment will generate the next great earthquake remains open, however.

3) The program of three-dimensional excavations begun in 1979 at Pallett Creek has resulted in documentation of right-lateral offsets that increase downward in the section. Analysis of the complex pattern of faulting and deformation is now complete and a manuscript which assesses the relative sizes of the many events has been submitted for publication.

4) Work at Wallace Creek, in the Carrizo Plain, was completed and a manuscript has been submitted for publication. The long-term slip rate there is now limited to 34 ± 3 mm/yr and we conclude great events like the 1857 earthquake may recur about every 300 - 400 years.

5) Ray Weldon has made progress in his field studies of the Quaternary and Tertiary history of the San Andreas fault and surrounding area including, and east of Cajon Creek.

6) Howard Shifflett and I are completing a manuscript describing our studies of fault slip rates using old fences in the creeping central of the San Andreas fault (Shifflett and Sieh, 1982).

7) Matsuo Tsukada and his associates at the University of Washington have finished with their palynological studies of the late Holocene sediments at Pallett Creek.

8) Scott Paine and George Karas have nearly completed five new slipmeters that will be installed by the end of December. These instruments are designed to measure the slip history of a fault during a major earthquake.

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Shifflett, H., and K. Sieh, in preparation, Long-Term Slip Rates in the Creeping Central Reach of the San Andreas Fault, Based on Offset Old Fences.

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Shifflett H., and K. Sieh, 1982, Increasing Fault Creep Rates Along Central San Andreas Fault: Seismological Society of America Meeting, 53, 10.

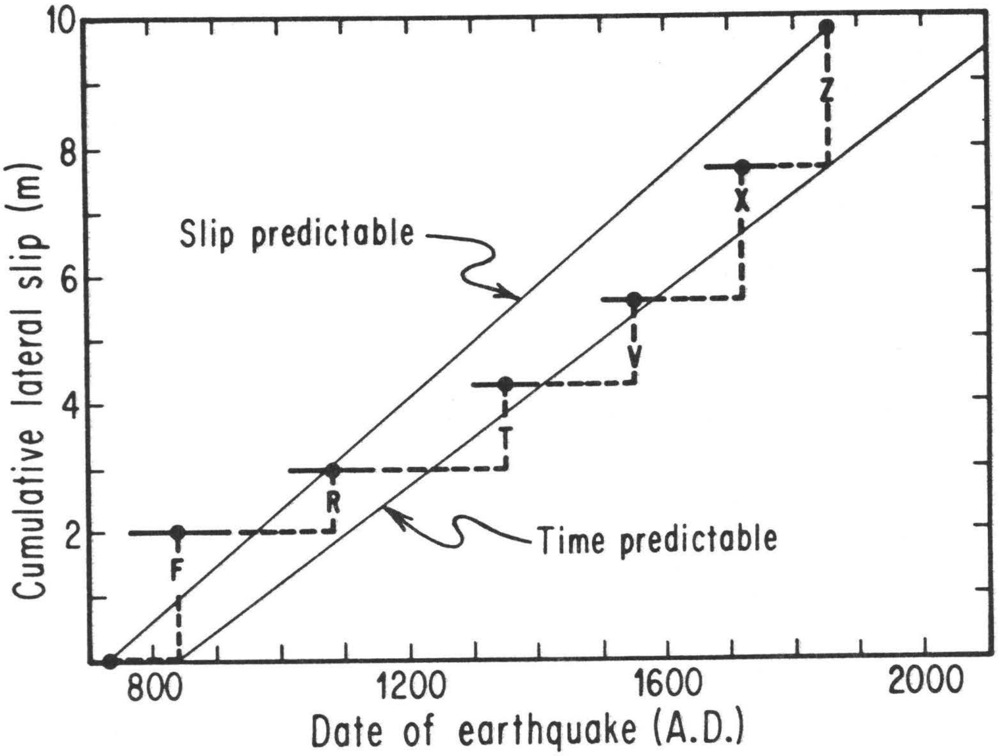

Figure 1. Dates of each of the past several earthquakes plotted against cumulative right-lateral slip. Neither a slip-predictable or a time-predictable model seems to be justified by the data. Instead slip is increasing as recurrence interval decreases.

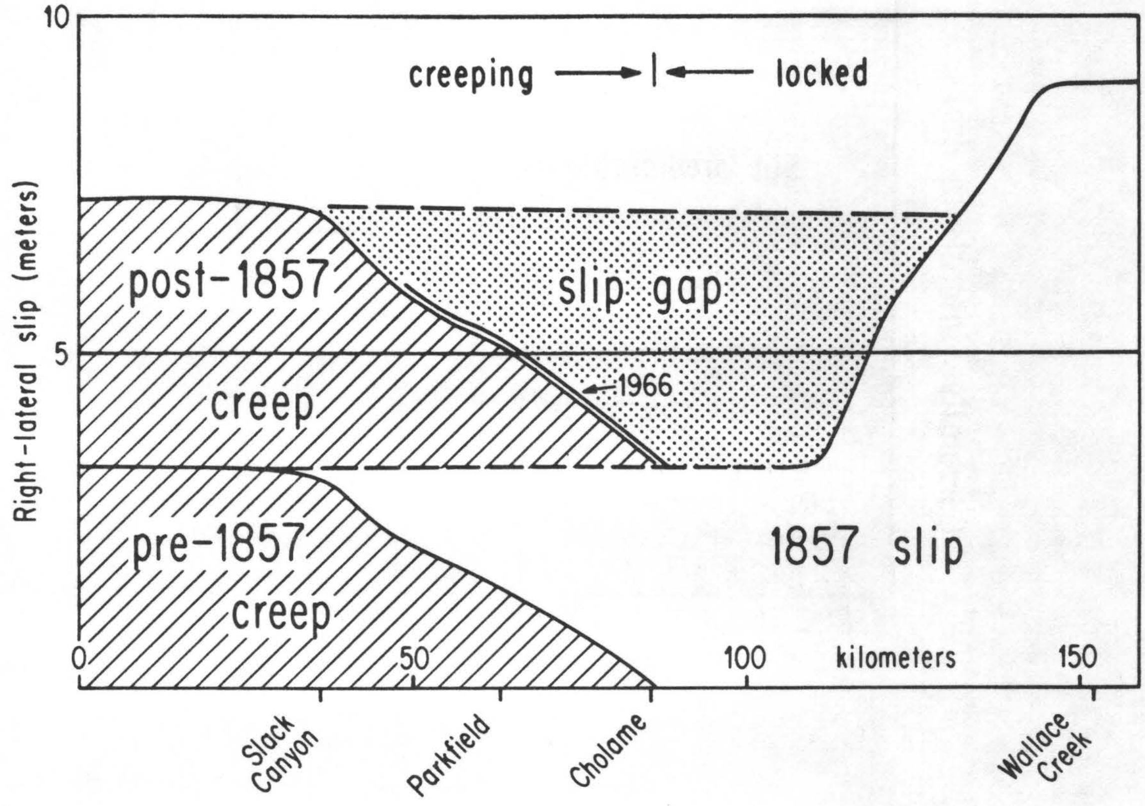

Figure 2. One conclusion from studies at Wallace Creek is that the 100-kn-long segment northwest of the Wallace Creek may produce a large earthquake in the near future.

Quaternary Reference Core, Clear Lake, California

9950-02394

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Investigations

Sedimentological and stratigraphic studies of cores from Clear Lake, California.

Results

The final writing of final reports for this project is being completed. I am also editing a volume of papers that deal with cores taken from Clear Lake in 1973 and 1980. No new results from the project. Project completed!

Reports

None.

Detailed Geologic Studies, Central San Andreas Fault Zone

9940-01294

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Investigations

Detailed geologic investigations of structure, surficial and bedrock deposits in and adjacent to the central section of the San Andreas fault zone (San Juan Bautista to Wallace Creek, Carizo Plain).

Results

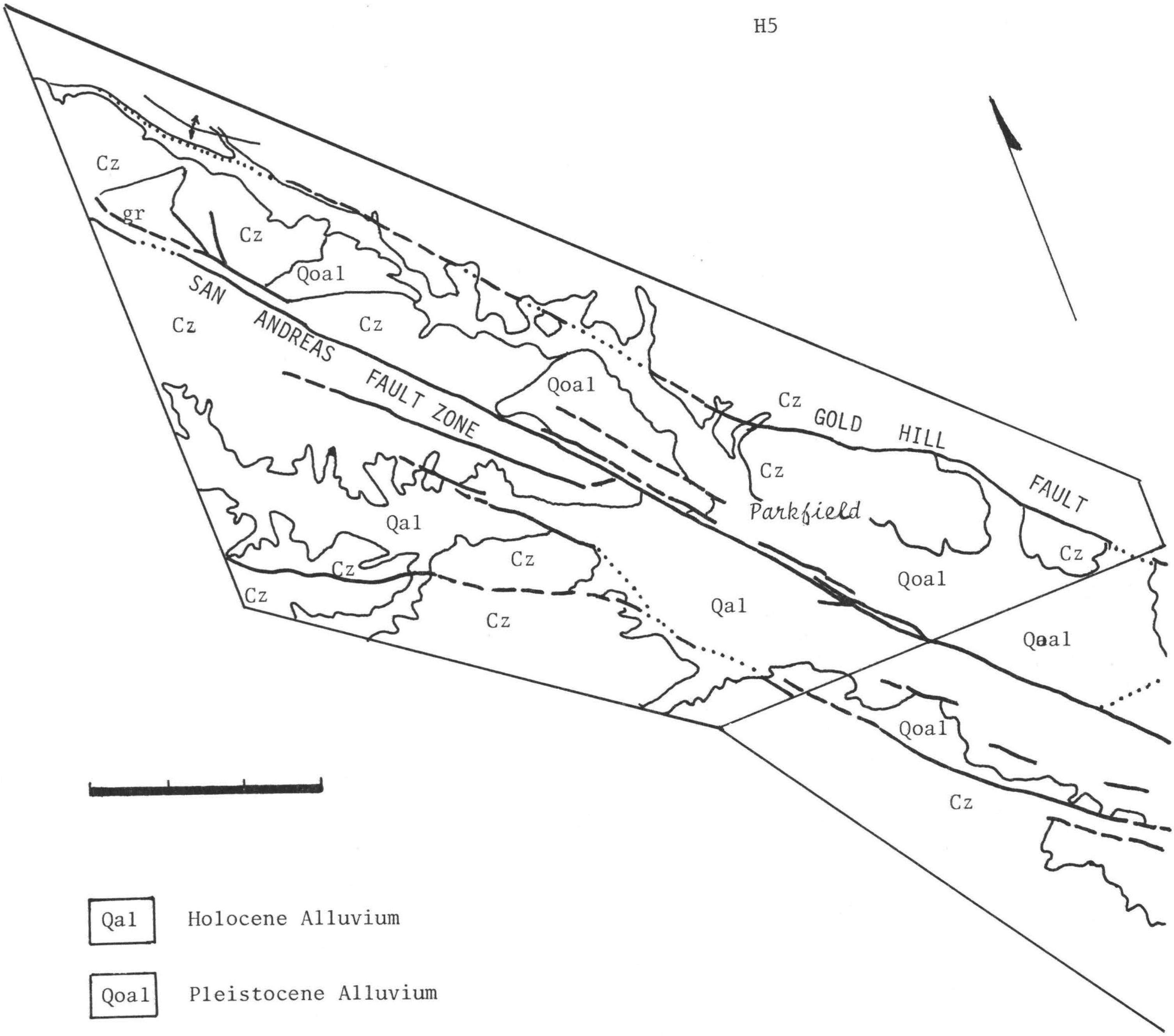
1. Detailed geologic studies in the Parkfield area led to the completion of geologic mapping in the Cholame Valley and Cholame Hills 7 1/2-minute quadrangles. Geologic mapping in the Parkfield and Stockdale Mountain 7 1/2-minute quadrangles is 60 percent complete. Geologic mapping in the Cholame and Orchard Peak 7 1/2-minute quadrangles is 20 percent complete.

The geologic map of parts of the Cholame Valley and Cholame Hills 7 1/2-minute quadrangles is the first non-reconnaissance style geologic mapping done in this area. This map encompasses the area surrounding Gold Hill and extends roughly 3 to 5 km on both sides of the San Andreas fault (SAF). Boundary faults subparallel to the San Andreas are also mapped. The mapping illustrates NE-SW compression on the east side of the SAF. The Miocene Temblor Sandstone is intricately folded in an arcuate belt concentric to a fault-bounded block containing the Gold Hill hornblende gabbro. Further evidence of the compression associated with the SAF in this area is a "diapiric" mass of serpentinite and Franciscan assemblage rocks SSE of Gold Hill, and intricately folded Miocene strata in the SE corner of the Cholame Valley Quadrangle (fig. 1).

Cholame Valley is the probable location of a small pull-apart basin, that is more complex than that described by (Aydin and Nur, 1982). The simple right step-over breaks seen in the 1966 Parkfield earthquake SE of the Jack Ranch in Cholame Valley (Brown, 1967) apparently have a more complex Holocene and Pleistocene(?) history. This latter feature of the SAF is seen in breaks mapped on the west side of Cholame Valley to the NW of the 1966 rupture. How these older Holocene and Pleistocene(?) breaks are related to the grabben and horst structure in the Cholame Hills quadrangle is not yet apparent.

2. Geologic field mapping of the SAF zone in the Bickmore Canyon quadrangle by J. A. Perkins is complete. Photogeologic and geologic mapping of the SAF zone in the San Benito and Cherry Peak quandrangles is 20 percent complete.

Three Holocene terraces of the San Benito River in the Bickmore Canyon quadrangle are transected by the SAF. The oldest terrace is offset 64 ± 2 m

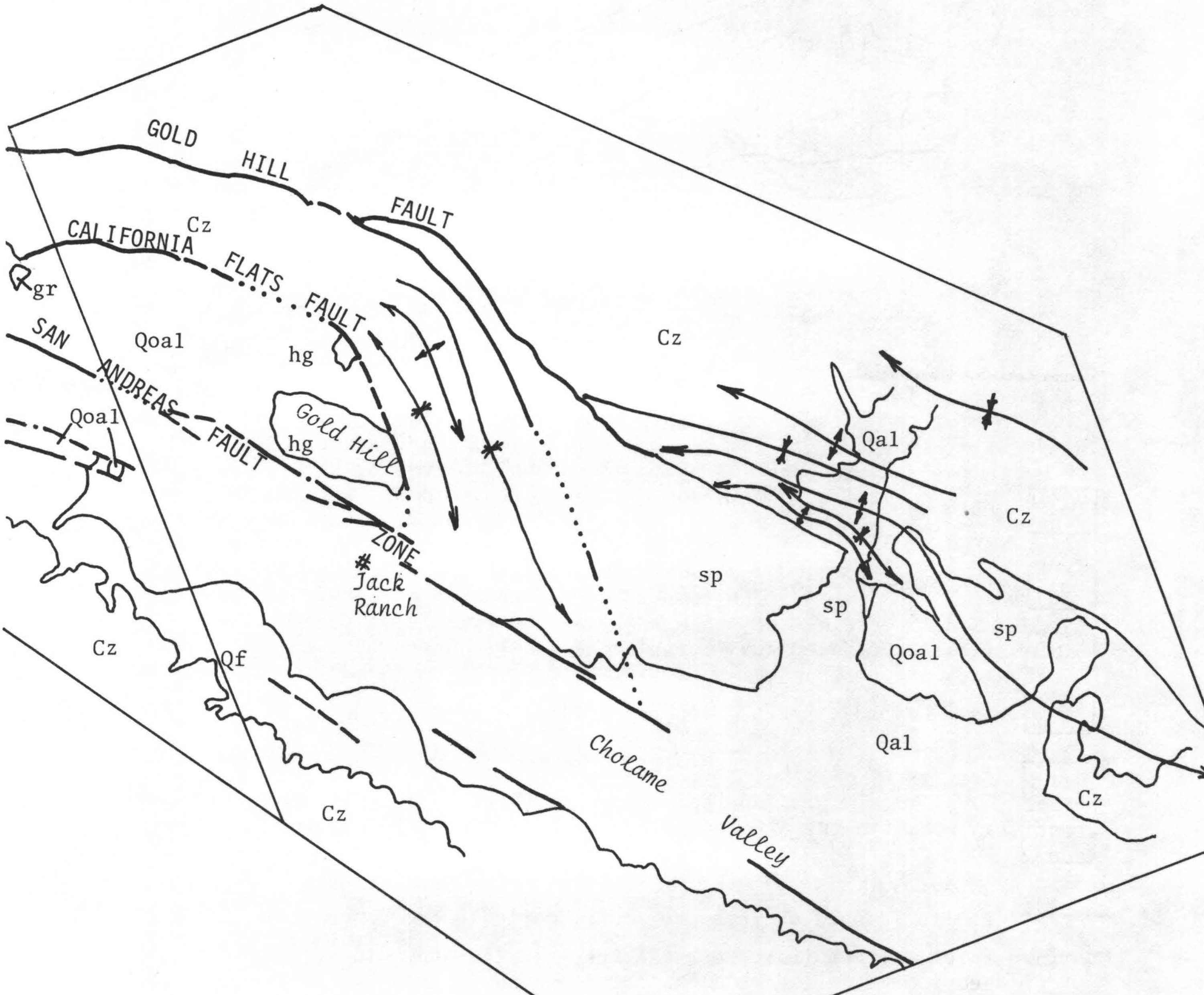


Qal	Holocene Alluvium
Qoal	Pleistocene Alluvium
Qf	Pleistocene(?) Alluvial Fan Deposits
Cz	Late Cenozoic Rocks (Miocene to Pleistocene)
gr	Granite
hg	Hornblence Gabbro

Faults (dashed where approximate, dotted whrre concealed)

Folds (arrows indicate anticline, syncline and plunge)

Contacts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CALIFORNIA FLATS FAULT
SAN ANDREAS FAULT ZONE
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Gold Hill
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Jack Ranch
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Qf
Cz
Cholame Valley
Cz
Qal
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Cz

and charcoal from this terrace yield an age of 1860 ± 160 years (1900 $^{+210}_{-200}$) when correlated to Bristlecone pine chronology). Thus the average apparent slip-rate for the last 1900 years is 33.7 mm/yr. This rate is significantly greater than that recorded from nearby creepmeters (19-22 mm/yr) and alinement arrays (22-26 mm/yr). However, a slip rate of 33.7 mm/yr is compatible with the 37 mm/yr rate determined by Kerry Sieh for the SAF in the Wallace Creek area, approximately 150 km south. The second oldest terrace (Qt_2) is offset 32 ± 2 m but no datable material has been recovered from this terrane.

No offset can be determined on the youngest terrace (Qt_1) owing to active erosion on the terrace scarps by the San Benito River during flood stage. Charcoal was collected from this terrace and submitted for radiometric dating. Scarp morphology profiles on these terraces were made to determine the relationship between scarp angle and scarp age (done in conjunction with Tom Hanks).

A study of the Plio-Pleistocene rocks found along the SAF is being conducted to detail the late Cenozoic tectonics of the region. An ongoing study of the San Benito Gravels has yet to determine an age for these deposits and no correlative unit on source terrane has been found west of the SAF.

Preliminary results of the ongoing study of the Etchegoin Formation suggests that these rocks were deposited in a shallow marine environment under strong tidal currents. The correlative Purisima Formation found west of the SAF may have been deposited in a deeper marine setting than those of the Etchogoin Formation as exemplified by the lack of tidal structures. This suggests a rapid increase in water depth westward across the SAF.

3. Geologic mapping by Michael Rymer of the Hepsedam Peak quandrangle (at 1:12,000 scale) and the Lonoak quadrangle (at 1:24,000 scale) shows that the SAF zone locally narrows and becomes less complex than in the Monarch Peak quandrangle (Rymer, 1981) to the southeast. The main trace of the SAF zone in the Hepsedam Peak and Lonoak quandrangles is significantly straighter and more continuous, containing fewer steps and bends, than to the southeast. The eastern boundary fault of the SAF zone reported to the southeast merges with the main trace near the join of the Hepsedam Peak and Lonoak quadrangles. In contrast, the western boundary fault is more complex in the Hepsedam Peak quandrangle than to the southeast. The western boundary fault in the Hepsedam Peak quadrangle consists of subparallel faults that constitute contacts between four stratigraphic units. Farther to the northwest, in the Lonoak quadrangle, one of these units is pinched out, making the western boundary fault less complex in this quandrangle. No secondary or subsidiary faults are recognized in the recent mapping like that reported earlier for the Monarch Peak quadrangle.

Klippen, or possibly erosional remanants of directly deposits units, on top of Franciscan rocks in the SAF zone along Mustang Ridge are now known to be younger than reported earlier. Earlier reports placed a Late Jurassic-Early Cretaceous age for these units (part of the Great Valley sequence), but analysis of benthic foraminifera by Kristin A. McDougall shows that the units are restricted to a mid-Eocene age. The change in age assignment of these units has tectonic implications, primarily in that the Coast Range thrust no longer needs to be called upon to transport the supposed Great Valley rocks to their present western position because the rocks post-date the formation of the thrust. Thus, metamorphic fluids released from Franciscan rocks along the SAF zone and inferred to be the controlling factor in aseismic slip in the creeping section of the zone are not localized by a capping effect of Great Valley rocks in this area.

Reports

No reports received Director's Approval this report period.

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 the Basin and Range province.

2. Evaluation of fault scarps and tectonics of central Nevada-eastern California seismic belt.

Results

Two previously unidentified tectonic subdivisions or zones of the Grean Basin province, are here termed the Black Rock-Carson Sink zone of extension and the Central Nevada downwarp. In addition, special characteristics of the central Nevada eastern-California seismic belt are beginning to become apparent.

The central Nevada seismic zone, in which the large earthquakes and surface faulting events of 1903, 1915, 1932, 1934 and 1954 occurred, lies along the southeastern margin of a parallelogram-shaped area here termed the Black Rock-Carson Sink zone of extension (fig. 1). This zone is recognizable on the geologic map of Nevada (Stewart and Carlson, 1977) as a zone of especially broad, alluviated grabens, separated by bedrock horsts and surrounded on the northeast, northwest and southwest by plateaus underlain by volcanic rocks less than 6-17 million years old. The zone also is defined by a gravity high on maps filtered to emphasize broad, thus deep (80-170 km), features (Hildenbrand, Simpson, Godson and Kane, 1982). The relatively large vertical displacements and related extension required to create the broad alluviated graben areas suggest that this zone has been a region of much more rapid extension than surrounding areas in late-Tertiary time, and that relatively greater thinning of the upper crust has occurred. The thinning, in turn, is interpreted to have brought denser, upper mantle materials relatively nearer the surface, accounting for the gravity high.

A rectangular area in central Nevada is here termed the central Nevada Downwarp (fig. 1). This area is characterized by a set of ranges in which volcanic rocks 17-43 million years are very abundant (see geologic map of Nevada by Stewart and Carlson, 1977). Stewart, Moore and Zietz (1977) indicate that the volcanic rocks were extruded in more or less east-west belts extending beyond the rectangular area; thus, the preservation of these volcanic rocks in the rectangular area seems to require a structural downwarp and relative protection from removal by erosion.

The Oregon-Nevada lineament of Stewart, Walker, and Kleinhampl, and a southeastward extension of it, bounds the two zones on the northeast, and their southwestern margins lie along the Walker Lane.

Three major gaps in large-scale surface faulting lie in the central Nevada-eastern California seismic belt; the Stillwater gap between the 1915 and 1954 surface faults in the northern part, the White Mountain-Mono Lake gap between the 1932 and 1872 faulting in the central part, and the southern Owens Valley between the 1872 fault and the Garlock fault. The Garlock fault tentatively is interpreted to be a barrier which may limit a faulting event that extends the 1872 break southward. Each of the three gap areas are potential sites of earthquakes larger than M7.

The belt of faults in the central Mojave Desert appears to extend the belt of faulting along the east flank of the Sierra Nevada southward to join the San Andreas fault system. Indeed, the en echelon pattern of faults lying under the Gulf of Lower California seems in some ways more akin to the belt of faulting in the Mojave and southern Sierra frontal areas than to the San Andreas fault system. For example, a belt of volcanic vents younger than a million years follows this belt of faulting rather than the San Andreas fault system.

Reports

1. Wallace, R. E., 1982, Patterns of strain release by faulting in the Great Basin Province, Western United States: International Symposium and Study Tour on Continental Seismicity and Earthquake Prediction, UNESCO, IASPEI and Seismological Society of China, Beijing China, September 8-19, 1982.

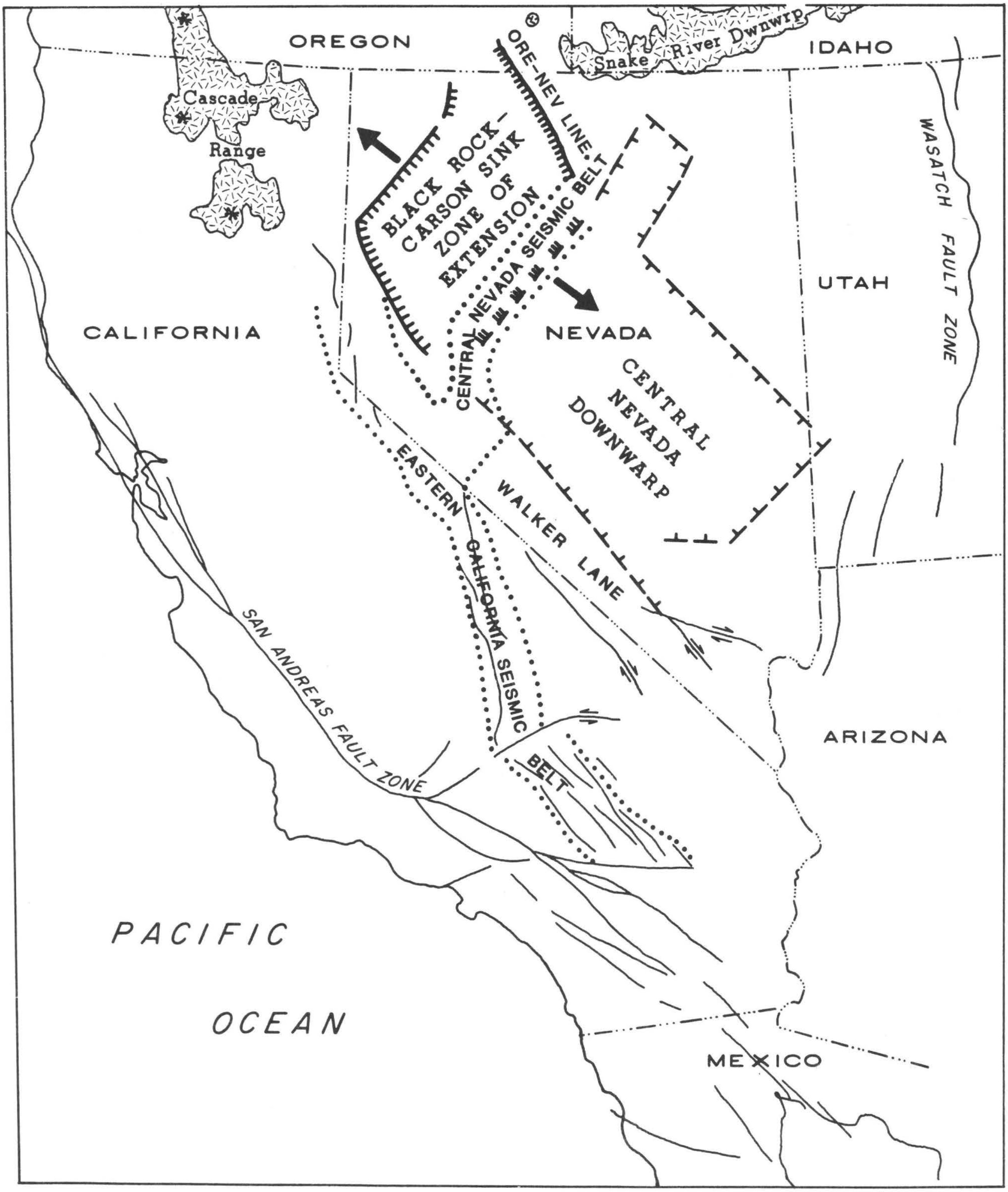

Figure 1. Some tectonic subprovinces in the Great Basin province, Nevada and California.

Physical Constraints on Source of Ground Motion

9940-01915

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Investigations

Digital recordings of small earthquakes are being analyzed to determine accurate source parameters. The objective is to find the probability distribution function of stress drop, which then might be applied to strong motion prediction.

Results

Work on coda spectra (reported in the last semi-annual report) showed that absolute source spectra cannot be inferred from coda spectra. Accordingly, I have undertaken analysis of the spectra of all high-quality S-waves recorded digitally during the 1980 Mammoth Lakes, California, earthquake sequence. Source parameters (corner frequency, stress drop, etc.) are determined from integrals of the spectra.

Well-determined corner frequencies are all below 10 Hz. All stress measures show no correlation with corner frequency. The distribution of stress over the ensemble of events is log-normal with a standard deviation of a factor of 2.

Reports

Andrews, D. J., 1982, Shear-wave and coda spectra and coda attenuation of two aftershocks at Mammoth Lakes, California [abs.]: AGU Fall Meeting, December, 1982, San Francisco, California.

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

9940-02674

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Investigations

By comparing synthetic particle velocity time histories with the integrated accelerogram records of the 1979 Imperial Valley earthquake a faulting model consistent with the near source data has been sought. The faulting model takes into account: (1) the vertically verging velocity structure of the Imperial Valley, (2) the geometry of the fault including length, depth and dip, (3) source parameters--a vectorial (both strike-slip and dip-slip) slip-rate amplitude, slip-rate duration, and rupture velocity--all of which can vary with position on the fault. The Green's functions for the Imperial Valley are computed using Olson's (1982) discrete-wavenumber finite element (DWFE) method which has been modified by Paul Spudich. The Green's functions are convolved with the slip function and integrated over the fault plane (Spudich, 1980) to produce synthetic particle velocity time histories at the observer locations. The modelling effort is a bootstrap approach in that successive models are generally based on the results from previous models.

Results

A faulting mechanism for the Imperial Valley earthquake has been obtained. It produces synthetic seismograms that agree within about 20% with the direct S-wave pulses on both horizontal components at stations 3, 5, 6, 7, 8, 11, Holtville, Meloland, and Bonds Corner. The vertical component is matched almost as well as the horizontal components. The basic features of this model are as follows: (1) the Imperial fault extends 35 km northwest from the epicenter (Archuleta, 1982) on a strike of 323^o measured clockwise from north. The Imperial fault has a depth of 13 km. The dip is 80^o NE. (2) The Brawley fault, beginning at its intersection with the Imperial fault, was triggered by rupture on the Imperial Fault. The Brawley fault is taken as 10 km in length striking due north. Faulting extends only to about 6 km depth on a vertical fault plane. (3) The rupture velocity on the Imperial fault starts slowly (about 1.3 km/s) but accelerates quickly and becomes faster than the local S-wave speed. The rupture breaks the fault between about 17.5 km and 22.5 km (measured from the epicenter) almost instantaneously, but decelerates to a slower velocity beyond 25 km. The average rupture velocity (at the hypocentral depth of 8 km) for the Imperial fault is 2.8 km/sec which is about 0.86 times the local shear wave velocity. (4) The total moment of the Imperial and Brawley faults is 5.2×10^{25} dyne-cm which can be compared to the surface wave moment of 6×10^{25} dyne-cm (Kanamori and Regan, 1982). The Brawley fault contributes only 10% of the total moment. However, the Brawley fault significantly affects the ground motion at Stations 5, 6, and 7. The maximum slip (the product of the slip rate and duration) on the Imperial fault is about 130 cm which occurs between 17 and 22 km north of the epicenter. However, the maximum slip rate is about 27 km north of the epicenter. The average slip over the entire Imperial fault is about 36 cm.

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National Strong Motion Data Center

9940-02085

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Investigations

The goals of the National Strong Motion Data Center are to:

1) Develop a strong capability for processing, analyzing, and disseminating all strong motion data collected on the National Strong Motion Network and portable arrays;

2) Support research projects in the Branches of Ground Motion and Faulting and Seismic Engineering by providing programming and cumputer support for computation of numerical models;

3) Provide digitizing and processing capabilities rapidly in the event of an earthquake as an aid to earthquake investigations.

Results

The National Strong Motion Data Center consists of a Digital Equipment Corporation PDP-11/70 minicomputer and associated peripherals running under the vendor supplied real-time operating system, RSX-11M-Plus, and a field deployable LSI-11/23 microcomputer system for locating and plotting aftershock sequences on-site. The PDP-11/70 is connected to several smaller computers (including the LSI-11/23) as well as the Office VAX-11/780 for file transfers, remote file access, and remote terminal access across the network. Real-time data are transmitted across this network to maintain up-to-date records of seismic activity on the larger office computers for interactive inquiry and analysis.

Center personnel are responsible for the maintenance of these systems and preparation of applications software for the processing of strong motion records.

Hardware

No new hardware was acquired during this report period. Future acquisitions may include additional disk storage for on-line time series data, improved field-based microcomputer systems, appropriate desk-top work stations (particularly for graphical presentation and manipulation of data), and possibly some special purpose processors, such as array processors.

Software

During this report period, the following software changes were made:

1) Operating system upgrades to RSX-11M-Plus V2.0 and RSX-11M V4.0;

2) DECnet upgrades to DECnet/M-Plus V1.1 and DECnet/M V3.1;

3) PDP-11 Fortran-77 was upgraded to V4.1;

Future acquisitions may include data query languages and report writers, data base management systems for time series data, spread sheet calculators for administrative support, and software to support mixed vendor local area networks, such as Ethernet.

Data

A limited amount of digital data has been collected as part of the continuing strong motion experiment in the Anza desert area along the San Jacinto fault in south-central California.

Reports

Baker, L. M., Berger, J., Fletcher, J. B., and Hanks, T. C., 1982, Collection of Real-Time Data from the Anza Digital Seismic Network, Earthquake Notes [abs.]: Seismological Society of America Meeting, April 19 - 21, 1982, Anaheim, California.

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Office Earthquake Analysis Center

9940-03430

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Investigations

The objective of this project is to provide strong support of research projects in the Office of Earthquake Studies. The OES/VAX Analysis Center provides rapid access to accumulated data needed to calculate predictive models involving complex differential equations to be solved by many methods, including large, finite-element modeling. Interfacing between the VAX and other 16-bit machines allows for the distribution of data management functions and aids in complex analyses. This facility is of vital importance in meeting the goals of the Earthquake Hazards Reduction Program -- predicting the occurrence and effects of earthquakes.

Results

The OES Earthquake Analysis Center consists of a Digital Equipment Corporation VAX-11/780 minicomputer and associated peripherals running under the vendor supplied operating system, VMS. The facility serves a diverse user community from all the branches in the Office of Earthquake Studies: Tectonophysics (29 users), Ground Motion and Faulting/Seismic Engineering (33 users), Seismology/ Network Operatings (66 users), and others on the office staff or branches not headquartered in Menlo Park (8 users). The disk and CPU resources are partitioned and distributed equitably among the various user groups such that any policy decisions that become necessary can usually be taken care of within the confines of a single group.

The configuration at the end of this report period includes:

- VAX-11/780 CPU with 3.5 MBytes MOS memory
- FP780 FLoating Point Accelerator
- 130 MBytes of system disk storage
- 750 MBytes of public disk storage
- One 800/1600 bpi tape drive
- One 600 lpm printer
- One 11 inch electrostatic plotter
- 32 terminal ports
- 1 Mbit links to each of two colocated minicomputers

The software in use includes:

- VAX/VMS operating system
- NASA Share scheduler
- DECnet/VAX

VAX Fortran
VAX PL/1
VAX C
IMSL library
SRI Eunice and LBNL Software Tools
Versaplot and CalComp plotting calls

Future acquisitions will include mountable disks to support data transfer and development of smaller mini and microcomputer systems, additional public disk storage, high speed, 6250 bpi tape drives for higher density data storage on tape, and software/hardware for improving communication between various computer facilities.

Reports

None.

Shallow Shear Wave Velocity and Q Structures at the El Centro Strong Motion Accelerograph Array

14-08-0001-20521

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At three sites in the U. S. Geological Survey El Centro Strong Motion Accelerograph Array (E05, E06 and E07), we have used the dispersive and attenuative properties of artificially generated Rayleigh waves to infer the depth dependence of shear wave velocity (β) and quality factor (Q) and a site dependent equivalent elastic source spectrum. This approach provides an inexpensive means for determining two important quanitites (β and Q) required to estimate the response of sites to earthquakes. We find that the shear velocities and the gradients in shear velocities are higher at station E06 (in the wedge between the Imperial and Brawley faults) then at either station E05 or E07 (east and west, respectively, of the wedge). Also, the seismogram character, surface wave dispersion and shear wave velocity structure at stations E05 and E07 are similar to each other while they are different from E06.

Global Accelerograph Program (GAP)

9940-02689

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Investigations

The objective of this program is to obtain critically needed records of damaging levels of ground motion close to the source of earthquakes of magnitude M6.5 and greater.

During the first half of FY 82, the following activities were carried out:

(1) Negotiation of formal GAP agreements with counterpart agencies in countries with significant earthquake potential was continued.

(2) Field checking of a general earthquake observation system (GEOS) for rapid deployment to record large aftershocks was continued.

Results

The prototype GAP agreement developed for the program identifies the following primary activity elements: (1) continued long-term strong-motion data and information exchange between the U.S. Geological Survey and the agency(ies) identified in the host country; 2) the rapid exchange (preferably as soon as possible--within 1-4 days following damaging events) of scientific teams to investigate engineering and scientific effects of large earthquakes in the U.S. and the host country; and 3) the rapid deployment of U.S. personnel and instruments to the host country after a large earthquake (M7.5 and greater) has occurred to record large (M6.5 and greater) aftershocks. In some cases, the installation and long-term operation of a permanent network of strong-motion instruments in the host country shall also be considered under the agreement.

(1) Follow-up responses were transmitted to the 10 countries initially asked to participate in the proram: Chile, Ecuador, Greece, Guatemala, Italy, India, Mexico, New Guinea, Peru, Turkey, and Yugoslavia.

(2) Inquiries were transmitted to additional countries identified as desirable locations for GAP-type agreements: Argentina, Columbia, Indonesia, New Zealand, Philippines, Romania, Taiwan, and Venezuela.

(3) A prototype GAP agreement, designed to be signed by the U.S.G.S. and the appropriate agency(ies) in the host country, was developed.

(4) Discussions were held with officials from counterpart agencies in the following countries: Korea, Indonesia, India, and Pakistan.

(5) The final field checking phase of the General Earthquake Observation System (GEOS) was initiated. A complete array of systems is expected to be in operation by April 1983. The low power, portable digital broad-band microprocessor based systems are expected to be especially useful for studies of aftershocks, strong-motion, seismic refraction, and teleseismic signals.

Reports

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Nonlinear Soil Response at Imperial Valley Recording Sites

9550-03390

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Investigations

(1). Assembled shear modulus and shear strength profiles for stations 6 & 7 of the El Centro Strong Motion Array from available field data.

(2). Continued to experiment with various analytical procedures for the development of an inverse procedure proposed for this project.

Results

(1). Cone penetration record alone is not sufficient to assess the past loading history of a soil deposit. Consolidation or similar tests should be included to determine the state of overconsolidation.

(2). The depth at which the artesian pressure at the station 6 site originates remains uncertain but is critical in computing the effective stress profile at that site which in turn affects the outcome of the interpretation of cone penetration record.

Reports

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Estimating Strong Ground Motion for Engineering Design and Seismic Zonation

9940-01168

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Investigations

1. Analysis of strong-motion data leading to the development of predictive equations for strong-motion parameters and development of methodology for making predicting maps of strong ground motion.

2. Cooperation with professional groups in the development of code provisions for earthquake resistance.

Results

1. Using data from 33 strong-motion sites we have analyzed the correlation between site shear velocity and residuals of measured ground motion values, taken with respect to prediction equations previously developed in terms of magnitude and distance. The results are an improved method for predicting the effect of site geology on peak horizontal velocity and response spectral values, using the site shear-wave velocity measured or estimated over a quarter wavelength of the period of interest.

Reports

Joyner, W. B., and Boore, D. M., 1982, Estimation of response-spectral values as functions of magnitude, distance, and site conditions: Proceedings of the 14th Joint Conference of the U.S.-Japan Panel on Wind and Seismic Effects, Gaithersburg, Maryland (also U.S. Geological Survey Open-File Report No. 82-881).

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Seismological Field Investigations

9950-01539

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Investigations

1. Soda Springs, Idaho, earthquake sequence--local investigation of aftershocks, October 17 to October 24, 1982.

2. Argentina aftershock study--regional investigation of aftershocks resulting from magnitude 7.4 (M_s) earthquake of November 23, 1977.

Results

1. The Soda Springs, Idaho, earthquake sequence of October 1982 began on October 8 with a series of three felt events ranging in magnitude between 3.2 to 3.8 (M_L). Several other earthquakes of lower magnitude (< 3.0), but still felt by many residents in the area, occurred during the following week. Then, on October 14, the largest earthquake of the sequence (M_L = 4.7) took place and within a six-hour period, it was followed by aftershocks of magnitude 3.9, 3.6, and 4.1 (M_L). This seismicity was also accompanied by many smaller felt events and intense microaftershock activity.

In cooperation with the University of Utah, the USGS established a temporary network of 17 portable, smoked-paper recording seismographs around the epicentral area. The complete network recorded for about one week (October 17 to October 24) during which time several thousand aftershocks were detected. The principal source zone was determined to be in the close proximity of Diamond Gulch, in the Aspen Range, about 10 km southeast of Soda Springs.

2. An aftershock investigation, using a network of eight portable and two permanent seismographs, was conducted for the San Juan Province, western Argentina earthquake (M_s = 7.4) of November 23, 1977. The monitoring began about 2 weeks after the main shock and continued for a period of 11 days. Despite the late start, a useful data set of 196 aftershock hypocenters, in the depth range from near-surface to 30+ km was obtained. The spatial distribution of those events was: (1) predominately south of the main shock epicenter indicating unilateral fault propagation in that direction, (2) spread throughout a volume of about 100 x 40 x 30 km (length x width x thickness, respectively), and (3) situated on the eastern half of the Sierra Pie de Palo, the dominant physiographic-geologic feature of the area. The volumnar nature of the aftershock distribution probably is a result of reativation of the two intersecting fault sets present in the vicinity of the main shock. Those fault sets appear to be distributed somewhat uniformly throughout the Sierra Pie de Palo. Thus, we have no explanation as to why only one side of that mountain should be selectively activated by the earthquake sequence.

Nine intermediate depth earthquakes (foci at 110 km to 135 km) were also recorded and located. From previous seismicity studies in the region, these are probably shocks in the subducted Nazca plate and not aftershocks of the 1977 earthquake. Their computed positions (depth range and clear separation from shallower aftershock activity) were derived from a velocity model developed specifically for the Sierra Pie de Palo region of the San Juan Province.

An empirical classification scheme, based upon a length to thickness ratio, was developed to describe the geometric configuration of seismogenic zones as planar, tabular, or volumnar. That scheme is applied to 25 recent, high-quality studies of seismicity patterns and aftershock sequences in the conterminous United States, Alaska, Nicaragua, Iran, New Zealand, and Greece. The classification results show that the majority (56%) of the seismogenic zones examined are volumnar as was the aftershock sequence studied in Argentina.

Effect of Lateral Heterogeneities on Strong Ground Motion in the Puget Depression

14-08-0001-20524

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Investigations

1. The response of a symmetric three-dimensional basin model to impinging P and SH plane waves was studied using an efficient ray tracing scheme to calculate synthetic seismograms. This was done to study the possible effects of 3-D structure on levels of strong ground motion in the Puget sound area.

2. Data on subsurface geologic structure under Seattle and adjacent areas are being collected for inclusion in a simulation of strong ground motions from the 1965 Puget Sound earthquake.

Results

1. The following is the abstract of a paper in preparation entitled "Wave propagation in a three-dimensional circular basin" by J.J. Lee and C.A. Langston.

Wave propagation in a three-dimensional circular basin model is studied by using a ray technique which employs the method of principal curvature for geometric spreading calculation. Three components of ground motion are calculated at surface stations assuming incident plane P and SH waves with various incidence angles. Computed results show that seismic energy is substantially enhanced in the central region of the basin while it diverges rapidly toward the edge of the basin. Compared to a two-dimensional basin with the same cross section, amplitudes are larger for stations in the central region and smaller for stations near the edge. Waveforms and amplitudes can change drastically between two nearby stations due to caustics and geometric focusing for different paths. It is found, for the particular basin geometry and velocity contrast used, that the first multiple P wave and other particular phases experience two caustics near the basin center which are associated with the principal curvatures of the wavefront. This results in the reversal of the polarity of the waveform. As incidence angle increases, later arrivals at near-edge stations and the stations in the diagonal direction are more strongly developed from the curved boundary of the basin, but amplitudes of ground motions generally decrease as incidence angle increases. In general, wave responses strongly depend on the incidence angle and station location. These results have important implications for site amplification of strong ground motions since wave behavior is so complex even for this simple idealized structure.

2. Subsurface geologic data is being acquired from Jim Yount at Menlo Park.

These data will be used in conjunction with the ray tracing scheme to investigate whether high intensities observed during the 1965 Puget Sound earthquake were caused by wave focusing effects in 3-D structure.

Reports

Lee, J.J. and C.A. Langston (1982). Three-dimensional ray tracing and the method of principal curvature for geometrical spreading, (abstract) Earthquake Notes, 53, p. 80.

Lee, J.J. and C.A. Langston (1982). Wave propagation in a three-dimensional circular basin, (abstract) EOS, 63, p. 379.

Methodology for Seismic Hazard Analysis

Contract No. 14-08-0001-20528

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A study is being conducted to investigate two aspects in developing ground motion prediction models; parameter characterization of strong ground motion and the functional form of the attenuation model. The study is concerned with a number of objectives. First, the question of whether the RMS_a has lower uncertainty than PGA when attenuated with with distance is addressed for a comprehensive data base. Second, to address issues with respect to RMS_a attenuation such as magnitude dependence, near-source saturation, and the relationship to PGA. And finally, to consider the variability in ground motion predictions due to differences in the form of the attenuation model.

The root-mean-square acceleration (RMS_a) and peak ground acceleration (PGA) are selected as alternative parameters to characterize strong ground motion. To determine the RMS_a, four definitions of duration are used so as to avoid possible bias in the conclusions due to the use of one or another method. Three functional forms of the attenuation relation were adopted, the nonlinear regression models of Campbell (1981) and Joyner and Boore (1981), and a linear model. The suite of functional forms provides a range of versatility and modeling assumptions as to the shape of attenuation curves and the degree of magnitude dependence of near-source ground motion. The study is also intended to provide an opportunity to identify the degree of uncertainty in ground motion prediction associated with modeling assumptions.

A data base is developed for the study that attempts to minimize the potential for large scatter. Stations with attributes known to bias and otherwise contribute to the variability in strong motion data are not considered in the data set. These factors include the effects of large buildings, and shallow layered soil deposits.

Preliminary results indicate that the variability in PGA and RMS_a is essentially the same, independent of the attenuation model. The results contradict the expectation that the root-mean-square value would have lower variability. We also observe that the uncertainty estimated in the analysis is not significantly greater than that observed for attenuation during a single earthquake. In this study a factor of 1.58 corresponding to one standard deviation in the prediction of peak ground acceleration is observed, while in a recent study of the data recorded during the San Fernando earthquake (McCann and Boore, 1982) this factor was 1.55.

The results of the study will be used in a subsequent task to develop a probabilistic seismic hazard methodology using geophysical input.

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Strong Ground Motion Data Analysis

9940-02676

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Investigations

The two basic goals of this project are to develop realistic models of the earthquake source and to use this information to predict potential ground shaking for these particular sources.

Plans for FY 82 were to:

Complete analysis of stress differences at Monticello, South Carolina.
Complete analysis of radiated energy between P and S waves using Monticello data.
Analyze the Oroville data set for Brune source parameters.
Organize workshop on Methodologies for Predicting Strong Ground Shaking.
Analyze stress differences at Mammoth Lakes.
Determine source parameters along the San Jacinto fault using data from the newly-installed digital seismograph array.
Study the degree of inhomogeneity in other earthquake sequences and synthesize ratio of asperity size to broad-scale fault zone to other tectonic and/or fault zone parameters.

Results

Stress Drops at Monticello Reservoir, South Carolina

Stress difference was computed from seismic waves using three techniques -- Brune stress drop, a_{rms} stress drop, and apparent stress for ten small events in the $M \sim 1 - 1.5$ range and four larger events with M near 3. Digital seismograms from four to five stations were utilized in the analysis of the smaller shocks, and strong-motion accelerograms from a dam abutment site were analyzed for the larger events. The greatest stress differences were found for events in the upper few tenths of a kilometer and decrease with depth. The a_{rms} and Brune stress drop yield similar values of between 50 to 100 bars for the largest events (at depths $\lesssim 0.2$ km) while the apparent stress is smaller by about a factor of 2 to 3. Two wells were drilled near the two centers of seismicity associated with the impoundment of the reservoir in December, 1977, and early 1978. From an analysis of the in-situ stress data obtained in each of the wells using the principal of effective stress, the conditions for failure are only met in the uppermost 0.3 km in the region. Thus while seismicity (and therefore failure) is detected down to a depth of 2 km, most of the stress release is in the upper few tenths of a kilometer, in agreement with the analysis of in-situ stress data.

Source Parameters and Strong Ground Motion in Arkansas

Linda C. Haar and Gene Sembera conducted a field investigation on the swarm of earthquakes near Conway, Arkansas that started in mid-January, continues to the present, and has yielded 3 events with M_d (duration magnitude) greater than 4.0. The swarm lies near the southern edge of the Arkoma basin where Paleozoic sediments, which have been folded and thrust-faulted, overlie pre-Cambrian basement. No observations of surficial offset associated with the swarm have been detected. During the two weeks the array of digitally recorded velocity transducers and accelerometers was in place, 53 events were recorded on three or more stations: the largest (M_d = 3.8) produced a .59g peak on a local SMA-1 strong motion accelerograph. The hypocenters are confined to a tight cluster about 2 km in radius with depths ranging from 4 to 6 km. Fault plane solutions which best fit the amplitude data are strike-slip with one plane striking NNE and the other striking WNW. Seismic moments for a suite of 16 digitally-recorded events range from 10^{18} to 10^{20} dyne-cm with stress drops that range from 3 to 40 bars. The M_d = 3.8 event had a moment of 7 x 10^{21} dyne-cm and a stress drop of 180 bars. These events have stress drops smaller than those reported by Mueller and Cranswick for aftershocks of the New Brunswick, Canada earthquake, but similar to those calculated by Fletcher for events at Monticello Reservoir, South Carolina.

Source Parameters for Aftershocks of the Oroville Earthquake

A suite of 111 accelerograms for 14 aftershocks of the Oroville earthquake (1 Aug. 1975, M_L = 5.7) have been analyzed with respect to the Brune model. The suite of accelerograms, all of which were recorded at epicentral distances less than 20 km, provide an unusually complete set of strong ground motion histories for the near field over the magnitude range 2.8 to 5.2, the magnitude range for which many of the critical facilities in the eastern US are designed. Source parameters seismic moment (M_0), source radius (r), and stress drop ($\Delta\sigma$) were obtained for all 14 events. The relationship of log M_0 vs. M_L for the aftershocks in the suite of accelerograms is not consistent with the moment and magnitude of the mainshock or other events in the $5.5 \leq M_L \leq 6.5$ range in central California. The response of the Wood-Anderson seismograph at small magnitudes ($M_L \lesssim 4.0$) would give a slope of $\log M_0 = aM_L + b$ with a near 1, suggesting that the log M_0 vs M_L relationship cannot be extrapolated from small magnitudes ($M_L < 4.0$) to values of M_L near 6.0, and that for events with $M_L \sim 6$ a value of a near 1.5 or slightly greater may be more appropriate.

The source parameter data appear to support a dependence of moment on stress drop below $M_0 \simeq 2 \times 10^{22}$ dyne-cm with larger events having stress drops near 100 bars except one event which had a stress drop of 15 bars and a moment of 9.5 x 10^{22} dyne-cm. The largest stress drop events have the deepest depths, suggesting that the largest stress drop at a depth interval increases with depth in a manner similar to the increase in shear stress from the overburden pressure on a fault whose orientation is consistent with the focal mechanism and hypocenter data.

ANZA

A section of the San Jacinto fault near the town of Anza has been identified as a seismic gap from the pattern of seismicity over the past 100 years. The northern section near Hemet broke in 1890 and 1899. To the south near Borrego, shocks in 1942 and 1968 appear to have relieved much of the strain up to Coyote Mountain which then marks the southern end of the gap. The seismicity is high in the southern half of the gap with a $M_L > 4.0$ every two years or so, but the northern half is quiet. This section of the San Jacinto fault has been chosen as the site of an intensive study of earthquake source parameters in and around a seismic gap. More specifically, we intend to calculate source parameters such as hypocenter, focal mechanism, moment and stress difference from seismic waves to study source-parameter scaling, the generation of a high-frequency ground motion and the interaction of rupture zones.

In order to calculate these source parameters precisely, an array of broad-band, high-dynamic range three-component seismographs is being installed along a 30-km section of the San Jacinto fault. Geophone signals are digitized on site by a 16-bit analog-to-digital converter at a rate of 250 samples/component and sent by VHF radio to Toro peak where all of the data are multiplexed together and sent by microwave to IGPP in San Diego. There a Pdp 11/34 collects the data, determines when an event has occurred and stores the digital records on a computer-compatible tape deck. As of this writing seven stations have been installed and are sending data through to IGPP. The computer has been programmed and has been saving event files since September, 1982. The microwave system has a greater dropout rate than guaranteed by its manufacturer necessitating development of a trigger alogorithm that would ignore such drop-outs. The software developed for the mini-computer is an extensive package developed by Larry Baker at the U.S.G.S. which incorporates many user-oriented features for easy startup of the array, error-checking, and monitoring of its status during operation.

Development is now being directed at modifying the existing software package for picking body-wave arrival times, calculating spectra, energy and rms-acceleration on a display of multiple traces and also to allow for the picking of windows for spectra and energy in one viewing session.

Seismograms from the array to date show a marked absence of secondary arrivals in contrast to data from Imperial Valley. Stations within 7 to 10 km of the epicenters are rich in frequencies as high as 30 to 50 Hz. The high resolution of the recording system is apparent in the data with a wide range in magnitudes being recorded on scale. While our emphasis to date has necessarily been focused on the acquisition of the data, we are now moving towards the analysis of the data, and we anticipate that the array will produce a collection of on-scale seismograms for a sequence of events that leads up to a $M_L \geq 4.0$ in the neighborhood of a seismic gap within just a few years.

Reports

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Post-Earthquake Shaking Effects and Fault Creep

9940-03027

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Investigations

1. The uniform use of the amount of distrubance in food stores was further developed as a technique for reliable seismic intensity rating.

2. Study of the major seismic intensity effects of the 1906 California earthquake continued.

Results

1. Comparison of foodstore intensity ratings with nearby strong motion measurements shows a correlation of intensity V with 0.01-0.04 g, intensity V1 with 0.08-0.15 g, and intensity VII with 0.21-0.28 g, with no conflicts.

2. Descriptions in the Lawson report and in 1906 newspapers indicate that the 1906 earthquake damage in eastern Alameda and Contra Costa counties was apparently much greater than is indicated on current seismic risk maps.

Reports

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Using Earthquake Hazard Maps for Lifeline Systems San Francisco Bay Area

Contract No. 14-08-0001-19831

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INTRODUCTION

In this project, ABAG extended the computer-based earthquake hazard mapping capability developed in two earlier contracts to the highly urbanized central San Francisco Bay Area. The earlier contracts focused first on San Mateo County, and second on the rapidly developing areas of the East Bay ridgelands and Petaluma.

Ways were explored to use the resulting maps for analyzing lifeline systems in the Bay Area, including water, sewage, and solid waste systems, major highways and railways, and electrical and gas networks. Since lifeline problems are associated largely with existing urban development, this project serves as a logical complement to the last project which focused on areas undergoing rapid new development. The results are being made available in forms useful to a variety of people working for and with local governments and lifeline systems.

PROJECT COMPONENTS

1. Selection of target areas and key lifeline systems
2. Map file development and manipulation
3. Lifeline networks and facilities analysis
4. Communication and use of the project's findings

DISCUSSION OF RESEARCH

1. Target 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 East Bay ridgelands, and the Petaluma area. The first task of this project was to choose those urban areas where expansion of the detailed hazard mapping work should occur. These areas were limited by cost to approximately fifteen 7-1/2 minute quadrangles. The sixteen quadrangles chosen, when added to the areas mapped in detail in the earlier two contracts, form a contiguous area that extends from Santa Rosa in the north, to Morgan Hill in the south, and east to Walnut Creek.

Next, various lifeline systems were examined to determine those most appropriate for analysis. The decision was made to concentrate on sewage, water supply, rail and highway systems. Less emphasis has been placed on air and water transportation, solid waste disposal and power systems. No data were collected on communications systems. The analysis of these systems covers the entire nine-county Bay Area, and is not limited to the 46 quadrangle area where detailed hazard information has been made available.

2. Map File Development and Manipulation

Information on bedrock geology, existing landslides, and topography has been added for the sixteen central urban quadrangles chosen for additional analysis. Also, the bedrock geology and landslide data have been added for those portions of five quadrangles which are outside of San Mateo County. (These data had been entered for the portion of the quadrangles within San Mateo County as part of an earlier contract.)

These upgraded basic data map files of bedrock geology, landslides, and topography were used to produce more refined ground shaking intensity maps for the central urban area. (Both a maximum ground shaking intensity map and several risk of damage maps were produced using data on the relationship between any new categories of geologic materials and intensity). In addition, these data, together with information on vegetation and precipitation, were used to produce both rainfall-induced and earthquake-induced landslide susceptibility maps for the central urban areas. Finally, new information on fault location prepared by the California Division of Mines and Geology as part of the Alquist-Priolo Special Studies Zones Act program was incorporated into the fault file to use in upgrading the earthquake intensity maps for the entire region. Other information on damage to buildings and on earthquake recurrence intervals also has been included in the intensity map revisions.

3. Lifeline Network and Facilities Analysis

These revised hazard maps--as well as maps of liquefaction, dam failure, and tsunasmi hazard areas completed as part of earlier contacts--proved useful in assessing the earthquake hazards associated with the three main lifeline system components: the networks, key facilities, and service areas. Analysis techniques used included simple overlay maps, area tabulations of hazard level by lifeline type or link, identification of points of concern on networks, a printout of hazards associated with the location of key facilities, and an assessment of hazard levels associated with utility service areas.

4. Communication of the Information

Much effort is being made to ensure that the findings of the lifeline analysis work are effectively communicated to a variety of professionals working for and with local governments and lifeline systems in the San Francisco Bay Area.

- A series of fifteen working papers previously developed to document the hazard mapping capabilities has been extended to include the documentation of this contract.
- Contacts with local government personnel made in the two previous contacts have been expanded.
- Discussions were held with key staff working with lifeline systems to design the analysis techniques so that they will be more interested in the project's findings.
- Talks were given at a conference and before a variety of groups.
- Help was provided to staff of other public agencies, consulting firms and individuals on how to best make use of our capabilities on a continuing basis.

Strong Ground Motion Prediction in Realistic Earth Structures

9940-03010

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Investigations

1. Analysis of calculated theoretical ground motions in the Los Angeles basin caused by a hypothetical magnitude 6.5 earthquake on the Newport-Inglewood fault.

2. Time-domain inversions of ground motions caused by the 1979 Imperial Valley, California, earthquake to determine subsurface distribution of slip on the Imperial fault.

3. Extension of the collocation seismogram method for calculating complete theoretical seismograms in media with arbitrary variation of velocity and attenuation with depth.

4. Testing of an improved method for calculating theoretical ground motions in the near-field of an extended earthquake source.

5. Cross-correlation analysis of ground motions observed on the El Centro Differential Accelerometer Array (EDA) during the 1979 Imperial Valley earthquake.

Results

1. Los Angeles ground motions: In the first half of FY 1982, ground motions in the period range from 30s to 0.5s were calculated for a magnitude 6.5 earthquake rupturing unilaterally from Long Beach to Westwood along the Newport-Inglewood fault. Strike-slip motion and a faulting width from 3 km to 13 km depth were assumed. Different seismic velocity models were used on either side of the fault to accomodate for the known large offset in basement depth across the fault. For this event ground motions were strongly enhanced in the direction of rupture propagation (NW), with peak velocities on the component perpendicular to the fault reaching 120 cm/s in the Inglewood region, midway along the fault, and 80 cm/s at the NW end of the fault in Westwood. By contrast, at Long Beach Airport, near the epicenter at the SE end of the fault, peak velocities were only about 5 cm/s. We have subsequently calculated theoretical ground motions for two different rupture velocities and have found that peak ground velocities are considerably higher in the forward direction for the faster rupture velocity. This work is being written into a contribution to the U.S. Geological Survey Professional Paper on earthquake hazards in the Los Angeles basin.

2. Time-domain inversion of the 1979 Imperial Valley earthquake: A least squares point-by-point inversion of strong-ground motion and teleseismic body waves is used to infer the fault rupture history of the 1979 Imperial Valley, California earthquake. The Imperial fault is represented by a plane embedded in a half-space where the elastic properties vary with depth. The inversion yields both the spatial and temporal variation in dislocation on the fault plane for both right-lateral, strike-slip and normal, dip-slip components of motion. Inversions are run for different fault dips and for both constant and variable rupture velocity models. Effects of different data sets are also investigated. Inversions are compared which use just the strong-ground motions, just the teleseismic body waves, and simultaneously the strong-ground motion and teleseismic records. The inversions are stabilized by adding both smoothing and positivity constraints.

Figure 1 shows the strike-slip component of the preferred simultaneous inversion model. Each frame in figure 1 is a side view of the Imperial fault plane (north to the left) where the dislocation in centimeters is contoured for one of three time windows (T_1, T_2, and T_3). T_1 is the part of the dislocation which occurs within 0.7 seconds of the passage of a rupture front traveling at 0.85 . T_2 is the cumulative dislocation after 1.2 seconds of the passage of the rupture front, and T_3 is the cumulative dislocation after 1.7 seconds of the passage of the rupture front. The hypocenter is located 36 km from the northern end of the fault at a depth of 10.5 km.

The moment is estimated to be 5.0 x 10^{25} dyne-cm and the fault dip $90^0 \pm 5^0$. Dislocation in the hypocentral region south of the border is relatively small and almost dies out near the border. Dislocation then increases sharply north of the border to a maximum of about 2 meters under Interstate 8. Dip-slip motion is minor compared to strike-slip motion and is concentrated in the sediments. The best fitting constant rupture velocity is 80 percent of the local shear wave velocity. However, there is a suggestion that the rupture front accelerates from the hypocenter northward. Over-all the 1979 Imperial Valley earthquake can be characterized as a magnitude 5 earthquake at the hypocenter which then grew into or triggered a magnitude 6 earthquake north of the border.

3. Extensions of the collocation seismogram method: We have previously developed a method for calculating complete theoretical seismograms in media whose velocity, density, and attenuation structures were arbitrary piecewise-continuous functions of depth. By double transformation from the space-time domain to the angular frequency (ω)- horizontal wavenumber (k) domain, the calculation of theoretical seismograms is reduced to the solution of many two-point boundary value problems in depth. In our previous work we used the collocation method exclusively to solve these boundary value problems. The collocation method is essentially an implicit Runge-Kutta method that approximates the solution by a piecewise-continuous polynomial that is implicitly integrated by Gaussian quadrature. The collocation method works best for those solutions in which propagator matrix techniques fail, e.g. highly evanescent solutions. However, collocation is not particularly advantageous to use for oscillatory solutions. Consequently, we now solve the boundary-value problems using a combination of collocation and other methods. If we define $\nu = (k^2/\omega^2-c^2)^{1/2}$, where c is either the P-wave or S-wave velocity, collocation is used for depth intervals where $Re(\nu)>>0$ (surface waves), where $|\nu| \sim O(|\omega^{-1}|)$ (turning points), and in regions of large

velocity gradients. When $Re(\nu) \sim O(|\omega^{-1}|)$ and $Im(\nu) >> 0$, corresponding to highly oscillatory solutions, a high frequency approximation developed by Richards is used. This combination of collocation with other methods provides a convenient way to obtain solutions in traditionally troublesome depth regions such as turning points, low-velocity zones, and high velocity gradient zones.

4. Near-field extended-source ground motions: We have continued to improve and validate our new method for calculating ground motions in the near-field of an extended seismic source. We have checked the method against results given by Bouchon for the Coyote Lake earthquake, for a thrust earthquake in a halfspace, and for other tests. The method is currently being used to model the 1979 Imperial Valley earthquake (Archuleta, this volume).

5. Differential array analysis: The 1979 Imperial Valley earthquake was recorded by a 210-m-long linear array of five digital, three-component accelerometers with preevent memory and 100-Hz sampling rate per component. Using a moving window cross-correlation-analysis technique we developed, we have measured the correlation and apparent velocity of seismic arrivals along the array as a function of time during the first 20 s after the initial P-wave motion. For the vertical component of motion, apparent velocities initially are about 10 km/s, rise to infinity about 5 s after the initial P-wave motion, and drop back to about 7 km/s 9 s after P. After 9 s, the vertical accelerograms rapidly become very poorly correlated, and the apparent velocity fluctuates randomly.

The observed behavior of apparent velocity along the array can be readily interpreted as direct body-wave radiation from a moving rupture front that progresses NW along the Imperial fault for about 12 s. In this interval, during which the strongest motions occur, the observed apparent velocities and high degree of correlation of the traces imply that very little surface-wave energy is present in the vertical component records, despite the observation that the earthquake rupture proceeded all the way to the earth's surface. Consequently, the inferred soil strains (vertical component) caused by the shaking are less than would be expected if the ground motion were due primarily to surface waves, and the inferred wavelengths of the ground motion are greater than would be expected. These observations have important implications for the distortions that large foundations would undergo, and for the averaging effect that a large foundation would impose on base motions to which it was subject. Although our present results are for the vertical component of motion only, we are currently beginning to apply the same analysis to the horizontal components.

Reports

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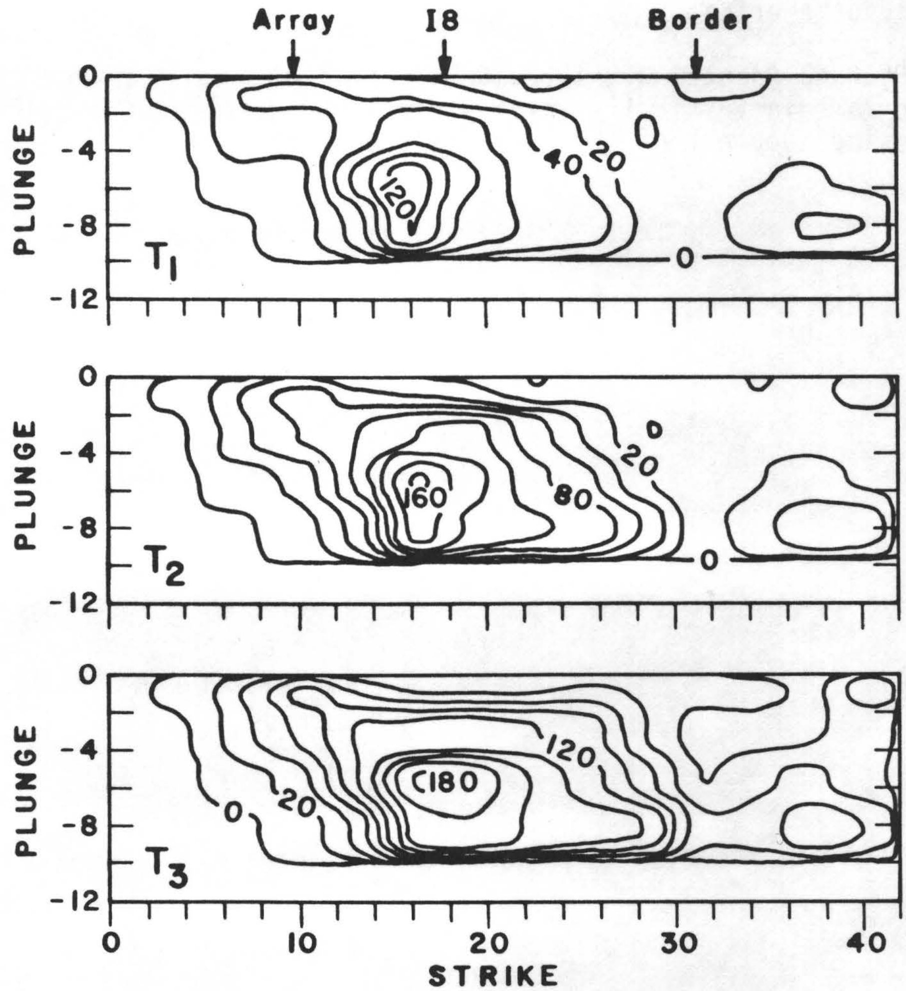
Figure 1. Cumulative strike-slip displacement (cm) on Imperial fault at 3 different times after rupture passage.



Array
I8
Border
PLUNGE
STRIKE
T1
T2
T3
120
40
20
0
160
80
C180

Earthquake Hazards of the Reno NE Quadrangle: Part I, Geology

14-09-0001-20563

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Investigation

The goal of this study is to map the surficial geology of the Reno NE 7 1/2-minute quadrangle, with emphasis on the Quaternary stratigraphy, in order to determine the recency and magnitude of movement on major faults in the area.

In order to accomplish this goal, the following tasks will be completed:

1) collection and compilation of all published and unpublished geologic studies for the area, and acquisition of 1:12,000-scale, low sun-angle photography for mapping;
2) mapping of the quadrangle at 1:12,000 and transfer to 1:24,000 topographic base;
3) detailed alluvial- and soil-stratigraphic studies to differentiate and date key deposits for fault hazard purposes;
4) description of geologic units with emphasis on physical (engineering) properties, and description of young faulting as it relates to major tectonic features of the region.

The resulting geologic map of the Reno NE quadrangle will serve as a base for a derivative earthquake hazards map to be done in the future.

Results

The Reno NE quadrangle is composed of several bedrock mountain ranges separated by the intermontane basins of Lemmon Valley, Hungry Valley, and Antelope Valley. Field mapping completed to date indicates that the bedrock areas are predominantly Mesozoic granodiorite intruded by lesser amounts of Mesozoic quartz monzonite. The granodiorite is typically light gray and phaneritic with variable enrichment by biotite and hornblende. Outcrops are usually highly jointed, forming large blocks of granodiorite which weather spheroidally in place. Aplite, pegmatite, and basalt dikes commonly cut through this unit.

In contrast, the quartz monzonite is generally lacking in ferromagnesium minerals, and it rarely crops out. This unit is often severely weathered and forms grussy colluvial hill slopes.

A prominent outcrop of mid-Tertiary volcanics has been mapped in the southwest quarter of the quadrangle, south of Hungry Valley. There appears to be at least four distinct ash-flow tuff formations represented in the volcanic sequence which may correlate with similar volcanics mapped by Bingler (1978) in the Carson City-Silver City area to the south. Thin sections of these rocks are currently being prepared for further study.

Lemmon Valley and parts of Hungry Valley that have been mapped contain piedmont-fan and lacustrine sedimentary deposits ranging in age from Tertiary (Mio-Pliocene) through late Quaternary (Soeller, 1978). Many of the deposits in Lemmon Valley are associated with pluvial Lake Lemmon which occupied the area in late Pleistocene. These deposits include beach, forebeach, and lake sediments. Although Lake Lemmon was hydrologically isolated from pluvial Lake Lahontan to the northeast, it may have been contemporaneous (Mifflin and Wheat, 1979). Part of this study will focus on dating Lake Lemmon more precisely for use as an important key in stratigraphic age control.

In addition to the deposits associated with Lake Lemmon, the following geologic units have been mapped: late Pleistocene to Holocene playa and associated clay dune deposits, windblown sand, stream and sheetwash alluvium, and alluvial fans; mid- to late Pleistocene older alluvium; and early to mid-Pleistocene alluvium, pediment gravels, and alluvial deposits of Peavine Mountain.

The Reno NE quadrangle is in a tectonic area dominated by three major features: the Sierra Nevada Frontal Fault Zone to the west, The Walker Lane, to the east, and the Olinghouse Fault Zone to the south. Structures in the quadrangle include northerly trending, range-bounding faults, northeasterly- and northwesterly-trending alluvial faults, and a series of northeasterly-trending lineaments. Trenching and detailed stratigraphic studies will be used to determine the recency and magnitude of faulting on selected faults and the relationship to the structural setting of the region.

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Development of General Earthquake Observation System

9940-03009

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Investigations

The objectives of this program are to complete assembly, testing, and documentation of the General Earthquake Observation Systems (GEOS). Investigations are continuing in expanding the program memory and implementing data transmission through the RS 232 port via telephone and microwave link.

Results

Ten systems have been completed and are being field tested. Results from these tests are extremely encouraging. Final documentation of hardware and software is about 50% complete. Circuit boards have been loaded and tested for all units and all manufacturing has been completed. Final assembly of the remaining systems is continuing.

Aftershock Investigations and Geochemical 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. Improvement in the methods used in generating recording and interpretation of shear waves in downhole surveys.

Results

1a. The DR-100 systems were maintained and operated by E. D. Sembera in the following activities:

- 4-8 May, Imperial Valley, CA, with C. Mueller
- 22 June-10 July, Arkansas earthquake swarm with L. Harr and J. Fletcher
- 6-13 August, Alaska volcanic earthquakes with J. Lahr
- 21-24 September, Vibration damage study of pre-historic monuments NW New Mexico with K. King

1b. E. D. Sembera assisted in the preparations for the new GEOS recording systems.

1c. Thirty-five, three-component accelerometer systems were delivered by the contractor, Kinemetrics, Inc. These were tested to determine if they met the technical specifications and calibrated. An open-file report detailing our findings is in process.

2a. A downhole shear wave survey was conducted in the deep hole at El Centro with the assistance of T. E. Fumal, R. L. Porcella, and E. F. Roth. The 244-meter hole was logged with the Geometrics Nimbus recording system in two days. A training program was conducted together with the logging operation to familiarize all participants with the Nimbus recording system.

L. J. Hwang, a U. C. Berkeley student, worked with us during the summer and with assistance from A. Walter set up a procedure for plotting seismic traces from the digital magnetic tapes of the El Centro work.

Preliminary interpretation yields a P-wave velocity of 1630 m/s S-wave velocity of 440 m/s averaged from surface to 240 m depth. Single impacts on the horizontal traction source yielded adequate shear-wave energy to the hole bottom. Multiple inputs were summed to compare to the single source impulses. The analysis is in progress.

Some peculiar noise sources were identified and corrections were made by the manufacturers of the Geometrics equipment.

Reports

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The Response of Weakly Cemented Sands to Seismic Loading

USGS 14-08-0001-19763 *

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Investigation

Most studies of the behavior of soils under seismic loading have concentrated on the rather idealized case of cohesionless sands. In actual fact, however, many soils have a small degree of cementation and this component of strength can have an important impact on the behavior of the sand. In the first phases of this work, a testing program was undertaken to define the effect of cementation on unsaturated material response. The latest phase has concentrated on saturated cemented sands in an effort to determine if, and how, these materials liquefy.

Results

1. Over 200 laboratory shear tests were performed on naturally and artifically cemented sands. The naturally cemented sands were located in exposed deposits along the Pacific Coast near Pacifica, California. Block samples of these materials were obtained to avoid disturbance. Artifically cemented sands were manufactured in the laboratory in order to produce a material parameter variation which was not obtainable from the natural material sources at hand. Verification tests were performed to guarantee that the artificial soils behaved in a manner similar to that of the natural ones.

2. The laboratory tests demonstrated that:

   a. Cementation in sands reduces the potential for liquefaction.

   b. Cementation causes two effects in the strength response. First, it adds a cohesion intercept to the failure envelope without altering the friction angle. Second the presence of the cementation at the point of contact between the grains causes the cemented sand to behave "denser" than its structural configuration would indicate.

   c. The amount of extra resistance to liquefaction due to cementation is a direct function of the degree of cementation.

   d. Relative density of a cemented sand is also an important parameter in the response of the soil as it is for uncemented sands.

e. The pore pressure development curves for cemented sands are different from those of uncemented sands, thus invalidating existing simplified models of pore pressure prediction for cemented sands.

Reports

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Use of Long-Period Surface Waves for Fast Evaluation of Tsunami Potential of Large Earthquakes

Contract No. 14-08-0001-19755

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Investigations

We developed a method to determine the mechanism and seismic moment of large earthquakes from long-period Rayleigh and Love waves. Some preliminary results were reported in the previous report. During this period we investigated the effect of lateral heterogeneity of the earth's structure and of the source delay times on the mechanisms determined with this method. Also, we made a numerical experiment for near-field tsunami warning system appropriate for a source-site geometry in Japan.

Results

1. Effect of Lateral Heterogeneity and Source Process Time

Spectra of mantle Rayleigh waves recorded on the IDA network are inverted to determine the seismic moment tensor of the June 9, 1980 California-Mexico Border earthquake, the July 29, 1980 Vanuatu Islands earthquake, and the July 9, 1980 Santa Cruz Islands earthquake. Examinations are made to correct for phase velocity lateral heterogeneity and source process time. A simple regionalization (stable continent, tectonic region, young ocean and old ocean) improves results of the linear inversion, but the phase correction is not large enough, and the discontinuous change of phase velocity across the boundary between regions causes an artificial rapid change in apparent phase velocity as a function of azimuth. Therefore a more detailed but gradual representation of the lateral heterogeneity is desirable to correct for the propagation effect in the linear inversion. A source process time which consists of the non-directional part of the apparent duration of main faulting and the delay time of the faulting from initial break is estimated by a phase analysis of Rayleigh waves. The source process time is generally proportional to the seismic moment on the log-log scale, but some earthquakes deviate considerably from the general relation. Therefore the measurement of the source process time should be made before the moment tensor inversion. The phase errors introduced by the lateral heterogeneity and source process time may cause a bias to low scalar time.

2. Numerical Experiment for Near-Field Tsunami Warning System

If an appropriate (long-period, low gain) recording system is available, long-period near-field displacements can be used to estimate the magnitude of an earthquake with a relatively simple form as

$$M = (1/1.5)\log \bar{A} + C$$

where M is the magnitude (at long periods), $\bar{A}$ is the average amplitude, and C is a constant. Using a source-site geometry appropriate for Japan, we determined the method of averaging the amplitude and the constant C by using synthetic seismograms computed by summation of modes.

This method provides a very fast and robust system for near-field tsunami warning system.

Reports

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Development of a Liquefaction Potential Map for San Francisco, CA

14-08-0001-20539

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Investigations

1. The objective of this project is to develop a map of the downtown San Francisco area giving the probability of earthquake induced initial liquefaction for return periods of 50 and 100 years. To achieve this objective, the following tasks must be completed: 1) Potentially liquefiable zones of soil within the study area must be identified; 2) Material properties required to describe pore pressure generation under seismic loading must be determined for the potentially liquefiable zones; 3) A hazard analysis must be performed to determine the seismic loading parameters for each liquefiable zone; and 4) A risk analysis must be performed to integrate items (2) and (3) and thus develop the desired map.

Results

To date (Nov. 1, 1982), the following results have been achieved towards the projects final objective:

1. Zones of potentially liquefiable deposits have been identified based upon U.S.G.S. surficial soil maps and the records of local geotechnical consulting firms. The criterion for a potentially liquefiable deposit is that it be saturated and cohesionless.

2. Material properties required to describe pore pressure generation have been related to Standard Penetration Test (SPT) blow counts by Clough and Chameau. Over 80 boring logs with blow counts have been collected from records of investigations for the new sewer system and from the files of three local consulting firms. Since the majority of these blow counts were for non-standard penetration tests, a method of converting non-standard blow counts to SPT blow counts was developed using a wave equation program for modelling dynamic penetration tests.

3. The seismic loading parameters for the pore pressure model used in this study are the root mean square (RMS) of the shear-stress time history and duration. To perform the hazard analyses, attenuation laws relating these parameters to earthquake magnitude and source distance are required. We have performed linear and non-linear regression analyses on all available earthquake strong motion records using four different definitions of duration on all available strong motion records. The sensitivity of our results to the type of regression analysis and the definition of duration is now being evaluated.

Seismic Slope Stability

9550-03391

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Investigations

1. We continued developing a method to predict the probabilities of landslides at susceptible sites in an earthquake of given magnitude.

2. We applied our methods of predicting earthquake-induced landslides to a portion of the Los Angeles Basin and prepared a paper describing our results.

3. We continued evaluating fracture characteristics of source rocks for rock falls from the 1980 Mammoth Lakes, California, earthquake sequence. Primary effort of field work was to examine the variation in fracture characteristics, spacing, roughness, orientation, and alteration within a fairly homogeneous rock mass.

4. We studied catastrophic rock avalanches in historical earthquakes and developed geologic and topographic criteria for identifying potential rock-avalanche sites.

5. We continued to analyze pore pressures measured in saturated lake sediments during the May 1980 Mammoth Lakes, California earthquake. Records of acceleration were compared with pore pressure records from the same events to see if pore pressures could be accurately predicted from the measured accelerations.

6. We assisted in planning installation of permanent instrumentation to record ground motions and dynamic pore pressures at a site in the Imperial Valley, California.

7. We investigated landslides caused by the January 4, 1982 storm in the San Francisco Bay area.

Results

1. A study of worldwide historical earthquakes has established relations between magnitude (M), the most distant occurrences of various types of landslides, and the total area surrounding the fault rupture that is at risk from landslides. By combining this data with a numerical study of seismic slope-stability, a catalog

of strong-motion records, and correlations involving M, distance, Arias intensity (Ia), duration, and peak acceleration, we have determined threshold shaking intensities for landslides and prepared maps showing probabilities of slope failure at various distances from a fault rupture. Shallow, internally disrupted landslides such as rock falls and debris slides from steep slopes are the most abundant landslides in earthquakes, occur farthest from fault ruptures, and are triggered at the lowest shaking intensities (min.≃Ia 0.1 m/s). More coherent, deeper-seated slides, primarily block slides and rotational slumps, from moderate slopes require stronger shaking (min. Ia≃0.5 m/s) and are restricted to lesser distances from fault ruptures. According to the historical data, the area potentially at risk from landslides of all types increases from 0 km^2 at M≃4 to approximately 500,000 km^2 at M=9.2.

Upper-bound magnitude-distance relations from the historical data establish maximum distances at which an earthquake of given M is likely to cause any landslides of a particular type. We determined probabilities of landslide occurrences at closer distances using an analytical technique adapted from the seismic slope stability method of Newmark and a catalog of strong-motion records. We developed relations (1) between slope displacements as determined from the Newmark analysis and Arias intensity, and (2) between Arias intensity and peak acceleration and duration. We then used these relations and the peak acceleration-magnitude-distance relations of Joyner and Boore to prepare contour maps showing probabilities of failure of susceptible slopes at various distances from the fault rupture of an event with given M.

2. As a demonstration of the prediction method described above, we estimated the distribution of landslides from a postulated M 6.5 earthquake on the northern Newport-Inglewood fault zone. Maps were prepared showing: 1) The postulated source segment of the fault; 2) an elliptical zone around the source within which there is a greater than 50% probability of the ground motion exceeding the threshold level required for failure of susceptible slopes (15 km for coherent slides, 32 km for rock falls); and 3) an elliptical zone around the source corresponding to the historic upper bound distance to landsliding for a M 6.5 event (65 km for coherent slides, 112 km for rock falls). These maps indicate that the postulated earthquake could cause slumps and block glides in the Baldwin Hills, the eastern Santa Monica mountains, the Palo Verdes Hills, and the western Puente Hills. This event would also produce rock falls in these same areas and also in the Verdugo mountains, the southwestern slopes of the San Gabriel range, and along the coastal sea cliffs from Pacific Palisades to west of Pt. Dume. These maps and a discussion of the methods used to prepare them are presented in a contribution to the forthcoming Professional Paper on earthquake hazards in the Los Angeles area (J. Ziony, editor). The manuscript is now in technical review.

3. Examination of fracture characteristics within the Round Valley Peak Granidiorite and their relation to distribution of rock falls from the 1980 Mammoth Lakes, California, earthquake sequence indicates that fracture orientation and openness of fractures may be the two most important factors governing the susceptibility of slopes to earthquake induced rock falls.

4. Study of catastrophic rock avalanches in historical earthquakes shows that they were restricted to slopes steeper than 25^0 and higher than 150 m. Nearly all of them originated on slopes undercut by active fluvial erosion or by glacial erosion that is active or geologically recent. For each of the historical rock avalanches for which data were available, one or more recognizable indicators of potential instability were present in the sources. These indicators were (1) intense fracturing, (2) deep weathering, (3) prominent discontinuities dipping out of the slope, (4) weak cementation, and (5) evidence of previous landslide activity.

5. Analysis of pore-water pressure and acceleration records from aftershocks of the Mammoth Lakes earthquake show that, for these levels of acceleration (up to 150 cm/sec^2) a linearly elastic solution is adequate to account for the pore pressures measured. The elastic analysis also predicts a quarter wavelength phase shift and high frequency loss in the portion of the pore pressure waveform corresponding to the s-wave compared to the acceleration record. These calculated differences between the acceleration and pore pressure are consistent in the records of the eight event data set.

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EXTENSION OF LIQUEFACTION CRITERIA FOR SILTY SOILS AND EVALUATION OF POST-CYCLIE BEHAVIOR

14-08-001-20565

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INVESTIGATIONS

1. Existing data on the cyclic strength characteristics of silty soils was collected and compared with that of sands. An evaluation of the data was made to develop a liquefaction criteria for silts.

RESULTS

1. The silt samples undergo strains in a manner different than the sands. There is usually a steady build up of strains right from the start of the test and it appears to be not too strongly associated with the build up of the pore pressure as it is in case of sands. In most cases the 5% and 10% double amplitude axial strain develop before the time pore pressures become equal to confirming pressure.

2. In most pure silt samples, the trend of pore pressure development was different than in the case of sands, such that it takes a large number of cycles of loading to reach one hundred percent pore pressure ratio. The presence of sand contents can however, offset this effect, and silts with significant percent of fine sands can have dramatic rise in pore pressures.

3. Silts, even after reaching one hundred percent pore pressure ratios, do not deform as rapidly as sands.

4. It is suggested that the liquefaction criteria of "one hundred precent pore pressure ration with strain potential" used for sand may not be applicable for silts which usually develop large strains well before one hundred percent pore pressure ratio is reached. For sandy silts the criteria should be based on actual observation of the sample behavior during cyclic loading. For clayey silts, the criteria for pure silts can also be applied.

Liquefaction Investigations

9550-01629

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Investigations

1. Continued compilation of liquefaction potential maps for Los Angeles Basin area and San Mateo County, California.

2. Made cone penetration and standard penetration soundings at nine sites where liquefaction occurred during earthquakes in 1957, 1979, and 1981 in the Imperial Valley, California.

3. Instrumented one site where liquefaction occurred during the 1981 Westmorland, California, earthquake and where liquefaction is likely to occur during future events in that area.

Results

A locality underlain by liquefiable sediment was selected and instrumented to measure ground motions and pore-water pressure response during future earthquakes in the area. The selected site is on the floodplain of the Alamo River, 3.5 km southwest of Calipatria, California (33.10^{o} N, 115.53^{o} W). Liquefaction occurred at this site during the 1981 Westmorland earthquake as evidenced by the eruption of several sand boils. Eight earthquakes in the past 53 years have generated sand boils or were capable of generating liquefaction in the vicinity of this site. Thus, the site is in one of the most opportune areas for liquefaction in the United States. A plan view of the site and a cross section are given in Figure 1. The site was investigated using cone penetration and standard penetration soundings and auger and tube samples. Sediment beneath the site consist of a 2.5-m thick layer of silt with 12 to 22 percent clay (nonliquefiable?) over a 4.4-m thick layer of silty sand (liquefiable) which inturn overlies a 4.8-m thick layer of clay (nonliquefiable). A strong motion seismometer was placed at a depth of 7.5 m, immediately below the liquefiable layer, and a second seismometer was placed at the ground surface. Piezometers, incorporating electrical pore-pressure transducers, were installed at depths of 3.0 m, 4.0 m, 5.0 m, and 6.5 m. All transducer signals feed into a 12-channel oscillographic recorder. This is the first liquefaction site in the United States to be so extensively instrumented. An earthquake in this area now could provide important data for analyzing development of pore-water pressures and the onset of liquefaction in a granular sediment during earthquakes.

Reports

Youd, T.L., and Bennett, M.J., in press, Liquefaction sites, Imperial Valley, California: Journal of the Geotechnical Engineering Division, American Society of Civil Engineers

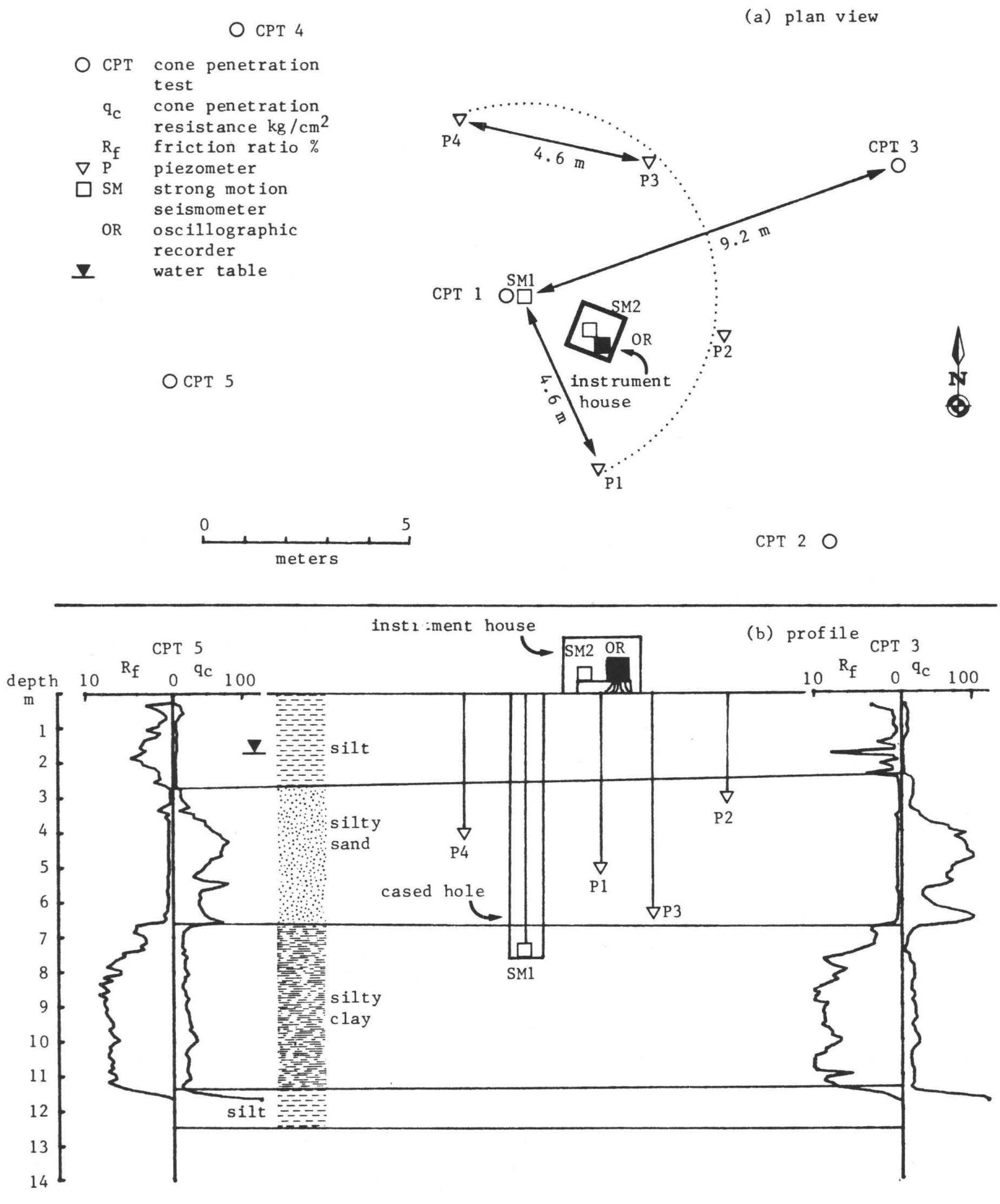

Figure 1.--Layout and cross section of site 3.5 km southwest of Calipatria (155 km east of San Diego), California, that has been instrumented to measure ground motions and pore-water pressures as liquefaction develops during future earthquakes.

SEISMIC DAMAGE ASSESSMENT FOR HIGH-RISE BUILDINGS

Contract No. 14-08-0001-19111

by

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SUMMARY

The purpose of this project, conducted by URS/John A. Blume & Associates, Engineers, for the U.S. Geological Survey, was to improve empirical and theoretical procedures for predicting losses to high-rise buildings damaged by earthquakes. The data bases and the empirical and theoretical procedures developed and described in this report should help to increase the reliability of quantitative loss predictions for high-rise buildings.

To improve empirical loss-prediction procedures, a computerized ground motion and building damage data base was developed using data from past earthquakes worldwide. The main purpose of the data base was to provide the means for developing empirical damage probability matrices (DPMs) for various building classifications. Data were collected in an extensive literature search, sorted, and entered into the data base. They were then used to generate DPMs that describe the probability that certain classifications of reinforced concrete and steel high-rise buildings would suffer various degrees of damage for given ground motion intensities. The ground motion intensity was expressed in values of both the Modified Mercalli Intensity (MMI) Scale and the Engineering Intensity Scale (EIS).

In order to use the damage data reported in terms of MMI to generate DPMs based on the EIS, a study was undertaken to correlate EI with MMI. A ground motion data base of 273 two-component records was compiled. Average response spectra corresponding to a given MMI and local geological classifications were derived and used to determine the relationships between the MMI scale and the EIS.

The theoretical studies included a thorough study and evaluation of the development of damage functions based on laboratory test data for various building components and on fundamental concepts of structural dynamics. On the basis of this evaluation, a probabilistic method of damage prediction that estimates earthquake damage to various structural and nonstructural building components was adopted and recommended for further development. With the use of available building component damage data, various practical applications of this method were demonstrated.

Many difficulties were encountered in the course of the project. One of the most significant was in the collection of motion-damage data from past earthquakes. The lack of complete data, the nonuniformity in reporting, and other factors led to the conclusion that the empirical approach has limited potential for future use in reliable damage predictions.

On the other hand, the theoretical studies were extremely encouraging. Prediction of loss by estimating damage to building components is a rational and straightforward approach based on engineering principles and probabilistic concepts, and it was concluded that this approach has the greatest potential for reliable application to earthquake damage-prediction problems. In addition, the theoretical damage-prediction procedure can be used by engineers in the process of designing high-rise structures to reduce losses due to earthquake damage.

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Analysis of Central California Network Data for Earthquake Prediction and Study of Physical Basis for Precursors

Principal Investigator: Keiiti Aki

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Investigations

In the present reporting period, we have investigated the following two problems. One is to find the secret of Chinese success in the prediction of Haicheng and several other large earthquakes. We wish to learn the reason of their success so that we can apply their method to our country. The other is to use the micro-earthquake spectral data obtained by the U.S.G.S. central California network for the purpose of monitoring the mechanical properties of fault zone. We measure the frequency dependence of the apparent attenuation of S-waves for various paths crossing the San Andreas fault system using the S to coda ratio method developed by the principal investigator.

Results

Let us first describe what we found about the secret of Chinese success. We conclude that their success was based on the following three rules implied in their selection of precursors.

(1) Precursors which almost always precede an earthquake are selected.

(2) Precursors with distinctly different precursor times (therefore, mutually independent) are selected.

(3) Precursors with short precursor times are selected even if they have poor success rate.

Let precursors be designated as A,B,C,..., and the occurrence of an earthquake within a volume of the magnitude-location-time space. Then, the conditional probability of M when A,B,C,... are observed is

$$P(M|A,B,C...) = \frac{P(A,B,C...|M)P(M)}{P(A,B,C...|M)P(M)+P(A,B,C...|\tilde{M})P(\tilde{M})} \quad (1)$$

where P(M) is the unconditional probability of M, and P(M) is that of non-occurrence of M.

From the selection rule (1), we find that

$$P(A,B,C...|M) \simeq 1. \quad (2)$$

From the selection rule (2),

$$P(A,B,C...|M) \simeq P(A)P(B)P(C) \quad (3)$$

since always P(M) is much less than 1, $P(\tilde{M}) \simeq 1$. Then, equation (1) can be rewritten as

$$P(M|A,B,C,...) \simeq \frac{P(A)P(B)P(C)}{P(M)+P(A)P(B)P(C)} \quad (4)$$

Thus, if the product of probabilities of occurrence of precursors become comparable or less than P(M), the conditional probability becomes significantly close to 1. The probabilitiy of the occurrence of precursor A can be expressed as

$$P(A) = \frac{\text{Number of occurrence of A x precursor time}}{\text{Total observation period}} \quad (5)$$

It is clear from equation (4), we need many, independent precursors which are rare, i.e., with small probability of occurrence. To make the probablity low, as shown in equation (5), we need either fewer occurrences and/or shorter precursor time.

Chinese selected precursors with four different precursor times (long, intemediate, short, and imminent), and used precursors with rélatively short duration such as Radon anomaly, animal behavior and water levels in shallow wells, even though they individually have extremely low success rates. The combination of these precursors enabled the total probability gain of about 10^4.

The progress with the analysis of the central California network data has been slow because of the difficulty encountered in reading the data tapes produced at Menlo Park. The problem was, however, completely solved, and analysis work has been proceeding very rapidly.

We have begun to lay the groundwork for the S wave study. Various practical considerations have to be worked through, including: (1) establishment of coda decay patterns for the regions of interest so that lapse time corrections can be applied to the coda wave spectra, and (2) optimal ways to window the data, especially the often diffuse S waves.

In the following we shall present the details of the study of Chinese precursors and some preliminary results from the analysis of central California network data.

Southern California Seismic Arrays

Contract No. 14-08-0001-19268

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Investigations

This semi-annual report summary covers the six-month period from 1 April 1982 to 30 September 1982. The contract's purpose is the partial support of the joint USGS-Caltech Southern California Seismographic Network, which is also supported by other groups as well as by direct USGS funding through its employees at Caltech. Other supporting groups during the report period include the California Division of Mines and Geology and the Caltech Earthquake Research Affiliates. According to the contract, the primary visible product will be a joint USGS-Caltech catalog of earthquakes in the southern California region; quarterly epicenter maps and preliminary catalogs are also required and have been submitted as due during the reporting period.

Results

Figure 1 shows the epicenters of all cataloged shocks that were located during the 6-month period; coverage above M = 3.0 is felt to be complete. Some of the seismic highlights during the period are as follows:

Number of earthquakes currently entered in catalog: 2,514
Number of earthquakes of M = 3.0 and greater: 132
Number of earthquakes of M = 4.0 and greater: 19
Number of earthquakes for which systematic
  telephone notification to agencies was made: 11
Largest earthquake (15 June, Anza area): M = 4.8
Smallest felt earthquake (13 April, Fullerton): M = 2.2
Number of earthquakes reported felt: 37

This was not a period of high seismic activity in southern California. Activity continued in the two small areas near China Lake (the Coso volcanic field) that were illustrated in the previous Technical Report Summary, and this activity culminated in a Magnitude 5.2 shock on 1 October, the day after the end of the report period. The Anza earthquake of 15 June was interesting in that, at first glance, it appeared to fall within the "Anza gap" along the San Jacinto fault that has been pointed out in previous reports. Its detailed location, however, was clearly not on the San Jacinto fault, but some 2-1/2 km southwest--thus tending increase the "ring" of activity surrounding the gap itself. Concentrated seismic activity in the Santa Barbara Island and Mammoth areas continued as has been typical for the past several years. Likewise the pronounced "hole" in activity centered in the Coachella Valley remains a conspicuous feature of the seismicity map.

Toward the end of the reporting period, a second PDP 11/34 Computer ws installed by the USGS at the Seismological Laboratory, to serve as a backup on-line computer, and, hopefully, for eventual real-time analysis.

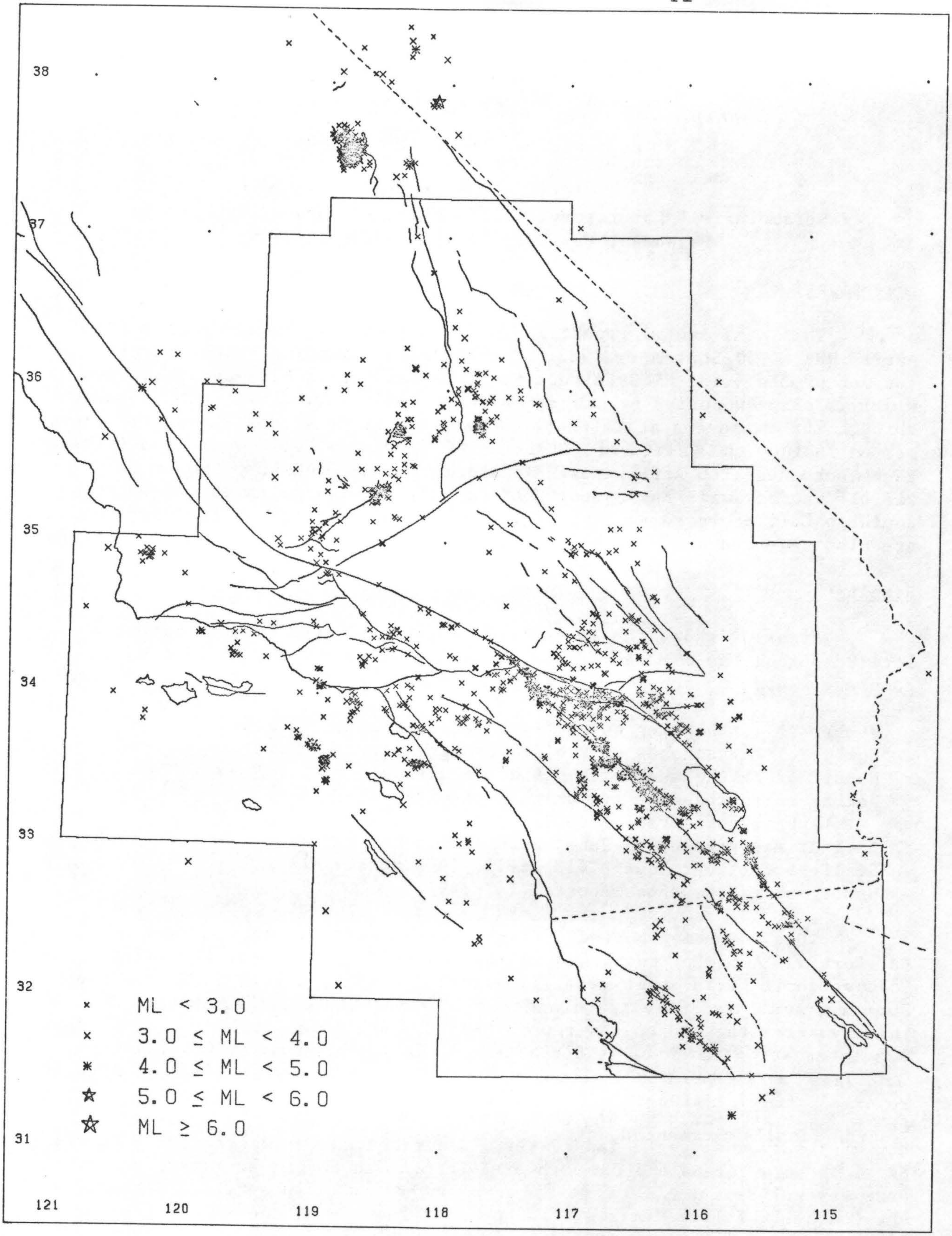

Fig. 1.--Epicenters of larger earthquakes in the southern California region, 1 April 1982 to 30 September 1982.

Creep and Strain Studies in Southern California

Contract No. 14-08-0001-19269

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Investigations

The semi-annual report summary covers the six-month period from 1 April 1982 to 30 September 1982. The contract's purpose is to monitor creepmeters and alignment arrays across active faults in the southern California region. Primary emphasis focuses on faults in the Coachella and Imperial Valleys.

Results

Imperial Valley.--The relative inactivity of faults, as well as low seismicity, continued in the Imperial Valley, with the exception of one creep event on a limited segment of the Imperial fault. Starting on about 18 July, 14 mm of right-lateral creep occurred at HEBER ROAD, commencing very abruptly and distributed in three pulses during a 40-hr period. No significant local seismicity was associated with the creep episode, and adjacent creepmeters across the Imperial fault at ROSS ROAD and TUTTLE RANCH (7 km NW and 5 km SE, respectively) showed no contemporaneous slip. During the six-month reporting period, continuously recording creepmeters were serviced twice at ROSS ROAD, HARRIS ROAD, HEBER ROAD, TUTTLE RANCH, as well as the dial-gauge creepmeter at SUPERSTITION HILLS. In addition, the nail-file arrays were remeasured twice at ANDERHOLT ROAD, ROSS ROAD, AND WORTHINGTON ROAD. No significant creep events were noted, with the one exception described above.

Borrego area.--The alignment array across the Coyote Creek fault at BAILEYS WELL has been measured occasionally since the time of the 1968 Borrego Mountain earthquake. The latest resurvey, in August 1982, shows a continuing uniform right-lateral slip rate of about 6.1 mm/yr at least since 1971.

Coachella Valley.--The alignment array across the San Andreas fault at DILLON ROAD was resurveyed during the reporting period, and creepmeters were serviced at least twice at MECCA BEACH and NORTH SHORE. In July 1982, telemetry from the creepmeter at MECCA BEACH to Pasadena, utilizing a TIM unit, finally commenced, after more than a year of various difficulties with the telephone company and land owners. The creepmeter is sampled once every 5 minutes, and this signal, along with two components of tilt from a Kinemetrics tiltmeter at the same location, is relayed to Pasadena once a day. No significant creep has occurred since commencement of telemetry, nor during the preceding period of strip-chart recording. Graduate student John Louie has been re-analyzing the alignment-array data from the Coachella Valley area, and Figure 1 shows the RED CANYON data through the last resurvey in January 1982. It is increasingly clear that the creep or episodic slip on this segment of the San Andreas fault described in previous Technical Report summaries is real and is continuing, with the dashed line of Figure 1 from 1977 to 1982 showing an average right-lateral slip rate of 3.8 mm/yr. Resurvey in July 1982 of the DILLON ROAD array, some 15 km northwest of RED CANYON, suggested similar continuing slip, although the scatter of observations was high due to unfavorable thermal conditions. Whether or not this slip is continuous or episodic is still not known, although episodic slip was observed in this area during both the 1968 Borrego Mountain and 1979 Imperial Valley earthquakes. It is interesting that the creepmeter at NORTH SHORE, some 15 km southeast of RED CANYON, has shown no significant slip for several years despite the continuing slip to the northwest. The absence of slip at NORTH SHORE is substantiated by the creepmeter data to date at MECCA BEACH, only 7 km father southeast. As was pointed out in earlier Technical Report summaries, the intriguing aspect of the continuing slip at RED CANYON and DILLON ROAD (as well as probably at INDIO HILLS) is that it is occurring along a segment of the San Andreas fault that appears to be a distinct seismic gap. Most other creeping segments of the San Andreas system are highly active with small and moderate shocks.

Garlock fault.--The alignment array across the Garlock fault at CAMERON, west of Mojave, was resurveyed during the reporting period, and although the data have not been completely analyzed as yet, continuing left-lateral creep appears to characterize this segment of the fault, as has been well documented by geodetic surveys still farther southwest--toward the junction with the San Andreas fault. Resurveys of alignment arrays at RAND and CHRISTMAS CANYON, farther northeast along the Garlock fault, are scheduled for November.

Cajon Pass area.--Because of recent claims that fresh cracks have been observed at the point where Interstate Highway 15 crosses the San Andreas fault in Cajon Pass, we resurveyed on 27 October 1982 the alignment array at CAJON, about 1 km northwest, as well as carrying out visual inspection of the fault trace. No significant changes were noted in the alignment array since the last measurement in January 1981, although the array is a "noisy" one. Old cracks in the asphalt of the nearby former freeway (Highway 66) have been observed periodically since 1966, and no significant changes were visible during the most recent observation by the Principal Investigator on 6 October 1982. Dr. Kerry Sieh observed the recent cracks on Interstate 15 in mid-August and reports that they most likely result from the fact that the freeway passes from crystalline bedrock to thick artificial fill at the point where it crosses the San Andreas fault in Cajon Pass. Furthermore, a large pipe for an access road almost directly underlies the cracks within the fill.

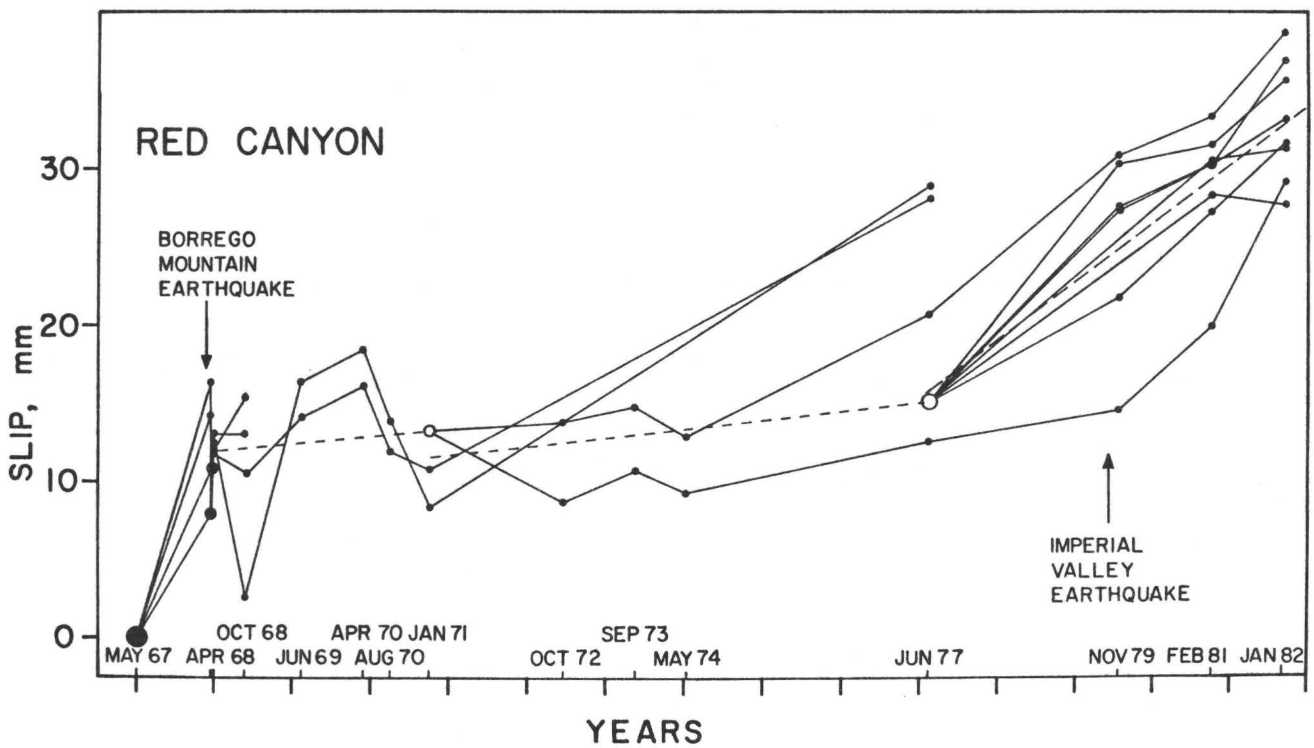

Fig. 1.--Results of resurveys of alignment array across San Andreas fault at RED CANYON (21 km SE Indio), showing one measurement in addition to those shown in Technical Report Summary of December 1981 (U.S.G.S. Open-File Rept. 82-65). Positive slip is right-lateral. Filled circles represent individual measurements between pairs of stations on opposite sides of the fault, usually within 300 m. Open circles represent assumed new values, based on averages of earlier readings, following loss of monuments and/or establishment of new monuments. Average creep rate indicated by dashed line from 1977 to 1982 is 3.8 mm/yr.

Earthquake and Seismicity Research Using SCARLET and CEDAR

Contract No. 14-08-0001-19270

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Investigations

Research supported wholly or in part by this contract during the six-month reporting period from 1 April to 30 September, 1982 has concentrated on:

1. Studies of small-scale earthquake clustering by cross-correlation of waveforms.
2. Study of Pn arrivals in Southern California.
3. The three-dimensional seismic structure beneath Southern California.

Results

1. Studies of Small-Scale Earthquake Clustering by Cross-Correlation of Waveforms.

Waveforms of Southern California earthquakes with M_L<3 appear to be insensitive to event size and dominated by the effects of radiation pattern and scattering from velocity heterogeneities in the crust. Small earthquakes with nearly identical waveforms over the entire length of record sometimes occur. These earthquakes must have similar mechanisms and hypocenters within 1/4 of the shortest wavelength to which the similarity extends. The highly localized sources they represent may be fault asperities or clusters of asperities.

In order to objectively compare waveforms of earthquakes within small (generally <5 km) areas, we calculate correlation coefficients between seismograms recorded at the same station and then average the results from several stations for each event pair. We have applied this technique to 5 regions along the San Fernando, Imperial, and San Jacinto faults. The results (Figure 1) suggest that seismicity for at least two years before the 1971 San Fernando earthquake (M_L 6.4) and the 1979 Imperial Valley earthquake (M_L 6.6) was characterized by clustering within source volumes less than 1/2 km in extent. This phenomenon appears to be relatively uncommon, though not limited to the periods before major earthquakes. For example, groups of similar events occurred after the Imperial Valley earthquake in one region studied, although compared to the pre-earthquake period many more sources were active simultaneously. Cross-correlation of waveforms may prove to be a useful technique for monitoring stress conditions along faults.

2. Pn Arrivals in Southern California.

The Pn arrivals from the Southern California Array have been used to investigate regional variations in crustal thickness and Pn velocity and also to demonstrate the presence of anisotropy in the mantle. The classical time-term method was improved to allow the Moho velocity to vary in a block structure. Rays are traced across the Moho and slowness perturbations for each block of mantle can then be determined. Also the time-terms and degree of anisotropy are also found. The time-terms determined depend on both crustal velocities and Moho depth. The Ventura and Los Angeles basins are clear examples of the former where the delays indicate sediment thicknesses near ten kilometers. The Moho discontinuity itself varies by ten kilometers over Southern California with a mean crustal thickness of about 30 km. Slightly thicker crust is prevalent throughout the Carrizo Plains - San Gabriel - Los Angeles region. Five kilometers of rapid thinning between the coast and the Channel Islands is evidenced by a sharp gradient in the delay times. Normal crustal thicknesses are prevalent over the rest of the array except the area east of the Salton Trough. There the crustal thickness is near 23 km. Velcocities east of the San Andreas fault are higher than west of the fault. The analysis supports anisotropy of 0.15 km/sec with the fast direction at W 15^{o} N. This value represents an average of a parameter that varies considerably in the region.

3. The Three-Dimensional Seismic Structure Beneath Southern California.

Raikes (1978) and Walck and Minster (1982) studied P-wave travel times observed at the Southern California Array and inverted them to obtain a three-dimensional structure beneath Southern California.

This study is another attempt to invert teleseismic P-delays. The major points that have yet to be resolved are the determination of depth to the prominent velocity anomalies and detailed examination of the borders of these areas. This study uses a more complete data set. These data include information at new recording sites and from new events, but also include arrivals from a set of events whose rays penetrate the core and are nearly vertically incident upon Southern California. These arrivals are expected to be important in resolving the deep structure which is thought to have a significant effect on the P residuals. In addition, a tomographic method of inversion is to be used to resolve structure since it allows for a rapid, inexpensive, and accurate velocity reconstruction. So far, the data have been gathered, reduced, and displayed in various forms, and are ready to be inverted.

A preliminary look at the data indicates that the most pronounced P-delay feature may be the result of a region of anomolously high velocity mantle located about 250 km below the surface.

Reports and Publications

Pechmann, J. C. and H. Kanamori, Waveforms and spectra of preshocks and aftershocks of the 1979 Imperial Valley, California earthquake: A test of the asperity model, J. Geophys. Res., in press.

Sauber, J., K. C. McNally, J. C. Pechmann and H. Kanamori, Seismicity near Palmdale, California and its relation to strain changes, J. Geophys. Res., in press.

Abstracts - American Geophysical Union Meeting - Fall Meeting 1982

Hearn, Thomas M., Pn anisotropy in Southern California.

Frankel, Arthur and Hiroo Kanamori, Use of rupture duration for the study of the regional variation of seismic stress drops in Southern California.

Pechmann, James C. and Hiroo Kanamori, Studies of small-scale earthquake clustering by cross-correlation of waveforms.

Clayton, Robert W. and Thomas M. Hearn, A tomographic analysis of lateral velocity variations in Southern California.

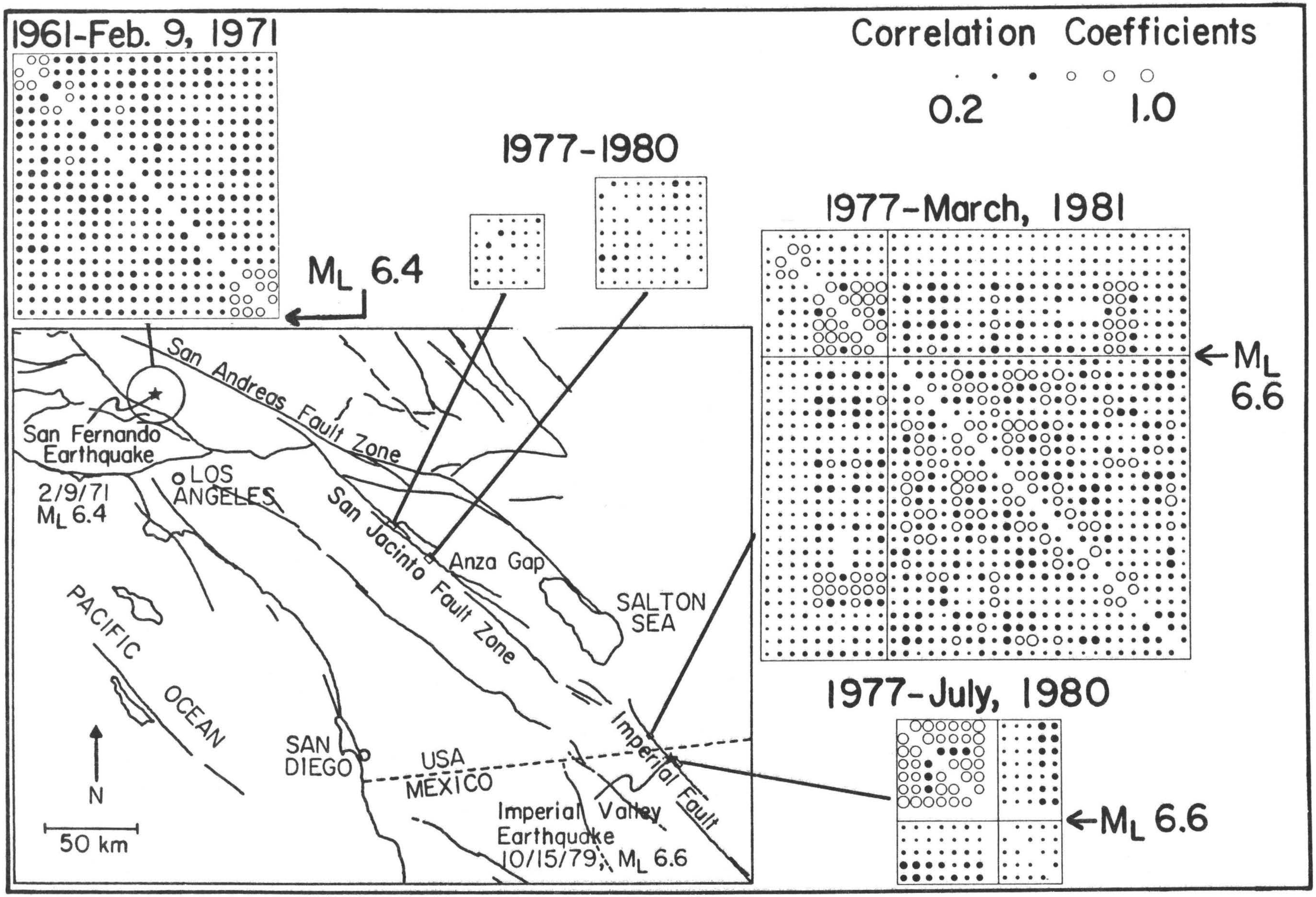

Figure 1. Cross-correlation matrices for seismograms of earthquakes in the magnitude range 2-3 within the regions shown during the time periods indicated. Each circle represents the mean peak cross correlation for the event pair corresponding to its position in the matrix. The radius of the circle is proportional to the correlation value, and circles representing values less than 0.6 are solid. Peak cross-correlation values from 2-5 different pairs of records were averaged to obtain each matrix element. Whole seismograms (usually 30 sec long) from CEDAR were used for these cross correlations except for the earthquakes from the San Fernando region, for which S waves digitized by hand from Wood-Anderson records were used. The order of the events within each matrix is chronological from top to bottom and left to right.

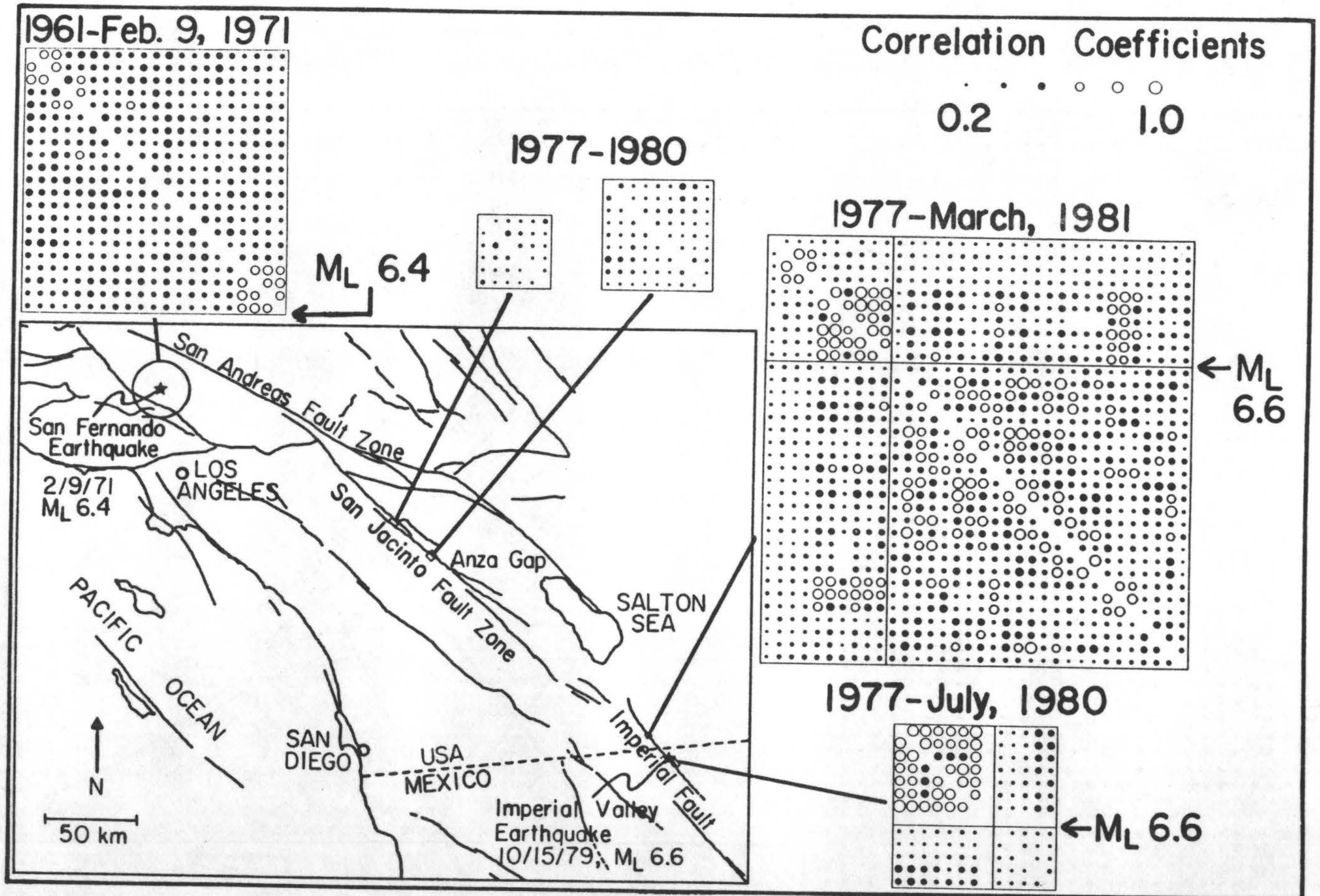

Figure 1. Cross-correlation matrices for seismograms of earthquakes in the magnitude range 2-3 within the regions shown during the time periods indicated. Each circle represents the mean peak cross correlation for the event pair corresponding to its position in the matrix. The radius of the circle is proportional to the correlation value, and circles representing values less than 0.6 are solid. Peak cross-correlation values from 2-5 different pairs of records were averaged to obtain each matrix element. Whole seismograms (usually 30 sec long) from CEDAR were used for these cross correlations except for the earthquakes from the San Fernando region, for which S waves digitized by hand from Wood-Anderson records were used. The order of the events within each matrix is chronological from top to bottom and left to right.

On-Line Seismic Processing

9970-02940

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Investigations and Results

No large changes were made in the Real Time Picker (RTP) systems during this period. Efforts were continued in improving the performance of the operating machines and attempting to understand better some of the problems that have arisen in operations of the systems.

A great deal of time has been occupied in looking for two bugs in the system. The first was finally identified as a manufacturer's hardware design error in the microprocessor chip that gives incorrect results for 'subtract' commands in certain cases. The second is still not completely understood but appears to be also a hardware problem. It is important because it prevents us from expanding the picker into additional memory space, which is needed to accomplish some planned improvements in the algorithm.

The Menlo Park RTP has been converted to operate entirely with programs in Read-Only Memory with a resulting improvement in reliability. The system is now protected by a 'watchdog timer' against failures caused by powerline flicker or other such 'glitches'.

The System Status reporting procedure has been modified to provide a report four times daily of each stations's noise level, dc offset, and several operating parameters used by the picker algorithm. These reports are saved in archival storage on UNIX, making it easy to check the status of any station or subnet for a given period in the past as well as to get a reasonably current status report at any time.

The Menlo Park RTP output is now routed to a PDP 11/23 as well as to the UNIX 11/70 and to a backup tape. The 11/23 locates events using the same HYPO71 locator used by UNIX and writes the results including diagnostics, phase and summary cards, etc. to the proper files in its disc space. These results are also transferred to the VAX system for storage. The 11/23's are much more reliable systems than their larger relatives, and will take over the main load of processing RTP data for use by Calnet as soon as a communications link between the 11/23's and the UNIX 11/70 is available.

Even though the 11/23 system is not 'officially' on-line yet, it has proved to be useful on several occasions when the UNIX data were not available immediately for a fairly large earthquake in the net. When required the data can be retrieved directly from the 11/23 at the terminal.

The RTP for the Hawaiian Volcano Observatory was delivered and is in satisfactory operation. The coda-length measuring algorithm in use at HVO is somewhat different than that at Menlo Park, in that they measure the coda until it subsides to background noise level instead of to a fixed level. The change was made as a field modification at delivery and seems to be satisfactory. This is encouraging because it opens the possibility of adding small special features and doing minor 'tuning' for individual RTP systems as the need arises in the field.

Reports

Allen, R.V., 1982, Automatic phase pickers: their present use and future prospects. *Bull. Seismol. Soc. Am.* (in press)

Seismological Data Processing

9930-03354

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Investigations

Computer data processing is absolutely necessary in modern seismological research; digital seismic data can be analyzed in no other way, and problems of earthquakes and seismic wave propagation usually require numerical solution. On the other hand, the interface between computers and people usually makes data processing unnecessarily difficult. The purpose of this project is to develop and operate a simple, powerful, well human-engineered computer data processing system and to write general application programs to meet the needs of scientists in the earthquake prediction program and monitor earthquakes in northern California.

Results

The PDP11-70 UNIX system has continued to operate smoothly, and performs a large amount of computing for program projects. Some current statistics:

200	registered users
590248	1024-byte disk storage blocks used
38	different users per weekday
150	hours login time

Recent events of particular importance include:

Hardware. Three 160 Mbyte winchester type disks have been added to the system incrasing the disk storage capacity by 50%.

UNIX Operating System. UNIX has been installed at the University of Nevada Seismology Lab.

Software. In addition, the following software additions and changes have been made:

** *Ppicker link.* The command files controlling the acquisiton of realtime earthquake data have been improved so that they are more realiable.

** *Geoplot.* A package for plotting maps, offering a choice of 29 different projections, has been added to Geoplot.

** *Digitizer* The capability to input digitized map data directly into UNIX has been added.

Seismic Hazard and Earthquake Prediction in Northwest Mexico and the California - Mexico Border Region: A Cooperative Study

14-08-0001-19852

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Results

1. Five stations of the northern Baja Seismic Array (RESNOR - Red de Estaciones Sísmicas del Noroeste) are telemetering data to Ensenada. Routine data processing has begun. Several additional stations are planned to improve coverage of individual fault zones.

2. Several studies were undertaken following the 9 July 1980 Victoria (Mexicali Valley) $M_L = 6.1$ earthquake. Aftershock locations by Wong and Frez are being published by the Earthquake Engineering Research Institute (EERI). S-wave spectral parameters have been calculated for 39 aftershocks. Stress drops of over a kilobar are observed, with corner frequencies in the band of 2 - 25 Hz. The results are similar to those of Luis Munguía for a swarm which occurred in 1978 in the epicentral region of the 1980 mainshock. One difference is that the 1978 corner frequencies are lower than about 14 Hz. Whether or not this is a real difference or a result of local site effects is being investigated.

These results are considerably different than those of Thatcher, who calculated very low stress drops for northern Gulf of California earthquakes, especially when compared with events from the Peninsular Ranges. These suggest that large regional variations in high frequency attenuation in the vicinity of the source. Since this may have significant effects on variations in strong ground motion and, hence, on local seismic hazards, we are investigating such variations more closely.

3. An extensive swarm which occurred in Laguna Salada during 1975 and 1976 has been examined by Reichle and Simons. Forty-one events were relocated using data from Río Hardy, approximately 25 km from the epicentral region. The considerable scatter of the original locations collapsed into a 5 km x 10 km area. Fault plane solutions indicate a primarily strike-slip mechanism for swarm events, similar to that found by C. Johnson in the Imperial Valley. Similarities of structure and seismicity between Laguna Salada and the Imperial Valley suggest similar tectonic processes. Since the Laguna Salada region is the probable southward continuation of the Elsinore fault zone, investigations of activity to the south may shed light on the seismic hazards of one of southern California's lesser understood faults.

4. Earthquake data sets collected from arrays of seismic event recorders and strong motion instruments operated in the Mexicali Valley and along the San Miguel fault (northern Baja California) and in the Imperial Valley and Anza (southern California) are analyzed in the thesis of Luis Munguía, a graduate student working on northern Baja California seismic data. Complementing near-source data sets with data from more distant seismic stations we have been able to begin to separate and understand the effects of stress drop, source size, sediment amplification, and physical attenuation on the variation of ground motion with distance. Surprisingly large ground accelerations, over 0.5g, were recorded for some relatively small (less than $M_L = 5$) earthquakes in the Victoria, Baja California earthquake swarm of March 1978. We conclude that this is a result of relatively high stress drops (around 1 kb) and a relatively high sediment amplification factor, about 3.4. The ground motion from these earthquakes was relatively high frequency, which was somewhat surprising since the well-established depth of the events is about 10-12 km and the energy thus passed through the 5 km thick column of sediments of the Imperial -Mexicali Valley, which might have been expected to produce severe attenuation. The occurrence of high stress drops is rather puzzling in view of their occurrence in a region of crustal spreading, basic rocks, high heat flow, and the presence of a large amount of water. For the smaller events, sites on sediments clearly show higher amplitudes than sites on solid rock throughout the distance range considered here (up to 57 km). For two larger events in the region (the $M_L = 6.6$ Imperial Valley 1979 earthquake and the $M_L = 6.1$ Victoria 1980 earthquake) the effect of source size (or geometrical saturation in the near field) begins to play an important role. We illustrate this effect by comparison with ground motion for the larger earthquakes, and also by modelling the ground motion the ground motion for the larger earthquakes by a superposition of records from the small earthquakes. In this way, gross features (duration of shaking, maximum amplitude and frequency) on the seismograms produced at short distances by two moderately large earthquakes of the region are modelled.

Another factor important in understanding the relationship between near source ground motion and Richter magnitude is the effect of scattering by geologic complexity, especially at the boundary region between the Imperial Valley and the granitic batholith of the Peninsular Ranges. We have been able to take this effect into account by using records from small earthquakes as point source responses of the medium. Spectra of high stress drop events recorded at Pasadena indicate that the spectra have been severely modified by scattering and attenuation, and this suggests that previous studies indicating relatively low stress drops for events in the Imperial Valley, Mexicali Valley, Gulf of California region, were not reliable.

<u>Reports</u>

Frez, José (1982). Main shock location and fault mechanism, in J.G. Anderson and R.S. Simons, eds., The Mexicali Valley earthquake of 9 June 1980, <u>EERI</u>, (in press).

Nava, F. Alejandro and James N. Brune (1982). An earthquake-explosion reversed refraction line in the Peninsular Ranges of southern California and Baja California Norte, Bull. Seism. Soc. Am., 72, 1195-1206.

Nava, F. Alejandro and James N. Brune (1982). Source mechanism and surface wave excitation for two earthquakes in northern Baja California, Mexico, Geophys. J. R. Astr. Soc.,, (in press).

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Fault Slip Measurements

9960-02943

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Investigations

1. Continued the analysis of the possible associations between variations in seasonal rainfall and variations in rates of shallow aseismic slip along the central section of the San Andreas fault (Watsonville to Cholame).

2. Repeat measurements of alinement arrays on the San Andreas fault in central California and analysis of the resulting data were continued.

3. Experiments to determine the response of carbon-fiber bundles to temperature and humidity changes and the long-term mechanical stability under constant loads in comparison with fused quartz have been initiated under contract with Lamont-Doherty Geological Observatory, Columbia University.

Results

1. Varying minor responses of creepmeter instruments and/or of soil and shallow slip-zone materials are associated with incidences of rainfall. However, the total annual (seasonal) rainfall amounts for each of the years 1970-1980 showed no significant statistical correlation with any of the tectonic variables such as total annual aseismic slip, number of $M_L \geq 2$ earthquakes, number of fault-creep events, and total annual creep-event slippages. Nevertheless, an apparently consistent effect of the annual dry season is to delay the onset of creep events, and certain creep events seem to be triggered by rainfall, especially by the first significant precipitation (~10 mm) marking the end of the dry season.

2. Departures from regional linearity in the relation of slip rate versus site position along the San Andreas fault have been identified for certain sites in the Parkfield region. Sites showing slip rates significantly below the regional trend are located near distinct changes in fault strike. Local complexities of fault-zone structure and relatively wider zones of deformation may explain these observations.

3. Results of the tests on stability of carbon-fiber bundles, when available, will be used to determine the applicability of carbon fiber for use as length standards in the design for deep-reference strainmeters.

Reports

Schulz, S.S., R.O. Burford, and B. Mavko, 1983, Influence of seismicity and rainfall on episodic creep on the San Andreas fault system in central Califonria, submitted to Journal of Geophysical Research.

Schulz, S.S., G.M. Mavko, R.O. Burford, and W.D. Stuart, 1982, Long-term fault creep observations in central California: Journal of Geophysical Research, v. 87, p. 6977-6982.

Burford, R.O., 1982, Introduction (to proceedings volume), in Hart, E.W., Hirschfeld, S.E., and Schulz, S.S., eds.: Conference on earthquake hazards in the eastern San Francisco Bay area, March 24-27, 1982, Proceedings, Calif. Div. of Mines and Geol., Special Pub. 62, p. ix-x.

Burford, R.O., and R.V. Sharp, 1982, Slip on the Hayward and Calaveras faults determined from offset powerlines, in Hart, E.W., Hirschfeld, S.E., and Schulz, S.S., eds.: Conference on earthquake hazards in the eastern San Francisco Bay area, March 24-27, 1982, Proceedings, Calif. Div. of Mines and Geol., Special Pub. 62, p. 261-269.

Harsh, P.W., and R.O. Burford, 1982, Alinement-array measurements of fault slip in the eastern San Francisco Bay area, California, in Hart, E.W., Hirschfeld, S.E., and Schulz, S.S., eds.: Conference on earthquake hazards in the eastern San Francisco Bay area, March 24-27, 1982, Proceedings, Calif. Div. of Mines and Geol., Special Pub. 62, p. 251-260.

Harsh, P.W., 1982, Displacement on the San Andreas fault near Parkfield, California, as determined from alinement-array surveys (abs.), presented at Amer. Geophys. Union Chapman Conference, Snowbird, Utah, Oct. 11-15, 1982.

Remote Monitoring of Source Parameters for Seismic Precusors

9920-02383

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Investigations

1. Broadband analysis of the New Brunswick earthquake of January 9, 1982. This earthquake provides a unique opportunity to study the source properties of events in eastern North America. Source parameters were extracted from waveforms recorded by the GDSN. Accurate relative locations were made of the early teleseismically recorded aftershocks.

2. Broadband analysis of large earthquakes. We are developing means of processing digitally recorded waveforms from the GDSN to analyse the rupture process of large earthquakes (magnitude > 7.0).

3. Monitoring changes in source parameters before large earthquakes with teleseismic data. The rupture characteristics of 4 moderate-sized ($5.4 < m_b < 6.1$) earthquakes that encircled the eventual rupture zone of the Miyagi-Oki earthquake of June 12, 1978, over a period of two years before the mainshock was studied.

Results

1. Broadband analysis of the New Brunswick earthquake. From broadband waveforms, we obtained strong constraints on static properties of the source such as depth (9 km), focal mechanism (thrust faulting on a west-dipping fault plane), moment (5.0×10^{24} dyne-cm), as well as the rupture plane, rupture direction and associated stress drops (45-75 bars).

2. Broadband analysis of large earthquakes. We are examining the rupture process of the large (M_s 7.8) Samoa earthquake of September 1, 1981. By using broadband waveforms, the depth of the initial nucleation has been determined. The rupture consisted of at least 4 main subevents for which we have obtaned focal mechanisms and relative locations.

3. Monitoring changes in source parameters before large earthquakes with teleseismic data. Static and dynamic source parameters of four earthquakes preceding the Miyagi-Oki earthquake of June 12, 1978, have been obtaned. The dynamic stress drop of the third event of the sequence was substantially higher than the stress drops of the first two events: the third event was considerably more complex than the first two, and it ruptured toward the focus of the eventual mainshock. Four months following the third event, the mainshock occurred.

Reports

Choy, G. L. and Boatwright, J., 1982, Broadband analysis of the extended foreshock sequence of the Miyagi-Oki earthquake of June 12, 1978: Bulletin of the Seismological Society of America, in press.

Choy, G. L., Boatwright, J., Dewey, J. W., and Sipkin, S. A., 1982, A teleseismic analysis of the New Brunswick earthquake of January 9, 1982, J. Geophys. Res., submitted.

Needham, R. E., Buland, R. P., Choy, G. L., Dewey, J. W., Engdahl, E. R., Sipkin, S. A., Spence, W., Zirbes, M. D., 1982, Special earthquake report for the September 1, 1981 Samoa Islands region earthquake, U.S. Geol. Surv., open-file report 82-781.

Contract No. 14-08-0001-19297

CONTINUED OPERATION OF STRESSMETER NET ALONG ACTIVE FAULTS IN SOUTHERN CALIFORNIA

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Investigations

1. Field Data Collection and Analysis

   Stressmeter data were collected and analyzed from all available sites on a weekly basis in the San Andreas Net (four sites) and the Sierra Madre Net (five sites). Regular temperature measurements in shallow arrays were begun at Buck Canyon and Lytle Creek.

2. Installation and Upgrading of Field Nets

   New sites at the Palmdale Waterworks in the San Andreas Net, and Lytle Creek and Pasadena Children's Home in the Sierra Madre Net were brought to full operational status. A new Net consisting of five sites near the San Jacinto fault in the Anza-Hemet area was also brought on line. Weekly readings and analysis were begun in the San Jacinto Net in April 1982.

3. Laboratory Testing of Installation Procedures

   Problems associated with grouting methods of installing Stressmeter arrays were analyzed using laboratory simulations to test for quality of bonding and sensitivity effects.

4. Earth-Tide Experiment

   An experiment to test for the presence of earth-tide signals was begun at the Dalton Canyon and Pinyon Flat arrays, where power and instrumentation shelter facilities are available.

Results

1. There was only one short-term event recorded by the Stressmeter Nets in this reporting period. It occurred at Valyermo and was detected on the EW and N45°W sensors in Array No. 1, and arguably on the EW and N45°W sensors in Array No. 2 (see attached Figure 1). It was not correlated with any seismic event.

2. Long-term trends at Valyermo (Figure 1) and San Antonio Dam (Figure 2) continued to match expected tectonic patterns for stress buildup associated with strike-slip faulting and thrust faulting, respectively, at the two sites. Of particular interest is the coherence between the San Antonio Dam No. 1 and No. 2 arrays. Both show all sensors in the horizontal plane increasing, the only two arrays in any Net to show this type of behavior.

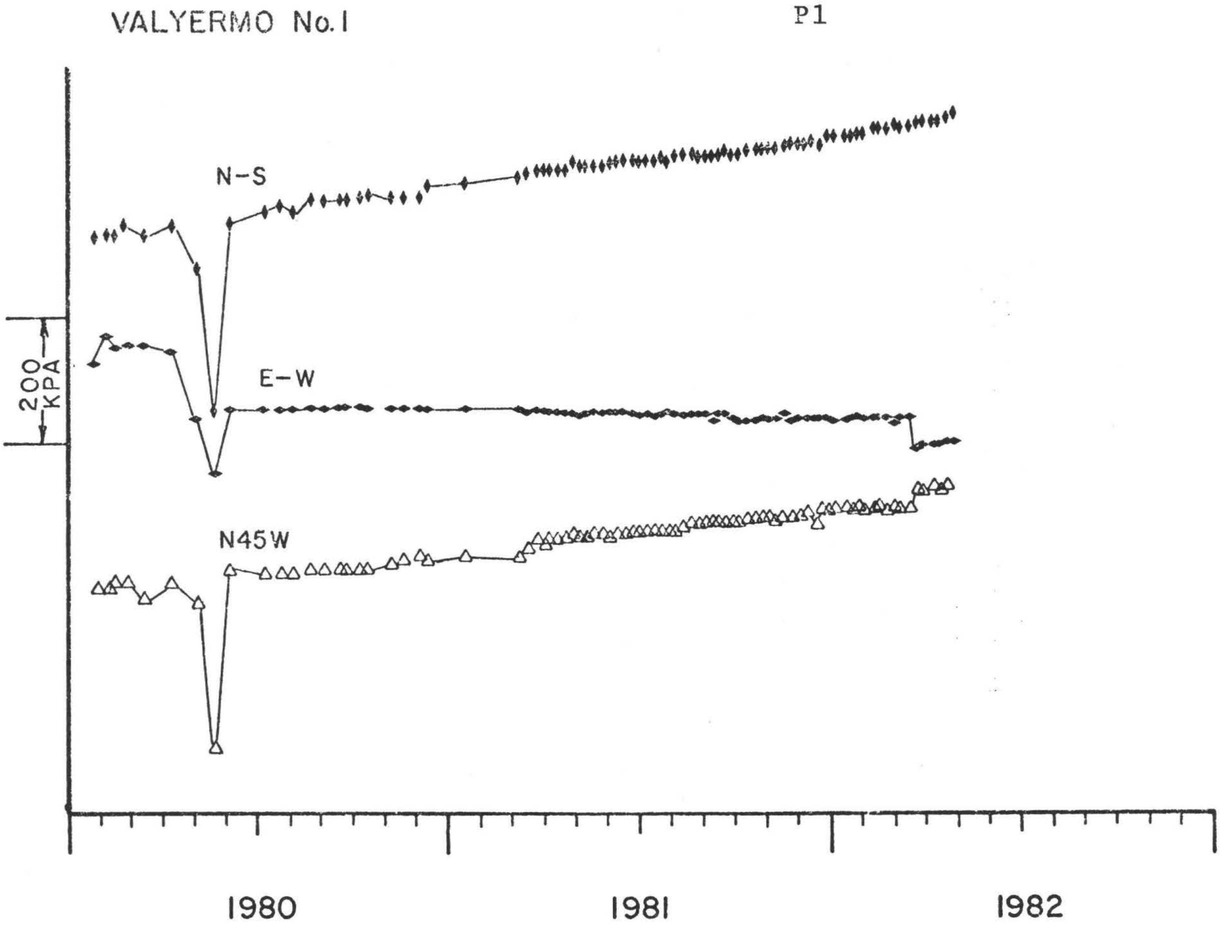
3. Grouting procedures were used successfully to install arrays of Stressmeters. This new technique removes most restrictions on the depth of installation achievable with the hydraulic setting tool (~20 m), the size of the borehole (38 or 48 mm), and to some degree, the quality of the available bedrock. Although the host rock must still be able to transmit stress changes elastically, a fractured rock which does not give a sufficiently smooth borehole wall to set the Stressmeters by wedging may be adequate for installation with grout.

Reports

Clark, Bruce R., 1981, Long-Term Changes in Southern California Stressmeter Net: EOS, Trans. Am. Geoph. Union, v. 62, p. 1052.

------, 1982, Monitoring Changes of Stress along Active Faults in Southern California: Jour. Geoph. Research, in press.

Figure 1


VALYERMO No. 1
P1
N-S
E-W
N45W
200 KPA
1980
1981
1982

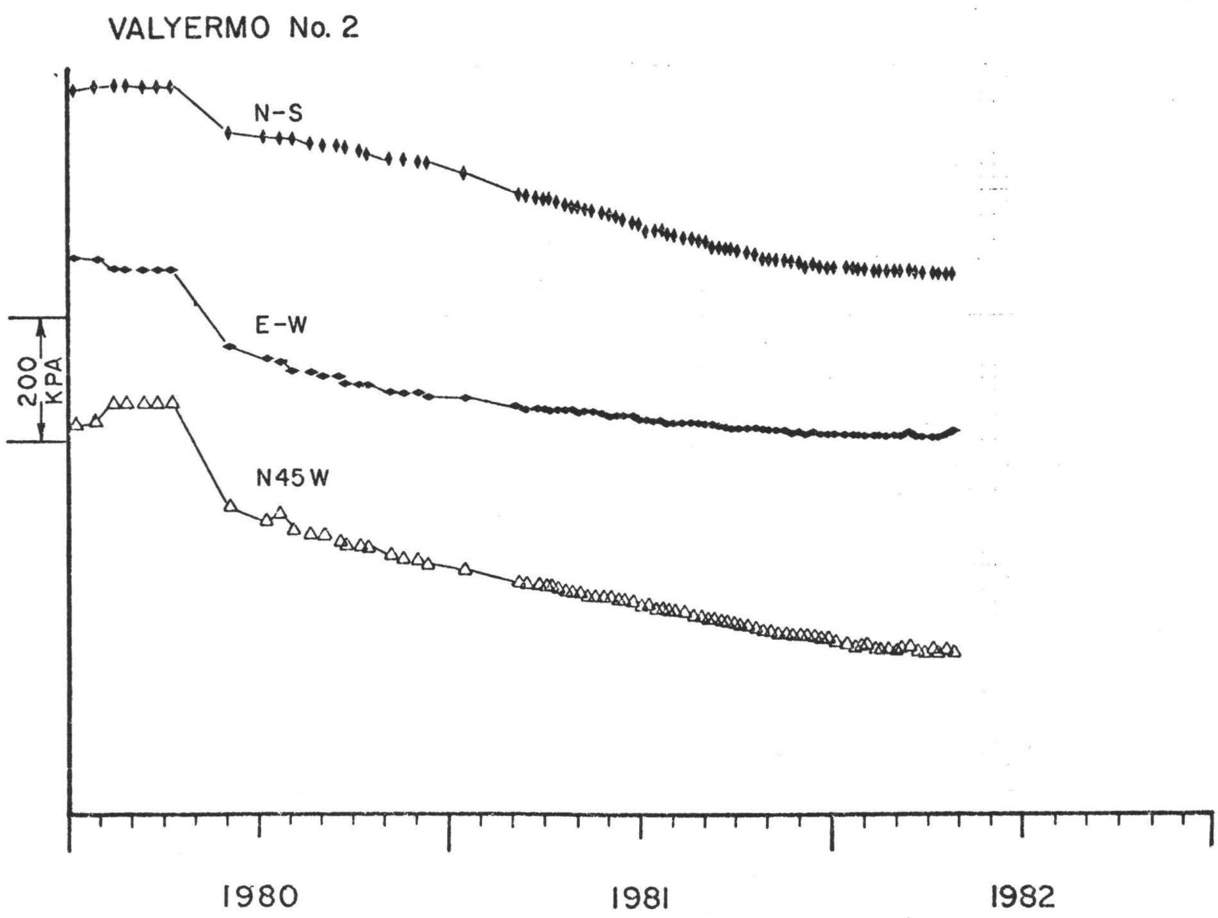
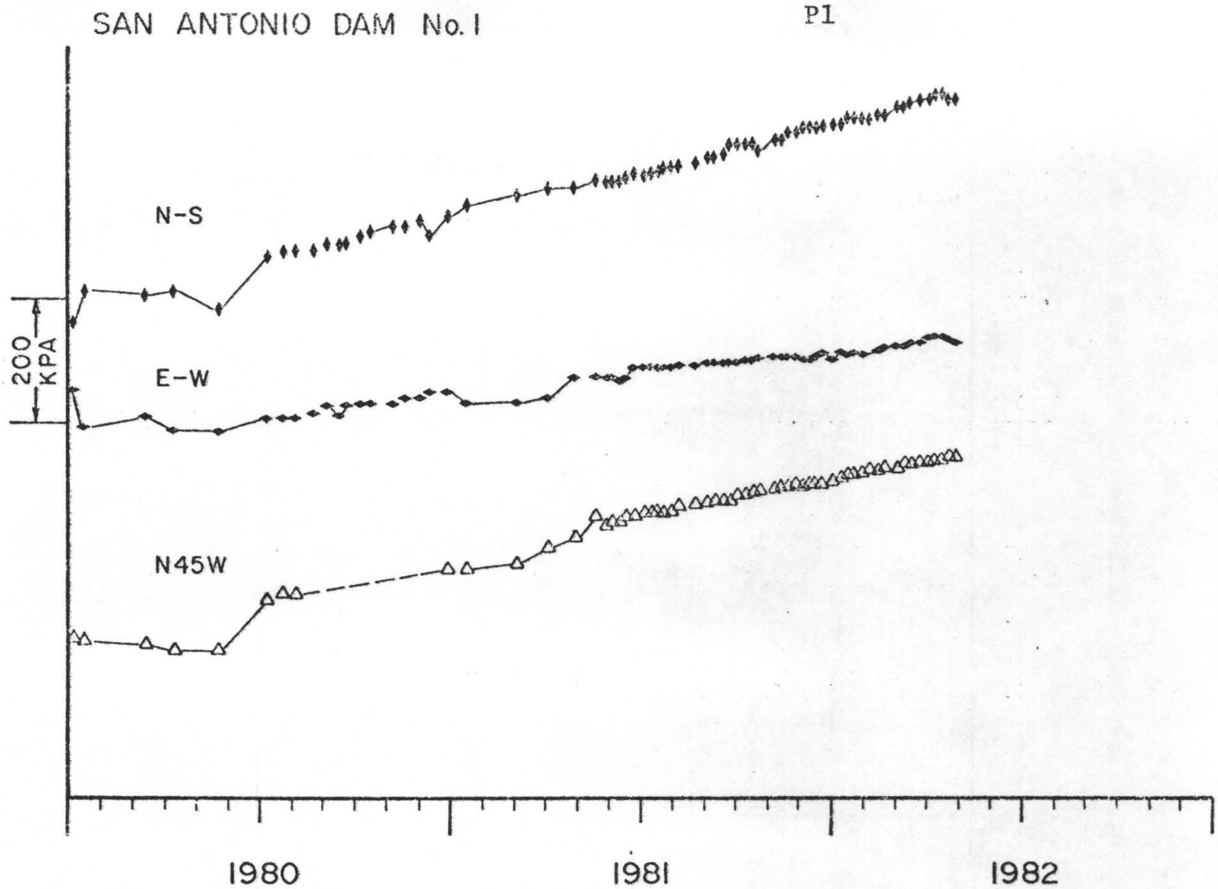
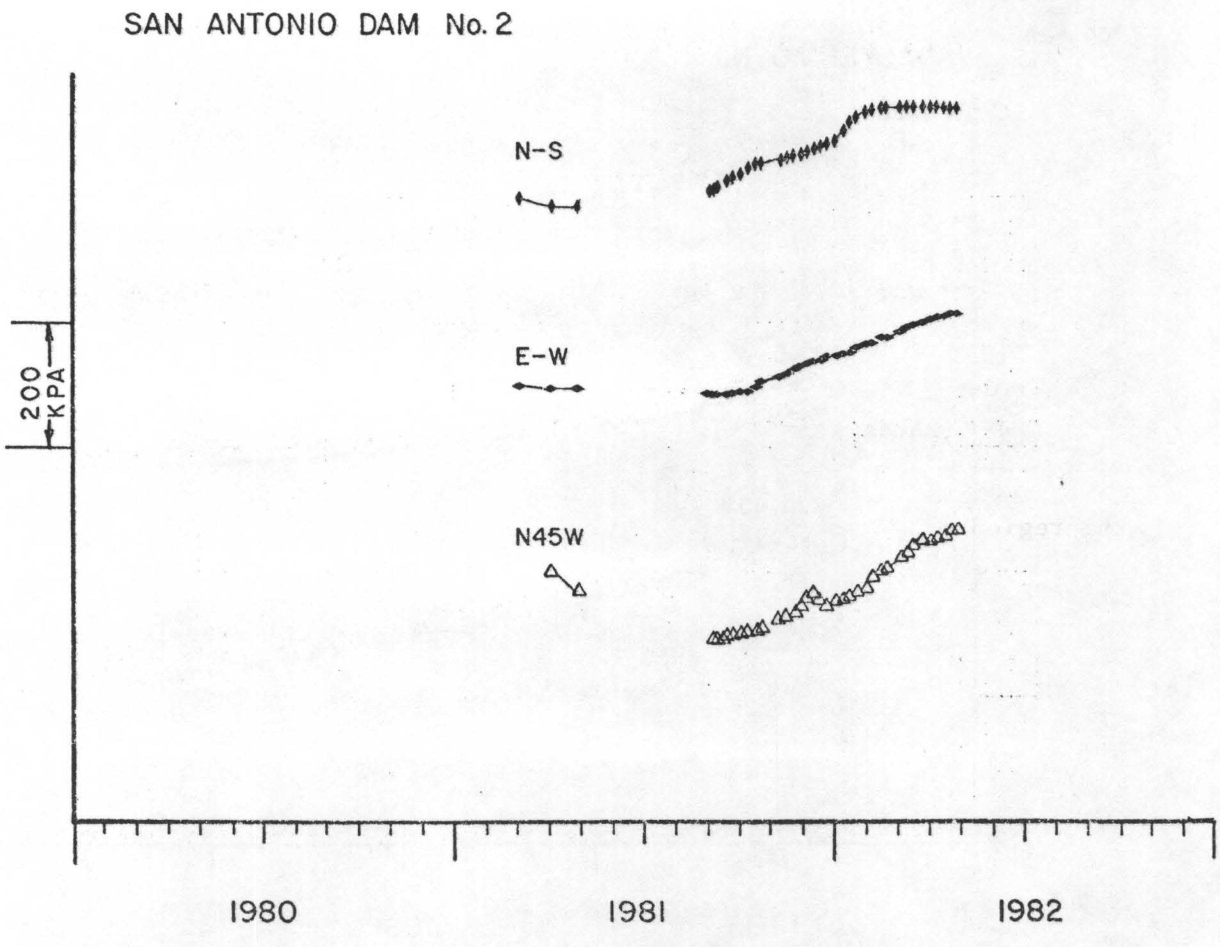

VALYERMO No. 2
N-S
E-W
N45W
200 KPA
1980
1981
1982

Figure 2



SAN ANTONIO DAM No.1
P1
N-S
E-W
N45W
200 KPA
1980
1981
1982



SAN ANTONIO DAM No.2
N-S
E-W
N45W
200 KPA
1980
1981
1982

Northern California Network Processing

9930-01160

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Investigations

Signals from 420 stations of the multipurpose Northern California Seismic Network (CALNET) are telemetered continously 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 forms of lists, computer tape and mass data files, and maps to summarize the seismic history of the region and to provide the basic data for futher 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 teleseisms is prepared to facilitate further detailed studies of crust and upper mantle structure and physical properties, and of the mechanics of earthquake sources.

Results

1. The months of May through October, 1982 are completed.

2. Figure 1 shows the seismic activity of Northern California for the period April 1 through September 30, 1982. The data plotted are all Calnet earthquake locations using 5 or more stations in the solution. The Coast Range has been screened for quarrys and they have been eliminated. The quarrys in the Sierra Nevada Foothills is a constant problem and all have not yet been identified.

3. Since the release of a Volcano Hazards Notice on May 27, 1982 for the Long Valley Caldera area of eastern California special attention has been placed on the monitoring of seismic activity in this area by R. Cockerham and A. M. Pitt. Figure 2 shows all earthquakes located in the Long Valley Caldera area from May 27 to Nov. 16, 1982.

Reports

Cockerham, R.S., Evidence for a 180-km-long Subducted Slab Beneath Northern California, submitted to Bull. Seis. Soc. Amer.

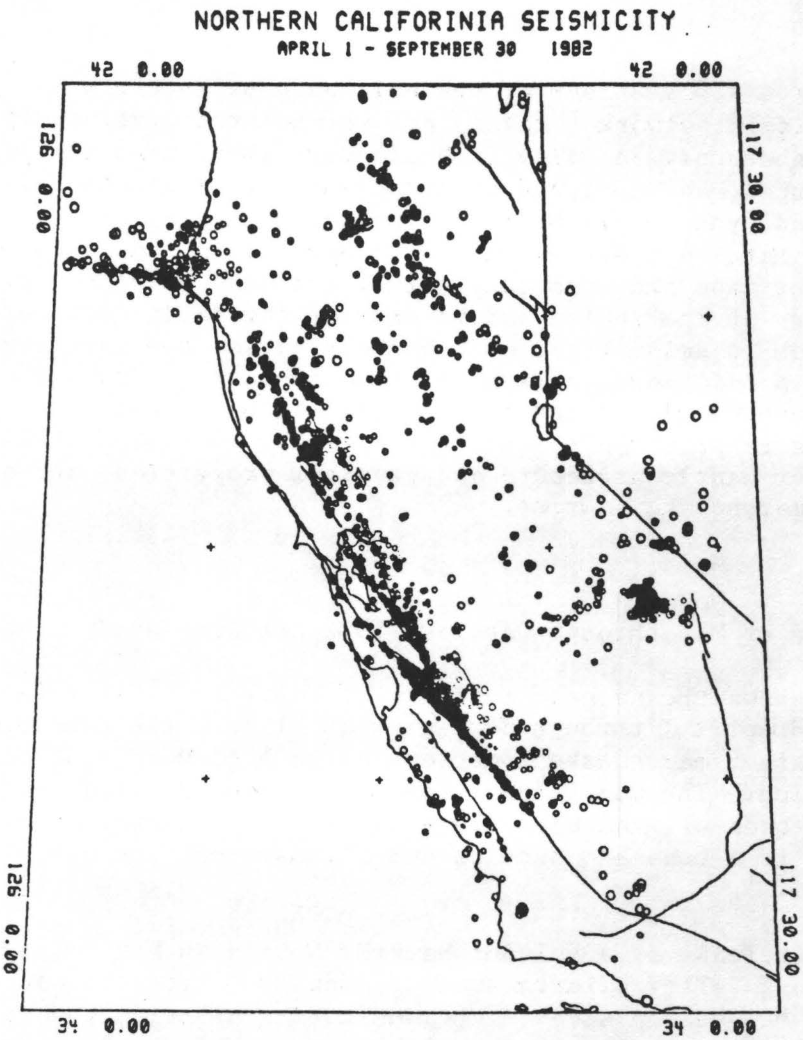

FIGURE 1

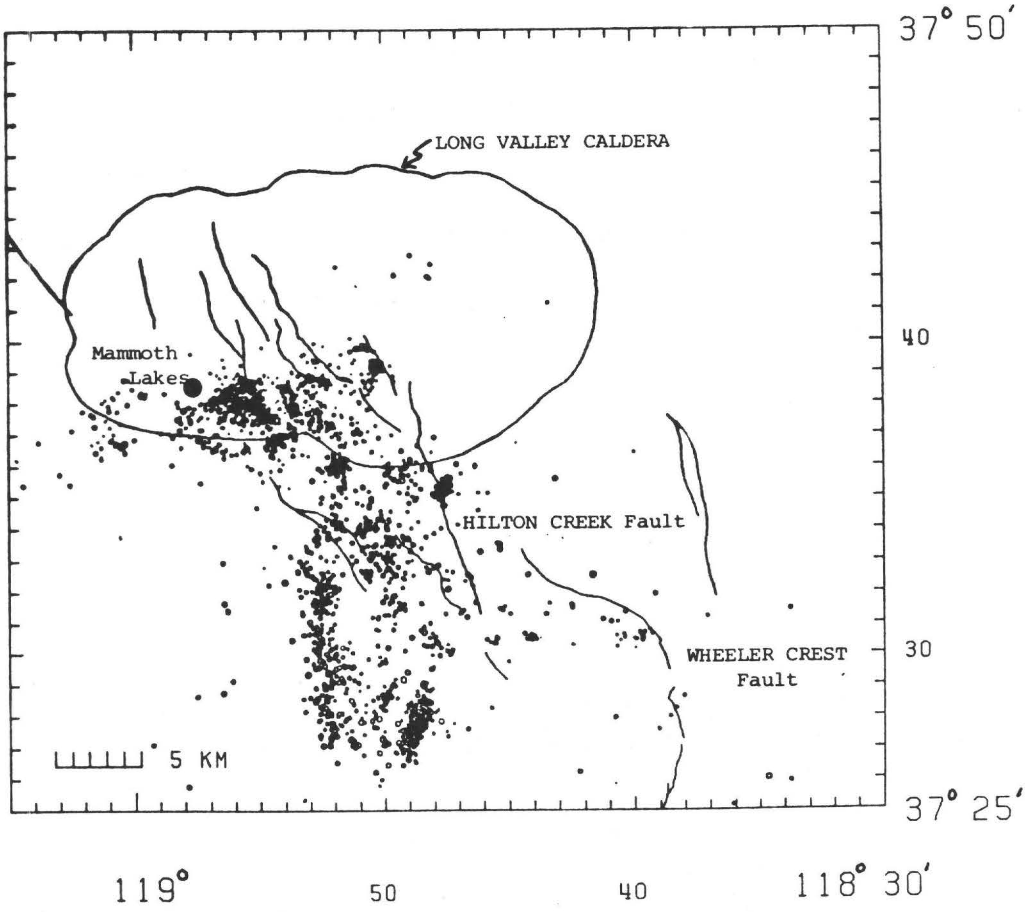
37° 50′
LONG VALLEY CALDERA
40
Mammoth
Lakes
HILTON CREEK Fault
30
WHEELER CREST
Fault
5 KM
37° 25′
119°
50
40
118° 30′

FIGURE 2

Very Long Baseline Interferometric Geodesy with GPS Satellites

USGS Contract No. 14-08-0001-19864

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SUMMARY

Modifications to the original Miniature Interferometer Terminals for Earth Surveying (MITES) to enable them to receive both of the GPS frequency bands have been completed. Because the Mark III data processor that we originally planned to use with the modified MITES equipment for very long baseline interferometry experiments with GPS is not available, we plan instead to use a new data acquisition system and data processor that are being built with U.S. Air Force support. The new equipment is much better for GPS observations than the Mark III system would have been in any case. The new equipment is expected to be available in October, 1982. Meanwhile, we have begun to measure short baselines using single frequency band equipment borrowed from the Steinbrecher Corporation. For two baselines 124 meters and 1,086 meters long, the determinations by interferometry with GPS differed from prior determinations by conventional astrogeodetic techniques by 5 millimeters or less in each vector component.

Seismic Studies of Fault Mechanics

9930-02103

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Investigations

The analysis of seismicity in central and southern California continues to be the primary focus of our work. The earthquake history of California is being examined to determine if there are regional-scale variations in seismicity associated with major earthquakes. Contemporary microseismicity studies are now underway to further our understanding of fault interactions through the detailed examination of earthquake sequences. A general theory for determining the orientation and relative magnitude of deviatoric stress from fault slip measurements was formulated. An investigation was undertaken of a shallow, reverse faulting microearthquake (M_L = 2.5) near Lompoc, California, and its relation to recent local crustal unloading.

Results

1. Stress Field Distortion and Complexities in the Geometry of the Calaveras Fault near Coyote Lake, California.

A study of the seismicity for the period 1 January 1969 through 5 August, 1979 in the area of the Coyote Lake earthquake of August 6, 1979 revealed that the complex structure of the slip surface infered from hypocentral locations and fault plane solutions of aftershocks, described in the previous report, prevailed during the pre-earthquake activity as well. The arrangement of overlapping, nearly vertical fault surfaces apparent in the aftershock set is consistent with the pre-earthquake seismicity.

Furthermore, an apparent clockwise rotation of approximately 15 degrees in the orientation of shear stress within the overlap zone, relative to that infered for the regional shear stress, which was observed for the aftershock set, was observed to the same degree for the pre-earthquake set as well. The observed stress field distortions are in good agreement with the fault-interaction model of Segall and Pollard. Agreement between the apparent stress distortion before and after the earthquake suggests that the fault complexities observed in the aftershock sequence are in fact enduring features of the fault zone.

2. New Reverse Faulting and Crustal Unloading, Northwest Transverse Ranges, California.

The first know surface rupture in California associated with a microearthquake (M_L 2.5) occurred on April 7, 1981 near Lompoc in the northwesternmost Transverse Ranges, a region noted for late Quaternary compressive deformation across east-trending folds and seismically active reverse faults. The earthquake was felt strongly at a plant near the surface rupture, but not at Lompoc, about 5 km north; it was recorded instrumentally at distances from 20 to more than 100 km. The 575-meter-long narrow zone of ruptures cut a quarry floor; it formed in thin clay interbeds in well-bedded diatomite and diatomaceous shale of the Neogene Sisquoc Formation. The ruptures parallel bedding, dip 39-59^o S., and trend about N. 84^o E. on the north limb of an open symmetrical syncline. Maximum net slip was 25 cm at about 185 m from the west end of the rupture; maximum reverse dip slip was 23 cm, average net slip was about 12 cm, and maximum right-lateral strike slip of about 9 cm is indicated by slickensides and striae.

P-wave first arrivals recorded as close as 20 km were very emergent for this size earthquake which indicates a very shallow focus. The radiated seismic moment is estimated at 1-2 x 10^{18} dyne-cm and the static stress drop at about 3 bars. The removal of an average of about 44 m of diatomite from an area of about 0.54 km^2 during about 20 years of quarrying resulted in an average load reduction of about 5 bars; this, combined with the existing north-south horizontal compressive stress field resulted in a decrease in normal stress of about 3.5 bars and an increase in shear stress on the tilted bedding plane of about 2 bars. The increase in shear stress is essentially identical to the estimated stress drop of the earthquake.

The April 7, 1981, event was a very shallow rupture, apparently triggered by crustal unloading. Its properties are consistent in all respects but one with the local and regional tectonic setting; we cannot readily explain the right-lateral component of displacement except to appeal to a local, shallow residual stress field.

3. A General Theory for Determining the State of Stress in the Earth from Fault Slip Measurements.

The frictional instability model of earthquakes provides the physical basis for a linear theory relating fault slip to the state of deviatoric stress in the Earth. If the stress field can be expressed as a linear function the foreward problem can be inverted to determine the orientation and relative magnitude of the stress tensor for an ensemble of fault slip measurements or focal mechanism solutions. This method is a generalization of the one first proposed by Angelier (1979). The underlying assumption of the theory is that the slip vector μ in an earthquake parallels the component of the shear traction $\vec{\tau}$ that acts in the fault plane. The theory also permits the formal inclusion of a Coulomb failure criterion $|\vec{\tau}| - \mu\sigma_n \geq 0$, where μ is the coefficient of friction and σ_n is the normal stress acting on the fault plane. The solution is given by maximizing the objective function:

$$\max \left[k|\hat{u}^t S(x) \hat{n}|^2 - (1-k)|\hat{b}^t S(x)\hat{n}|^2 \right]$$

subject to $|x| = 1$, where $(\hat{u},\hat{n},\hat{b})$ are the slip, normal and null vectors, respectively, for each fault in the ensemble, and the stress tensor $S(x)$ is a function of parameters x. The parameter $0 \leq k \leq 1$ controls the relative importance of maximizing the component of $\vec{\tau}$ acting in the slip $(\hat{u})$-direction $(k=1)$ and minimizing the component of $\vec{\tau}$ acting in the null $(\hat{b})$-direction $(k=0)$. We shall also require that $S(x)$ be a deviatoric stress tensor $(Tr(S(x))=0)$ because neither the effective pressure nor the cohesive strength of the faults can be determined. The Coulomb condition enters the problem as an inequality constraint. An auxiliary condition $\hat{u}^t S \hat{n} \geq 0$ must also be satisfied. This condition assures that the faults have the proper sense of slip, i.e. the angle between $\hat{u}$ and $\vec{\tau}$ is $\leq 90°$.

Errors in the solution arise from imprecise knowledge of $(\hat{u},\hat{n},\hat{b})$ and can be evaluated using first-order perturbation theory on the objective function. The sensitivity of the solution to data errors can be approximately described by a condition number, taken as the difference of the largest two eigenvalues of the matrix associated with the objective function. In general, the solution is stable when the eigenvalues are well separated.

In the case of a spatially invariant stress field, the solution that maximizes the objective function is chosen from the set of tensors with equal octahedral stress. When earthquake focal mechanisms are the data and the fault plane cannot be unambiguously assigned, it is necessary to consider all acceptable solutions drawn from the full set of possible combinations (Ellsworth and Xu, 1980). In some cases, the auxiliary condition $\hat{u}^t S\hat{n} \geq 0$ may exclude some choices from the feasible solution set.

Reports

Reasenberg, P. and Ellsworth, W. L., Complexities of the 1979 Coyote Lake earthquake: relationship to the ongoing faulting process (abs.): American Geophysical Union-Chapman Conference on Fault Behavior and The Earthquake Generation Process, (1982).

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Ellsworth, W. L., Lindh, A. G., and Moths, B. L., Regional Seismicity and Great Earthquakes: Implications for the San Andreas System, California (abs.): Terra Cognita, 2, No. 2, p. 171 (1982).

Yerkes, R. F., Ellsworth, W. L., and Tinsley, J. C., New reverse faulting and crustal unloading northwest Transverse Ranges, California; submitted to Geology (1982).

Theodolite Measurements of Creep Rates on San Francisco Bay Region Faults

Contract No. 14-08-0001-19767

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We began to measure creep rates on various faults in the San Francisco Bay region in September 1979. The total amount of slip is determined by noting changes in angles between sets of measurements taken across a fault at different times. This triangulation method uses a theodolite set up over a fixed point used as an instrument station on one side of a fault, a traverse target set up over another fixed point used as an orientation station on the same side of the fault as the theodolite, and a second traverse target set up over a fixed point on the opposite side of the fault. The theodolite is used to measure the angle formed by the three fixed points to the nearest tenth of a second. Each day that a measurement set is done, the angle is measured 12 times and the average determined. The amount of slip between measurements can be calculated trigonometrically using the change in average angle. Details of our measurement method are included in the semi-annual technical report for this contract.

We presently have theodolite measurement sites at 19 localities on faults in the Bay region. Most of the distances between our fixed points on opposite sides of the faults range from 75-215 meters; consequently, we can monitor a much wider slip zone than can be done using standard creepmeters. The precision of our measurement method is such that we can detect with confidence any movement more than a millimeter or two between successive measurement days. We measure most of our sites about once every two months.

The following is a brief summary of our results thus far:

<u>Seal Cove fault</u> - We began our measurements in November 1979 and for several months the fault showed left-lateral slip of a few millimeters. The Seal Cove fault then moved about a centimeter in a right-lateral sense from February 1980 to April 1981. We then lost three months' data due to road resurfacing. During the next ten and one-half months our measurements indicate a slight right-lateral net movement of an additional two millimeters.

<u>San Andreas fault</u> - Since March 1980, our site in South San Francisco has shown a net right-lateral slip of about one millimeter. This indicates that the San Andreas fault is virtually locked in the San Francisco area. Our site in the Point Arena area showed slightly more than one millimeter of right-lateral slip between January 1981 and January 1982.

Calaveras fault - We began monitoring the Calaveras fault at two sites in the Hollister area in September and October 1979. Virtually no slip occurred in late 1979; however, about one-half centimeter of right-lateral slip occurred at both sites during the first two months in 1980. One of the sites showed no additional slip in 1980, but about 18 millimeters more between mid-January and mid-August 1981. The other site had an additional 15 millimeters of slip in 1980, was virtually locked during the first half of 1981, and then slipped about a centimeter between mid-June and mid-August 1981. Both sites showed little movement between mid-August 1981 and mid-April 1982. Our results suggest that the Calaveras fault in the Hollister area moves quite episodically with an overall right-lateral slip rate that is relatively high (8 and 13 millimeters per year at our two sites) compared to the other faults we are monitoring. In contrast, our site in San Ramon near the northwesterly extent of the Calaveras fault has shown virtually no movement in the 19 months since we started our measurements.

Rodgers Creek fault - Since we began our measurements on the Rodgers Creek fault in Santa Rosa in August 1980, there has been no overall net movement. However, our results show large variations in the amounts and directions of movement from one measurement day to another which may be due to seasonal and/or gravity-controlled mass movement effects.

West Napa fault - Since we began our measurements on the West Napa fault in Napa in July 1980, the overall net movement has been less than two millimeters in a left-lateral sense. Similarly to our results for the Rodgers Creek fault, however, large variations between measurement days have occurred. We hope that continued monitoring of the West Napa fault will help sort out tectonic creep from other possible effects.

Hayward fault - We began our measurements at sites in Fremont and Union City in late September 1979. Both sites showed left-lateral movement at first, until December 1979 in Fremont and until April 1980 in Union City. About eight millimeters of right-lateral slip occurred in Fremont in early 1980 and about seven millimeters of right-lateral movement occurred in Union City a few months later. The fault has moved right-laterally only about an additional eight millimeters at each site in the past two years. Both sites again showed a tendency for left-lateral movement near the end of 1980 and beginning of 1981, though of a smaller amount than for 1979. This tendency, however, did not occur in late 1981 or early 1982. Creepmeter results also show seasonal aberrations in direction of movement on the Hayward fault.

We began our measurements at two sites in the City of Hayward in June 1980. In the last two years one site has had a net right-lateral slip of about seven millimeters and the other about ten millimeters.

In summary, results at four sites along the Hayward fault indicate that after relatively rapid movement ended in mid-1980, the Hayward fault has been moving right-laterally at a rate of about four millimeters per year.

Concord fault - We began our measurements at two sites on the Concord fault in the City of Concord in September 1979. Both sites showed about a centimeter of right-lateral slip during October and November 1979, perhaps the greatest amount of movement in a short period of time on this fault in the past two decades. In the two and one-half years since the rapid slip, both sites have shown additional right-lateral movement of only a few millimeters.

Antioch fault - We began our measurements at the more southeasterly of our two sites on the Antioch fault in the City of Antioch in January 1980. After measuring a few millimeters of apparent left-lateral slip, we measured about a centimeter and one-half of right-lateral slip in the six-month period from May through October 1980. During the next year and one-half we measured a net of about half a centimeter of additional right-lateral movement. A tendency toward left-lateral displacement seems to occur toward the end of one calander year and/or beginning of the next. This seasonal effect has occurred three times at our southeasterly site. Where the fault zone appears to be less specifically delineated at our northwesterly site, we measured a few millimeters of left-lateral slip in the more than two years we have been monitoring it. Much subsidence and mass movement creep are occurring inside and outside the Antioch fault zone and it is probable that these nontectonic movements are influencing our theodolite measurement results for this fault.

Central California Network Operations

9970-01891

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Investigations

1. Maintenance and recording of 375 seismograph stations, located in northern California and Oregon. The area covered is approximately 81,000 square miles. Recording 20 tiltmeters, 8 strainmeters, and 18 creepmeter sites.

Results

1. Due to continuing budget cut backs it was necessary to reduce contract maintenance responsibility of Stanwick Corporation. Staff was reduced from six technicians and one team leader to 3 technicians and 1 team leader. USGS has taken over responsibility for maintenance of 118 seismic stations in the Bay area, San Jose area, and Paso Robles area.

2. All J402 VCO's that are now returned to Menlo Park for maintenance will under go additional temperature checks ($0^{o}F$ - $100^{o}F$) before being redeployed. This will make the units more temperature stable and reduce future site visits.

New Seismic Stations Installed:

2 new stations in Parkfield area
1 new station in Calaveras area
5 new stations in Klamath area
5 new stations in Oregon area
1 new station in Oroville area
5 new stations in Shasta area
7 new stations in Mammoth Lakes area.

4. Completed building and final testing of 29 J402 VCO's units.

5. Responsibility of maintenance of central and northern Oregon has assumed by University of Washington.

6. Responsibility of China Lake and Walker Pass has been assumed by Caltech, Pasadena.

7. USGS has assumed responsibility of maintenance of seismic stations in Mammoth Lakes area.

Support of the Southern California Geophysical Data and Analysis Center

14-08-0001-19267

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This report covers the six-month period from April 1, 1982 to September 30, 1982.

Goals

1. This contract supports the data collecting and processing activities of the CEDAR (Caltech Earthquake Detection And Recording) and CROSS (Caltech Remote Observatory Support System) systems at the Seismological Laboratory.

Results

1. CEDAR

The CEDAR system was originally developed and supported by this contract and its predecessors (contracts # 14-08-0001-16629, 17642, 18330, and 19267), and is now an element of the joint USGS-Caltech SCARLET system (Southern California Array for Research on Local Earthquakes and Teleseisms). Its product is a component of the results produced by the contract "Southern California Seismic Arrays", contract # 14-08- 0001-19268, i.e., the recording and processing of earthquake data effecting a digitized data base of seismic events stored on "Archive" 800 BPI magnetic tapes.

2. CROSS

This contract supplies continuing operational support for CROSS developed under the predecessor contracts (given above). During this reporting period fifteen data loggin (TIM) units have been maintained on site.

Stations currently in operation:

SITE LOCATION	TYPE OF MEASUREMENT	PRINCIPAL INVESTIGATOR
Fairmont (FM)	water well	T. Ahrens
Anza (AZ)	water well	Lamar/Merifield
Caltech campus (RO)	tilt	T. Ahrens
Hollister (HO)	tellurics	T. A. Madden
Kresge Lab. (KR)	tilt	Test site
Lake Hughes (LH)	tilt, meterology	T. Ahrens, T. Henyey
Palmdale (PD)	tellurics	T. A. Madden
Palmdale (PM)	water well baro. pressure	Lamar/Merifield
Palmdale (GP)	water well	Lamar/Merifield
Palmdale (AQ)	water well	Lamar/Merifield
Ocotillo Wells (OW)	water well	Lamar/Merifield
Borrego Springs(BS)	water well	Lamar/Merifield
Pallett Creek (PC)	water well	Lamar/Merifield
Mecca Beach (MB)	tilt, creep	C. Allen
Dalton tunnel (DT)	tilt, meterology	T. Ahrens

Note: Some sites listed in previous reports have been removed from service by the P.I.'s for operational reasons.

The data at these Southern California sites are collected once or twice a day via a telephone telemetry polling procedure and are being accumulated as a data base on the Caltech Seismological Laboratory PRIME computing system. For non-Caltech investigators the data is made available on hard copy, magnetic tape or via a modem port into the PRIME computer through which investigators may transmit the data to devices at their location by telephone.

A MULTI-PURPOSE CRUSTAL STRAIN OBSERVATORY, DALTON TUNNEL COMPLEX, SAN GABRIEL MOUNTAINS

#14-08-0001-19263

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U.S.C. operates two water level tiltmeters (100 nrad sensitivity), two carbon fiber strainmeters (10 nstrain sensitivity), tunnel and canyon face thermistor arrays, and a weather station (barometric pressure, rainfall, wind speed). Additional instruments at Dalton include a pair of bubble tiltmeters (Caltech) and a pair of vibrating string borehole stressmeters (Bruce Clark of Leighton and Associates). Additionally, U.S.C. maintains the site (controlled environment recording blockhouse and tunnel integrity) and has two fluid tiltmeter proto-type installations, a pressure transducer for a zero-flow long baseline (> 1000 meter) tiltmeter, and an ultra sensitive fluid displacement sensor. Eight channels of data are available for transmission to Caltech via the TIM module program.

The annual records for the U.S.C. strain and tiltmeters were greatly disrupted by lightening strikes in the fall of '81 and winter of 81-82. After a major electric disturbance in October '81 (destroying all sensor circuitry and damaging recording instruments) there remained numerous intermittant power failures that were not ended until the entire power facility (overhead power lines, power meters, circuit breakers and tunnel power cables) was replaced. Throughout the summer, and through recent fall storms, there have been no failures; all instruments are functioning.

Tilt Measurements in the New Hebrides Island Arc: Search For Aseismic Deformation Related to Earthquake Generation in a Major Zone of Lithosphere Subduction

14-08-0001-18350

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Investigations

The seismograph network and tilt instrumentation in the Vanuatu (formerly New Hebrides) islands continued to operate well during the period covered by this report. The arcwide episode of large, shallow earthquakes that began in 1980 appears to have ended with the large (Ms=6.8) event of February 1982 beneath the Santa Cruz islands.

Analysis is continuing on the spatial and temporal patterns of seismicity along the arc using two distinct data sets. One data set includes the four moderate and large-sized (Ms=6-7) events that were recorded by Cornell's local seismograph and tilt networks in the central part of the arc from 1978 to 1981. The other data set includes all events of magnitude $m_b \geq 5.0$ reported in the ISC bulletins from 1961 to 1981 along the entire arc.

The following section presents (1) results of recent research on the spatial and temporal characteristics of seismicity at the time of large earthquakes, (2) a summary of seismic activity during the past six months, and (3) the results of the 1982 field program.

Results

1. Large, interplate, thrust-type earthquakes in the northern, central, and southern parts of the central Vanuatu island arc have had aftershock zones that increased in area during the days following the mainshocks. Detailed observations of the expansion have been obtained for the three most recent (1979-1981) earthquakes (Ms=6-7) using Cornell's local networks of seismograph and tilt instruments. For each event the aftershocks in the first few hours defined an area that was consistent with the rupture zone for an earthquake with the observed seismic moment. For the 1981 event the small size of the coseismic rupture zone is supported by measurements of coseismic tilting. During the days following each mainshock, the area of the aftershock zone increased 5 to 10 times the area of the inferred rupture zone. The implied migration of stress away from the region of coseismic slip is manifested by aftershocks located both along the interplate thrust zone and in the overriding and descending plates. The growth of aftershock area (A) versus time (t) is best described by a function of the form $A(t) = A_0 \ln (kt + 1)$, which has the same form as the cumulative version of Omori's aftershock law.

Most of the expansion of the aftershock zone occurs within the first 10 days following the mainshock. Ten days appears to be a characteristic time associated with many earthquakes in the Vanuatu islands. Very commonly large and moderate-sized earthquakes occur in sequences with the initial events in the sequence separated from the later events by a time period of 10 $\pm$ 5 days. The first event of the sequence is always an interplate, thrust-type event, while the later events include both inter- and intraplate earthquakes. The later events are sometimes larger than the first events in the sequence. This 10 day characteristic time is intermediate between the 1 day time period characterizing the immediate aftershocks and the 100 day time period which we have observed between large interplate events and moderate-sized upper plate events.

2. Seismic activity that occurred in the past six months was characterized by a predominance of shallow intraplate activity in both the overriding and descending plates. One event with Ms=5.1 occurred in the back-arc region close to the northern end of Maewo Island in April 1982. Its focal mechanism, is a thrust type solution and confirms the existence of a compressional stress regime in the back-arc region in the central part of the arc. Another back-arc event (Ms=5.3) occurred in the nest of shallow activity between Tanna and Erromango islands in August 1982. Activity within the oceanic plate incuded one event with Ms=5.8 in May 1982 south of Tanna Island; three events with Ms=4.8, 7.1, 5.5 in June and August 1982 that appear to be long-term aftershocks of the major (Ms=7.9) July 1980 Santa Cruz intraplate thrust event; and one event with Ms=4.9 in September 1982 located in the nest of oceanic plate events triggered by the October 1980 Loyalty Island event. The only notable earthquake located along the interplate thrust zone occurred in May 1982 between Santo and Erromango islands with Ms=5.2.

3. The goal of the 1982 summer field program was to install and test modifications to the existing equipment. We designed, built, and installed calibrators at each of the seismograph stations in the network. Each calibrator consists of a 24 hour clock and a sine-wave generator. Every day, at the same time, a four Hertz sine wave is superimposed on the seismic data for five minutes. This provides an automatic means for regularly testing the amplifier, VCO, VHF telemetry, discriminator, and recorder at every station in the network. During the 1982 field work we also installed high pass filters in the Kinemetrics borehole tiltmeters. These filters are designed to filter out the long period (greater than 1 day), non-tectonic drift while preserving the short period response at a greatly amplified level. In this way, the instruments are now much more sensitive to tilts at periods of minutes while not drifting out of their dynamic range between bi-monthly maintenance visits. The long-baseline, water-tube tiltmeter installed at Devils Point has been working quite reliably for more than a year now. During the 1982 field work we installed a float and displacement transducer at each end of one of the tubes to continuously monitor the water level. In the short time that this system has been running it has worked well and it confirms the results of our previous system which measured the water level only once every 11 minutes.

Reports

Cardwell, R.K., J.-L. Chatelain, B.L. Isacks, and M. Bevis, Spatial expansion of aftershock zones with time: examples from the Vanuatu (New Hebrides) island arc (abstract), EOS, Trans. Am. Geophys. Union, 63, 384, 1982.

Cardwell, R.K., B.L. Isacks, J.-L. Chatelain, and M. Bevis, Postseismic expansion of aftershock zones following interplate, thrust-type earthquakes in the Vanuatu (New Hebrides) island arc, paper presented at AGU Chapman conference on Fault Behavior and the Earthquake Generation Process held at Snowbird, Utah, October 11-15, 1982.

Chatelain, J.-L., R.K. Cardwell, and B.L. Isacks, Spatial expansion of the aftershock zone following the Vanuatu (New Hebrides) earthquake on 15 July 1981, submitted to Geophys. Res. Letters, 1982.

Marthelot, J.-M., and B.L. Isacks, Space-time distribution of shallow and intermediate-depth earthquakes in the New Hebrides island arc from 1961 to 1981 (abstract), paper presented at the 13th International Conference on Mathematical Geophysics, Terra Cognita, 2, 172, 1982.

Southern California Repeat Gravity Studies

9730--3074

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Investigations

1. Conducted ninth reoccupation of southern California secondary reference station network (figure 1) and selected parts of the general precision gravity network.

2. Continued investigation into correlation between changes in gravity, elevation and areal strain along the San Andreas fault at Tejon Pass, Palmdale, and Cajon Pass between 1977 and 1982.

Results

Gravity time histories covering the past six years at the 12-station secondary reference network (figure 1) are characterized by cyclic gravity fluctuations of 15-30 μGal amplitude and 1-2 year duration. No long-term trends are evident at any station. The latest results indicate that gravity values at all stations in May 1982 were within 15 μGal of the initial gravity determinations made during the fall of 1976 and that at 8 of the 12 stations, the apparent gravity changes (1982-1976) were within one computed standard error of zero.

The most recent survey included gravity measurements at Tejon Pass and Cajon Pass, nearly coincident in time with measurements of areal strain by J.C. Savage at these locations. Combined with the observations reported in the previous semi-annual report, we now have 18 nearly coincident measurements of gravity and areal strain, and 11 nearly coincident measurements of gravity and elevation during the past six years at three locations along the San Andreas fault. Correlation coefficients between changes in gravity and strain and changes in gravity and elevation were determined from the population of changes between temporally adjacent pairs of nearly coincident gravity and strain or gravity and elevation observations. The correlation between changes in gravity and strain (correlation coefficient $r=0.59$, sample size $n=15$, significant at better than the 5% level) is stronger than the correlation between changes in gravity and elevation ($r=-0.63$, $n=8$, significant at the 10% level). This probably is due to a number of factors including: 1) the larger number of nearly coincident gravity and strain observations compared to gravity and elevation observations (18 verses 11); 2) only one large excursion in the elevation data was detected during the observation period; and 3) the elevation data from Palmdale do not reflect the changes seen by the gravity and strain data between 1978.1 and 1980.3.

<u>Reports</u>

Jachens, Robert C., Wayne Thatcher, Carter W. Roberts, and Ross S. Stein, 1982, Correlation of changes in gravity, elevation and strain in southern California, Science (in press).

Roberts, Carter W. and Robert C. Jachens, 1982, Temporal gravity variations near Long Valley, California, 1980-1982, submitted to EOS, Trans. Amer. Geophys. Union.

Jachens, Robert C., Wayne Thatcher, Carter W. Roberts and Ross S. Stein, 1982, Correlation of changes in gravity, elevation and strain in southern California, submitted to EOS, Trans. Amer. Geophys. Union.

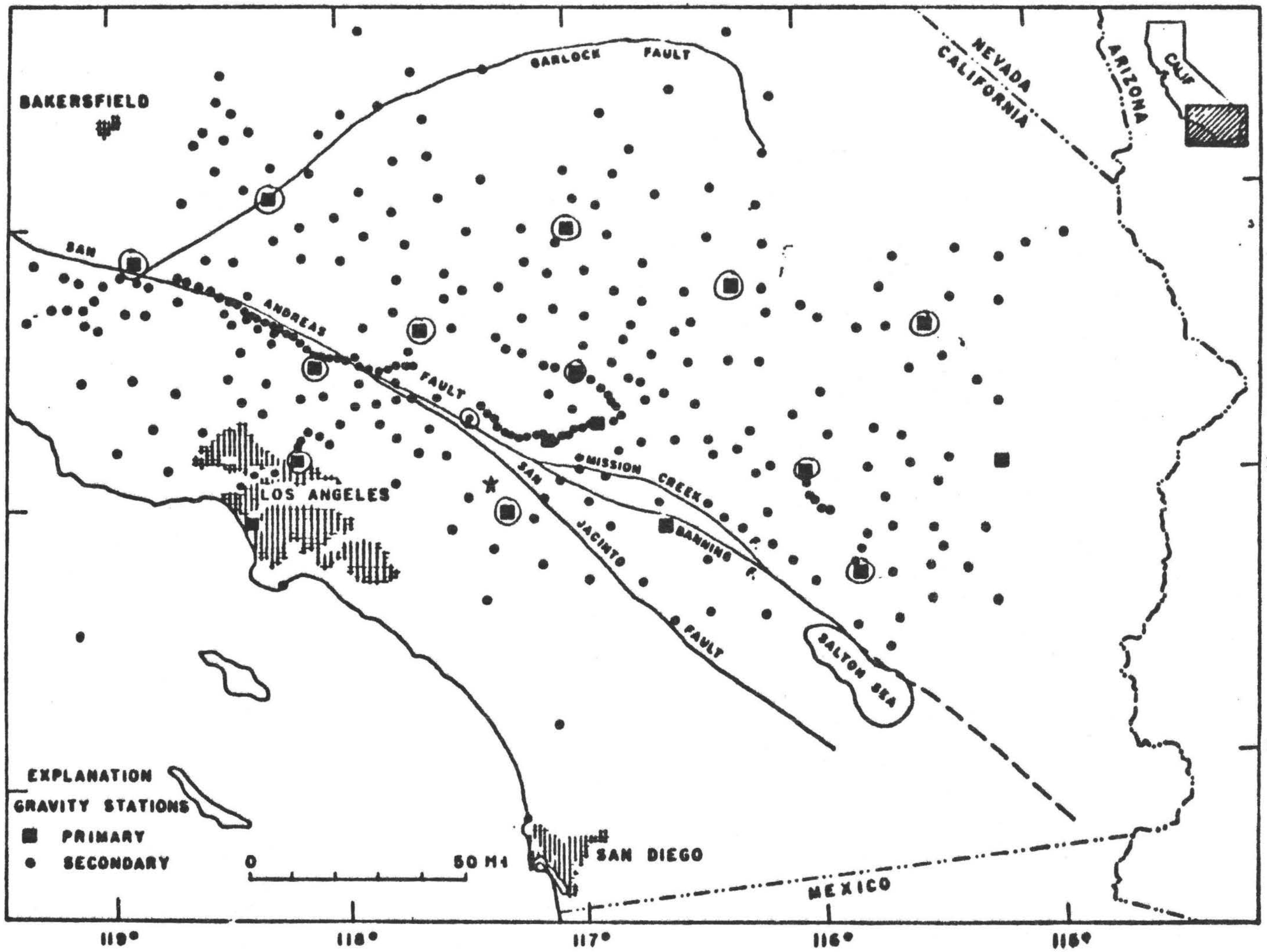

Figure 1. Precision gravity network in southern California. Circled stations are those remeasured in January and May 1982. Starred station is primary base at Riverside, CA.

CRUSTAL DEFORMATION OBSERVATORY, PART A

14-08-0001-19254

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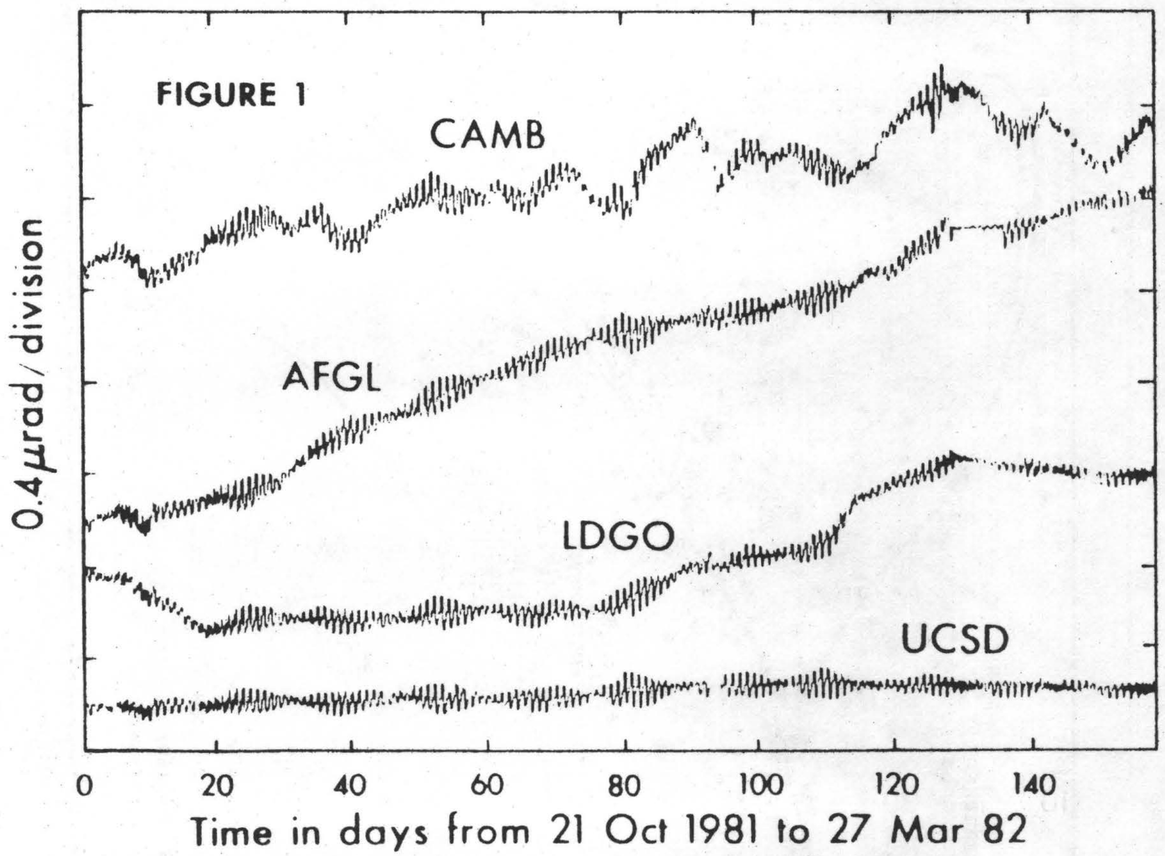
Tiltmeter data

Three different long-baseline fluid tiltmeters (535 m) and a biaxial borehole tiltmeter have been installed and operated side by side at Piñon Flat Observatory, California. The long-baseline tiltmeters are operated by Cambridge University (CAMB), Lamont-Doherty Geological Observatory (LDGO), and the University of California at San Diego (UCSD), while the borehole tiltmeter is operated by the Air Force Geophysics Laboratory (AFGL). Edited data for the period 21 Oct 81 through 27 Mar 82 are shown in Figure 1. Tilts are resolved in the

EDITED TILTMETER RECORDS, PIÑON FLAT OBSERVATORY



direction N107E, with east-down tilt measured positive. Apparent drift rates for the four tiltmeters are:

AFGL	4	microrad/yr
CAMB	2	microrad/yr
LDGO	2	microrad/yr
UCSD	0.2	microrad/yr

We infer that no tectonic tilting occurred in the time interval shown. Figure 1 shows the value of redundancy; some individual records show variations that might have been interpreted as tectonic.

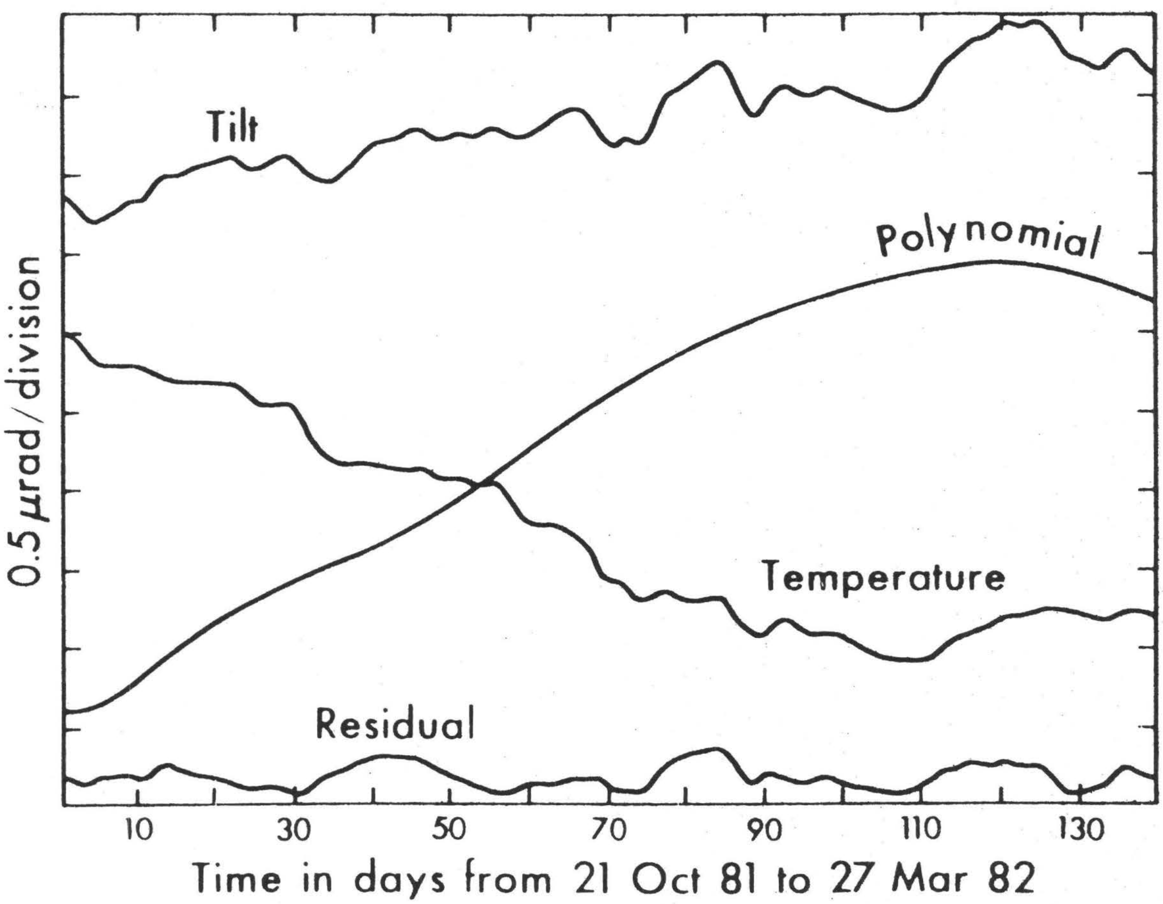
We tested all the tilt records for temperature dependence, first filtering both tilt and temperature to remove frequencies above 3 μHz. We then fit the tilt with the equation:

$$\mathrm{tilt}(t) = k\ \mathrm{temp}(t) + \sum_{i=0}^{8} b_i t^i + \mathrm{residual}\ (t)$$

where t = time and k and b_i are estimated by least squares. Figure 2 shows the various terms in the equation for the CAMB tiltmeter. All

FIGURE 2

DECOMPOSITION OF CAMBRIDGE TILT



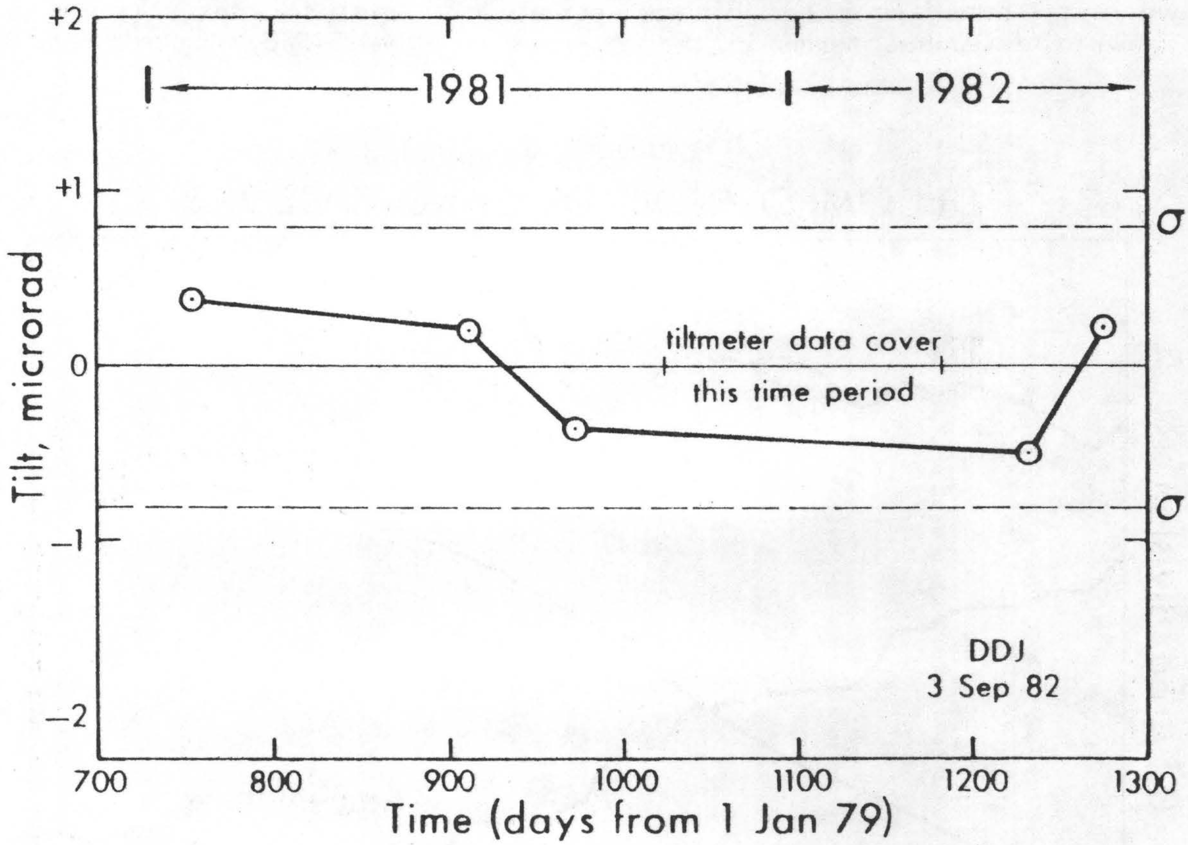
curves are plotted at the same scale (in tilt units, 0.4 μrad/division), so that the top curve is the sum of the other curves. The value of k is 0.24 μrad/deg C, so that the equivalent temperature scale is 1.7 deg C/division. For this tiltmeter, temperature changes appear to cause most of the variations within the period range of ten days to one month. The other instruments are less sensitive to temperature.

Leveling

UCSB has conducted ten leveling surveys over an array of benchmarks at Piñon Flat Observatory. The UCSD tiltmeter piers are included in this array. Figure 3 shows the tilt estimated by leveling between these piers. The variations are well within the estimated errors, so we conclude that no significant tilting occurred.

FIGURE 3

UCSB LEVELING TO UCSD TILTMETER PIERS



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 in order to maintain high quality in the data acquired by the Office. During this period some personnel from this project were assigned to the GEOS project (9940-03009) on a part-time basis.

Results

A parallel interface connecting the Real Time Processor's digital clock to the Calnet PDP 11/34 on-line event digitizer was built and installed. This allows accurate time to be instantly read in by the computer eliminating the need to decode WWVB signals which had caused problems in the past. Specifications for new A/D converter systems to be set-up on a PDP 11/44 as a back-up for the on-line 11/34 and to be installed at other sites have been established and the new systems are being acquired. In addition, 20 communications lines and 6 line driver switches were added to Office computers.

A new VCO stabilizer for Calnet telemetry with four times the resolution of the previous model was developed and 50 units have been built. Thirty-five are currently in the field and working well. A technique for normalizing the time scale on recordings of magnetometer data with tape speed fluctuations was developed. Engineering drawings for the installation of an emergency generator system were prepared and sent to GSA.

General maintenance was provided for the equipment at the Hawaiian Volcano Observatory while technicians there were on an extended field project. Maintenance of the Seismic Cassette Recorder system was provided through several field projects. During this period approximately 70 radio transmitters and receivers were aligned or repaired and 65 seismometers were calibrated.

Southern California Cooperative Seismic Network

9930-01174

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Investigations

1. Routine processing using stations of the southern California cooperative siesmic network was continued for the period April through September 1982. Routine analysis includes the timing of phases, event location and preliminary catalog production using the newly developed CUSP analysis system.

2. We are proceeding with the development of a southern California earthquake prediction data base. Geophysical data (e.g., seismicity, strain, tilts, radon, water levels) are collected from a variety of researchers in southern California. These data are cataloged and included in a computer data base. Plots of these data are made on a common time scale and copies are made available to other workers.

3. We are continuing operation of a system for the timely recognition of anomalous activity of southern California water wells. Yearly requests are mailed to private and municipal water companies requesting that anomalous activity be immediately reported to our staff. These data are logged and, if necessary, further investigation is conducted.

4. Topical investigations were conducted as required to monitor departures from background seismicity levels. This effort was dominated by the recurrence of seismicity in Indian Wells Valley with a swarm comprising several events in the range 4.0 to 5.2.

Results

1. The seismicity increase in Indian Wells Valley noted in the last semi-annual report was continued during the present reporting period with an intense swarm of earthquakes beginning in late September. This sequence includes 4 events exceeding a magnitude of 4.0 with the largest (M_L = 5.2) on 1 October, 1982. The overall activity continued in its spatially progressive nature with the newest activity extending the area affected to the southwest. The activity in the Indian Wells Valley area began in April, 1982 and has continued in a series of swarms of generally increasing severity. Bursts of activity

typically begin with a few large events ($M_L > 3$) with an apparently very low b-value grading into a more normal appearing swarm over a period of several days. Sequences are separated by period of quiessence lasting from a few weeks to several months. Average event production rates now stand at better than 10 times the long-term background.

2. In an effort to delineate some of the details of the three-dimensional structure of the trifurcation in the San Jacinto fault zone near Anza, approximately 1500 earthquakes that occurred in the area were relocated using a master event technique. These data indicate that the Coyote Creek fault dips about 70° to the northeast the that the Clark fault dips about 85° in the same sense. The orientations and locations of these two members of the SJFZ suggests that they meet at depth. Detailed structure in the seismicity further suggests that the faults merge into a single break at about 12 km depth and continue as a single break down to the bottom of the seismogenic zone (16 km). A model is proposed in which slip is transferred from the nearly vertical Clark fault (northwest of the Anza gap) to the more shallowly dipping Coyote Creek fault (southeast of the gap) along a continuous break at depth. The change in dip along stike would cause a warp in the fault that would inhibit right lateral movement.

3. A seismicity study of the San Andreas-Banning-Mission Creek fault system was concluded. This study involves the master event relocation of 2000 earthquakes recorded in this area from 1977 to 1982. Earthquakes occur primarily in the areas bounded by the San Andreas, Banning, and Mission Creek faults with little activity occurring along or near the surface traces of these major faults. Focal mechanism plots are primarily strike-slip and describe generally north-south compression. In an area near Kitching Peak both strike-slip and thrust focal mechanisms are determined and indicate generally north-south compression with interchangeable east-west to vertical tension axes. It is in this area that the deepest earthquakes (to 22 km) occur. Background activity during the period studies appeared complex and spatially diffuse revealing little direct information about major active faults in the region.

Reports

Given, D. G., 1982, Three-dimensional structure of the trifurcation in the San Jacinto fault zone near Anza, California (abs.): EOS, American Geophysical Union Transactions, v. 63, p. 1036.

Liu, H. I., and T. H. Heaton, 1982, Array Analysis of the ground velocities and accelerations from the 1971 San Fernando earthquake, Earthquake Notes, vol. 53, No. 2

Variable Rupture Mode of Seismic Gaps and the Relation to Foreshock-Mainshock Sequences

Contract No. 14-08-0001-19265

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Investigations

Research supported wholly or in part by this contract during the six-month reporting period (1 April to 30 September, 1982) includes:

1. Study of the El Salvador earthquake of June 19, 1982.
2. Study of an earthquake doublet in Guerrero, Mexico, June 7, 1982.

These events occurred in seismic gaps along the Mid-American trench.

Results

1. The El Salvador Earthquake of June 19, 1982.

The source mechanism of the June 19, 1982 El Salvador earthquake (m_b = 6.1, M_S = 7.0; 13.2^{o}N, 89.4^{o}W) is determined by long period P-wave modeling and moment tensor inversion of Rayleigh and Love waves recorded by the GDSN. The P-waves require a nearly vertical dipping normal fault mechanism with strike $\phi = 307^o$, dip $\delta = 75^o$, and slip $\lambda = 260^o$, and a moment of 2.0-2.5 x 10^{27} dyne-cm. The best-fitting point source depth is about 54 km, substantially less than the USGS preliminary depth determination of 83 km. An 8 to 10 sec source duration is indicated by the P-waves. Simultaneous inversion of the Rayleigh and Love waves does not uniquely constrain the source depth, due to the steep dip of the nodal plane. For a source depth of 53 km the moment tensor solution has a major double couple orientation ($\phi = 309^o$, $\delta = 74^o$, $\lambda = 280^o$) consistent with the body wave solution, and a moment of 2.0 x 10^{27} dyne-cm. Assuming greater source depths gives shallower dipping mechanisms, which are consistent with the body waves. Few aftershocks occurred for this event, so the rupture extent is not well determined, but the large moment and the body wave source duration indicate a source dimension of 30 to 60 km. If the steeply dipping plane is the fault plane, it appears that a substantial percentage of the relatively young, subducting Cocos plate ruptured in this event. We also attempt to constrain the vertical rupture extent using the relative excitation of fundamental and overtone Rayleigh waves. Events with similar moments, depths and mechanisms have also occurred in young subducting lithosphere in Colombia (Nov. 23, 1979), Chile (Mar. 28, 1965) and Peru (May 31, 1970), and these are compared with the El Salvador earthquake.

The location and the mechanism of this event are summarized in Figure 1. This work will be reported at the 1982 Fall AGU meeting by Thorne Lay, Luciana Astiz, and Hiroo Kanamori.

2. An Earthquake Doublet in Guerrero, Mexico, June 7, 1982.

On June 7, 1982 an earthquake doublet occurred in the Ometepec seismic gap, which was considered by Singh et al. (1981) to have high seimsic potential. The first event (M_s = 6.9, m_b = 5.9) was at 06^h 52^m 32.8^s and 16.589°N, 98.150°W, 51 km. The second one (M_s = 7.0, m_b = 6.0) was at 10^h 59^m 40.9^s and 16.589°, 98.321°W, 39 km.

We made a detailed study of the source parameters for both events to investigate the process that led to the rupture of this seismic gap.

The source parameters of the doublet were first determined by modeling long-period P waves at teleseismic distances recorded by WWSSN and GDSN stations. Synthetic seismograms were generated for a point source in a half space with v_p = 6.1 km/s, v_s = 3.5 km/s and ρ = 2.6 g/cm^3 using the method described by Kanamori and Stewart (1976).

Both events have a very similar mechanism: a shallow dipping thrust fault, the first event with strike = 114.5°, dip = 78°, slip = 100° and the second with strike = 113.0°, dip = 77°, slip = 92°. Although the relative depths of the two events as located by the USGS are consistent with those determined by P-wave modeling, the absolute depths required to fit the observed seismograms are 20 ± 3 km and 10 ± 3 km respectively. The first event requires a source time function with a duration of 7 seconds (1.5, 5.5, 7) while the second event needs a 17 second (7, 10, 17) source time function. The observed waveforms for the second event are slightly more complicated than those of the first one. Although a single source fits the seismograms reasonably well, a double source seems more adequate. The seismic moments determined from P-waves are: 2.7 x 10^{26} dyne-cm and 3.7 x 10^{26} dyne-cm for the first and second events respectively.

Rayleigh and Love waves recorded by GDSN stations were used to determine the source mechanism (Kanamori and Given, 1981) at 256 sec. One of the nodal planes was constrained by the body wave solution. The solution for the first event with a distributed source at 24.5 km gives: strike = 113.5°, dip = 78°, slip = 85° and M_o = 2.0 x 10^{26} dyne-cm.

The aftershock area for both events combined was 1300 km^2 (Emilio Nava, personal communication). The seismic moment from surface waves is similar for both events; however, the duration of the source time function, determined from the body-wave data, differs by a factor of 2. This suggests a higher stress drop for the first deeper event than for the second one. We interpret that the first event represents a smaller deeper asperity with higher stress concentration than the second one, and the failure of the deeper asperity triggered the shallower one.

Singh et al. (1981) compiled a list of large earthquakes (M_s>7) in the Mexican subduction zone since 1800. Approximate recurrence intervals can be calculated from this list. For the Ometepec region, a 30 year recurrence interval is observed. In the neighboring regions, the Acapulco region to the west and the western end of Oaxaca to the east, the recurrence period is 40 years on the average, with larger magnitude earthquakes. This observation suggests that the size of the earthquakes observed in a certain region is proportional to the recurrence interval of the region.

Reports

Zhou, Huilan, Hsui-Lin Liu and Hiroo Kanamori, Source processes of large earthquakes along the Xianshuihe fault in southwestern China, Seismol. Soc. Am. Bull.

Lay, Thorne, Luciana Astiz, and Hiroo Kanamori, The El Salvador earthquake of June 19, 1982, abstract, Amer. Geophysical Union, Fall Meeting, 1982.

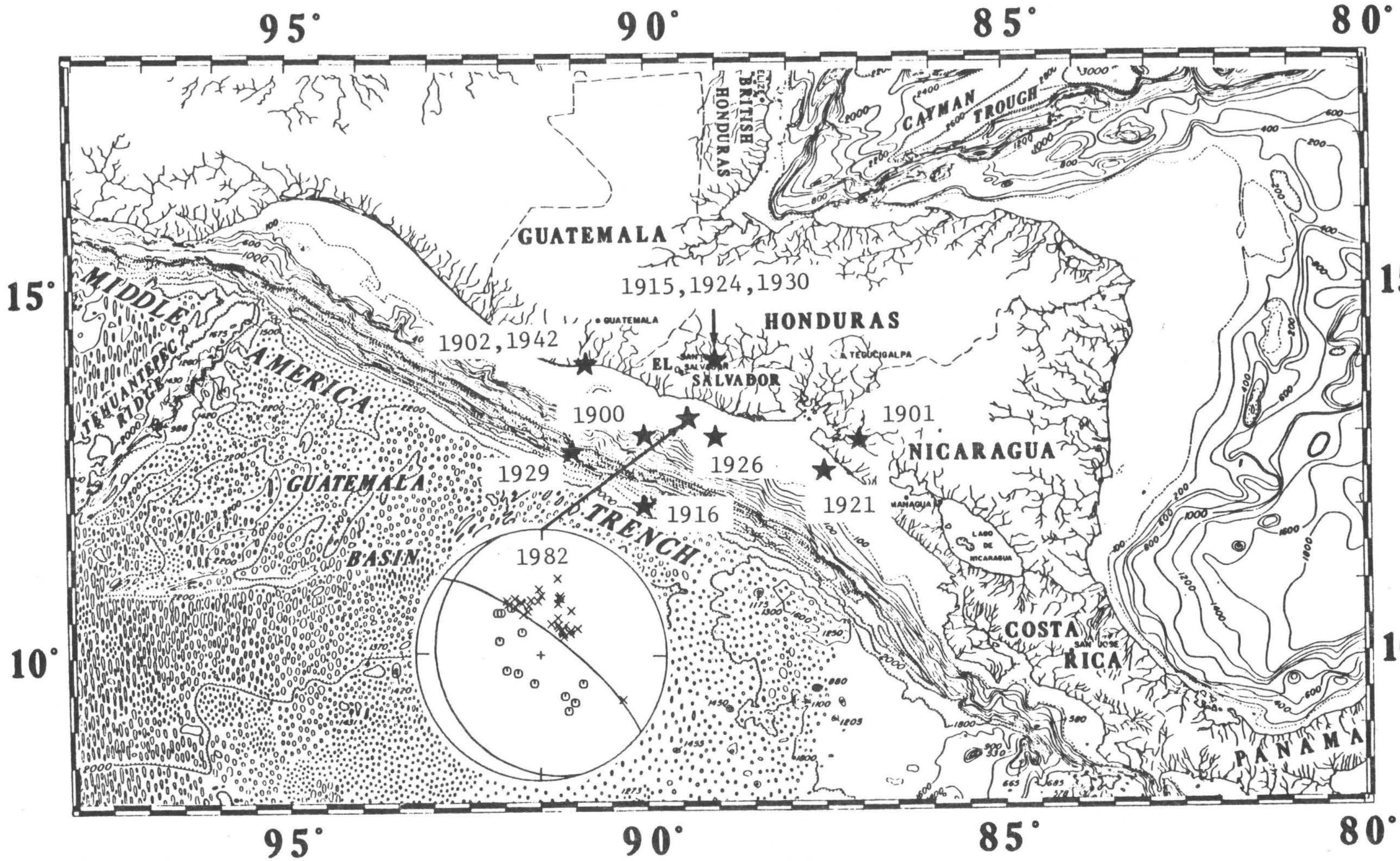

Figure 1. The location and the mechanism of the June 19, 1982 El Salvador earthquake. The mechanism diagram shows the equal-area projection of the lower focal hemisphere. Crosses and open circles are compressional and dilatational first motions. Locations of large historical events are also shown.

Pre-Seismicity and Inferred Stress Accumulation for Strike-Slip Earthquakes

14-08-0001-19796

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Investigations

1. This study examines the patterns of seismic activity before recent shocks in California in order to develop understanding of the mechanics, geometry and timing of stress accumulation.

Results

1. Recent seismic data of high quality make possible a detailed examination of the depth distribution of seismicity along the San Andreas system. Hypocenter data of about the past ten years from the CALNET (USGS) network of central-northern California and the CALTECH network of southern California display surprising and distinct variations in maximum earthquake depth along the fault system. Zones of deeper activity are not smoothly distributed but cluster noticeably along certain faults or fault segments. In addition, some major fault structures which are clearly defined by linear trends of shallow seismicity virtually disappear when examined below depths of 5 or 10 kilometers. In southern California the strongest concentrations of deeper activity ($H \geq 15$) during the past ten years occurred near the rupture zone of the 1979 Imperial Valley earthquake, along the San Jacinto fault near each end of the Anza seismic gap, near the northern end of the San Jacinto fault zone and near the Banning fault zone in the vicinity of San Gorgonio Pass. Near central California, strong clusters of deeper activity occurred north of Antioch and near the complex juncture of the Calaveras-Paicines fault system with the San Andreas fault. These zones of deeper activity do not correlate in any obvious way with any distinct type or class of tectonic feature. There is some circumstantial evidence that the amount of deeper activity may be relatively strong near the time of and in the vicinity of larger earthquakes ($M \geq 5.5$). Therefore while tectonic structure may be dominant in controlling the location of deep activity, there may also be a time-dependent component to deeper activity along the San Andreas system. That is, the increasing regional stress associated with major earthquake activity may temporarily contribute to an increase in deeper activity near those locations that are tectonically appropriate.

2. Statistical plots of magnitude distributions with time before several recent events ($M \geq 5.5$) provide indications of quiescence starting several years before the mainshock. This quiescence is especially noticeable for small magnitude earthquakes ($M \leq 1.5$). Each of the earthquakes examined by this method however occurred near the same time and thus the quiescence occurred near the same time (mid to late 70's) in each case. Therefore alternate explanations for the quiescence require careful consideration.

Earthquake Prediction in Chile: Cooperative Program with the University of Chile

14-08-0001-20583

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Investigations

1. This study examines historic and instrumental seismic data (1) to understand the process of pre-earthquake loading and the occurrence patterns of large shocks, (2) to identify and understand the patterns of seismicity that precede larger shocks, and (3) to integrate information on seismicity, tectonics and geology of western South America.

Results

1. Efforts to date have been directed toward compiling an accurate and complete data set and toward examining seismicity patterns before large thrust earthquakes. Several features of pre-seismicity have been identified and these may be associated with important classes of thrust earthquakes. Additional focal mechanisms have been determined and depth estimates made from synthetic P-waves.

2. Three specific features of seismic activity preceded some large thrust earthquakes near western South America and other subduction zones: (1) patterns of seismic activity were observed which migrated seaward or toward the trench axis during an interval of several years before the mainshock. (2) Certain large thrust earthquakes were preceded by earthquakes with strike-slip fault plane solutions. These strike-slip events occurred near the edges of the pending rupture zone with inferred plate of faulting either perpendicular or oblique to the axis of the trench. (3) Several large thrust earthquakes were preceded by lineations in seismicity which were oblique to the axis of the trench. At present we are attempting to model these patterns of seismicity using finite element programs developed by Bischke (1974, 1976). Assumptions include (a) precursory seismicity occurs near concentrations of stress, (b) pre-earthquake loading is input only from seaward. This directional loading is modeled by maintaining constant stress along a line seaward of the trench axis and by maintaining zero displacement along a line near the volcanic axis.

3. A compilation of South American earthquakes for the years 1900-1980 is complete. Sources include standard catalogs, Barazangi and Isacks (1976, 1979) and Sykes and Hayes (unpublished data). Twelve new focal mechanisms have been obtained for large shallow events. Depths for these events are being determined from synthetic P-waves.

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

14-08-0001-19272

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Network Status.

The Adak seismograph Network remote stations were serviced during July-August, 1982 for the first time in two years. Because the required helicopter support was not available, the three western-most stations could not be reached, but the other 11 were completely reworked, with the installation of a new electronics cannister at each designed to permit a minimum of two years of operation without further maintenance. These cannisters also include an automatic calibration system for each seismic channel. This work has restored the core of the network to full capacity, with only the loss of adequate coverage of the western part of the Adak seismic zone resulting from the inability to reach some stations. Monitoring of those portions of the zone for which the coverage has always been the best, and within which we have identified some sites as especially interesting as locations of future strong earthquakes, will continue as before.

The maintenance was accomplished at the cost of considerable physical effort on the part of the field party, but at a great saving in money, by the use of a chartered ship to reach most of the outlying stations and hired off-duty personnel from the Adak Naval Station to help carry the heavy items to the high points at which the stations are located. It is fortunate that this proved possible, as it saved the network from abandonment. Nevertheless, this experience demonstrated clearly that helicopter transportation is the only really effective way in which to accomplish this work.

The routine processing of the network data continues to be done as before, with the A-D conversion and processing of the digital data carried out in CIRES on the PDP 11/34 -- 11/70 systems.

Recent Seismicity.

A total of 608 earthquakes were located with the network during January through July, 1982. Many more regional and teleseismic events were recorded, but these are not located. The seismicity data are summarized on epicenter map and cumulative number-of-events plots in Figures 1 and 2. For the most part, the distribution of hypocenters was the same as that defined during the eight years of observations. An unusual observation was that of a swarm of events in the Aleutian Trench, in a 25-hour interval in early June. Because of the local velocity structure, the network is in a shadow zone for most trench events and earthquakes seaward of the trench.

Four earthquakes with m_b 5.0 or greater were observed during the seven months. The largest of these has become the subject of a special study, as described below. A strong earthquakes, m_b 6, occurred on October 4, just after the close of the period covered by this report. Because of its location in a region previously selected for special study, it, too, will be thoroughly investigated in the immediate future. These two strong earthquakes in places that we have previously identified as probable sites of larger events have given us some confidence that we are beginning to understand the seismotectonics of this region.

Earthquake in Adak Canyon, June 4, 1982.

The Adak Canyon sub-region has been the subject of special interest from the beginning of this project. The canyon itself it tectonically significant. In addition, an M_s 7.1 event occurred there in 1971, the strongest in this region in many years. Since then, the epicentral region has been remarkably devoid of events strong enough to be located teleseismically, in contrast to the zones on either side. In spite of this absence of moderate-to-strong events, the microearthquakes occur in this place just as they do along the whole zone. On the basis of the concept of 'gap-within-gap', we have postulated that this is a likely site for a major event in the near future. The m_b 6 earthquake does not qualify, nor does it fill the gap. The question to be answered by observations over the next year or so is whether it is the first event in a sequence that will end with the big one.

The search for precursors to the June 4 event has been disappointing. Nothing in the seismicity distribution during the past five years appears indicative. Work on the focal mechanisms of the background seismicity is incomplete, but the results so far are totally inconclusive.

The focal mechanism of the main shock is still to be fixed. Only a few first motions from the local network are available (this was before the summer maintenance trip), and they are insufficient to constrain the mechanism. The teleseismic first motions available are only the unchecked reports from many stations routinely submitted to NEIS, Golden, Colorado. These data are contradictory and the many inconsistencies can only be resolved when the seismograms are available for examination. The distribution of the few dilatations reported, coming from stations only beyond 61° , and the distribution of the aftershocks of the event suggest a steeply dipping fault plane, tentatively identified as a normal fault. If this mechanism turns out to be correct (this is very uncertain at this time), it and the location would confirm that Adak Canyon is the surface expression of a graben.

Stress Redistribution along Major Plate Boundaries due to Large Earthquakes

This is the summary of work done under Contract No. 14-08-0001-20570, awarded for the period June-August 1982 as a supplement to the main contract.

Calculations based on the theoretical model developed by Rice (1980) and Lehner, Li and Rice (1981) were carried out for selected points along the Aleutian-Adak zone and the northeast Japan - southern Kurile Islands zone. The calculations yielded the stress changes at these points due to great earthquake at other points along the zone. The points selected were either the epicenters of major earthquakes in these regions or within gaps.

The calculations show that the shifting of stress due to rupture of one segment of a subduction-zone plate boundary is significant, compared to the loading due to plate motions, only to distances of 2-3 lithospheric thicknesses. The induced stress changes are a combination of an instantaneous elastic part and a time-dependent part caused by mantle relaxation. The latter appears to be strongly influential in determining repeat times of great earthquakes. The stress changes induced in a plate boundary segment by a great earthquake in an adjacent segment are small, of the order of a few bars.

For the Aleutian-Alaskan region, the calculations show that the places most likely to be approaching the stress level required for failure are: the Rat Islands region, the Unalaska gap and the east end of the Shumagin gap. The last of these yielded the highest calculated stress of any location tested.

Publications and Theses

Bowman, J. R. (1982), *Occurrence of and characteristics of foreshocks in the Adak seismic zone*, M.S. thesis, University of Colorado.

Bowman, J. R. (1982), Characterization of foreshocks in the central Aleutian Island arc (abstr.), *EOS*, *63*: 374.

Engdahl, E. R., J. W. Dewey, and S. Billington (1982), Evidence for contortion of the subducted plate in the central Aleutians (abstr.), *EOS*, *63*: 438.

Frohlich, C., S. Billington, E. R. Engdahl, and A. Malahoff (1982), Detection and location of earthquakes in the central Aleutian subduction zone using land and ocean bottom seismograph stations, *J. Geophys. Res.*, *87*: 6953-6864.

Kisslinger, C., J. R. Bowman, and K. Koch (1982), Determination of focal mechanisms from SV/P amplitude ratios at small distances, in press, *Phys. Earth Planet. Int.*.

Pohlman, J. C. (1982), *A study of the a shallow-focus earthquake swarm possibly related to volcanism*, M. S. thesis, University of Colorado.

Pohlman, J. C., C. Kisslinger, and S. Billington (1982), Investigation of a shallow-focus earthquake swarm possibly related to volcanism (abstr.), *EOS*, *63*: 374.

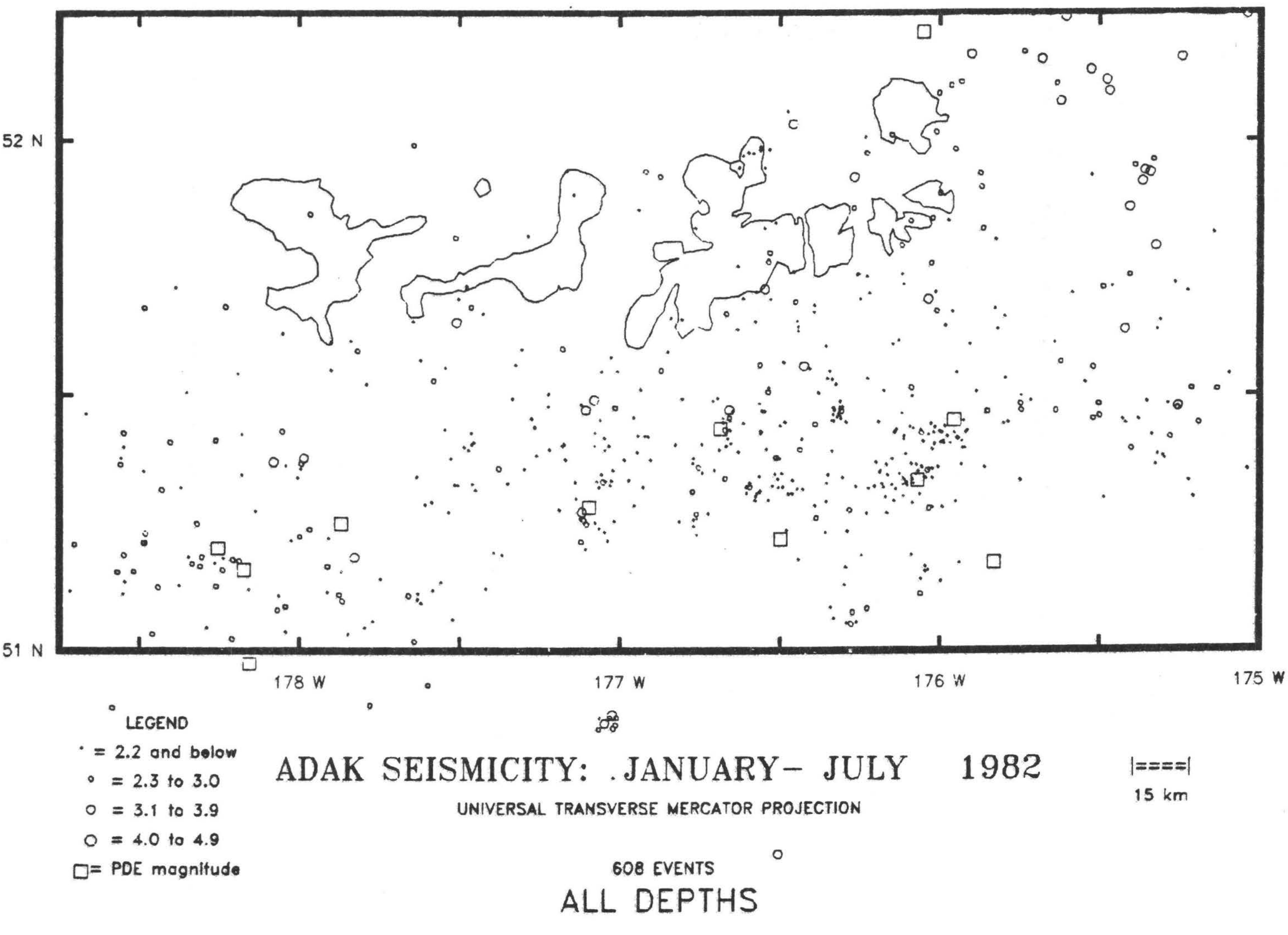

Figure 1 : Map of seismicity near Adak which occurred from January through July, 1982. All epicenters were determined from Adak network data. Events marked with squares are those for which a teleseismic body-wave magnitude has been determined by the USGS; all other events are shown by symbols which indicate the duration magnitude determined from Adak network data. The islands mapped (from Tanaga on the west to Great Sitkin on the east) indicate the geographic extent of the Adak seismographic network.

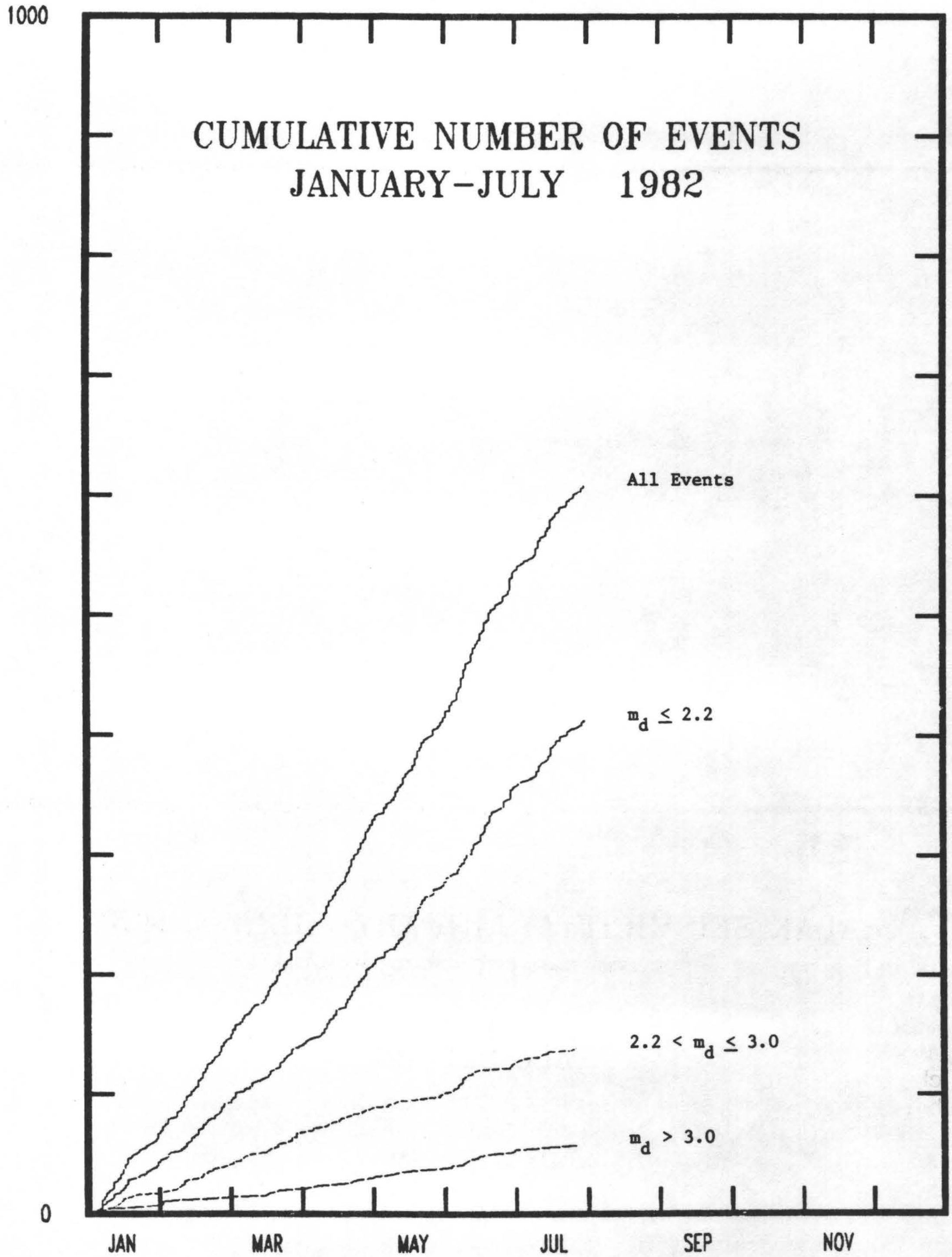

Figure 2 : Plot of cumulative number of earthquakes as a function of time for January through July, 1982, broken down by arbitrary duration magnitude bands. Each unit on the vertical axis is 100 events; 608 events were located.

CARBON FIBER STRAINMETER STUDIES NEAR PALMDALE, CALIFORNIA

#14-08-0001-19759

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Summary

Of the projected six-site nine-instrument carbon fiber strainmeter network (Figure 1), eight instruments at five sites are operational.

Figure 2 shows strain records for strainmeters BQ II (top trace) and strainmeter BQ I (lower trace). Strain normalization is given by the tidal amplitude; BQ I is incomplete because of delays in record digitization. The Bouquet instruments are adjacent to Bouquet Reservoir which, after being empty for nine months began filling in December, 1981; the reservoir was full in April-May, 1982 and began to lower according to the seasonal cycle in May, 1982. The major strain trends are accounted for by reservoir loading. Uncorrelated with reservoir level but correlated with nearby deep well water level anomalies are the rapid strain shifts in mid to late March, 1982. The cumulative rainfall plot at Bouquet Reservoir (Figure 2) shows these strain changes are due to rainfall. The quality of strain signal for BQ II is very good; thermal effects, if not precipitation effects, can be controlled through proper measures.

Of four new instruments at three sites, the pair at Jackson Tunnel are stabilizing. The instruments have significant thermal interference, about the level of the tidal signal. A greater degree of thermal isolation will be given by insulating the instruments and blocking the tunnel more effectively. Rainfall is less likely to affect the JK instruments as the tunnels are deeper (200') into the hillside than are the BQ instruments (40'). The instrument at AQ is dominated by thermal effects; this instrument is exposed to several thermal changes: 1) it is not insulated; 2) it is in a large aperture tunnel with no barrier to air movement; and 3) the tunnel is shallow. Measures to insulate the instrument will be taken. The fourth instrument, TS, has been subject to several episodes of vandalism; it itself is not damaged but batteries, recording gear and satellite antennas have been destroyed. We have extensively re-inforced the tunnel opening; the site has been secure throughout the summer; recording gear has recently been re-installed. This instrument will be particularly useful for correlation with the deepwell monitoring net.

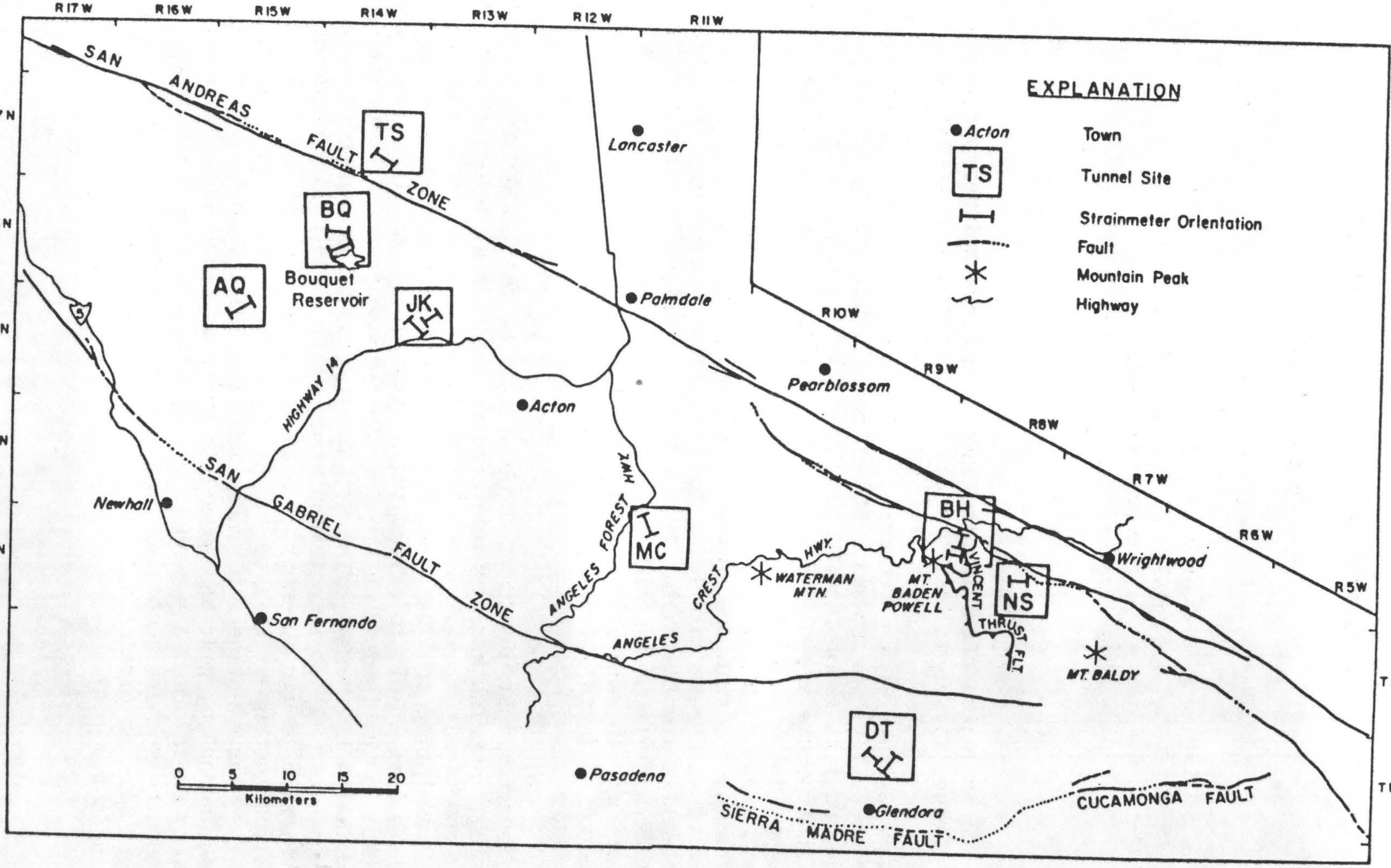

Figure 1. Location map for carbon fiber strainmeter array in San Gabriel Mountains of southern California.

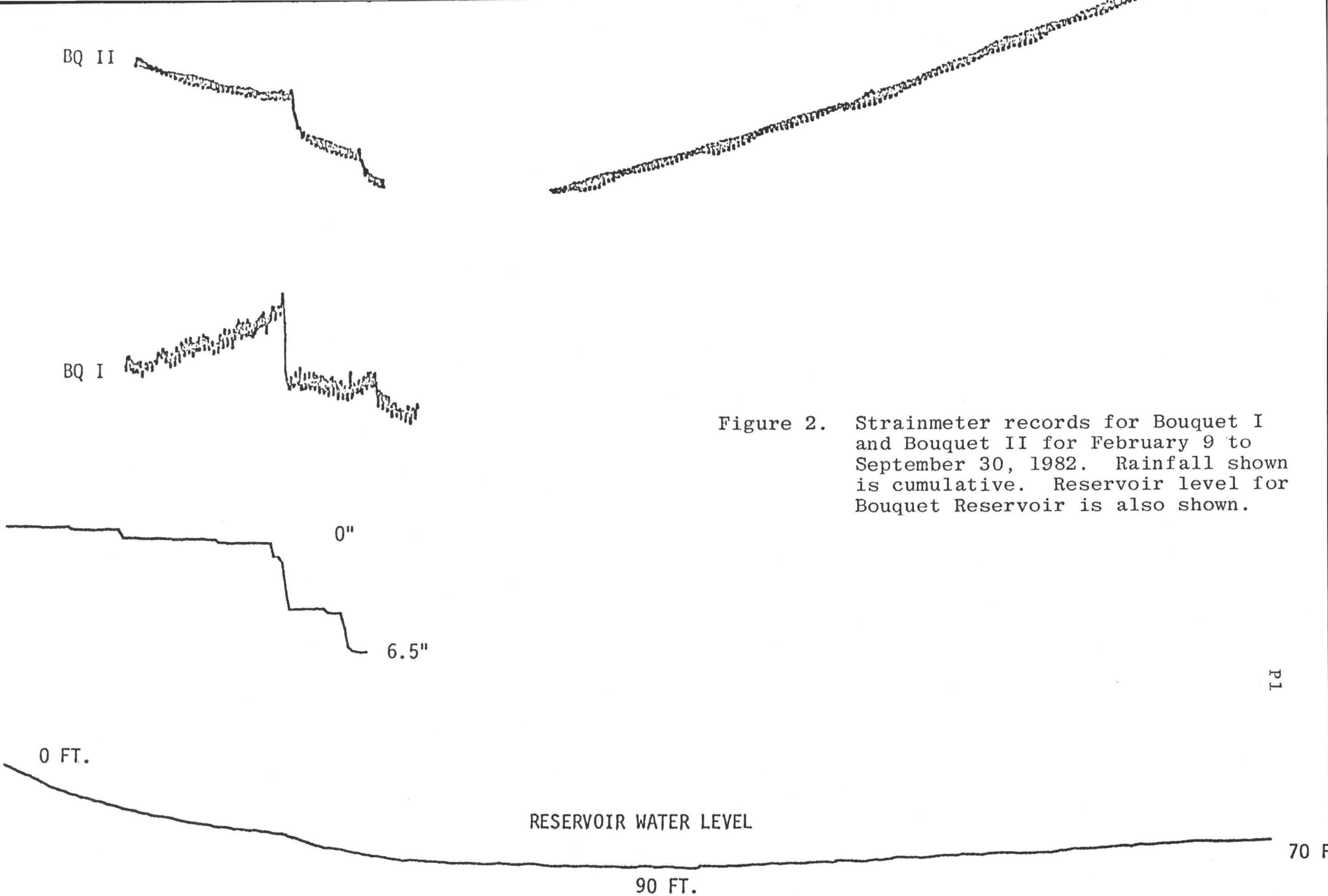

Figure 2. Strainmeter records for Bouquet I and Bouquet II for February 9 to September 30, 1982. Rainfall shown is cumulative. Reservoir level for Bouquet Reservoir is also shown.

Microearthquake Data Analysis

9930-01173

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Investigations

The primary focus of this project is the development of state-of-the-art computation methods for analysis of data from microearthquake networks. Two major topics were investigated during the past 6 months.

1. Development of an archiving and retrieval system for earthquake data.

2. Documentation of a 3-dimensional ray tracing program and its 2-dimensional counter-part.

Results

1. A major problem in processing and analyzing earthquake data is getting a particular data set in a form that one can use. A simple computer based system to document, archive, and retrieve earthquake data sets has been designed, and is now being implemented. This system has 5 components: (1) input and editing, (2) archiving and verification, (3) updating a database which contains keywords and pointers, (4) a query sub-system to allow users to search data sets, and (5) a retrieval sub-system to allow users easy access of the desired data sets and output them on magnetic tapes. This system is scheduled to be completed by the end of December 1982 and will be ready for trial use early next year. We hope the system will be fully operational by summer, 1983.

2. A 3-dimensional ray tracing program using the initial-value formulation is being documented for general use. In order to speed up testing, a 2-dimensional ray tracing program was generated from the 3-dimensional one. We added graphic capabilities so that we can view the ray paths interactively. We plan to finish the documentation in the next couple of months.

Reports

Lee, W. H. K., 1982, Three-dimensional seismic ray tracing in a geologically complex region (abs.): Final Program, 30th Anniversary Meeting of the Society for Industrial and Applied Mathematics, Stanford University, Stanford, p. 14.

Lee, W. H. K., 1982, Historical seismogram filming project and progress towards an international earthquake data bank, in Program and Abstracts, Regional Workshop of IASPEI/UNESCO Working Group on Historical Seismograms, Earthquake Research Institute, University of Tokyo, Tokyo, Japan, p. 1-20.

Seismic Data Library

9930-01501

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This is a non-research project and its main objective is to provide access of seismic data to the seismological community. This Seismic Data Library was started by Jack Pfluke at the Earthquake Mechanism Laboratory before they joined the Geological Survey. Over the past ten years, we have built up one of the world's largest collections of seimograms (almost all on microfilms) and related materials.

Major holding of seismograms are:

(1) WWNSS film chips and fiches (1963-present) -- about 4,000,000 seismograms.
(2) USGS local network develocorder films (1966-1979) -- equivalent to about 1,500,000 seismograms.
(3) Historical seismograms (1903-present) -- about 300,000 seismograms so far.

The historical seismograms were made through an international effort in filming "old" seismograms (anything prior to 1963). The goal is to build up a library of a few million seismograms containing all available records from 30 or so key stations around the world, and selected seismograms for some 2,500 selected earthquakes. Key stations selected for U.S. are:

College, Alaska	(1935-63)
Denver, Colorado	(1909-45)
Honolulu, Hawaii	(1903-21, 1933-63)
Mt. Hamilton, Calif.	(1911-63)
Pasadena, Calif.	(1923-63) -- being filmed now
Tucson, Arizona	(1910-63)
Vieques/San Juan	(1903-63)

In addition, we have also filmed several other U.S. stations for selected events. Filming seismograms in other countries has just begun. A camera has been set up in China, and another one is on its way to USSR. However, it will be a few more years later before we will have any significant amount of seismograms from other countries.

We have also an extensive collection of station bulletins and related materials. In particular, we have filmed all the available phase cards from Caltech (1927-69).

Parkfield Prediction Experiment

9930-02098

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Investigations

Over the past 20 years growing concern has been expressed within the seismological community concerning the possibility of a great earthquake on the San Andreas fault in southern California. This concern was heightened by the publication in 1976 of an analysis of precise leveling surveys in the region which indicated that a broad region stretching almost 300 km along the San Andreas had uplifted about 30 cm during the period between 1961 and 1971. Stimulated by this concern, a great deal of additional work has been conducted in the region since that time, and subsequent observations include a partial collapse of the uplift starting in about 1974, a dilatational anomaly in geodetic measurements in the Palmdale region since 1979, and an accompanying regional seismicity increase. In addition detailed geologic work has provided a much clearer picture of the history of great earthquakes along the San Andreas in the last 2000 years.

Results

In response to a national need (for strategic and emergency planning purposes), for a broad over-view of seismic hazard along the Pacific Coast of California, the U. S. Geological Survey recently undertook a study of the long-term probabilities of large earthquakes along the San Andreas system. This resulted in, amongst other things, an estimated annual long term probability of about 2% for a great earthquake on the southern San Andreas. This short report summarizes the result of applying this methodology to the remainder of the San Andreas system.

The data used in these calculations are recurrence interval estimates ($\overline{\Delta}t$) based on geologic and/or geodetic estimates of slip rates, combined with estimates from the historic record of when a large earthquake last occurred on a given segment (TO). The segments were chosen on the basis of historic earthquakes, with other geologic or seismological criterion added in a few cases.

The statistical model used is the simplest possible, and assumes that earthquake recurrence on a given segment can be characterized by a mean recurrence time ($\overline{\Delta}t$), a Gaussian distribution, and a standard deviation (δt). (Because so little information exists with which to estimate δt, I have assumed it is equal to 30% of $\bar{\Delta}t$, that is,that the scatter in inter-event times is about 1/3 of the mean recurrence time.) Starting with estimates of To, $\bar{\Delta}t$, and δt, a conditional probability can then be calculated (given that an event has not yet occurred), for any future time period. The results of these calculations, for those fault segments for which I could obtain sufficient data, are shown in Table 1 and displayed in Figure 1.

Also shown in Figure 1 are estimates for a number of faults in southern California for which approximate recurrence intervals have been estimated (Ziony et al., in preparation) but for which no historic earthquake is known. The algorithm used for these faults was that 1 mm or more of slip implies a recurrence time of 1000 years or less, and .1 mm or more a recurrence time of 10000 years or less. This assumes about 1 m of slip and magnitudes between 6 and 7.

These estimates are preliminary and a more detailed discussion is in preparation. While the recurrence data are very limited in some cases, we believe they are adequate to allow a broad overview of this sort; however, specific probability estimates on specific faults should not be interpreted more literally than prudence dictates. Before use is made of a specific probability for a given fault segment, one should make his own evaluation of the data and assumptions on which it is based. Given the current state of our knowledge these calculations are meaningful primarily at the order-of-magnitude level, and are subject to abuse if taken more literally without the prudent exercise of due caution.

The probabilities shown for various time intervals,in the column to the right of the table, are the conditional probability (CP) of an event, given that one has not yet occurred, between time T and Δ T.

$$CP(T, \Delta T) = P(T, \Delta T)/P(T,\infty)$$

where $P(T, \quad T) = ERF(U \quad) - ERF(U \quad)$
where $U \quad = (T - To - \bar{\Delta}t)/\delta t$
and $U \quad = (T + \Delta T - To - \bar{\Delta}t)/\delta t$

T is the time for which the calculation is being made (1982 in this case).
ΔT is the time interval following T to which the probability applies (1, 10, 20 and 30 years).

In a few cases, two or more values of To, Δt and δt are shown for a given segment in cases in which significantly different estimates are obtained by geologic or geodetic data; the preferrred (more conservative) value is listed first.

For the Mojave segment multiple values are shown to illustrate the impact of δt = 20%, and 10%, respectively, of $\bar{\Delta}t$.

Table 1

	Fault	Segment	Characteristic Earthquakes Date	Characteristic Earthquakes MAG	Date T	Aver. Recur. t	S.D. Recur. t	Probabilities % Annual 1982	Cummulative(years) 10	20	30
A	San Jacinto	Coyote Mtn.	1968	6 3/4	1955	100	30	0.07	1.0	3.1	6.9
B	San Jacinto	Anza	1890	6 3/4	1890	100	30	2.1	22	43	62
C	San Jacinto	Riverside	1899	6 3/4	1908	100	30	1.1	13	28	45
D	San Andreas	Indio	1857	7 1/2-8	(1382)	500	150	0.8	8.2	16	24
E	San Andreas	Mojave	1857	7 1/2-8	1857	136	41	1.6	16	32	47
							27	2.1	22	44	63
							14	2.8	33	68	90
F	San Andreas	Carrizo	1857	8	1857	228	68	0.2	2.2	4.9	8.2
G	San Andreas	Parkfield	1966	6	1966	22	6.6	5.2	67	98	99.98
H	San Andreas	Creeping		(7)	(1792)	(400)	(120)	(0.08)	(0.8)	(1.7)	(2.8)
I	San Andreas	San Juan Bautista	1865	6 1/2	1906	100	30	1.2	14	30	47
						75	22.5	3.7	35	64	83
J	San Andreas	S. F. Penninsula	1838	7	1906	167	50	0.16	1.9	4.5	8.0
						125	38	0.5	6.0	14	23
K	San Andreas	Olema	1906	8	1906	225	68	0.05	0.6	1.5	2.6
						150	45	0.24	2.8	6.8	12
L	Hayward	South	1868	6 1/2-7	1868	200	60	0.26	2.9	6.5	10.8
M	Hayward	North	1868	6 1/2-7	1836	200	60	0.55	5.8	12.4	19.7

ANNUAL EARTHQUAKE PROBABILITIES
for selected fault segments of the San Andreas Fault System

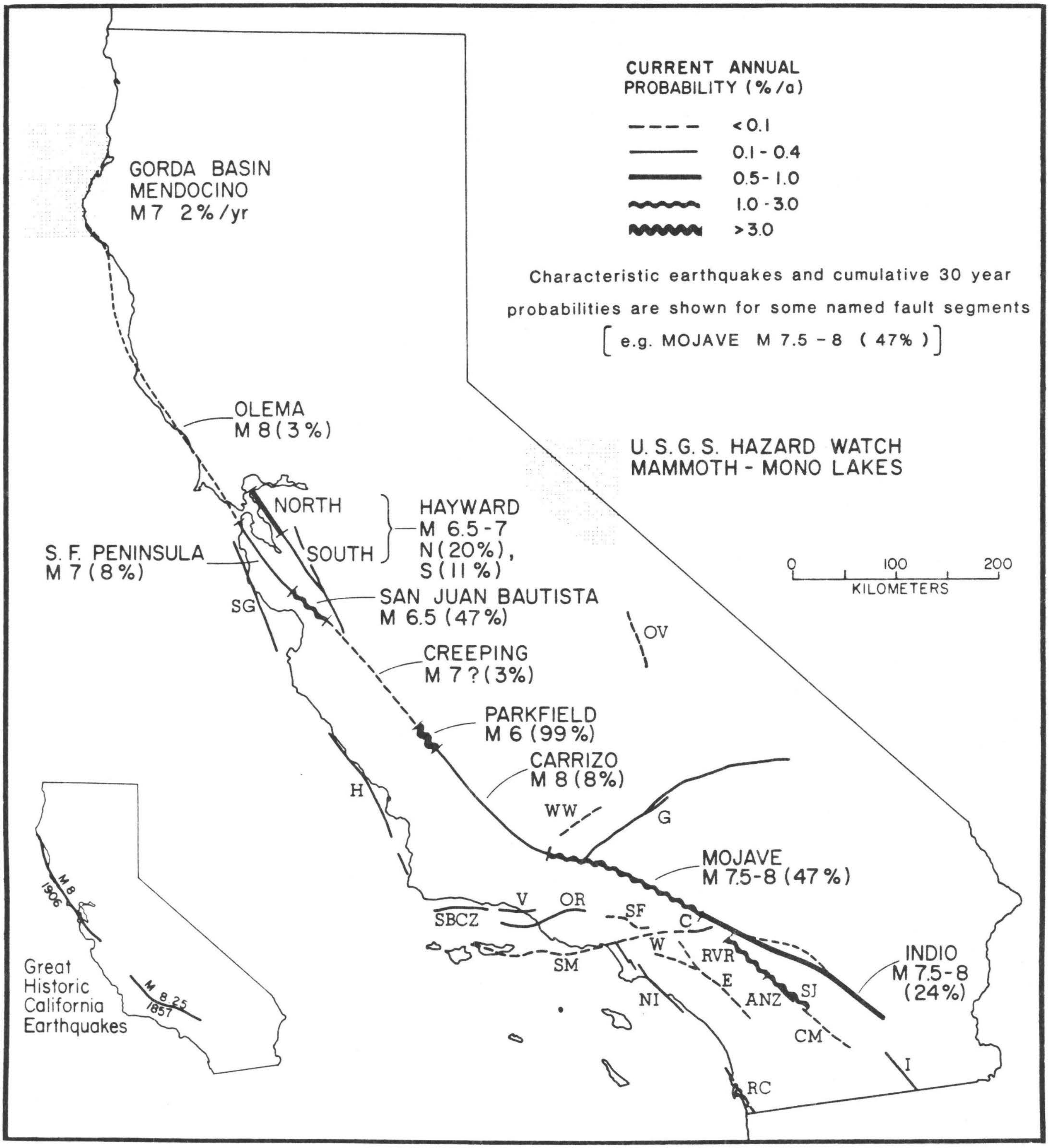

Figure 1

Seismic Studies of Block Tectonics

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Investigations

Development of a seismomechanical model of the intersection of the Hayward and Calaveras faults southeast of San Francisco Bay.

Results

Seismic, geodetic and geologic data have been combined with dislocation calculations to construct a mechanical model of the intersection of the Hayward and Calaveras fault zones southeast of San Francisco Bay. The region modeled is a complex zone of deformation extending roughly from Fremont and Livermore on the north to Coyote Lake on the south. The seismicity in the region is predominantly right lateral strike-slip, consistent with the broad scale plate motion, but the geometric complexity of the faults has caused numerous compressional (folds, thrust faults) and tensional (normal faults, pull-aparts) features.

Strike-slip faults from maps of Quaternary and Holocene faulting were digitized and modeled as two-dimensional cuts in an otherwise homogeneous elastic crust. Geodetically determined slip rates were specified on faults outside of the modeled region and remote displacements were imposed parallel to the plate boundary. Slip on the faults was computed, subject to frictional boundary conditions on the fault surfaces.

The inclusion of different fault traces and variation of the remote stress in the model determine which faults are mechanically favorable for slip and can account for the observed geodetic displacement across the zone. Well-defined narrow zones of epicenters suggest that slip on the Hayward fault is transferred to the Calaveras fault approximately between Fremont and the Calaveras Reservoir. Furthermore, the uneven distribution of epicenters and moment along the Hayward-Mission Peak-Calaveras trend suggests that some surface complexities of the fault trace extend to seismic depths. Models in which the Hayward and Calaveras faults are connected along the trend of the Mission Peak fault permit enough slip to accomodate the observed slip across the zone, but only if the model faults are much smoother than the mapped surface traces. This smoothness requirement can be relaxed if numerous short faults are distributed southwest of the Calaveras fault. The absence of significant epicenters, seismic moment, or evidence of surface creep to the west of the Calaveras fault suggests that appreciable slip on such short faults is unlikely.

Reports

Mavko, B. B., and Mavko, G. M., A Seismomechanical Model of Interacting Faults (abstract submitted to EOS).

Schulz, S., Burford, R. O., and Mavko, B. B., Influence of Rainfall of Fault Creep (submitted to J. Geophys. Res.).

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

USGS-14-08-0001-19748

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Investigations

1. Our present estimate of the seismic potential of the Puerto Rico-Virgin Islands region is significantly higher than was thought previously. The increased seismic hazard is based on historic records of large shocks and an improved understanding of the style and rate of plate interactions.

Results

1. A near great or great earthquake occurred near Puerto Rico in 1787 (Figure 1). This event, previously unknown to researchers estimating the region's seismic hazard, was associated with intensities as high as VIII on the modified Mercalli scale throughout Puerto Rico except the south coast. The discovery of this event as well as our revised estimate of rate of plate movement (3.7±0.5 cm/yr) suggest that the potential for a large damaging shock on the main plate boundary is quite high. We estimate the magnitude of the 1787 event at about 8-8 /1/4 (Figure 2). The repeat of such a shock in the Puerto Rico-Virgin Islands region could be devastating to the local economy and poses great danager to those living in the major population centers such as San Juan.

Anomalous features on the subducting North American plate appear to influence the short and intermediate term seismic activity and may delimit large segments of the plate boundary which act as coherent blocks during large earthquakes (Figure 1). These features are believed to limit the maximum size of expected shocks. The maximum size for an event north of Puerto Rico is 8-8 1/4 and near the northern lesser Antilles it is 8-8 1/2.

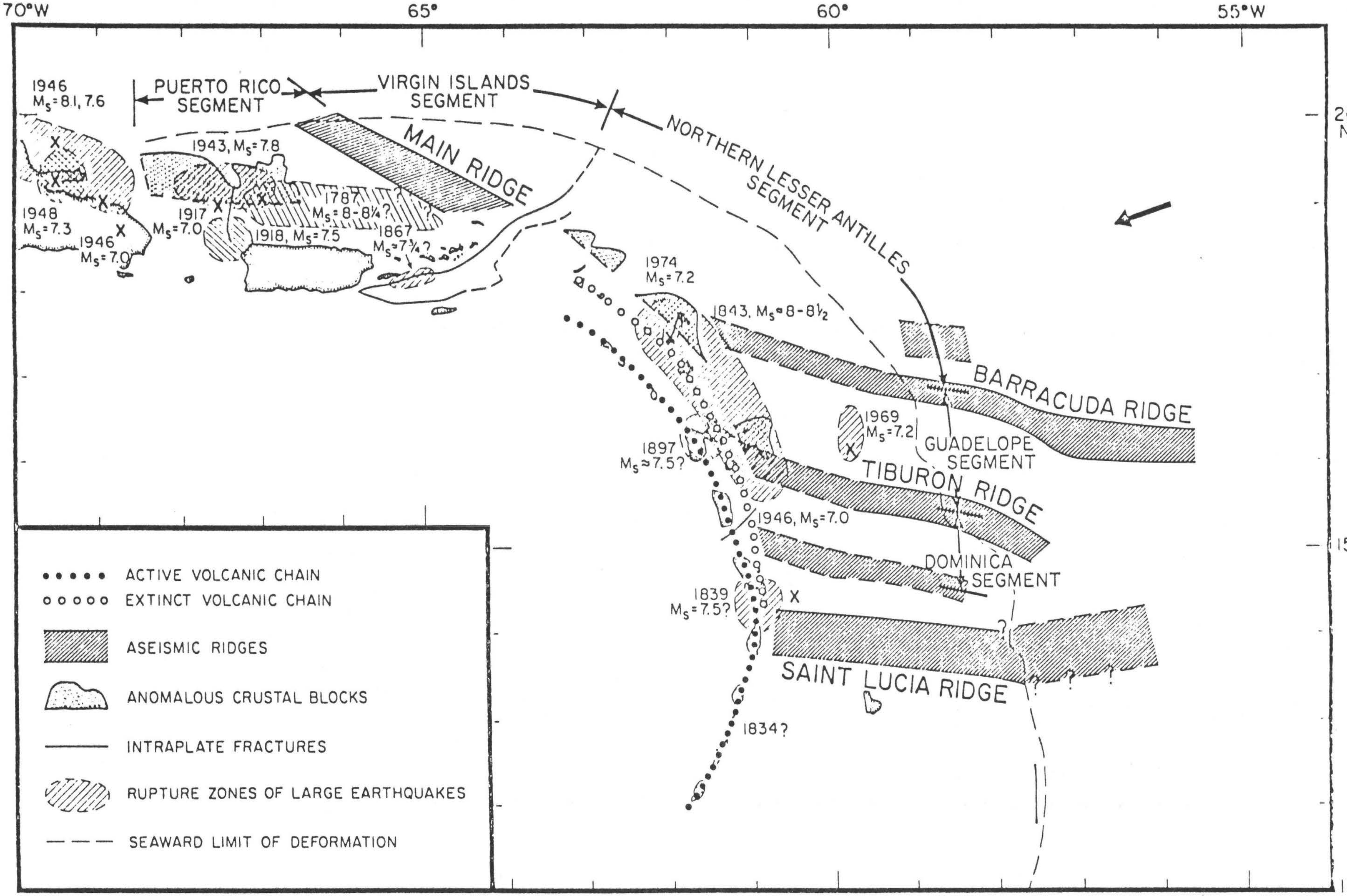

Figure 1. Rupture zones of larger earthquakes ($M_s \geq 7$) in the eastern Caribbean and their relationship to features that bound ends of rupture. Several bathymeyric highs intersect the plate boundary dividing it into tectonic segments. The Guadeloupe and Dominica segments were the site of a great earthquake in 1843. Rupture during this event may have been limited by the Barracuda ridge on the north and on the south by either an unnamed ridge or the Tiburon ridge. Three anomalously shallow portions of the frontal arc in the Lesser Antilles (stippled areas) may be either exotic blocks accreted to the inner wall of the trench or blocks uplifted by the subduction of aseismic ridges. The large block northwest of Puerto Rico represents a part of the Bahama Bahnk that has been accreted to the Caribbean plate in the last few million years.

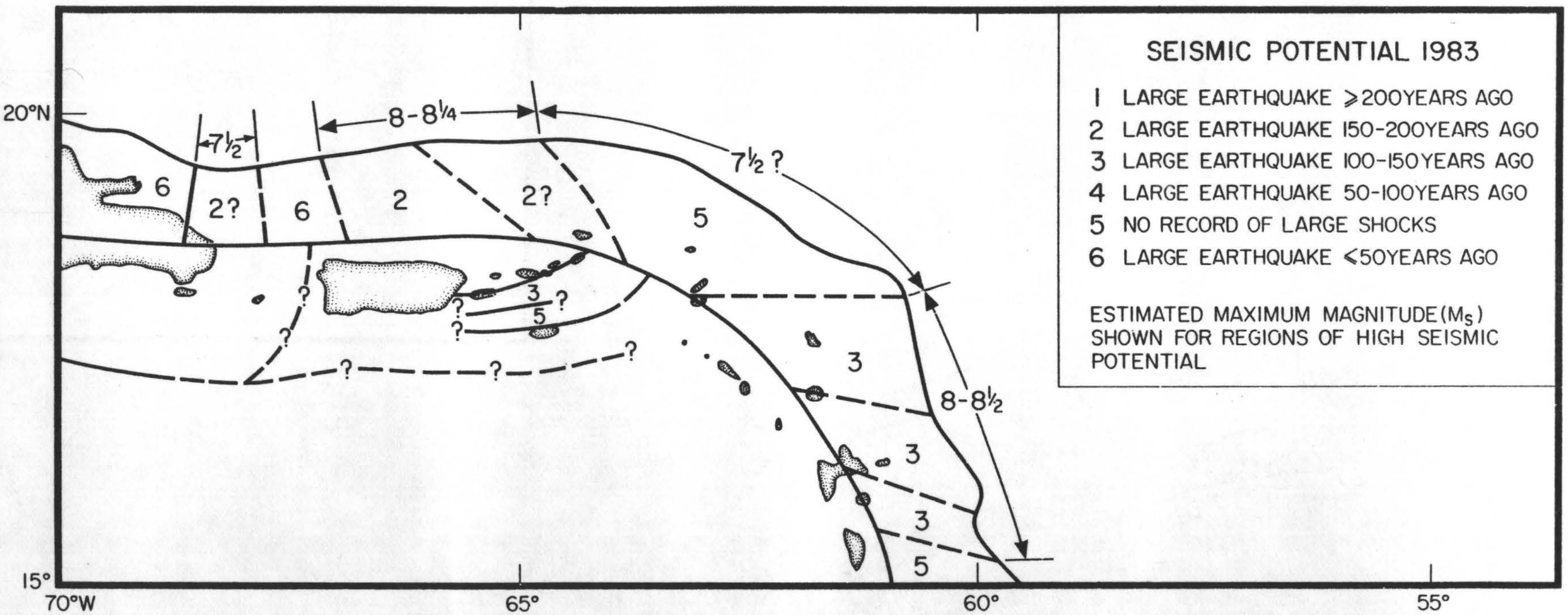

Fig. 2. Estimate of seismic potential for the northeastern Caribbean. Potential for large or great shocks to occur is estimated by the time elapsed since the last large earthquake. This method assumes repeat times throughout the region are about the same. Magnitudes of future shocks are estimated for those regions of high potential. Question marks (?) denote uncertainty in boundaries of seismic zone or level of seismic potential.

Geodetic Strain Monitoring

9960-02156

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Investigations

1. A portable two-color laser geodimeter (terrameter) is being used in high-resolution trilateration surveys in selected areas of the San Andreas fault system.

Results

1. The preceding semi-annual report referred to an abrupt dilatation of the Pearblossom network of about 0.8 ppm, which occurred in March, 1982. This event marked the start of a distinct change in the character of the strain accumulation inferred using the terrameter and, thus, generated some suspicion as to its reality. Accordingly, a comprehensive program was initiated to check both the instrument and the survey procedure to determine the possible extent and source of systematic errors, especially in the inferred dilatational component of strain. First, we investigated the possibility that proper account might not have been taken of the meteorological variables, pressure, temperature, and water vapor pressure. To test this hypothesis, the observed line length changes were assumed to be linear functions of the meteorological variables as well as genuine tectonic strain changes. An inversion of the data set yielded coefficients for the meteorological variables that were not significantly different from zero. Using similar techniques systematic errors from not having the instrument properly positioned over the monument, or not knowing the correct height of the terrameter above the monument, were investigated, but the results were also negative. The only significant correlation found was between orthogonal strain components, indicating a systematic dilatational component in the data set but not indicating whether the cause was tectonic or instrumental. Second, an independent test of the terrameter frequency standard, variations of which might have caused systematic errors in the inferred dilatation, proved negative. Third, to test the stability of the terrameter a 24-hour test of continuous line length monitoring was run in July, 1982. During this test, an unacceptably high level of monotonic drift in line length estimation was observed. The drift was considerably higher than could be explained on the basis of misestimating any of the meteorological variables along the measurement path. Fourth, following the results of the July testing, we decided that the only conclusive test of the amount of systematic drift in the terrameter measurements would necessarily involve an intercomparison with Dr. Larry Slater's two-color geodimeter, which had been operating in Pearblossom until February, 1982. Slater's geodimeter was moved from San Juan

Bautista to the Pearblossom Observatory in late July, 1982, and the intercomparison commenced on August 1st. Both instruments showed acceptable stability during the 24-hour stability run on August 6th except for one series of terrameter measurements made about seven hours after the test commenced; at this time the terrameter indicated distances about 3 mm shorter than were recorded during the remainder of the test over a 3 km line (1 ppm). This discrepancy has since been shown to be due to the terrameter computer incorrectly analyzing the data. Although the terrameter and Slater's geodimeter both showed acceptable stability over the initial 24-hour test, the two instruments indicated substantially different strain changes over a two-month period from the beginning of August. As seen in Figure 1, Slater's instrument, the C-meter, showed a constant level of dilatation while the terrameter indicated substantial fluctuations in this strain component. The good agreement between the shear strain changes for the two instruments (Figure 1) tends to suggest that the disagreement in dilatation is not due to errors in observational procedure or data analysis. This accord also indicates that although the dilatations measured with the terrameter, beginning in February, 1982, are highly suspect, the shear strains are most probably reliable. In any case, the results of the intercomparison (Figure 1) make it clear that the terrameter is subject to unexplained and substantial drift in its baseline measurements. The drift is sufficiently large and unpredictable as to render the absolute baseline measurements useless. Bench testing of the terrameter is currently underway to try to establish the cause of the problem. In the meantime, the C-meter continues to operate at the Pearblossom Observatory to maintain the strain monitoring program that commenced in November, 1980. The most recent version of this data set is summarized in Figure 2.

Reports

Langbein, J.O., Linker, M.F., McGarr, A., and Slater, L.E., Observations of strain accumulation across the San Andreas fault near Palmdale, California, using a two-color geodimeter, Science, in press, 1982.

Langbein, J.O., McGarr, A., Johnston, M.J.S., and Harsh, P.W., Geodetic measurements of postseismic crustal deformation following the Imperial Valley earthquake, 1979, submitted to Bull. Seismol. Soc. Am., 1982.

McGarr, A., Zoback, M.D., and Hanks, T.C., Implications of an elastic analysis of in situ stress measurements near the San Andreas fault, J. Geophys. Res., 87, 7797-7806, 1982.

McGarr, A., Analysis of states of stress between provinces of constant stress, J. Geophys. Res., 87, 9279-9288, 1982.

McGarr, A., Sacks, I.S., Linde, A.T., Spottiswoode, S.M., and Green, R.W.E., Coseismic and other short-term strain changes recorded with Sacks-Evertson strainmeters in a deep mine, South Africa, Geophys. J. R. Astr. Soc., 70, 717-740, 1982.

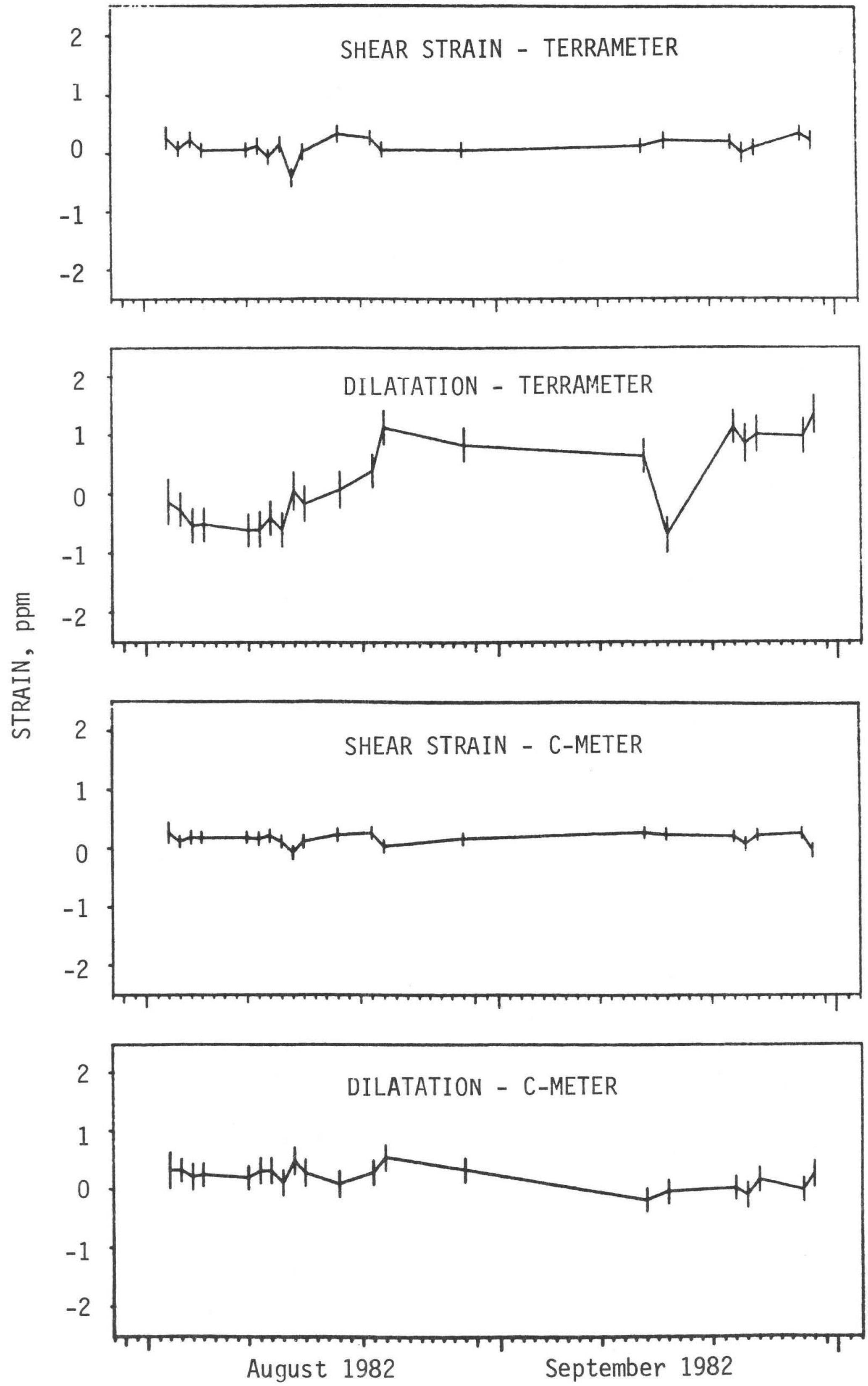

Figure 1. Intercomparison of strains over the Pearblossom network measured with the terrameter and the CIRES two-color geodimeter. Whereas the shear strain changes are in good accord, the dilatations determined using the two instruments are in substantial disagreement.

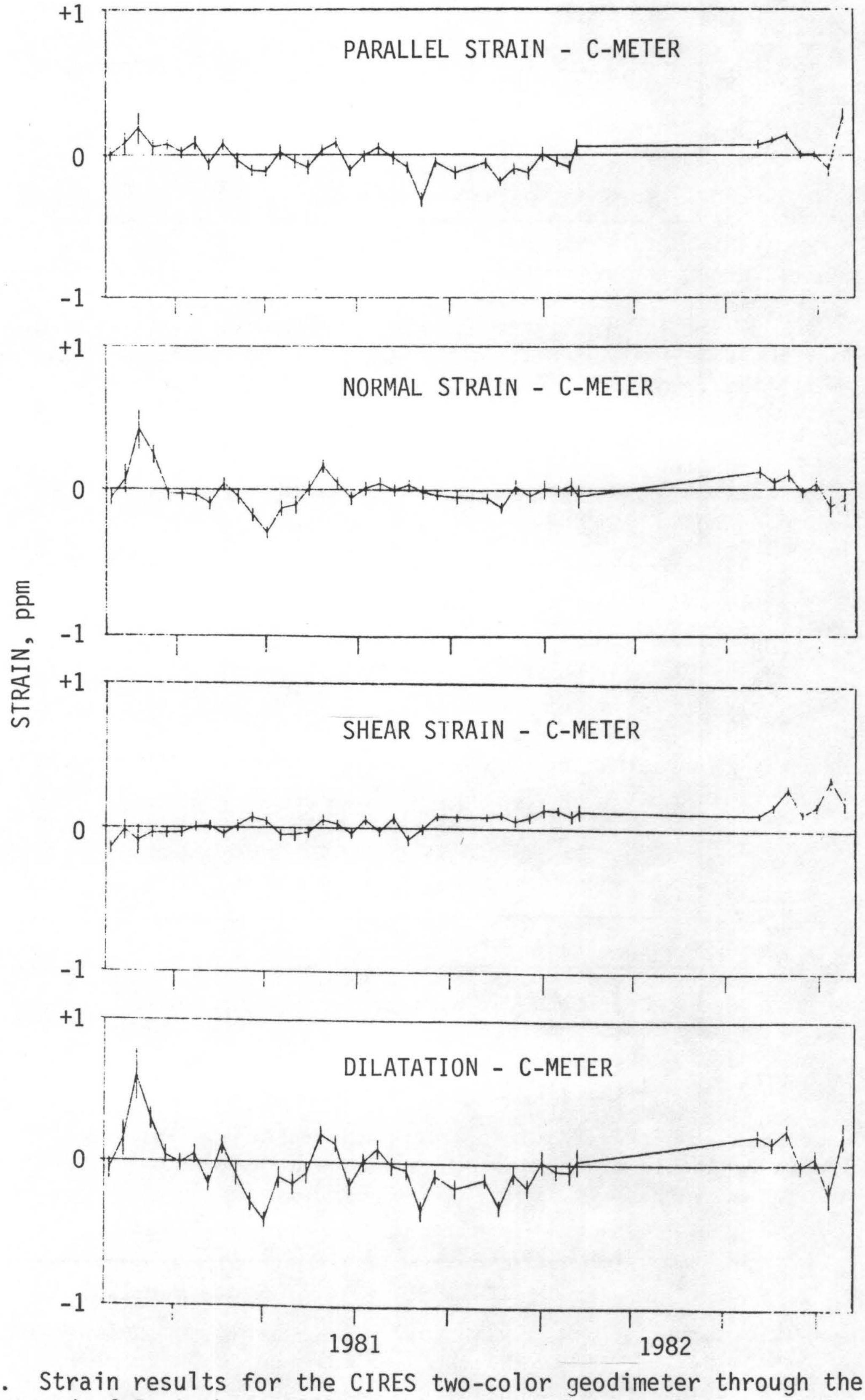

Figure 2. Strain results for the CIRES two-color geodimeter through the end of September, 1982.

Reevaluation and Interpretation of Releveling Observations in the Western U.S.: Implications for Earthquake Prediction

20585

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Investigations

This research program is designed to clarify the nature and causes of contemporary vertical movements of the crust primarily as evidenced by precise releveling in seismically active areas of the western U.S. with emphasis on southern California. Our approach involves: 1) evaluating releveling measurements in seismically active areas from the perspective supplied by analysis of the entire U.S. data base (i.e. what constitutes an "anomalous" signal?); 2) applying reliability criteria (e.g. Reilinger and Brown, 1981) to releveling observations of potential importance to the earthquake prediction problem, 3) reinterpreting those movements which appear to reflect tectonic activity, in light of other relevant geophysical and geological information.

Results

1. Reevaluation of some of the releveling measurements in southern California indicates that: 1) 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. 2) 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. 3) There is strong evidence of contamination by rod calibration errors in some of the releveling observations used to define the southern portion of the Palmdale Bulge (Llano to Azusa, California). 4) Possible tilting southwest of Palmdale between 1961 and 1965 is not easily related to systematic errors or near-surface movements and thus may represent tectonic deformation. Whether this tilt anomaly is due to preseismic effects of the San Fernando earthquake or a mechanically separate tectonic event is presently unknown.

2. Contemporary east-west tilting along the northwest coast of the U.S. from the Olympic Peninsula of Washington to southern Oregon appears to be accumulating at rates comparable to the long term (≈10,000 yrs) averages inferred for geomorphic evidence (tilted marine terraces). This apparent consistency over two vastly different time intervals is interpreted as evidence that the tilting represents aseismic deformation (as opposed to elastic strain accumulation).

3. Relative vertical displacements of bench marks in extreme western Kentucky have been determined by comparison of successive leveling surveys in 1947 and 1968. The resulting pattern of apparent surface deformation shows a steep offset which can be closely modeled by a normal fault in an elastic half-space. The offset is located near the northern boundary of the New Madrid seismic zone, an area where faults have previously been inferred on the basis of both geological and geophysical evidence. Reported inter-survey earthquakes near the offset appear to be too small to account for the amount of slip required by the fault model suggesting that the observed deformation may have accumulated with several undetected small earthquakes, or as aseismic creep.

4. Relative elevation changes deduced from first-order leveling surveys conducted between 1910 and 1957 show that at least two areas in western Texas near the epicenter of the 1931 Valentine earthquake ($M = 6.4$) subsided relative to their surroundings. Apparent subsidence east of Van Horn, Texas, is attributed primarily to the combined effects of groundwater withdrawal and topography-related survey errors. In contrast, relative subsidence near Valentine, Texas, of 11.2 ± 1.0 cm extending over a distance of about 20 km does not appear to be due to either near-surface effects or leveling errors and thus may represent coseismic deformation of the Valentine earthquake. If the observed subsidence was caused by the 1931 earthquake, the leveling data suggest that the epicenter for this event lies considerably closer to Valentine than originally reported. This new location is supported by a recent relocation for the Valentine earthquake, and by local intensity reports.

5. Because of existing uncertainties as to the influence of errors and non-tectonic movements on releveling estimates of vertical crustal movement, we have taken an empirical approach to investigate some characteristics of the U.S. releveling data base as a whole. Our primary purpose is to establish typical magnitudes of apparent tilt which can serve as a basis for defining anomalous apparent tilts (the term "apparent" is used since differences between levelings can result from errors as well as surface movement). Our analysis is sensitive to apparent tilts with characteristic lengths (i.e. lenghts over which tilt is coherent) of 10 to about 70 km. Preliminary results include: 1) The typical magnitude of apparent tilt (see table below) for the entire data base is around 2 μ rad for tilt lengths averaging around 35 km. This is approximately four times larger than the magnitude of apparent tilt expected from random errors. 2) The typical magnitude of apparent tilt averaged over all lengths in the Western U.S. is about 1 μ rad higher than that in the east (≈ 1.6 μ rad); part of the higher typical magnitude of apparent tilt in the west may be due to the greater degree of tectonic activity in this region. 3) While a number of tectonically active areas are characterized by high average apparent tilts, the average magnitude of apparent tilt in releveling data defining the Southern California Uplift is not significantly different from that for the entire Western U.S. 4) The largest observed apparent tilts for the entire data base occur along approximately flat routes. For the most part, these large apparent tilts result from real surface movement and are directly associated with sediment compaction due to water withdrawal in flat lying sedimentary areas.

Typical level of apparent tilt by region.

Location	Average |Tilt| (μ rad)+	Rms Deviation on |Tilt| (μ rad)	Average Length (km)	Average BM spacing (km)	Number of segments
U.S.	2.0 ± 0.1	2.6	36	3.2	1908
E.U.S.	1.6 ± 0.1	1.9	42	3.7	1039
W.U.S.	2.6 ± 0.1	3.2	29	2.7	869
Coastal Plain	2.0 ± 0.1	2.5	42	3.8	455
Great Valley	5.4 ± 0.5	5.2	18	1.6	132
Alaska	4.6 ± 0.8	3.7	48	3.4	23
S. Cal. uplift	2.7 ± 0.2	3.2	22	1.8	246
Hebgen Lake	4.0 ± 0.8	4.0	27	4.0	23
S. Imperial Valley (pre 1960)	5.7 ± 1.4	5.7	29	2.5	16

+Standard error on mean calculated assuming normal distribution.

Reports

Reilinger, R.E., Bevis, M., and Jurkowski, G., 1982, Tilt from releveling: An overview of the U.S. data base: J. Geophys. Res., submitted.

Reilinger, R.E., and Adams, J., 1982, Geodetic evidence for active landward tilting of the Oregon and Washington coastal ranges: Geophys. Res. lett., 9, 401-403.

Schilt, F.S., and Reilinger, R.E., 1981, Evidence for contemporary vertical fault displacement from precise leveling data near the New Madrid seismic zone, western Kentucky: Bull. Seismol. Soc. Amer., 71, 1933-1942.

Ni. J.F., Reilinger, R.E., and Brown, L.D., 1981, Vertical crustal movements in the vicinity of the 1931 Valentine, Texas, earthquake: Bull Seismol. Soc. Amer., 71, 857-863.

Reilinger, R.E., and Brown, L.D., 1981, Neotectonic deformation, near-surface movements and systematic errors in U.S. releveling measurements: Implications for earthquake prediction: in Earthquake Prediction: An International Review, eds. Simpson, D.W., and Richards, P.G., AGU, Washington, D.C., 422-440.

Crustal Strain

9960-01187

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Investigations

The principal subject of investigation was the analysis of deformation in a number of tectonically active areas in the Western United States.

1. Deformation across the Long Valley, Califronia, caldera. The Excelsior trilateration network that extends north from near Bishop, California to Mono Lake and thence northeast to Luning, Nevada, was resurveyed in 1972, 1973, 1976, 1979 (July), and 1980 (Sept.). The deformation observed in the 1980-82 interval was comparable to that observed in the 1979-80 interval, indicating that inflation of the magma chamber continued well after the 1980 Mammoth Lakes earthquakes. To investigate deformation imposed by the Mammoth Lakes earthquakes, the deformation due to magma chamber inflation in the 1979-82 interval as defined by leveling surveys was removed from the horizontal surveys. The residual deformation suggests oblique slip on an eastward dipping fault that roughly conincides with the projection of the Hartley Springs fault to the south side of the Long Valley caldera. The tentative fault model dips 60° ENE and involves a rupture area (defined by aftershocks) of about 20 km X 10 km with 0.5 m left-lateral and 0.2 m normal slip.

2. Deformation measured in the Yakataga seismic gap, Alaska. A Geodolite network that extends northward from Cape Yakataga was surveyed in 1979 and 1980 and resurveyed in 1982. The changes in measured lengths define the principal strain rates to be 0.05 ± 0.08 μstrain/a extension N 65° ± 8° E and 0.20 ± 0.08 μstrain/a contraction N 25° ± 8° W. The orientation of principal axes is consistent with the known relative motion between the Pacific and North American plates, and the magnitude of strain rate is comparable to that observed in Japan. Thus, deformation in the Yakataga gap does not appear unusual at the present time. A small network was established across Icy Bay (60 km east of Cape Yakataga) in 1982. The National Geodetic Survey had measured eight lines in that network to second-order precision in 1974. The 1974-82 line length changes implied about 8 μstrain extension N 83° E and 8 μstrain contraction N 7° W in the 8 year interval. These measured strains are at

best marginally significant, however, because of the second-order precision of the 1974 survey. What is important is the small magnitude of the strain change considering that Icy Bay was thought to be the southwestern corner of the 1978 Mount St. Elias rupture (Ms = 7.2).

3. Deformation across the Denali fault, Alaska. A Geodolite network across the Denali fault in the Delta River canyon, previously surveyed in 1975 and 1979, was resurveyed in 1982. The new measurements were consistent with a linear extrapolation of the 1975-79 measurements and imply principal strain rates of 0.31 ± 0.05 μstrain/a extension N 38° ± 4°E and 0.12 ± 0.04 μstrain/a contraction N 52° ± 4° W. The Denali fault in this sector strikes about N 63° W (i.e., roughly parallel to the contraction axis), and the deformation is principally extension perpendicular to the fault with only a minor component of right-lateral shear on the fault. This same deformation pattern had been deduced from the earlier surveys. A new Geodolite network was established in 1982 on the Denali fault at its crossing of the Nenana river (160 km west of the crossing with the Delta river). Comparison with Geodimeter measurements made there in 1970 again suggests deformation that is predominantly an extension perpendicular to the Denali fault.

4. Systematic Error in Geodolite Surveys. Cheng and Jackson [Eos, 62, 1051, 1981; Eos, 63, 430, 1982] have suggested that variations in areal dilatation measured in the Geodolite surveys of the U.S. Geological Survey may be simply an artifact of the measuring system. Although systematic error could conceivably account for excursions in dilatation, we maintain that the specific arguments of Cheng and Jackson are incorrect; i.e., the excursions in dilatation cannot be attributed to changes in the zero-offset correction nor to proportional error associated with temperature. We have demonstrated the former by manually changing the zero-offset and showing it has no effect upon range. The absence of a temperature effect was established by examining a large number of pairs of length measurements made at significantly different temperatures.

5. Geodolite monitor net on San Andreas fault near San Francisco Bay. In September 1981 we began making biweekly measurements of three lines near the San Andreas fault. The lines were measured more than 20 times between September 1981 and September 1982. The measurement conditions spanned a temperature range of 20°C. Despite the large atmospheric variations the line lengths show no excursions. Scatter in the observations is consistent with previously published estimates of the errors, about 7 mm for these 30 and 40 km long lines. Strain field components calculated from the observed line length changes also show no sigificant perturbations above the 0.2 microstrain level. Regression of the distances on the refractive index, temperature, pressure and water vapor pressure indicates that there is no significant correlation.

6. Southern California monitor nets. Monthly measurement of 5 nets of 3 lines each along the southern California section of the San Andreas fault began in May. The first six months of data show no anomalies or significant strain events. A histogram of the normalized residuals (observed length - mean length, over standard deviation) indicates that the residuals are normally distributed.

7. 1868 Hayward Fault earthquake report. A unpublished letter to the Bulletin of the Seismological Society of America gives details on the preparation and suppression of a report on the 21 October 1868 Hayward, California earthquake. During November and December 1868 the newspapers carried accounts of the formation of a committee to investigate the earthquake. No mention is made of a report coming from the Committee. Forty years later, after the 1906 earthquake, George Davidson, a member of the committee, wrote a letter to the Seismological Society relating some of the findings of his subcommittee. Davidson further states that a report was prepared, but suppressed by George Gordon, the committee chariman. The letter is reproduced in the December Bulletin of the Seismolgical Society of America.

Reports

Savage, J.C., and M.M. Clark, Magmatic resurgence in Long Valley caldera, California: Possible cause of the 1980 Mammoth Lakes earthquakes, Science, 217, 531-33, 1982.

Prescott, W.H., Circumstances surrounding the preparation and suppression of a report on the 1868 California earthquake, Bull. Seism. Soc. Am., 72, (6), 2389-2393, 1982

Crustal Deformation Observatory
Part G

14-08-0001-19758

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Investigations

This effort consisted of a portion of the initial field testing and evaluation of a new 2-fluid tiltmeter. Because of the new concept and design of this instrument it was decided that it would be advantageous to consider a detailed comparison of the 2-fluid tiltmeter with as many other types of vertical deformation monitoring instruments as possible. The number of such instruments at Pinon Flat Observatory made that location an obvious choice. It was anticipated that this instrument would provide a measure of relative height differences between monuments 500 meters apart to an accuracy of better than 0.1 millimeters with good long-term stability.

Results

We have not yet begun measurements using the 2-fluid tiltmeter at Pinon Flat Observatory. Initial field tests of the 2-fluid tiltmeter in central California indicated that the instrument would not function at distances greater than 200 to 300 meters. Various portions of the system have been modified and it now appears that the increased length capability has been realized. The installation at Pinon Flat is nearly complete. One of the fluid tubes at Pinon Flat appears to have a trapped bubble which must be removed before measurements can begin. Measurements with the tiltmeter in central California are being made every 2 or 4 hours and the short-term scatter of the data is characterized by a standard deviation of a few tenths of a millimeter.

A Crustal Deformation Observatory Near the San Andreas Fault in Central California

14-08-0001-19300

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Investigations

1. The goal of this effort was to establish a crustal deformation observatory in central California. The observatory was to utilize both a multiwavelength EDM instrument and a 2-fluid tiltmeter. It was hoped that both horizontal and vertical deformation data would be collected simultaneously to a precision of approximately 0.1 mm.

2. A short-term comparative test was conducted using the CIRES multiwavelength EDM and the commercially produced Terrameter.

3. The CIRES multiwavelenth EDM instrument reoccupied the Pearblossom, California array to update the geodetic strain data base collected there last year.

Results

1. Lines within the central California crustal deformation observatory net near San Juan Bautista were monitored for approximately 1 month in the summer of 1982. The measurements served to establish initial line lengths but no substantial line length changes were detected. Modifications to the 2-fluid tiltmeter were completed during this reporting period and the instrument now seems capable of data collection over extended periods. Measurements with the tiltmeter are typically made every 2 or 4 hours and the short-term scatter of the data is characterized by a standard deviation of a few tenths of a millimeter in the relative heights of the two ends of the instrument (approx. 250m in length).

2. A cooperative effort with the U.S. Geological Survey to monitor strain in Southern California near Pearblossom was concluded in Feb. 1982 when it appeared that the new Terrameter was functioning properly and was capable of assuming the measurement program. By early summer very rapid changes in the measured line lengths were detected within the Pearblossom network. By mutual agreement it was decided to return the CIRES multiwavelength EDM instrument to the Pearblossom site and conduct a detailed comparison with the Terrameter. Results indicated that the rapid changes in line length were most likely the result of an instrumental problem within the Terrameter.

3. It was determined that the CIRES instrument should remain in Pearblossom until either the Terrameter problem was solved or until a few months of data was collected with the CIRES multiwavelenth EDM. The re-occupation of

the Pearblossom network with the CIRES instrument was successful with no apparent offset in the total data set caused by the re-occupation. We feel that a third occupation (if necessary) of the network would present no difficulties. The CIRES instrument will probably be removed from the Pearblossom site within a month or two.

Reports

M.F. Linker, J.O. Langbein, A. McGarr, and L.E. Slater, Time dependent strain accumulation across the San Andreas fault near Palmdale, California: Results from two-color laser ranging and leveling, Trans. American Geophysical Union, Vol. 63 (18), May 1982.

Consolidated Digital Recording and Analysis

9930-03412

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Investigations

1. Development and operation of an automated system for detection and analysis of local earthquakes continues. A DEC PDP 11/34 computer is used for online, realtime detection of local earthquakes within a 141-station subnetwork of the Central California Earthquake Network. A DEC PDP 11/44 computer is used to process and archive the detected events. Both computers use the DEC RSX11M operating system. The detection and analysis software was written by Carl Johnson in Pasadena.

2. Data generated by the above systems are transferred to the UNIX 11/70 computer, and are processed to put them in a format suitable for comparison with, the eventual integration into, the Calnet routine timing and processing operation.

Results

1. The 11/44 seismic trace analysis and archiving system was installed and brought into operation, along with the 11/34 realtime earthquake detection system. On August 20, 1982 we went into an "operational" mode, the object being to remain in routine, daily operation, or to identify those factors that prevent us from becoming operational. We are using a 141-station array confined mostly to the southern third of the Calnet array, but with stations from Lassen and Shasta also included. About 5-8 local events are timed and archived each day, on the average.

2. Programs have just been written, and procedures established, to transfer the processed results from the 11/44 computer to the UNIX 11/70 computer. Phase card data area routinely made available to the Calnet project. Comparison studies between the two processing methods are underway. Results are not yet available.

3. A few hardware/software changes have been made, particularly to the realtime detection system, either to increase the data thru-put rate of the system, or to increase the reliability of

maintaining an absolute time base, tied to WWVB. For example, a faster digitizer, faster memory, faster tape drive, cache memory, and a more reliable DMA interface to the digitizer were all added. Also, a parallel IRIG-E time code is now read once every minute by the realtime system, and is used as the basis for maintaining absolute time.

Reports

None.

"Crustal Deformation Observatory, Part B: Precision Geodesy"

Contract No. 14-08-0001-19292

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Investigations

To establish and monitor geodetic networks at Pinyon Flat and Dalton Canyon as a complement and control for investigations of tilt and strain other investigators are doing by means of electro-optical and fluid systems.

The network at Pinyon Flat is a quadrilateral-shaped array of 70 permanent benchmarks 2583 m long. The benchmarks are no more than 40 m apart and all consist of coupled steel rods driven to refusal, each capped by a stainless steel nipple. Red steel fence posts are witness posts, and each instrument point is marked by a boulder or concrete block.

The network in Dalton Canyon is an irregular-shaped leveling array consisting of 35 permanent benchmarks in a line 309 m long. All monuments are similar to those at Pinyon Flat. The array was surveyed initially in spring 1981 to First Order, First Class precision.

Results

The Pinyon Flat array is scheduled for resurveys during the summer and fall, 1982. The array in Dalton Canyon array was resurveyed in May 1982 with no significant height changes of tilt having been observed. Two more resurveys are scheduled.

Nearfield Geodetic Investigations of Crustal Movements
Southern California

14-08-0001-19226

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Investigations

To monitor and document the following physical phenomena in central and southern California:

1) the regional pattern and timing of nearfield crustal tilt, if any, and

2) the nature of strain accumulation and release, if any, across well defined active and potentially active faults, chiefly by means of precise leveling of short arrays of permanent benchmarks across faults.

Results

Releveling of two arrays show interesting tilt and height changes: 1) the array across the Punchbowl fault near Palmdale has tilted back and forth over the last five years in concert with long-term oscillations of other geophysical phenomena measured by other investigations; and 2) benchmarks in the San Jacinto fault zone near Anza rose 1/2 mm in one month relative to benchmarks outside the fault zone.

EARTHQUAKE HAZARD RESEARCH IN THE GREATER LOS ANGELES BASIN AND ITS OFFSHORE AREA

14-08-0001-19261

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SUMMARY

Relative Pn travel-time residuals for elevation-corrected stations in southern California were obtained from 8 regional events using hypothetical mantle velocities of 7.8 and 8.3 km/sec. Contour maps of these residuals show the Pn apparent velocity in certain areas to be dependent upon source azimuth. Although apparent velocities vary from slower than 7.8 to faster than 8.3 km/sec, a true Moho velocity of 7.8 km/sec seems to exist in general. A slightly slower Moho velocity, however, may apply between the Elsinore and San Jacinto faults.

Deviations from a 7.8 km/sec apparent velocity are explainable in terms of either Moho topography or crustal velocity irregularities. Fast crustal velocities appear to exist in the western Santa Monica Mountains and in the Perris Plains area. The Imperial Valley region is marked not only by a general crustal thinning, but also by a fairly abrupt shallowing of the mantle beneath the southern half of the Salton Sea. The Moho in the eastern Mojave Desert east of the San Bernardino Mountains, however, appears arched like a broad ridge with a north-northwest to north-northeast trending crest. In the San Bernardino Mountains area, evidence for a 3 to 8 km crustal "root" suggests that this region is isostatically compensated. In contrast, there does not seem to be crustal thickening under the western Transverse Ranges.

The previously proposed existence of an 8.3 km/sec refractor at 40 km depth below the Transverse Ranges is not apparent under the western Transverse Ranges. However, it is possible that a locally shallow medium of unknown high velocity does exist below the Moho in the San Bernardino Mountains area.

These results neither confirm nor negate earlier explanations for the southern California tectonic regime. Nevertheless, the usefulness of travel-time residual contour plots in an area as complicated as southern California lies in their ability to depict local velocity anomalies against a background of regional velocity trends.

Reference: Lamanuzzi, Victor Dan, 1981, Relative Pn Travel-Time Residuals for Stations in southern California, M.S. Thesis, University of Southern California, 117 pp.

Geodetic Modeling and Monitoring

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 study of the mechanical implicatons of an observed longterm temporal decline in shear strain rate on the two locked segments of the San Andreas fault.

2. An analysis of all available geodetic data relevant to the earthquake deformation cycle at the Nankai Trough, a convergent plate boundary in S.W. Japan, and an assessment of its implications for the mechanics of strain accumulation and the estimation of earthquake recurrence intervals.

3. Analysis of geodetic and seismic data relevant to the 1979 Homestead Valley, California earthquakes and their aftershock sequence.

Results

1. Two contrasting models of the earthquake deformation cycle on strike-slip faults predict significant temporal declines in shear strain rate near the fault, accompanied by a progressive broadening of the zone of deformation adjacent to it. In the thin lithosphere model, transient deformation results from flow in the asthenosphere due to stress relaxation following faulting through most or all of the lithosphere. For an earth model with a thick elastic lithosphere (depth of seismic slip   plate thickness), transient motions are due to postearthquake aseismic slip below the coseismic fault plane. Data from the San Andreas fault indicate a long-term temporal decrease in strain rate that persists for at least 30 years and may extend through the entire earthquake cycle. Observations support a cycle-long rate decrease and a temporal spreading of the deformation profile only if movement cycles on the northern and southern locked sections of the fault are basically similar. If so, the lower strain rates and broader deformation zone observed on the southern San Andreas represent a later evolutionary stage of the nothern locked section, where a great earthquake is a more recent occurrence. Although the data allow some extreme models to be discarded, no sufficiently strong constraints exist to decide between the thin or thick lithosphere models. Regardless of the appropriate model, however,

the geodetic observations themselves indicate that strain buildup is sufficiently nonlinear to cause significant departures from recurrence estimates based on linear strain accumulation and the time-predictable model.(W. Thatcher)

2. Geodetic measurements made landward of the Nankai Trough, site of great subduction zone thrust earthquakes in 1854 and 1946, provide a uniquely detailed picture of the strain buildup process, supply constraints on the mechanism of strain accumulation, and allow for improved estimates of earthquake recurrence. Provided the two most recent movement cycles are similar, the observations, dating from about 1890, may be used to reconstruct a single complete deformation cycle (coseismic strain release, postseismic transients, interseismic strain accumulation). Very complete leveling and tidal gage data indicate that postseismic deformation extends more than 300 km inland from the plate boundary, persists for at least 30 years, and shows a clear tendency to become longer wavelength with increasing time. The transient movements have two timescales. The first, of about a year or less, corresponds to deformation, largely uplift, concentrated close to the coseismic fault, and is most easily explained by aseismic slip or very localized deformation downdip of the earthquake rupture plane. The second, longer, timescale is associated with a diffusion-like spread of the deformation further landward, an effect qualitatively similar to that first predicted by Elsasser to be an expected consequence of faulting in an elastic plate overlying a viscoelastic asthenosphere. Cumulative uplift since 1890 correlates well with the distribution of uplifted marine terraces, although average post-1890 tilt rates exceed late Quaternary and Holocene averages by at lest factor of three. Because of the nonlinearity of strain buildup and the significant permanent deformation, simple recurrence calculations typically overestimate the true interval between great earthquakes by a factor of two to a factor of three. Strict application of the time-predictable model, assumed correct, overcomes some, but not all of these difficulties.(W. Thatcher)

3. Geodetic observations constrain the coseismic faulting parameters of the 1979 Homestead Valley earthquakes, which in turn can be used to compute the effective shear stress changes (shear stress change + 0.75 fault opening normal stress change) in the surrounding region. Results show that off-fault aftershocks tend to be concentrated in regions whose effective shear stresses have increased by ~3 bars and are relativewly sparsely distributed elsewhere (See Figure 1) (R.S. Stein and M. Lisowski).

Reports

Jachens, R.C., W. Thatcher, C.W. Roberts, and R.S. Stein, 1982, Correlation of changes in gravity, elevation, and strain in southern California, Science, in press.

Stein, R.S., W. Thatcher, W.E. Strange, S.R. Holdahl, and C.T. Whalen, 1982, Field test for refraction in leveling, Southern California, EOS, 63, in press.

Stein, R.S., and M. Lisowski, 1982, The 1979 Homestead Valley earthquake sequence, California: Control of aftershocks and postseismic deformation, J. Geophys. Res., submitted.

Stein, R.S., and M. Lisowski, 1982, Post earthquake stress changes control off-fault aftershocks and ground rupture for the 1977 M_s = 5.6 Homestead Valley., CA, earthquake, AGU Chapman Confr. Abs., Snowbird, UT.

McTigue, D.F., and R.S. Stein, 1982, Topographic localization of surface displacements; a model test, EOS, 63, in press.

Stein, R.S., 1982, Comment on "The impact of refraction correction on leveling interpretations in southern California", by William E. Strange, J. Geophys. Res., in press.

Thatcher, W., 1982, Seismic triggering and earthquake prediction, Nature, 299, 12-13.

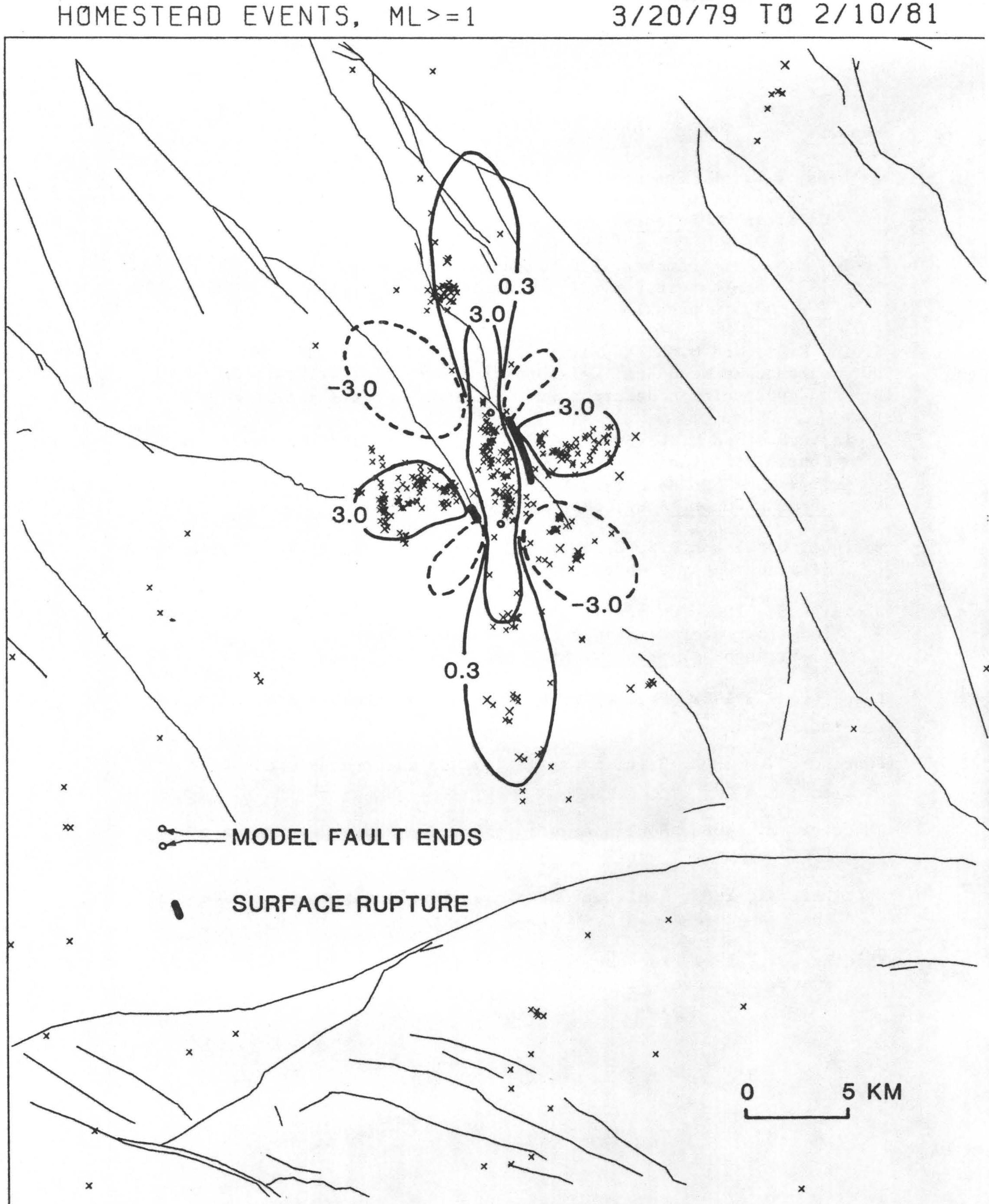
Thatcher, W., 1982, Seismic triggering and earthquake prediction, EOS, 63, 463.

Thatcher, W., 1982, Nonlinear strain buildup and the earthquake cycle on the San Andreas fault, J. Geophys. Res., submitted.

Thatcher, W., 1982, Nonlinear strain buildup and the earthquake cycle on the San Andreas fault, EOS, 63, in press.

Thatcher, W., 1982, The earthquake deformation cycle on the Nankai Trough, Southwest Japan, J. Geophys. Res., submitted.

P1



HØMESTEAD EVENTS, ML>=1
3/20/79 TØ 2/10/81
0.3
3.0
-3.0
3.0
3.0
-3.0
0.3
MODEL FAULT ENDS
SURFACE RUPTURE
0
5 KM
POSTEARTHQUAKE STRESS CHANGES CAUSED BY FAULT SLIP (BARS)

Data Processing Center Operations

9970-01499

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Investigations

This project has the 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 magnetic 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 U.S.G.S. telemetered seismic network event library tape dubbing facility (for California, Alaska, Hawaii, and Oregon).
4. Projection of usage of critical supplies, replacement parts, etc., maintenance of accurate inventories of supplies and parts on hand, uninterrupted operation of the Data Processing Center.

Results

Procedures and staff for fulfilling assigned responsibilities have been developed, and the Data Processing Center is operating smoothly and serving a large variety of sceintific user projects. 5-day recorder tapes can now be digitized under control of the Eclipse computer.

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. "Cassette" seismic refraction trucks.
d. 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

Seismic Refraction. Five seismic refraction experiments were carried out from June through September. The first experiment consisted of 2 reversed and 1 unreversed profiles in the northern part of the San Joaquin Valley. A total of 8 shots were fored at 7 shotpoints. The second experiment consisted of a reversed line running from Delano, California to San Luis Obispo, California. This experiment consisted of 8 shots at 7 different locations along the line. The third experiment was conducted in the Lee Vining-Mammoth Lake area. It consisted of 2 reversed profiles; one running between Lee Vining and Mammoth Lake and the other from June Lake to a point 30 miles East. Shots were fired at 6 shotpoints on the North - South line and 5 shotpoints on the East - West line.

The fourth experiment was carried out near Medicine Lake in Northern California. A total of 11 shots were fired at 9 different shotpoints. The last experiment was conducted near Mt. Lassen California and consisted of 3 shots along a northwest - southeast line across Mt. Lassen.

Telemetry Networks. A ten station network was installed northwest of Redding California to measure seismic activity around Shasta Lake for the Bureau of Reclamation. The seismic network in Oregon has been modified so that the data from the northern part of the net is transmitted to the University of Washington in Seattle.

Portable Networks. Fifteen 5-day recorders were operated in West-central Nevada from March through June and in Southern Oregon from July through October.

Central American Studies

9930-01163

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Investigations

1. Compilation of the Catalog of Historical Earthquakes in Central America is continuing and is probably now as complete as the records permit for Guatemala. The goal of this work is to estimate locations and magnitudes of damaging historical earthquakes in Central America and to determine recurrence intervals, identify active faults, and determine seismic risk.

2. Seismograph records were obtained from 20 local high-gain stations in Central America to study the Ms 7.0 earthquake of June 19, 1982. The epicenter of this earthquake lies at the NW edge of the El Salvador seismic gap.

Results

1. Damage caused by subduction zone earthquakes in Guatemala and adjacent areas have been mapped for over 30 large or great earthquakes since 1700. We are studying the reliability of these damage areas as indicative of the main event rupture zone and we believe it is comparable or better than the technique of using the aftershock zone determined from teleseismic data.

   A significant result is that the entire subduction zone from SE Chiapas, Mexico to central El Salvador appears to have ruptured 3 to 4 times since 1700. A significant exception is an area around Puerto San Jose, Guatemala that has not ruptured for over 120 years and looks to be an excellent candidate for an earthquake of M 7 3/4 to 8 before the end of this century.

2. The epicenter of the Ms 7.0 June 19, 1982 earthquake lies at the northern edge of the recognized El Salvador (or Fonseca) seismic gap. A well-constrained normal mechanism has been determined. Local stations virtually directly above the epicenter give depth estimates of 60 km while teleseismically determined depth estimates are 60 km from P_n - P, and 83 for P only free solution. A very good intensity map has also been obtained for this earthquake showing good spatial overlap with the aftershock zone determined from local data.

Reports

White, R. A., 1982, Studies of Historical Earthquakes in Central America: Proceedings of the Regional Workshop of the IASPEI/UNESCO Working Group on Historical Seismograms, p. 98-115.

Harlow, D., Rial, J. A., and McNally, K. C., 1982, The June 19, 1982 Earthquake near El Salvador: A double event double mechanism earthquake: (abs.): EOS Transactions, vol. 63, p. 1040.

White, R. A., 1982, The earthquake cycle: evidence from strike-slip and subduction zones of Guatemala: AGU Chapman Conference on Fault Behavior and the Earthquake Process.

COOPERATIVE EARTHQUAKE PREDICTION RESEARCH WITH INSTITUTE OF GEOPHYSICS, SSB, PRC

14-08-000-19141

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Investigations

1. Augmentation of the Beijing-Tianjin-Tangshan (BTT) telemetered seismic network to lower event-detection threshold and improve the data acquisition system.

2. Seismicity and tectonics of the Beijing-Tianjin-Tangshan area.

3. Analysis of strain, water well and other data before and after the Tangshan earthquake.

Results

1. At the end of May, 1982, a total of about 30 stations are in service, with an increase of 10 over the last two years. About 20 more stations, many of them bore-hole installations, are expected to be in operation by the end of 1982. Eventually a total of 66 stations (100 or so components altogether) will be telemetered to the recording center in Beijing, where a PDP 11/44 based data acquisition system will be located.

2. Aftershock monitoring in the Tangshan seismic zone has verified the existence of a normal fault in the area where the largest aftershock (M=7.1) occurred. This NW oriented fault and the strike-slip N40°E Tangshan fault form a mechanically consistent system.

3. Further analyses of short baseline geodetic data across faults at distances from 100 to 200 km away from the 1976 Tangshan earthquake epicenter shows that before the event there were clear changes at hard rock sites. For faults buried under thick sediments, surface measurements are noisy and difficult to interpret. Water wells in the Tianjin region about 100 km from the Tangshan epicenter indicate subtle changes more than a year before the earthquake. With some exceptions, water wells in the Beijing area did show clear changes around the time of the earthquake.

P1

Although no break-through has occurred, with a number of medium size ($5.5<M<6.5$) earthquakes taking place every year in China, several claimed successes in prediction seem plausible and deserve further study.

Crustal Deformation Observatory
Part D - Data Logging Facilities

14-08-0001-19762

Frank Wyatt and Jonathan Berger

Institute of Geophysics & Planetary Physics
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Under this contract support was provided to a group of investigators conducting a comparative study of crustal deformation instrumentation at Piñon Flat Observatory (PFO).

Accomplishments (June 1981 - October 1981)

1. Figure 1 shows a segment of the records from the Cambridge, Lamont-Doherty, and UC San Diego tiltmeters at PFO. As these records indicate, the instruments are now in generally good agreement. However, when the L-DGO tiltmeter was first installed last year there were several problems. During the year Roger Bilham and John Beavan modified the sensors for this tiltmeter so that we were able to begin reliable operation of the instrument in October of 1981.

2. Similarly, the Cambridge tiltmeter became operational in October, 1981. Although Tim Owen completed the fabrication of the instrument in July, electronic grounding problems prevented the signals from being properly recorded until they were recognized in October.

3. Two different types of borehole tiltmeters (at depths of 4.5 and 26 m) and the UCSD fluid tiltmeter (535 m in length) were operated throughout 1981. Records from these sensors were analyzed by Frank Wyatt, Gerry Cabaniss (Air Force Geophysics Laboratory), and Duncan Agnew, and were presented at the fall AGU meeting. Though they show no agreement at low frequencies, the tidal signals agree to within a few percent; suggesting that each of the transducers is capable of faithfully recording signals of the order of 10^{-7} radians.

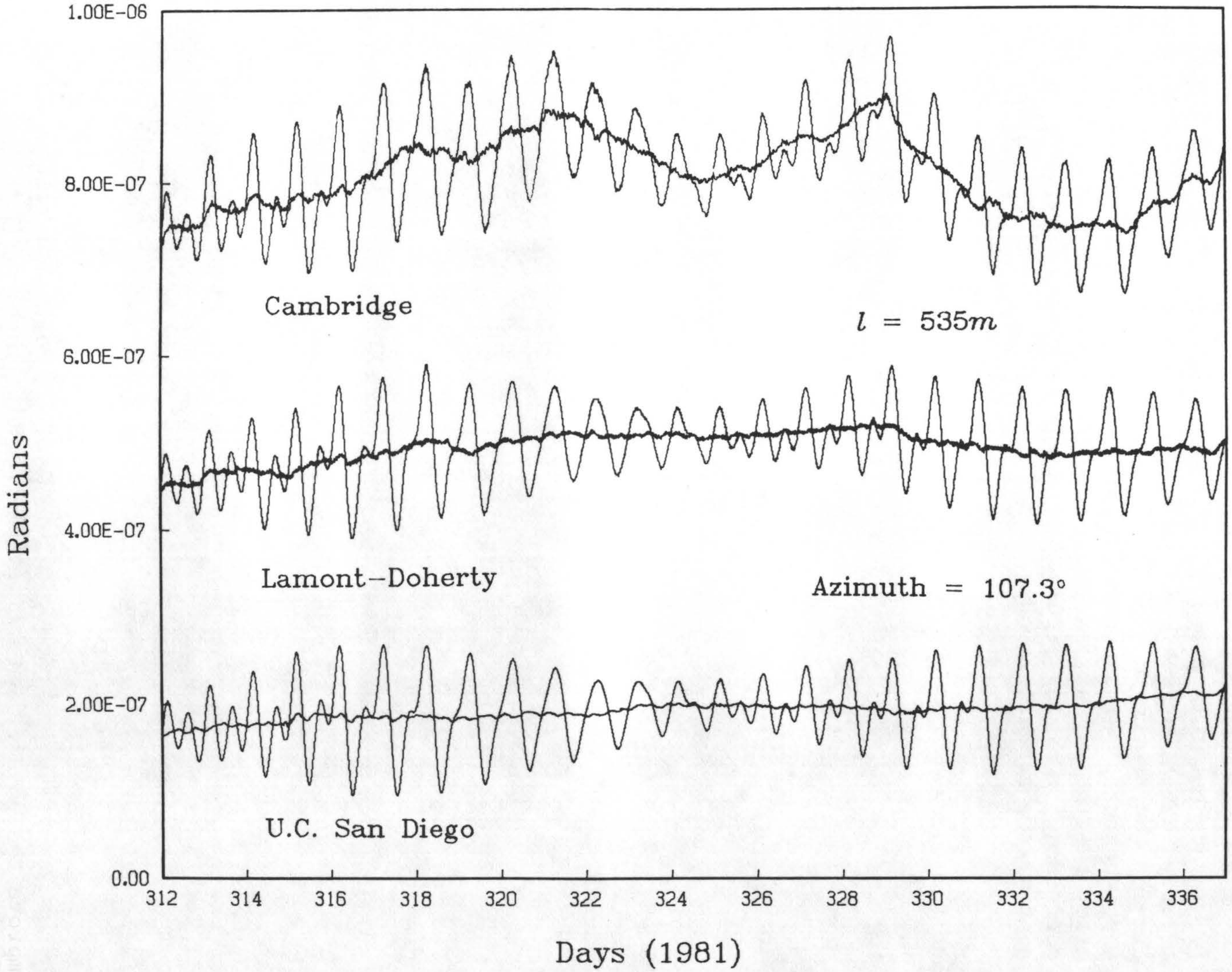
4. Under the supervision of UCSD personnel three deep (244 m) boreholes were drilled at PFO to be used by the Carnegie Institution of Washington for measurement of volumetric strain.

5. In July of 1981 Dave Jackson and Abe Cheng spent a week in our lab, familiarizing themselves with the IGPP data analysis programs. They intend to use this software on a VAX computer to compare the crustal deformation signals which we are now recording.

6. During this past summer Art Sylvester's surveying team measured the benchmark array at PFO for the seventh and eighth times. Not only can these results be compared to the tiltmeter records from the site but they can also be used to verify the stability of the different end monuments used in the long fluid tiltmeters.

7. Throughout this period we routinely monitored the quality of the data recorded by the cassette data loggers at the site. This preliminary examination of the records enabled us to fix instrument problems quickly and, when necessary, notify the investigators of potential problems. After the individual cassettes were examined, the observations were corrected for timing error, joined together, and forwarded to the appropriate research groups.

TILT OBSERVATIONS – *Piñon Flat Observatory*



Crustal Deformation Observatory
Part D - Data Logging Facilities

14-08-0001-19762

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Accomplishments

1. Three deep boreholes, intended for use by the Carnegie Institution of Washington, were completed at Piñon Flat Observatory in November, 1981. Shortly thereafter concrete pads and enclosures were built at the well head and wiring to our recording facility was completed. In February, 1982, these holes were measured for heat flow by Arthur Lachenbruch's group from the U.S. Geological Survey. In March, 1982, the borehole diameter, gamma ray, self-potential, resistivity and televiewer pictures were logged by Tom Urban, also of the U.S. Geological Survey. In April, the Carnegie strainmeters were installed under the direction of Alan Linde. Initial recordings show a large compressive signal from all three instruments, most likely due to expansion of the bonding cement.

2. The Lamont-Doherty and Cambridge tiltmeters both functioned well throughout this period, as maintenance procedures were sorted out. In November, a new vertical strainmeter transducer was installed at the westerly end of these instruments. This measurement, along with the associated measurement from the easterly end, will be used to determine the tilt at a depth of 25 m below the surface of the ground.

3. Abe Cheng, from UCLA, visited our lab in January, 1982, for additional training in the use of our data editing and analysis programs. The records prepared at that time were presented by Dave Jackson at the Spring AGU meeting.

4. Although not part of the formal CDO program, Bruce Clark, of Leighton and Associates, installed two triaxial stressmeters at the site in March, 1982.

5. For another independent program, a building and monument were prepared for the absolute measurement of gravity by Mark Zumberge, of the National Bureau of Standards. The value obtained, $9.79284081 \pm 1.1 \times 10^{-7}$ m/sec^2, has been used by other investigators as a reference.

6. Late in April, the A.D. Little borehole tiltmeter provided by the Air Force Geophysics Laboratory was recovered from its borehole in order to improve the physical stability of the hole-lock.

Studies of the Seismic and Crustal Deformation Patterns of an Active Fault: Piñon Flat Observatory

14-08-0001-18398

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Goals

While the overall goals of this research effort are addressed towards increasing our understanding of the mechanics of faulting in southern California, the specific objectives of the program at Piñon Flat Observatory (PFO) are threefold:

1. To provide a location, facilities, and support for the development of geophysical instrumentation.

2. To establish the "ground truth" in the geophysical quantities which these instruments measure.

3. To monitor the state of the strain (including tilt) in the crustal rocks in the region of the observatory--an area of high seismic risk.

Status

Piñon Flat Observatory serves, in addition to our own needs, a growing community of researchers involved in measuring crustal deformations. At this time there are some 18 different groups operating equipment at the site. This contract supports most of the facilities at PFO (Item 1 above) and hence its benefits are shared by all of these groups. Our hope is that the observatory will continue to grow, as a sort of national laboratory, where research teams can come to develop and test geophysical instrumentation. Currently the physical plant consists of two laboratory trailers, many instrumentation vaults (∿15), seismic and environmental monitoring equipment, electrical power service, and over 35 km of signal wiring. This contract also supports essential technical personnel who assist in the installation and operation of the equipment and instrumentation, and maintain the digital data recorders.

Summary.

Records from the first six months operation of the Cambridge Tiltmeter at the Pinyon Flat Observatory show good agreement with other tiltmeters at the same site at Tidal periods but have conspicuous components in the period range of a few days to a week which are not present on the other instruments. This discrepancy is probably due to temperature changes occuring in the end vaults and the centre vault of the Cambridge tiltmeter. There is some correlation between the tilt and the temperature records, however,since errors in measured tilt are caused by temperature gradients within the instrument, and because there are few temperature sensors near critical parts of the tiltmeter, a high degree of correlation is not likely. The records suggest a long term drift of the order of 1 to 2 micro-radians per year. This level is comparable with that observed on the UCSD instrument and in that instrument it is attributed to settling of the end mounts. A longer data span is needed before the long term performance of the instrument can be assessed, and further insulation and temperature monitoring are necessary to study the intermediate period noise.

Cooperative Studies at Piñon Flat Observatory

Investigator	Affiliation	Program
	Independent Investigations	
D. Agnew	U.C. San Diego	IDA Global Seismic Network
R. Allenby	NASA	VLBI/ARIES
J. Berger	U.C. San Diego	ANZA Seismic Array
B. Clark	Leighton & Associates	Borehole stressmeters
J. Goodkind	U.C. San Diego	Superconducting gravimeter
J. Healy	U.S. Geological Survey	Borehole logging
L. Hothem	NGS	Satellite Doppler Survey
J. Melvin M. Shapiro	California Institute of Technology	Borehole radon measurements
D. Moyle	U.S. Geological Survey/WRD	Water well recording
A. Lachenbruch	U.S. Geological Survey	Heat flow measurements
J. Orcutt	U.C. San Diego	Seismometer testing
P. Pammel	DMA - Geodetic Survey	Survey gravity meter
F. Wyatt	U.C. San Diego	Long baseline tiltmeter Long baseline strainmeters Laser optical anchors Shallow borehole tiltmeters
M. Zumberge	NBS/JILA	Absolute gravity meter
	Crustal Deformation Observatory Project	
R. Bilham J. Beavan	Lamont-Doherty Geological Observatory	Long baseline tiltmeter Benchmark stability
G. Cabaniss	A.F. Geophysics Laboratory	Borehole tiltmeter
D. Jackson	U.C. Los Angeles	Data analysis and distribution
T. Owen	Cambridge University	Long baseline tiltmeter
S. Sacks A. Linde	Carnegie Institution	Borehole strainmeters
L. Slater	CIRES	Long baseline tiltmeter Benchmark stability
A. Sylvester	U.C. Santa Barbara	Precision levelling
F. Wyatt	U.C. San Diego	Coordination of experimental research, field support, data collection, environmental monitoring, preliminary data analysis

Earthquake Prediction Based on Seismicity Patterns

Contract Number 14-08-0001-19757

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CIRES
Univ. of Colo./NOAA
Boulder, Colo. 80309

Our work on seismicity patterns during the last year has advanced on three fronts. We have further increased our understanding of the teleseismic seismicty data set using quantitative techniques for recognizing detection changes. We have found several possible precursors to great earthquakes of the last several years. Finally, we have begun the development of quantitative techniques for describing spatial variations in background seismicity. These techniques show great promise for asperity recognition in subduction zones.

Teleseismic Detection.

We have done detailed studies of changes in teleseismic detection in the Aleutians and in South America. The reporting of events in these regions has been strongly affected by the installation of local or regional networks. The Amchitka network operated in the Aleutians from the late 1960's until April 1973. Reporting by this network delayed the occurrence of the major world wide detection decrease in the late 1960's (related to the closure of the VELA arrays) until 1973, when the network was closed. The installation of a regional network in Venezuela during the mid-1970's resulted in a sharp increase in the number of events reported in the South American subduction zone with no m_b's. Ironically, the number of events reported with small m_b's (≤ 4.6) decreased at this time, contrary to the expected effect.

Both of these cases demonstrate the complexity of both spatial and temporal detection changes which the interaction of local, regional and teleseismic reporting can cause. They underline the importance of a complete understanding of man-made changes in any study of seismicity patterns.

Precursors.

We have discovered two possible precursors during the last year. The first is a simple quiescence type precursor to the 1971 Valparaiso, Chile event (M_s=7.5). The quiescent period lasted from November 1967 until the time of the mainshock (July 1971) and the quiescent zone was somewhat larger than the rupture zone (like in the Oaxaca 1978 case). We believe that this quiescence ranks with the Oaxaca case as the two clearest cases of teleseismically recognized precursory quiescence.

The second precursory pattern is perhaps the most complex documented to date. It occurred prior to the July 1980 events in the northern New Hebrides (M_s= 7.8, 8.0). The precursor to these events included prolonged periods of quiescence and apparent activation of the rupture zones by a high stress drop (~300 bars) in a central asperity. The asperity showed the following characteristics: rupture stopping during 1966, high background seismicity, clusters of moderate to large events, high stress drops relative to the surrounding region, and initiation of the great events during 1980. The observation of high stress drops in this asperity is the first direct evidence of stress inhomogeneity in the rupture zones of upcoming earthquakes from teleseismic data.

Asperity Recognition.

The asperity characteristics mentioned above for the 1980 case and several others (clusters of aftershocks and transverse features) have been combined into a preliminary technique for recognizing asperities in subduction zones. A major feature of our approach to this problem is a quantitative algorithm for recognizing segments of plate boundaries with anomalously high or low levels of background seismicity. This technique has been applied to the New Hebrides and several regions with many possible asperity characteristics have been recognized. The relationships of these asperities to great earthquakes and the role of the asperities in the precursory process are just beginning to be examined.

Further Reading.

Papers which have appeared recently:

Consistency of Teleseismic Reporting Since 1963; R.E. Habermann, Bull. Seis. Soc. Amer., 72, 93-111, 1982.

Seismicity Rates in the Kuriles Island Arc, 1963-1979; R.E. Habermann, Earthquake Prediction Research, 1, 73-94, 1982.

Conversion of m_b to M_s for Estimating the Recurrence Time of Large Earthquakes; M. Wyss and R.E. Habermann, Bull. Seis. Soc. Amer., 72, 1651-1662, 1982.

Papers in press:

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REAL TIME MONITORING OF RADON AS AN EARTHQUAKE PRECURSOR IN ICELAND

Contract #14-08-0001-19774

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354-1-21340

Investigations

We report radon data collected during May 1981 to April 1982 from geothermal wells and fumaroles in Iceland. Discrete radon samples are being collected weekly from seven stations in the Southern Iceland Seismic Zone (SISZ) and two stations in the Northern Iceland-Tjörnes Fracture Zone (TFZ) to determine the potential for earthquake prediction. One continuous radon meter is operated at one of the radon stations in the SISZ. 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. At the presently active Krafla caldera volcano we monitor radon in fumarole gas to study changes in radon emission associated with periodic uplift and subsidence of the caldera floor.

Results

No earthquakes exceeding M_L 2.6 were recorded in the SISZ during the report period. Tectonic activity was greater in the TFZ but most earthquakes occurred off shore at 60-80 km distance from the radon stations. No distinct correlation of radon anomalies with earthquakes was found during this period.

The drastic increase in radon concentration in fumarole gas observed at the Krafla volcano during 1981, culminated in November at values about four times the average level of the period 1978-1980. Then a fissure eruption broke out with one of the craters only 200 meters distant from the sampling site. It is suggested that the increase in radon emission was caused by a magma intrusion near the sampling site.

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INVESTIGATION OF RADON AND HELIUM AS POSSIBLE FLUID-PHASE PRECURSORS TO EARTHQUAKES

14-08-0001-19227

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This report presents new data on radon, helium, temperature, and conductivity in thermal wells and springs along our Southern California network for the period October 1981 to March 1982. Several less important sites have been removed from the network since October 1981 in order to increase the sampling frequency at some sites which appear to be more responsive to local seismic events.

No major earthquakes occurred in our network region within the last six months. The largest tremor, M=4.5, occurred between the Elsinore and San Jacinto faults near Borrego Springs (33°04'N, 116°13'W) at 12:53 AM (local time) on March 22, 1982. This quake was followed by a series of aftershocks, two of which had magnitude greater than 3. Along the San Jacinto fault, there were many small seismic events during the present report period, seven of which had magnitude greater than 3. No clear precursory effects were observed at nearby network sites except for the conductivity at Robison's Well, which shows a systematic decrease from the June 1981 peak. Along the San Andreas fault to the east of the Salton Sea, seismic activities have been quite low for the past six months. However, both radon and helium at Hot Mineral Well decreased to a minimum in December 1981, and have been increasing since February 1982. If this increase continues, it may be a significant precursory phenomenon.

At Hot Mineral Well, the radon level shows at least 20 to 30% higher than the baseline during the period between February 1980 and October 1981 except for two brief drops. The first drop occurred immediately after the M=6.1 Imperial earthquake on June 9, 1980. The second drop to a minimum in March 1981 was accompanied by a similar drop in helium, and was followed by the Westmorland earthquake (M=5.6) in the Imperial Valley on April 26, 1981. The temperature at this site increased systematically from 1978 to 1980 and reached a maximum during the summer of 1980 after the Imperial earthquake. It then began to decrease continually to a minimum right before the Westmorland earthquake occurred. Since then the temperature has been fluctuating substantially. The variation pattern of temperature during 1981 and 1982 is clearly different from that before 1981.

At the Niland Slab Well, the radon maximum and the small helium maximum observed in early 1981 were perhaps related to the Westmorland earthquake. The conductivity at this site also shows a distinct maximum in early 1981. With a brief drop to the baseline in August 1981, the conductivity returned to the previous maximum level after November 1981.

Helium concentration at Robison's Well on the San Jacinto fault was constant during 1979 and 1980. However, a peak about 25% above the baseline was observed in June 1981. This peak is also correlated with a conductivity peak which shows a sharp increase from May to June and a gradual decrease toward the baseline during the last 9 months. This peak was considered to be precursory to the September 3 earthquakes (M=3.9, 3.8) which occurred near Julian. We learned later that there was a significant reduction in water consumption in June 1981. This might have caused the observed anomalies in helium and conductivity. Another earthquake of the same magnitude (M=3.9) occurred nearby on October 17, which was also preceded by the June helium and conductivity peak. There were no precursory anomalies observed at this or any other nearby sites prior to the March 22, 1982 earthquake swarm. Radon at this site has been fairly constant throughout the entire monitoring period. Because of the change in water consumption in June 1981, it is not clear whether the anomalies in helium and conductivity are really precursory to the seismic events. The temperature at this site also shows a distinct maximum during the summer of 1981.

We have observed that radon, helium, and other dissolved gases at Arrowhead Hot Springs increased simultaneously in May 1979 prior to the Big Bear earthquake in June 1979. These increases had lasted for about a year before returning to the baseline levels in April 1980. Plots of radon versus helium and helium versus nitrogen show a linear correlation, supporting a two-component mixing model. The radon-helium and helium-nitrogen relationships at other network sites are not so clearly defined for a lack of significant simultaneous anomalies such as those observed at Arrowhead. Consequently, the radon-helium and helium-nitrogen plots cluster generally in a confined area. Using baseline values, we have looked at the spatial variation of the radon-helium relationships in our network sites. In the Salton Sea area, Hot Mineral Well, Frink Spring and CO_2 Well are linearly correlated, showing higher radon with higher helium at Hot Mineral Well. However, Niland Slab Well and Arrowhead Springs show much higher helium at lower radon or an enrichment of helium. Other sites showing helium enrichment include Robison's Well and Murrieta Hot Springs. The low radon and helium values at CO_2 Well are clearly due to stripping effect of the bubbling CO_2 gas. Hot Mineral Well, CO_2 Well and Arrowhead Hot Springs occupy three apexes of a triangular distribution in the radon-helium plot.

Other activities during this report period include a preliminary study of suspended particulate matter in S. California groundwaters for earthquake prediction using a laser particle counter, development of a sampling and measuring technique for soil helium, and installation of film strips for C.Y. King of USGS at Menlo Park for his soil radon monitoring program.

INVESTIGATION OF RADON AND HELIUM AS POSSIBLE FLUID-PHASE PRECURSORS TO EARTHQUAKES

14-08-0001-19227

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This annual report presents our initial results on continuous radon monitoring with a CRM (Continuous Radon Monitor) at Arrowhead Hot Springs and 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, 1981 to September, 1982. During this period, three less ideal sites have been abandoned in order to carry out more frequent monitoring (biweekly) tasks at four sites which appear to be more responsive to local seismic events.

The CRM data at Arrowhead Springs show diurnal variations which are sometimes significantly different from date to date. Except for a distinct one-day spike on October 9, the mean radon increased continually by about 8% from October 1 to 18, 1982. No significant earthquakes occurred in the vicinity during this period.

During the first 8 months of this report period, our S. California network region went through a period of quiescence. There were very few seismic events which were greater than magnitude 3. The largest tremor, M = 4.5, occurred near Borrego Springs on March 22, 1982. However, the seismic activities have been increasing significantly in this region since June, 1982. There were many shocks with $M \geq 3$, which occurred mostly along the San Jacinto fault zone.

On June 15, 1982, a significant earthquake (M = 4.8) occurred near Anza, on the San Jacinto fault (33°34'N, 116°40'W, focal depth = 12 km). It was followed by a series of aftershocks, four of which had $M \geq 3$. Two of our adjacent monitoring sites displayed distinct anomalies which were apparently precursory to these seismic events. At the Indian Canyon Springs (INCA-1P), both radon and helium showed a significant drop (about 40% in radon, 20% in helium) to a minimum about 2 months prior to these earthquakes. At Murrieta Hot Springs (MURI-2P), both radon and helium dropped by more than 50% about a month prior to these events.

Another significant earthquake (M = 4.4) occurred at the southern end of the San Jacinto fault about 30 km to the west of Brawley in the Salton Sea area on September 5, 1982. On August 10, 1982, an earthquake (M = 3.6) took place at the northern end of the Imperial fault. Although it is located on the San Andreas fault zone, the Hot Mineral Well (HMIN-2W) displayed a distinct minimum in radon and methane in January, 1982 before reaching a maximum in July, 1982, which was followed by the August 10 event about a month later. At Robison's Well, helium and conductivity decreased by more than 20% to a minimum about 2 months before a series of M > 3 events which occurred nearby along the San Jacinto fault.

Other network sites which also displayed some precursory anomalies include Arrowhead Hot Springs (AROW-1P), Agua Caliente (ACAL-1S) and Niland Slab Well (NILA-2W). At AROW-1P, radon and helium variations are linearly correlated. Nitrogen and methane variations are also quite similar and are well correlated to radon and helium variations. These features can be explained by a two-component mixing model which was proposed previously by us.

DEEPWELL MONITORING ALONG THE SOUTHERN SAN ANDREAS FAULT

#14-08-0001-19760

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Investigations

U.S.G.S. funding has provided for the acquisition and refurbishment of a group of deep, abandoned, wildcat wells along the San Andreas fault between Gorman and San Bernardino. These wells have been instrumented with continuously recording high-precision water-level transducers and thermal sensors to monitor changes in groundwater characteristics which may be precursory to seismic slip. Data are recorded on digital cassettes and returned regularly to the laboratory for playback and analysis.

Results

Water levels from two representative wells in our Palmdale deep-well array are presented for the period January 1, 1982 to September 30, 1982. Barometric pressure and tidal induced fluctuations continue to be a major factor in short term water level variation. In the long term, all but the Fairmont well have shown a decrease in water level during the past several months, although changes in this trend are apparent during the Jan.-Sept. time frame.

Finally, a major "anomaly" beginning about March 11, corresponding to an increase in water level, is well developed on the Anaverde and Chief Paduke records (see Figures 1 and 2). A further rapid increase is observed to occur about March 17. We believe that the onset of the "anomaly" is due to a major change in barometric pressure accompanying the major seasonal storm which resulted in several inches of precipitation beginning on March 17. Water flow into the aquifers resulted in an elevation of the ambient water table. Decay toward equilibrium occurred subsequently. Interaction between downward percolation, hydraulic decay of the aquifer and changes in barometric pressure result in complex records. Coincidentally, a small "swarm" of M = 1.5-2.5 earthquakes bracket the "anomaly" time period. These are the only nearby seismic events to occur within the deep-well array during the period. Any water level effects of these events would be masked by the meteorologically induced changes.

ANAVERDE 1982

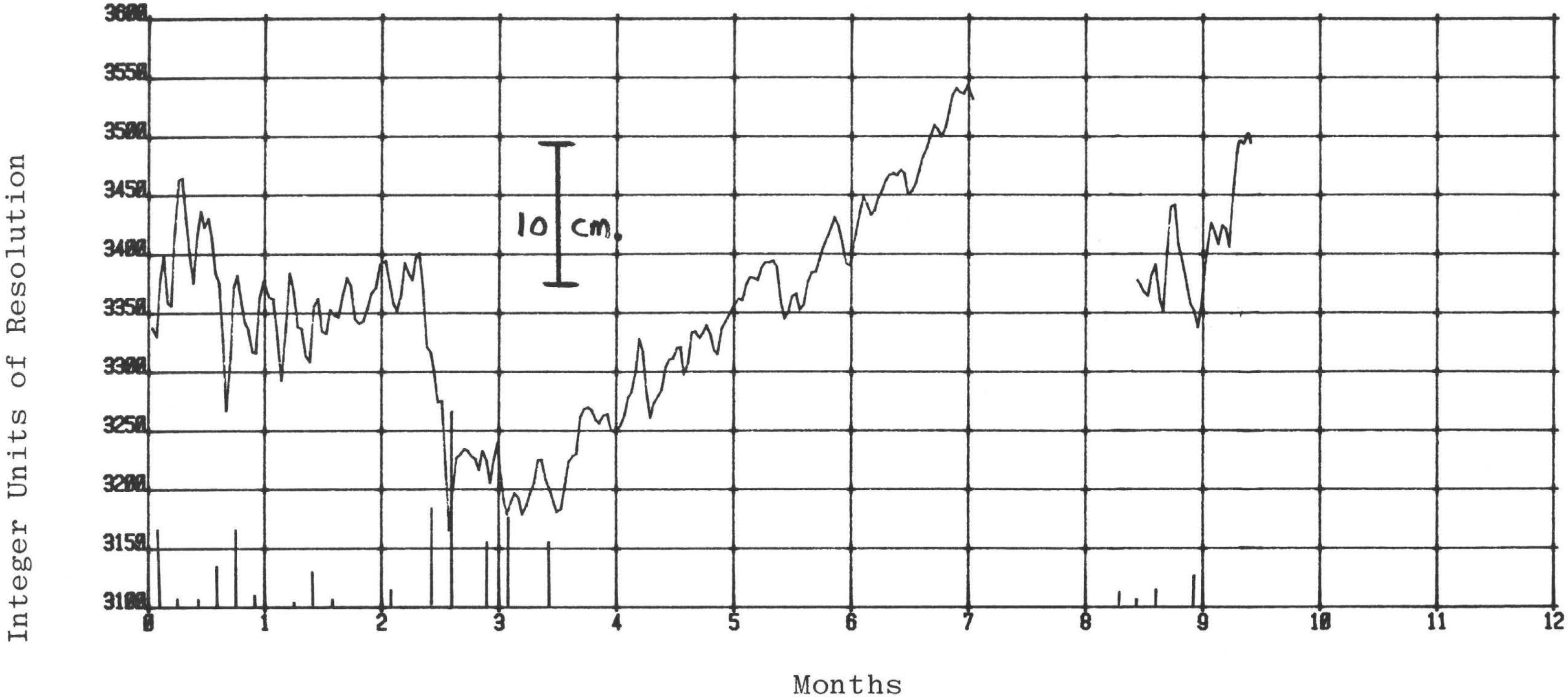

Figure 1. Water level for the Anaverde Well for January-September, 1982. Rainfall totals are shown by bars in five day sums. Higher water levels are down on the graph.

CHIEF PADUKE 1982

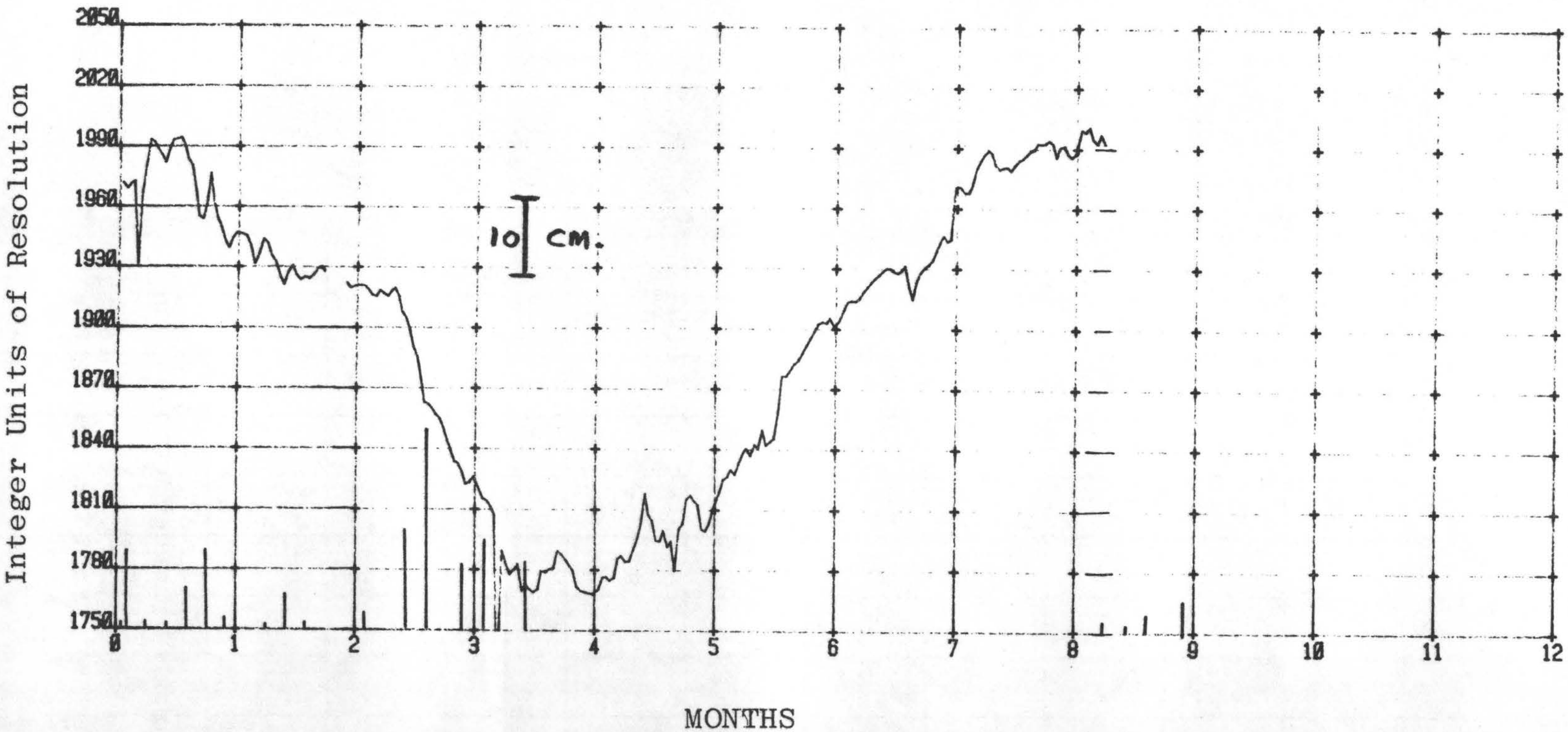

Figure 2. Water level for the Chief Paduke Well for January-September, 1982. Rainfall totals are shown by bars in five day sums. Higher water levels are down on the graph.

Low Frequency Data Network

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01 October 1982

9960-01189

Investigations

[1] Real-time monitoring, analysis, and interpretation of tilt, strain, magnetic, telluric, and other data within the San Andreas fault system and other areas for the purpose of understanding and anticipating crustal deformation and failure.

[2] Compilation and maintenance of long-term data sets free of telemetry-induced errors for each of the low frequency instruments in the network.

[3] Development and implementation of real-time algorithms for the purpose of detecting earthquake precursors in the low frequency data.

Results

[1] Data from low frequency instruments in both Southern and Central California have been collected and archived using the Low Frequency Data System. In the last year ten million measurements from 200 channels have been received and subsequently transmitted on the OES 11/70 UNIX computer.

[2] The Low Frequency Data System has been augmented to include an additional PDP 11/44 processor. This is machine is now in full operation and is making possible the consolidation of Low Frequency processing on to one integrated system.

[3] The data from the Network have been made available to investigators in real time. Data only minutes old can be plotted. Events such as creep events can be monitored while they are still in progress.

[4] The working prediction group of the Branch has made extensive use of the timely plots which are produced routinely by the System.

[5] Preliminary work is completed on a network connecting the UNIX PDP 11/70 with the Low Frequency System's PDP 11/44 processor. Files can be transfered quickly between the two machines.

[6] Historical data is being processed using a new algorithm in order to produce near-error-free daily records of each of the tilt and strain instruments for the past several years.

[7] Graphics on the UNIX system have been improved with the addition of a fast and easy to use program. This new software allows plotting of data in various forms including the System's special data base form as well as universal ascii data.

INTERPRETATION OF DATA
14-08-0001-19246

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Trilateration Data

We have explained the apparent dilatations observed by Savage *et al.* (1981) at Palmdale and Hollister. The apparent dilatations result, we believe, from a combination of two systematic errors: a 2.85% overcorrection for atmospheric refraction, and a -2.61 mm bias during the time period 1977.4 and 1979.4. We used a model of the form:

$$\Delta\bar{L}_j = a\Delta\bar{R}_j + b\Delta B_j \qquad (1)$$

where L is line length, averaged over the entire network for survey, j; R is the refraction correction, similarly averaged; and B is a unit step function equal to one for surveys during 1977.4 to 1979.4 and zero otherwise. Δ indicates a difference between survey j and the mean of all surveys. Figure 1 shows the results for ten Palmdale surveys. The statistical significance exceeds 98%. Procedural changes

PALMDALE: BOXCAR + REFRACTION
$R^2 = 0.89$

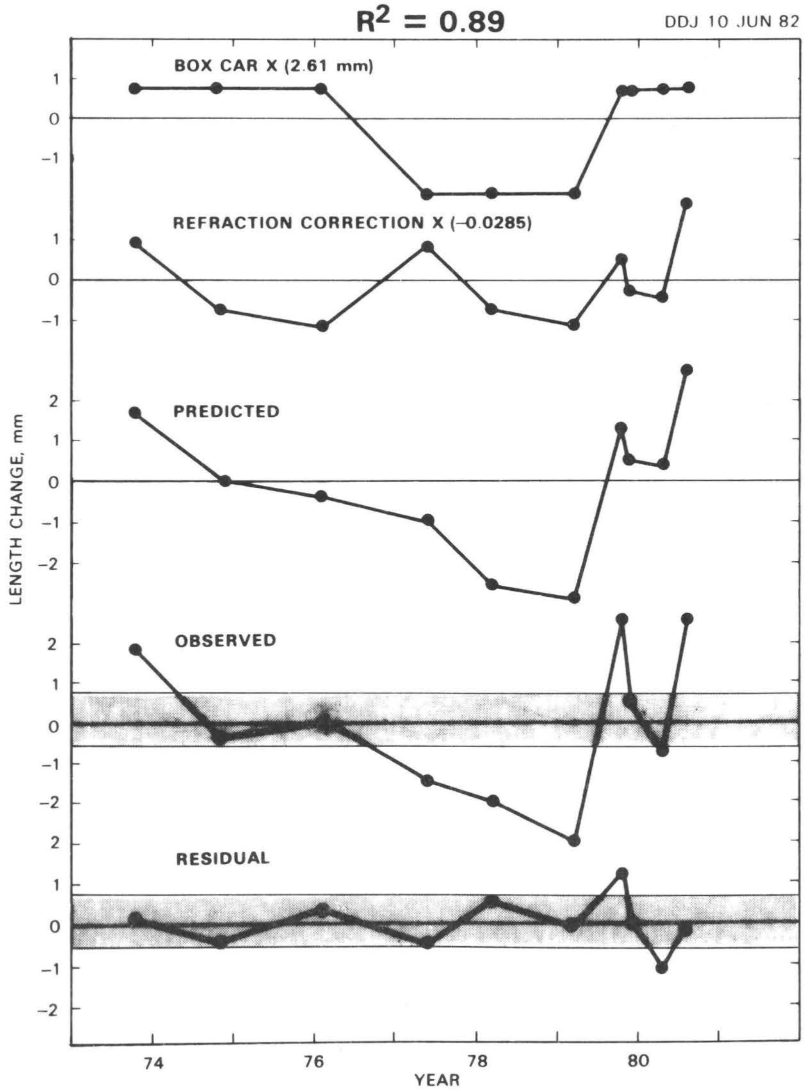

FIGURE 1

may explain the bias: the USGS Office of Earthquake Studies made the early measurements, the USGS Topographic Division made the measurements from 1977.4 to 1979.4, and a private contractor made the more recent measurements. We tried complex models involving uniform strains, including dilatations, as well as the systematic errors. The data cannot distinguish between true dilatations and systematic errors. However, the apparent dilatations are remarkably similar at Palmdale and Hollister, about 400 km apart; and neither is well explained by simple tectonic models.

Equation 1 did not fit the Hollister data as well as it did the Palmdale data. Earthquakes within the network in 1974 and 1979 caused length changes that are not represented by the model. We assumed that the systematic errors detected at Palmdale would also be present in the Hollister data, so we corrected the Hollister data using the Palmdale

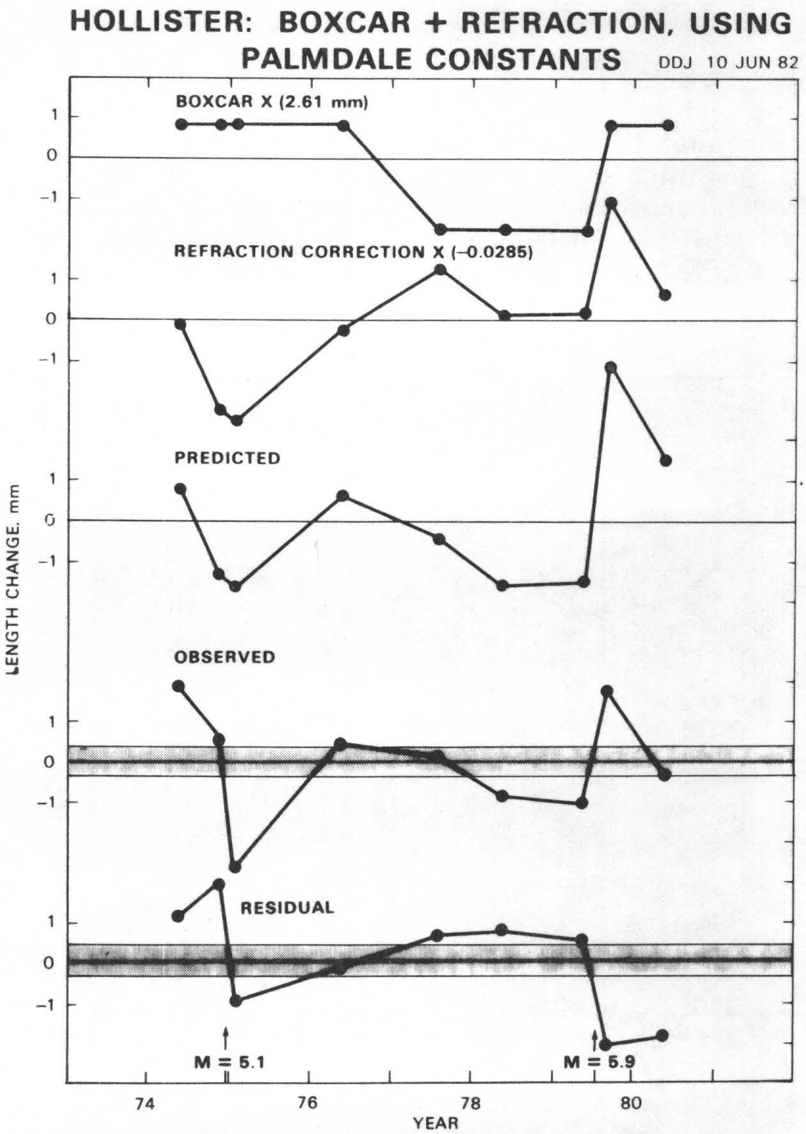

FIGURE 2

parameters. Figure 2 shows the result. Residuals show no significant change in average line length except for the 1974 and 1979 earthquakes.

We fit the Hollister data with a dislocation model, having different uniform displacement rates above and below an arbitrary depth on both the San Andreas and Calaveras faults. The data are best fit when the arbitrary depth is 2±1 km. The displacement rate below 2 km is 15 mm/yr on the San Andreas and 22 mm/yr on the Calaveras. Residuals to this model suggest that the fault segment that broke in 1979 was locked during the interval 1971-1979.

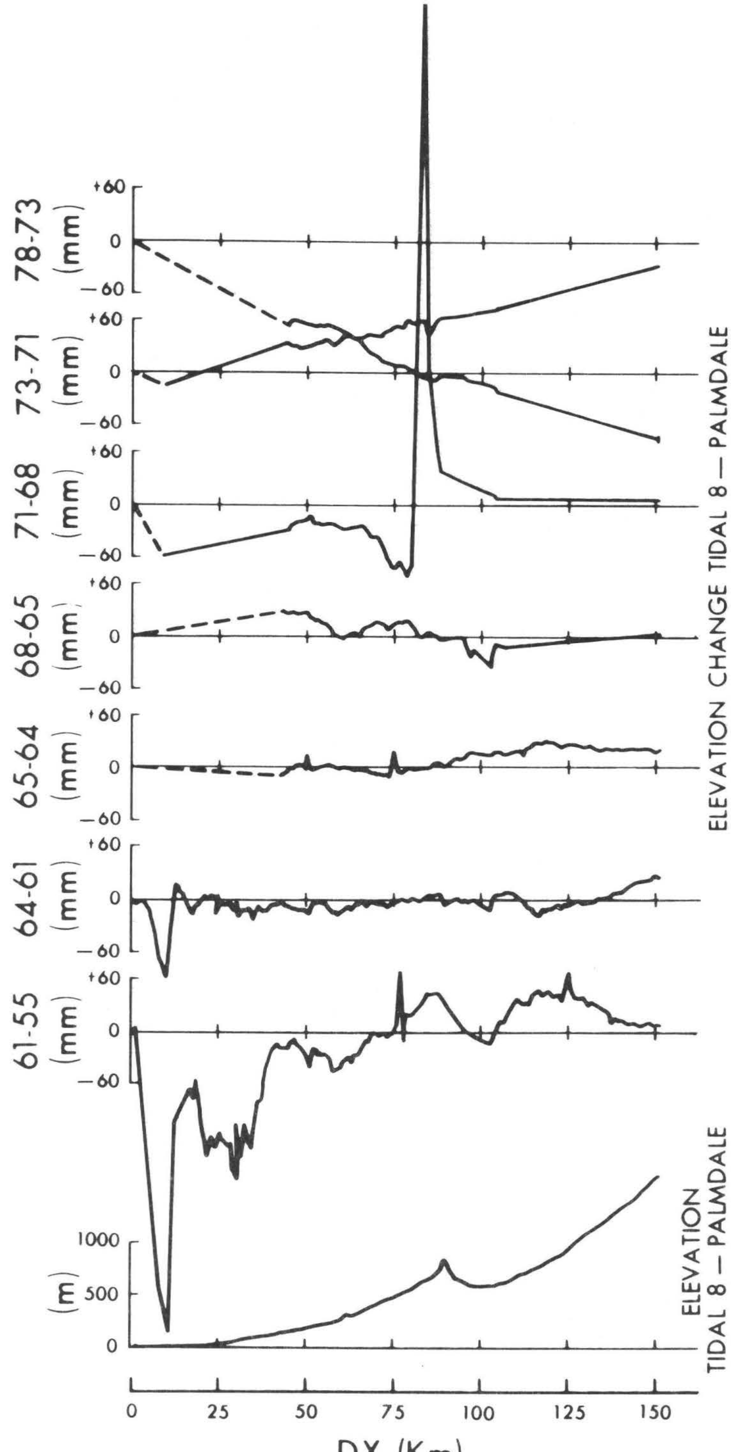

FIGURE 3

Leveling

We continue to analyze leveling data for Southern California. In addition to height-dependent errors as previously reported, we find evidence that local subsidence may cause significant errors. Subsidence errors can accumulate if junction-point benchmarks subside between survey segments. We found many examples where 10 mm of differential subsidence occurred within 10 km and within a few months. We also infer that Tidal 8, a commonly used reference benchmark, was subsiding during the period 1955-1965. Figure 3 shows elevation (bottom curve) and elevation changes during successive intervals for the profile Tidal 8-Saugus-Palmdale. Data for 1955, 1961, and 1964 were corrected for known height-dependent errors, including refraction and rod errors. Benchmarks at 90 km (on a ridge south of Saugus) and at 130 km (east of Saugus) appear relatively stable with respect to one another over the entire period. If either of these is taken as a reference, then the elevation changes between 1955 and 1965 can be interpreted as subsidence within the Los Angeles and Saugus basins. Subsidence was about 50 mm at Tidal 8, 60 mm at Saugus, and as much as 300 mm in some places. Equal but opposite slopes of the two top curves suggest an error in the 1973 survey. The San Fernando earthquake caused the large elevation changes in 1971.

Tilt, Strain, and Magnetic Measurements

9960-02114

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Investigations

Rapid changes in deformation parameters are expected before moderate to large earthquakes. We are attempting to develop a prediction capability from the analysis of continuously monitored tilt, strain and magnetic field perturbations that occur as a result of fault activity within the San Andreas fault system. Since our recent results show that crustal strain noise is about 100 times less at 200 m depth than at a 2 m depth strain measurement efforts have been primarily concentrated on deep-hole instruments. The state of mean crustal stress is monitored with arrays of absolute magnetometers.

Results

1. The first of four Carnegie dilatometers has been installed in the San Juan Bautista. The data are now digitally telemetered to Menlo Park. Thanks to the efforts of Dennis Styles, Jack Healy, Tom Urban and Mark Zoback, holes for five more instruments have been drilled in Parkfield and San Juan Bautista. Installation is planned for spring.

2. Measurements of regional magnetic field during gravity, strain and level surveys near the San Andreas fault at Cajon, Palmdale, and Tejon indicate transient anomalies which correlate with changes in gravity, strain and uplift. The preferred explanation appeals to short-term strain episodes independently detected in each data set. A common source of crustal noise provides an alternate explanation. Inferred sensitivities to strain, gravity and uplift are 0.90 nT/ppm, -0.06nT/μgal, and 9.1 nT/m, respectively.

3. Explanations of earthquake lights have failed to show how large charge densities can be concentrated and sustained in a conducting Earth. We have proposed a physical model based on frictional heating of the fault that solves this and related problems.

4. Magnetic fields were recorded at five sites on Mt. St. Helens over a 20 day period, which included a dome extrusion-eruption of the volcano. Two of the magnetometers located in the crater measured reversible

magnetic changes, which correspond to fluctuations in tilt measured nearby. However, the correlation is highly nonlinear. Electric fields were measured on the east flank of the volcano near its summit to search for electrokinetic effects. They show no correlation with the magnetic changes and in the long term are uncorrelated with eruptive activity. Our favoured interpretation of the magnetic changes is that they result from piezomagnetic changes in the the magnetization of the volcano induced by eruption stresses. Their reversibility rules out pressure induced magnetization as the dominant mechanism and places an upper limit of $\sigma \sim 300$ bars on the stresses. The limited spatial extent of the magnetic anomaly field places the source of stress at shallow depth beneath the crater floor consistent with models based on strain data.

5. Measurements of magnetic fields along the San Andreas fault indicate that inhomogeneous tidally generated current systems flow in and around the fault system. These currents limit measurements of short-term local fields of tectonomagnetic origin to about 0.3 nT but can be easily removed. Ocean tidal induction into a complex fault zone with higher than average electrical conductivity appears to be a more likely explanation than either piezomagnetic effects due to the solid earth tides or ionospheric tidal induction. The amplitudes of the induced diurnal harmonics decrease in a fairly linear manner to the southeast along the fault. This result is consistent with expectations from a hotter and more conducting crust and upper mantle in southern California, as indicated by heat flow data in this region.

6. Daily averages of magnetic difference fields, for the years 1974-1980, between 23 magnetometers on the San Andreas fault (between San Francisco and the Mexican border) have been analysed in order to isolate the geomagnetic variation that originates in the crust and to test if it is related to stress. Field changes due to non-uniform secular variation from currents in the core have been identified and removed. External currents in the ionosphere and magnetosphere induce changes in the difference fields due to contrasting impedances at magnetometer sites. These are identified and removed using methods of multichannel predictive filtering using Boulder magnetic observatory component fields as inputs to the prediction operator. The remaining fluctuations (up to several nT) are attributed to crustal magnetization changes. Evidence that these changes are stress related includes the variation prior to the Busch fault earthquake, 1974, seen at the two closest stations within 10 km of the epicenter. Also, stations within 50 km of the 1979 Coyote earthquake undergo localized change in fields up to a year prior to that event. If truly precursive, these variations are on a broader spatial and temporal scale than those for the Busch fault event. During the period 1975-1978, the geomagnetic variation is approximately uniform across the array, without the development of any significant anomalies. This period is nearly coincident with the 1975.7-1978.7 seismic lull in nearly all of California. It is followed by a marked increase in crustal secular variation. Long-range coherence between anomalous variation at different

stations is not seen, other than the variation before the Busch fault earthquake, suggesting that localized variations occurs on a scale of less than 10 km.

7. A linear regression of differnetial proton magnetometer measurements at distances from a few meters to 50 kilometers indicates a standard deviation of hourly means that varies with site separation as $\sigma = a + bd$ where $a = 0.07 \pm 0.02$ nT, $b = 0.01 \pm 0.003$ nT/km and d is the site separation in kilometers. At a few meters separation, at sites with low cultural noise in both seismically inactive and active regions, the standard deviation of hourly mean data ranges from 0.09 to 0.15 nT for instruments with 0.25 nT sensitivity and from 0.07 to 0.08 nT for instruments with 0.125 nT sensitivity. The least-count noise contributions are expected to be less than 0.10 nT and 0.05 nT, respectively. Instrument temperature sensitivity does not exceed 0.001 nT/°C over a range from -6° to 21°C. For typical site separations of 10 to 15 km throughout the San Andreas fault, estimates of σ for hourly mean data range from 0.15 to 0.3 nT depending on local magnetization characteristics. Spectral density estimates indicate difference field noise power increases with decreasing frequency at about 20 db/octave. Dominant spectral peaks occur at diurnal harmonics and at the tidal M_2 frequency. Geomagnetic difference-field noise limits measurement capability at all frequencies below about 2 c.p.h. Where instrument precision starts to limit detection capability, instruments of higher sensitivity may be useful if the noise spectrum can be reduced by predictive filterning techniques.

8. Sources of noise in surface and near surface measurements of earth srain are sometimes obvious - for instance extensometers and tiltmeters often show sensitivity to rainfall - but are not always easy to isolate. Here we discuss data from Sacks-Evertsen borehole strainmeters. Some noise sources which we have isolated are: Changes in aquifer flow resulting temperature changes in the rock $\varepsilon \sim 10^{-5}/°C$); chemical instability of the surrounding rock (clay minerals change volume with eater content); mechanical instability of the rock (motion on local fractures and joints. For an installation at Pinon Flat, temperature and drill log information shows that the drilling interconnected aquifers and the changes in water flow disturbed the thermal environment. A number of instruments were installed (1979) in Iceland in 10 year old holes. Most of these showed large strain changes during the first 1 1/2 years, after which the strain rate decreases. This is possibly due to the change in aquifer flows resulting from blocking the hole with the instrument. Several instruments in Japan sited in mudstone showed large compressive strain changes over a number of years. Borehole instruments in the Mojave are installed in fractured granite. These show short period (~1/2 hour) noise which is not coherent over a scale of a few kilometers. These signals appear to be due to local motion on one or more of these fractures.

Increased understanding of these noise signals is necessary for reliable interpretation of the data in terms of tectonic effects.

9. Our ability to measure magnetic changes related to earthquakes (seismomagnetic effects) can be improved if noise due to non-seismic sources is reduced or removed. Two new sources of noise, which tend to obscure short period changes (ranging from several seconds to several days), have been identified. Removal of this short period noise is important because the largest, most easily identified seismomagnetic effects are expected to occur coseismically.

First, we have identified tidal noise in USGS tectonomagnetic array data, which can be larger than 1nT, as shown by peaks at lunar periods (M2) in the Fourier spectrum of total field measurements.

The second noise source is instrumental. Tests using high accuracy (0.01nT) rubidium magnetometers show that sensitivity, particularly to coseismic events, can be improved by decreasing the least count uncertainty of the USGS proton magnetometers from 1/4nT to 1/16 or 1/82nT.

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Fault-Zone Water and Gas Studies

9960-01485

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Investigations

1. Water temperature and radon content were continuously monitored at two water wells in San Juan Bautista, CA.

2. Water level was continuously recorded at eight other wells.

3. Water quality and chemistry were periodically measured at the above mentioned 10 wells.

Results

Ground-water radon content monitored at the MFC well in San Juan Bautista dropped from 580 pC/L to a minimum of 140 pC/L during a 11-day period between December 29, 1981 and January 9, 1982, when the well became self-flowing. This radon anomaly was not accompanied by any significant earthquake activity.

A new radon monitor manufactured by the University of Southern California was installed on July 29, 1982 at the MFC well to be compared with the existing monitor made in Japan.

Reports

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Air-gun Seismic Velocity Measurements in the San Andreas Fault Zone

9960-02413

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Investigations

1. Tidal stress variation of seismic traveltimes in shallow crust.

2. Ultrasonic velocity measurement of large rock core samples (4.5 cm dia. X 15 cm long) under confining pressures up to 0.4 GPa (in collaboration with Lou Peselnick, 9960-01490).

3. Review of laboratory measurement of rock and mineral internal friction at seismic frequencies (in collaboration with Lou Peselnick, 9960-01490).

Results

1. The experiment on traveltime variation of a 19.2 Hz surface wave over a 600 m baseline in fractured quartz monzonite 2 km west of the San Andreas fault near Hollister has been concluded. Over a period of 1 year, we have conducted 8 precise seismic traveltime surveys. Each survey consists of ~100 traveltime measurements over ~12 hours. The first survey, conducted at a spring tide in August 1981, showed a variation of $\Delta t/_t \sim 2 \times 10^{-3}$, five time the measurement standard deviation, and correlated in time with the extensional tidal strain component along the direction of the seismic experiment baseline. The next two surveys, conducted at two neap tides, showed variations 2 times the standard deviation, and also correlated with the same tidal strain component. However, the other 5 surveys conducted after the onset of 1981 rainy season and into the 1982 dry season, 4 at spring tides and 1 between a spring and a neap tide, showed traveltime constant to within 1 standard deviation.

Two holes 45 m deep have been drilled by a contrctor in quartz diorite in El Granada, California, in preparation for the investigation of the tidal stress variation of the first P arrivaltime of seismic waves generated by a borehole air gun placed below the weathered surface layers.

2. A pressure vessel with internal dimensions 8 cm dia. X 50 cm long and a presssure generating system have been set up for ultrasonic velocity measurement in large rock core samples. This work was undertaken by the request of two Survey investigators in the Geothermal Program who need laboratory data to help the interpretation of field seismic data.

3. A review paper on laboratory measurement of rock and mineral internal friction at seismic frequencies is being prepared for publication in the volume Geophysics, of the series Methods of Experimental Physics, published by the Academic Press.

Report

Liu, H.-P., R.E. Westerlund, and J.B. Fletcher, Precise measurement of seismic traveltimes -- Investigation of variation from tidal stress in shallow crust, Director approval.

High Sensitivity Monitoring of Resistivity and Self-Potential Variations in the Hollister and Palmdale Areas for Earthquake Prediction Studies

Contract No. 14-08-0001-19249

P.I.: T.R. Madden Co-I.: M.N. Toksöz

Improved data analysis methods have revealed long-term, perhaps seasonal, variations of resistivity of about 0.2 to 0.3%. Variations related to the Coyote Lake Event of 1979 are also seen on the dipole nearest to the aftershock zone. These are the largest variations seen during a three-year period. A coseismic electric impulse of some 100 mv-sec/km was found across the array.

We have undertaken a complete reanalysis of the entire Hollister array digital data set with the aim of improving our sensitivity and breaking through a signal-to-noise barrier. This barrier was preventing us from seeing the background resistivity variations and only allowing us to set upper limits which reduced our ability to recognize anomalous behavior. The new analysis has made a considerable improvement in our results. It has also revealed some short-term behavior which we do not fully understand yet. We have confidence that the weekly and probably even the daily averages are real and we have been able to eliminate artificial effects of damping.

Figure 2 shows the daily average results for 1979-1981 at Hollister in which dipoles C, D, E, and F are compared to dipoles A and B. The daily scatter is roughly inversely proportional to the dipole telluric signal amplitude and must be partly due to ordinary noise, most probably electrode noise. Changes with time scales of the order of a year are also seen with amplitudes of around 0.3%. No significant net drifts are seen during the three-year period.

The largest significant variation seen during this period is a 1% variation peak to peak seen on dipole F for a two-month period immediately following the Coyote Lake earthquake (figure 3). The fact that dipole D is the closest to the aftershock zone of this event and that nothing comparable to these changes has occurred since suggests that this change is due to readjustments associated with the earthquake. It is unfortunate that our digital system in Hollister did not become fully operational until a few months before and dipole F itself was incorporated into the array only one month before the event. (Dipole E became disconnected one week before Coyote Lake.) We therefore cannot talk about precursory phenomena. The magnitude of the observed change seems large to us, but if we can improve our electrode noise figures future changes of even smaller magnitudes should be readily apparent.

We do have analog records (minus dipole F) for earlier periods which we plan to incorporate into this analysis, but there will be a calibration gap as well as the problems of analogue records.

A coseismic electric impulse which we had thought was due to microphonics in the recording equipment was shown to be a real and large-scale electric signal. We estimate the impulse magnitude was about 100 mv-sec/km. This seems too large to be explained by the dynamo action of the ground motion and we suspect a smaller but slower effect due to pore pressure might be responsible.

A similar analysis is presently underway for the Palmdale data. The technical aspects of the data analysis are presented in the final report for 1982.

Hollister Telluric Array

Palmdale Telluric Array

Fig 1

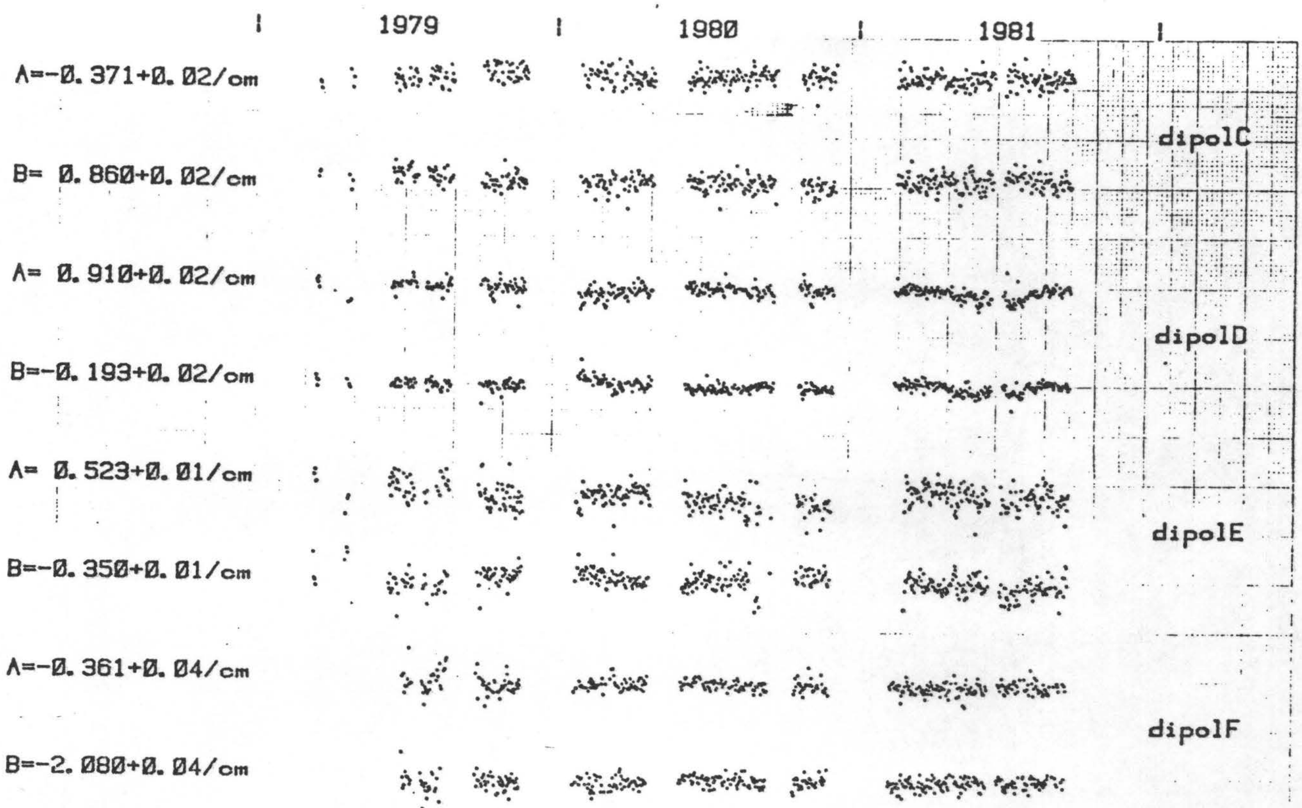

Fig 2 Hollister Array Resistivity Variations

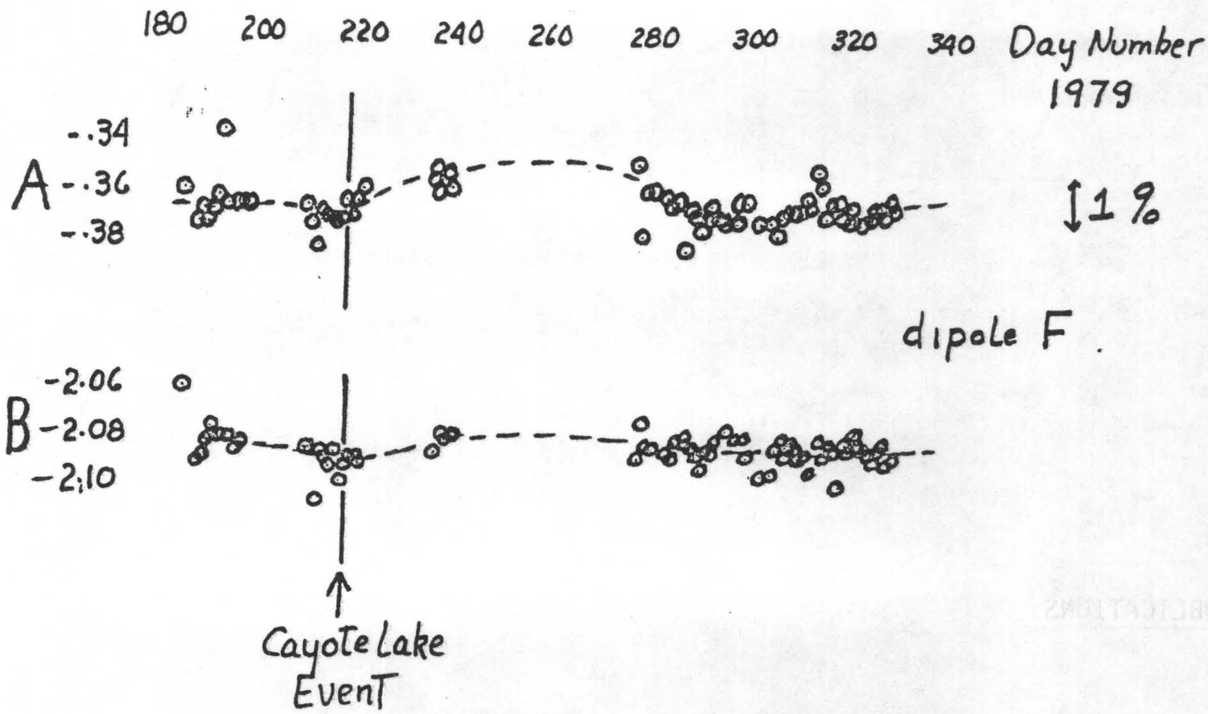

Fig 3. Apparent Resistivity Variations on dipole F (Hollister) Following Cayote Lake Earthquake

A SEARCH FOR PRECURSORY SEISMIC VELOCITY ANOMALIES NEAR PALMDALE, CALIFORNIA OVER FIXED BASELINES

#14-08-0001-19262

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SUMMARY

Using a repeatable airgun source, we have monitored the travel times of several seismic phases along 13 and 18 km baselines from Bouquet Reservoir to boreholes on the San Andreas fault near Palmdale, California. The first arriving phases refract at a depth of 2-3 km, while one later arrival is possibly a reflection from 10 km. The majority of some 200 travel time determinations for the most prominent phases were made between August 1979 and March 1980; isolated measurements were made in November 1978 and March 1981. There exists ample geodetic and other evidence for significant strain changes during this period. Allowing for source variation due to fluctuating reservoir water levels, we observed no travel time changes to the limit of our precision of ± 1-2 msec for the first arrivals and ± 3-5 msec for secondary arrivals, or about .1% of the total travel time. An earlier study which monitored rays penetrating only 500 meters into the crust found that travel times varied by up to .3% over a period of several days. The variations showed some correlation with strain changes due to local seismic activity and were not permanent. To understand this different behavior of crustal rocks between 500 and 2000 meters, we investiage the depth dependence of their velocity-strain sensitivity. Using measured P and S velocity profiles to gauge the rate at which confining pressure increases velocity, we find that 1 bar of over-pressure at 500 meters can vary the P-velocity by .1% while 1 bar at 2000 meters will vary the velocity by only .01%. Applying the O'Connell-Budiansky physical model for cracked rock to the velocity depth profiles we can further characterize the local crust as having a high crack density, a mobile fluid component and an average crack aspect ratio of 2.5×10^{-3}. The combination of a mobile fluid content and high crack density suggests that fluids play a role in the transient velocity anomalies observed at a depth of 500 meters.

PUBLICATIONS

Leary, Peter C. and Peter E. Malin, Millisecond Accurate Monitoring of Seismic Travel Times Over 13- and 18-Kilometer Baselines, JGR, vol. 87, no. B8, p. 6919-6930, 1982.

Fault Zone Tectonics

9960-01188

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Investigations

1. Maintained and upgraded creepmeter array in California.

2. Updated archived creep data on PDP 11/70 computer. Began switching data set to the new 11/44 computer for low frequency data.

3. Submitted for publication results of study on the effects of rainfall and ground water on creep observations.

4. Developed experimental procedures aimed at an operational prediction program.

Results

1. Currently 38 extension creepmeters operate; 26 of the 38 have on-site strip chart recorders; and 18 of the 26 are telemetered to Menlo Park (see Figure 1). Interruptions in telephone service from the Gold Hill creepmeter near Parkfield were ended by the construction of an overhead data transmission line over Cholame Creek to the phone drop. Previous lines buried under the creek seldom survived long.

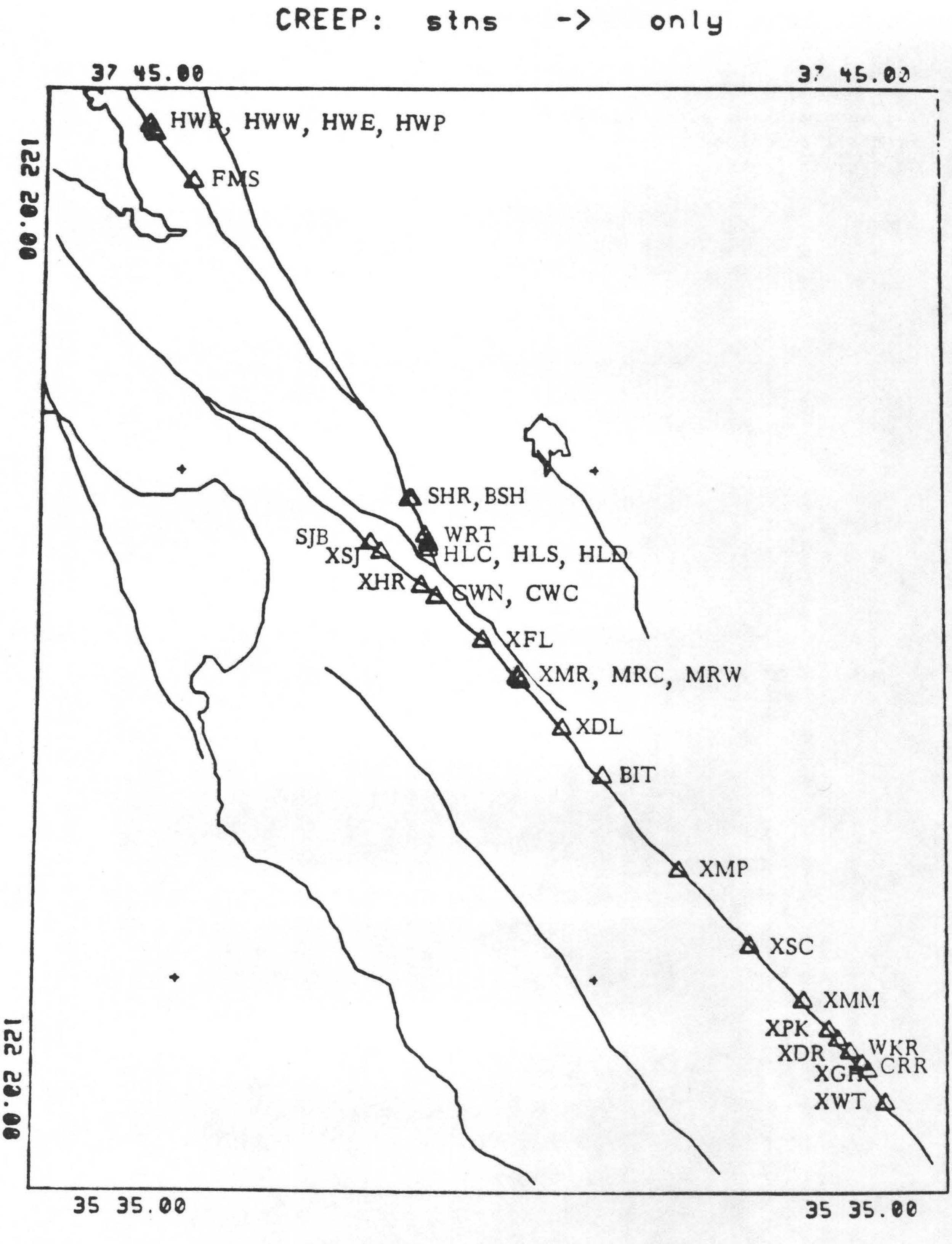
2. Fault creep data from all 38 U.S.G.S. creepmeter sites on the San Andreas, Hayward, and Calaveras faults have been updated (through August 1982) and stored in digital form (1 sample/day). A report of all data from recently operating creepmeters was published in August, 1982.

3. More frequent examination of daily creepmeter data has begun in order to document and analyze the relation between fault creep and earthquakes. This was prompted by (1) the accumulation of nearly 15 years of creepmeter data, (2) the increased occurrence of moderate central California earthquakes, and (3) our desire to develop inputs to an operational prediction program.

Reports

Schulz, S.S., G.M. Mavko, R.O. Burford, and W.D. Stuart, Long-term fault creep observations in central California, J. Geophys. Res., 87, B8, 6977-6982, 1982.

Schulz, Sandra, R.O. Burford, and B. Mavko, Influence of seismicity and rainfall on episodic creep on the San Andreas fault system in central California (submitted to J. Geophys. Res.).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XHR
CWN, CWC
XFL
XMR, MRC, MRW
XDL
BIT
XMP
XSC
XMM
XPK
XDR
WKR
XGH
CRR
XWT

Figure 1

Hydrological/Geochemical Monitoring Along San Andreas and San Jacinto Faults, Southern California, During Fiscal Year 1982

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Contract No. 14-08-0001-19253

Investigations

Water levels in over thirty wells along the San Andreas and San Jacinto fault zones were monitored during the current reporting period. Water levels in seven wells and barometric pressure at two wells were monitored by the Caltech Remote Observatory Support System (CROSS). Another ten wells were monitored continuously with Stevens Type F recorders, two of the recorders are maintained by W. R. Moyle, Jr., of the Geological Survey. The remaining wells were probed monthly, weekly, semi-weekly or daily with the aid of volunteers. 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. In addition, water samples were analysed monthly for fluorine, chlorine and sulfate ion concentrations.

Geochemical parameters, including radon utilizing the track-etch technique, temperature, salinity and conductivity, were measured in ten selected wells at the time the water-level charts were changed. Equipment to monitor water temperature and conductivity was installed in one well in Anza on CROSS.

Results

A M4.8 event occurred beneath Anza on 15 June 1982. The Stevens record for one Anza well (7S/3E-13D5) shows a sudden 0.12-foot drop in water level at the time of the earthquake. No premonitory water level changes are apparent on records for this well, nor those for 7S/3E-23B1, which was operating on CROSS. No geochemical anomalies were observed for well -23B1, which is located 2.5 km east of the epicenter. However, high radon concentrations in June occurred in three of four wells being monitored in Borrego Valley. Anomalous conductivity/salinity measurements were also obtained in two wells in Borrego Valley in late June 1982.

A radon concentration 10 times normal was obtained from a well in Anza (7S/3E-23B1) for the period 22 August to 19 September, 1982. This anomaly straddles the time (8 September 1982) for which a water-level anomaly was recorded in four wells in Borrego Valley. Decreases in water level up to 0.1 foot occurred over about a 6-hour period (Fig. 1). The microbaragraph shows no barometric pressure change that could account for the water-level anomaly. No seismic events correlate with the anomaly, which is postulated to have been a creep event.

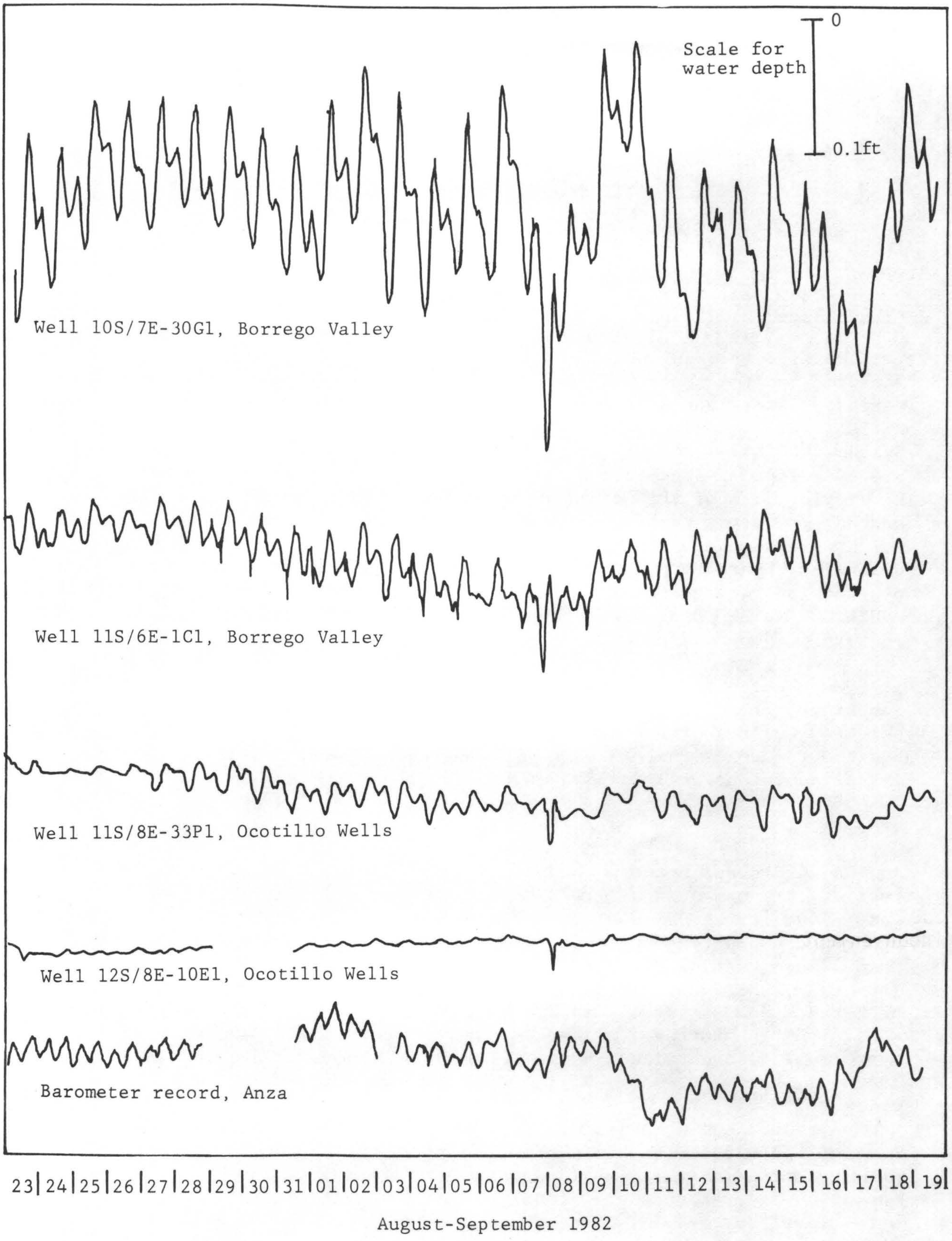

Fig. 1 - Water level variations in wells with continuous recorders in Borrego Valley and Ocotillo Wells and barometer record for Anza, 23 August - 19 September, 1982.

Experimental Tilt and Strain Instrumentation

9960-01801

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Investigations

1. Most of the effort during this reporting period involved routine maintenance of the tiltmeter and strainmeter networks. Routine maintenance responsibility was assumed from Stanwick at the beginning of this fiscal year. Since then project personnel have been trained or retrained in maintenance procedures and new procedures for monitoring and responding to situations in the field have been established. Several instrument sites have been refurbished or repaired after the winter rains. Further reduction in the numbers of tiltmeters and strainmeters planned for FY 83 should permit project personnel to become involved in a wider range of activities while providing better maintenance of the remaining instruments through a greater emphasis on preventative maintenance.

2. In September, project personnel travelled Alaska to maintain the tiltmeters there and were greeted with a constant rainfall. At Cape Yakataga the two tiltmeters histroically produced data of high quality, but were prone to flooding due to poor drainage. There were also problems with the reliable transmission of the data to the GOES satellite due to interference with a nearby mountain. Furthermore, the site was inconvenient to service because it was a considerable distance form the airstrip and local transportation was undependable at best. The site at Cape Yakataga therefore was dismantled and reconstructed near the airstrip. The instruments were sited in an alluvial sand and gravel deposit near the "Butler" building storage facility owned by OES. The electronic cables were run into the building and electronics, batteries and satellite transmitter were located inside for protection from the severe environment and for easy serviceability. However, installation of the instruments themselves in the rain and high wind was anything but easy. Shelters rigged over the hand-dug holes were blown away. Electronics and test gear had to be placed in plastic bags and adjustments had to be done carefully to avoid shorting out circuits with water. The electronics that interfaced the tiltmeters to the satellite transmitter were partially replaced to improve reliability and servicability. The instruments are now operating stably and are returning good quality data.

At Icy Bay the tiltmeters were operating and had returned good quality data for the year preceeding; however, apparently a bear had damaged the antenna. The antenna was replaced and the tiltmeters were rezeroed. Because the heavy rainfall made working conditions difficult, the electronics were not replaced. The transmitter failed a few weeks after the visit, however the data are recorded onsite.

At Yakutat the antenna also had to be replaced with a more robust type. The tiltmeters were rezeroed and the electronics and batteries were replaced. These instruments are returning data that may be compared with the water-level data from Harlequin Lake obseved by Spence Wood.

3. A remotely rezeroing tiltmeter developed by Klaus Franz, an engineer from Santa Cruz, was tested at the Presidio as a possible candidate for deep borehole application.

4. Doug Myren helped install a dilatometer at Echo Valley near San Juan Bautista. He also designed and built a circuit to automatically open the zeroing bleed-valve on the dilatometers when the output drifts to the limit of the telemetry. This device permitted the continuous recording of a large dilatational strain signal observed at the Crystalaire (CCSS) dilatometer that otherwise would not hve been recorded.

5. In August Carl Mortensen spent a week accompanying an offical visitor from Washington, D.C. on a tour of facilities supported by the Earthquake Hazards Reduction Act. This tour and the associated presentations offered an unparalleled opportunity to gain an overall perspective of the earthquake hazards reduction constituent programs.

Results

1. A test has been conducted at the Presidio for a period of five months to determine if a remotely rezeroing tiltmeter developed by Klaus Franz, an independent engineer, has sufficient sensitivity and stability for use in deep boreholes for fault monitoring. The instrument employs a bubble level sensor and an ingenious and carefully constructed alignment mechanism. The instrument is easy to setup and adjust and has sensitivity equal to the Kinemetrics tiltmeter. Results show that the instrument has a typical drift-rate from three to twenty times greater than the mercury-tube tiltmeters. Thus, at least in its present form, the instrument is not a good candidate for use in longterm deformation monitoring.

Biological Premonitors of Earthquakes: A Validation Study

14-08-0001-19112

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INTRODUCTION

Popular reports of anomalous animal behavior before earthquakes are common and extend throughout most of recorded human history. Birds, household pets, fish, and farm animals are cited most frequently, with occasional mention of dozens of other species with which man comes into contact (1,2).

Unfortunately, these reports are of little scientific value because they are anecdotal and subject to the inaccuracies of observations, recall, and assessment of significance that usually accompany laymen's reports of disasters. Moreover, the reports provide scanty data and the credentials of the observer are rarely provided. The results of recent retrospective studies, however, have lent support to the hypothesis that anomalous animal behavior precedes at least some earthquakes (3-6). Also, the recent successful short-term predictions of earthquakes in the People's Republic of China (7) has encouraged further investigation of the animal hypothesis; one element of the Chinese program is reports of unusual behavior of animals by volunteer observers.

Relevant to the animal hypothesis are reports from a number of independent laboratories that a wide variety of animal species are acutely sensitive to levels of energies that characterize precursory phenomena (8-14). A report by Buskirk et al. (14) summarized a recent USGS-supported conference that examined the laboratory findings of leading investigators, and the extant literature, on the sensitivity of reptiles, fish, birds, and selected mammals to physical stimuli known to precede at least some earthquakes. Buskirk et al. concluded that many species, especially fish and birds, are more sensitive than man to many physical stimuli and also respond to certain stimuli (such as electrical and magnetic fields) that man, apparently, does not sense. In their view, the precursory phenomena to which animals might respond are low-frequency sound (< 10 Hz), electric field changes, odor, and ground vibrations. Tributsch (15) supports the view that animals respond to aerosol anomalies induced by an excess of positive ions preceding at least some earthquakes.

Over the past four years the SRI project has accumulated and analyzed the only extensive data set of anomalous behavior of over 250 animal species using volunteer observers residing in seismically active areas of California. We have collected reports <u>before</u> the occurrence of an earthquake* and, using

*Reports received after an earthquake were not utilized in our data analysis.

identical space and time parameters in our computational model, have found seven instances where the frequency of reports before an earthquake was significantly greater than during baseline periods.

INVESTIGATIONS

A network of approximately 1500 volunteer observers of animal behavior has been recruited. Volunteers own or work around animals and have ample opportunity to observe their behavior. Observers report instances of unusual animal behavior, rated from 0 to 4 on a scale provided by the principal investigator, on a toll-free incoming telephone line (hot line), which tape-records their message. The hot line is operational 24 hrs/day, 7 days/wk. Apart from reports of unusual animal behavior, the observers also use the hot line once weekly to "report in" (i.e., verify their continued participation in the project). Observers also complete a daily log entry and the log sheet is returned to SRI at the end of each month. Log data, however, are not used in the data analysis, since the validity of the date and time of log entries cannot be verified. The verification calls and the log entry requirements allow us to monitor observer participation in the project and to derive an observer performance rating, which indicates the conscientiousness of each observer in meeting his or her responsibilities.

A unique feature of our approach is the provision of a means for independent verification of the date and time that the unusual behavior is reported on the hot line. The hot line records the message and the exact time each day that it is received. Calls that postdate earthquakes are not considered reliable.

Volunteer observers have been recruited from selected, seismically active regions of California, principally from portions of Humboldt County; San Benito, Santa Clara, Santa Cruz, and Monterey Counties; Los Angeles, and Ventura Counties; San Francisco, Alameda, Contra Costa, Marin, Mendocino Counties; Sonoma, Napa Counties; and, to a lesser degree, San Diego and Orange Counties. These areas were selected on the basis of California seismicity during the period 1900-1975, which yielded the probability that the next major earthquake(s) will occur in one of them, and other factors such as human and animal population densities. Figure 1 shows the distribution of observers in these areas.

A computer-programmed model and analysis procedure that treats earthquakes and reports as independent events in time was developed during 1979 to evaluate the statistical significance of report frequency preceding earthquakes.

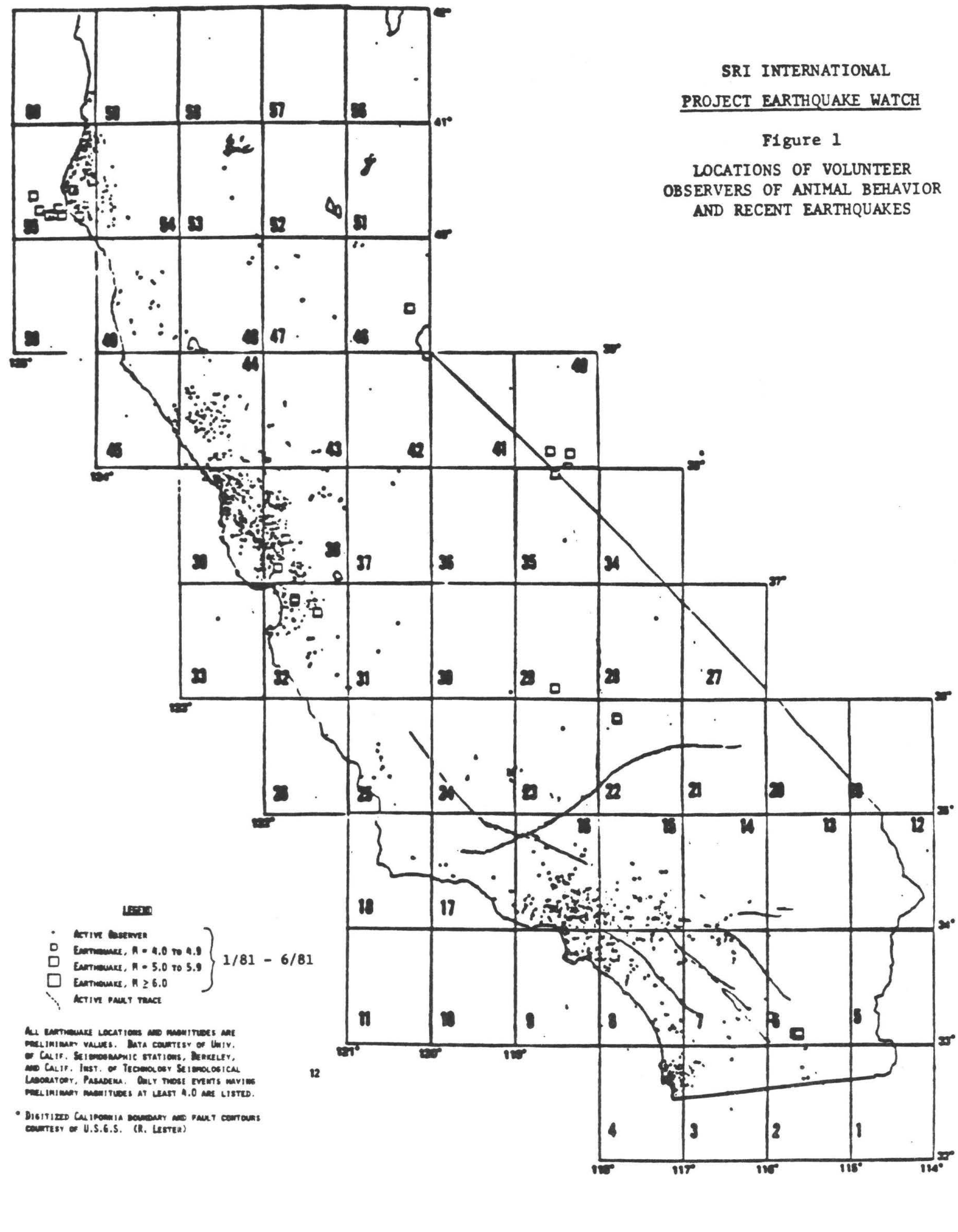
Data analysis requires that a set of parameters be chosen to describe the sizes of the forespace and afterspace of each earthquake (time and distance ranges and magnitude thresholds) and the size of a "control cylinder" used to define a baseline measure of "normal" reporting. For each earthquake evaluated, the data analysis enumerates the number of reports received in the forespace relative to the number received in the control space--the control cylinder minus the portions of all afterspaces and all other forespaces contained within it. This ratio is then compared with the volume ratios of the two regions being tallied. A binomial test is applied to test the null hypothesis: that the report density in the forespace is merely a random extrapolation of that

SRI INTERNATIONAL

PROJECT EARTHQUAKE WATCH

Figure 1

LOCATIONS OF VOLUNTEER
OBSERVERS OF ANIMAL BEHAVIOR
AND RECENT EARTHQUAKES



observed in the control space cylinder. A small probability for the null hypothesis is tantamount to its rejection and preliminary acceptance of the main hypothesis, within the confidence limits of the analysis and subject to the assumptions made.

Results whose probability is $\geq$ .05 are considered significant if other events that may have produced the increased frequency of reports (unusual environmental or man-made events--e.g., rain or wind storms, floods, construction, fires) can be ruled out.

RESULTS

A series of trial runs conducted during 1979 used various space and time parameters for the forespace, afterspace, and control space. Provisional space and time parameters for the model were selected and then applied to data collected during 1980 and 1981. Significant results have been found in 7 of 13 cases of earthquakes that were close to or on the fringes of our network using identical time and distance parameters in the model. Two of these cases occurred in 1979, two in 1980, and three during the first quarter of 1981. The probabilities range from 0.025 to < 0.00005. Table 1 displays these data.*

The middle section of Table 1 lists the seven earthquakes under analysis; the date and time of each, followed by its geographical location and magnitude, then the numbers of other earthquakes that intersected its forespace and afterspace. The next four columns tabulate the numbers of hot-line reports that fell in various protions of the time-space continuum, according to the code printed at the bottom of the table. The columns of immediate concern are the fourth, labeled KR = 3, which enumerates the number of reports in the forespace of the earthquake in question, exclusive of the afterspaces of all other earthquakes; and the second, labeled KR = 1, which enumerates the number of reports in the control space exclusive of the forespaces and afterspaces of all earthquakes. The volumes of these two regions are given in the next two columns, and the final null hypothesis probability in the last column.

It is clear from the probability values that the seven earthquakes achieved significance ($P < 0.05$). Considering the 1981 earthquakes, for example, 21 reports were received in the forespace of #7, which has volume 337 km^2-years, while 207 reports were received in the control space, whose volume is 28,666 km^2-years. This corresponds to a volume ratio of 1:138, indicating that less than a single report would have been expected in the forespace of this earthquake. Application of a binomial test reveals that the chance that as many as 21 or more reports would be received is less than 1 in 20,000. For earthquakes #5 and #6, the number of reports received was rather small, but the expected number was even smaller, hence the statistical significance. Consequently, it may be concluded that the numbers of reports received

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*Substitution of other parameters for the forespace distance (160 km instead of 40 km) or the afterspace time of 3 days instead of 10 days has resulted in other significant findings, suggesting that different earthquakes require application of slightly different parameters for adequate evaluation.

Table 1

STATISTICAL ANALYSIS OF REPORTS AND EARTHQUAKES

All reports included with R-rating at least 2.
All EQs included with magnitude at least 4.00

Forespace range: Min. Magnitude = 4.00
Max. distance = 40.00 + Mag 0.00 km.
Max. time before EQ = 30.00 + Mag· 0.00 days.
Afterspace range: Min. magnitude = 4.00
Max. distance = 160.00 + Mag 0.00 km.
Max. time after EQ = 10.00 + Mag 0.00 days.

Radius of control space = 160.00 km.
Time interval covered is 1/1/79 to 1/1/80
Max. vol. of control space = 80370. km²-yrs.

No.	Date and Time (PST)				Location	No. of EQs Mag.	Fore	Aft.	No. of Rpts, Kr= 0	1	2	3	Volume (km²-Yrs.) VE	VC	Prob. P1
1	1979	2	3	1:58	15 Mi. NW Eureka	5.30	6	7	1385	100	22	9	394	70321	<0.00005
2	1979	8	6	9:05	Coyote Lake	5.90	6	21	697	652	159	8	413	69246	0.0344

Time interval covered is 1/1/80 to 12/31/80
Max. vol. of control space = 40075. km²-yrs.

3	1980	1	24	11:0	10 Mi. SE Antioch	5.50	5	13	320	397	178	10	323	32727	0.0027*
	1980	1	24	11:1	10 Mi. SE Antioch	5.20	5	13	320	397	178	10	323	32727	0.0027*
	1980	1	26	18:34	10 Mi. SE Antioch	5.80	5	14	321	395	180	9	323	32410	0.0115*
4	1980	4	12	22:16	7 Mi. E Prunedale	4.90	5	14	395	335	166	9	413	31842	0.0247

Time interval covered is 1/1/81 to 12/31/81
Max. vol. of control space = 40295. km²-yrs.

5	1981	1	15	4:48	40 Mi. ESE Milpitas	4.60	6	11	265	206	217	3	85	27989	0.0092
6	1981	1	27	14:11	2 Mi. S Aromas	4.00	6	7	305	174	209	3	118	27650	0.0214
7	1981	3	3	2:45	2 Mi. NE Fremont	4:30	6	11	264	207	199	21	337	28666	<0.00005

Prob. = Probability that null hypothesis holds for indicated earthquake

KR = 0 for reports outside of control cylinder
KR = 1 for reports inside control cylinder but outside all fore- and afterspaces
KR = 2 for reports inside at least one fore- or afterspace, except for those for which KR = 3
KR = 3 for reports in main forespace not also in any afterspace

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*For purposes of our analysis these 3 earthquakes are treated as a single event.

before these three earthquakes were associated with the pre-earthquake time periods and geographical locations. The results are particularly strong for the Fremont event (#7).

To complete the argument, we must next establish that there were no other events that were not associated with the earthquake that might have given rise to the increases in hot-line reports of unusual animal behavior. There is no way to do this with absolute certainty, of course, since animal behaviorists do not fully understand all of the stimuli to which animals respond. (For that matter, neither are human observation and reporting habits fully understood.) The most likely alternative explanations for the unusually high reporting level may be explored, however; these are:

- Dramatic weather changes.
- Social events known to affect animals (county fair, dog shows, etc.).
- Local fires.
- An influx of predators or an infestation.

These possibilities have been checked through weather reports and news reports from the media and found to be absent in all cases. We may, therefore, provisionally conclude that the increases in reporting frequency were associated with the earthquakes themselves, and that the animals in these areas were somehow sensing the pre-earthquake condition and behaving in a noticeably unusual manner.

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Helium monitoring for earthquake prediction

9440-01376

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Investigations

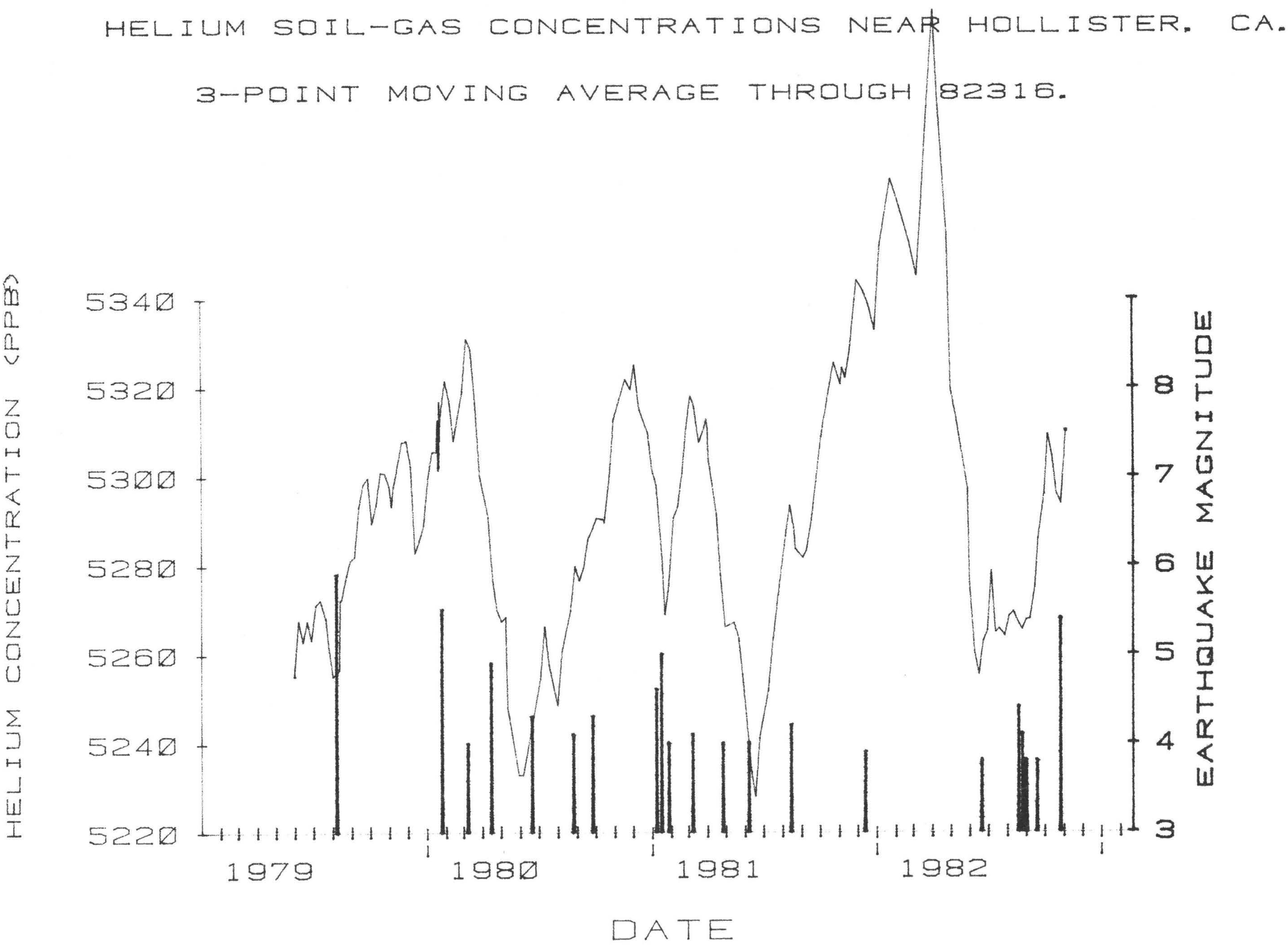
Helium soil-gas concentrations are being monitored at nearly 20 stations along the San Andreas Fault near Hollister, California. Data collected weekly for over 3 years have revealed a seasonal pattern and some anomalous decreases that seem to precede seismic activity by several weeks. Additional data accumulation is continuing to build a longer baseline in hopes of gaining a better insight of the various factors contributing to shorter term helium changes. This, in turn, will greatly aid interpretative efforts in using helium variations as an earthquake forecasting technique.

Results

Monitoring of the helium soil-gas concentrations provided two interesting observations during the last 6-month period. The first was that a notable deviation of the helium began in July from the trend established in previous years. The average helium concentrations stayed low for a 3-month period during which time there were several low-magnitude earthquakes within our empirically derived observation area. That pattern seems analogous to the decrease cycle that occurred in December-February, 1980-1981. The second observation was that there did not appear to be any major helium decrease before the October earthquake near Coalinga. That corresponds to a previous situation in which no decrease was noted before the September 1980 Coalinga earthquake.

The latter observation may imply that there is no communicational link of our stations eastward into the San Joaquin Valley. We may, therefore, modify our observational model from circular to elliptical, centered on our sample collecting stations.

Figure 1 shows the averaged helium variations from May 1979 through October 1982. The extremely high helium during the Spring of 1982 was caused by above average precipitation. The broad, nearly flat region from July to September is the region of helium low values preceding a period of earthquake activity.



HELIUM SOIL-GAS CONCENTRATIONS NEAR HOLLISTER, CA.
3-POINT MOVING AVERAGE THROUGH 82316.
P2
HELIUM CONCENTRATION (PPB)
5340
5320
5300
5280
5260
5240
5220
EARTHQUAKE MAGNITUDE
8
7
6
5
4
3
1979
1980
1981
1982
DATE

382

Fault demarcation from helium soil-gas profiles near Oroville, CA

9440-01376

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Investigations

An attempt to delineate the northern extent of the Cleveland Hill Fault near the Oroville, California reservoir will be made through the application of a helium soil-gas survey. Helium has been shown in the past to be an indicator of some fault systems by exhibiting either high or low concentrations along or parallel to the fault trace dependent upon the nature of the local geology, related hydrology, and the occurrence of any fault-controlled mineralization. Because of the strong influence of ground water movement on the helium distribution, the proximity of the reservoir to the helium survey area may be advantageous. The reservoir might exert some control over the local ground-water movement that would provide sharper gradients in helium concentrations associated with a fault than would be found in other areas.

Results

A preliminary survey was conducted in August 1982. The purpose of that study was to test the feasibility of collecting soil-gas samples in the area of interest. Two east-west traverses with a sample spacing of 1.6 km were run perpendicular to the known fault and fault projection. The northern traverse followed the Olive Highway and Forbestown Road and the southern traverse followed Foothill Boulevard, the Oroville Bangor Highway and Swedes Flat Road.

Although soil cover is thin in some areas, there is generally adequate cover to insert probes to a depth of 0.75 meter. The average soil-gas helium concentration for 20 samples was 115 parts per billion (10^9) above the concentration of ambient air. The highest values were found in western part of the study area.

Future Study

During the summer of 1983, a detailed survey will be conducted consisting of several traverses across the area of the known fault and the northern region of the fault projection. Sample spacing will be on about 300 meter intervals which should provide adequate resolution if a helium variation is present due to fault control.

THE EXTENSION AND OPERATION OF A COMPUTER-CONTROLLED RADON MONITORING NETWORK FOR EARTHQUAKE PREDICTION, INVESTIGATIONS OF ENVIRONMENTAL EFFECTS ON SUBSURFACE RADON, AND COMPARISON OF RADON MONITORING TECHNIQUES

14-08-0001-19752

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INVESTIGATIONS

During the first half of FY82, we upgraded several of our radon monitoring sites to permit the monitoring of additional geochemical and environmental parameters. This included the installation (in collaboration with Gulf Science and Technology Corp.) of several continuous CO_2 monitors; the installation of a dual gas chromatograph to measure hydrogen, helium, and hydrocarbon gases at Kresge; the installation of several fuel cell type hydrogen monitors (in collaboration with Dr. Sato -- USGS-Reston); the replacement of flexible bubbler tubes with rigid tubes and pressure sensors for water level measurements at several sites; and the installation of water temperature sensors at several sites.

During this period, the development of the final version of the software for automatic network interrogation, data storage and archiving, and daily printing of the network data was completed and placed in operation. The radon/geochemical network now is interrogated daily at 0000 UTC, and the information is stored in continuous, contiguous archive files. Hard copies of data are produced automatically six days a week, and full graphic plots are produced automatically on Monday, Wednesday, and Friday.

RESULTS

Several changes occurred in the patterns of radon data and other geochemical parameters at several sites on our network during this period. The anomalous radon and CO_2 levels at our Lake Hughes and Lytle Creek stations returned to normal, as did the anomalously low radon level at Sky Forest. The Lytle Creek pattern changed near the end of 1981, while the changes at Lake Hughes and Sky Forest occurred in March of 1982. The latter changes were coincident with changes in strain, radon and other parameters observed by several investigators at sites near the San Andreas fault.

While no major seismicity accompanied any of these changes, a high degree of correlation has been observed between seismic energy release for a recent sequence of offshore events and the Lake Hughes-Lytle Creek radon and CO_2 anomalies. At this point, however, no definite causal connection between the two phenomena can be made.

The archive plot of radon data from the network is shown in figure 1.

REPORTS

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M.H. Shapiro, J.D. Melvin, T.A. Tombrello, Jiang Fong-liang, Li Gui-ru, M.H. Mendenhall, A. Rice, S. Epstein, V.T. Jones, D. Masdea, and M. Kurtz, Correlated radon and CO_2 variations near the San Andreas fault, Geophys. Res. Lett., 9, (1982) 503-506.

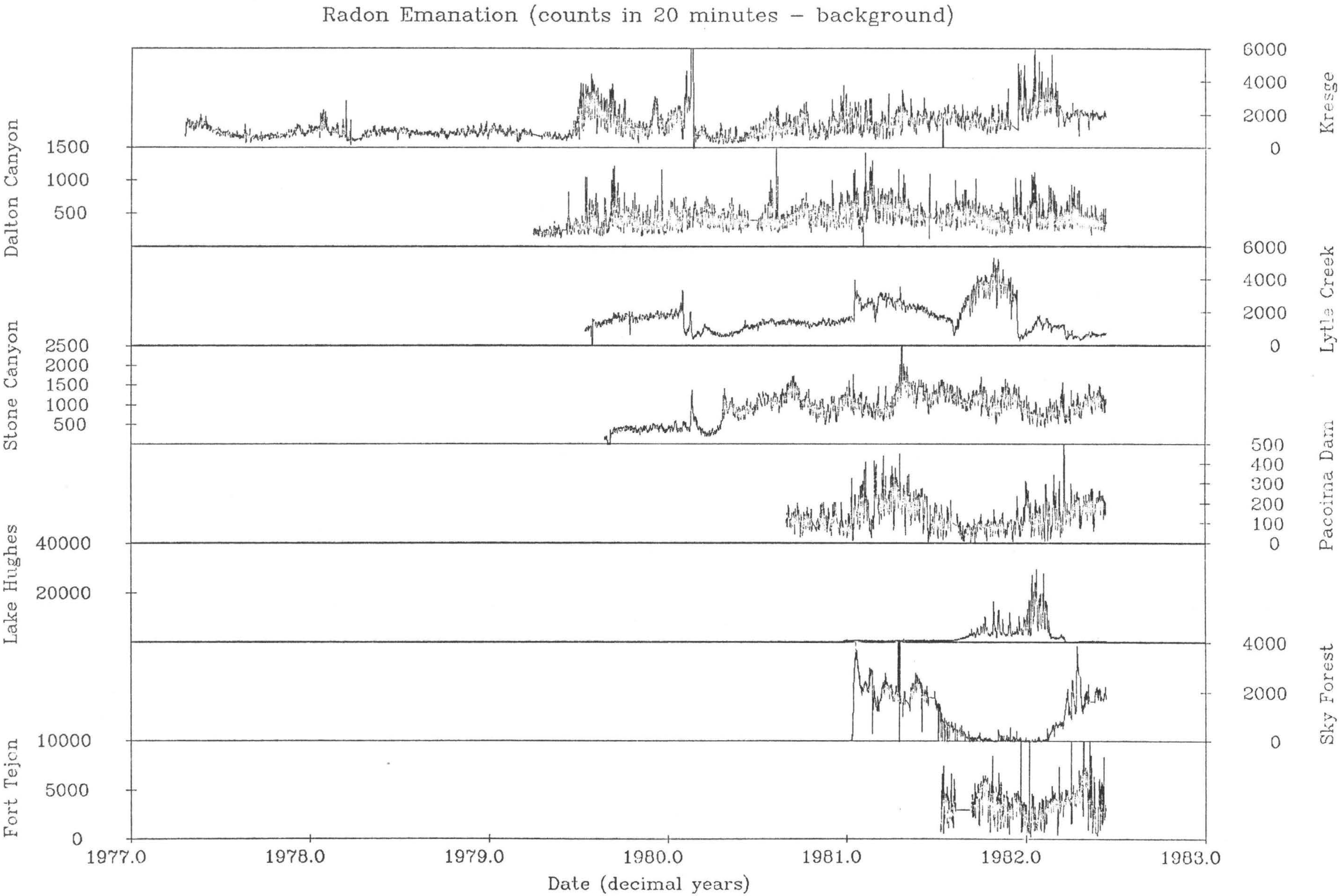
Radon Emanation (counts in 20 minutes - background)
Kresge
6000
4000
2000
0
Dalton Canyon
1500
1000
500
Lytle Creek
6000
4000
2000
0
Stone Canyon
2500
2000
1500
1000
500
Pacoima Dam
500
400
300
200
100
0
Lake Hughes
40000
20000
Sky Forest
4000
2000
0
Fort Tejon
10000
5000
0
1977.0
1978.0
1979.0
1980.0
1981.0
1982.0
1983.0
Date (decimal years)

Fig 1.

P2

GROUNDWATER RADON CONTENT AS AN EARTHQUAKE PRECURSOR

#14-08-0001-19264

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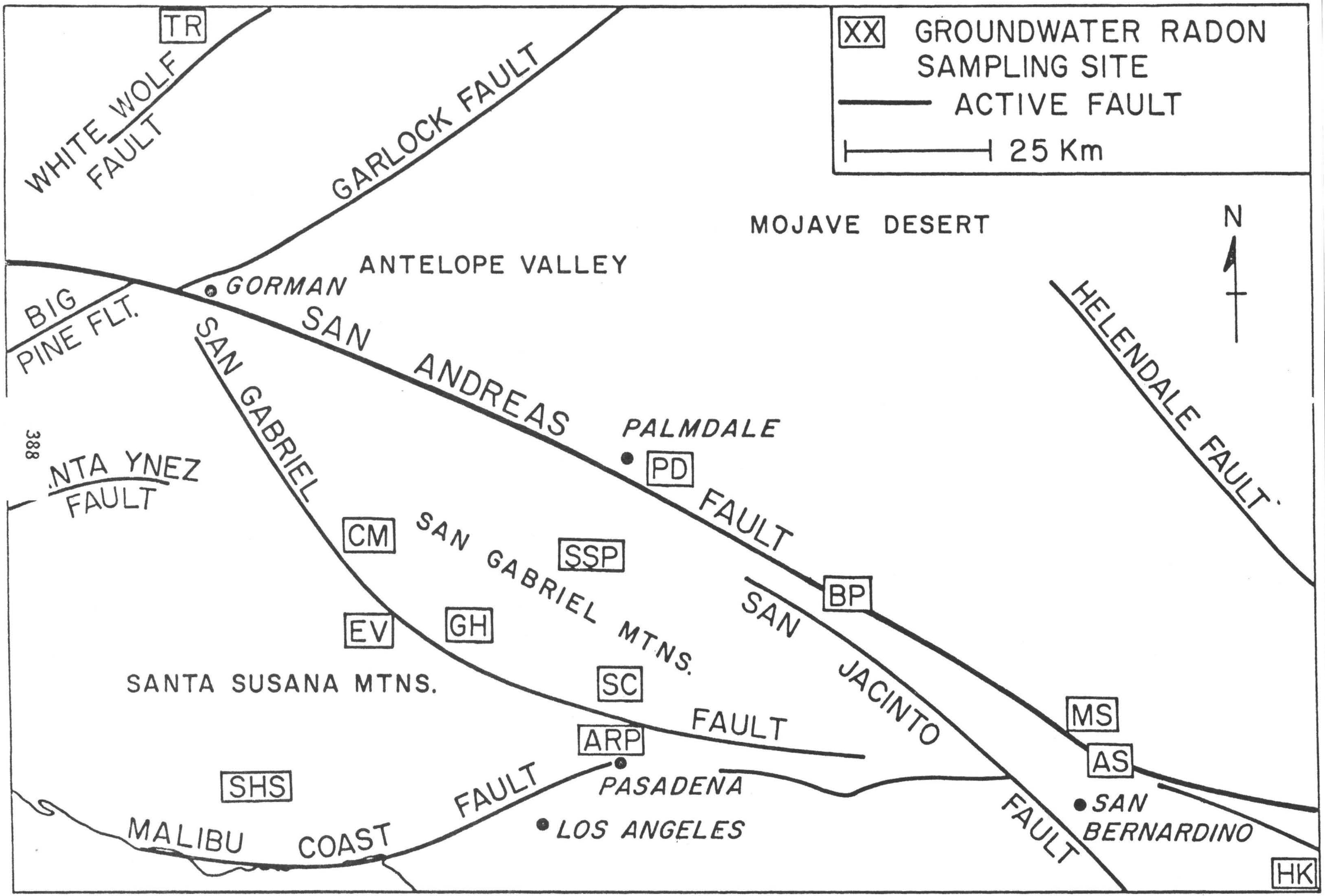
Summary

The University of Southern California is monitoring groundwater radon content at 14 sites (Figure 1) in the Central Tranverse Ranges of southern California. Radon monitoring has been underway since 1974. Nine sites are still monitored on a weekly basis while five sites are now being monitored on an hourly basis with the new continuous radon monitor (CRM) recently developed and built by our laboratory. The five sites with CRMs are Haskell Ranch (HK), Arrowhead Hot Springs #2 and #4 (AS), Wrightwood (WW), and Seminole Hot Springs (SHS).

We have not seen any unusual activity at any of our research sites during the past six months. Annual cycles of relatively high radon values in summer and lower values in winter continues at several sites (most notably Arp, Eternal Valley, Glen Haven, and Big Pines).



XX GROUNDWATER RADON SAMPLING SITE
ACTIVE FAULT
25 Km
N
TR
WHITE WOLF FAULT
GARLOCK FAULT
MOJAVE DESERT
ANTELOPE VALLEY
GORMAN
BIG PINE FLT.
SAN ANDREAS FAULT
HELENDALE FAULT
SAN GABRIEL FAULT
PALMDALE
PD
NTA YNEZ FAULT
CM
SAN GABRIEL MTNS.
SSP
BP
SAN JACINTO FAULT
EV
GH
SANTA SUSANA MTNS.
SC
MS
ARP
AS
SHS
PASADENA
SAN BERNARDINO
MALIBU COAST FAULT
LOS ANGELES
HK

FIGURE 1.

Local Changes in the Gravity and Magnetic Fields Due to Tectonic Strain

14-08-0001-19792

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Investigations

Surface displacements and tilts and local changes in the gravity and magnetic fields provide complementary information about tectonic events at depth. The changes in these parameters measured at the surface before and after an earthquake, for example, all depend on the tectonic strain which occurred, but each depends on different components of the strain field. I have been studying the local changes in the earth's gravitational and magnetic fields. My work has been analytical in nature and has been directed towards understanding fundamental aspects of the problem.

Results

Working in collaboration with Teng-fong Wong, a Research Associate in this department, I analyzed the changes in gravity due to faulting in a viscoelastic half space. The results were completely unexpected: we found that the coseismic change in gravity in any viscoelastic half space is the same as the change in an elastic half space and further, that no post-seismic changes occur, no matter what viscoelastic behavior is operative. Note that time-dependent deformation of the half space does occur, but the redistribution of mass at each stage of deformation is such that gravity does not change. Wong and I have written a short paper describing our analysis which has been accepted by Seismologika Sinica. We chose Seismologika Sinica because an analysis of this same problem using numerical techniques, with application to the Tangshan earthquake (1976), recently appeared in that journal.

Wong and I have embarked on a new analysis of gravity changes due to faulting in an elastic half space, employing a more fundamental approach than Rice and I used in our previous analysis. Wong and I are attempting to derive the Green's functions relating dislocations in the half space and the associated gravity change using only the definition of the gravitational potential and the Galerkin vectors representing the dislocation source. Our hope is that this work, if successful, will provide insight to the solution of gravity changes in layered media and the tectonomagnetic problem.

During the past reporting period, I revised a manuscript 'Changes in gravity due to changes in topography'. This manuscript has now been accepted for publication in the Journal of Geophysical Research. In addition, I completed a review paper, 'Precursors to fracture in laboratory experiments' which has been accepted for publication in 'Seismicity in Mines Conference' in Johannesburg.

I have been working with Teng-fong Wong, on an analysis of gravity changes due to faulting in a viscoelastic half space. This analysis was prompted by an article in Seismologika Sinica, in which gravity changes in a viscoelastic half space were calculated numerically and compared with data from a Chinese earthquake. We think that we can carry out the analysis in a much simpler way by using the Reciprocal Theorem and the Correspondence Principle.

Reports

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Walsh, J. B., 1982, Precursors to fracture in laboratory experiments, Seismicity in Mines Conference, International Society of Rock Mechanics, Johannesburg, Sept. 13-17, in press.

Continuation of Gravimetric Monitoring in Southern California 14-08-0001-20556

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Investigations

During the February-August period of 1982, four field observation sessions were conducted over the gravity network shown in Figure 1 during the months of February, April, June, and August.

In April, absolute gravitational acceleration measurements were made with M. Zumberge at four key stations within the Network using the instrument developed at the University of Colorado Joint Institute for Laboratory Astrophysics (Zumberge and Faller; 1980). Measurement of absolute gravity now allows the network to be tied to a fixed gravitational frame of reference instead of a floating frame as was the case during the first eight years of network observations.

Results

The absolute stations and their preliminary acceleration values (cm/sec^2) are the base station at Pasadena (979.560445), Goldstone (#23) (979.444215), Ownes Valley (#40) (979.444404), and Pinon Flat (#57) (979.284080) (station numbers correspond to those in Figure 1).

Most of the recent gravity changes in the network are small and close to the resolution of the technique, about 30 microgals (Whitcomb et al., 1980; Whitcomb, 1980). Only two stations have significant gravity changes that cannot be attributed to groundwater or other causes. They are at LUCAS (#38) and CIT2 (#5). LUCAS is a crystalline rock site in the middle of the Transverse Range's San Gabriel mountains and shows a decrease of about 40 microgals from early 1979 to late 1982. The CIT2 data shows a larger offset. The station is located on the Malibu coast (see Figure 1) on a bridge abutment 5.5 meters above sea level and about 100 meters north of the shore line. Figure 2 shows the CIT2 data and data from neighboring stations CIT1, CIT4, and CIT5 which are observed on the same loop during the same day as CIT2 readings are made. Unfortunately, temporary lack of project support has made a gap in the data so that details cannot be discerned in 1981. However, data from resumed operations in 1982 show continued high or higher values 50-80 microgals above the average levels in the 1974-1978 period. No similar 1982 increase in gravity is seen at the nearby stations: CIT1 is about 13 km to the east of CIT1, CIT4 is 27 km to the west, and CIT5 is 35 km to the west.

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Zumberge, M. A., and J. E. Faller, Performance of a new, portable, absolute gravimeter, *EOS, Trans. Am. Geophys. U., 61*, 938, 1980 (abs.).

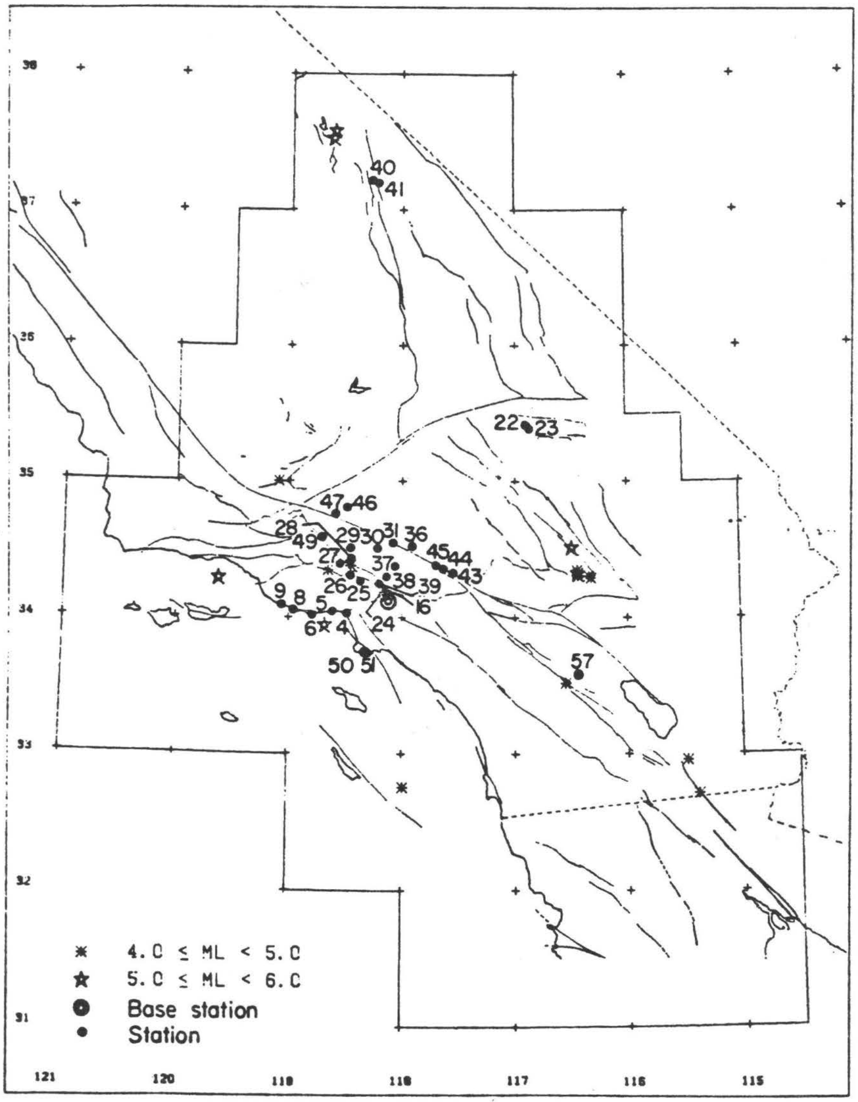

Figure 1. Locations of stations of the Southern California gravity network.

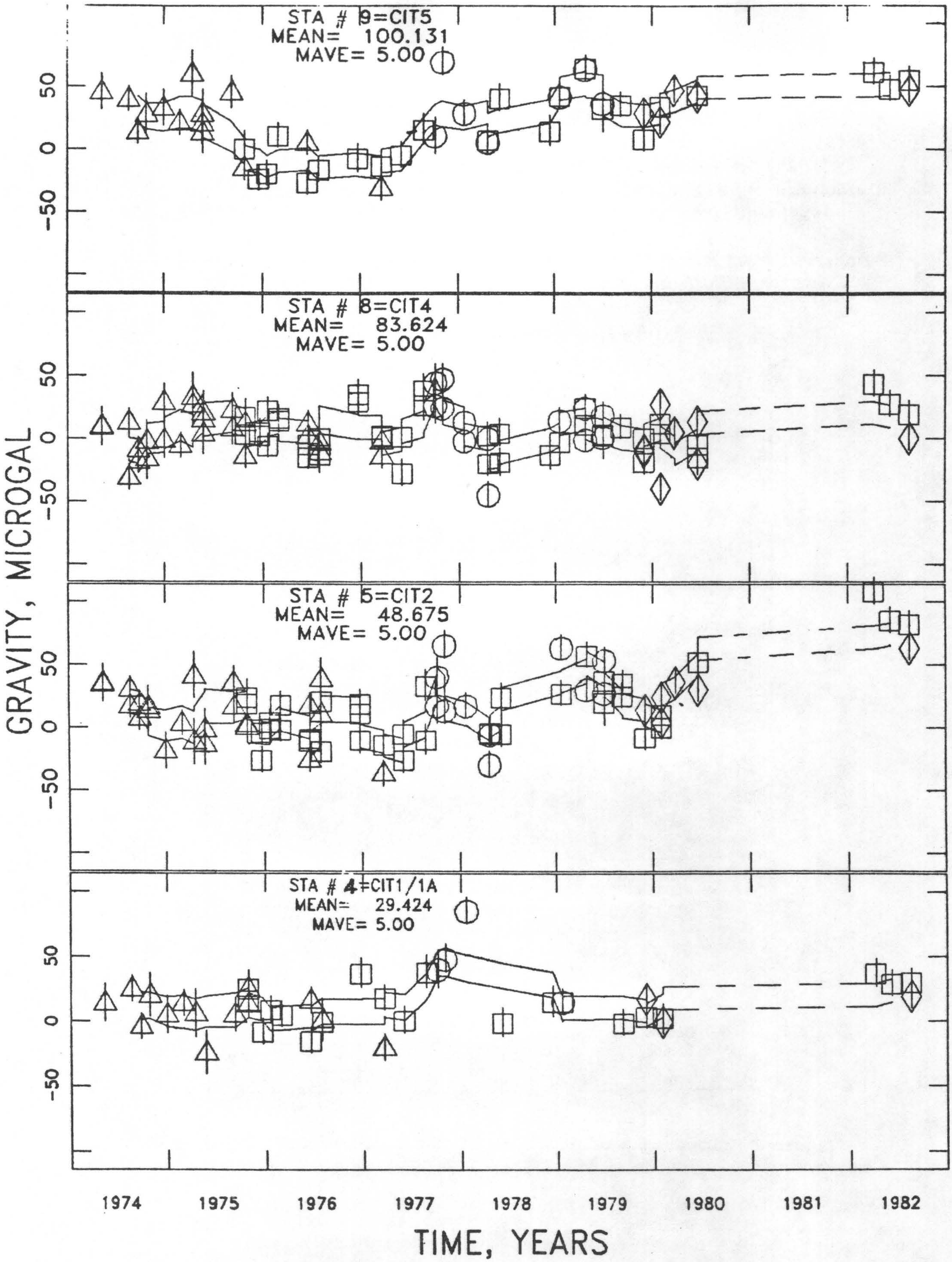

Figure 2. Gravity data from CIT1 (# 4), CIT2 (#5), CIT4 (#8), and CIT5 (#9) relative to the Pasadena base station.

Synthesis of Seismicity and Geological Data in California

14-08-0001-G-501

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Investigations

1. Compile as complete as possible a set of slip rates for major faults in California.

2. Compare the historical seismicity on each of these faults with activity rates which are needed to maintain the slip rate.

3. Determine if this information will be useful in predicting earthquakes.

Results

1. A list of 73 faults or fault segments in California has been compiled; to date an estimate of slip rate has been compiled for about 95% of these faults. Faults for which no estimate has yet been found appear to be, for the most part, of secondary importance. This data set is probably sufficient to estimate whether slip rates help with the earthquake prediction problem.

2. Geological boundaries for earthquakes associated with each fault have been chosen and digitized. Computer searches for seismicity within these regions have been completed. At the present time, a manuscript describing the correlation with seismicity as derived from slip rate is being prepared (Anderson, 1983b).

A study has been made on the theoretical distributions of seismicity which will generate a given slip rate. This study (Anderson and Luco, 1983) extends the methods of Anderson (1979) to additional shapes for the distribution curve of the number of earthquakes at each magnitude, and investigates sensitivity of seismicity estimates to the estimate for maximum magnitude. It also explores ways in which point observations of historical seismicity such as those of Sieh (1978) at Pallett Creek can be interpreted. One interpretation of the Pallett Creek earthquake sequence could imply that the distribution of magnitudes recorded in the record is consistent with a $\log n = a - bM$ distribution as used by Anderson (1979), but with a very low b-value not distinguishable from zero.

3. While results from parts 1 and 2 are still too preliminary to proceed with step 3, investigation of the tools for such a comparison is continuing. Two manuscripts pertaining to this study are now published (Anderson, 1981,1982). The model for evaluation of precursory data in Anderson (1982) gives results comparable to the approximate method of

Aki (1981) for evaluating the risk gain due to a precursory observation. This method is exact, however, and an extension of the Aki (1981) method to risk gains as a function of earthquake magnitude results naturally from the analysis.

The method of Anderson (1982) has now been applied to the southern California earthquake prediction program results, excluding slip rate and seismicity data which has been gathered under this contract. The probability for the largest earthquake in 1982 to be magnitude greater than 6 appeared to be approximately 0.42, compared to a probability of about 0.29 for a randomly chosen year. The method can easily be applied on a routine and timely basis to insure that the results of the U.S. Earthquake Prediction program are rigorously synthesized.

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Stress Corrosion and Microseismic Activity During Tensile, Shear and Compressive Failure of Rocks

14-08-0001-20558

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Investigations

This project has the aim of understanding more about the chemical effects of pore water on the long-term strength of rocks in the upper levels of the Earth's crust. To this end fracture mechanics studies of subcritical cracking in rocks under conditions of geophysical interest are being run so as to aid the interpretation of triaxial deformation experiments on hot, wet rocks at low strain rates. Various studies relating to the microstructural aspects of chemically-enhanced weakening are involved. These include acoustic emission studies, ion-microprobe analyses and electron microscopy. Crack-healing and strength recovery, memory effects and non-linear behaviour during failure are also being studied.

Results

1. An extensive review of the current state of research on subcritical crack growth in geological materials has been made. This work also included an extended discussion on the problems of extrapolating the experimental data base to geophysically interesting conditions. Some of the main conclusions are as follows.
(i) There may be several mechanisms of subcritical crack growth relevant to crustal processes. These include stress corrosion, diffusional mass transport, dissolution, ion-exchange and microplasticity. Dissolution could produce crack growth rates in calcite rocks at room temperature of ca. 10^{-10} $m.s^{-1}$ under tension. Grain boundary diffusion in quartzite could lead to crack growth under tension at velocities of ca. 10^{-11} $m.s^{-1}$ to 10^{-13} $m.s^{-1}$ at 400 ^{o}C as grain size changes from 10 to 1000 micrometres. These are not insignificant crack velocities on a geophysical time scale. The overwhelming body of evidence suggests that at temperatures below 300 ^{o}C, at least, stress corrosion is the main mechanism of subcritical crack growth over all crack velocities studied in experiments.
(ii) In general, for silicate rocks the less quartz present and the more ferromagnesion minerals present then the greater is the fracture toughness. Porosity, grain size, etc. can upset this trend. The

more complex the microstructure the lower is the susceptiblity to subcritical crack growth.

(iii) In general, the more isotropic the material or the less ductile the closer are the values of fracture energy for different crack tip displacement modes. It is possible that subcritical crack growth in shear mode is faster than in tensile mode for the same crack driving force.

(iv) At low crack velocities subcritical crack growth may be terminated by dissolution or by general diffusion creep before a true subcritical crack growth limit is attained. At temperatures of 200 ^{o}C and below, at least, the subcritical crack growth limit due to stress corrosion is much lower than that due to diffusional processes and falls at around 0.2 of the critical stress intensity factor, relatively independent of temperature.

(v) It is not clear whether stress corrosion crack growth in silicates is due to ionized or to molecular water. This is of considerable geophysical significance because the potential range of activities of molecular water in the Earth's crust is much smaller than that of ionic water species. Above a temperature of about 250 ^{o}C the activity of hydroxyl ions decreases whereas that of molecular water continues to increase. This suggests a way of distinguishing between the two models.

(vi) Apparent stress intensity factors will increase with pressure, but the true stress intensity factor at a crack tip will be independent of pressure, even if pore fluid pressure is not hydrostatic, provided that surface or blunt cracks are considered.

(vii) Residual strains of palaeotectonic origin can influence both fracture toughness and subcritical crack growth behaviour.

(viii) Microstructural features, such as grain size, porosity, mineralogy and nature of the grain boundary probably exert a key influence on the details of subcritical crack growth in rocks.

(ix) With a data base limited to crack velocities that are attained in most laboratory experiments it is impossible to distinguish between the several mathematical models of subcritical crack growth. The predictions of these models diverge significantly, however, at geophysically interesting slow crack velocities.

2. Very long term stress relaxation and constant strain rate experiments on wet, pre-faulted Preshal More basalt have been run at 300 ^{o}C and 400 ^{o}C. Strain rates down to 10^{-10} s^{-1} have been reached. These experiments were run in collaboration with S. M. Dennis. Preshal More basalt is a fine-grained olivine basalt.

In line with our earlier work on granite and quartz rocks we note a pronounced weakening effect due to the presence of water that is only apparent at strain rates below 10^{-6} s^{-1}. The stress exponent characterizing the stress dependence of strain rate in a log/log plot varies from 20-30 and is not much affected by temperature or water pressure.

3. Non-linear behaviour in the fracture of granite has been studied using the short-rod technique. We find that locked-in residual strains can cause estimates of fracture toughness to be out by 20-30%, or more. We have developed a method whereby these residual strains can be detected and corrected for.

4. An extensive series of experiments to study the influence of temperature (up to 400 ^{o}C) and water vapour activity, separately and combined, on subcritical crack growth in granite, gabbro and quartz has been completed. This program utilized a new environmental cell for double torsion testing. These experiments were run in collaboration with P. G. Meredith. For subcritical crack growth data both the load relaxation and the incremental displacement rate technique were used.

The fracture toughness of Black gabbro and Westerly granite measured in a vacuum of 1 Pa shows a distinct increase as temperature is raised to 100 ^{o}C followed by a fairly uniform decrease as temperature is further raised to 400 ^{o}C. This behaviour is attributed to the development of thermal microcracks which at first are not well linked or inter-connected. As temperature is raised above 100 ^{o}C the density of cracks is such that crack linking can occur to weaken the rocks.

The subcritical crack growth properties of quartz, gabbro and granite under the influence of temperature and water vapour activity show similar trends. In general, increasing the water vapour activity or temperature will increase the rate of crack propagation at constant crack driving force. Raising the temperature from 20^{o} to 200 ^{o}C at a water vapour pressure of 300 Pa increased the crack propagation rate in quartz by up to 5 orders of magnitude.

Gabbro and granite show subcritical crack growth curves that are shifted to higher stress intensity factors on raising the temperature from 20 ^{o}C to 100 ^{o}C rather than lower stress intensity factors. On further raising the temperature the crack growth curves shift to lower stress intensity factors. This behaviour mirrors the trend in fracture toughness noted above.

The stress corrosion index, or stress intensity factor dependence of crack velocity depends on the water vapour pressure. A lower resistance to subcritical crack growth is found at higher water vapour pressures.

5. Theoretical calculations indicate that geophysically significant rates of crack healing in dry quartzite will be attained once temperatures exceed 300 ^{o}C. Once the crack changes its aspect ratio to resemble a pore, however, the rate of crack healing will drop by several orders of magnitude. Much higher temp-

P3

eratures of 500°C or so will be required to maintain the same rate of crack healing as for narrow slit like cracks.

Reports

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Digital Signal Processing of Seismic Data

9930-02101

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Investigations

1. Seismograms from the 1922, 1934, and 1966 Parkfield, California earthquakes recorded at DeBilt, the Netherlands (1922, 1934, 1966), Edinburgh, Scotland (1922, 1934), Strasbourg, France (1934, 1966), St. Louis, Missouri (1922, 1934). Tacubaya, Mexico (1934, 1966), La Paz, Bolivia (1934, 1966), and Berkeley, California (1922, 1934, 1966) were used to compare the source parameters of the events.

2. Eighteen digital event recorders were deployed during May-June 1981 along the creeping-to-locked transition of the San Andreas fault zone near San Juan Bautista. Eighteen well-recorded microearthquakes were used to characterize the nature of the transition zone.

Results

1. The recurring Parkfield, California earthquakes are characteristic, having the same epicenter, magnitude, seismic moment, rupture area, and southeast direction of unilateral rupture expansion. The comparable seismic moments and disparate interevent times, 12 versus 32 years, are incompatible with a simple application of either the time- or slip-predictable earthquake recurrence models.

2. Source parameters for microearthquakes near San Juan Bautista are consistent with a more segmented and splayed fault geometry toward the northwest locked end of the creeping-to-locked transition of the San Andreas fault zone.

Reports

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THERMODYNAMIC DETERMINATION OF HYDRATION BOUNDS FOR WEAK CLAYS AND RECONSIDERATION OF THEIR FRICTION

14-08-0001-19795

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Investigations

1. Literature search for data on hydrated phase structures and hydration humidities of monoionic Na- and Ca-montmorillonites (MM) of known concentration of exchangeable cations (CEC).

2. Selection of six dominant phases for Na-MM, and calculation of their hydration bounds under laboratory and fault conditions using the generalized Clapeyron equation.

3. Construction of equipment to measure humidity and solid pressure at hydration bounds of Ca-MM.

Results

1. Approximately 37 useful papers since 1930 report investigations of differential thermal analysis (DTA), hygrogravimetry (HG), X-ray diffraction (XRD), calorimetry, infrared absorbtion (IRA), and nuclear magnetic resonance (NMR). Fortunately, most authors have exchanged cations to form monoionic clays; unfortunately, no standard materials have been maintained and the references cover a range of CEC from 75-140 meq/g. The greatest number of studies center on CEC=80 meq/g for Na-MM and 120 meq/g for Ca-MM, and it is suggested that future investigations might adopt such materials (e.g., standards SWy-1 and SAz-1 available from the Clay Minerals Society, U. Missouri). The DTA data are useless for thermodynamic purposes because of gross disequilibrium; the clays dehydrate when their interlayer water is in equilibrium with total ambient pressure rather than ambient water pressure. The HG data must be used with care because with ultrafine grain sizes, the surface adsorption becomes comparable to the interlayer filling; however, they provide an upper limit on interlayer water. Studies of d_{0001} spacing by XRD yield useless "mixed" values unless the samples are pre-equilibrated and measured at controlled humidity, in which case a clear progression of water layers is detected (here called D for none, I for one, II for two, etc.). Calorimetry is of marginal value because in contact with water, the change in water-surface energy is a complication, and in contact with air the large water/stream enthalpy dominates the small wet-clay/(dry-clay + water) enthalpy. Dehydration enthalpies are thus best inferred from HG studies at different temperatures. IRA and NMR data principally shed light on the bonding of interlayer water and its probable structure.

2. From the above data was extracted everything relevant to a typical Na-MM with 0.67 Na per unit cell [$O_{20}(OH)_4$ basis] and CEC=0.88 meq/g. The inferred major phases are D (dehydrated; contains only OH groups in gibbsite sheet), I3 (one interlayer of water with 3 H_2O/Na), Ii (one sheet of ice structure with Na substituting for H_2O), II6 (double water layer in octahedral configuration, 6 H_2O/Na), IIh (same as II6, but with remaining interlayer space filled by ice structure), and IIIh (analagous, with three layers). Higher hydrates occur in gels and muds, but are not geologically important because very little solid pressure is required to dehydrate them. Some authors argue for a denser close-packed structure (water density 1.30 g/cc) on the basis of HG data, but there is no support for this in theoretical mineralogy. Most likely, the HG data have been biased by surface adsorption. The ice structure, on the other hand, is supported by the fact that its theoretical density (0.87) and observed free energy are almost identical to ice.

The definitions of the phases plus XRD data yield molar volume changes for dehydration. Calorimetry and HG at varying temperature yield molar enthalpies. These were used in the Clapeyron equation to calculate hydration bounds with increasing solid pressure from the observed transition humidities (Fig. 1). The grey transition bands in these figures are the projection of observed transition humidities at zero confining pressure; they are thought to result from variation of CEC among the grain size fractions of the natural sample rather than from disequilibrium or experimental error.

The major conclusion is that Na-MM will be fully dehydrated at 4 km in a typical strike-slip fault (Fig. 1C). At greater depths it should have normal high friction.

3. Ca-MM is expected to be hydrated to greater depths because in the lab it retains some water down to approximately 1% RH. The measurement of this very small transition humidity is crucial to determine the state of Ca-MM deep in faults. A hygrometer based on the principle of varying capacitance of a hygroscopic plastic capacitor has been constructed and is being calibrated. It is hoped to achieve ±0.1% RH.

To complete the phase diagram of Ca-MM, it will also be necessary to observe the collapse of partially filled II structures to full I structures of equal water content. A liquid-pressure-medium, 3 kb, room-temperature press with internal strain gauges has been assembled for this purpose.

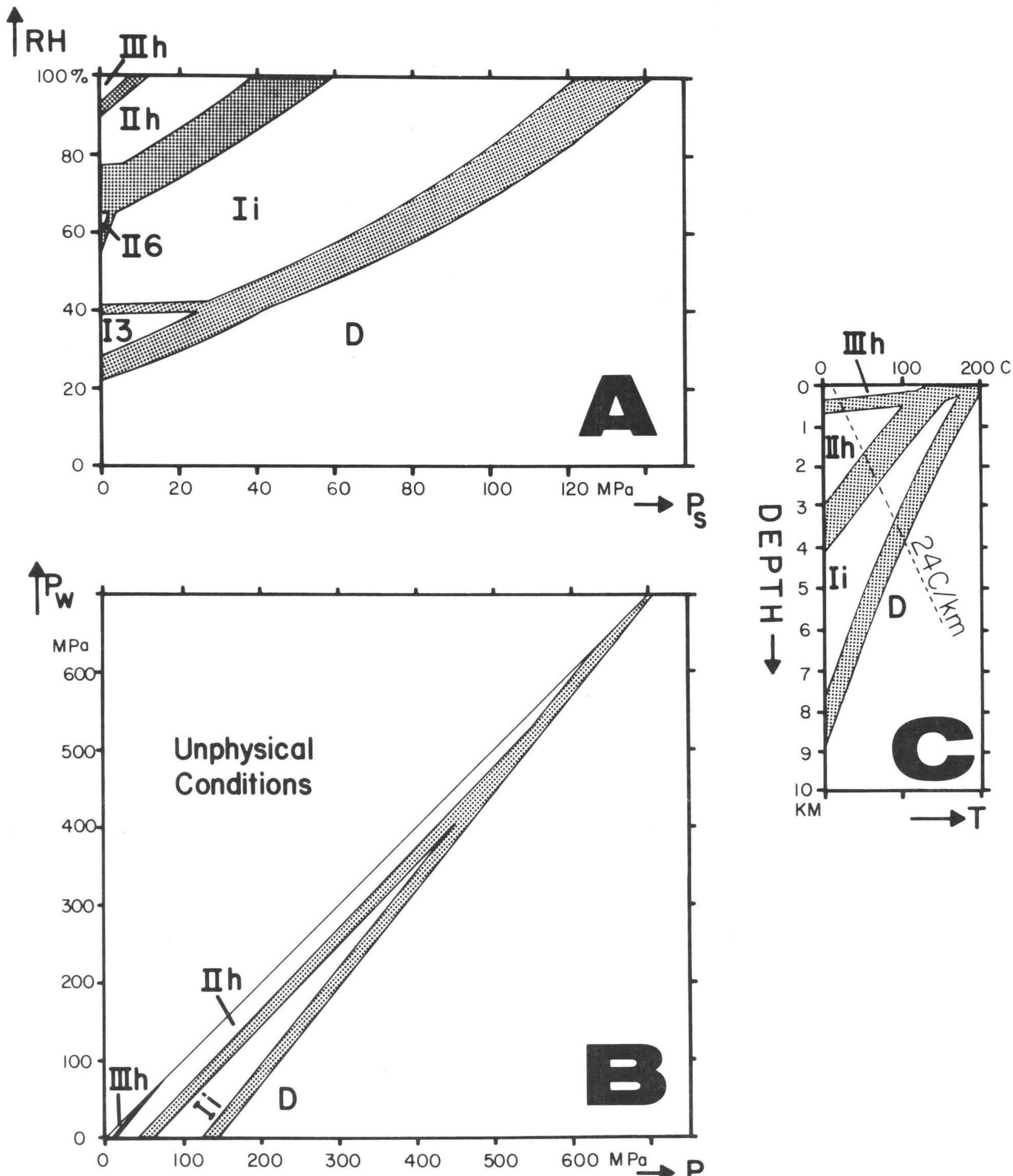

FIGURE 1: Hydration phases of Na-MM with CEC=0.88 meq/g.
A: In contact with air at 20C, varying humidity (RH) and solid pressure (P_S).
B: In contact with water at 20C, varying solid and water pressures.
C: In saturated fault zones of lithostatic solid pressure and hydrostatic water pressure.

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 whether we can predict or control them.

Results

The occurrence of significant electromagnetic disturbances associated with some earthquakes has received little acceptance in the scientific community even though a large number of eye-witness reports exist. A main objection of critics has been that significant charge cannot be concentrated in a conducting earth. We propose a mechanism by which large electric fields would be produced near the earth's surface.

Frictional heating of the fault during a large earthquake produces a thin zone of heated rock extending to near the earth's surface. If the earthquake is large enough a thin envelope about the fault exists in which water is vaporized. A consequence of this is that the conductivity of this zone would drop by 5 to 10 orders of magnitude depending on the water vapor pressure and temperature. If the fault is heated to over 500°C, conductivity of the fault itself increases resulting in a plane conductor surrounded by an insulator. This geometry is favorable for concentrating any charge, generated by vaporization, fluid transport, piezoelectric, triboelectric or other effects near the earth's surface.

An electric field intensity sufficient to cause coronal discharge over the fault could be produced in this manner. For earthquake lights to occur in this way frictional work done during the earthquake would have to be large. This may explain why in China it has been observed that earthquake lights are only observed during magnitude 7 earthquakes or larger.

Reports

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Earthquakes and the Statistics of Crustal Heterogeneity

9930-03008

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Investigations

Both the initiation and the stopping of earthquake ruptures are controlled by spatial heterogeneity of the mechanical properties and stress within the earth. Ruptures begin at points where the stress exceeds the strength of the rocks, and propagate until an extended region ("asperity") where the strength exceeds the pre-stress is able to stop rupture growth. The rupture termination process has the greater potential for earthquake prediction, because it controls earthquake size and because it involves a larger volume within the earth. Knowledge of the distribution of mechanical properties and the stress orientation and magnitude may enable one to anticipate conditions favoring extended rupture propagation. For instance, changes in the slope of the earthquake frequency-magnitude curve ("b-slope"), which have been suggested to be earthquake precursors and which often occur at the time of large earthquakes, are probably caused by an interaction between the stress field and the distribution of heterogeneities within the earth.

The purpose of this project is to develop techniques for determining the small-scale distributions of stress and mechanical properties in the earth. The distributions of elastic moduli and density are the easiest things to determine, using scattered seismic waves. Earthquake mechanisms can be used to infer stress orientation, but with a larger degree of non-uniqueness. Some important questions to be answered are:

** How strong are the heterogeneities as functions of length scale?

** How do the length scales vary with direction?

** What correlations exist between heterogeneities of different parameters?

** How do the heterogeneities vary with depth and from region to region?

Scattered seismic waves provide the best data bearing on these questions. They can be used to determine the three-dimensional spatial power spectra and cross-spectra of heterogeneities in elastic moduli and density in regions from which scattering can be observed. The observations must, however, be made with seismometer arrays to enable propagation direction to be determined. Three-component observations would also be helpful for identifying and separating different wave types and modes of propagation.

The stress within the crust is more difficult to study. Direct observations require deep boreholes and are much too expensive to be practical for mapping small-scale variations. Earthquake mechanisms, on the other hand, are easily studied and reflect the stress orientation and, less directly, its magnitude, but are often not uniquely determined by available data.

This investigation uses earthquake mechanisms and the scattering of seismic waves as tools for studying crustal heterogeneity.

Results

Scattering Theory

The general theory of weak scattering of elastic waves in anisotropically random solids has been worked out and a paper on the subject is nearing completion. Allowing the heterogeneity distribution to be anisotropic is necessary to deal realistically with the earth, which usually exhibits microstructure such as layering and foliation. The most important conclusion of this study is that the inverse scattering problem has a simple solution; if the intensity of the scattered waves can be measured as a function of direction and frequency, the power spectrum of the heterogeneity distributions in the medium can be inferred.

Probably the most important heterogeneities, in their effects on the mechanical behavior of rocks, however, are cracks. These are strong scatterers of elastic waves, so the theory discussed above cannot be applied to them. Therefore, much of the effort during this period has gone into investigating the theory of scattering from cracks. Recently published methods based on Huygens' principle seem to be capable of dealing with strong scattering from objects of arbitrary size and shape, although numerical integration must be used in all but the geometrically most simple cases. These investigations are continuing.

Data Analysis

The main effort during this period has been directed at obtaining observational data on seismic wave scattering and developing analysis techniques for such data.

A computer program for calculating the maximum-likelihood (or "high-resolution") frequency-wavenumber power spectra of data from seismometer arrays has been obtained from David Oppenheimer and converted to standard FORTRAN (it was dependent on MULTICS system features.) In this process, a change was made to the algorithm, greatly increasing its speed. Each spectrum can now be computed in about one minute on a PDP-11/70 minicomputer. With this program, we can analyze scattered elastic waves to determine their type and direction of propagation, information needed for the inversion process of determining the statistics of the earth's microstructure.

To analyze scattered seismic waves with a frequency of 10 Hz, data from seismic arrays with an aperture of about 1 km are needed. Attempts to identify any such data that may have been obtained from previous experiments (by the USGS or anyone else) have so far been unsuccessful. Therefore during the past summer, Walter Mooney deployed a 1-km array for just this purpose during a seismic refraction experiment in the coast ranges of southern California. The data obtained are unfortunately noisy, but their analysis is not yet complete.

Crack Fusion Dynamics

14-08-0001-20529

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Investigations

The physical processes of the fusion of small cracks into larger ones are nonlinear in character. A study of the nonlinear properties of fusion may lead to an understanding of the instabilities that give rise to clustering of large earthquakes. We have investigated the properties of simple versions of fusion processes to see if a catastrophic cascade of crack fusion events can produce the time delays (macroscopically) associated with anelastic creep and stress-corrosion in the laboratory and whether large scale instabilities culminating in repetitive massive earthquakes are possible.

Results

1. We have taken into account such diverse phenomena as the production of aftershocks, the rapid extension of large cracks to overwhelm and absorb smaller cracks, the influence of anelastic creep-induced time delays, healing, the genesis of "juvenile" cracks due to plate motions, and others. A preliminary conclusion is that the time delays introduced by anelastic creep may be responsible for producing catastrophic instabilities characteristic of large earthquakes as well as aftershock sequences.

2. By modifying the model of the preceding paragraph to take into account the stress release associated with the occurrence of large earthquakes, we obtain repetitive periodic cycles of large earthquakes. A preliminary conclusion is that a combination of the stress release or elastic rebound mechanism plus time delays in the fusion process are sufficient to destabilize the crack populations and, ultimately, give rise to repetitive episodes of seismicity.

3. Employing scale-invariance of fracture surfaces of earth materials that range from millimeter to ten kilometer size-scales, we have constructed a skeletal, dynamic model of crack fusion utilizing renormalization group techniques. We have shown that a critical value for microcrack densities exists above which crack fusion events proceed in a catastrophic way. The time required for the cascade of crack fusion events conforms with the time-to-failure observed in the experiments of Griggs and others.

Reports

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Fundamental Studies of Fault Mechanics and Earthquake Precursory Processes

14-08-0001-19793

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Investigations

1. Constitutive description of fault creep by solution/precipitation processes.

Results

The development of a constitutive theory for solution/precipitation creep of fluid-saturated, porous rocks has been pursued in this investigation along two lines. In the approach chosen, we are seeking to derive the relevant continuum 'creep-law' from a fine-scale (i.e., pore-scale) description of the solution/precipitation process through use of analytical averaging techniques. The problems encountered have concerned both the correct thermodynamical formulation of phase transformation on the pore-scale as well as the scope of the averaging technique. Although the latter is familiar (Lehner, 1978, 1979a,b), its application to fluid-saturated, porous materials that undergo a phase change poses difficult questions concerning the conversion of averages into meaningful macroscale variables. At the same time much insight is gained into aspects of the pore-scale constitutive description relevant to macro-scale behavior, such as the local thermodynamics of coherent phase transformations. Here we summarize our investigations (F. K. Lehner and W. Heidug) into:

Equilibrium conditions for coherent solid-solid and solid-liquid phase transformations

In order to find the equilibrium conditions for a non-homogeneously stressed solid in contact with another solid or in contact with a fluid, a generalization of the thermodynamic theory of homogeneous systems is necessary. The first steps in this direction were taken by Gibbs (1875-1876, 1877-1878), who assumed that the solid can only undergo elastic deformations and used a variational principle to determine the equilibrium condition that has to hold across a solid-liquid interface. Gibbs' results were reviewed and applied to the problem of recrystallization in a nonhydrostatically stressed solid by Kamb (1959a).

Detailed attempts to generalize Gibbs' result to a phase boundary which supports shear stresses are due to Fletcher (1973) and Robin (1974). Both authors restrict themselves to coherent phase transformations, but define this term differently.

Fletcher defines coherence as continuity of the infinitesimal strain components tangential to the interface, whereas Robin's definition of coherence is equivalent to requirement of continuity of the displacement

For small strains this result may be reduced to expressions found by Fletcher and Robin, upon observing that $[\underline{S}\underline{N}] = \underline{0}$ in equilibrium.

The condition (7) contains as a special case Gibbs-equilibrium condition for a solid-fluid interface. If we assume that the Cauchy stress in one of the phases is spherical, $\underline{\sigma} = -p^f I$, we get from (7)

$$[f] - [\underline{F}\underline{N}\cdot\underline{S}\underline{N}] = [f] + [\underline{F}\underline{N}\cdot p^f(\det\underline{F})(\underline{F}^{-1})^T\,\underline{N}]$$

$$= [f] + p^f\,[\frac{\rho_o}{\rho}] = 0$$

which is just another way of writing Gibbs' result.

Going back to (5) one may -- using the terminology of linear irreversible thermodynamics (de Groot and Mazur, 1962) -- identify U_N as a thermodynamic flux and $1/T\ [u-Ts-\underline{F}\cdot\underline{S}]$ as a thermodynamic force and postulate the linear force-flux relationship

$$U_N = \frac{L}{T}\,[u-Ts-\underline{F}\cdot\underline{S}]$$

where the phenomenological coefficient L does not depend on U_N and $[u-Ts-\underline{F}\cdot\underline{S}]$. One thus gains an expression for the rate at which the phase transformation occurs.

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vector across the phase boundary. Other differences between the theories are that Robin assumes a non-linear elastic behavior of the deforming solids, in contrast to Fletcher, who allows only infinitesimal deformations and, while making no explicit constitutive assumption, uses a somewhat unsatisfactory thermodynamic formulation.

Here we outline a derivation of the equilibrium conditions at coherent phase boundaries which avoids the shortcomings of the theories of Fletcher and Robin in that it does not rely on any constitutive or geometrical restrictions, while taking as essential the use of Hadamard's well-known geometric and kinematic conditions of compatibility.

We model the coherent solid-solid interface as a singular surface, assuming as a definition of coherency that the motion x(X,t) of some particle X is continuous across the interface.

For a singular surface of order 1 the kinematic and geometric conditions of compatibility read (Truesdell and Noll, 1965):

$$[\underline{F}] = \underline{a} \otimes \underline{N} \quad , \quad [\underline{FN}] = \underline{a} \quad , \quad [\underline{v}] = -U_N \, \underline{a} \tag{1}$$

F is the deformation gradient, N a vector normal to the interface, U_N the normal referential velocity of the singular surface, $\underline{v}$ the material velocity, $\underline{a}$ the amplitude of the singular surface and [ ] denotes the jump bracket. Further, one has the jump conditions (Truesdell and Noll, 1965) for linear momentum

$$\rho_o U_N [\underline{v}] + [\underline{SN}] = 0 \quad , \tag{2}$$

for energy

$$U_N [u + \frac{1}{2} \rho_o \underline{v}^2] + [\underline{v} \cdot \underline{SN}] - [\underline{Q} \cdot \underline{N}] = 0 \tag{3}$$

and for entropy

$$U_N [s] - \frac{1}{T} [\underline{Q} \cdot \underline{N}] = -\phi \leq 0 \tag{4}$$

δ_o denotes the mass density in a reference configuration, $\underline{S}$ is the Piola-Kirchhoff stress, $\underline{Q}$ the referential heat flux vector, T the temperature, u and s are the densities of internal energy and entropy, respectively, and ϕ is the non-negative entropy production term due to the phase transformation. Combining (1), (2), (3), (4) gives

$$0 \leq \phi = \frac{U_N}{T} [u - Ts - \underline{F} \cdot \bar{\underline{S}}] \tag{5}$$

where $\bar{\underline{S}} := \frac{1}{2}(\underline{S}^+ + \underline{S}^-)$. We make the plausible assumption that the interfacial entropy production ϕ depends -- among other quantities -- on U_N and we recall (de Groot and Mazur, 1962) that in equilibrium ϕ assumes its minimum and is equal to zero to conclude from (5) that in equilibrium

$$[u - Ts - \underline{F} \cdot \underline{S}] = 0 \quad , \tag{6}$$

or, equivalently with f: = u-Ts and use of (1)

$$[f] - [\underline{FN}] \cdot \underline{SN} = 0 \tag{7}$$

Laboratory Studies of Premonitory Slip and Other Precursory Phenomena

14-08-0001-09293

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30 September 1982

Investigations

The overall objective of this project is to investigate fault mechanics of gouge-host rock systems through controlled laboratory experiments with emphasis on understanding operative physical principles that govern shallow focus earthquakes. The focus of this research is to study in the laboratory premonitory slip and the behavior of polymineralic gouge materials and to correlate the results with the properties of natural fault zones.

Results

Structural analysis of the Polochic fault zone in western Guatemala. The deformation adjacent to, and within, a 40 km segment of the seismogenic Polochic fault zone is studied with a view towards investigating the processes and environment of deformation within the fault zone, and from these identify mechanical properties important to the earthquake process. The regional deformation is studied in order to relate the amount, and distribution, of displacement along the Polochic fault to the deformation within the fault zone.

The regional analysis focuses on two major structures: a high-angle reverse fault (Rio Ocho fault) and a fault north of the Polochic (Taluca fault). It is shown that (a) the Rio Ocho fault must correspond in age with the Cenozoic fold belt, (b) both predate the Polochic fault, (c) the Rio Ocho and adjacent sedimentary rocks have subsequently deformation to accommodate fault-induced strain, and (d) these deformations are produced by combined pure and simple shear. The Taluca fault is shown to be a left-lateral, strike-slip fault which is structurally continuous with the Polochic fault. A model is proposed for the structural history of the Polochic fault in which the Taluca represents an older, now abandoned, trace of the Polochic. The Polochic fault is not older than Tertiary.

Sedimentary and basement rocks are deformed in the fault zone. Limestone microbreccias have, across a 350 m distance, a 45% reduction in ultimate strength, a 4-5-fold increase in effective and total porosity, and a three order of magnitude in grain size. Permeabilities are in the nano-darcy range. Dilatancy may account for this deformation. Basement rocks are deformed by crystal-plastic and cataclastic processes.

Microstructures in a mylonite-gneiss show that simple shear describes the deformation and that a north-block-up component of vertical movement is associated with the Polochic fault. Isotopic compositions, paleo-temperatures calculated from these, and mineralization are evidence for hydrothermal fluids in the fault zone. Pore fluids must be present at least in the upper 5-10 km of the crust. Shear-localization and strain-softening processes produce a weak fault zone in which only small changes in the state of stress are required to promote an instability.

PART II. Effect of Displacement Rate and Gouge Composition on the Sliding Behavior of Simulated Gouge

The effects of displacement rate and gouge composition on the sliding behavior of simulated gouge are studied. The experiments are conducted at room temperature, constant confining pressure of 65 MPa, and variable displacement rates from 10^{-2}cm/s to 10^{-6}cm/s in triaxial experiment. Gouge materials are pure calcite, pure quartz, and their mixtures.

The results indicate that both displacement rate and gouge composition influence the sliding behavior of gouge. As displacement rate decreases, the sliding mode changes from stick-slip to stable sliding for pure quartz gouge. The mixed calcite-quartz gouge shows that the more abundant component controls the overall sliding mode as displacement rate decreases.

Although mixed calcite-quartz gouges deformed at 10^{-2}cm/s show the gradual and monotonic change in the sliding mode, the sliding behavior is more complicated as displacement rate decreases from 10^{-2}cm/s to 10^{-6}cm/s.

Ultimate frictional strength of gouge depends both on displacement rate and on gouge composition. Pure calcite gouge has higher frictional strength than the other gouges texted. Generally, the ultimate frictional strength of mixed gouge decreases with increasing quartz content. As displacement rate decreases, the frictional strength of the gouge increases.

Microscopic observations indicate that regardless of the sliding behavior, cataclastic fracture is the major deformation mechanism within the gouge at testing conditions. No direct relationship between the fabric of deformed gouge and the sliding mode is recognized.

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Theoretical Mechanics of Earthquake Precursors

9960-02115

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Investigations

1. Continued analysis of strain-induced pore pressure changes in a seismically active region.

2. Studied the mechanics of interaction of the Hayward and Calaveras faults southeast of San Francisco Bay (with B. Mavko).

Results

1. Pore water in earth materials is known to affect seismic wave velocity and attenuation, fault strength, and certain kinds of soil failure such as liquefaction. Simultaneous in-situ recordings of acceleration and wave-induced pore pressure changes (recorded by E.L. Harp, Engineering Geology Branch, U.S.G.S., project 9550-01452) were analyzed to determine the fluid effects on wave propagation and to test existing models of pore deformation. The recordings were made in saturated lake gravels near the epicenters of the 1980 Mammoth Lakes, California, earthquakes.

   Near-surface strains, determined from the acceleration records, were less than 10^{-4}, and the relation between pore pressure and acceleration indicates primarily linear deformation. Measured pore pressure, P, is proportional to, and in phase with, surface vertical acceleration during the P-wave train, and it lags by 1/4 cycle the surface acceleration during the S-wave train. In both cases, P is approximately proportional to the solid dilatational strain and the phase difference between P-waves and S-waves is due to interference and mode conversion at the free surface.

2. A theoretical model of the zone of intersection of the Hayward and Calaveras faults was constructed on the basis of seismic and geodetic data and dislocation calculations. The strike-slip faults were modeled as two-dimensional cuts in an otherwise homogeneous elastic plate. Geodetically determined slip rates were specified on faults outside of the modeled region, and remote displacements were imposed parallel to the plate boundary. Slip on the modeled faults was computed, subject to frictional boundary conditions on the fault surfaces. Models in which the Hayward and Calaveras faults are connected along the trend of the Mission Peak fault can account for the observed geodetic displacement across the

zone, but only if the model faults are much smoother than the mapped surface traces. (See also B. Mavko, Seismic Studies of Block Tectonics, this volume.)

Reports

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Probabilistic Approach in Earthquake Forecasting (I - Compilation, Evaluation and Preliminary Analysis of Data)

14-08-0001-19908

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During the period covered by this report, substantial effort was directed towards compilation of a worldwide data base of precursory reports. Thus far, around 700 reported precursors of about 350 earthquakes, including the negative observations, have been compiled in 11 categories with 31 subdivisions. The data base was subjected to an initial sorting and screening by imposing three restrictions on the ranges of main shock magnitude ($M \geq 4.0$), precursory time ($t \leq 20$ years), and the epicentral distance of observation points ($X_m \leq 4.10^{0.3M}$). Of the 31 subcategories of precursory phenomena, 18 with 9 data points or more were independently studied by regressing their precursory times against magnitude. The preliminary results tend to classify the precursors into four groups:

- o The precursors which show weak or no correlation between time and the magnitude of the eventual main shock. Examples of this group are foreshocks and precursory tilt.

- o The precursors which show clear scaling with magnitude. These include seismic velocity ratio (V_p/V_s), travel time delay, duration of seismic quiescence, and, to some degree, the variation of b-value, and anomalous seismicity.

- o The precursors which display clustering of precursory times around a mean value, which differs for different precursors from a few hours to a few years. Examples include the conductivity rate, geoelectric current and potential, strain, water well level, geochemical anomalies, change of focal mechanism, and the enhancement of seismicity (few years), only reported for larger earthquakes.

- o The precursors with bimodal patterns of precursory times such as leveling changes, the occurrence of microseismicity, and to some extent resistivity change.

In addition to the reported magnitude and precursory time, some observations also contained estimates of distance and signal amplitude. Each category with a sufficient number of multiple parameters reported was subjected to multiple linear regression. The usefulness of these regressions at this stage appears to be limited to specifying which of the parameters shows a more significant correlation. Standard deviations of residuals of precursory time against magnitude are generally reduced when observation distance enters as a second independent variable. The effect is more pronounced for water well level and conductivity rate changes.

While a substantial portion of the data seem to suffer from personal bias, hence should be regarded as noise, the observations of a number of strain sensitive phenomena such as strain, water well level, and conductivity rate changes, appear to be internally more consistent. For instance, their precursory times suggest a scaling relationship with the strain energy surface density associated with the main shock. The scaling is not identical for all three phenomena so that they may constitute the imminent, short- and intermediate-term manifestation of the same process, respectively.

The predictive capability of a logistic model is tested in southern California for the variation of regional b-value over the past 50 years. It is found that a decrease over a three-year window in this parameter slightly enhances the probability of occurrence of larger earthquakes $M \geq 5\text{-}3/4$ during the succeeding year. The same model was applied to the seismicity of five separate tectonic units (i.e., Transverse Ranges, Gulf, Mojave Desert, Peninsular and Coast Range regions) to which southern California was subdivided. Very preliminary results indicate that:

- The probability of occurrence of events of $M \geq 5\text{-}3/4$ in the Transverse Ranges is enhanced by the increase of seismicity in the Peninsular and Mojave Desert regions over the previous three-to five-year window, and by a decrease of seismicity in the Gulf region over the previous five years.

- An increase of seismic activity in the Mojave Desert, Gulf and Peninsular regions increases the probability of seismic activity in the Gulf region with a four-year lag.

Internal Friction and Modulus Dispersion

9960-01490

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Investigations

1. Internal friction in rocks at seismic frequencies and strain amplitudes. The manuscript "Internal friction in fused-quartz, steel, plexiglas and Westerly granite from 0.01 to 1.00 Hz at 10^{-8} to 10^{-7} strain amplitude", by Liu and Peselnick was revised and resubmitted to J. Geophys. Research. A new manuscript was started for inclusion as a chapter in the volume Geophysics of the Methods of Experimental Physics series (Academic Press). The title is "Laboratory measurements of internal friction in rocks and minerals at seismic frequencies" by Peselnick and Liu.

2. Elastic Properties of Rocks; (a) Development of quasistatic, small strain Young's modulus apparatus for determining the influence of cracks on anisotropy and internal friction. (b) Ultrasonic methods.

Results

2. Elastic properties of rocks (a) The determination of quasi-static Young's modulus of rocks at small strain (10^{-8} - 10^{-7}). Experimental errors were found to result from (1) unknown displacements in the steel base plate of the apparatus, (2) unknown displacements at the interface between the sample and the base plate, (3) inhomogenous stress in the sample and (4) non reproducible strain calibration. Two of the uncertainties were removed. The strain in the steel base plate was eliminated by mounting the sample on a thick (rigid) granite surface plate so that the loading of the sample does not greatly affect the strain in the steel base plate resting on the granite block. (The sample was previously mounted on the steel base plate). The uncertainty resulting from unknown interface deflections was detected and eliminated by providing a means for measurement of the displacement as a function of position on the sample. The large displacements observed near the interface were not observed at more remote positions along the sample. The error in the measurement of Young's modulus (E) for plexiglas at 10^{-7} strain was determined by comparison of the static value of E with the value determined from ultrasonic velocity measurements:
E (static) = (0.65 to 0.69) x 10^6 psi
E (ultrasonic) = 0.89 x 10^6 psi
Further experimental study is required to resolve this 30 percent difference.

The apparatus for determining ultrasonic velocities in larger rock samples (4.5 cm diameter) as a function of pressure was completed.

Reports

L. Peselnick, The Differential Path Phase Comparison Method for Determining Pressure Derviatives of Elastic Constants of Solids, J. Geophys. Res., 87, 6799-6804, 1982.

Fundamental Studies of Fault Mechanics and Earthquake Precursory Processes

14-08-0001-20535

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Investigations

Studies carried out under this project have been a continuation of basic studies on the fundamental mechanics of fault instability, and on the relation of pre-instability deformation to the generation of earthquake precursors. The work involved the following topics:

1. Pre-seismic rupture progression across a slip-deficient gap zone at a tectonic plate boundary.
2. Fault instability mechanics in relation to state- and rate-dependent descriptions of frictional slip.

Results.

1. Pre-seismic rupture progression across a slip-deficient gap zone at a tectonic plate boundary has been studied in detail, with the use of general plane stress theory and thickness-averaged values of all considered variables in the lithosphere to describe transmission of stress in the lithosphere-asthenosphere system. The coupling of elastic lithospheric plate to the viscoelastic asthenospheric layer was realized with the use of generalized Elsasser model (Rice, 1980). The deformation front, rising from some depth of lithosphere where conditions for total creep prevail, was modelled as quasi-statically growing crack, progressing upwards, the process culminating in a breakage of the most shallow part of lithosphere (great earthquake analog). Detailed studies allow prediciton of the time-dependent slip on the fault during the whole earthquake cycle, as it depends on tectonic load rate, thickness of the lithosphere and its strength distribution in the depth-wise direction (in the model expressed by an assumed depth distribution of critical fracture energy $\mathcal{G}$, characterized by a bell-shaped curve as proposed by Stuart and Mavko (1979)), rupture length, and relaxation time of the asthenosphere. Some numerical results are presented in Table 1; all data given there have been calculated for an earthquake rupturing a segment of plate boundary five times longer than assumed plate thickness. The co-seismic slips and stress drops predicted, for a given depth locations of the fracture strength peak and width in the bell-shaped distribution, are proportional to $(\mathcal{G}_{max})^{1/2}$, where $\mathcal{G}_{max}$ is the fracture energy at the peak of the bell curve. The slips and stress drops are found to have a range appropriate for great earthquakes, as shown in Table 1, when $\mathcal{G}_{max} = 4 \times 10^6 J/m^2$. A paper covering this part of work has

been submitted to J. Geophys. Res. (Li and Rice, 1982).

In our continuing work we have calculated strains at the Earth's surface implied by the model of rupture progression. Preliminary results suggest that in a time period ranging from approximately 2 months to 5 years (depending on length along strike of the rupturing segment and on tectonic stressing rate), the strain rate directly above the rupture will have more than doubled over its background level as it accelerates towards final fracture. We also predict a simultaneous but modest strain rate reversal at distances from the surface trace of the order of a third to one lithosphere thicknesses.

2. We are examining models of fault instability assuming a rate and state dependent constitutive framework for fault slip. In this, the shear strength $\tau(t)$ at time t is assumed to be a direct function of the slip velocity V(t) and a functional of prior slip velocities V(t'), $-\infty < t' < t$. This functional dependence may be regarded as being equivalent to a dependence on state of the surface, sometimes represented explicitly (see below) in terms of one or a few evolving state parameters. Most of the modelling has been done for constant normal stress, but we have considered some effects of perturbing the normal stress during slip and, in such cases, we assume a direct linear dependence $\tau(t)$ on the normal stress $\sigma(t)$ so that $\tau(t)/\sigma(t)$ satisfies constitutive relations of the type outlined above.

General features of the constitutive response (positive instantaneous dependence of strength on velocity, negative long-time dependence), and of our manner of developing a linearized functional representation appropriate for small perturbations of velocity, have been discussed in our last report in the series. In terms of this functional representation, we were able to develop very general solutions for the critical spring stiffness (below which instability occurs) of a one-degree of freedom sliding dynamical system, subjected to a small perturbation from steady state sliding. We also described creep waves on interfaces between sliding elastic solids and derived expressions for the critical spatial wavelength of a small perturbation, above which the perturbation grows in time. Effects of inertia were included in both types of calculation, and quantified in terms of the ratio of the fundamental vibration frequency of a freely slipping system to the frequency of the flutter oscillations of slip speed, that characterize instability at critical stiffness according to linearized theory. This flutter frequency is completely determined by the constitutive relation for slip and, among other results, it was shown that no steadily slipping system is stable when its fundamental vibration frequency is smaller than this flutter frequency. Some of our earlier results in this area were given in the last report. A full manuscript, including the more recent results on inertial effects, has been completed and accepted for publication (Rice and Ruina, 1982).

Current work in the area focuses on non-linear aspects of stability, specifically for the two-state-variable constitutive relation

$$\tau = \tau_* + A\sigma \ln(V/V_*) + \sigma\psi_1 + \sigma\psi_2 ,$$

$$d\psi_i/dt = -(V/L_i)[\psi_i + B_i \ln(V/V_*)], \ i = 1, 2,$$

and (more extensively thus far) for the one-state-variable form to which it simplifies when $L_1 = L_2$. Progress includes completion of the non-linear Hopf bifurcation analysis for the two-state-variable law in description of quasi-static slip motion of a single degree of freedom elastic system. This shows that for $L_1 \neq L_2$, there exists an extremely small range of spring stiffness, just below the critical stiffness according to linear stability theory, for which small but finite amplitude limit cycles oscillations in V exist.

Most additional work has been on numerical solutions for a single degree of freedom system, finitely perturbed from a state of steady slip. We find that even when the spring stiffness is large enough to assume stability according to linear stability theory, a sufficiently large perturbation will lead to instability. Nevertheless, the critical size of such a perturbation is found to increase in an approximately exponential relation with the ratio of spring stiffness to its critical value according to linearized theory.

References

Rice, J.R., The mechanics of earthquake rupture, in: "Physics of the Earth's interior", A.M. Dziewonski and E. Boschi (eds.), Italian Physical Society, North Holland Publ. Co., pp. 557-649, 1980.

Stuart, W.D., and G.M. Mavko, Earthquake instability on a strike-slip fault, J. Geophys. Res., 84, pp. 2153-2160, 1979.

Reports

Li, V.C., and J.R. Rice, Pre-seismic rupture progression and great earthquake instabilities at plate boundaries, August 1982, submitted to J.Geophys.Res.

Rice, J.R., and A.L. Ruina, Stability of steady frictional slipping, April 1982, to be published in Trans. ASME, J. Applied Mech.

Stopinski, W., and R. Dmowska, Rock resistivity in the Lubin (Poland) copper mine and its relation to variations of strain field and occurrence of rockbursts, presented at symposium "Seismicity in mines", organized by International Society for Rock Mechanics, Johannesburg, South Africa, September 13-17, 1982; to be published in Proceedings of symposium.

Publication:

Dmowska R., and V.C. Li, A mechanical model of precursory source processes for some large earthquakes, Geophys. Res. Letters, vol. 9, N. 4, pp. 393-396, 1982.

Table 1.

Some numerical results of modelling a pre-seismic rupture progression across a slip-deficient gap zone at a tectonic plate boundary.

thickness of lithospheric plate (km)	75	75	35	35
depth of seismogenic layer (km)	7.5	15	7	7
width of seismogenic layer (km)	5	10	5	10
estimated maximum coseismic slip (m)	4.4	3.7	2.5	2.3
seismic stress drop (bars)	45	30	43	40

Appendixes

Li, V.C., and J.R. Rice, Pre-seismic rupture progression and great earthquake instabilities at plate boundaries, August 1982, submitted to J. Geophys. Res.

Rice, J.R., and A.L. Ruina, Stability of steady frictional slipping, April 1982, to be published in Trans. ASME, J. Applied Mech.

Stopinski, W., and R. Dmowska, Rock resistivity in the Lubin (Poland) copper mine and its relation to variations of strain field and occurrence of rockbursts, presented at symposium "Seismicity in mines", organized by International Society for Rock Mechanics, Johannesburg, South Africa, September 13-17, 1982; to be published in Proceedings of symposium.

THEORETICAL STUDIES OF RUPTURE PROCESSES IN GEOLOGICAL MATERIAL

14-08-0001-19850

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During the year May 21, 1981 to May 30, 1982 we have continued work on effects of dilatant hardening on the development of incipient shear rupture and on energy radiation from seismic sources.

Effects of Dilatant Hardening on Shear Rupture

Dilatant hardening as it may occur in situ is being studied by considering shear deformation of a layer containing an initially weakened sublayer. The sublayer represents a fault zone that has been weakened mechanically by past faulting, or, perhaps, by chemical effects. Displacement imposed at the boundary of the layer at a constant rate $\dot{U}$ represents the slow increase of large scale tectonic loading. A perturbation expansion in small values of $\dot{U}h/c$, where h is the layer height and c is the diffusivity, yields as the zeroth order term uniform pressure throughout the layer and homogeneous deformation in each sublayer. Succeeding terms in the expansion introduce gradients in pressure that become increasingly localized near the interface as instability develops. An expansion for large $\dot{U}h/c$ indicates essentially undrained response in each sublayer, with a boundary layer of high gradients at the interface. An approximate approach, motivated by these asymptotic results, idealizes the region of high gradients as negligibly small: the deformation in each sublayer is homogeneous and the fluid mass flux between the sublayers is assumed to be proportional to the pressure difference. Results computed from this approach agree adequately with a direct finite difference solution although there are some discrepancies in the details.

As expected, dilatant hardening introduces a strong rate dependence into the development of localized deformation. Larger values of average strain in the layer are achieved for more rapid rates of boundary loading although the total time to instability is less than for smaller rates of boundary loading. For very slow rates of boundary loading representative of tectonic strain rates, dilatant hardening does not appear to increase substantially the maximum stress or average strain achieved in the layer. Nevertheless, dilatant hardening does cause a significant time delay in the onset of localized deformation and during this period the rate of deformation is controlled by the rate of pore fluid diffusion.

Energy Radiation from Seismic Sources

An examination of the energy radiated from two simple sources, a spherically symmetric source and a constant stress drop (crack) fault model have been used to clarify the meaning of the general expressions for radiated energy obtained by Rudnicki and Freund (1981). Calculations with the spherical source demonstrate that the point source approximation for the radiated energy is not asymptotic in the sense that it does not approach the actual radiated energy for small source dimension. The energy radiated from the spherical source for a ramp time function is compared to that for a modulated ramp in order to simulate the effect of "chattering" or complexity of faulting. The comparison demonstrates that the modulation is not effective in increasing the total radiated energy even though it does cause a peak in the spectrum of the farfield particle velocity at the characteristic frequency of the modulation. For $a/cT > 2$ where a is the radius of the spherical source, c is the wave speed and T is the rise time, the strain energy change overestimates the radiated energy by less than a factor of two. The simple fault model is used to examine further the circumstances for which the radiated energy can be predicted adequately from the knowledge of the difference between the static end states. The conditions given by Rudnicki and Freund (BSSA, 1981) are shown to generalize the assumption of Orowan (1960) that the final stress equals the dynamic friction stress.

Seismic Source Mechanism Studies in the Anza - Coyote Canyon Seismic Gap

14-08-0001-28397

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I. Review of Anza Seismicity

Recent seismic activity in the Anza area is shown in Figure 1 for the period of April, 1980 through March, 1981. The main aspects of the local seismicity are:

1. A diffuse spread of moderate seismicity along the three fault zones of Anza (San Jacinto, Coyote Creek and, possibly, Buck Ridge). This extends southeastward through the Borrego Valley.

2. A more intense band extends nearly east-west from beneath Toro Peak to west of Horse Canyon. This area has produced about one magnitude 5 earthquake per year for the last several years, and has also been the site of relatively intense microearthquake activity for at least the last 15 years.

3. To the northwest of this active region is the so-called Anza Gap. This part of the San Jacinto fault has not ruptured in a major earthquake since 1900. For the last decade it has also shown a paucity of small events (magnitude 2 to 4) relative to the regions adjacent to it; this may have been true earlier but the accuracy of routine location is insufficient to show this. It is of course tempting to speculate that this is a locked zone. It has been suggested that this locking may be in part caused by higher stress normal to the fault, for which they find evidence in composite focal mechanisms of nearby events.

4. To the southwest of this locked zone is an area of sporadically intense seismicity. Figure 1 shows two examples: a very intense swarm beneath Cahuilla Valley, at the extreme west side of the figure, and a small cluster beneath the town of Anza. The Cahuilla Valley swarm was not active in 1979, but was in 1978; also in 1978, there was a cluster of events to the southeast, near Beauty Peak. The surface geology in this area is granitic rocks of the Coast Range batholith, with no evidence of faulting, so it is unclear what this activity means.

5. Northwest of the locked zone there is activity on the San Jacinto and Hot Springs faults which is comparable to that southeast of it. The length of the quiet zone is about 20 km.

Figure 2 illustrates the relative activity in some of these areas. Region A corresponds to the northwest zone (#5), region B to the zone of the San Jacinto (#4), and region C to the Horse Canyon area (#2). The most obvious feature is the intense activity from the Cahuilla Valley swarm in 1980 and 1981. This began several months after a magnitude 5 event under Horse Canyon on February 25, 1980. The seismicity of the fault zone seems to be fairly steady, although there is a suggestion of a decrease in the number of larger events in region C during the swarm.

Clearly, the present tectonics around the Anza area are not simple. The seismicity patterns provide a skeletal view of what is happening, but further understanding will require more information about the stress field in this area. This, our source mechanism studies should provide.

II. Network Status

The initial seven stations of the Anza network were installed during the past summer (1982). Each site consists of a cement vault and pad which act both as a base for the seismometers and as a protective enclosure. Inside the cement vault, the seismometers and electronic package are enclosed in a steel box. Outside the vault are the antenna, usually a short fiberglass whip, and cables to either a nearby line power source or to solar panels.

The three component data are digitized at the site at 250 times per second. The multiplexed serial bit stream is transmitted *via* VHF FSK telemetry to Toro Peak where data from the different stations are further multiplexed into a single serial bit stream. These data are then transmitted to IGPP *via* a dedicated microwave link with a repeater on Mt. Soledad in La Jolla. The demultiplexing and buffering of the data is handled by a 6809 based microcomputer which is connected by DMA to a PDP 11/34 microcomputer. This machine further buffers the data, performs event detection and recording of the selected data on magnetic tape. The software system for the 11/34 was developed by Larry Baker of the U.S. Geological Survey at Menlo Park.

Since early fall, the seven station network has been operating continuously with only a few communication outages of significant duration. Occasional parity errors caused by transmission path noise are bothersome in that they usually cause the detection to trigger, but fairly simple processing of the raw data tapes eliminates most of these false events.

This project is conducted in cooperation with Tom Hanks, Joe Fletcher and Larry Baker of the U.S. Geological Survey at Menlo Park.

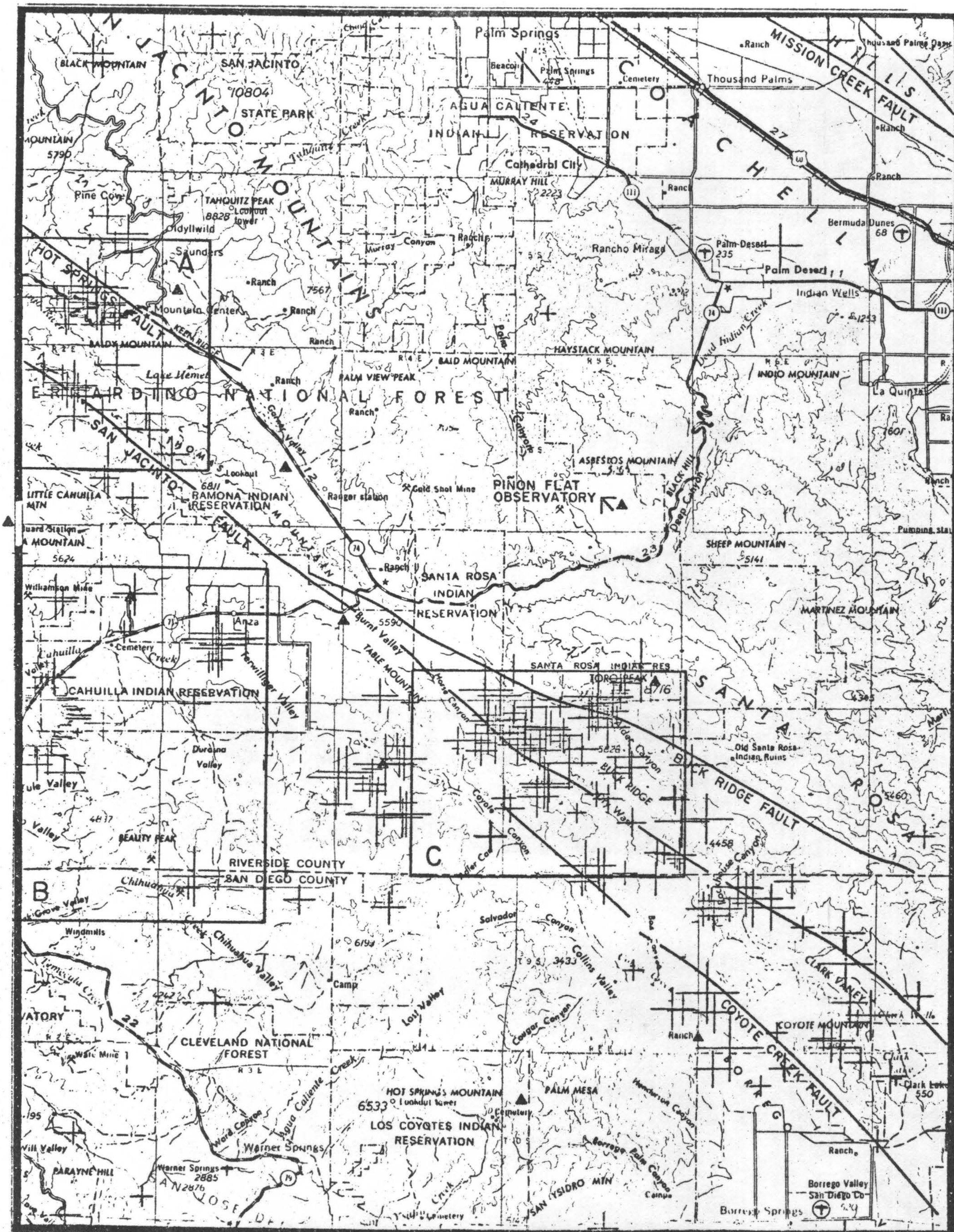
Palm Springs
SAN JACINTO
STATE PARK
SAN JACINTO MOUNTAINS
AGUA CALIENTE INDIAN RESERVATION
Cathedral City
Thousand Palms
MISSION CREEK FAULT
COACHELLA
Rancho Mirage
Palm Desert
Indian Wells
Bermuda Dunes
La Quinta
TAHQUITZ PEAK
Idyllwild
Mountain Center
HOT SPRINGS FAULT
SAN JACINTO FAULT
BALDY MOUNTAIN
Lake Hemet
SAN BERNARDINO NATIONAL FOREST
HAYSTACK MOUNTAIN
INDIO MOUNTAIN
ASBESTOS MOUNTAIN
PIÑON FLAT OBSERVATORY
RAMONA INDIAN RESERVATION
SANTA ROSA INDIAN RESERVATION
SHEEP MOUNTAIN
MARTINEZ MOUNTAIN
Anza
CAHUILLA INDIAN RESERVATION
Burnt Valley
TABLE MOUNTAIN
SANTA ROSA INDIAN RES
TORO PEAK
BUCK RIDGE FAULT
SANTA ROSA
BUCK RIDGE
Old Santa Rosa Indian Ruins
RIVERSIDE COUNTY
SAN DIEGO COUNTY
A
B
C
CLARK VALLEY
COYOTE MOUNTAIN
COYOTE CREEK FAULT
Collins Valley
CLEVELAND NATIONAL FOREST
HOT SPRINGS MOUNTAIN
LOS COYOTES INDIAN RESERVATION
Warner Springs
Borrego Valley
Borrego Springs

Figure 1.

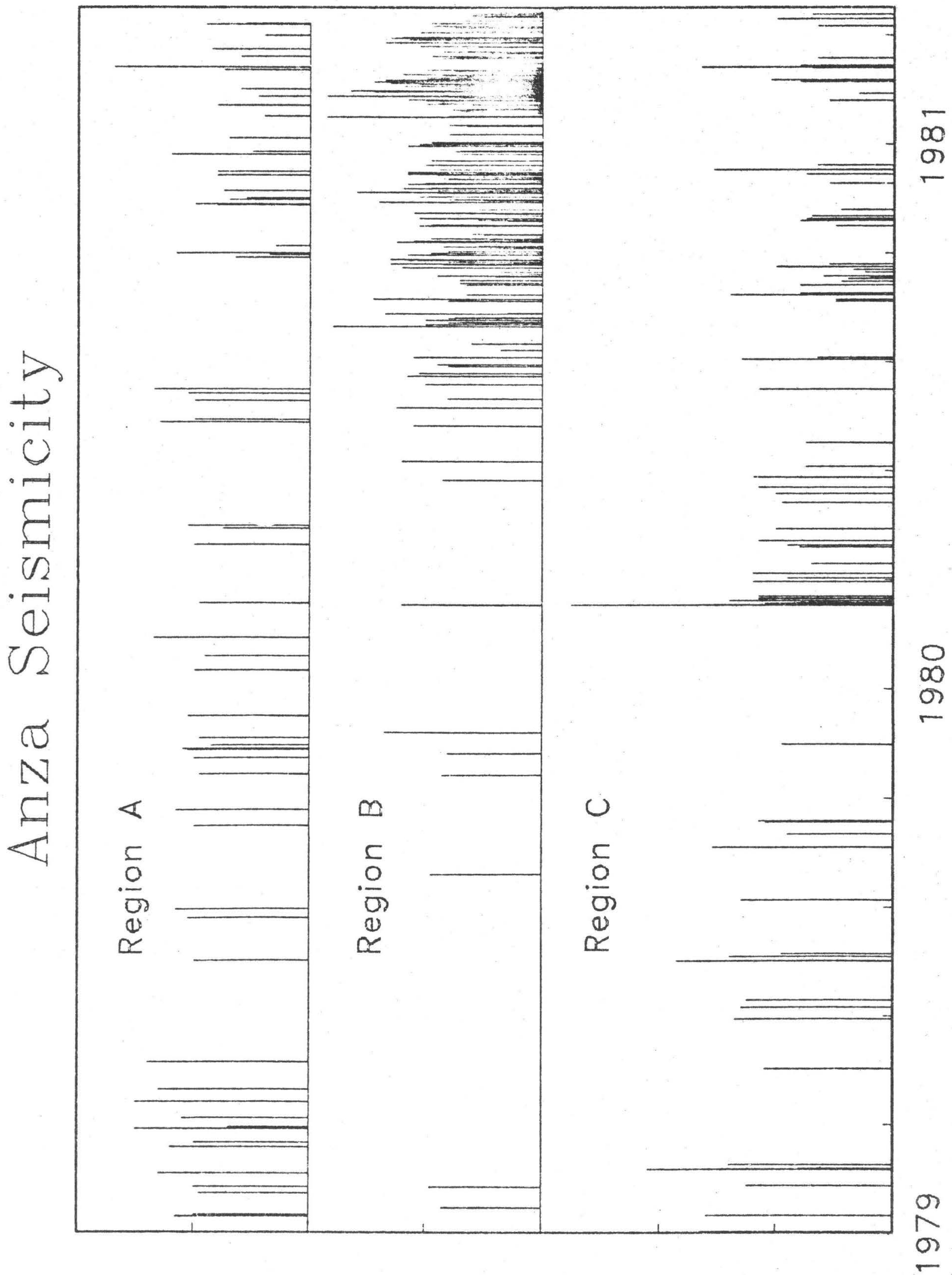

Figure 2.

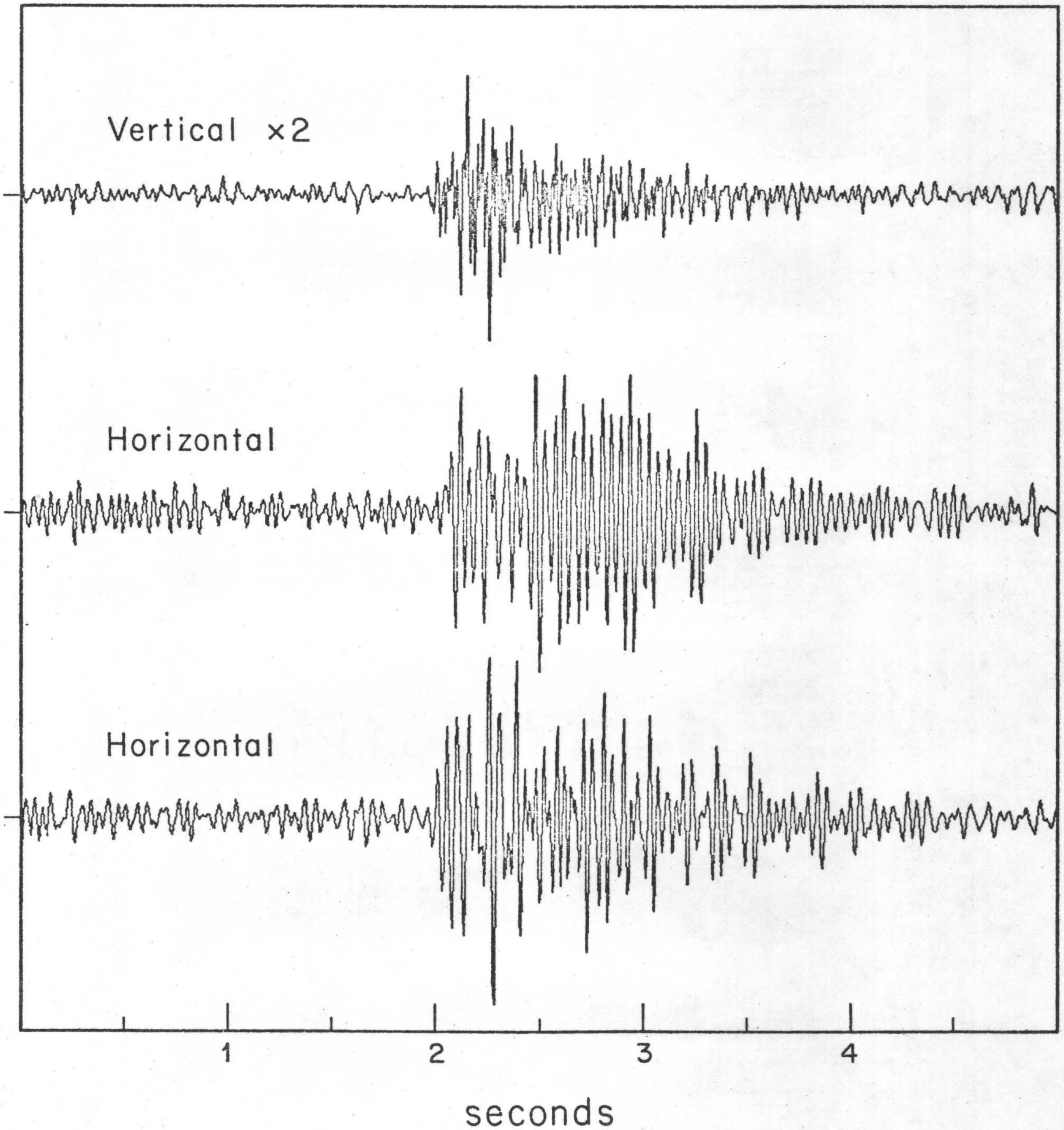

Figure 3.

Experimental Study of Ultra Fine-Grained Granular Fault Gouge
(Contract No. 14-08-0001-19789)

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Investigations

(1) Preparation of ultra fine-grained (UFG) quartz and feldspar powder for the study of frictional and sintering properties of granular gouge.

(2) Investigation of the mechanisms for pore pressure generation in a gouge layer.

Results

(1) Following the procedure for quartz, we have completed the preparation of UFG feldspar by purifying and separating crushed Amelia albite into 5 different fractions with median grain sizes ranging from 1 to 25 µm. Sintering experiments are in progress.

(2) 1 mm thick layer of UFG quartz (median grain size = 1 µm) was sandwiched between Westerly granite endpieces and deformed in a conventional triaxial configuration. In most of the experiments, confining pressure was fixed at 200 MPa and pore pressure at 10 MPa. Direct access to the gouge layer is not possible in such a configuration and therefore pore volume change in the gouge can not be measured with high accuracy. Under dry condition, or if the sample is fully drained, the peak frictional resistance is expected to increase slightly with an increase in slip rate. On the other hand, the opposite effect of 'strain rate weakening' is to be expected if shear-induced compaction results in pore pressure transients within the gouge layer. In our study, we compared the effect of strain rate cycles (ranging from 10^{-4}/s to 10^{-6}/s) on the peak frictional strength for two deformation stages: the initial loading stage when both the deviatoric and normal stresses increase significantly, and subsequently the frictional sliding stage when the stress state is relatively stable and the deformation is basically direct shear across the gouge layer.

Typical results are shown in Figures 1 and 2. The saturated sample Q1 in Figure 1 was loaded at 10^{-4}/s. Its peak strength is about 60 MPa lower than that of a dry sample, indicating the generation and maintenance of a pore pressure anomaly. Another sample Q2 initially loaded at 10^{-4}/s experienced several stick slip events before achieving the residual strength comparable to that of Q1. The piston was held at H and we observed a pore pressure transient lasting about 1 hour which is the characteristic time for fluid diffusion in our system. When the sample was reloaded at 10^{-5}/s, it showed strain rate weakening and reached a strength comparable to that of a dry sample. A significant pore pressure effect is therefore evident in the initial loading stage.

During the subsequent frictional sliding, when we change the strain rate from high to low and then back to high, we observed strain rate strengthening, indicating an absence of pore pressure effect.

For comparison, we did some preliminary studies on montmorillonite (Figure 2). M3 initially loaded at 10^{-4}/s has a strength only about half of the 'drained' sample M1. Furthermore, it showed evident softening in contrast to the hardening usually expected of this clay gouge. To dramatize the effect, we held the sample for only a very short time. Before the pore pressure transient has completely decayed, we changed the strain rate in two successive steps. Notice the strain rate weakening effect and the transition from hardening to softening. As indicated by the softening during the last stage with strain rate of 10^{-4}/s a pore pressure anomaly is still maintained within the gouge layer after such extensive deformation. A third sample M2 with Berea endpieces was loaded well into the hardening stage, allowed to equilibrate the pore pressure at H, and then reloaded at a slower strain rate. The pore pressure effect of strain rate weakening is evident. But in the second episode of strain rate cycling, the opposite effect of strain rate strengthening was observed during frictional sliding indicating a significant reduction in pore pressure generation.

Our results show that, in general, a significant contribution to the pore pressure anomaly occurs during the initial loading stage, whereas the contribution is inappreciable after a certain amount of frictional sliding. Recent measurements of permeability of gouge materials show that it can be as low as nanodarcy. Furthermore, most of the studies show that permeability decreases with loading, and therefore the condition during the frictional sliding stage is more favorable to the maintenance of a pore pressure anomaly, if it is being generated. One has to conclude therefore that no appreciable pore pressure was generated during most of the frictional sliding stage under our experimental conditions.

This is not unexpected of soils. For a given set of stress conditions, a soil will, if deformed under drained conditions and given sufficient time to consolidate or swell, arrive ultimately at the final water content or void ratio, regardless of the initial state of the soil. This residual condition, termed the critical state in soil mechanics, represents deformation under conditions of constant volume.

Our results may therefore simply be due to the fact that the gouge layer was able to reach a critical state after a small amount of frictional sliding. Subsequent deformation does not introduce any pore volume changes, and therefore no pore pressure can be generated. Experiments are in progress to investigate the effect of grain size on pore pressure generation.

Report

Wong, T.-F. and W. F. Brace, Comparison of frictional behavior of quartz powder and montmorillonite, EOS Am. Geophys. Union Trans. 62 1037, 1981.

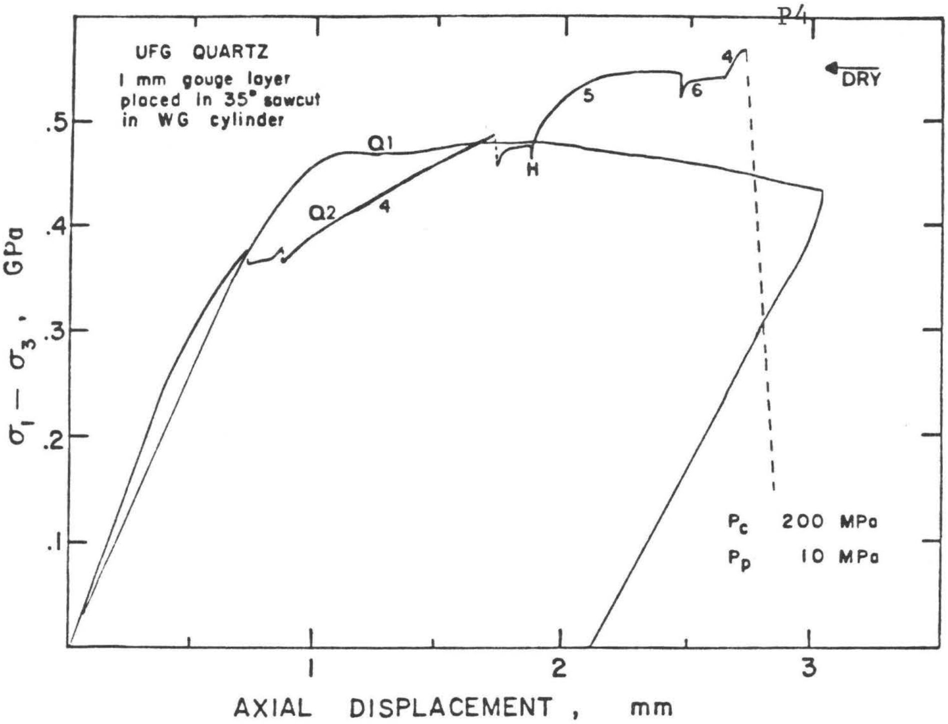

Figure 1. Effect of strain rate on frictional strength of UFG quartz. The numbers indicate strain rates, e.g. 4 implies 10^{-4}/s. The arrow at the upper right corner marks the strength of a dry sample at 190 MPa confining pressure.

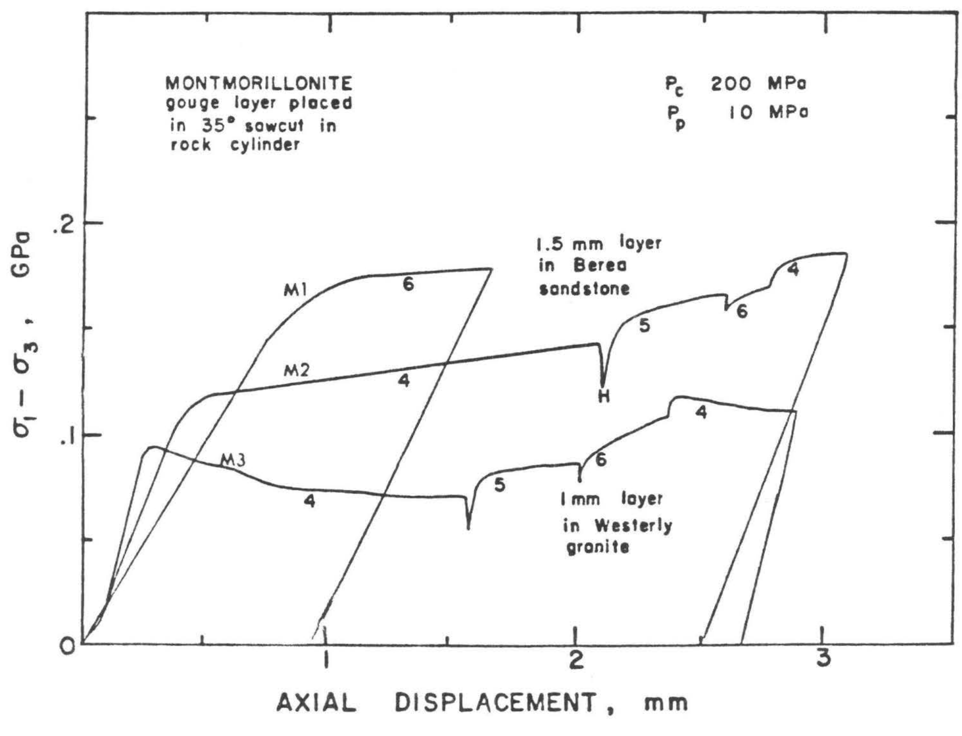

Figure 2. Effect of strain rate on frictional strength of montmorillonite.

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 program was not funded in FY81, all programs and data files resident in MULTICS were lost. Major effort this year was spent on bringing up the programs on the DEC 11/70 and VAX computers. This effort will also be wasted, since the program is not being funded next year.

3. Because the project budget can only cover salary and computer charges, any prediction scoring or evaluation has been impossible. Predictions received can only be dated and filed.

Reports

No reports were published during this period.

Heat Flow and Tectonic Studies

9960-01176

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Investigations:

1. Heat flow and tectonics of the western United States: Additional data on temperature, thermal conductivity, and radiogenic heat production were obtained in the Cascade Ranges, the San Joaquin Valley, and the Mojave-Salton Trough area of California. Interpretive studies of the Salton Trough are under way.

2. Heat flow and tectonics of Alaska: A final set of temperatures were obtained in the National Petroleum Reserve (Alaska). Several hundred conductivities were measured, and a catalog of conductivities was prepared by formation. Analysis of data from southeastern Alaska was completed.

3. Thermal studies related to nuclear waste isolation: Several additional wells have been drilled in the Yucca Mountain area. Preliminary temperature measurements have been completed on these, and final temperature measurements were made on the wells drilled earlier. Additional conductivity data have been obtained, and interpretation is continuing.

4. Equipment development: A portable digital data-acquisition system was perfected and tested in Alaska with the portable temperature-logging equipment.

Results:

1. Heat flow and tectonics of the western United States: Thermal data from 29 wells in northeastern Arizona were analyzed and heat-flow estimates were made. In the area of the San Francisco volcanic field near Flagstaff (Figure 1), mean heat flow is only 27 ± 5 mWm^{-2}--only a third to a quarter of what would normally be expected in this tectonic setting. It appears that the missing heat is being removed by the regional aquifer and is discharged at low enthalpy and low elevation in springs and streams of the Colorado Plateau and Mogollon Rim. Near Black Mesa, heat flow averages about 60 mWm^{-2} characteristic of the cool interior of the Colorado Plateau. North of the White Mountain volcanic field near Springerville, the average heat flow is about 95 mWm^{-2} (Figure 1).

A profile of five wells was drilled in the San Joaquin Valley at about the latitude of Fresno. Thermal conductivities and temperatures were measured in situ during the drilling process. The heat flow ranges from 44 to 64 mWm^{-2} with a mean of 52 ± 4 mWm^{-2}. This is in the same range as heat flows obtained from deep oil wells in the southwestern part of the San Joaquin

Valley. It is inconsistent with predictions of high heat flows (85 to 105 mWm^{-2} and greater) from silica geotemperatures on non-thermal waters presented by C. A. Swanberg and Paul Morgan.

2. Heat flow and tectonics of Alaska: Thermal data from 14 wells in the oil field at Prudhoe Bay, Alaska, have permitted an evaluation of heat flow, recent climatic change, and the establishment of a simple model for predicting the depth and distribution of permafrost beneath the land and sea in a broad region under active exploration for petroleum. The anomalously deep permafrost results from its anomalously high thermal conductivity; the heat flow is normal (55 mWm^{-2}). The surface temperature has warmed ~1.8°C as a result of a net accumulation of ~5 $kcal/cm^2$ by the solid earth surface in the last century or so. Ice-rich permafrost, which extends to a depth of ~600 m on land, is probably 300-500 m deep as far as 25 km from land on the continental shelf. The offshore permafrost is close to its melting point and vulnerable to costly engineering disturbances during exploration drilling and oil production. The thermal model provides a reliable new method for determining the chronology of Arctic shoreline movements.

An inventory of thermal conductivities for various formations have been compiled for the National Petroleum Reserve (Alaska). It is presently being applied to near-equilibrium temperatures in the upper kilometer and to corrected bottom-hole temperatures for greater depths in an attempt to obtain estimates of regional heat flow. For nine sites in southeastern Alaska, the reduced heat flow is in the same range found to the south and the Coast Ranges of British Columbia. Heat flow also increases inland in a similar fashion to that observed to the south.

3. Thermal studies related to nuclear waste isolation: Continuing studies of the proposed Yucca Mountain repository site indicate a complicated thermal and hydrologic regime with potential for both upflow and downflow locally. The proposed repository is probably within a region of slow (a few mm/yr) downward percolation of groundwater.

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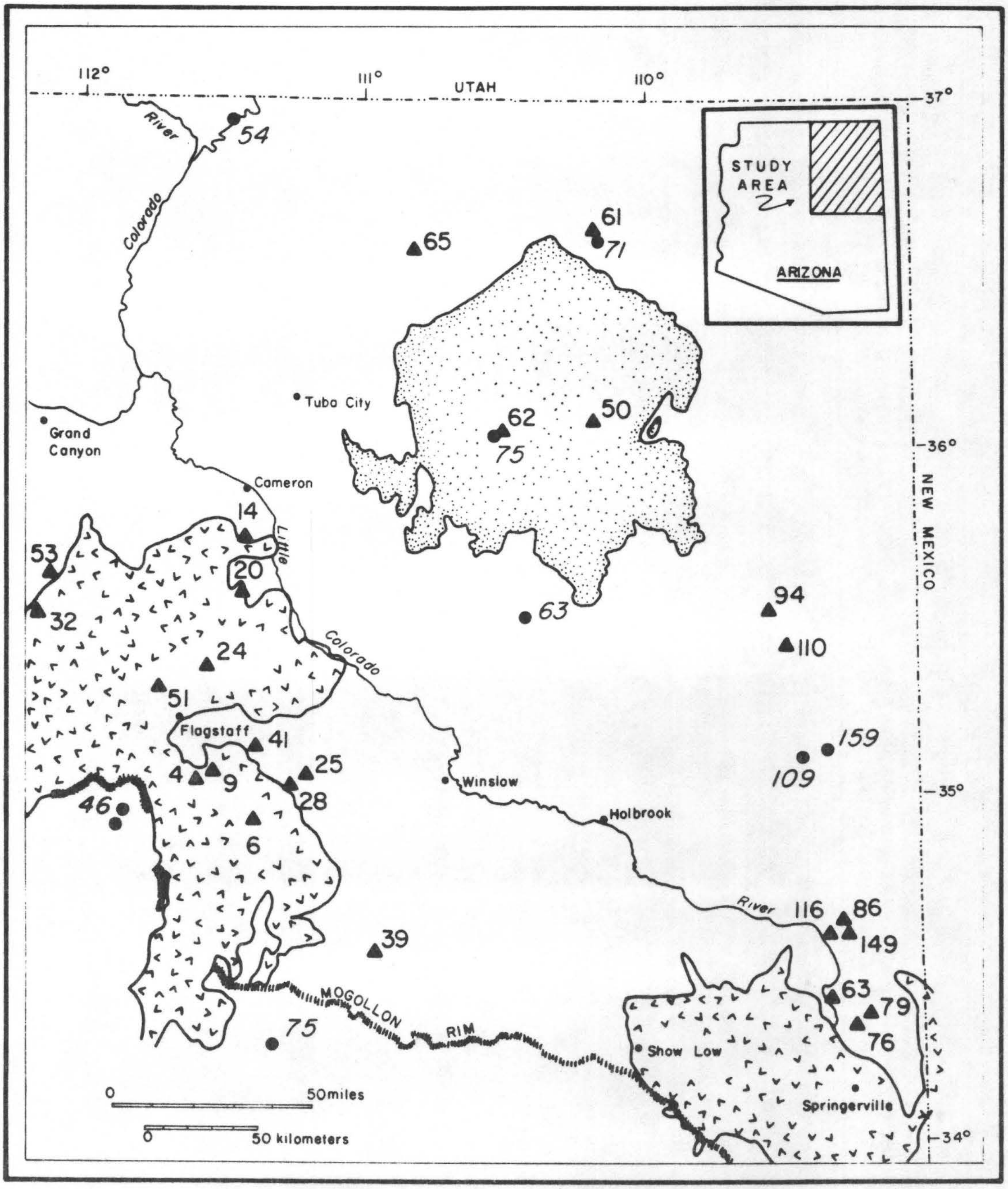

Figure 1. Map showing locations of wells (triangles) and heat-flow estimates (in mWm^{-2}) for the present study of heat flow in northeastern Arizona. Also shown (as solid dots) are the published heat flows of Reiter and Shearer (1979) and Shearer and Reiter (1981).

P_n Anisotropy and Subcrustal Deviatoric Stress in Southern California

14-08-001-20520

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Investigations

1. Collect P_n arrival times from local and near regional events recorded at SCARLET stations through the CEDAR and CUSP systems, for a systematic inversion in terms of a regionalized model of moho dips and azimuthal anisotropy of upper mantle material.

2. Interpret the results in terms of constraints on the geometry and lateral extent of the Pacific-North America plate boundary below the seismogenic layer, as well as constraints on the mode of ductile deformation in the upper mantle.

Current Status

1. P_n arrival times from a set of 65 events routinely recorded on the CEDAR system have been collected with the help of Mr. Thomas Hearn (Caltech Seismological Laboratory). These events comprise all events with magnitude $m_L \geq 4$ for the period 1976-1980, and for which more than 2808 P_n times were available. Analysis of these arrival times in terms of station time terms was reported by Hearn and Minster (1981).

2. In addition, a set of 1334 P_n times collected by Vetter and Minster (1981) was added to the routine data set. These represent arrival times from 81 events, at a 150 km aperture subarray of SCARLET centered on the Central Transverse Ranges, as well as a smaller data set collected at stations across the Mojave block. Since this second data set was assembled specifically for the purpose of studying P_n anisotropy, with a special effort to insure good phase identification and timing accuracy, we compared this with the data acquired by routine analysis in order to evaluate the overall quality of routine data.

Figure 1 shows a comparison of P_n residuals for both data sets. The figure shows only the subset of events located between 0 and 5.5 km depth and the travel times have been corrected to first order to a fiducial depth of 2.75 km. The travel time curves shown on the figure have been calculated for the structure used in locating the events. For each event, the residual travel time anomalies about the theoretical travel time curve have been demeaned prior to plotting. As shown by Rodi et al. (1980), this procedure eliminates to first order the portion of the scatter due to mislocations and errors in origin times.

The noteworthy feature of Figure 1 is that the overall scatter of routinely acquired data is only slightly greater than that of the specialized data set collected by Vetter and Minster. Thus it does not seem that routine processing introduces a large component of noise in the data, especially in view of the fact that the second data set samples only a small region.

3. A reduced travel time plot has been produced for each event in the joint data set. This set of plots has then been examined carefully in order to identify blunders and grossly erroneous data. Such data have been simply eliminated from the data set unless examination of the seismograms showed that the corresponding P_n arrival could be repicked. We feel that the current joint data set is reasonably free of gross errors.

4. In spite of the fact that the size of the data set appears to be adequate for our current purposes, there remains a serious problem associated with the distribution of P_n paths. This is due to the practice used in routine analysis of not processing events which lie outside the station network unless they are very well recorded. The complementary data set of Vetter and Minster uses a well distributed set of sources covering most of the azimuths about the network, but times are only available for a small subarray, and not for the entire network. On the other hand, the newer offline analysis system CUSP which has supplanted the CEDAR system since 1981 does permit more systematic and reliable timing of P_n phases. As a result, routinely acquired data for 1981 alone should allow us to double the number of usable P_n times, with a much improved station coverage. These data should be available in the near future.

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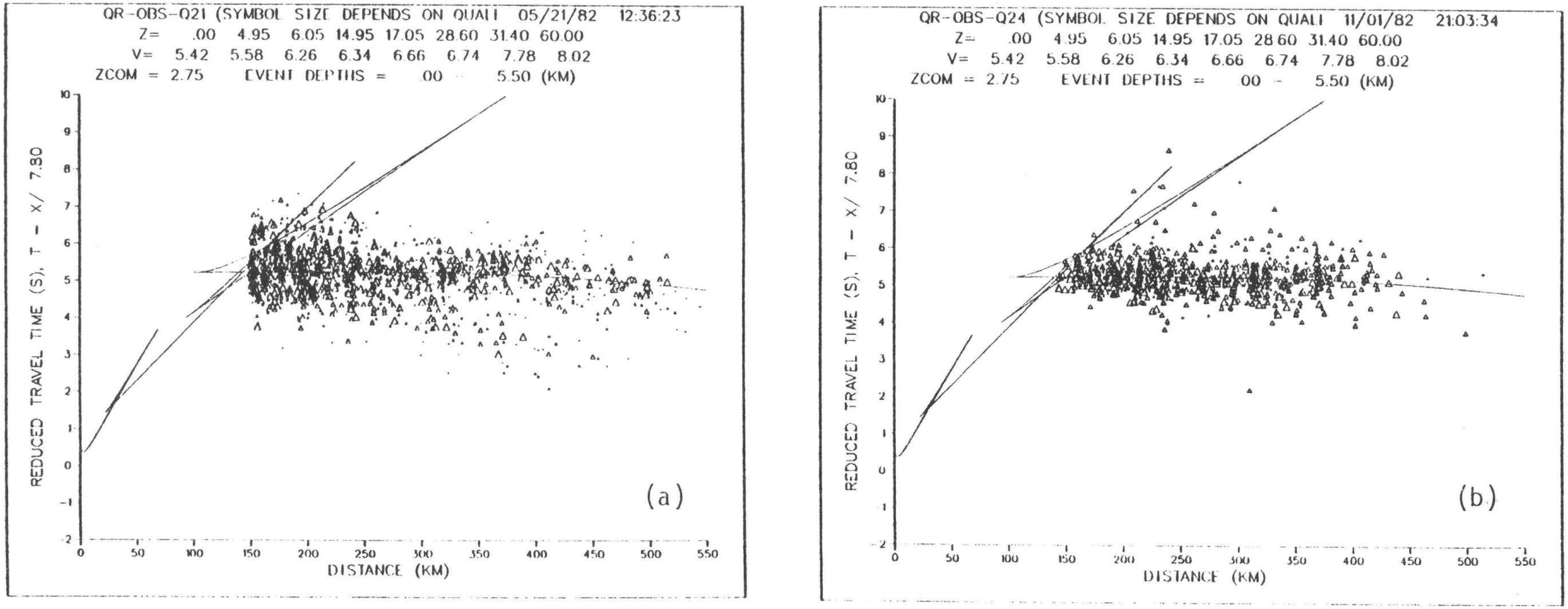

Figure 1. (a) P_n travel times recorded routinely on the CEDAR system for events with focal depths between 0 and 5.5 km during the period 1976-1980.

(b) Similar data set collected by Vetter and Minster (1981) across a 150 km aperture subarray of SCARLET centered on the central transverse ranges. Symbol size is proportional to pick quality.

Fault Zone Structures

9930-01495

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Investigations

1. Analysis of seismic refraction data along the Calaveras fault, central California.

2. Interpretation of the deep crustal structure and tectonic evolution of the Mississippi Embayment, central United States.

3. Preparation of journal articles on the crustal structure of Saudi Arabia, based on U.S. Geological Survey Open-File Report OF-02-41. (Healy and others, 1982).

Results

1. On August 6, 1979 a magnitude 5.7 earthquake occurred in the Calaveras Fault Zone in the Coyote Lake area. Although this earthquake and the aftershocks took place within a very dense seismic network the RMS error for many of the stations was as high as 0.25 s because the structure of the area deviates from the standard model used to locate the events (Lee et al., 1979).

   In 1980, the U.S. Geological Survey conducted a seismic refraction profile in the Calaveras Fault Zone to obtain detailed p-wave velocity information directly within the fault zone. The interpretation of these explosion-seismic data gives a detailed knowledge of the upper crustal structure. Combined with results of other crustal investigations nearby in the Diablo Range (Blumling and Prodehl, 1982; Walter and Mooney, 1982), the Santa Clara Valley and the Santa Cruz Mountains (Mooney and Luetgert, 1982) this investigation is aimed to develop a three-dimensional velocity-depth model of this area.

   Results obtained to data strongly suggest that the Coyote Lake earthquake occurred at an upper-crustal 'asperity' which is evidenced in the crustal structure as a high velocity zone. These results therefore give strong evidence that there is a causal relationship between fault zone structure and seismicity.

2. We have developed a tectonic model for the Mississippi Embayment based on new geophysical and existing geologic data. The model is constrained by two features of the crust: a high velocity, high density lower crust, interpreted to be a fossil rift cushion, and an upper crustal low velocity zone, interpreted to be a rift graben.

Based on the geophysical model for the crustal structure of the Embayment and on geologic evidence the following model for the evolution of the Embayment is proposed. The intrusion of mantle derived material into the lower crust occurred in the Late Precambrian causing the initiation of crustal rifting in the northern Embayment area. Isostatic subsidence caused by the cooling of the lower crustal intrusion created a broad, elongate basin in Cambro-Ordovician time that accumulated thick sequences of carbonate sediments. In the late Paleozoic, compressive tectonic forces from the south, at a high angle with the rift zone, caused uplift and igneous activity along previously faulted zones in the Embayment. Another phase of uplift was initiated before late Cretaceous time. This uplift and associated igneous activity was in response to isostatic rebound forces caused by renewed injection of mantle material into the lower crust. Major subsidence followed in late Cretaceous and early Tertiary time due to cooling of the altered lower crust. It was during this time that the present configuration of the embayment was established.

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Active Seismology in Fault Zones

9930-02102

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Investigations

1. Collection and preliminary analysis of seismic refraction data in several locations in the Great Valley of California and adjacent Coast Ranges and Sierran foothills (A. Walter and W. Mooney).

2. Collaboration with C. Wentworth and others in the purchase and processing of existing seismic reflection data in the Great Valley and contracting for new data (A. Walter, W. Mooney, and W. Kohler).

3. Development of traveltime and time-term maps of the Imperial Valley region of southern California (W. Kohler and G. Fuis).

4. Continued analysis of a seismic refraction profile in the Mojave Desert region of California (G. Fuis and A. Walter).

5. Collaboration with D. Howell and others in construction of Continent-Ocean Transect C-3, from southern California to New Mexico (G. Fuis).

Results

1. Refraction data was collected in the Great Valley between Stockton and Fresno, California, along five reversed profiles. Three of the profiles are subparallel to the Valley axis and are located on the west side, at the center, and on the east side of the Valley. Two transverse profiles extend from the Diablo Range to the Sierra Nevada and are located near the latitudes of Tracy and Los Banos, California. Along each profile, 100 seismic cassette recorders were deployed at spacings of 1.0 to 1.5 km and shots were fired at shotpoints located near the endpoints and centers of the profiles. The collected traveltime data will be used to construct a crustal velocity model for the Great Valley between the Coast Ranges and the Sierra Nevada. This model will better delineate the feature producing the aeromagnetic and gravity highs in the Great Valley. Refraction

data was also collected along two end-to-end 120-km long profiles extending from Morro Bay, on the California coast, across the southern Great Valley to the Sierra Nevada east of Delano, California. For each of these profiles, the 100 cassette recorders were deployed at 1 to 1.2 km intervals and shots were fired at four shotpoints spaced 20 to 50 km apart.

2. Vibroseis reflection data was purchased from Western Geophysical along the route of our seismic refraction profiles from Morro Bay to the Sierra Nevada. The refraction data are being analyzed to provide velocity-depth functions that can be used to reprocess the reflection data. Geophysical Systems Corporation has been contracted to collect vibroseis reflection data along our refraction profile through Los Banos, California. The line is east-west and 120 km long. The reflection records will have a two-way time dimension of 15 seconds in order to study the deeper parts of the crust.

3. A contour map of reduced traveltimes from our most widely recorded shotpoint in the Imperial Valley region of California (Fuis and others, 1983, U.S.G.S. Professional Paper 1254, Ch. 3) reveals in plan view the trend of a number of large buried scarps in the Imperial Valley region and also reveals something of the subsurface nature of the known geothermal resource areas. Traveltimes from several other widely recorded shotpoints in the Imperial Valley region have now been contoured in a similar fashion. The new contour maps confirm many observations made from the first map but also reveal new features. All of the traveltime data were next integrated to produce a time-term map, which in principle eliminates distortions of features seen on traveltime maps and can be converted to a sediment isopach map. Striking features seen on this map include the following: 1) A complex buried scarp along the west side of the Imperial Valley. This feature, seen on the earlier traveltime maps, trends roughly north-south; it appears to be terraced and also segmented. The Superstition Hills fault and Superstition Mountain fault bound one segment and northwest-striking buried faults(?) farther south appear to bound other segments. 2) A prominent scarp is also seen northeast of the Salton Sea and appears to be a continuation of the modern mountain front beneath the sediments. (We had surmised earlier than such a scarp existed about 10 km farther southwest, along the San Andreas fault.) 3) Geothermal areas are reflected on the maps as areas of relatively low time-terms. These areas have varied shape and relief on the map. The Salton geothermal area has the strongest relief and is the largest areally. In conjunction with this investigation a computer program was written for machine contouring of data points. We have experimented extensively with the program in order to establish optimum grid spacing and distance weighting functions.

4. Ocean-continent transect C-3, constructed for the U.S. Geodynamics Committee's Transect Program, extends from offshore southern California, across southern California and Arizona to central New Mexico. The transect consists of: 1) a one-degree-(110-km-) wide, 1:500,000 geologic strip map, 2) two 1:500,000, ve 1:1 geologic cross sections, one colored by age, the other by lithotectonic "kindred", 3) gravity, magnetic, heat flow, and seismic-velocity profiles, and 4) ancillary diagrams explaining the progressive tectonic development of the region. The major tectonic provinces crossed by the transect include, from west to east, the southern California borderland, the Transverse Ranges, the Peninsular Ranges, the Salton Trough, the southern Basin and Range, the northern Sierra Madre Occidental, and the Rio Grande Rift provinces.

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Tiltmeter & Earthquake Prediction Program in S. California and at Adak, AK

14-08-0001-19273

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Objectives

1) To continue to improve the performance of bubble-sensor tiltmeter systems and to investigate alternative methods of detecting tilt and strain, with low cost, easily deployed instrumentation.

2) To improve the installation methods for such instruments.

3) To continue to develop and operate a digital data acquisition system to acquire geodetic data and to thoroughly monitor the environment of the instrument installations.

4) To process the digital data and make efforts to remove the environmental noise from the data, and to present the results in a meaningful format, such that any evidence of precursory tilting will be enhanced.

Accomplishments

1) A completely new tiltmeter electronics system has been designed and produced that exhibits an order of magnitude improvement in thermal stability over the best of our well-modified TM-1 electronics systems. It incorporates a digital sine wave generator for excitation, operating at 600 hz (rather than 5 K hz) to reduce reactance changes with temperature. The system is fully C-MOS, and employs full wave synchronous demodulation. Thermal noise has been measured at 3-5 nanoradians/^{o}C, from -20 to +40^{o}C. The system includes the digital servo auto zeroing system, and fits in the same housing as the old interface system. Upgrading existing installations with this electronics results in a remarkable removal of diurnal thermal noise. The predominant energy in the records is now tidal, and tiltmeter polarities can readily be verified by comparison with the theoretical tide.

2) A new housing has been designed for the bubble that reduces the noise due to "pipe bending" and which incorporates a fitting on the top that engages a 10 meter sectional installation tool for installing the borehole unit in deep holes. The pipe is tapered slightly, being 4 mm larger on the top, and allows the borehole to be removed by pulling it out of the bonded sand installation matrix. The tiltmeters in the Southern California Palmdale area will be installed in 10 meter deep holes. A test facility at CCMO has been completed for practicing the installation method in a 30 cm diameter hole of that depth.

3) Significant improvements have been made in the digital data telemetry system, and it continues to operate well. At Adak, where there are eight tiltmeters, there are five remote digitizers for a total of 70 channels of data, while Southern California will initially have 3 units for 42 channels of data for six tiltmeters. The receiving microsystem has been fully programmed in E-Prom to come up operating after a power outage and resume logging the data onto floppy discs. A subsystem has been developed that recovers any 24 incoming channels and converts them to analogue for real-time strip chart monitoring. The meteorological data base has been augmented by sensitive thermo-electric heat flow sensors installed 50 cm below the surface; sensitivity is (2.7 cal/m^2-hr)/mv. A new self contained water level tide sensor with a resolution of 1 mm of water was installed at Adak and so far has performed well, as have the new low power self-calibrating hybrid micro-barometers.

The processing of Adak data disks is kept current in order to verify system operation. Less than a week of data is missing out of a 2 year continuous set, and the file of raw data now amounts to over 40 megabytes. The Southern California project was delayed by the funding vicissitudes of last year, so data acquisition will not begin until later this year.

4) In addition to routine processing of the Adak data, some effort has been made in compiling long time series of the data and removing the direct thermal effects. Efficient removal of the environmental noise awaits the availability of a multiple input/output time series correlation program. Since some correlations with temperature, rainfall, and barometric loading are readily visible, a computer program should easily extract them. We do not expect to see precursory tilts by examination of the raw data.

The processed data is presented in several methods. The routine plots are of the two orthogonal axes versus time, as in Figure 1, which shows 2 years of data from the WS tiltmeter. Another method is to plot the net vector displacement on an orthogonal grid, as in Figure 2, which shows 1 year of cumulative data from several tiltmeters. Note the similarity of 1 year of data between the SE and WS tiltmeters, which are about 2 km apart. A most interesting presentation, first developed in 1977, is to plot tilt rate vectors along a time axis. Figure 3 is an example of this, showing the great sensitivity of the plot to very small changes of the tilt rate. For this plot, a spline fit is made to the data, and a first derivative is obtained. The orthogonal derivatives are then plotted as a vector for every time interval, with the orthogonal scaling equal to the scale on the left. This results in a portrayal of tilt rotations and rate changes that greatly enhances small changes, but readily shows similarities where inspection of the time series trace shows nothing of interest. No implications of any precursory patterns can be made from this data until the meteorological contamination is removed. Notes on Figure 3 explain this interpretation.

An interesting and unexpected result is the recording of four large co-seismic tilts at Adak; these are characterized by general agreement among all 8 tiltmeters. Unfortunately, the data is generally dismissed as being only a direct result of over-excitation of the instrument and/or regional site adjustment. However, nothing in the instrument system has time constants even beginning to approach the one hour duration of these events, and we usually see only passing surface waves for the many m_b 4-5 events. We would suggest that the co-seismic tilts are a real a-seismic movement of the descending slab, momentarily dragging the over-riding plate down, which then rebounds. The tilt has generally been down in the direction of the co-seismic event, which in itself would be too small a source for the observed tilt, although the co-seismic earthquakes for these events are usually located at the top of the more plastic section of the slab.

A strong argument in favor of this interpretation and opposed to the "site effects" explanation is the record of a recent m_b 6.0 event, the largest since the instruments were installed, in which site effects are obvious and incoherent behavior is clearly recorded. The tiltmeters grouped at each site were in agreement, but the data from the four sites are quite different. This event was probably not accompanied by large a-seismic slip. Figure 4 shows the data from a coherent event on 4 June 1982 located SW of the array. (This is the first and only "co-seismic" event that does not show the usual tilt down toward the source; here the tilt is down to the SE.) Figure 5 is of the larger event of 4 October 1982, where we see coherence only at each site, and generally less tilt than the other co-seismic events. The earthquake was due south of the array, but the tilts were North down at the South site, SE down at the North site, NW down at the West site, and SW down at the East site. Preliminary processing of the output of the two tiltmeters (SE and WE) that are recorded at high speed and digitized at 100 sampes/sec along with the seismic network data shows large broadband-type tilts in the first 30 seconds of the record that are well in excess of 20 ppm and clipped. Three minutes into the record the surface waves are dying out and there remains a static tilt of the same amplitude as recorded by the tiltmeter digital system (10 minute samples).

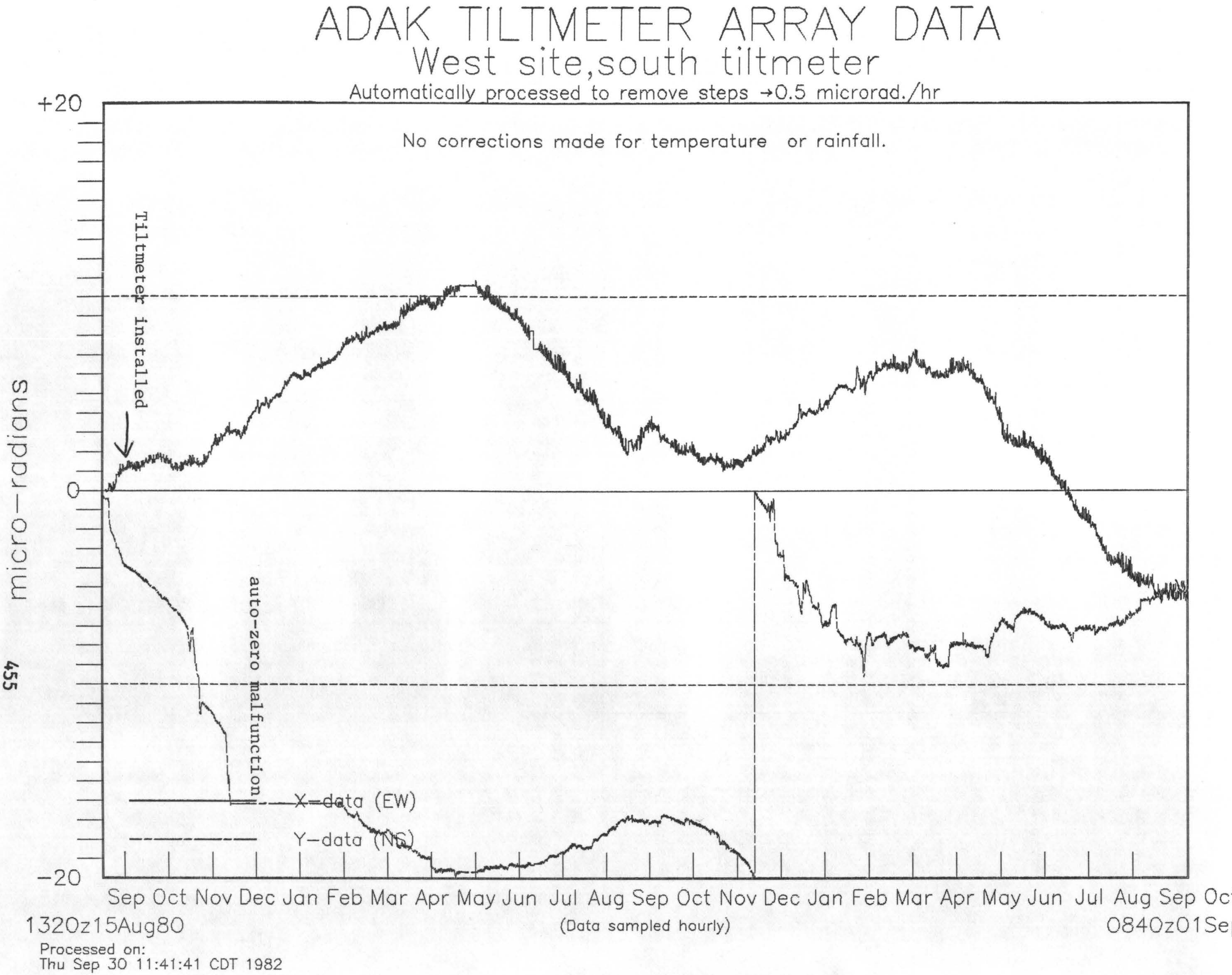
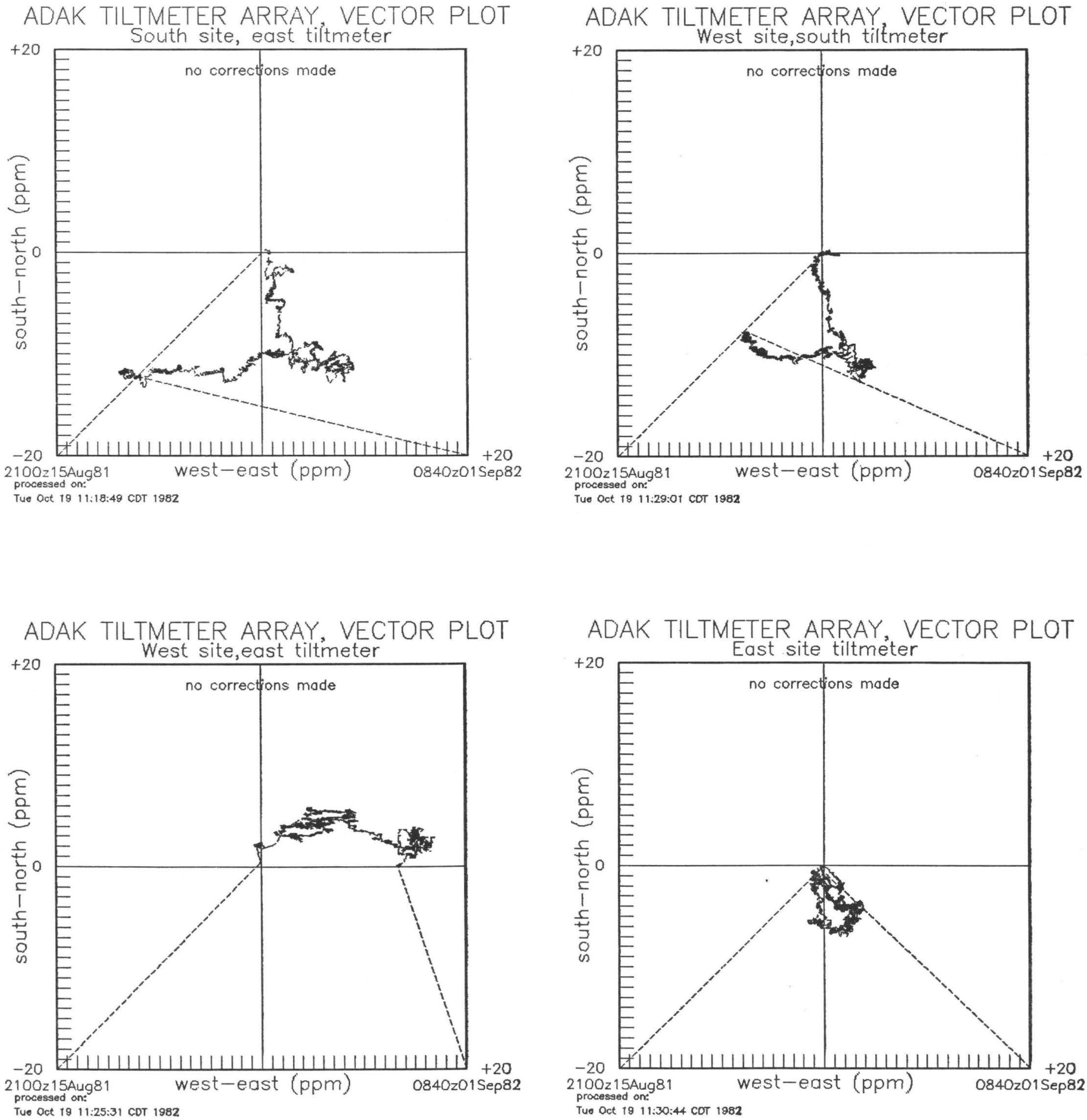


Figure 1: Two years of data from West-South tiltmeter.

P4

Figure 2: Cumulative tilt over one year of several Adak tiltmeters. (No corrections have been made for temperature, et cetera; cyclic pattern is annual thermal cycle.)



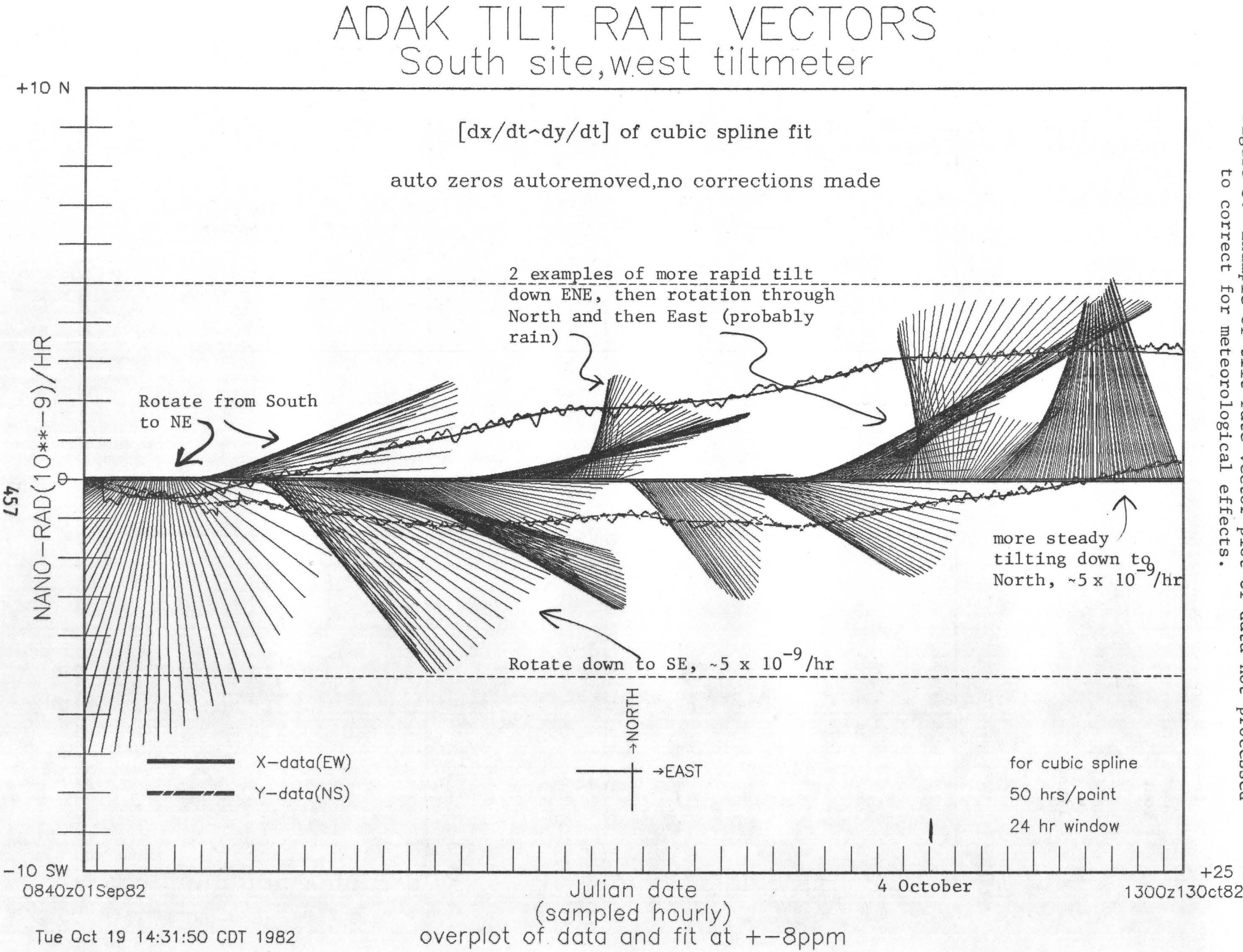


Figure 3: Example of tilt rate vector plot of data not processed to correct for meteorological effects.

Figure 4: "Co-seismic" tilt event of 4 June 1982, m_b 5.8, Δ 106 km, showing relatively coherent record on all eight tiltmeters.

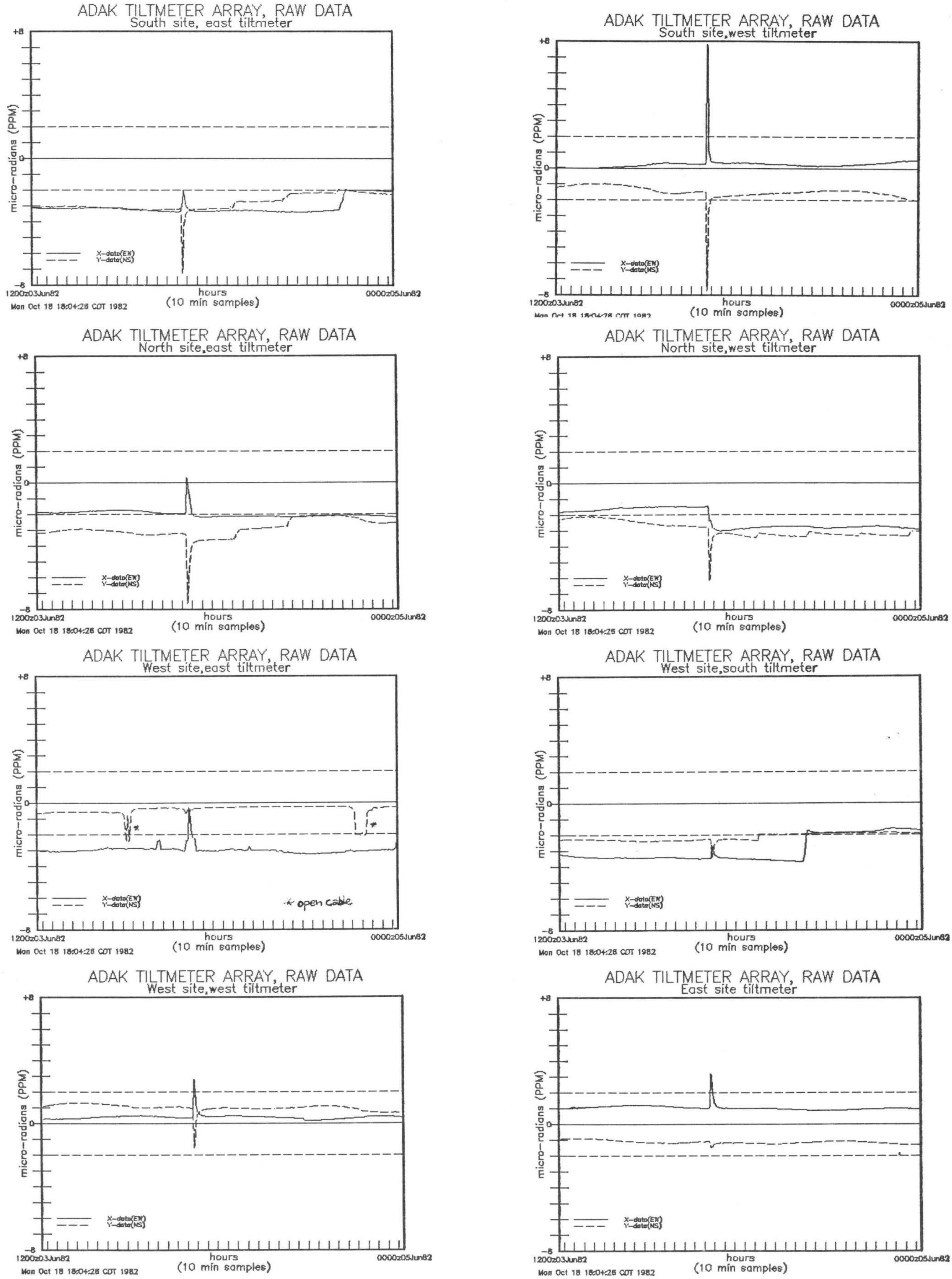
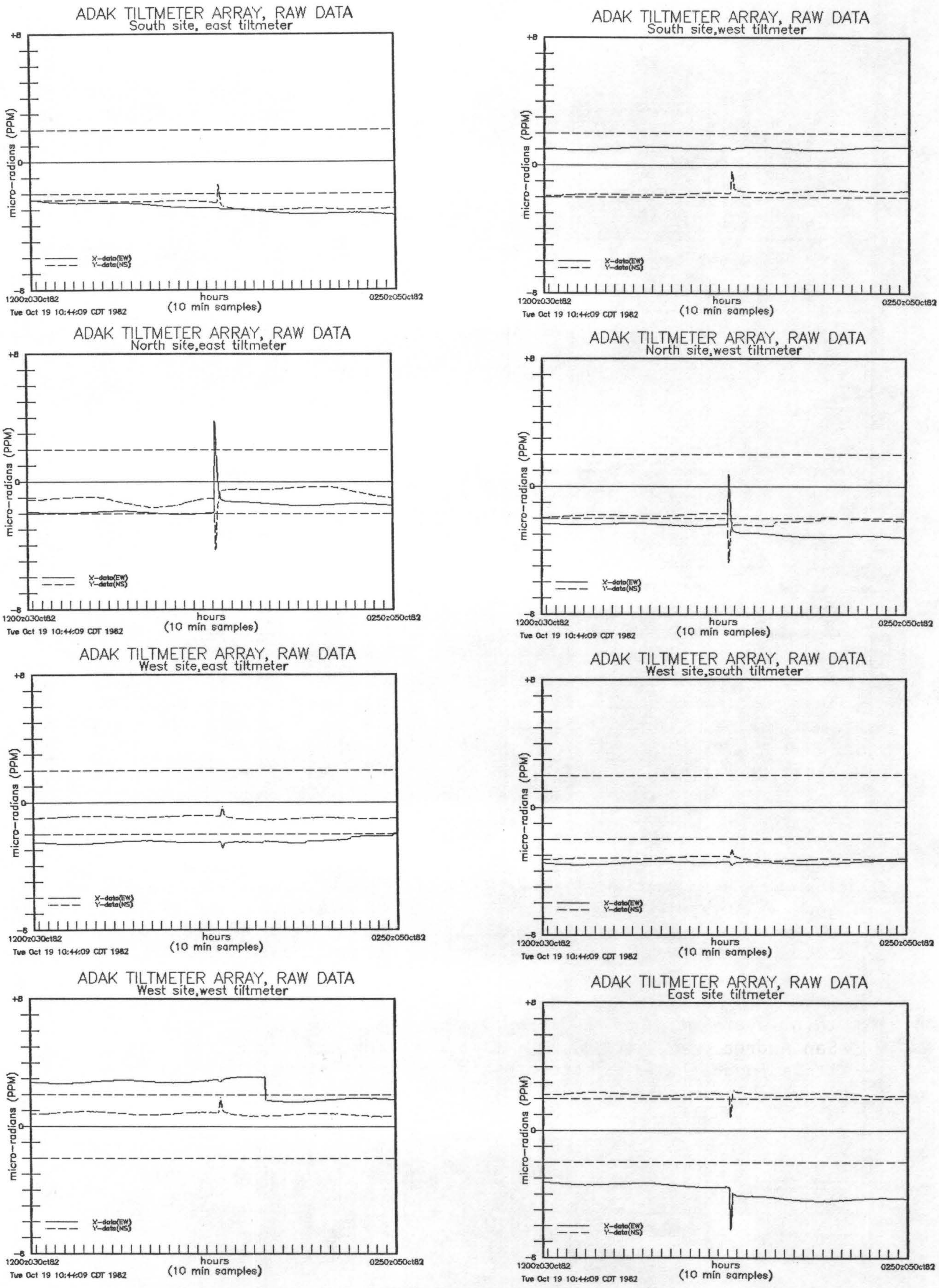


Figure 5: "Co-seismic" tilt event of 4 October 1982, m_b 6.0, Δ 64 km, showing agreement at each site, but incoherence in the array.



Strain Rate Effect on Strength and Dilatancy of the San Andreas Fault Gouge

14-08-0001-20530

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Investigations

1. Time-dependent mechanical properties of San Andreas fault gouge and clays were determined experimentally in the laboratory at pressures equivalent to those at mid-crustal depths. The goal of the experiments is to provide some fundamental data for the construction of the constitutive relation of clay-rich fault gouge.

Results

1. The time-dependent volumetric constitutive relation for a San Andreas fault gouge and a consolidated kaolinite are experimentally determined at confining pressures to 200 Mpa, under transient creep condition and at ultrasonic frequency. At any given pressure, the bulk modulus determined at 1 Mhz frequency is identical to the "elastic" modulus determined at a stepwise change of pressure. After the pressure change, there occurs a time-dependent change of volume and thus the effective bulk modulus. The constitutive relations may be modeled by a standard linear viscoelastic medium with pressure-dependent moduli and viscosity. For the San Andreas fault gouge, viscosity increases from $2x10^{13}$ poise, at 17 Mpa, to 10^{14} poise, at 100 Mpa. For kaolinite sample, the corresponding values are $3x10^{12}$ poise and 10^{13} poise. These results imply that both stress and pore pressure in fault zones may show time-dependent variations in response to a change of state of stress, such as that occurring after an earthquake.

2. The volumetric strain of gouge samples under sustained shear stresses was found to increase continuously as a function of time, even though the mean stress was held constant. We interpret this shear-induced, time-dependent compaction of fault gouge as due to rate-dependent processes such as the rotation of clay platelets, viscous shearing of the contacts between the particles, etc., in the deforming fault gouge.

3. Frictional sliding experiments at strain rates from 10^{-4} to 10^{-6} sec^{-1} and confining pressures from 100 to 300 Mpa were performed on thin layers of saturated clay-rich fault gouge from locations along the San Andreas and Hayward faults in California, as well as on pure clays. It is found that the strength and the co-efficient of friction of these materials are functions of strain-rate. Under drained condition, time-dependent compaction gives rise to strain-hardening of the fault gouge samples. On the other hand, if the condition is undrained, this gives

rise to excess pore-pressure which may lead to strain softening. In our experiments, both strain-hardening and strain-softening of the fault gouge have been observed. We suggest that the onset of either strain-softening or strain-hardening is controlled by the rate of volumetric strain and the permeability of the system which determines the generation and dissipation of excess pore-pressure in the fault gouge under shear.

Reports

Chu, Chaw-long and Wang, Chi-yuen, 1982, Time-dependent volumetric constitutive relation for fault gouge and clay at high pressure, Issues in Rock Mechanics, Editors: R. E. Goodman and F. E. Henze, American Institute of Mining, Metallurgy, Petroleum Engineering, Inc., New York, N.Y.

Chu, Chaw-long and Wang, Chi-yuen, 1982, Rate-dependent strength of clay-rich fault gouge, EOS, Trans. American Geophysical Union, v. 3, (abstract).

Crustal Changes North of San Francisco

9930-03353

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Investigations

1. Review of the feasibility of developing energy directly from molton rock.

2. Review of the origin of magma especially at mid-ocean ridges and at the sites of intra-plate volcanism.

Results

A detailed review of seismic-refraction studies at sea indicates only four basic types of oceanic crust: continental fragments and margins, normal oceanic crust, normal oceanic crust thickened by the addition of basalt primarily from above, and hot young crust at the center of spreading ridges. Aseismic ridges have structures similar to the Hawaiian Islands, whereas plateaus, such as the Ontong-Java Rise, are continental fragments. The normal, deep-water, oceanic crust does not thicken after formation except by the addition from above of sediment. Oceanic crust seems to form only when the upper part of the mantle rises to depths of about 8 km and differentiates into depleted peridotite below the Moho and gabbro and basalt above. The Moho, which is typically a kilometer or more thick, is probably an interlayered mixture of crustal materials and peridotite as observed in ophiolite complexes. Typical lower continental crust appears to be oceanic crust and so the continental Moho in most places may have orginated under the ocean. Formation of new lithosphere is a natural consequence of mantle material cooling under near equilibrium conditions of temperature, density, and state in cracks of the older lithosphere. The crust cools quickly, and the lower lithosphere cools slowly gaining flexural strength over tens of millions of years. From this point of view, any convection in the upper mantle is a result rather than a cause of sea floor spreading, and the geometric arguments for hot spots can be explained by stress systems causing fracturing of the lithosphere.

Reports

Ward, Peter L., 1982, The Origin of the Oceanic Crust and Lithosphere (abs.): EOS Transactions (Fall AGU Meeting).

Seismicity and Structure of the San Pablo Bay-Suisin Bay Seismic Gap from Calnet and Explosion Data

9930-02938

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Investigations

Previous reports have mentioned that the dominant occurrence of earthquakes in the San Francisco Bay Area is in clusters. A study was made of the distribution of earthquakes within several of the denser clusters.

An unusual occurrence of activity in some of the clusters occurred in 1977 along an east-northeast trend just south of the San Pablo and Suisin Bays. This occurrence was studied.

Results

Many clusters are concentrated centers of activity with roughly 80% or more of the earthquakes in a spherical volume of 1-2 km from the center of the cluster.

The east-northeast trend of clusters just south of the Bays cuts across the northwest trending faults of the San Francisco Bay Area. Along this trend in 1977 there was activity from the San Andreas fault to the Antioch fault, on all the major faults except for the Concord fault, which was quiet. Almost all of the activity was in clusters, in short bursts, and in semi-vertical orientations ten or more kilometers long. This seems to be an example of multiple sympathetic seismicity.

World-Wide Standardized Seismograph Network (WWSSN)

9920-01201

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Investigations

1. Technical and operational support was provided to the World-Wide Standardized Seismograph Network (WWSSN) as required and as funding and staffing permitted.

2. During this report period, 247 modules and units were repaired, and 382 separate items were shipped to support the network. Regular photographic paper and chemical shipments were delayed because of funding problems and delivery schedules. These regular shipments were replaced or supplemented by emergency shipments in order to assure continuous operation of the stations.

3. Training was provided to Mr. Robert Pratt, Raytheon Technician, in the maintenance and troubleshooting of the WWSSN system. Two station operators (Mr. Alvaro Hidalgo Urrutis and Mr. Manual Calderon) from La Palma, El Salvador visited ASL during September. As much training as possible in the short four day period was provided.

Results

A continual flow of high quality seismic data from the network of 115 observatories for use by the seismological community.

U.S. Seismic Network

9920-01899

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Investigations

U.S. Seismicity: Data from the U.S. Seismic Network are 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 were recorded continuously in real time at the NEIS main office in Golden, Colorado. At the present time, 78 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, 12 channels of LPZ data are recorded in real time on multiple pen Helicorders.

Data from the U.S. Seismic Network are interpreted by record analysts and the seismic readings are entered into the NEIS data base. The data are also used by NEIS standby personnel to monitor seismic activity in the U.S. and worldwide on a real time basis. Additionally, the data are used to support the Alaska Tsunami Warning Center and the Pacific Tsunami Warning Service. 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 are used in such NEIS publications as the "Preliminary Determination of Epicenters" and the "Earthquake Data Report."

Due to the almost tripling of Long Line charges in 1981, a major cost cutting effort is under way. As part of this, the network is in the process of being converted almost exclusively to digital telemetry. This will make possible the combination of several Long Lines into one as it will then be possible to multiplex more than one data stream per Long Line. We expect the use of digital data transmission to save at least $60,000 per year in Long Line charges.

The conversion of the East Coast part of the network has been completed. At the present time, 27 channels of SPZ data from the Eastern U.S. are being transmitted to Golden on one Long Line resulting in savings of $30,000 per year in Long Line charges.

The conversion of the Western U.S. to digital telemetry is proceeding according to plan, but is slightly behind schedule. However, we expect to complete the conversion of the network to digital telemetry within the next two months.

Objectives

The U.S. Seismic Network is an operational program as the data generated are routinely used to support the NEIS operational requirement of timely location and publication of earthquakes worldwide. Also, the network data directly support the NEIS standby personnel who are responsible for locating and reporting to the media, disaster agencies and other organizations, all significant earthquakes worldwide. Thirdly, support is given to the Alaska Tsunami Warning Center and the Pacific Tsunami Warning Service as network data are exchanged with both organizations.

Data Processing Section G1

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 are reviewed and checked for quality.

2. Network-Day Tape Program - Data from the Global Digital Seismograph Network are assembled into network-day tapes which are distributed to Regional Data Centers and other government agencies.

3. Event Detection Program developed for the Global Digital Seismograph Network - This event detection program has been upgraded and revised and is now in use at the ANMO station and is also used with the RSTN stations.

Results

1. Data processing for the Global Digital Seismograph Network - During the past six months 359 digital tapes (165 SRO/ASRO and 194 DWWSSN) from the global network were edited, checked for quality, corrected when feasible, copied, and archived at the Albuquerque Seismological Laboratory. A GDSN Newsletter containing pertinent information on the Global Network was distributed in May, 1982. The more than 200 copies were forwarded to digital data users around the globe. The second newsletter is in its final stages of editing and will be distributed during the latter half of October, 1982.

2. Network-Day Tape Program - The Network-Day Tape Program is a continuing program which assembles all of the data recorded by the Global Digital Seismograph Network for a specific calendar day onto one magnetic tape. This tape includes all the necessary station parameters, calibration data, and time correction information for each station in the network. The production of these day tapes is normally about 60 days behind the actual recorded date to allow for delays in shipping the data to Albuquerque. Six copies of the network-day tapes are forwarded to various Regional Data Centers in this country. Individual distribution is handled by the Environmental Data and Information Service in Boulder, Colorado. Long-period data will be added during the month of October when modifications to the event detection software are complete.

3. Event Detection Program developed for the Global Digital Seismograph Network - This event detection program has been implemented on the ANMO system at the ASL. The algorithm not only detects signals it also times their onsets and makes estimates of their amplitudes and periods. This program appears to be operating satisfactorily as it accurately picks the onsets of very small signals with few false alarms. Work has started on a more advanced detector that will pick secondary phases. The preliminary algorithm has been coded, and it appears to perform very well. We are presently comparing this event detector with others using seismic data with known events buried in the background noise.

Abstracts

Murdock, J. N., and L. Jaksha, 1982, P_g Time Terms and P_g Refractor Velocity in the Rio Grande Rift, Preliminary Estimates (draft).

Newsletter

Hoffman, J. P., R. Buland, and M. Zirbes, GDSN Newsletter, Spring, 1982, 12 p., available from Albuquerque Seismological Laboratory, Albuquerque, New Mexico.

Socorro Magma Bodies

9920-03379

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Investigations

1. We have installed seismic stations at South Baldy Peak, Bear Mountains, Carthage, Barren Radio Site, and San Marcial. These stations, along with four stations previously used for monitoring seismicity in the southern Albuquerque basin (Albuquerque Seismological Laboratory, Mesa Lucero, Los Pinos, and Woods Tunnel), are being recorded at the USGS/NMT Observatory on the New Mexico Tech campus. We plan to install three more stations (Ladron Peak, Oscura Peak, and Magdalena) in the near future. Two radio repeater sites are operational, one at South Baldy and another at Socorro Mountain. Our facility at Socorro Mountain has the capability of taking signals off of the New Mexico State microwave network and retransmitting them to the observatory. We presently receive seismic data from Carlsbad and Chaco Canyon from the microwave. All of the routine operations at the observatory, record changing, record reading, hypocenter location, cataloging, and minor repairs are being done by New Mexico Tech students under the direction of the professional staff.

2. Jim Murdock and I are analyzing P-waves in the Rio Grande rift to determine the P_g refractor velocity and P_g time terms of the seismic stations there.

Results

Three quite extensive earthquake swarms containing several hundred shocks (four of which were felt) have been observed. The largest earthquake attained a magnitude (M_L) near 3.0. A preliminary fault plane solution for this event suggests normal faulting along a north-south striking fault. In addition to the swarms, a "background" of about two to three earthquakes/day is being observed.

Preliminary results of the time-term analysis suggest a P_g velocity of 6.0 ± .05 km/s for the Rio Grande rift. Stations on bedrock typically show time terms less than 0.4 s and stations on thick Phanerozoic sections within the rift range up to ~1.6 s. An abstract summarizing the study is being drafted.

Seismic Observatories

9920-01193

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Investigations

1. Recorded and provisionally interpreted seismological and geomagnetic data at observatories operated at Newport, Washington; Cayey, Puerto Rico; and Guam. At Guam, 24-hour standby duty was maintained to provide input to the Tsunami Warning Service operated at Honolulu Observatory by NOAA and to support the Early Earthquake Reporting function of the NEIS.

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.

During this report period, the personnel complement at Newport Observatory was reduced, and the facility is now operating with one employee. Management of this project was moved to Albuquerque Seismological Laboratory with Leonard Kerry assuming responsibility for it.

Albuquerque Observatory

9920-01260

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Investigations

Recorded seismological data at Albuquerque Observatory, Albuquerque, New Mexico on a continuing basis.

Results

Continued to send seismograms to the National Earthquake Information Service for use in ongoing USGS programs. Responded to requests from the public, interested scientists, state and federal agencies regarding geophysical data and phenomena.

During this report period, management and responsibility of this project was assumed by Leonard Kerry.

Global Seismograph Network Evaluation and Development

9920-02384

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Investigations

1. Peterson and C. R. Hutt completed an analysis of the operations characteristics of the DWWSS system. L. G. Holcomb began an evaluation of the Streckeisen broadband seismometers. Hutt continued collaborating with J. Murdock in the development and testing of a new event detection algorithm. Peterson presented an instrumentation plan for a China digital seismograph network in Beijing and held discussions with counterparts in the USSR concerning instrumentation and networks.

Results

The results of DWWSS test and evaluation have been documented in an open-file report. The report includes a description of the system and sections describing the development of transfer functions, calibration procedures and stability, noise characteristics, linearity and distortion. The evaluation results are generally satisfactory although there is excessive noise in the long-period electronics that must be reduced to improve data quality.

A three-component set of Streckeisen (Wielandt) broadband seismometers has been received for test and evaluation. The seismometers have been installed in a subsurface vault and test data are being recorded. The data will be evaluated using SRO and DWWSS data for comparison.

The Murdock detector, which had been extensively tested off line, has been implemented on the ANMO SRO system and has been successfully evaluated on the operating system. In addition to providing an event declaration used to trigger recording, the detector outputs the arrival time, polarity of first motion, amplitude, and period of the event. A report describing the detector and its evaluation is being prepared by J. Murdock and Hutt.

Reports

Peterson, J. and Hutt, C. R., 1982, Test and Calibration of the Digital World Standardized Seismograph: USGS Open-File Report (in press).

Global Digital Network Operations

9920-02398

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Investigations

1. The Global Network Operations continued to provide technical and operational support to the SRO/ASRO/DWWSSN observatories, which include operating supplies, replacement parts, repair service, redesign of equipment, training and on-site maintenance, recalibration and installation. Maintenance is performed at locations as required when the problem cannot be resolved by the station personnel.

2. The Raytheon O&M contract remains at one team leader and three technicians.

3. The software coding on the SRO event detector has been completed, and final testing of the detector is in progress. The testing is being done on the ANMO SRO system.

4. The following station maintenance activity was accomplished:

ANMO - Albuquerque - SRO
Two visits made for tape unit problems. One repair job on the ICS inverter. The teletype was exchanged for a DECWRITER matrix printer in August.

ANTO - Ankara, Turkey - SRO
One maintenance visit in July.

BCAO - Bangui, Central African Republic - SRO
One maintenance visit. The borehole cable was repaired after damage by lightning.

BOCO - Bogota, Colombia - SRO
One maintenance visit.

CHTO - Chiang Mai, Thailand - SRO
One maintenance visit. The replacement power system was shipped to CHTO during September.

CTAO - Charters Towers, Australia - ASRO
No maintenance visit.

GRFO - Grafenberg, W. Germany - SRO
No maintenance visit.

GUMO - Guam - SRO
No maintenance visit.

KONO - Kongsberg, Norway - ASRO
No maintenance visit.

KAAO - Kabul, Afghanistan - ASRO
No maintenance visit.

MAJO - Matsushiro, Japan - ASRO
No maintenance visit.

MAIO - Mashhad, Iran - SRO
Out of operation.

NWAO - Mundaring, W. Australia - SRO
No maintenance visit.

SHIO - Shillong, India - SRO
No maintenance visit.

SNZO - Wellington, New Zealand - SRO
No maintenance visit.

TATO - Taipei, Taiwan - SRO
No maintenance visit.

ZOBO - La Paz, Bolivia - ASRO
One maintenance visit.

DWWSSN

ALQ - Albuquerque, New Mexico
The DWWSSN system for ALQ was taken out of operation and is now being used for special tests.

AFI - Afiamalu, W. Samoa
One maintenance visit.

TAU - Hobart, Tasmania
One maintenance visit.

TOL - Toledo, Spain
Two maintenance visits were made.

Three DWWSSN installations were completed during this period:

GDH - Godhavn, Greenland
LEM - Lembang, Indonesia (Finalized)
BDF - Brasilia, Brazil

ASL Repair Facility

The DWWSSN system for Zaria, Nigeria was tested and packed for shipment. A digital calibration system was designed, assembled, and sent to College, Alaska for the DWWSSN system. A La Marche uninterruptible power system was received, checked out, and shipped to Chiang Mai, Thailand SRO station. This is a replacement for the ICS system.

In addition, routine repair and testing of replaceable modules for SRO/DWWSSN systems took place as time permitted.

Results

Installation of the DWWSSN systems has expanded the digital network to a combined total of 29 SRO/ASRO/DWWSSN stations. This expansion has resulted in a much broader digital data base through the improved geographical coverage of the digital systems.

Seismic Review and Data Services

9920-01204

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Investigations and Results

Technical review and quality control were carried out on 101,100 seismograms (553 station-months) generated by the Worldwide Standardized Seismograph Network (WWSSN). Ninety station-months of the ASRO and SRO network analog seismograms were provided on a current basis to the National Earthquake Information Service (NEIS) for their PDE programs. These, as well as, the WWSSN recordings are forwarded to the microfilming service: weekly schedule for the WWSSN; and as released by the NEIS for the SRO and ASRO recordings.

Ninety-two station-months of original microfiche seismogram copies were furnished to a special studies program monitored through this project.

Forty-nine WWSSN station performance reports were sent during this period. The overall standards in the WWSSN station operations remained at high levels. However, some reductions in total recordings are beginning to become evident though this has not shown up significantly in the figures for this period. The drop is due to a shortage in photographic paper supplied to the stations necessitated by funding cutbacks and high paper costs. Stations run the vertical components only during short supply.

Consultations regarding station data and operations were provided to researchers and government officials as needed. Some attention is being directed towards microfiche short period seismogram copy to possibly improve their resolution.

National Earthquake Information Service

9920-01194

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Investigations and Results

The weekly publication, Preliminary Determination of Epicenters (PDE), continues to be published on a weekly basis, averaging about 50 earthquakes. The PDE, Monthly Listings, and Earthquake Data Reports (EDR) are all on the VAX and are working very well. We continue to publish all earthquakes which have data available within 30 days of the earthquake on the PDE. We have not had many improvements on rapid data flow from our foreign contributors.

These problems are still being worked on and some improvement is taking place. The personal contact with many of our foreign visitors explaining the need for faster reporting of data has been helpful. We continue to receive telegraphic data from the USSR on magnitude 6.5 or greater earthquakes and some damaging earthquakes with magnitudes less than 6.5. Data from the PR China via the American Embassy is still being received, but not in time for the PDE. The American Embassy is unable to transmit these data in its present form from the State Seismological Bureau in time for the PDE. However, this problem should be eliminated within a few weeks with the arrival of an IBM Selectric Typewriter, on loan from our office to SSB. This will enable SSB to prepare a ready copy of these data for transmission to us by the American Embassy. At present we are receiving a total of 21 stations from SSB in time for the Monthly Listing.

The Monthly Listing of earthquakes is up to date. To date the Monthly Listings have been completed through May 1982 and have been mailed through April 1982. The Earthquake Data Reports (EDR) are computed through May 1982 and printed and mailed through April 1982. Fault Plane Solutions continue to be determined when possible for any earthquake having a magnitude $\geq$ 6.5 and published in the Monthly Listing and EDR. Centroid Moment Tensor Solutions from Harvard University continue to be published in the Monthly Listing and EDR.

The Earthquake Early Alerting Service continues to provide services on recent earthquakes on a 24 hour basis in response to the ever increasing demands from scientists, news media, and the general public.

Reports

Prelininary Determination of Epicenters (24 weekly publications April 22 to September 30--Numbers 13-82 through 36-82). Compilers: W. Leroy Irby, Reino Kangas, Willis Jacobs, John Minsch, Waverly J. Person, Bruce Presgrave, William Schmieder.

Monthly Listing of Earthquakes and Earthquake Data Reports (EDR) (6 publications--December 1981 through May 1982). Compilers: W. Leroy Irby, Reino Kangas, Willis Jacobs, John Minsch, Russell Needham, Waverly Person, Bruce Presgrave, William Schmieder.

Seismological Notes, BSSA: Waverly J. Person
May - June 1981
July - August 1981
September - October 1981

Earthquake Information Bulletin:

Vol. 13, No. 8	Earthquakes	Waverly J. Person	May - June 1981.
Vol. 14, No. 2	Earthquakes	Waverly J. Person	September - October 1981.

United States Earthquakes

9920-01222

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Investigations

1. Seventy-five earthquakes in 20 states were canvassed by a mail questionnaire for felt and damage data. Forty of these occurred in California. Only one earthquake for this period reported minor damage; it occurred on May 24, 1982 in Utah and was located at 38.73N, 112.04W, depth 3 km, magnitude 4.0 ML.

2. The United States earthquake parameters for the period April 1, 1982 to September 30, 1982 have been computed and the hypocenters, magnitudes, and maximum intensities have been published in the Preliminary Determination of Epicenters.

3. The seismicity map of Texas has been printed at a scale of 1:1.000.000. The data for Colorado and New Mexico maps have been completed and the maps are being prepared. The data for Idaho and Wyoming are being compiled.

Results

The maximum Modified Mercalli intensity of VI was evaluated for the Utah earthquake of May 24, 1982. The damage was centered on the town of Annabella where chimneys and brick walls were cracked, furniture overturned, many broken glasswares, and one house sustained a cracked and bowed out brick wall. An unusual earthquake was located in South Dakota near Sioux Falls on July 11, 1982 which was felt at intensity V in an area northeast of the city. This is the first event of this intensity in this area since the one on October 11, 1938.

The circulalar containing United States earthquake data for January-March, 1981 and April-June, 1981 has been printed. July-September, 1981 is being printed.

Reports

Stover, C. W., Minsch, J. H., Smith, P. K., and Baldwin, F. W., 1982, Earthquakes in the United States, October-December 1980: U. S. Geological Geological Survey Circular 853-D, 33 p.

Minsch, J. H., Stover, C. W., Dunbar, P. K., and Baldwin, F. W., 1982, Earthquakes in the United States, January-March 1981: U. S. Geological Survey Circlar 871-A, 33 p.

Stover, C. W., Minsch, J. H., Dunbar, P. K., and Reagor, B. G., 1982, Earthquakes in the United States, April-June 1981: U. S. Geological Survey Circular 871-B, 33 p.

Reagor, B.G., Stover, C. W., and Algermissen, S. T., 1982, Seismicity map of the state of Texas: U. S. Geological Survey Miscellaneous Field Studies Map MF-1388.

Digital Data Analysis

9920-01788

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Investigations

1. Moment Tensor Inversion. Develop methods for inverting body phase waveforms for the best point source description.

2. Computation of Free Oscillations. Develop practical methods for computing free oscillations of the Earth and combining them to construct synthetic seismograms.

3. Computation of Travel-Times. Develop practical methods for computing body phase travel-times directly from arbitrary, realistic Earth models.

4. Intermediate Period Band Studies. Use the IP channel of the DWWSSN instruments to study the frequency dependence of Q and mantle anisotropy.

5. Network Day Tape. Support and enhance portable software for retrieving data from the Global Digital Seismograph "Network Day Tapes." Develop software for monitoring the consistency of the data.

6. Special Event Reports. Contribute to NEIS publications pertaining to selected events and to waveform catalogs of significant earthquakes.

7. Fault Plane Solutions. Determine fault plane solutions for all earthquakes of magnitude 6.5 or greater (6.0 in the conterminous U.S.) using first motion directions.

Results

1. Moment Tensor Inversion. In its first large scale test, the method has been applied to about 100 events of magnitude 5.8 or larger in the time interval 1 January 1981 to the present. The new automated algorithm has in general performed very satisfactorily. However, investigation into optimization and limitations of the scheme on a case-by-case basis is continuing.

2. Computation of Free Oscillations. Two distinct computational algorithms have been combined into a hybred. Experiments with the hybred have allowed definitive testing of the precision, robustness, correctness, reliability, and speed of all three methods. An optimal algorithm has been selected and problem areas identified. Work is progressing in the resolution of these problems and in the construction of a standard computer program.

3. Computation of Travel-Times. A sufficiently robust interpolation for the tau table method has been found and the computation has been extended to all source depths. The precision and correctness of the method has been extensively tested for different models, source depths, and wave types. A journal article describing the method has been prepared for publication.

4. Intermediate Period Band Studies. Preliminary work on the feasibility of using the intermediate period band of the new DWWSSN instruments for mantle body wave propagation studies is in progress.

5. Network Day Tapes. Distribution of the third revision of the software and documentation awaits final testing. The first version handled network day tapes. The second version added capability for station tapes and old format network day tapes. The third version handles network event tapes, corrects a few minor bugs and portability problems reported by end users, and handles the new RSTN data.

6. Special Event Reports. The first special event report, on the 1 Sept. 1981 Tonga event, has been submitted for publication as an open-file report. Members of the project contributed to the report as well as taking responsibility for manuscript editing and figure preparation. Project members also contributed to a special study of the New Brunswick event of 9 January 1982 as well as supporting development of a new "waveform catalog" publication. As a result of these experiences, extensive work has been done on providing identical data acquisition, time series analysis, and plotting software on our VAX11/780 as well as our PDP11/70 computer system. Additionally, work is well underway to provide a direct file transfer link between the two machines.

7. Fault Plane Solutions. Fault plane solutions are being routinely produced for selected events, less than 4 months behind real time. The results are summarized in the NEIS Monthly Listing and will also be compiled into a separate catalog. About 15 solutions for events of magnitude 6.5 and larger have been done for the first half of 1982.

Reports

Buland, R. and Chapman, C. H., "The Computation of Seismic Travel-Times", in preparation for BSSA.

Choy, G. L., Boatwright, J., Dwewy, J. W., and Sipkin, S. A., 1982, A teleseismic analysis of the New Brunswick earthquake of January 9, 1982: Journal of Geophysical Research in press.

Earth Structure and its Effects Upon Seismic Wave Propagation

9920-01736

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Investigations

1. Use of short-period and broadband waveforms to infer earth structure. Develop methods of generating synthetic waveforms that correctly incorporate the frequency dependent effects that arise from source directivity and from propagation through the earth. Apply these methods to infer the fine structure of velocity and of attenuation at specific regions in the earth.

2. Source parameters from GDSN data. Extract source parameters from digitally recorded data of the GDSN by developing techniques of processing data and by determining corrections to waveforms to distinguish source effects from propagation effects.

Results

1. Use of short-period waveforms to infer earth structure. Programs have been developed to synthesize seismograms by combining full wave theory with a causal rupture model to describe both propagation and source effects. The comparison of 8 digitally recorded PKP body waves from a deep earthquake with synthetic seismograms has permitted the resolution of the C and D cusps to better than $\pm 2°$. Strong gradients in P-velocity, S-velocity and attenuation were inferred for the top 100-300 km of the inner core.

2. Source parameters from GDSN data. We are examining rupture characteristics of a suite of four moderate-sized ($5.4 < m_b < 6.1$) earthquakes that encircled and preceded over a period of two years the eventual rupture zone of the Miyagi-Oki earthquake of June 12, 1978. We are also developing programs to model the large (M_s 7.8) Samoa earthquake of September 1, 1981. This was a very complex rupture. Thus far, four major subevents and their relative locations have been identified.

Reports

Choy, G. L. and Boatwright, J., 1982, Broadband analysis of the extended foreshock sequence of the Miyagi-Oki earthquake of June 12, 1978: Bulletin of the Seismological Society of America, in press.

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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 recording systems.

Results

1. The Saudi Arabian System development and modifications were completed. The following modifications were incorporated into the basic DWWSSN system for custom operation:

   a. Manual Programmable Current Calibration System.

   b. Two Magnetic Tape Recorder capability.

   c. Special Front Panel configuration and operation.

   d. Systron Donner Time Encoder operation.

2. All equipment and parts for the Peldehue, Chile system were procured. Design of the special GOES Satellite Data Platform for seismic telegraph format reporting has started. GOES Satellite authorization for operation has been approved.

3. All hardware and system development for the low cost 2400/9600 Baud Digital Telemetry System has been completed. Final assembly and test are under way.

4. Redesign of the Berkeley/Jamestown DWWSSN telemetry system was completed. This redesign was required to operate over the long telephone circuit and associated telephone company line delays. Final checkout and evaluation are completed. The system is working satisfactorily.

5. The DWWSSN laboratory microprocessor simulation system design and assembly have started. This system will be used to check out and test new DWWSSN software and hardware changes.

Seismicity and Tectonics

9920-01206

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Investigations

1. Peru Seismicity and Tectonics. Provide tectonic setting for and analysis of the 1974 Peru gap-filling earthquake series. Determine plausible models to explain the well-ordered process of stress release during the 1974 earthquake series.

2. Mantle Structure Beneath the Rio Grande Rift and the Jemez Lineament. Use a 3-D, seismic ray-tracing algorithm to invert a set of teleseismic P-wave delay data, with the objectice of determining the maximum depth and degree of velocity anomaly in the upper mantle beneath the Rio Grande rift and the Jemez lineament.

Results

The great 1974 Peru thrust earthquake of October 3, 1974 (M_S 7.8, M_W 8.1) occurred within a well-documented seismic gap. The stress release of the 1974 main shock and aftershocks ocurred in a spatially and temporally irregular pattern. The space-time distribution of aftershocks, combined with focal mechanism solutions for the largest events, indicates that (1) Pre-main shock stresses were highest in the northern half of the thrust zone; (2) Subduction was impeded on the downdip side of the main rupture zone; (3) The subducting Nazca plate was internally deformed doing this earthquake series; and (4) The stress release throughout the aftershock zone was non-randomly sequenced between several primary areas of aftershock activity.

The 3-D P-wave velocity inversion shows scant evidence for pronounced low P-wave velocity beneath the 240-km-long section of the Rio Grande rift covered by our array. However, the inversion shows a primary trend of low P-wave velocity underlying the northeast-trending Jemez lineament, down to a depth of about 160 km. The Jemez lineament is defined by extensive Pliocene-Pleistocene volcanics and late Quaternary faults. The upper mantle low-velocity segment beneath the Jemez lineament is at most 100 km wide and at least 150-200 km long, extending in our inversion from Mt. Taylor through the Jemez volcanic center and through the Rio Grande rift. This zone is 1-2 percent lower velocity than the upper mantle beneath the rest of array, which itself has a P-wave velocity 4-6 percent lower than in the mantle of the adjoining High Plains province. A Backus-Gilbert resolution calculation indicates that this result is well resolved.

Report

Spence, W., Gross, R. S., and Jaksha, L. H., 1982, P-wave velocity structure beneath the Jemez lineament, New Mexico (abstract): EOS (in press).

Permeability of Fault Zones

9960-02733

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Investigations

Laboratory studies of the permeability of fault gouge were carried out to provide information that will assist us in evaluating whether, in a given region, fluid can navigate to a sufficient depth during the lifetime of a reservoir to trigger a large destructive earthquake.

Results

Frictional sliding experiments at confining pressures from 50 to 400 MPa were performed on thin layers of clay-rich fault gouges from locations along the San Andreas and Hayward faults in California as well as pure clays from other locations. Both dry and saturated, drained samples exhibited a strain hardening that increased systematically with increasing confining pressure for each particular gouge. In addition, the amount of strain hardening was greater with progressively stronger gouges among the suite of different samples. Tests using various lubricating mediums at the sample ends and different jacketing materials all showed that these possible constraints on frictional sliding had no effect on the strain-hardening process. Therefore, the observed strain hardening was a material property of the fault gouges. The presence of water lowered the strength, coefficient of friction, and amount of strain hardening of the samples. The coefficient of friction ranged from around 0.21 to 0.58 under saturated, drained conditions at 200-MPa confining pressure with the exception of pure montmorillonite. This sample had anomalously low strength and friction ($\mu \sim 0.13$) in relation to the other specimens. The strength of the gouges did not correlate well with mineral composition, grain size distribution, or location along the San Andreas fault; in particular, gouge samples from creeping and 'locked' sections of the fault showed no systematic differences in strength.

Reports

C. Morrow, L.Q. Shi and J. Byerlee, 1982, Strain hardening and strength of clay-rich fault gouges, J. Geophys. Res., v. 87, no. B8, pp. 6771-6780.

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Self-Potential Measurements Near Dams

9780-02917

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Investigations

Self-potential (SP) and electromagnetic induction measurements (EM-31 slingram) measurements were made at four Colorado locations including: Ralston Reservoir, Upper Long Lake, Dillon Reservoir, and Gross Reservoir.

Results

The SP measurements at four dam sites have revealed several interesting anomalies. The largest anomalies were seen in the vicinity of the dam outlet tunnels. These are typically, but not always, negative. They are due either to corrosion of the metal in the tunnel, or to an oxidation-reduction reaction pair which uses the tunnel as a means of coupling electrons between these reactions. The inlet end of the tunnel in the reducing environment would be the site of the oxidation reaction, and the outlet end of the tunnel in the oxidizing environment would be the site of the reduction reaction. Additionally, there were anomalies associated with the corrosion of buried pipes. These represent a noise source which would be present at most dam sites.

The Ralston and Gross sites had a small negative anomaly associated with the crest of the dam. The cause of this anomaly is not clear. It may be due to water flow around the end of the dam. Modelling will be necessary to test this hypothesis.

Electrofiltration effects were seen along the eastern section of Dillon dam where there is a flow of water which probably comes from the jointed sandstone outcrop near the middle of the dam crest. In regions where there is a toe drain system, this anomaly is absent. Since the drain provides such a good flow path for seepage, it eliminates the percolation of water through the ground and electrofiltration effects.

Seepage along bedding planes in the Pierre shale at Upper Long Lake produced small positive anomalies due to the increased moisture content of the soil. This phenomenon has been previously reported in the literature.

While no anomalies were seen which could be unequivocally attributed to water flow near the dams, this does not completely rule out the possibility of the self-potential method being useful for detecting dam leaks. All of the sites studied are not considered to have leaks, thus the method has not been tested under optimum conditions. Furthermore, most of the sites (Ralston, Long Lake, and Dillon) were in fairly conductive sedimentary rocks which would minimize streaming potential effects.

The EM-31 slingram measurements proved very helpful in determining if SP anomalies were due to buried pipes. When there was a coincidence between the SP and EM-31 anomalies, the anomaly was considered to be due to a buried conductor. The EM-31 instrument is ideally suited for locating shallow (6 m deep) conductive bodies.

Reports

The following Open-File Report has been written and is in Branch review:

Fitterman, D. V., 1982, Self-potential surveys near several Denver Water Department dams: U.S. Geological Survey Open-File Report No. 82-????.

DEVELOPMENT OF IMPROVED HYDROFRACTURING INSTRUMENTATION AND ITS APPLICATION AT A SITE OF INDUCED SEISMICITY

Contract No. 14-08-0001-20537

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Report Summary

The objective of this project is to improve the existing technique of field hydrofracturing so as to render it substantially cheaper and faster than the present norm, and then use it at one or more sites of induced seismicity. It is primarily the high costs that have kept hydrofracturing stress measurements from being conducted at many sites of induced seismicity.

The major improvement in the field technique is its conversion from a drillrod to a wireline method using separate hydraulic lines for the packers and for the hydrofracturing interval. The new tool will be not unlike a geophysical logging instrument and will employ a 7-conductor wireline and an appropriate hoist. The lowering and lifting time of the equipment will be drastically cut as would expenses, since a tripod over the testhole head will be sufficient for "tripping" the tool and the need for a drill rig and crew will be eliminated.

In the first six months of this project, we have acquired some of the major components of the modified equipment, have converted an existing truck so it can house the wireline hoist and take all the equipment to the field, and have all but completed the designing of the pertinent mechanical, electrical and hydraulic parts necessary for the conversion of the present tool to a wireline hydrofracturing instrument.

The next phase is the fabrication of the newly designed parts, followed by tool assembly and testing. A site of induced seismicity will be used for the first run of the wireline hydrofracturing device.

In Situ Stress Measurements

9960-01184

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Investigations

The efforts of this project were devoted to a variety of investigations. During March and April we ran several types of logs in the three holes drilled in Pinon Flats, California, and installed a Sachs meter in each one. In April we finished the stress measurements and ultrasonic borehole televiewer logs in the 5,250-ft Auburn, New York, borehole. In April and May we made caliper and televiewer logs in two boreholes, San Juan Grade and Echo Valley, that we had drilled previously in San Juan Bautista, California, and assisted with the installation of a Sachs meter in the Echo Valley hole. During April through July we finished the stress measurements and water level recording that we had begun in February and March in the Oroville, California, borehole, and then ran velocity logs in the hole. In August we ran televiewer logs in a 4,450-ft borehole drilled near Hanford, Washington, for the Rockwell International Corporation. During August and September we drilled one 600-ft borehole at Searle Road in San Juan Bautista and two holes, 600 ft and 400 ft, in Parkfield for the future installation of dilatometers. In September we began in situ stress measurements in a borehole located on Yucca Mountain at the Nevada Test Site. Also during this period, research continued on the development of our ultrasonic borehole televiewer system, the electronics for other downhole measuring instruments, and new designs for our downhole packer systems.

Results

We are continually making progress in the operational aspects of this project. As we gain experience from field work we are able to continually develop and redesign our instrumentation systems to further economize the operations of drilling boreholes, installing downhole instruments, and making measurements. We have purchased a new ultrasonic borehole televiewer with redesigned electronics that have made the instrument more reliable by using printed circuit boards and up-dated, higher-quality components, and by combining several functions on each circuit board. We have also devised a new technique for processing borehole televiewer data to produce horizontal cross sections of a borehole. We have redesigned and constructed surface electronics for the new model downhole pressure transducers that we are using to record downhole pressures during hydraulic fracturing tests and for precision water level measurements in a well we drilled last year at Hi Vista, California. Additional electronics have also been designed and constructed for atmospheric pressure, rainfall, and wind speed gauges to be used for future water level monitoring. We have redesigned our downhole packer assemblies to make them resettable and to eliminate the necessity of tripping the drill pipe in and out of the hole for each test. The new packers, which contain many fewer moving parts and tool joints, greatly increase the speed and efficiency of our stress measurements and reduce time lost due to equipment failure.

Analysis of the hydraulic fracturing stress data and televiewer survey taken in the Auburn borehole indicate that the minimum horizontal principal stress increases in a nearly linear manner from 99 bars at 593 m to 305 bars at 1,481 m. The maximum horizontal principal stress increases from 149 to 499 bars over the same depth range. Orientations of hydraulic fractures at depths of 593 and 917 m indicate that the direction of maximum horizontal compression is approximately N83°E $\pm$ 10°. The televiewer log reveals a large number of natural fractures in the borehole, the majority of which are apparently related to bedding planes and stratigraphy. The steeply dipping fractures observed in this well are concentrated in the lower Paleozoic section and Precambrian basement below about 1,340 m. The fractures in the basement show no clear preferred orientation, but those in the overlying sandstones and limestones tend to strike in a direction approximately parallel both to the contemporary direction of maximum horizontal compression and to the axes of late Paleozoic Appalachian Plateau folds to the south.

The San Juan Grade hole in San Juan Bautista was drilled for the emplacement of a Sachs meter, but as the hole extends to a depth of only 220 ft due to the continual collapse of surrounding fault zone rocks into the hole, the meter was not installed. Also, televiewer and caliper logs revealed no suitable interval in this hole for the emplacement of the meter. The logs run in the Echo Valley hole in San Juan Bautista revealed two good zones in the rock, and a Sachs meter was installed in this hole.

The Oroville borehole was drilled to a total depth of 1,940 ft and penetrated a major fault zone at a depth of about 1,100 ft. We believe this fault zone to be that associated with the August 1975 Oroville earthquake and aftershocks. We encountered considerable difficulty keeping the hole open below the fault zone due to the continual caving of fault zone rocks into the hole, but after cementing the fault zone, we were able to obtain televiewer, caliper, and velocity logs throughout the well. Natural fractures seen with the televiewer show a diversity of orientations, a significant number parallel to the fault zone. The P-wave log indicates high velocities (about 6 km/s) and signal amplitudes that decrease in the proximity of the fault zone. Hydraulic stress measurements indicate a strong, localized decrease in the magnitudes of both horizontal principal stresses and the maximum shear stress below the fault zone. Also, water level records taken in the hole above and below a packer set at 968 ft reveal tidal signals from both levels, though the amplitude of the signal below the packer is dramatically reduced in comparison to that above the packer.

We used the new ultrasonic borehole televiewer (modified to work in a 3-in hole) in the Hanford borehole to log from about 2,244 to 4,450 ft. The televiewer log revealed prominent wellbore breakouts similar to those observed at Auburn, New York. The Hanford hole is cased to 2,200 ft and may be used for future stress measurements.

Stress measurements and a borehole televiewer log were begun in late September at the Nevada Test Site in hole USW-G2. The results of these tests will be reported in the next semi-annual report.

Reports

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Induced Seismicity and Earthquake Prediction Studies at the Koyna Reservoir, India

9930-02501

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Under this project it is proposed to install 13 portable seismic stations in the Koyna Dam region, Maharashtra State, India. The installation of the network and data analysis will be done in collaboration with the National Geophysical Research Institute, Hyderabad, India. The proposed field work is still awaiting approval from the government of India.

The only activity in this project during the second half of FY-82 was the visit to the U.S.G.S., Menlo Park, of Dr. H. K. Gupta from the National Geophysical Research Institute, Hyderabad, India. Dr. Gupta spent two months in Menlo Park, and during this period examined the earthquakes in the Koyna region recorded by the WWSSN seismograph station at Poona, located 120 km from Koyna. He found that of the six magnitude ≥ 5 earthquakes which occurred at Koyna, three were preceded by two magnitude ≥ 4 earthquakes during the preceding 15 days. All the other magnitude ≥ 5 earthquakes in the region were singular, that is no two such events occurred within 15 days of one another. Thus, he concluded that there is a typical foreshock-aftershock pattern in the induced seismic activity at Koyna with a 50% probability of occurrence of a magnitude ≥ 5.0 earthquake if two earthquakes of magnitude ≥ 4.0 are closely spaced in time in the Koyna regon. A short paper entitled "Are reservoir earthquakes of magnitude ≥ 5.0 at Koyna, India, preceded by a couple of earthquakes of magnitude ≥ 4.0?", is in review.

Investigation of the Influence of Depth of Focus on a Seismic Spectral Discriminant for Reservoir Induced Earthquakes

14-08-0001-02517

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Investigations

In a general sense, all earthquakes are triggered. The problem of discriminating reservoir induced earthquakes from natural events is that of determining whether the triggering mechanism(s) are directly related to changes caused by reservoir impoundment. A study by Castle et al. (1980) found that tectonic environments characterized by normal or strike slip faulting were correlated with reservoir induced seismicity. In our previous work (Long and Johnston, 1979) we found that a cubic high-frequency spectral decay of displacement was a discriminant for earthquakes triggered by reservoir impoundment. Earthquakes occurring near Oroville (Calif.), Clark Hill (Ga.), Jocassee (S.C.), and Monticello (S.C.) showed similar spectral (ω-cube) properties and satisfy the spectral discriminant for reservoir induced earthquakes. Also, theoretical considerations imply that spectra with cubic decay are derived from earthquakes on pre-existing lubricated surfaces slipping under low tractional resistance. A common factor in these discriminants based on tectonic environment and spectra is the implication that earthquakes occur under conditions where the vertical stress is the minimum or intermediate deviatoric stress axis. Such conditions would predominantly be observed in areas where a horizontal stress is less than the vertical and areas subjected to tensional deviatoric stress conditions. Also, in these areas, existing cracks, joints or faults could retain significant porosity and water would be expected to penetrate to greater depths. In contrast, areas of compressive tectonic stresses would have tight faults or joints which would exhibit high tractional resistance. Earthquakes on these surfaces would exhibit ω-square spectral decay. Hence, the existence of open or porous faults and joints in a tensional environment provides easy access for ground water to penetrate the rock and provides lubricated or weak surfaces for earthquakes. These environments are conducive to the occurrence of triggered earthquakes and the penetration of ground water to do the triggering. Areas of tight fractures, probably under compressive stresses, do not allow easy ground water penetration and some other triggering mechanism must explain the occurrence of earthquakes. If one then accepts pore pressure changes as a triggering agent for reservoir induced earthquakes, the discrimination between natural and induced earthquakes is then the problem of defining the stress conditions or relative porosity. The successful tectonic environment discriminant utilizes largely geological data and the spectral discriminant uses earthquake displacement spectra and source mechanism theory to determine the relative ambient stress conditions (extensional or compressive tectonics) and the existence of surfaces which can facilitate slip.

Having shown the feasibility of identifying or, perhaps if data allow, predicting reservoir induced seismicity, the next question to be considered is: what is the largest earthquake a given reservoir might trigger. Since it is known that the maximum magnitude of an event is limited by the maximum area of possible faulting and since most explanations of reservoir induced earthquakes require existing lubricated faults or joints, a logical hypothesis would be that the maximum induced earthquake could be computed (not necessarily directly) from the maximum depth at which smooth or lubricated faults or joints will allow earthquakes. Areas exhibiting high residual or tectonic tensional stress will have reduced tractional friction on potential fault surfaces extending to greater depths and reservoirs in such areas could induce larger earthquakes. Reservoirs in areas of moderate tectonic or residual stress would not have available lubricated planes to as great a depth and only smaller events could be triggered. The transition with increased depth from low to high hydrostatic stress requires a parallel increase in tractional friction on the slip surfaces. Theoretical considerations in source spectra imply that the high-frequency content of the deeper focus events should increase because of the increased contact between the two sides of the fault plane. Such an increase should be reflected in the displacement spectra by a change from ω-cube to ω-square decay. Data presented by Fletcher (1979) are suggestive of such a transition. The specific problem of this proposed research is to determine by observation whether a change with depth in the high-frequency spectral slope can be observed and, if observable, can it be used to predict the maximum depth of faulting (and hence maximum magnitude) of an induced earthquake.

During the first half year of work, the major portion of the research time was expended in finding and evaluating data sources, in developing analysis techniques and programs, and in preliminary examinations of acquired data. The remaining period of the project will be used to process as much data as time or resources will allow.

Results

On 23 April 1982 we obtained two tapes with digital event recorder data from the vicinity of Monticello Reservoir and from Mammoth Lakes. These data were obtained through the courtesy of the U.S. Geological Survey in Menlo Park, California. Unfortunately, none of the data fully satisfies all criteria including depth control. The choice of data is a compromise between reservoir induced seismicity and good data. However, the Monticello data are perhaps the best and can be combined with some of our own data. The first efforts will be directed toward the use of this data.

While only two quantities, high-frequency slope and depth of focus, are needed to define the relation between depth and spectral content, their computation and evaluation requires consideration of many techniques and parameters. These include data processing, focal mechanism, surface wave contamination, absorption attenuation, and scattering phenomena.

Accessing and reading the foreign tape provided with the Monticello and Mammoth Lakes data turned out to be non-trivial. Special programs were developed to allow reading and plotting of this data. Figure 1 shows an example of the Monticello data taken from the data tape and plotted at Georgia Tech.

Focal mechanism is important in spectral estimates because the frequency content can be a function of the point of departure from the focal sphere. A masters thesis titled "Investigation of SV to P wave amplitude ratio for determining focal mechanism" by Wen Shyr Tzeng was partially supported by the project. The thesis is attached to this report as an appendix. The results, which include a computer program to find valid P, T, and B axes, indicate that the SV to P wave amplitude ratio can significantly improve the resolution of focal mechanisms. Clearly defined (<±10°) strike slip (2) and diagonal dip slip (2) focal mechanisms were found for Monticello data using only 5 or 6 stations. With only first motions, the valid solutions were poorly defined (>±20°) or indeterminant.

Scattering proved to be a factor in the interpretation of SV to P wave amplitude ratios. Only the first part of the arrival can be assumed to represent the takeoff azimuth and dip computed from travel time curves. All later arrivals in the coda are scattered arrivals which take a random propagation path and represent a random sampling of the focal sphere. Hence, with increased time into the coda the SV to P wave amplitudes ratios should represent the averaged amplitudes about the focal sphere. Correction at the recording site for angle of incidence is more difficult since the distribution of angles of incidence must be considered. This distribution depends on the scattering mechanism and is not always well understood. Likewise, the spectral content exhibited in the coda will represent a random sampling or average of the focal sphere. As with the SV to P wave amplitude ratio, the most reliable spectra must be obtained from the first part of the P or SV phase.

Surface waves contribute to almost all the observed seismograms. These are typically lower in frequency and follow the SV arrival at sufficient time intervals to allow isolation from the sample time window. The degree of contamination by converted surface waves within the P or SV phase is uncertain.

Attenuation, if frequency independent, can usually be estimated for each site. In the Piedmont Province, where Monticello is located, the Q_p is approximately 750 and the Q_s approximately 400 (Long and Johnston, 1979). At these high values, attenuation does not strongly affect traces recorded at close range. At Mammoth Lakes, the attenuation may be a significant factor in the interpretation.

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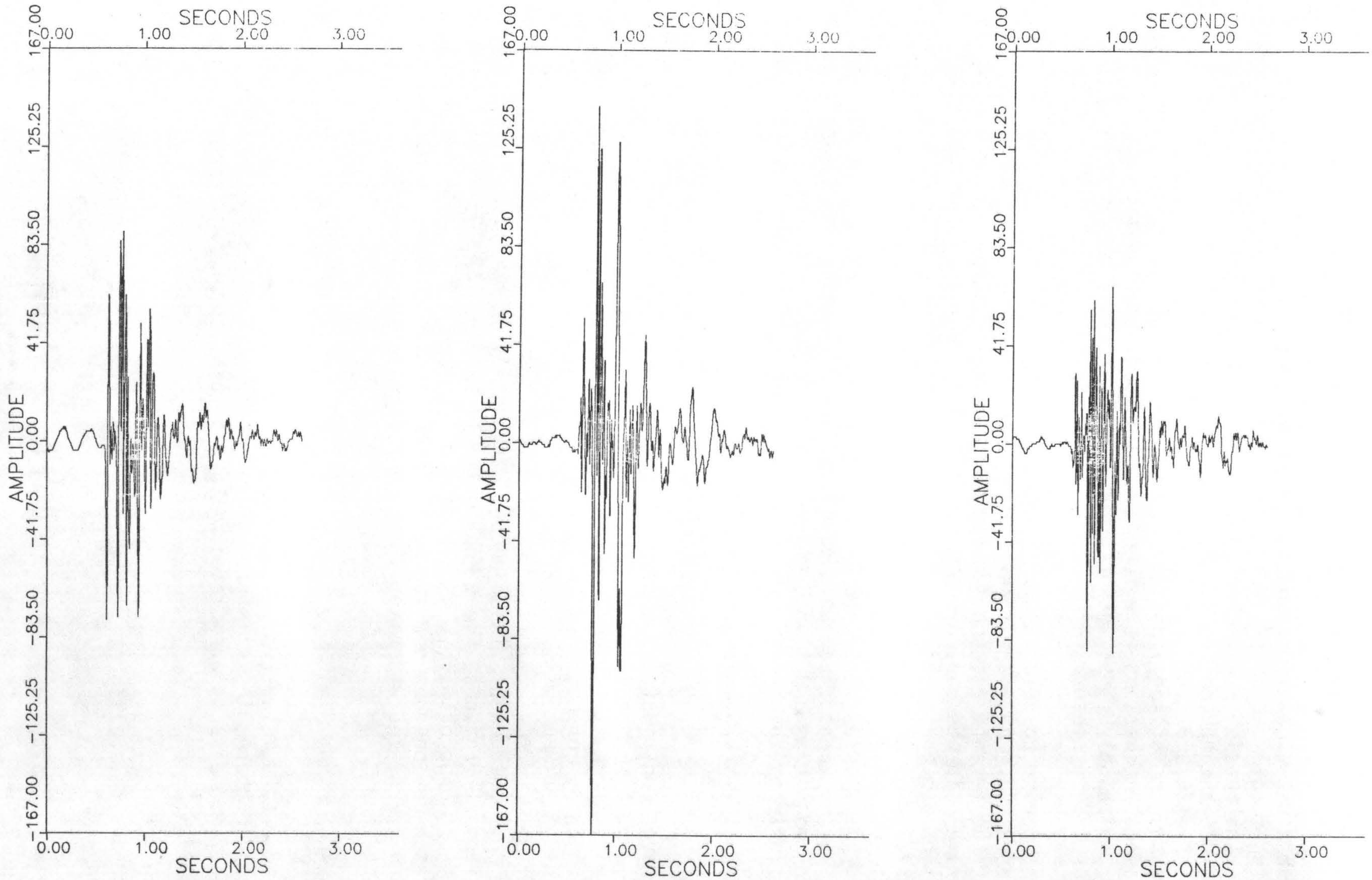

Figure 1. Three components of Monticello earthquake plotted from tape data.

INDUCED SEISMICITY - SLEEPY HOLLOW OIL FIELD

14-08-0001-20544

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BACKGROUND.

Based on preliminary locations of microearthquakes by the Eastern Kansas Seismic Network, Rothe (1981) installed a temporary four-station network which revealed that seismicity in southwest Nebraska was confined to the vicinity of the Sleepy Hollow Oil Field. The injection of fluids for the purpose of enhanced recovery of hydrocarbons from the field and the proximity of the earthquakes to the field suggested the possibility of induced seismicity. Rothe (1981) discovered further, that some of the earthquakes were on the order of fifteen to twenty kilometers deep, far below the injection depth of 1.1 kilometers at the base of the sedimentary rocks. Thus, the possibility exists that at least some of the seismic activity may be due to tectonic causes. The purpose of this study is to determine the relationship between the fluid injection, tectonic stresses, and the observed seismicity.

ARRAY INSTALLATION AND OPERATION.

The preliminary stages of the installation of the eight-station, telemetered Sleepy Hollow Seismic Network were accomplished in mid-December of 1981, when the station sites were permitted, forty-foot holes were drilled and cased with PVC pipe, and antenna masts for FM radio transmitters were erected. In addition, a radio repeater site was permitted and radio masts errected for transmission from the southern edge of the Network, across the Kansas-Nebraska border to a telephone drop about ten miles northwest of Norton, Kansas. The seismometers and telemetry equipment were installed in early March, but because of delays in telephone telemetry the network did not become fully operational until April 1.

RECENT SEISMICITY.

During the period April 1 to June 12, 1982, fourteen (14) microearthquakes of magnitude ranging from -0.3 to 1.7 were recorded well enough at a sufficient number of stations to allow preliminary locations to be determined. The network configuration and located events are shown in Figure 1. The right-side-up deltas represent USGS supported stations which are temporarily complemented by three University supported stations (upside-down deltas). Event locations are preliminary pending the determination of accurate station adjustments and velocity model. The seismicity located so far is consistent with that reported by Rothe (1981) in that it appears to be restricted to two general areas, one in the north-central part of the Sleepy Hollow Oil Field, and the other on the southwestern edge of the oil field.

HYPOCENTER DETERMINATION.

For the purpose of preliminary hypocenter determinations the computer program FASTHYPO (Hermann, 1979) was modified to run on an Apple II microcomputer in our lab. Arrival times are read from Geotech Helicorder records with a time scale of 1.5 mm/sec. Arrival times can be read to within 0.10 seconds.

Locations shown in Figure 1 were determined by the computer program HYPO71 (Lee and Lahr, 1975) using P- and S-arrivals. The velocity model used was inferred from the results of a refraction survey in northwest Kansas (Steeples, 1976) and consists of a 1.1 km thick, 4.0 km/sec layer overlying a halfspace of velocity 6.0 km/sec. A Vp/Vs ratio of 1.73 is assumed.

To compare the hypocenter determination capabilities of FASTHYPO and HYPO71 eight representative events 2.0 km deep were synthesized by tracing rays through the same model used for preliminary locations in order to create phase lists which were then treated as events of unknown hypocenter for the two programs to process. Using P-arrivals only, FASTHYPO out performed HYPO71 by producing solutions with smaller summed squared travel-time residuals in fewer iterations.

The next stage of the experiment consisted of adding random errors with a normal distribution and random weights (0,1,2,3) with a uniform distribution to the synthetic phase lists and repeating the comparison. HYPO71 slightly outperformed FASTHYPO, but FASTHYPO locations were satisfactory to justify the continued use of FASTHYPO for preliminary hypocenter determination.

DIRECTION OF CONTINUED EFFORT.

The relation of the seismicity to the injection in the Sleepy Hollow Oil Field is unknown at this point as we are currently establishing a working relationship with Amoco engineers. Amoco has agreed to provide sonic logs, injection records, and the results of stimulated fracture tests. There is about a four month lag between injection and its coding into a form which Amoco will release.

A reversed-profile refraction experiment is planned in order to get a better handle on the velocity of the Precambrian basement as well as the sedimentary section (upper 1.1 kilometers). A twenty-kilometer long profile line through the network (Figure 1) will utilize the recording equipment of the current network and additional recorders. In addition to the refraction experiment several blasts within the network are planned for the purpose of individual station delay determinations.

DIGITAL RECORDING.

A digital recording system comprised of the analog trigger described by Wolf and Steeples (1978) and an eight-channel digital exploration seismograph was attached in parallel with the analog recorders on June 12th. No earthquakes have occurred since then to evaluate the system, which should provide eight digital seismograms, each consisting of 125, sixteen-bit samples per second for sixteen seconds including five seconds of preevent data.

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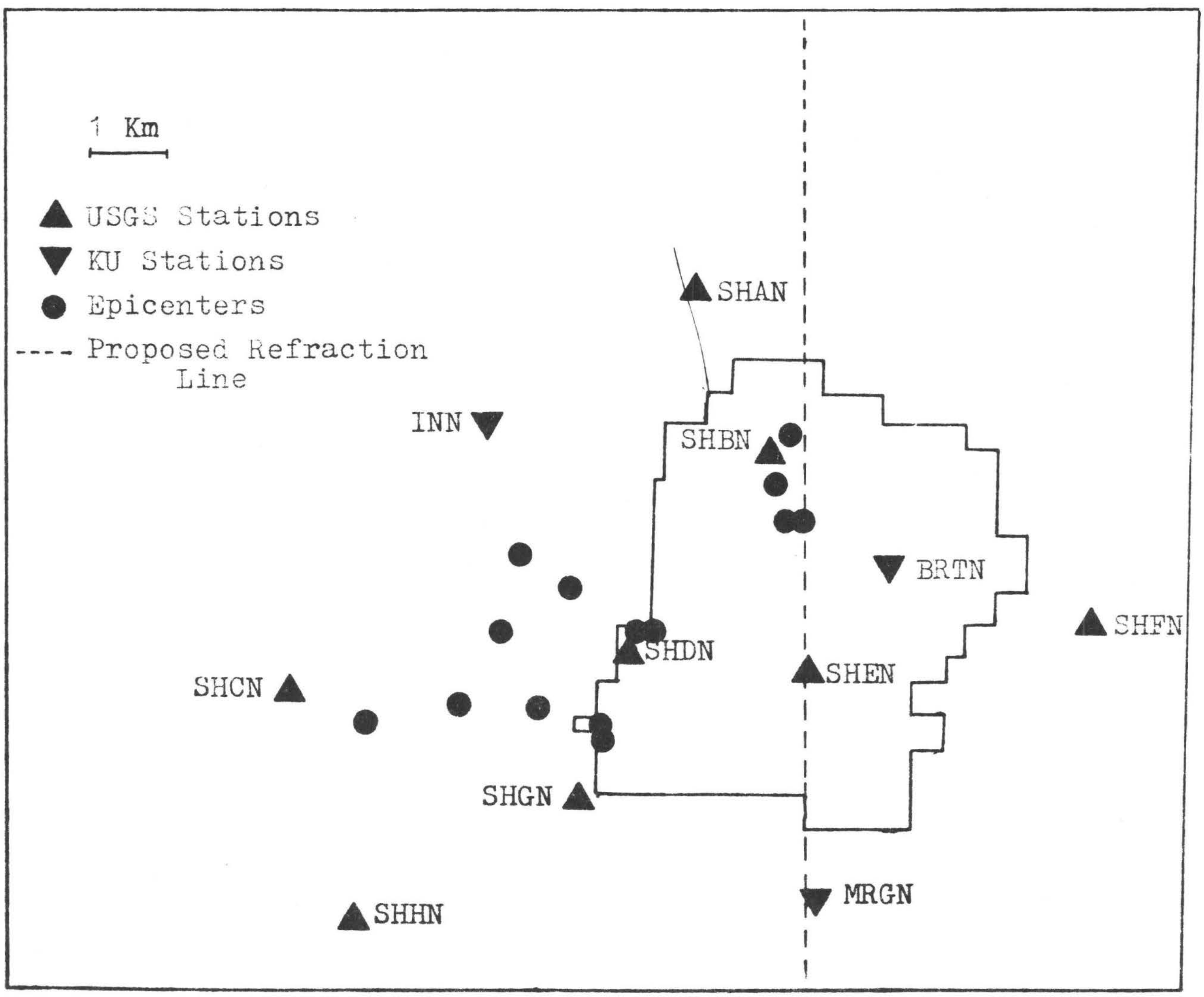

Figure 1: Station locations, preliminary epicenters, and refraction line.

Induced Seismicity at Nurek, Toktogul and Aswan Reservoirs: Seismicity, Geology and Tectonics

USGS-13-08-0001-19743

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Investigations

1. Seismological and geological studies of induced seismicity at Nurek and Toktogul Reservoirs, Soviet Central Asia.
2. Seismotectonics and geology of Central Asia.
3. Induced seismicity studies at Aswan Reservoir, Egypt.

Results

1. Since late 1978, Nurek Reservoir (dam height 310 m) has operated between water depths of 225 and 260 meters. Low level induced seismicity continues near the reservoir, but there have not been any major bursts of activity such as those in 1972 and 1976 when the water level rose rapidly by more than 75 meters. A monograph on the Soviet and American studies at Nurek is being prepared. It will contain a complete earthquake catalog 1955-1979; tables of waver level in the reservoir; yearly epicentral maps; and descriptions of geological and geophysical studies.

The maxium water level at Toktogul Reservoir (dam height 210 m) was 170 m in mid-1980. Since then the water level has remained below 160 m. Low-magnitude induced activity continues near the dam, but there has not been any pronounced increase in activity along the Talas Fergana fault.

Stratigraphic and structural geology studies are continuing at both Nurek and Toktogul. Earlier studies at Nurek have been extended along the strike of the Vakhsh foldbelt, towards Garm and into the Peter I Ranges.

A geological map of the Nurek-Garm area is being prepared, using Landsat and RBV imagery as a base map, which incorporates field studies under this program and the results of Soviet studies in the area.

2. Soviet earthquake catalogs for Central Asia show considerably more detail on seismicity patterns than is available from international sources. Lineations in seismicity divide the region into separate crustal blocks which correspond to distinct topographic and geologic provinces. Reviews of the available geologic literature, with special emphasis on the Tadjik Depression, are being combined with our field studies at Nurek and Toktogul in an interpretation of the present structure and tectonic development of the southern margin of this part of Asia.

3. On November 14, 1981, a magnitude 5 1/2 earthquake, followed by a long sequence of aftershocks, occurred on the western edge of Aswan Reservoir, Egypt, 50 km south of the High Aswan Dam. In June-July 1982, an eight station network was installed around the active area by

Lamont-Doherty and the Helwan Institute of Astronomy and Geophysics, with support from the USGS and the Government of Egypt. The seismicity is concentrated at depths of 10-25 km along the Kalabsha fault, an east-west structure which intersects the reservoir east of the active area. Fault plane solutions show predominantly right-laterial strike-slip faulting. The November 1981 mainshock occurred just after a seasonal peak in water level (94 m) and a large aftershock (magnitude 4 1/2) followed the seasonal minimum (89 m) in mid-August 1982. The reservoir began to fill slowly in 1964, but did not approach capacity until 1975, when a water depth of 93 m was reached. Since 1975 the water level has varied seasonally between 89 and 96 m. The delay between the first filling and the onset of induced seismicity may be related to the gradual flooding of the thick sequence of permeable Nubian sandstone which underlies the reservoir.

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Induced Seismicity and Earthquake Prediction Studies in South Carolina

Contract No. 14-08-0001-19252

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Investigations

In the reporting period (April 1 - September 30, 1982) we continued to monitor seismicity at Lake Jocassee and Monticello Reservoir in South Carolina. The concentration of radon was also monitored at a spring near Lake Jocassee and at three sites near Monticello Reservoir. Aftershock studies were also carried out following earthquakes in the Piedmont Province near Newberry, South Carolina.

Results

1. Induced Seismicity at Monticello Reservoir

There was a marked increase in seismicity in 1982 as compared to 1981. In the period January - September 1982, 264 events were recorded (8 with $M_L > 2.0$), compared to a total of 170 in 1981 (1 with $M_L \geq 2.0$). The most active period was in April-June 1982, when 133 events, including 6 with $M_L \geq 2.0$ were recorded (Figs. 1 and 2). Another feature of this activity was the observation that a significant proportion of events (17 of 79 in April) were deeper than 3 km. In the past years, well over 90% of the activity has been shallower than 2 km.

2. Seismicity at Blair and Newberry

An unusual feature in this reporting period was the occurrence of seismicity in two areas in the general area of Monticello Reservoir, but not immediately adjacent to it. The seismicity occurred far enough to be considered independent, yet a general lack of activity in those areas in the previous years does not preclude the suggestion that it may be related to Monticello Reservoir.

On May 7, 8 events (largest magnitude $\sim$ 1.5) occurred in a 9-minute span near Blair, located 12 km NNW of the south shore of Monticello Reservoir. The events occurred between 07.31 and 07.40 UTC (3:31-3:40 AM local time) and awoke residents.

In July and August two swarms occurred near Newberry, located about 22 km to the west of the reservoir. The July swarm occurred between July 16 and 22. In the swarm, 9 events were recorded on the Monticello network supplemented by 3 portable seismographs. The largest event,

$M_L \sim 2.3$, was felt over a 10 sq. km area. Five more events occurred at the same location on August 12-13. The largest, $M_L \sim 1.6$, was also felt. Analysis of the Newberry events revealed that the earthquakes were occurring in the top 2 km with the two nodal planes oriented N-S or E-W. Local topography and aeromagnetic data support the N-S oriented solution, whereas regional geology and gravity data support the E-W solution. The seismicity appears to be related to the edge of the Newberry granite pluton.

3. Induced Seismicity at Lake Jocassee, South Carolina

In the period January - September 1982, 81 events were recorded near Lake Jocassee, with two events, $M_L \geq 2.0$ occurring in September (Fig. 3). Most of the seismicity is located to the south of the lake. Although the seismicity has been fairly widespread at Lake Jocassee, its spatial extent has been confined to within an epicentral area defined within the first year of activity.

4. Earthquake Prediction Studies at Lake Jocassee and Monticello Reservoir

We have continued to monitor radon concentration and other geochemical parameters in an observation spring at Lake Jocassee. No notable anomalies have been observed.

At Monticello Reservoir we have continued to monitor water levels in two observation wells and geochemical parameters at three sites. No anomalous changes in radon concentration were noted in the reporting period.

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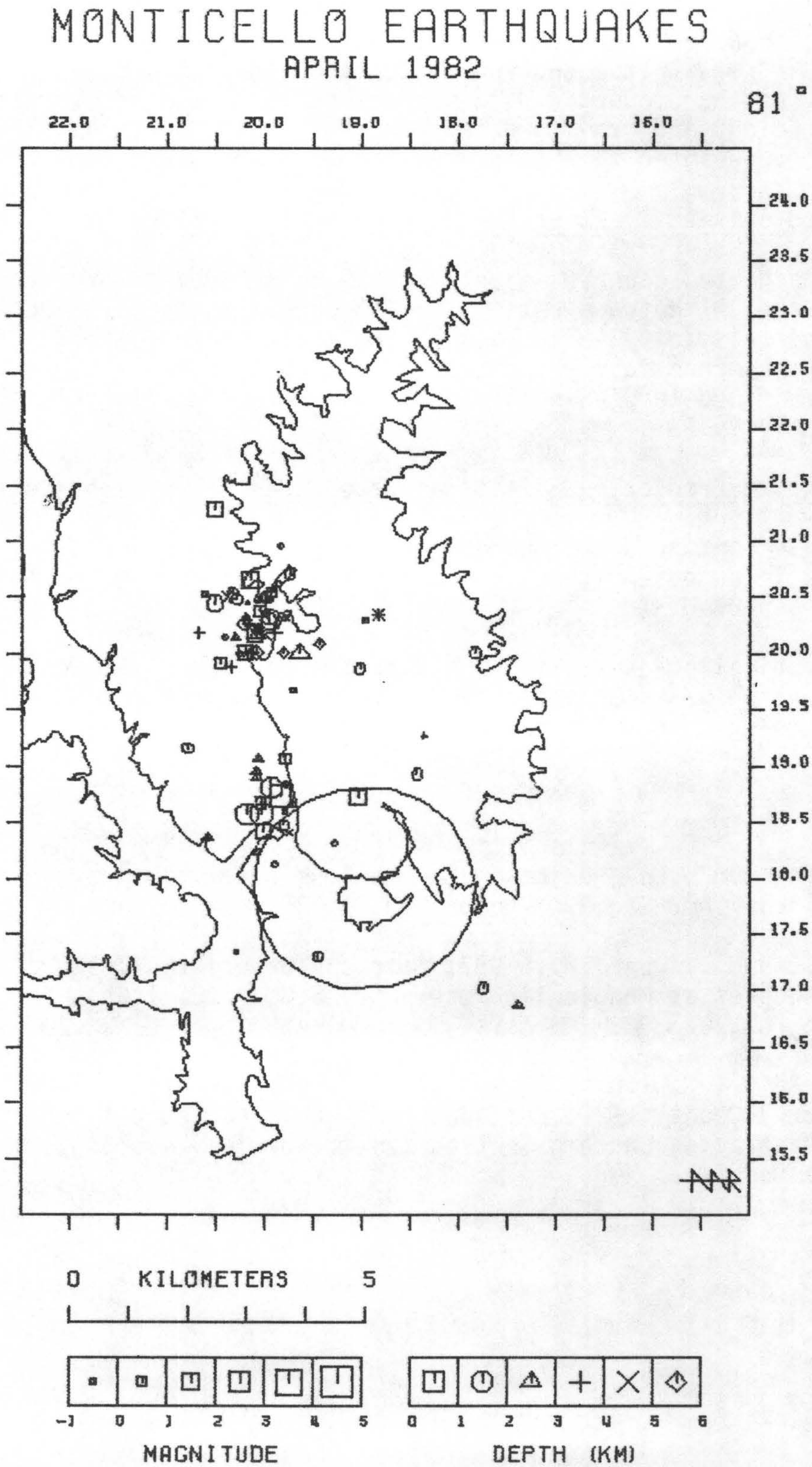
MØNTICELLØ EARTHQUAKES
APRIL 1982
81°
22.0
21.0
20.0
19.0
18.0
17.0
16.0
24.0
23.5
23.0
22.5
22.0
21.5
21.0
20.5
20.0
19.5
19.0
18.5
18.0
17.5
17.0
16.5
16.0
15.5
34°
0 KILOMETERS 5
-1 0 1 2 3 4 5
MAGNITUDE
0 1 2 3 4 5 6
DEPTH (KM)

Figure 1

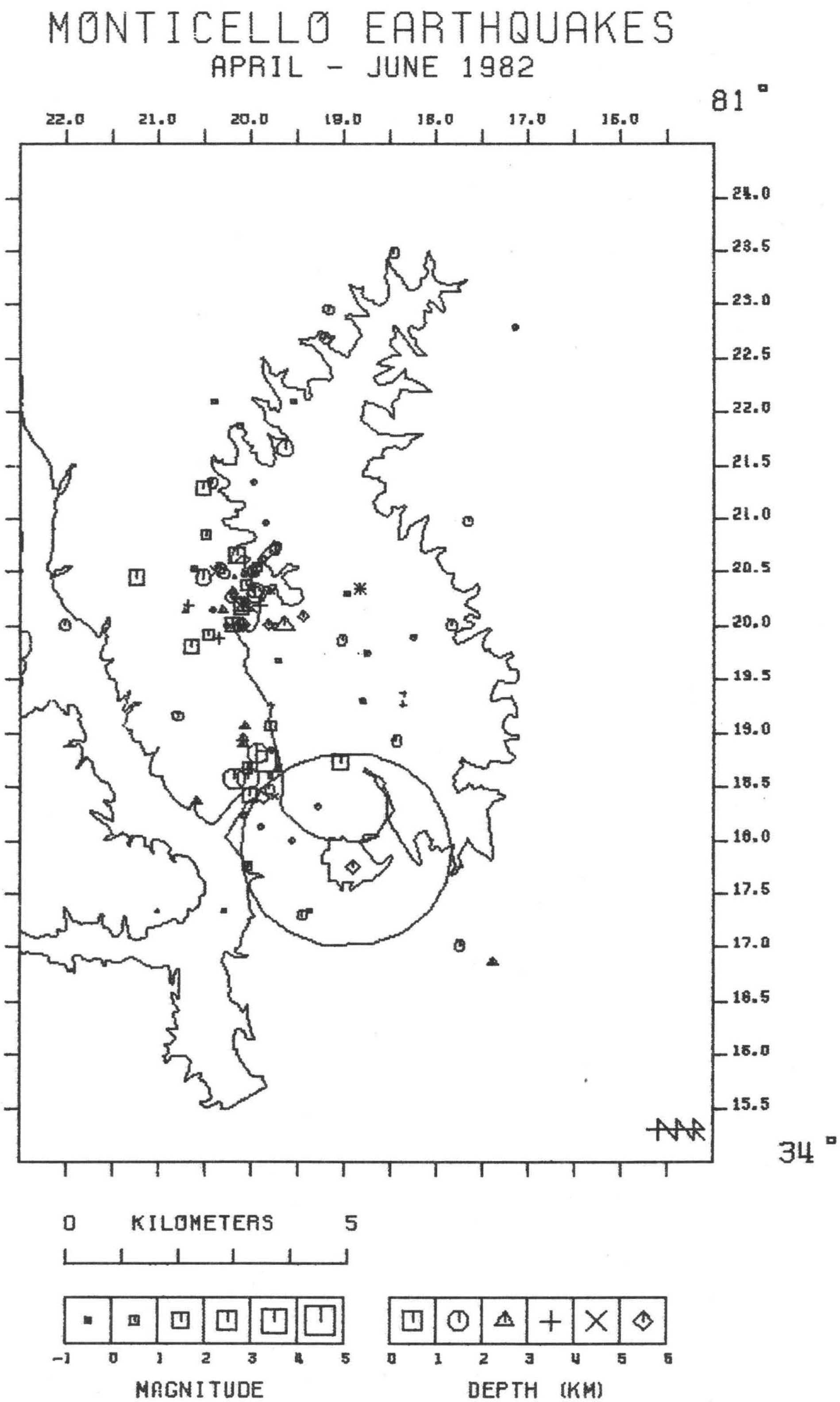
MONTICELLO EARTHQUAKES
APRIL - JUNE 1982
81°
22.0
21.0
20.0
19.0
18.0
17.0
16.0
24.0
23.5
23.0
22.5
22.0
21.5
21.0
20.5
20.0
19.5
19.0
18.5
18.0
17.5
17.0
16.5
16.0
15.5
34°
0 KILOMETERS 5
-1 0 1 2 3 4 5
MAGNITUDE
0 1 2 3 4 5 6
DEPTH (KM)

Figure 2

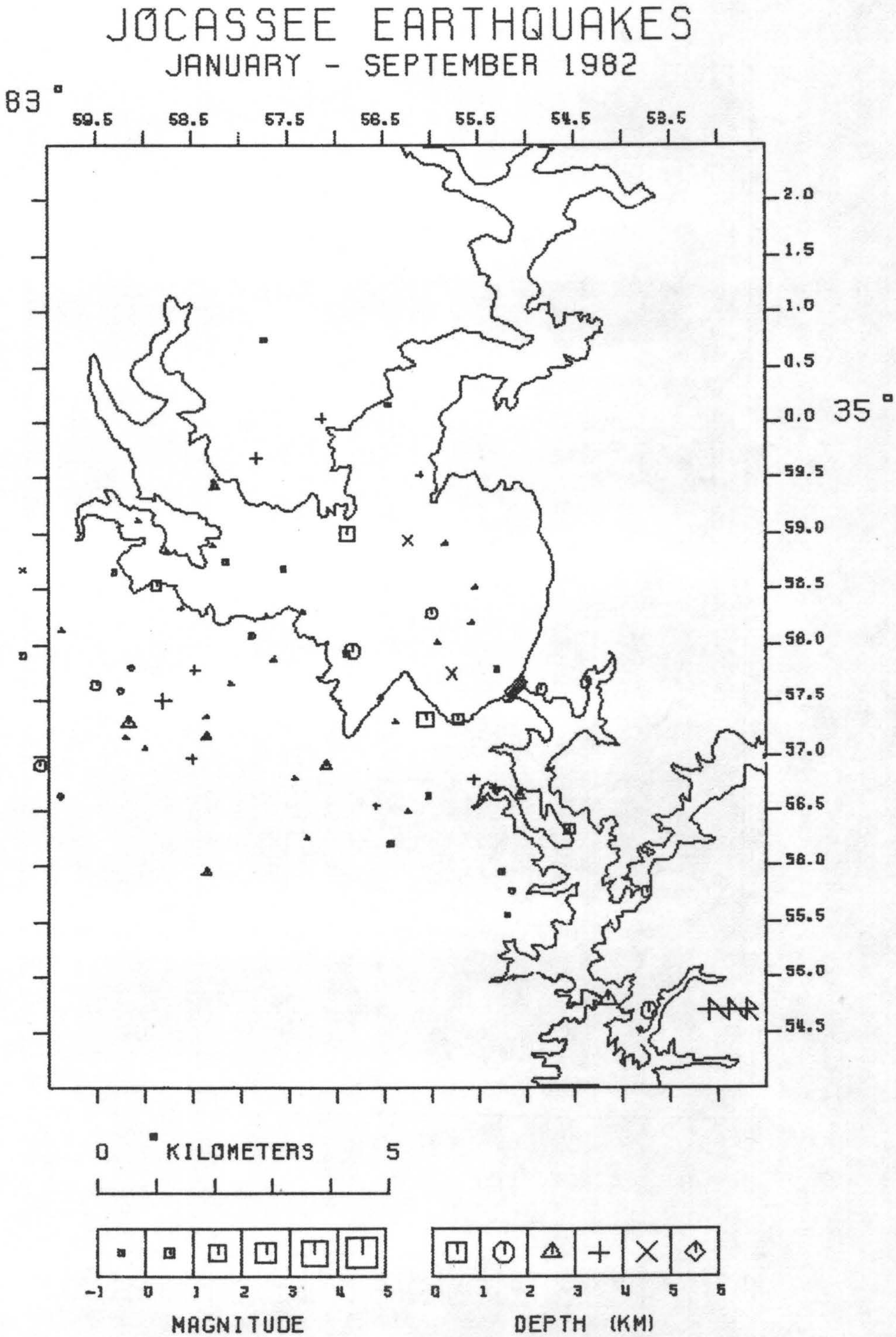
JØCASSEE EARTHQUAKES
JANUARY - SEPTEMBER 1982
83 °
59.5
58.5
57.5
56.5
55.5
54.5
53.5
2.0
1.5
1.0
0.5
0.0
35 °
59.5
59.0
58.5
58.0
57.5
57.0
56.5
56.0
55.5
55.0
54.5
0
KILOMETERS
5
-1
0
1
2
3
4
5
MAGNITUDE
0
1
2
3
4
5
6
DEPTH (KM)

Figure 3

Induced Seismicity at Lake Oroville, California
Contract No. 14-08-0001-20531

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Within 60 km of Oroville, earthquakes of magnitude M4 or greater are quite rare, only one such earthquake having occurred during the twenty years before filling Lake Oroville. First filling of Lake Oroville was accompanied by a magnitude M4.7 earthquake in April 1968. This earthquake was located by U.C. Berkeley 45 km west of Oroville. Earthquakes of M3 to M4 occurred sporadically thereafter until the damaging M5.7 earthquake of August 1975. Up to the time of the 1975 earthquake, seismographic coverage in the area was poor, and epicentral uncertainties on the order of 10 km were possible. Arrival times are being obtained from U.C. Berkeley in order to improve the epicentral locations of the pre-1975 earthquakes, with the use of well-determined 1975 epicenters as master events. This should improve the picture of the seismicity before the seismographic coverage was improved in 1975, in order to determine any effects the reservoir might have had on the natural seismicity.

Improved seismographic coverage following the M5.7 earthquake of 1975 permits a detailed comparison of seismicity to the seasonal fluctuations in water level in the lake. Toppozada and Morrison (California Geology, June 1982) have shown that earthquakes near Oroville occur mainly in the summertime when the reservoir is drawing down, and that the local seismicity decreases markedly during refilling in the winter and spring. Hypocentral locations for the post-1975 seismicity are available partly from the California Department of Water Resources and partly from the U.S. Geological Survey. These locations are being compiled and compared to determine the spatial distribution of the seismicity that is related to the seasonal variations in reservoir storage.

INDEX 1

INDEX ALPHABETIZED BY PRINCIPAL INVESTIGATOR

INDEX 2

INDEX ALPHABETIZED BY INSTITUTION