UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

SUMMARIES OF TECHNICAL REPORTS, VOLUME XIV

Prepared by Participants in

NATIONAL EARTHQUAKE HAZARDS REDUCTION PROGRAM

July 1982

OPEN-FILE REPORT 82-840

Menlo Park, California

1982

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 May 15, 1982 and cover the 6-month period from October 1, 1981 through March 31, 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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Induced Seismicity (IS)
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Open File Report No. 82-840

CONTENTS

Earthquake Hazards Reduction Program

Portable Broad-Band Seismic Systems (Northeastern United States Seismic Network)

14-08-0001-18262

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Investigations

1. To assemble two 12-element portable broad-band digital systems that can be used in a variety of deployment configurations.

2. To develop utility software for data collection, storage and retrieval.

3. To obtain improved crustal models from wide angle reflection and refraction data from regional quarry explosions and earthquakes.

Results

In co-operation with Princeton University (R. A. Phinney, Principal Investigator) two 12-element portable broad-band seismic systems have been assembled and field tested. Each system consists of a central recording system (PDP 1103 special purpose processor with dual floppy disks, 16 channel A/D converter, CRT and hard copy display, and 800 or 1600 bpi magnetic tape unit), Geotech S-500 seismometers (interchangeable as verticals or horizontals), and telemetry.

Utility software for data acquisition in either a continuous or event-detection mode have been developed and tested. Data storage and retrieval software have also been developed and tested.

A user's manual describing the Seismic Event Detection and Analysis System (SEDAS) software has been prepared. SEDAS is a software package written for the PDP 1103 computer. SEDAS can collect data from up to 16 analog input channels and, optionally, display the data graphically, record the data on magnetic tape and perform event detection analysis. Data on magnetic tapes previously recorded by SEDAS can also be graphically displayed. In addition, SEDAS has an assistance capability which can provide online information pertaining to the operation of the system. SEDAS is interactive, command driven, and intended to be "user friendly". A separate programmer's manual is provided for those who may need to make programming modifications.

Field applications in progress using the systems include recording of wide-angle reflections and refractions from timed quarry explosions on a linear spread and three-component recording of regional and teleseismic signals both for crustal phases and mode-converted (P-SV) teleseismic body waves. Data from these systems are being used as part of three M.S. theses at Penn State and one Ph.D. thesis at Princeton.

One complete system will be operated by Lamont-Doherty Geological Observatory during the coming year.

Reports

Alexander, S. S., 1981, Lateral Variations in Crustal Structure from Combined Use of Wide-Angle Reflections, Refracted Arrivals and Mode-Converted Phases, EOS, Vol. 62, No. 45, p. 962.

Gross, P., 1982, Seismic Event Detection and Analysis System (SEDAS). User's Manual, Geophysics Program, The Pennsylvania State University.

Sienko, D. A., 1982, Crustal Structure from Wide-Angle Reflections and Refractions, M.S. Paper, The Pennsylvania State University, 125 pp.

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

Jim Dewey has computed preliminary epicenters and magnitudes (m_{blg}) of over 200 instrumentally recorded earthquakes from Colorado, New Mexico, and southern Wyoming. The following conclusions are based on these data:

(1) Because of radical differences in properties of seismic wave attenuation across the Rocky Mountain front, regionally dependent and azimuthally dependent attenuation functions must be used to estimate m_{blg} (Nuttli, JGR, p. 876, 1973) for Rocky Mountain earthquakes. If attenuation of Lg waves propagating to the east from the Rocky Mountain front is described by an anelastic attenuation coefficient (γ) of 0.07 deg^{-1}, a value typical of the Central U.S., then attenuation coefficients for Lg to the west of the mountain front must have values of 0.3 deg^{-1} or 0.4 deg^{-1}, if the m_{blg} values computed for westerly traveling waves are to agree with those computed for easterly traveling waves.

(2) The list of relocated earthquakes should be essentially complete above magnitude (m_{blg}) 3.5 for the period 1964-1980.

(3) Forty percent of the earthquakes of magnitude (m_{blg}) 3.5 or larger occurred in the man-induced sources at Rangely and Denver, Colorado. Another 25 percent were part of the aftershock sequence of the magnitude 5.1 Dulce, New Mexico, earthquake of January 23, 1966.

(4) Excluding the man-induced earthquakes and the Dulce aftershocks, the seismicity data for 1964-1980 suggest a recurrence time of between 500 and 2000 years for a magnitude 6.5 earthquake occurring anywhere in southern Wyoming, Colorado, and New Mexico. This recurrence time seems unexpectedly long, in view of the number of late Cenozoic faults in the region. In fact, Kirkham and Rogers (Colorado Geological Survey, Bulletin 42, 1981) estimate a similar recurrence time for magnitude 6.5 earthquakes on a single trenched scarp of the Sangre de Cristo fault in Colorado. It may be that the recent instrumentally-recorded seismicity has been anomalously low compared to the long-term seismicity.

(5) The recent moderate earthquake activity is not well correlated with mapped Late Cenozoic faults. The Sangre de Cristo fault, cited in the previous item, was aseismic at the magnitude level of this study for the period of this study. In order to reconcile the recent aseismicity of the Sangre de Cristo fault with the high activity suggested for the Holocene by trenching studies (ibid), it is necessary to postulate that the Sangre de Cristo fault is currently in the quiescent stage of its seismic cycle.

(6) The New Mexico earthquakes of Jan 06, 1976 (m_b = 5.0) and Mar 05, 1977 (m_b = 4.5) are reliably located at focal depths of about 41 km beneath the surface of the Colorado Plateau near Gallup. These depths are substantially greater than focal depths usually observed away from current subduction zones. They indicate that the crust beneath the Colorado Plateau is stressed at great depth and that it is unusually strong, since otherwise the stress would be relaxed aseismically.

Reports

Choy, G. L., Dewey, J. W., Needham, R. E., Sipkin, S. A., and Zirbes, M. D., 1982, Teleseismic study of the central New Brunswick earthquake of 9 January, 1982 (abs.): Earthquake Notes, v. 53, no. 1, p. 18.

Dewey, J. W., 1982, Instrumental seismicity of New Mexico, Colorado, and southern Wyoming (abs.): Earthquake Notes, v. 53, no. 1, p. 86.

Montero, P. W., and Dewey, J. W., Shallow focus seismicity, composite focal mechanism, and tectonics of the Valle Central of Coast Rica: Bulletin of the Seismological Society of America (accepted for publication).

Strong Ground Motions in Two Seismic Gaps: Shumagin Islands, Alaska, and Northern Lesser Antilles, Caribbean

USGS 14-08-0001-19744

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Investigations

This program, to establish a bare-bone strong-motion recording capability in two seismic gaps, nears completion. A total of 12 sites are now monitored by analog accelerometers in the Shumagin seismic gap, and one on Unalaska Island. Five sites were occupied in the Lesser Antilles but high attrition of instruments due to some adverse site conditions requires frequent replacemente with refurbished units. Two triaxial digital accelerometer units (PDR-1) have been acquired, are lab-tested, and are scheduled for deployment during the summer of 1982. One unit will be installed at the central recording site at each network. Their installation completes the purely technical program.

Results

Since installation of the Shumagin accelerometers in 1980/81 at least six triggers occurred for which records have been retrieved and of which five were earthquakes. By station (see Figure 1) and triggering wave (P or S) they comprise the following set

No. of Records	Station	Trigger Phase
3	BKZ	2S, 1P
1	CNB	S
1	SGB	S

Additional triggers have been noted since the last station visits and include events as small as M_L = 3.8 (on 12/28/81 near SAN). An example of a processed record from BKZ of a M_L = 4.8 earthquake of June 8, 1981, is shown in Figure 2. No triggers are reported from the Lesser Antilles. The next data retrieval for Alaska is planned for ≈July 1982.

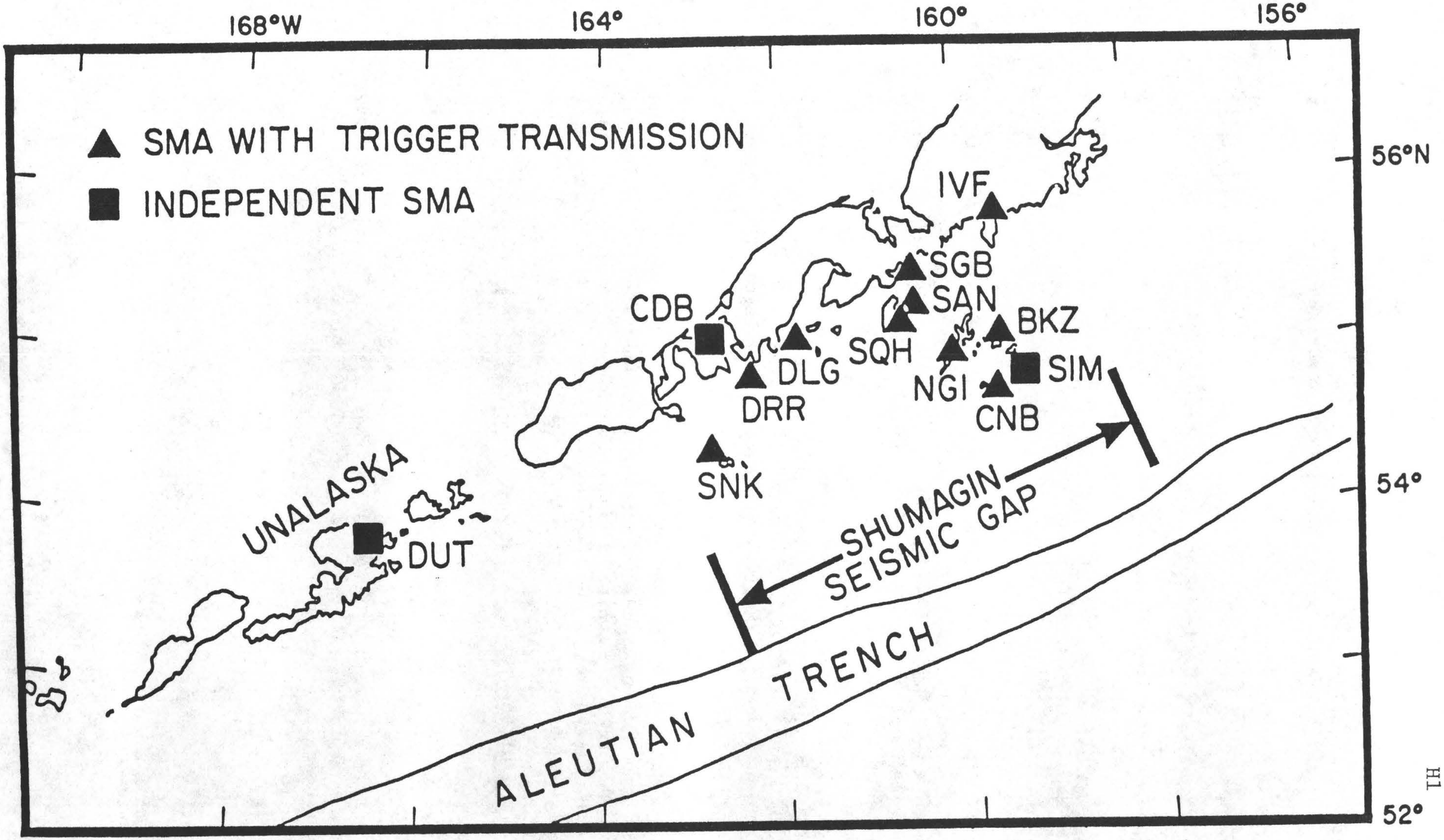

Figure 1. Distribution of strong motion stations near the Shumagin seismic gap, Alaska, as of August 1981. Stations indicated by triangles transmit trigger moment through telemetry of Shumagin seismic network to central recording site at Sand Point (SAN). Squares indicate strong motion sites unrelated to telemetered short-period network.

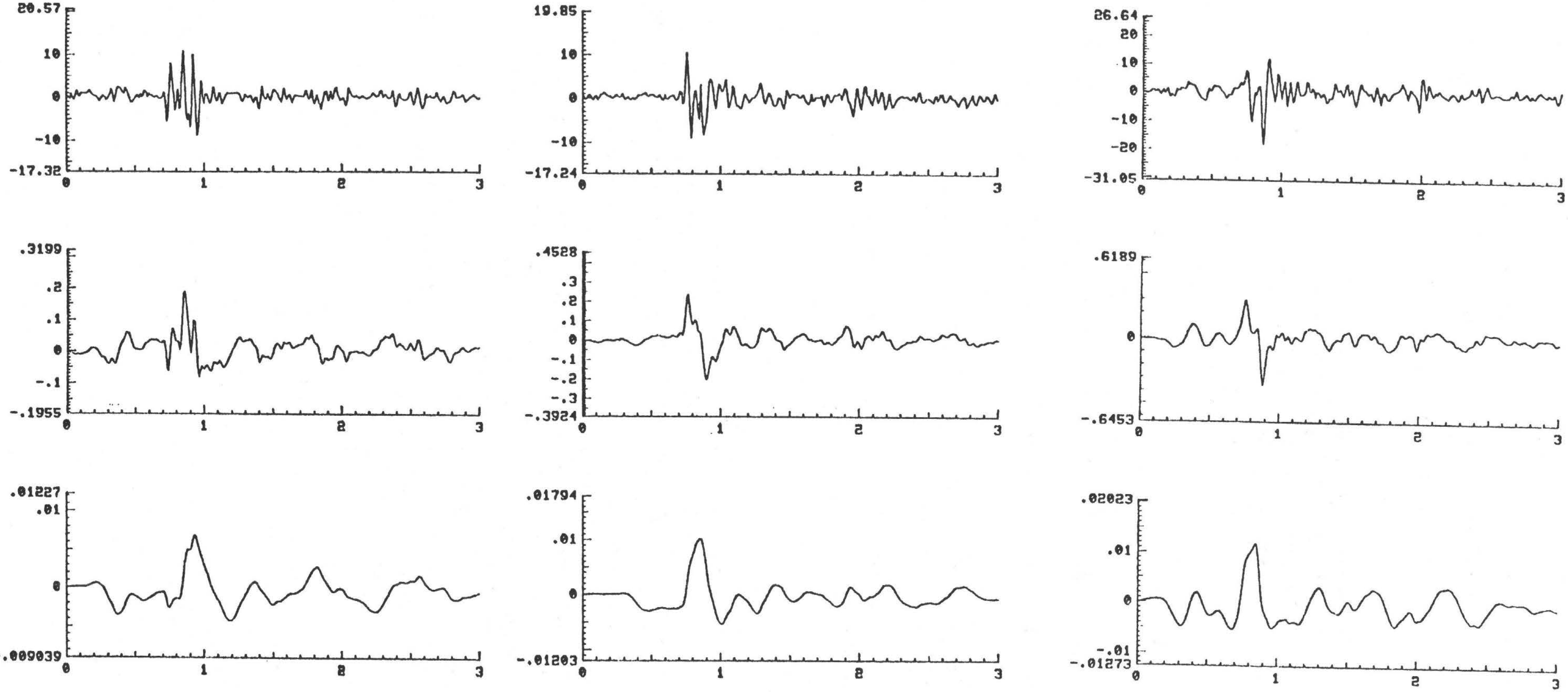

Figure 2. Example of digitized and processed strong motion records of station BKZ (see Figure 1) of a M_L = 4.8 earthquake of June 8, 1981, about 30 km from the site. The up direction of the traces (from left to right) represents: Up, S70°W and S20°E; and their traces display (top to bottom): acceleration (cm/sec^2), velocity (cm/sec), and displacement (cm). Time units on abscissa is in seconds.

National Earthquake Catalog

9920-02648

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Investigations

1. Coordinate the preparation of a nationl earthquake catalog.

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

3. Confirm locations, origin times and magnitudes of poorly described western United States earthquakes.

4. Convert codes written for the SLAC SVS operations system to the new VM operations system.

Results

1. During this reporting period emphasis was placed on the collection of high quality earthquake data for the national events list data base. Carl Stover and coworkers have now completed seismicity maps for the 37 states east of the Rocky Mountains. The event lists for these maps have been assembled into a single large computer file in a standard data base format. This file will be slightly modified and expanded by adding earthquake data through 1979 from research investigations, local network bulletins and the USGS Monthly List of Hypocenters. The research investigations include a major contribution by J. W. Dewey and D. W. Gordon (Project 9920-01901) on relocation of most of the larger instrumentally recorded earthquakes that occurred in the eastern United States since 1930. Gordon is nearing completion of a similar investigation for the central United States.

An editing routine (NEQREV) developed by Glen Reagor was used to correct listings in one or more large standard format files for New England, Montana, Alaska, Puerto Rico and Guam. Reagor has also developed a versatile manipulative code (AXX) that will create, merge, modify parameters or list the standard format files.

2. Carol Thomasson, James Taggart and Frank Baldwin checked an additional 12,000 listings against original references during this reporting period, bringing the total verified earthquake listings to 53,000, exclusive of California. About 700 previously unlisted Alaskan earthquakes have been identified from the bulletins of the ISS, BCIS and the USCGS for the years prior to 1960.

With funding from Project 9940-02907 (R. F. Yerkes) W. H. K. Lee has duplicated event lists and phase data for local southern California earthquakes from C. F. Richter's notebooks (1926-1939) and the Cal Tech bulletins (1932-1963). These will serve as the basic references for verification of southern California event list files for 1926-1963.

Karen Meagher has collected and evaluated a large amount of phase data from pre-1960 California earthquakes ($M \geq 5$). Meagher also is assembling a file of newspaper descriptions of historical earthquakes.

3. Taggart and Baldwin have submitted for publication an investigation of a 1938-1939 sequence of earthquakes in the Mogollon Mountains of southwestern New Mexico. Taggart has completed the collection and analysis of data for a similar investigation of the Dulce, New Mexico, earthquake sequence of 1966-1967. Both investigations are based on the measurement of Lg amplitudes relative to calibration events. The mbLg magnitude of the largest event in each sequence is about 5.1. The Mogollon Mountains sequence has the characteristics of an earthquake swarm (30% of the total seismic energy or moment in the largest event), whereas the Dulce earthquakes are a main event and aftershock sequence (96% of the total seismic energy or moment was released in the main event).

4. The SVS Operations System is being phased out at the SLAC Computer Facility. W. H. K. Lee has nearly completed the massive, but unwanted job of converting his codes and data files to conform with the VM Operations System.

Areas Damaged by California Earthquakes, 1900-1949

Contract No. 14-08-0001-19934
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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 about 50 earthquakes meet these criteria. The areas shaken at intensity VI or greater will be 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 will be included in the annual technical report scheduled for completion in October 1982. This will provide the relative sizes of the earthquakes independently of the variations in seismographic instruments.

The newspaper search of the State Library was almost complete at the end of March 1982. About 1,800 newspaper issues were searched, and one-third provided earthquake reports. A bibliography of the newspaper issues searched is being compiled. The process of drafting isoseismal maps has begun. Summaries of the reported effects that were used to determine values of intensity are being prepared.

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

14-08-0001-19173

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Investigations

1. Completed surface geologic map of Goleta-Santa Barbara-Montecito metropolitan area on Kronaflex base at a scale 1:24,000 and sent to USGS for completion.

2. Constructed cross sections across Coal Oil Point, Mesa, More Ranch, and Lavigia faults in Santa Barbara area.

3. Continued detailed structural analysis of San Miguelito and Rincon late Quaternary anticlines to test hypotheses of structural evolution based on Ventura Avenue anticline.

Results

Most of the faults of the Goleta-Santa Barbara-Montecito metropolitan area have reverse separation, south-side-up. They cut the Pleistocene Santa Barbara Formation, and at least some of them deform late Pleistocene terrace deposits. They belong to the same set of faults as the Carpinteria, Holloway, Rincon Creek, and Shepard Mesa faults of the Carpinteria area (Jackson and Yeats, in press). The largest fault in terms of separation is the Coal Oil Point fault, in the offshore area south of Goleta, with over 1500 m separation. There is no geological justification for connecting any of these faults with the 1978 Santa Barbara earthquake sequence.

The Red Mountain fault loses separation and is difficult to recognize westward from the Summerland Offshore oil field. Fault A and the Santa Barbara fault of Hoyt (1976), 2 km south of Santa Barbara Point, appear to have north-side-up separation; these may be related to the Red Mountain fault. Alternatively, the main trace of the Red Mountain fault may be farther south, beyond our study area.

Age-calibration of the Pleistocene sequence on the south flank of the Ventura Avenue anticline, together with detailed subsurface structural data, permit an analysis of the structural history of the anticline for the last 2 m.y. (Yeats, 1982; Yeats, in review, 1982). The earliest thrusting (Taylor thrust set) occurred along weak siltstone interbeds in a sequence dominated by competent basin-plain turbidite sandstone. Because sedimentation continued during thrusting, the age, rate, and direction of thrusting can be worked out. Faulting began 1.3 m.y. ago and ceased 0.65 m.y. ago, with a maximum slip rate of 3.3 mm/y to the southeast. North of the anticline, the fault set followed bedding. In the vicinity of the anticline, the fault set moved up a 45^{o} ramp and ended as a blind thrust. The ramp had topographic expression on the sea floor, diverting turbidites around the ramp and preserving ash beds along with other hemipelagic sediments on its crest. The ash beds are preserved only in strata 1.2 to 0.6 m.y. old, as dated by zircon fission-tracks and by tephrochronology; these ages are very close to the age of faulting as based upon differences in sediment thicknesses in the hanging wall and footwall of the Taylor thrust set. The sediments associated with the ash beds are fine-grained hemipelagic mudstone, in contrast to older coarse-grained turbidite sandstone and younger coarse-grained shallow-marine sandstone and conglomerate in the vicinity of the anticline and turbidite sandstone in the Santa Clara syncline south of the anticline which are in part coeval with the ash beds on the anticline.

Following the end of deposition 0.2 m.y. ago, the competent basin plain turbidites underwent flexural-slip folding over an incompetent Miocene sequence dominated by shale; underlying competent Paleogene strata were not folded. The south flank of the Ventura Avenue anticline tilted at 3.4 microradians per year, the anticlinal crest rose at a rate of 11 mm/y, and the anticline and an adjacent syncline shortened at a rate of 20 mm/y. The high rate of folding in the Ventura Avenue oil field resulted in overpressured sandstone reservoirs and oil-water interfaces which have not had time to reach gravity equilibrium. Study of Ventura River terraces folded across the anticline suggests to E. Keller and G. Dembroff of UCSB that the uplift rates are slowing down, as would be expected if the fold were buckling upward above a ductile detachment at depth.

Reports

Jackson, P. A., 1982, Structural evolution of the Carpinteria basin, western Transverse Ranges, California: Geol. Soc. America Abs. with Programs, v. 14, p. 174-175.

Jackson, P. A., and Yeats, R. S., in press, Structural evolution of the Carpinteria basin, western Transverse Ranges, California: Am. Assoc. Petroleum Geologists Bull.

Yeats, R. S., 1981, Classification of active faults according to seismicity: Assoc. Engineering Geologists Ann. Mtg., Sept. 27-Oct. 2, 1981, p. 60.

Yeats, R. S., 1982, Low shake faults of the Ventura Avenue anticline, Ventura basin, California: Geol. Soc. America Abs. with Programs, v. 14, p. 246.

Yeats, R. S., 1982, Low-shake faults of the Ventura basin, California: Guidebook, Neotectonics in Southern California, Field Trip Numbers 3, 4, 14 prepared for the 78th Annual Meeting of the Cordilleran Section of the Geological Society of America, Anaheim, California, April 19-21, 1982, p. 3-15.

Yeats, R. S., 1982, Reply to comment on "Low-shake faults of the Ventura basin, California" by A. M. Sarna-Wojcicki and R. F. Yerkes: ibid., p. 21-23.

Yeats, R. S., Keller, E. A., Rockwell, T. K., Lajoie, K. R., Sarna-Wojcicki, A. M., and Yerkes, R. F., 1982, Field trip Number 3, Neotectonics of the Ventura basin -- road log: ibid., p. 61-76.

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

Regional and National Seismic Hazard and Risk Assessment

9950-01207

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Investigations

1. Multivariate analysis of site intensity assessments.

2. Review of the probable magnitude and location of the 1872 Washington earthquake.

3. Analysis of the sensitivity of seismic hazard maps to:

   A. Magnitude - earthquake frequency relationships.

   B. Various attenuation curves.

4. Intensity data for damaging earthquakes in the Mississippi Valley are being reviewed in connection with FEMA supported disaster preparedness study in the Midwest.

5. Development of innovative computer programs for transformation of mapped data and improved plotting of data.

6. Continued investigation of probable future economic losses in the Los Angeles area.

7. Continued investigation of national probabilistic hazard assessment.

Results

1. Multivariant analysis of intensity assignments was applied to the data for the 1872 Washington earthquake. Comparison of ten researchers' assessments for the location of the 1872 earthquake shows that a crucial element is the placement of the MMI VI isoseismal. A rough comparison of the different researchers' isoseismal maps show that there appears to be a natural grouping of similar assessments. Single linkage cluster analysis and principal components analysis were used on the matrix of observer site intensity assessments to objectify this grouping.

The observer clusters seem to reflect two opposing tendencies: One cluster of observers tends to underassess the intensity reports, that is, many of the site descriptors do not correspond precisely to items in the Modified Mercalli Intensity (MMI) scale, or an observer is reluctant to place geologic effects on the scale because these are held to be unreliable estimates of ground shaking. As a result many sites are unassessed or are assessed as simply "felt" rather than assigned an MMI number. On the other hand, another observers enthusiastically over interpret (or "fully" interpret) the site descriptors, by placing elements at particular levels of the MMI scale by analogy or through some sense of cross-consistency when other descriptors are present, or by literal interpretation of the MMI geologic descriptors.

If ranked scores are averaged for the clusters, a measure showing the spatial character of the difference in intensity assessments is possible. Preliminary results for the 1872 earthquake show that two crescents of spatial coherence are present: one of positive sign to the southeast of a proposed Lake Chelan epicenter, the other of negative sign to the northwest. These are the locations of the discrepancies in assessment of the VI isoseismal. Thus the analysis successfully explains the differences in the interpretations of the size and location of the 1872 earthquake.

2. Intensity assignments and isoseismals for the 1872 earthquake have been reviewed. It is concluded that the 1872 earthquake had a probable maximum intensity of IX (MM) and an epicenter in the vicinity of Lake Chelan Washington. These results were presented by M. G. Hopper at the 1982 annual meeting as a paper "The Earthquake of December 14, 1872 in the Pacific Northwest" by M. G. Hopper, S. T. Algermissen, D. M. Perkins, S. R. Brockman and E. P. Arnold.

3. A comparison among various techniques for fitting earthquake frequency - magnitude data with an equation of the form log N = a-b shows that many of the resulting b-values are biased toward estimating b-values that are too low. Maximum likelihood formulas by Aki-Utsu and Page give incorrect results if magnitudes are grouped into a number of fairly wide intervals (as is the case when intensity data are fitted).

For N earthquakes (restricted to occur in n magnitude intervals of width m) the correct maximum likelihood formula permits only N(n-1) + 1 distinct b-values to be estimated. It has been possible to obtain these estimated b-values and their distribution for any underlying "true" or population b-value. The probability of obtaining a particular set of N magnitudes for any given b-value can be determined, and assuming an apriori uniform distribution for the population b-value, an aposteriori distribution for b can be calculated. From these results it is possible to obtain confidence limits for the underlying b value as a function of sample size and sample mean. For small samples, a wide range of population b values may be about equally likely, resulting in high uncertainty in the estimate.

The assumed magnitude range ($n\Delta m$) may be important in estimating the b-value. For a given sample of N earthquakes and fixed Δm, the fitted value of b increases to some limiting value as the maximum magnitude increases. It is important to use the assumed maximum magnitude rather than the observed maximum magnitude in obtaining the b value. It should also be noted that failure to include zeroes for intervals in which no earthquakes have occurred may result in the computer program assuming the maximum magnitude corresponds to the last interval containing an observation.

A paper "Maximum Likelihood Estimation of b-Values for Magnitudes Grouped Data" incorporating the results of these studies was presented by B. L. Bender at the Annual Meeting of the Seismological Society of America at Anaheim, California.

Probabilistic ground motion values were computed for the New Madrid, Missouri and Charleston, South Carolina areas using several different acceleration and velocity attenuation curves and the seismic source zone parameters used in the computation of ground motion for the new national probabilistic hazard maps. It was found that all of the attenuation curves tested yielded comparable values of ground motion except near the center of source zones with high seismicity.

4. Geological data on liquefaction in the Midwest has been gathered as part of a FEMA sponsored earthquake mitigation study. Emphasis has been on cities specified by FEMA (Memphis, TN; Paducah, KY; Poplar Bluff, MO; Little Rock, AR; Carbondale, IL; and Evansville, IN. For purpose of an earthquake scenario, a shock with $M_s = 8.7$, equivalent to the earthquake of February 7, 1812 has been selected.

5. A system of computer routines have been written to plot maps of seismic data that are of publication quality. A technical paper and computer program for the transformation of mapped data to grid systems has been completed by Bonny Askew. It is anticipated that this computer technique will have considerable application in the analysis of intensity data. An Open-file Report, "Transformation of Mapped Data to Grid Systems with Applications to Earthquake Data" by Bonny Askew which describes the technique has been completed and is in review.

6. Estimated earthquake loses to single family dwellings in Los Angeles and Orange Counties, California are being computed for a variety of postulated earthquakes. This work is to be a contribution to the forthcoming Professional Paper on earthquake hazards in the Los Angeles area.

7. A paper "Probabilistic Estimates of Maximum Acceleration and Velocity in Rock in the United States" by S. T. Algermissen, D. M. Perkins, P. C Thenhaus, S. L. Hanson and B. L. Bender was presented by S. T. Algermissen at the annual meeting of the Seismological Society of America in Anaheim, California.

Reports

Barnhard, L. M., P. C. Thenhaus, and S. T. Algermissen, 1982, Distribution of Intensity for the Westmorland, California Earthquake of April 26, 1981, U.S. Geological Survey Open-file Report 82-485.

Seismic Wave Attenuation in Conterminous United States

9950-01205

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Investigations

1. Data analysis of 136 events in the $2.0 \leq M_b \leq 6.0$ range recorded on short-period seismographs in the United States for the P_g and L_g phases is in progress.

2. Data analysis of 29 NTS events recorded on strong-motion accelerographs is in progress.

3. Data analysis of 50 events in the $1.8 \leq M_b(L_g) \leq 3.2$ recorded in Northeastern U.S. on short-period seismographs for the P_g and L_g phases is in progress.

4. A dislocation model for a thrust-fault representing the short-period focal mechanism solution of the Algerian October 10, 1980, damaging earthquake is being evaluated theoretically. The vertical displacement field for a series of normal faults is also being computed.

Results

1. A report on L_g-wave attenuation in conterminous U.S.A. is in the process of being written.

2. An Open File Report on the L_g-wave data tabulation is in the process of being written.

3. A preliminary evaluation of the intensity distribution for the Algerian earthquake of 1980 shows similar inconsistencies in the Modified Mercalli Intensity Scale as has been documented in past post-earthquake studies in Venezuela, Peru, and Guatemala.

Reports

Espinosa, A. F., 1981, Seismology and earthquake engineering in Latin America: Earthquake Information Bulletin, v. 14, no. 1, January-February Issue, 1-4.

Espinosa, A. F., 1982, Editor of a series of papers by our Latin American Colleages (10 papers): Seismology and earthquake engineering in South, Central America, and Mexico: Earthquake Information Bulletin, v. 14, no. 1, 46 p.

Strong-Motion Instrumentation/Structural Engineering Studies

9910-02759

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Investigations

The principal objective of these studies is to acquire, analyze, and disseminate information related to the strong-motion response of engineering structures. This information is primarily obtained from strong-motion records and the research is directed towards understanding basic problems in earthquake engineering and improving engineering analysis and design procedures.

During the first half of FY 82 the studies have concentrated in the area of strong-motion instrumentation of earth dams.

Results

A review of existing strong-motion instrumentation programs for earth dams has been conducted. This information, in addition to that obtained from a survey of the dynamic characteristics of earth dams, was used as a basis for developing guidelines for the selection of earth dams to be instrumented. Guidelines for instrumentation locations at earth dam sites were developed. Specific recommendations regarding free-field, input, response, and potential failure motions were established. Recommendations for instrumenting earth dams to various degrees were also proposed.

One earth dam (Long Valley Dam) was identified as being suitable for analysis using the procedures derived in the investigations. Strong-motion records have been obtained for this dam for the Mammoth Lakes Earthquakes of May 1980. Preliminary analysis of these records has been made.

Additional investigations have been conducted to locate appropriate dam(s) for strong-motion instrumentation according to the guidelines discussed previously. Communications have been established with various agencies involved in instrumenting earth dams regarding the selection of earth dams for instrumentation.

Reports

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

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 2.4 Mbytes and disk space will be approximately 1.8 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. 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 Tectonics 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 supported 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.

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. In-house proposal for study of central California tectonics through deep-crustal reflection profiling was successful. With working group, began search for relevant existing data, infomation to better frame the experiment, and acquisition of data.

2. Helped carry to completion 1:2,500,000 maps of Quaternary faults (with John Nakata) and seismic source zones (with Paul Thenhaus) in the Basin and Range province.

3. Through contract with Arizona Bureau of Geology and Mineral Technology (Chris Menges), pursued late Cenozoic tectonic history of Arizona, particularly delineation of surface breaking faults, age of faulting inferred from scarp morphology, tectonic classification of mountain fronts, and delineation and interpretation of topographic envelopes.

4. Continued work (by Larry Mayer) on estimation of age of fault offset from scarp morphology and examination of the effect of variability in physical processes on these estimates, using regression and discriminant analysis.

5. Began compilation and original photo study (with Steve Reneau) of surface breaking faults in the Death Valley 1 x 2 degree sheet.

6. Continued efforts to have four delinquent contract reports carried to respectable conclusion.

7. Participated in review (Behrendt committee) for the Director, USGS, of recent work bearing on the long-standing Federal position that, for the purpose of safety regulation of power reactors, future occurrence along the eastern seaboard of an earthquake as large as 1886 Charleston, S.C., is limited to the Charleston area.

Results

1. Work in compiling surface-breaking faults in the Basin and Range Province at both 1:2,500,000 for the whole province and at 1:250,000 for the Death Valley sheet demonstrate that available data are extremely variable in character, quality and completeness for this purpose. As a result, the small-scale province map represents what is now generally known, but cannot be used to confidently identify areas lacking young faults. At 1:250,000 we found that study of aerial photos (about 1:40,000) raised questions about almost all compilation sources; by using the photos as a filter, test, and original

source, however, in concert with available map sources, a reasonable small-scale fault map can be made.

2. Photo study of the western Death Valley sheet reveals the presence of numerous large landslides expressed in the topography that have not been incorporated in geologic mapping of the region. These landslides range in length from 1 or 2 km to possibly as much as 50 km and extend 1 to as much as 10 km back from the range fronts; the larger ones inflict major influence on range topography and extend to or across range crests. The slides produce bulges and outliers along otherwise straight faulted fronts, but are most readily recognized by topographic steps and scarps at the crown of the slide and by internal ponding of alluvium. The landslide toes lie below the alluvial valley floor, but only the largest landslide yet recognized, at the north end of the Coso Range, seems to show surface deformation in the toe area. These major landslides have formed surface scarps that must be distinguished from fault scarps, and presumably have produced fault-like breaks and other bedrock deformation that should be distinguished from tectonic structure in geologic mapping.

3. Inspection of available reflection data in central California suggests that the basement surface marked by major unconformity beneath the eastern Great Valley extends at gentle dip continuously westward across the whole valley and could extend beneath at least the eastern edge of the Coast Ranges.

4. Statistical analyses of 200 fault-scarp profiles in the southern Basin and Range province indicate that estimation of the morphologic age of fault scarps are strongly, although not exclusively, affected by measurement and stochastic errors, lithologic variations, sampling deficiencies, recurrent movement, and fault branching. Stochastic errors in the relation between maximum scarp angle and scarp height due to natural variations in scarp degradation render wholly deterministic models of scarp evolution, derived from solutions to the diffusion equation, inadequate for ranking scarp age.

Reports

Mayer, Larry, 1982, Constraints on morphologic-age estimation of Quaternary fault scarps based on statistical analyses of scarps in the Basin and Range province, Arizona, and northeastern Sonora, Mexico (abs): Geological Society of America Abstracts with programs, v. 14, no. 4, p. 213.

Wentworth, C. M., and Mergner-Keefer, Marcia, 1982, Regenerate faults of small Cenozoic offset: probable earthquake sources in the southeastern United States: Chapter in U.S. Geological Survey Charleston Professional Paper, in press.

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 October 1981 through 31 March 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 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 period; coverage above M = 3.0 is felt to be complete. Some of the seismic highlights in the southern California region during the six-month period are as follows:

Number of earthquakes located: about 10,000
Number of earthquakes currently entered in catalog: 1,754
Number of earthquakes of M = 3.0 and greater: 100
Number of earthquakes of M = 4.0 and greater: 12
Number of earthquakes of M = 5.0 and greater: 0
Number of earthquakes for which systematic telephone notification to agencies was made: 8
Largest earthquake (two such events NW of Catalina - 23 October 1981): M = 4.6
Smallest felt earthquake (felt in El Monte - 14 November 1981): M = 1.9
Number of earthquakes reported felt: 34

With the adoption of new data-analysis equipment and techniques, we are now projecting to locate some 20,000 earthquakes per year, although software remains to be developed so that all of these can systematically be entered into the catalog. About 220 telemetered signals are being received, but only 162 of these are currently being systematically used because of limited computer capacity; presumably this situation will be ameliorated during the coming year.

There were no earthquakes of M = 5.0 or greater during the reporting period. Of those sequences containing M = 4.0 and larger events, the following are of interest:

1. Two aftershocks, each with M = 4.6, of the 4 September 1981 (M = 5.3) shock.
2. Two events (M = 4.5 and 4.2) on 10 November 1981 in the Wheeler Ridge section of the Kern County aftershock alone.
3. High activity, peaking in early March 1982, in the Coso volcanic area (see Figure 2).
4. A M = 4.5 event in the Ocotillo Wells area of the southern San Jancinto on 22 March 1982.

The Coso activity is probably the most interesting. During the period of high activity (20 February to 10 March) 225 events appear in the catalog. There were four events of M = 4.0 and greater, the largest one being M = 4.5 on 7 March. During the height of the activity three of the "Coso net" USGS stations were recorded on helicorders as well as the computer and many events were seen that were too small to trigger the on-line system. On 13 March a very high b-value swarm, lasting a little over an hour, was observed on WCS, suggesting the possibility of intrusive activity related to the volcanos in the area.

The following abstracts were submitted during the reporting period, using local seismicity data from the Network:

Astiz, L. and C. R. Allen, Seismicity of the Garlock Fault (1982 Spring SSA meeting)

Corbett, E. J. and K. A. Piper, Santa Barbara Island, California earthquake, September 4, 1981 (1981 Fall AGU meeting)

Hutton, L. K. and C. E. Johnson, Preliminary study of the Westermoreland, California earthquake swarm (1981 Fall AGU meeting)

Johnson, C. E. and L. K. Hutton, Imperial Valley Seismicity and the San Andreas fault (1981 Fall AGU meeting)

Sanders, C., K. McNally and H. Kanamori, The state of stress near the Anza Seismic gap, San Jacinto Fault zone, Southern California (1981 Fall AGU meeting)

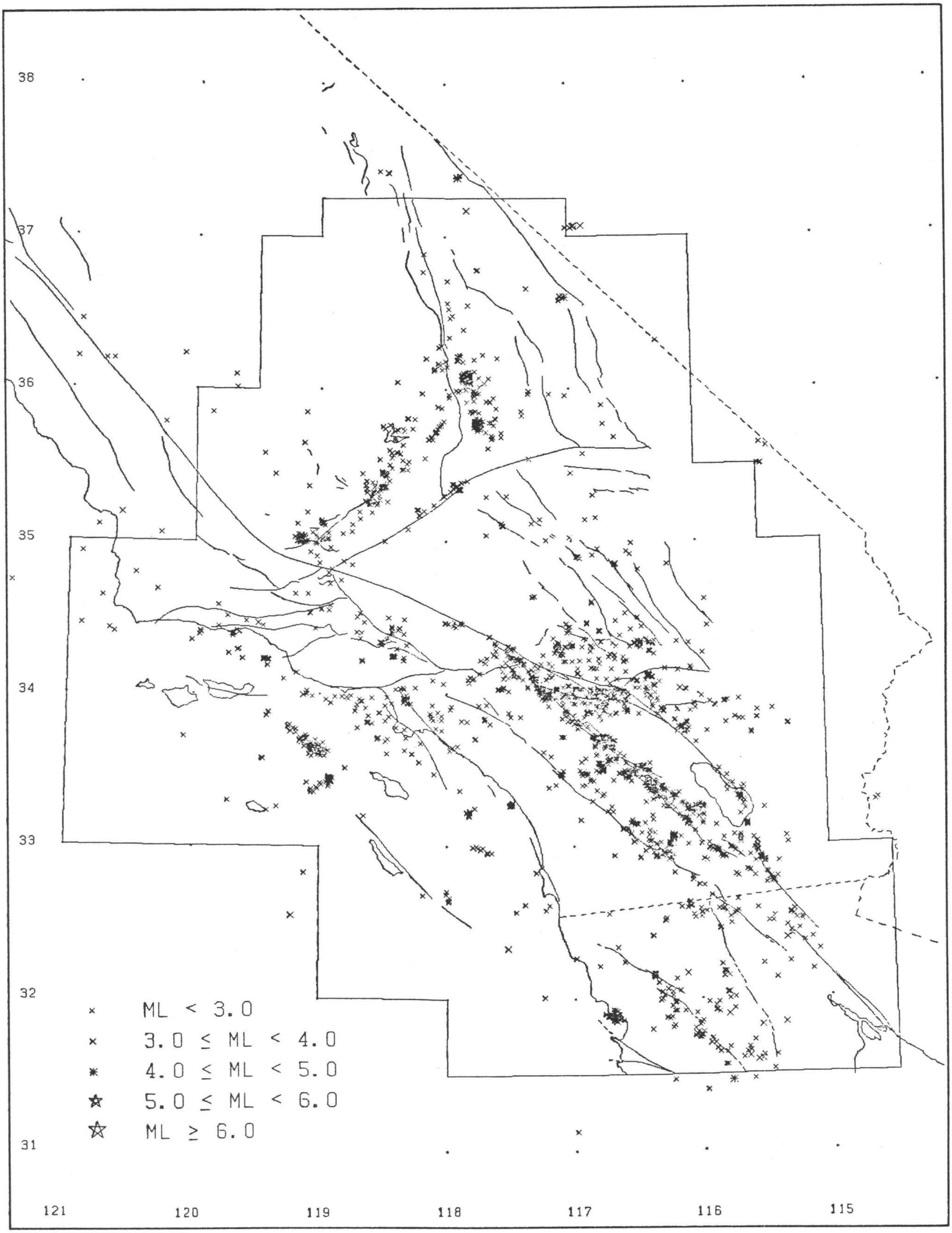

Fig. 1 Epicenters of larger earthquakes in the Southern California Region, 1 October 1981 through 31 March 1982.

COSO ACTIVITY

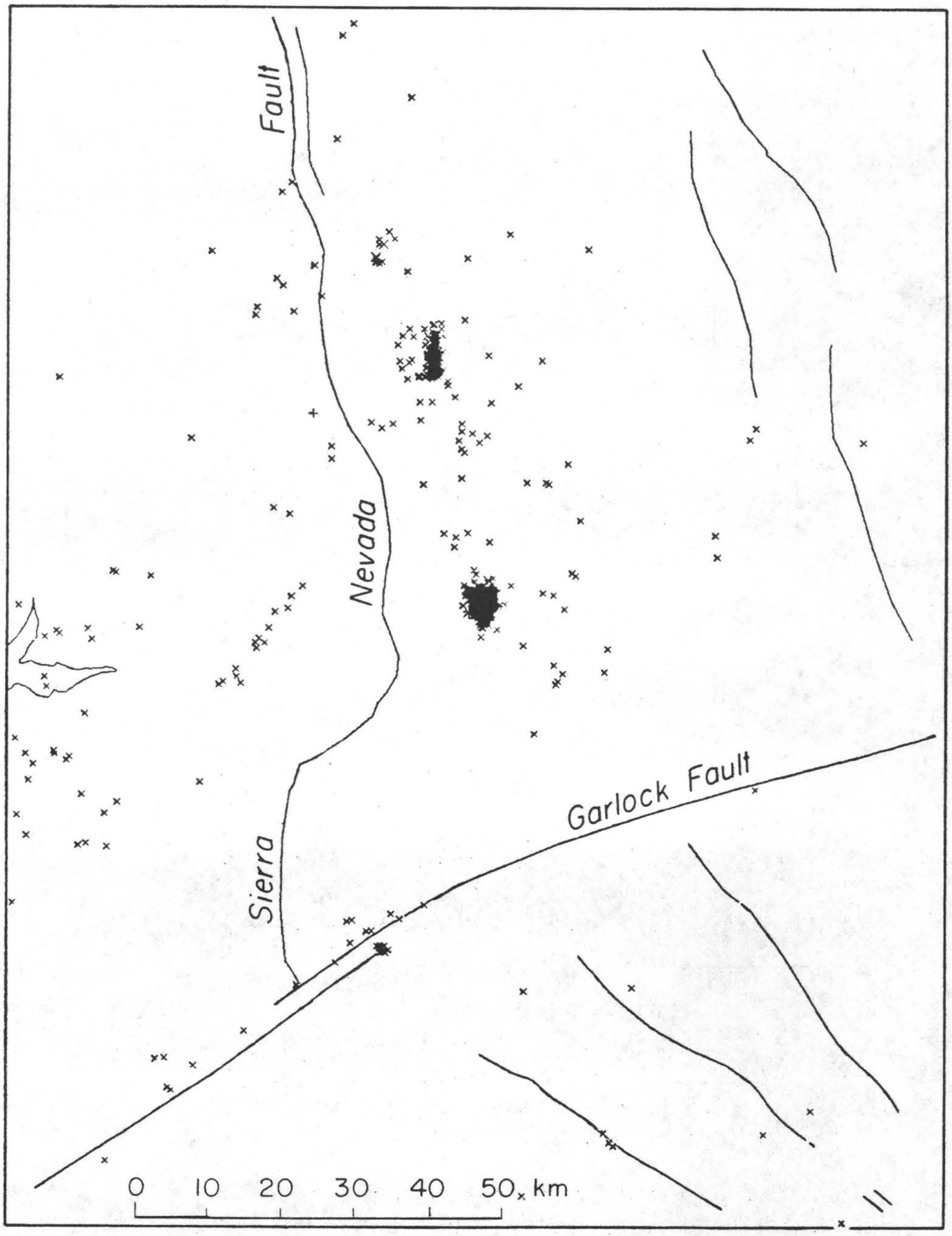

Fig. 2 Seismic activity in the Coso area during the reporting period.

Seismic Hazards of the Hilo 7 1/2' Quadrangle

9550-02430

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Investigations

1. Geologic mapping and ^{14}C dating of lava flows in the Hilo quadrangle continues.

2. Geologic investigations, U. S. Army Corps of Engineers, on the drainage basin of the Alenaio Stream has completed review.

3. A text and accompanying map showing distribution and thickness of ash deposits, the thickness of the underlying clay bed, and, when exposed, the type of bedrock material in portions of the Hilo, Papaikou, Akaka Falls and Pi'ihonua quadrangles has completed review and is in TPU.

Results

A detailed geologic map and explanation of the northwest portion of the Hilo quadrangle was prepared for the U. S. Army Corps of Engineers and has completed the review process. The reconnaissance geologic map showing the thickness and distribution of the ash deposit in the greater Hilo area is awaiting review by the Technical Reports Unit.

X-ray diffraction and grain-size analyses of samples collected from the thick ash deposit and the yellow-gray clay bed that locally underlies it show clear mineralogical and physical differences between the two units. No clay minerals were detected in the ash deposit; it is composed mainly of gibbsite with quartz as a minor constituent. The yellow-gray clay bed, on the other hand, contains an average of nearly 60% illite, with kaolinite and chlorite as minor constituents. Grain-size analyses of ash samples taken from varying depths show a range in sand size material from as much as 40% in some layers to as little as 8% in others. Sand/silt/clay ratios for the yellow gray bed were impossible to obtain because the amount of colloidal material present in the samples prevented them from separating.

The ash, which reaches a maximum of 6 meters within the map area, is generally believed to an air-fall deposit erupted mainly from Mauna Kea Volcano, with minor contributions probably from Mauna Loa and Kilauea volcanoes. The yellow-gray clay bed which locally overlies a'a flows from Mauna Kea Volcano may also be in part an air-fall deposit. This bed is usually very fine-grained, however, lava fragments similar in composition to the upper a'a rubble are present near the base, suggesting that this deposit was derived at least partially from weathering of the a'a.

Reports

Buchanan-Banks, J.M., 1982, Reconnaissance map showing distribution and thicknesses of ash deposits in the greater Hilo area, Hawaii: U. S. Geological Survey, MF Map - , scale 1:24,000.

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 82- , scale 1:24,000.

Vertical Tectonics

9950-01484

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Investigations

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

2. Continued investigations designed to understand the nature of the drainage divide between the Gulf of California and the Salton basin.

3. Extended investigations into western Arizona to determine the nature of historic crustal movements and its relation to the rapid and often oscillatory vertical movements that characterize historic tectonic activity in southeastern California. Preliminary investigations suggest that western Arizona has remained remarkably stable during latest Holocene time and that a major contemporary tectonic boundary exists roughly coincident with the California/Arizona border.

4. Acted as co-convenor and served as general chairman of the organizing committee for a conference on earthquake hazards in the eastern San Francisco Bay area held during March 24-27, 1982, on the campus of California State University, Hayward.

5. Continued assistance to R. O. Castle and R. K. Mark in investigations to assess the accuracy of the geodetic measurement system, especially the effects of suspected height- or slope-dependent systematic errors.

Results

1. A report concerning the nature of vertical crustal movements in Southern California between 1974 and 1978, which is now in final stages of preparation following technical reviews and editing, will be submitted for publication in the near future. Some of the principal conclusions of the study are a) the 1978 leveling was conducted during a period of rapid tectonic deformation; b) the 1974-1978 deformation consisted primarily of north to northeastward tilting over much of the area of the southern California uplift; and c) numerous minor earthquakes and occasional moderate shocks occurred throughout

the region of the southern California uplift during its partial collapse, but seismic activity was particularly intense in the regions of the eastern Transverse Ranges and the Salton Trough, where an almost complete collapse of the previous maximum uplift and a rapid continuation of tectonic subsidence, respectively, occurred.

2. An abstract and a report on the nature of the divide between the Salton basin and the Gulf of California have been reviewed and are undergoing final revisions. Examination of the historic vertical control record suggests that the continued maintenance of the divide is, at least in part, the result of aseismic tectonic uplift and not simply rapid deltaic sedimentation. Comparisons of first-order levelings referred to the virtually invariant San Diego tide station indicate that the southern Imperial Valley, immediately north of the crest of the Colorado River delta, rose more than 0.40 m during the period 1926/27-73/74 and collapsed in part between 1973/74 and 1978, for a net uplift of 0.15 m. This geodetic evidence, coupled with various geologic and geophysical observations, suggests that crustal swelling along the deltaic crest during latest Holocene time has biased the flow of the Colorado River away from the Salton basin and toward the southeast flank of the delta.

3. Preliminary investigations of historic crustal deformation in southeastern California and western Arizona have revealed the existence of a contemporary tectonic boundary roughly coincident with the course of the Colorado River. The boundary is defined as a sharp discontinuity in the vertical displacement profiles at four separate crossings. That part of southwestern Arizona east of this geodetically defined discontinuity has sustained no measurably significant differential displacements since accurate geodetic measurements were begun in 1905, which is in marked contrast with the large, aseismic and oscillatory vertical movements recognized within tectonically active areas of adjacent southeastern California.

4. A total of 62 papers on various aspects of earthquake-hazards problems in the region northeast of San Francisco Bay were presented to an audience of nearly 400 over a 3-day period. An excellent 1-day field trip along the Hayward fault was held on Saturday, March 27, and the guidebook for that excursion represents a very useful, permanent document. A proceedings volume containing a collection of papers and abstracts presented and discussed during the conference is in preparation at present. This volume will be published in August or September 1982 by the California Division of Mines and Geology as a Special Report.

Reports

Burford, R. O., and T. D. Gilmore, Vertical crustal movements in southern California, 1974-1978: U.S. Geol. Surv. circular.

Castle, R. O., and T. D. Gilmore, A tectonic explanation for the persistence of the divide between the Salton basin and the Gulf of California (abstract): Geol. Soc. of Amer., Fall Meeting, October 1982, New Orleans.

Gilmore, T. D., and R. O. Castle, A contemporary tectonic boundary coincident with the Arizona-California border (abstract): Geol. Soc. of Amer., Fall Meeting, October 1982, New Orleans.

Gilmore, T. D., and R. O. Castle, A tectonic explanation for the persistence of the divide between the Salton basin and the Gulf of California: Geology.

Earthquake Effects, Tomales Bay Sediment

9830-02890

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Investigations

1. Approximately 22 nautical miles of high resolution seismic reflection and side-scanning sonar, and approximately 40 nautical miles of bathymetry were collected in Tomales Bay in a preliminary reconnaisance of faulting and earthquake features in the sediment of the bay.

2. 40 cores and 23 grab samples were collected in the weeks following the January flooding in Marin County. The cores have been photographed and X-rayed in an effort to outline the pattern of sedimentation and to delineate the character of internal structure in the Bay sediment. Size and compositional analyses have been made from selected samples.

3. Examination of the Pleistocene terrace deposits on the western side of the bay was initiated.

Results

1. Numerous faults are evident within the seismic reflection profiles. Because of the broad spacing of the profiles it is not yet possible to connect these faults confidently, but the existing data will provide a framework for the direction of further surveys this year.

2. Steep-walled closed depressions mark the bathymetry in many parts of the bay. The largest of these are up to 7 m deep, and about 200 m across. Their long axis, curiously, lies transverse to that of the bay, and their origin is uncertain. More detailed surveys will better define these features and provide a potential for palinspastic reconstructions within the bay, should such depressions prove to be remnants of an older, fault-truncated drainage system.

Much smaller steep-walled depressions (a few tenths of a meter deep and approximately 10-20 m across) occur on muddy sediment in the southern end of the bay. These features are irregularly in outline and may be collapse depressions formed during the 1906 earthquake. Diving observations and precise coring should further delineate their origin.

3. The January floods provided a mechanism for understanding the pattern of sedimentation within the bay, a prerequisite for relating sedimentary features to earthquake effects. Considerable sediment was introduced during the episode of flood, but nearly all of it accumulated proximal to the mouths of

contributing streams. Cores from areas away from these sources indicate that no significant deposition occurred as a consequence of the flood. It appears that sediment accumulates in the bay largely in the vicinity of the deltas at the northern and southern ends, and that, otherwise, the rate of sedimentation in the bay is surprisingly low. This observation bears strongly on our ability to recognize and date earthquake-generated features in the sediment.

Neotectonics of the San Francisco Bay Region, California

9540-01950

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Investigations

1. Map syntheses (scale 1:125,000 and 1:250,000) of the principal recently-active faults and earthquakes in the San Francisco Bay area and surrounding Coast Ranges of central California were prepared with W. L.Ellsworth (Project #9930-02103, Seismic Studies of Fault Mechanics).

2. In a joint investigation with R.S. Cockerham (Project #9930-01160, Central California Network Processing), seismicity at the north end of the San Andreas fault system was compared with recently discovered late-Pleistocene and Holocene-age faults near Cape Mendocino.

3. At the invitation of the Branch of Western Regional Geology, Herd participated in an inventory and investigation of the landslides that were initiated in the San Francisco Bay area during a tropical storm on January 3-4, 1982.

Results

1. Preliminary drafts of maps (scale 1:250,000) of the principal recently-active faults and earthquakes (1969-1980) in the San Francisco Bay area have been completed. The maps, which will be published as Miscellaneous Field Studies Maps, are part of a series of maps that will document the seismotectonics of the central California Coast Ranges.

One map shows all of the important faults of late Pleistocene and Holocene age in the central Coast Ranges between latitude 36°15' N. (Big Sur) and 39°00' N. (Point Arena). The map summarizes previously published maps of Quaternary-age faults in the northwestern and eastern San Francisco Bay area, and includes many previously unpublished fault lines, as well as new interpretations of fault mapping of others. Particularly, the map includes: a) the newly recognized continuation of the Green Valley fault north to Cache Creek (east of Clear Lake); b) numerous recently-active thrust faults that extend almost the entire length of the foothills flanking the Santa Clara Valley from San Jose south to Hollister; and c) normal, reverse, and strike-slip faults at the east edge of the Diablo Range, from Tracy south to Panoche.

A second map shows earthquakes of magnitude ≥ 1.5 in the central Coast Ranges between 1969 and 1980 located by the Central California Network. These are plotted on the map of the principal recently active faults. There are prominent alignments of epicenters with almost all of the principal recently-active strike-slip faults east of the San Andreas fault. Epicenters in the foothills east and west of the Santa Clara Valley appear to be associated with the numerous recently-active thrust faults that dip away from the valley floor. There are also a number of earthquakes along the east flank of the Diablo Range south of San Luis Reservoir that are areally coincident with the many reverse and strike- slip faults of late-Pleistocene and (and Holocene?) age that have been mapped there. The San Andreas fault north of San Juan Bautista is strikingly aseismic, except for a cluster of epicenters near Daly City, where an earthquake of magnitude (M_L) 5.3 occurred on March 22, 1957.

2. Two distinct seismotectonic regions are evident in northern coastal California. North of latitude 40^0 N. (Cape Delgada), earthquake epicenters appear to be randomly distributed, except for a small cluster of events just offshore of Cape Mendocino. The hypocenters outline a 20^0 - 25^0 southeast-dipping Benioff zone, representing subduction of the Gorda plate. South of latitude 40^0 N., there are two alignments of epicenters that coincide with the Rodgers Creek-Maacama faults, on the west, and the Green Valley-Barlett Springs faults, to the east.

3. An article entitled "Catastrophic Landslides in the San Francisco Bay Area, California, 3-5 January 1982," intended for publication in Science, has been completed by Herd and others and submitted for Branch technical review. The article documents the thousands of landslides that were initiated by the January 1982 storm in the San Francisco Bay area. The downpour of 3-4 January caused shallow soil slides and slumps that typically mobilized into viscous flows of debris-laden mud. The debris flows coursed down slopes and ravines, and inundated or crushed tens of homes, killing 15 people. In the Santa Cruz Mountains several large slabs of layered rock and soil parted and slid down steeply inclined bedding planes, at Love Creek burying 9 houses and 10 people. The rain temporarily created perched zones of ground water in the soil mantle (and locally, in bedrock) where elevated pore-water pressures decreased the frictional resistance to sliding.

4. A map synthesis of the subsurface stratigraphy of eastern Hollister Valley near the Calaveras fault (with an accompanying description of the vegetative and climatic history of Hollister Valley) has been fowarded to Technical Reports Unit for final review and editing, prior to printing. A map of surface faulting in the Sonoran earthquake of 1887 (scale 1:50,000) has been technically reviewed, and will soon be forwarded to Technical Reports Unit.

Reports

Herd, D. G., and McMasters, C. R., 1982, Surface faulting in the Sonora, Mexico, earthquake of 1887: Geological Society of America Abstracts with Programs, v. 14, p. 172.

Cockherham, R. S., and Herd, D. G., 1982, Seismicity of the north end of the San Andreas fault system: EOS, v. 63, in press.

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 and 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. A seismic study was made to discern the difference between surface and subsurface ground motion in a waste repository site.

Results

1. The activities this fiscal year are designed mainly to prepare and to publish data reports and journal manuscripts. One such publication is the forthcoming 3rd International Conference on Microzonation. The Wasatch data report is 50% complete.

Reports

1. Hays, W. W., and King, K. W., 1981, Zoning of the earthquake groundshaking hazard along the Wasatch fault zone, Utah [abs.]: 3rd International Conference on Microzonation, Seattle, Washington, July, 1982.

2. King, K. W., 1982, Ground response in the Cedar City, Utah area [abs.]: Seismological Society of America 1982 (report in peer review).

3. King, K. W., 1981, A study of surface and subsurface ground motion at Calico Hills, Nevada Test Site (report in review).

4. Hays, W. W., King, K. W., 1982, Ground response under low- to high-strain ground shaking [abs.]: Seismological Society of America 1982.

Alaska Seismic Studies

9940-01162

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Investigations

1. Continued collection and analysis of data from a network of 51 high-gain short-period seismograph stations extending across southern Alaska from Juneau to Cook Inlet and inland across the Chugach Mountains.

2. Continued operation of one three-component and four vertical-component seismic stations and one strong motion instrument for the Army Corps of Engineers around the proposed Bradley Lake hydroelectric project on the Kenai Peninsula.

3. In cooperation with the Seismic Engineering Branch, continued operation of a network of 24 Kinemetrics SMA1 strong motion instruments in southern Alaska from the Kenai Peninsula to Juneau. Fourteen of these instruments are located in or around the Yakataga seismic gap, but two will be closed this summer due to monetary constraints.

Results

1. During the past 6 months, data processing has remained on schedule, and preliminary earthquake locations have been obtained for September 1981 through February 1982. The average number of events located each month was 375. In addition, progress was made in completing the processing for a 6-month break following the 1979 St. Elias earthquake. 335 events were located during a 2-week period in July 1979.

Preliminary epicenters for 1981 are shown in Figure 1. The seismicity west of Prince William Sound is dominated by Benioff zone activity dipping northwestward below Cook Inlet and the Alaska Range. Events of about magnitude 2 and larger are routinely included in the processing for this area, but large numbers of smaller events in the vicinity of Anchorage and near southern Kenai Peninsula reflect special studies in these areas. The Benioff zone events below 70 km deep are non-uniformly distributed along the strike of the subducted Pacific plate. Concentrations of the deeper events occurred beneath Iliamna volcano west of Cook Inlet, and in two areas located immediately southwest and northeast of Mt. McKinley.

East of Prince William Sound the seismicity occurs at depths shallower than 35 km and earthquakes as small as magnitude 0.5 are routinely included in the processing. Prominent spatial clusters of events, the most striking aspect of this seismicity, include: a northeast trending zone 40 km northwest of Valdez; activity around the Copper River delta; a cluster 75 km northeast of Kayak Island in the Waxell Ridge area; aftershocks of the 1979 St. Elias earthquake north of Icy Bay; and a zone of seismicity that parallels the Duke River fault north of the network. A few shallow events appear to line up with the Denali fault, including a magnitude 4.4

event which occurred in April 1981. A northwest-striking alignment of epicenters also occurred along the northeast boundary of the Yakutat foreland north and east of Yakutat Bay. This boundary marks the location of an inferred northeast-dipping thrust fault assumed to have been active during a series of great earthquakes in 1899-1900 (Thatcher and Plafker, 1977).

The Yakataga seismic gap is located along the northeastern Gulf of Alaska approximately between the longitudes of Icy Bay and eastern Prince William Sound. During 1981 most of the seismicity in this area was located at or near the eastern and inferred northern perimeter of the gap. The central portion of the gap north of the Aleutian trench appears to have been nearly aseismic, which is supported by the observation that events as small as about magnitude 2 were located 100 km or more offshore south of the network.

2. In the last semi-annual report it was noted that, in terms of total numbers of events processed per month, the rate of seismicity in and near the Yakataga seismic gap during October 1980 through May 1981 was higher than during the previous year. Over the past 6 months the rate of located events has returned to near the pre-October 1980 level. Further review of this data indicates that the threshold for completeness is about coda-duration magnitude 2, and that, except for a normal t^{-1} decay in the rate of aftershocks from the 1979 St Elias earthquake, the rate of activity for events of magnitude 2 and larger has not changed significantly since October 1979. The apparent temporal increase in the rate of seismicity based on the number of events processed per month is due almost entirely to changes in the number of smaller events. It is possible that there may have been a real temporary increase in the number of shocks smaller than magnitude 2. Alternatively, we are investigating the possibility that as yet unrecognized subtle changes in the data processing procedures or network operation may have produced inhomogeneities in the data set.

3. Over 900 earthquakes were located around the proposed Bradley Lake hydroelectric project on the southern Kenai Peninsula during the period November 27, 1980-November 30, 1981. Of these earthquakes, 127 were located at depths of 20 km or shallower. Although many of the earthquakes occur close to the principal mapped faults and may indicate activity on portions of these faults, other as yet unmapped and possibly buried faults must be active to account for the observed distribution of shallow seismicity. Forty-two events had coda-duration magnitudes of 3 or larger; all of these earthquakes were located at depths of 40 km or greater, which would place them in the Benioff zone which extends beneath the area. The largest shallow earthquake within 25 km of Bradley Lake had a coda-duration magnitude of 2.1. Focal mechanisms determined for selected shallow earthquakes in the southern Kenai Peninsula are compatible with predominantly normal faulting controlled by east-west to northwest-southeast oriented tension.

4. Two new seismograph stations near Mount Spurr, the closest active volcano to the Anchorage area, are providing detailed information on the seismicity associated with the volcano, which last erupted in 1953. Since mid-November 1981, a total of three high-gain vertical seismographs have been operating in the configuration of a shallow triangle with sides of 8 to 14 km, with one station situated 4 km east of Crater Peak, the site of the 1953 eruption. The additonal stations have increased the number of locatable earthquakes at the volcano by more than an order of magnitude. On February 22-25, a prominent swarm of more than 50 small (magnitude less than 0.0)

shocks occurred at shallow depth beneath the volcano. Other less prominent swarms of several shocks per day have occurred, but none have been as intense as the 9 September 1979 swarm reported in our last semi-annual summary.

The Crater Peak seismograph, which is on the volcanic pile, records a large number of low-frequency (2-4 Hz) signals with duration of up to several tens of seconds. These events are further characterized by emergent beginnings and the absence of clear body-wave phases. They appear to be similar to events observed by Fehler and Chouet (1982) at Mt. St. Helens. Based on amplitude and arrival time patterns most of the events seem to originate from the volcanic pile. Precise locations are not possible, however, because phases cannot be identified and correlated between neighboring stations. A shallow origin for the events is suspected, but whether they result from volcanic processes or surficial processes, such as glacial movement or avalanching, is not yet resolved.

5. The rate of seismicity in the rupture zone of the 1964 Alaska earthquake for the past 80 years, exclusive of the 1964 earthquake and aftershock sequence, has been found to be about 3.5 times lower than that expected based on a Gutenberg-Richter (GR) distribution with b=1, a maximum magnitude M_W=9.25, and an activity level normalized for the expected moment rate from long-term plate motion of 6.5 cm/yr. A number of possible explanations are possible, including 70 percent aseismic slip, large temporal fluctuations in seismicity rate, or a magnitude distribution that differs from the GR distribution. If the latter case is true, the 1964 rupture zone seismicity could be described by two separate distributions. The first distribution of less than great events follows the GR distribution with b=1 up to magnitude 7.5. Above 7.5 the distribution is attenuated, with few events above magnitude ~8. The second distribution, which would account for about 95 percent of the moment release, might peak at about magnitude 9.0 and taper to zero near 8.5 and 9.3. Distinguishing between these alternatives is important to reduce the uncertainty in estimates of earthquake potential.

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Reports

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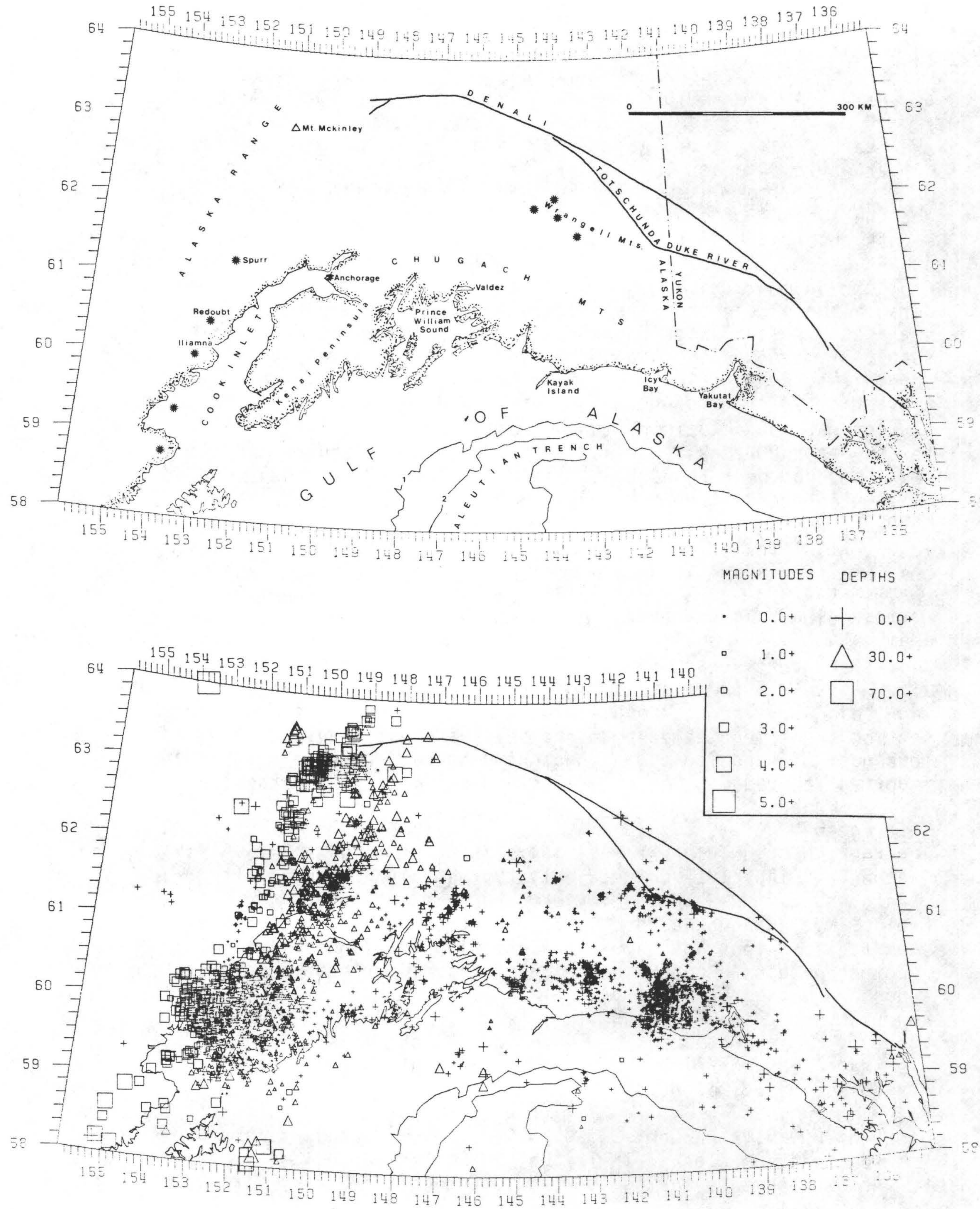

Figure 1. Upper - Map showing principal geographic and tectonic features of the southern Alaska region. Depth contours are in thousands of fathoms.
Lower - Epicenters of earthquakes which occurred in southern Alaska and western Canada during 1981.

Applications of Mathematical Modeling to Problems in the Earth Sciences

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 in selected parts of California and Arizona.

2. Continued our investigation of an early 20th century uplift in southern California coupled with a detailed consideration of those sources of systematic error that may have contaminated the results of the relatively ancient surveys that define the existence of this feature.

3. Continued studies of the geodetic record to evaluate magnitude of the systematic component of the refraction error in geodetic leveling; continued atmospheric physics studies in cooperation with the University of California, Davis.

Results

1. Examination of the geodetic record from a variety of points of view suggests that the residual refraction error inherent in any geodetic leveling generally does not rise above the predicted random error.

2. A relatively detailed examination of the results of the Saugus-Palmdale refraction experiment, which was designed to assess the systematic accumulation of this error, indicates: 1) that the single-run, long sight-length survey used in the basic comparison was associated with a much highter noise level than that normally encountered in first-order (double-run) leveling and thus may have sampled atmospheric conditions not ordinarily encountered; and 2) that systematic error other than refraction appears to be present in the experiment.

Reports

Castle, R. O., Elliott, M. R., Gilmore, T. D., Mark, R. K., Newman, E. B., and Tinsley, J. C. III, 1981, Aseismic uplift in California (comment): Science, v. 213, p. 246-247.

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

9540-01616
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Investigations

1. Studies of the Quaternary history of the upper Santa Ana Valley. Emphasis is currently on: (a) 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 neotectonic patterns within the Cucamonga Fault zone. The study has focussed mainly on faulting recurrence based on the morphology and distribution of scarps in multiple Holocene and late Pleistocene alluvial units. Together with J. C. Tinsley we have attempted to reconstruct possible seismic moments and vertical ground-surface displacements for ground-rupturing earthquakes within the fault zone.

3. Studies of the Banning Fault zone. The study has focused on: (a) mapping fault strands that deform crystalline basement rocks, Tertiary sedimentary rocks, and Quaternary surficial units; (b) evaluating the sedimentary and tectonic evolution of Tertiary sedimentary units within the fault zone; (c) identification of Quaternary units to establish Quaternary depositional patterns and the relative ages of fault strands within the Banning Fault system; and (d) interpreting inter-relationships between the Banning Fault system, the South Branch of the San Andreas Fault, and the Crafton Hills-Yucaipa Valley fault system.

Results

1. As part of a regional liquefaction-potential evaluation, Scott E. Carson and Jonathan C. Matti have statistically evaluated water-level data for a minimum-depth-to-groundwater map for the upper Santa Ana River Valley region (results portrayed on this map are summarized in Technical Report XIII, p. 51-52). For most areas underlain by groundwater shallower than 50 feet, subsurface water levels rose during and following the wet winters of 1977-1978 and 1978-1979. Prior to these wet winters, groundwater in almost all areas was significantly deeper than 50 feet. Shallow-groundwater areas within and marginal to the channel of the Santa Ana River form an exception: here, groundwater levels are variable, but water levels shallower than 50 feet subsurface occurred commonly throughout the 1973-1979 period of record. For shallow-groundwater areas other than the Santa Ana River Channel and environs, water-level patterns suggest that groundwater shallower than 50 feet should not be encountered except following periods of abnormally heavy rainfall, high surface runoff, and accelerated natural recharge of groundwater basins.

Shallow-groundwater conditions during wet winters are enchanced by simultaneous artificial recharge of imported water through percolation and pumping. In some areas (e.g. San Bernardino metropolitan area and the Claremont area), shallow groundwater conditions have persisted to the present. However, in most areas where shallow groundwater occurred during the wet winters, water levels have fallen significantly below 50 feet. These groundwater patterns lead us to conclude that, for those shallow-groundwater areas indicated on our minimum-depth-to-groundwater map, water shallower than 50 feet is likely to recur in the future with the coincidence of abnormally wet winters and continued artificial recharge in the upper Santa Ana River Valley region. This preliminary conclusion is important because, although long-term water-level patterns suggest that average groundwater depths throughout the valley area are generally deeper than 50 feet subsurface, certain parts of the valley region periodically are underlain by shallow groundwater and thus represent areas where liquefaction may occur provided conditions of susceptibility and opportunity are met.

2. Continued studies of the Cucamonga Fault zone have led to our refining of faulting recurrence and faulting geometry. Several of the hypotheses discussed in Technical Report Volume XIII, p. 52-53, have been strengthened, especially the recency of Holocene faulting and the occurrence of at least 36m of vertical uplift in approximately 13,000 years of latest Pleistocene and Holocene time. J. C. Tinsley, L. D. McFadden, and J. C. Matti recently examined soil profiles on the upper surfaces of alluvial fans in the Day Canyon area and demonstrated that some alluvial units previously thought to be younger Holocene in age (based on photogeologic interpretation) more likely are early Holocene in age. This observation calls into question an earlier interpretation by Morton and Matti in Technical Report Volume XIII: these workers measured relatively low fault scarps in the ostensibly young units and higher scarps in demonstrably older units and concluded that a systematic relationship existed between age of alluvial units and height of fault scarps (older units have higher scarps, younger units have lower scarps). The new soil-based age estimates for some units suggest that the faulting scenario in the Day Canyon area is more complicated than originally suggested in Volume XIII, p. 52-53, although the 700-year recurrence-interval estimate most likely will continue to be a reasonable ball-park figure. Earlier interpretations relied on the assumption that ground-surface displacement during any single earthquake was relatively uniform along local fault segments a few kilometers long. This assumption was based on the ostensible systematic relationship between scarp height and age of alluvial unit. New data suggest that this assumption is unrealistic, and future studies will be directed toward testing a new hypothesis that displacements during any single earthquake can fall off significantly from some maximum displacement to some minimum displacement along a fault-scarp reach of as little as two kilometers.

3. Studies of the Banning fault zone continue, with emphasis on the Crafton Hills-Yucaipa Valley horst-and-graben complex. No significant new results have been obtained since the last summary report in Volume XIII, p. 53-54.

Reports

Matti, Jonathan C., Tinsley, John C., Morton, Douglas M., and McFadden, Leslie, D., 1982, Holocene faulting history as recorded by alluvial stratigraphy with the Cucamonga fault zone: a preliminary view: Geological Society of America Field Trip Guide Number 12, J. C. Tinsley, J. C. Matti, and L. D. McFadden, eds., p. 29-44.

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Morton, Douglas M., Matti, Jonathan C., and Tinsley, John C., 1982, Quaternary history of the Cucamonga fault zone, southern California: Geological Society of America Abstracts with Programs, v. 14, no. 4, p. 218.

Surficial Geology of the Wasatch Front, Utah

9550-01622

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Investigations

1. Continued compiling the surficial geology in the Utah Lake valley portion of the Wasatch Front Surficial Geology project. The project is in the final stages of completion; the surficial geologic maps have either been published as MF- maps or are in the process of being released. This fulfills a portion of the purpose of this project, which is to provide basic surficial geologic and physical property data in support of the compilation by others of microzonation maps along the Wasatch Front.

2. Preparation of physical property maps along the Wasatch Front is underway, representing the last phase of this project. No new field investigations or laboratory tests were undertaken during the first half of fiscal year 1982. Results obtained earlier have been incorporated into the data needed for the final preparation of the physical property maps. It is planned that the remaining reports and maps will be transmitted for review and Director's approval by the end of fiscal year 1982.

3. It is anticipated that with support of W. W. Hays and K. W. King (9940-01919) the relative intensity information they gathered earlier from man-induced micro-earthquakes will be placed on the physical property maps as equal intensity contours. Such representations should aid the user in relating the potential intensities derived from the ground response to earthquakes to the different physical properties of the surficial deposits along the Wasatch Front.

Results

1. Deposits have been delineated on the 1:100,000-scale base maps as basic textural units.

2. The secondary subdividion of the textural units into physical property units on the Utah Valley sheet is complete. Laboratory data has been received but remains to be incorporated with other data into the final physical property units and descriptive explanation.

3. The Surficial Geologic Map of Utah Valley (1:100,000 scale) is in process of being released as an MF- map.

Reports

Miller, R. D., Olsen, H. W., Erickson, G. S., Miller, C. H., and Odum, J. K., 1981, Basic data report of selected samples collected from six test holes at five sites in the Great Salt Lake and Utah Lake valleys, Utah: U.S. Geological Survey Open-File report 81-179, 49 p., 6 well logs, 8 figs., 12 tables.

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

9940-03005

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Investigations

1. 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. Pursued the precise relocation of teleseismically-recorded, historic earthquakes in and around the Yakataga seismic gap.

Results

1. Earthquakes from August 1978 and October 1976 were timed, scaled, and located using the four-film digitizing table and interactive minicomputer. With the completion of August 1978, routine processing of earthquakes is now complete for 17 months prior to the 1979 St. Elias earthquake (M_S 7.1). The quarterly catalog for April-June 1978 has been completed, and the catalog for July-September 1978 will shortly be submitted for Director's approval. Earthquakes from November 1976 are currently being located; data from December 1976 through September 1977 are yet to be processed.

The pattern of seismicity in the vicinity of the 1979 St. Elias rupture zone observed during the second quarter of 1978 is similar to that observed by Stephens and others (1980) for earlier and later times. The eventual St. Elias rupture zone is one of the two most active areas for small earthquakes between Yakutat Bay and Prince William Sound. The other active area is the Waxell Ridge region about 75 km northeast of Kayak Island, in the Yakataga gap between the 1964 Prince William Sound and the 1979 St. Elias aftershock zones.

2. Experiments were conducted using Dewey's master-event program to locate a group of 24 aftershocks of the 1964 Prince William Sound earthquake that occurred on the western edge of the postulated Yakataga seismic gap. One objective was to explore the quality of phase data routinely reported in the bulletins of the International Seismological Centre. The 24 events were located with a subset of stations consisting of those stations that reported P readings for 13

or more of the events. The RMS weighted deviation of the station residuals about the average weighted station residual for all the shocks was examined at each station to assess the reliability of the data reported by individual stations. In addition to providing information on the reliability of stations, the exercise showed (1) that data from stations generally reporting times to the nearest 0.1 second are not necessarily as consistent as those from stations reporting to only the nearest second, and (2) that the impulsive or emergent phase onset description bears little information on the consistency of the arrival-time data.

A strategy has been established for relocating teleseismically-recorded shocks that occurred in and around the Yakataga gap. Larger recent shocks, whose locations can be constrained by regional data, have been selected as master events to be used in the joint determination of hypocenters for groups of shocks occurring within small source areas (dimensions less than 100 km). The station traveltime adjustments determined from the joint hypocenter determinations will be analyzed for evidence of variations in travel-time corrections as a function of geographic location of the source. Using appropriate station corrections, all the teleseismically recorded earthquakes will then be relocated. Wave-form modeling will be used to resolve more precisely the focal depths of selected earthquakes.

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Reports

Stephens, C. D., Astrue, M. C., Pelton, J. R., Fogleman, K. A., Page, R. A., Lahr, J. C., Allan, M. A., and Helton, S. M. (1982), Catalog of earthquakes in southern Alaska, April-June 1978: U.S. Geological Survey Open-File Report 82-488.

Geologic Earthquake Hazards in Alaska
9310-01026

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Investigations

1. Working on the neotectonic map of Alaska and active fault data file.

2. Working on photointerpretation of active Bendeleben, Kigluaik, and Brevig faults on Seward Peninsula.

Results

1. Work in progress; about 50 percent completed.

2. Preparation of MF strip maps and text about 75 percent complete.

Reports

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.

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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.

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: (In press)

SEISMIC ZONATION STUDIES

9940-01730

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Investigations

1. Studies of the effects of geological conditions and site properties on ground shaking.

2. Cluster analysis and discriminant analysis of the geologic properties data set.

3. Comparison of theoretical and observed spectral ratios.

4. Contribution to 3rd International Earthquake Microzonation paper.

Results

Three-component recordings of 19 nuclear explosions have been obtained at about 100 sites throughout the Los Angeles basin and vicinity in order to estimate the geographic variations in ground shaking due to underlying site geology. Fourier spectra were computed for each site and alluvium-to-crystalline rock spectral ratios were calculated over the period band 0.2 to 10 seconds in order to estimate the site's response characteristics (Rogers and others, 1980). These spectral ratios minimize the effects of source transmission path and instrument response. The spectral ratios have been further reduced by computing geometric mean ratios over several period bands. A data matrix has been constructed for the station data set employing the mean spectral values and geologic parameters such as age of surficial deposits, thickness of Holocene and Quaternary deposits, depth to basement, void ratio, percent silt-clay, texture of surficial deposits, and shear velocities in the upper 30 meters (Tinsley (personal communication), Gibbs and others (1980) Fumal and others (1981)). Examination of this data set reveals several correlations between mean site response and the geologic parameters. For instance, table 1a shows mean horizontal response in 3 period bands as a function of age of underlying surficial deposits. This table shows that sites underlain by soil (Holocene and Pleistocene) experience levels of shaking 3 to 4 times greater than sites underlain by crystalline rock (the base station in the ratios) in all period bands. Table 1b shows that void ratio, which is inversely related to shear modulus, has a strong influence on short-period response with void ratios in the 0.8 to 0.9 range producing a mean response on soil 6 times greater than on crystallinne rock and 3 times greater than low void ratio soils. The thickness of the soil deposits also plays a role in this behavior, however, as shown below. The effect of Quaternary thickness and depth to basement on the long-period response is shown in Tables 1c and

1d. Increasing amplitudes in this period band as structure thickness increases is a fundamental property of surface waves propagating in layers of variable thickness.

More critical examination of the data reveals other phenomena reflecting the physics of wave propagation in layered media. For instance, Figure 1 shows the mean short-period response plotted as a function of Holocene thickness (holding velocity constant), where the peak that occurs near 15 meters and the secondary peak at greater thickness indicate the shift of the fundamental and second mode peaks of a quarter wavelength layer on a half-space through this period band, as demonstrated by the theoretical results for incident SH that are also shown. The shift in the level between the two curves is probably due to the absence of layering below the Quaternary in the theoretical model. This result, incidently, demonstrates the importance of deeper layering on the short-period response. A closer correspondence between the position of the theoretical and observed peaks might have been obtained by adjusting the average velocity of the Holocene layer slightly, but no attempt was made to do this; the mean observed velocity of the Holocene layer, 200 m/s, was assigned in the calculation. Similar resonant effects occur in the data in other period bands for larger structure. These data emphasize the importance in taking into acount more than surface properties if site response is to be predicted accurately.

The critical question here is "Is it possible to produce a map predicting geographic variations in site response that takes into account the complexity of the physics, reflecting the effects of variations in near-surface properties as well as underlying structure?" The data suggest that it may be possible to use simple theoretical models to predict response, but it would be difficult to obtain enough data over this broad an area to do this accurately. We suggest a compromise between a theoretical approach and simply computing mean response of sets of stations grouped according to age of surficial deposits or surface velocities. This approach requires clustering the stations based on surface properties as well as underlying structure. The mean response in each period band can then be computed for each cluster or generic site type. Initial results indicate that 8-12 generic site types are obtained, representing the most commonly occurring site conditions and structure in the Los Angeles region, with mean site response varying between 0.7 and 8.0 and an average geometric standard deviation of 1.3. Application of these results to produce a map requires gridding the region and assigning each point of the grid to a particular cluster on the basis of those data that can be obtained for the location. The grid points are then assigned response values and contour maps are drawn for each period band. Although this work is still in progress, this technique appears to be a viable method for improving prediction of site response by basing the prediction on near-surface site properties and underlying geologic structure.

Table 2 compares mean observed horizontal site response and mean theoretical transverse site response for 46 Holocene sites. The theoretical response was computed using a damped Haskell-Thomson formulation with site properties determined on the basis of each sites Holocene thickness, shear velocity or void ratio, Quaternary thickness, and depth to basement. Velocities in the Pleistocene and underlying layers are estimated from other studies. Paired T-tests of the 46 observations indicates that the equality of observed and theoretical cannot be rejected at the 5% significance level in the two short-period bands, but can be rejected in the two longer period bands.

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Reports

Ziony, J. and others (1982). Seismic zonation of the Los Angeles region in a progress report, Procedures of the Third International Earthquake Microzonation Conference.

Table 1

A

AGE	Short-Period Mean Response (0.3-0.5 s)	Intermediate-Period Mean Response (0.5-3.3 s)	Long-Period Mean Response (3.3-10 s)
Holocene	3.7	3.3	2.6
Pleistocene	3.2	3.1	2.6
Pliocene	1.4	1.6	2.0
Miocene	2.5	2.1	1.6
Mesozoic	1.7	1.1	0.8

B

VOID RATIO	Short-Period Mean Response (0.3-0.5 s)
$0.2 \leq e < 0.4$	2.3
$0.4 \leq e < 0.6$	3.1
$0.6 \leq e < 0.7$	3.0
$0.7 \leq e < 0.8$	4.1
$0.8 \leq e < 0.9$	6.2

C

Quaternary Thickness (m)	Long-Period Mean Response (3.3-10.0 s)
$0.1 \leq QTHK < 75$	1.4
$75 \leq QTHK < 200$	2.7
$200 \leq QTHK < 500$	3.1
$500 \leq QTHK < 1000$	5.9
$1000 \leq QTHK$	3.7

D

DEPTH TO BASEMENT (km)	Long-Period Mean Response (3.3-10.0 s)
$0 < dtb < 2.0$	1.5
$2.0 \leq dtb < 4.0$	2.5
$4.0 \leq dtb < 6.0$	4.1
$6.0 \leq dtb$	3.9

Table 2

MEAN SPECTRAL RATIO

Period Band	Observed	Theoretical
0.2-0.3	3.8	3.6
0.3-0.5	3.7	3.2
0.5-3.3	3.3	2.8
3.3-10.0	2.7	1.8

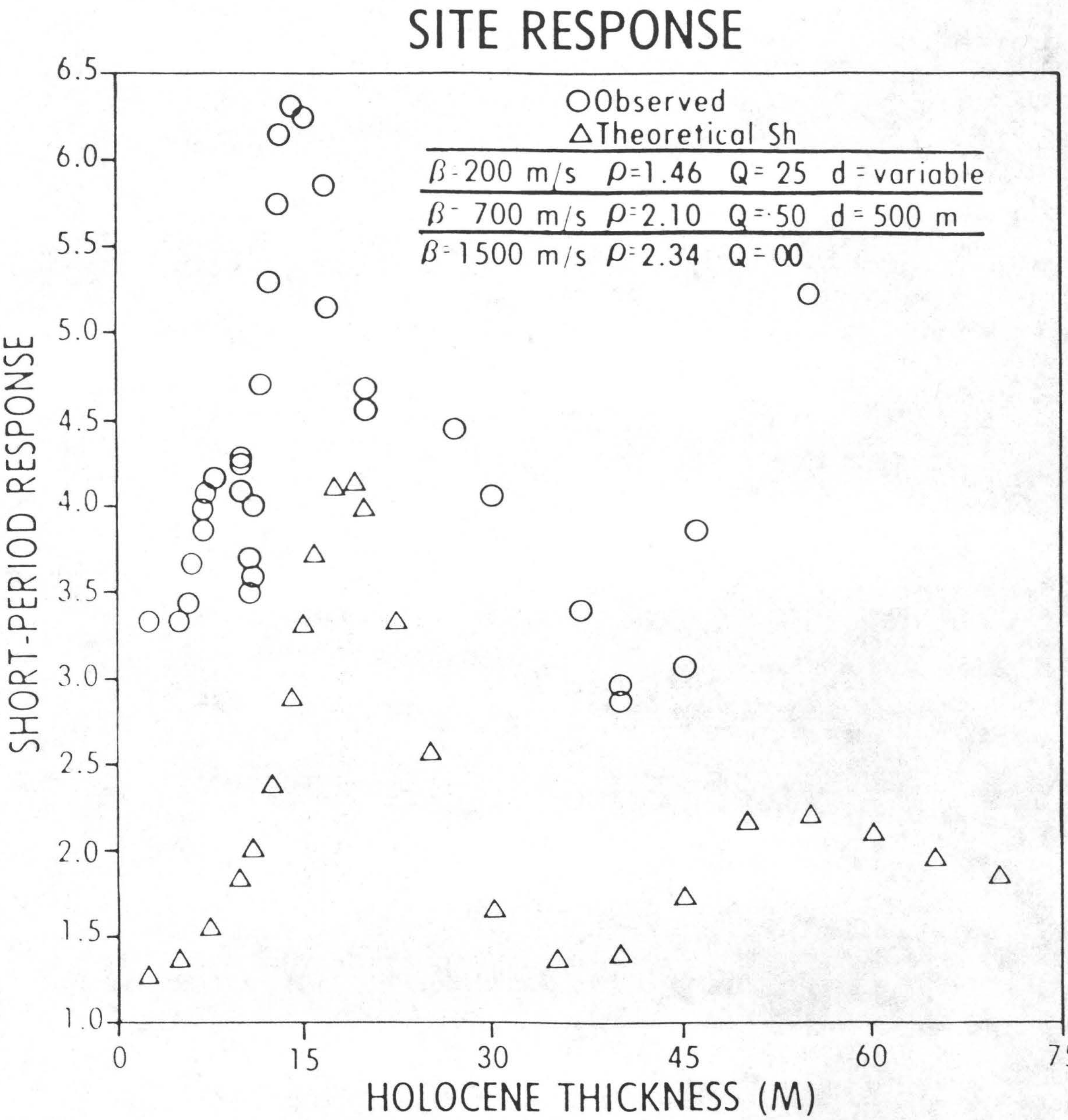

Figure 1. Comparison of observed and computed mean site response in the period band 0.3-0.5s (velocity in the Holocene layer held nearly constant). The observed results have been smoothed by a 3-point running median smoother.

Earthquake Hazard and Prediction Research in the Wasatch Front--Southern Intermountain Seismic Belt

14-08-0001-19257

October 1, 1981 to March 31, 1982

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Investigations

1. Subsurface geometry of major normal fault zones based on seismic reflection data and contemporary seismicity.

2. Ogden strain reversal: Dislocation models of curvilinear dip-slip (listric) fault surfaces.

3. Testing of SV/P amplitude ratio technique for constraining focal mechanisms of Utah earthquakes.

4. Software development for application to digital earthquake data.

5. University of Utah network calibration.

6. University of Utah network operations and seismicity for the period: October 1981-March 1982.

Results

1. Results from several investigations indicate that current deformation in the eastern Basin and Range Province may be occurring, at least partially, on low-angle or listric normal faults: (a) A numerical modeling study of the compressional strain across the Wasatch fault, is consistent with a model of westward block motion of a portion of the adjacent Wasatch Mountains along a listric normal fault within the mountain block (Zandt and Richins, 1981). (b) Seismic reflection data obtained from industry sources suggest that listric normal faulting may be intrinsic to current extensional deformation of thrust-belt structure along the eastern Great Basin. Well determined focal depths cluster near 7 km and 80% of all events occur above an inferred upper-crustal low-velocity layer at ∿10 km--suggesting correlation of a basal detachment with a zone of low rigidity (Smith, 1981). (c) A detailed study of an intense microearthquake swarm in the Mineral Mountains of west-central Utah (June-August, 1981) delineated a zone of activity suggestive of seismic slip on a listric fault surface. Focal mechanism studies as well as local geologic studies further support the hypothesis that a normal listric fault may be involved in the relief of east-west tensional strain in this region (Zandt, in prep.).

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*Semi-Annual Technical Report includes contributions also from D.I. Doser and G. Randall.

However, not all the investigations produced results consistent with the idea of seismic slip on low-angle normal faults. A detailed analysis of microseismicity and fault-plane solutions at the southern end of the Wasatch fault, where independent (seismic reflection) information on subsurface low-angle faulting is available, indicates that seismic failure seems to predominate on relatively high-angle fracture planes--either the upper portion of west-dipping, downward-flattening faults, related east-dipping antithetic faults, or moderately-dipping secondary faults within the major fault blocks (Arabasz, 1981).

2. Ever since its discovery, the geodetically observed compressional strain across the Wasatch fault near Ogden, Utah (Prescott et al., 1979), has been an enigma. A model for the observation has been developed in which the compression is caused by westward block motion of a portion of the adjacent Wasatch Mountains along a low-angle detachment within the mountain block (Zandt and Richins, 1981). Evidence favoring this interpretation includes normal-faulting seismicity east of Ogden, geological evidence for normal faults with significant displacement in the back-valley areas east of the Wasatch fault, and numerical modeling of displacement on a listric-style dip-slip fault. The latter shows that observed compression could be due to several millimeters per year of aseismic slip on a back-valley listric normal fault (see Figure 1).

3. We have obtained a set of programs (from C. Kisslinger and others at CIRES) for estimating focal mechanisms using an inversion of the ratio of SV to P amplitudes on vertical component seismograms. This technique has been applied with some success to well-recorded, well-located earthquakes in the southern Wasatch Front area. The estimated focal mechanisms have provided useful insight for small earthquakes recorded by as few as 5-10 local stations. Further testing is underway to determine more precisely the accuracy and limitations of this technique for source determinations of local earthquakes recorded by the University of Utah seismic network.

4. A moment-tensor inversion program, INVERT 02 developed by A. Lindh (personal communications, 1981) has been implemented for use in obtaining the source parameters of small (M_L<4.0) earthquakes in the Utah region. INVERT 02 uses only direct waves in a half-space velocity model to determine the moment tensor parameters. First arrivals from earthquakes at stations in the Utah network are commonly not direct waves, but rather head waves, so the inversion scheme must be modified to allow the use of head waves in the data set and more complex velocity models. Routine application of this technique awaits completion of a systematic calibration of our network (see below) for amplitude control.

5. During this report period we initiated a major program to calibrate our entire seismic network for absolute amplitude and phase response. Start-up work has included development of reliable and theoretically sound calibration techniques--both for bench calibration of individual system components and complete in-situ system calibration from seismometer through computer recording. To date, instruments representing samples of all equipment used in the telemetry stations (seismometers, amplifiers, VCO's, discriminators) have been bench-tested for amplitude and phase response. For

in situ system calibration, it became apparent that, due to several factors, a reliable mechanism would be needed to trigger the computer system from the field during a calibration. Design and fabrication of necessary equipment is in progress.

6. During the 6-month period: October 1, 1981, to March 31, 1982, 170 earthquakes were located within the Wasatch Front study area (283 within the Utah region) including eight events with $M_L \geq 3.0$. Seismic telemetry was significantly improved during this period when several new radio and/or microwave links became operational replacing old links subject to lightning problems. A significant earthquake sequence near Soda Springs, Idaho, just north of the Wasatch Front study area, occurred during December 1981 including 40 events with $M_L < 4.0$. On December 17, 1981, a magnitude 2.1 earthquake near Edgemont, Utah, 10 km north of Provo was felt by local residents. This earthquake was apparently associated with the Wasatch Fault near the epicenter of a magnitude 3.0 event on February 20, 1981. Both earthquakes occurred within a prominent seismicity gap associated with the Wasatch fault zone.

Reports and Publications

Doser, D. I. and R. B. Smith, 1982. Seismic Moment Rates in the Utah Region, *Bull. Seism. Soc. Am.* *72*, 525-551.

Bashore, W. M., R. B. Smith, G. Zandt, and J. Ansorge, 1981. Upper crustal structure of the Salt Lake Valley and the Wasatch Front from seismic modeling, *EOS* *Trans. Am. Geophys. Union* *62*, 961.

Smith, R. B., 1981. Listric faults and earthquakes, What evidence?, *EOS*, *Trans. Am. Geophys. Union* *62*, 961.

Zandt, G. and W. D. Richins, 1981. Interpretation of high- and low-angle normal faults along the Eastern Basin and Range, Northern Utah, *EOS*, *Trans. Am. Geophys. Union* *62*, 960.

Arabasz, W. J., 1981. Seismicity and Listric Faulting in the Central and SW Utah, *EOS*, *Trans. Am. Geophys. Union* *62*, 960 (work partly supported by USGS contract).

Richins, W. D., G. Zandt, and W. J. Arabasz, 1981. Swarm seismicity along the Hurricane Fault Zone during 1980-81: A typical example for SW Utah, *EOS*, *Trans. Am. Geophys. Union* *62*, 966 (work complementary to USGS contract).

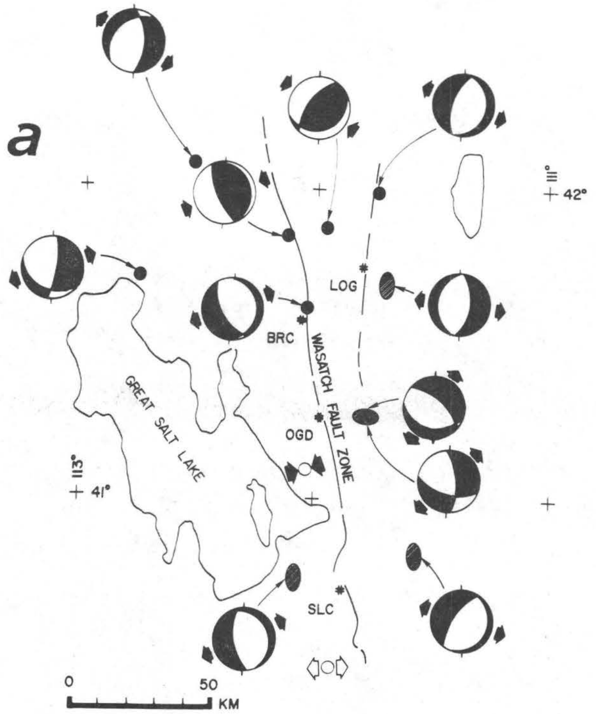
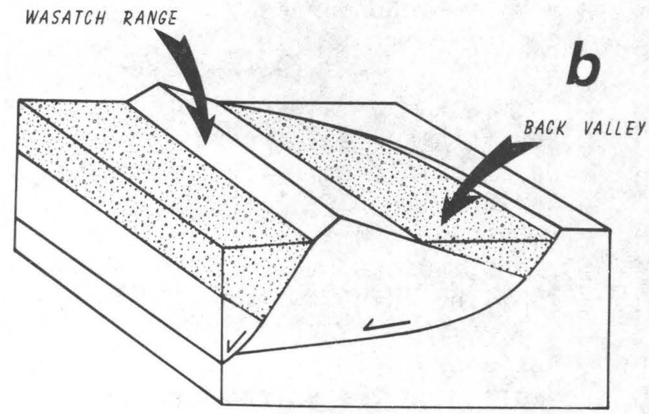


Figure 1a. Focal mechanisms (lower hemisphere, compressional quadrants shaded) in northern Utah. OGD = Ogden, SLC = Salt Lake City. Open circles with arrows depict geodetically-determined strain (from Zandt and Richins, 1981).

Figure 1b. Schematic 3-D block diagram showing hypothetical relationship of a listric "back-valley" fault to the major range-bounding Wasatch fault (from Zandt and Richins, 1981).



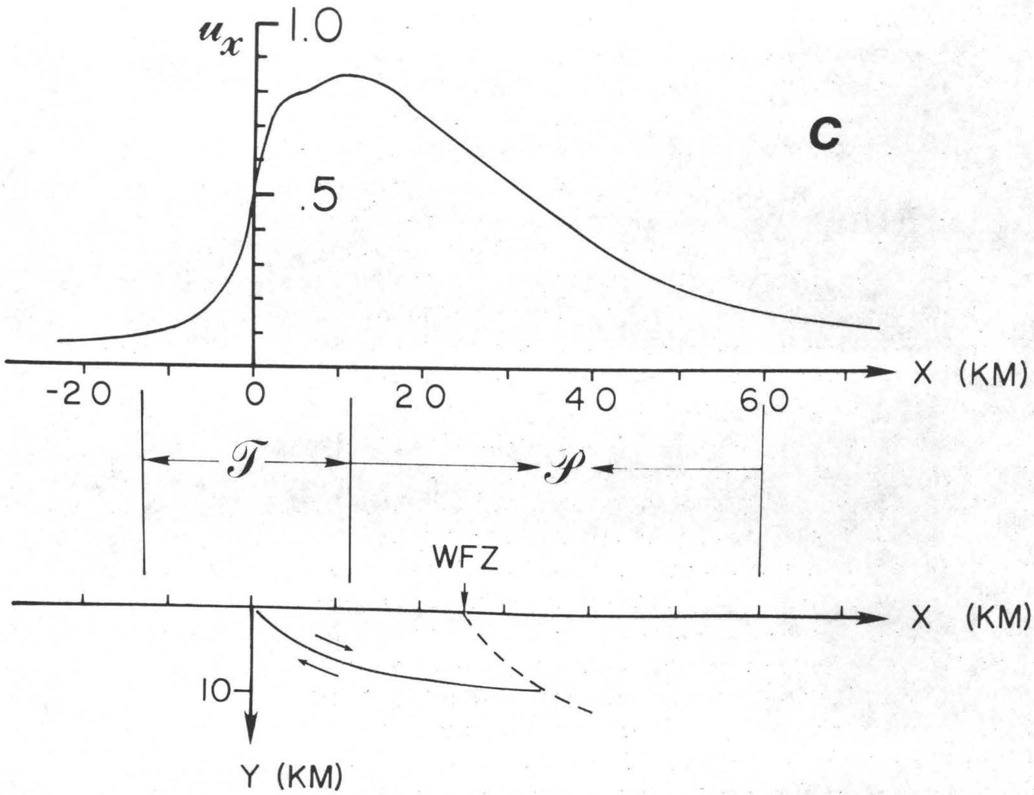


Figure 1c. Horizontal displacement (normalized to average slip on the fault) due to normal slip on a listric dip-slip fault (shown at bottom of figure). Stylized T and P show horizontal extent of resulting extensional and compressional zones, respectively. Note compressional strain in vicinity of Wasatch fault (from Zandt and Richins, 1981).

EARTHQUAKE HAZARD RESEARCH IN THE GREATER LOS ANGELES BASIN AND ITS OFFSHORE AREA

14-08-0001-19261

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Continued microseismicity monitoring of the greater Los Angeles Basin has two principal objectives:

1) Investigating relationships between microearthquakes and oil field operations (principally waterflooding), and

2) Compiling earthquake statistics for coastal zone faults, principally the Newport-Inglewood, Palos Verdes, and Santa Monica-Malibu faults.

We are currently upgrading our network with the addition of six-eight new sites in the Los Angeles area. All of these sites will be located in boreholes at depths greater than 100 m. We have recently completed the installation of a three-component package at a depth of 1.6 km in the Baldwin Hills area of Los Angeles.

Quaternary Framework for Earthquake Studies
Los Angeles, California

9540-01611

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Investigations

1. Continued entering on the U.S.G.S. computer the geotechnical data base in the eastern part of the San Fernando Valley and the northern part of the Coastal Basin (J. Tinsley, M. Nicholson, D. Ponti, K. Seals).

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, granulomety 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. Completed analysis and interpretation of the chemical and physical characteristics of pedogenic soils based on five chronosequences along a transect across southern California from the Los Angeles Basin through San Gorgonio Pass across the Mojave Desert to Vidal, CA (L. D. McFadden and J. C. Tinsley).

5. Edited and coauthored guidebook and co-led field trip to examine (1) the soil chronosequence in the San Gabriel mountains and (2) the Cucamonga faults zone in the Day Canyon area (J. Tinsley, J. Matti, L. D. McFadden).

6. Completed gathering shallow borehole data from L.A. County Flood Control Disrict, to check the occurrences of near-surface groundwater in the San Gabriel Valley and Coastal Basin areas of Los Angeles County, CA.

7. Co-authored paper synthesizing the results of the U.S.G.S. regional hazards evaluation program in southern California (J. Ziony, editor) for presentation at the 4th International Conference on Microzonation, Seattle, WA (6/82).

Results

1. Compilaton is complete in the San Fernando 7.5' quad.

2. Surficial geologic mapping is 85% 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 can be grouped consistently according to geotechnical parameters (J. Tinsley and A. M. Rogers).

4. Seven stages of soil formation are recognized in the Los Angeles basin area for deposits developed on lithic-arkosic alluvium. The soil profile characteristics are summarized in table 1. L. D. McFadden and J. Tinsley have authored a paper describing a model that correctly predicts the amount and depth at which $CaCO_3$ accumulates in the Mojave Desert soils as a function of time. Presented by McFadden at Geological Society of America, Cordilleran Section, Anaheim, CA 4/82.

5. Field Guide presents the soil chronosequence in the Los Angeles basin and San Gabriel Mountain area. Establishes Holocene surface faulting in the Cucamonga Fault Zone.

6. Initial but incomplete analyses of shallow water reported in borehole data shows that with few exceptions shallow ground water is present in much of the L.A. River floodplain areas near Downey and Artesia, Los Angeles County, CA.

7. Paper submitted for publication in the 3rd International Microzonation Conference Proceedings. See J. Ziony for complete summary.

Reports

McFadden, L. D.and Tinsley, J. C., 1982, Simulated calcic-horizon development in alluvial soils: Geological Society of America, Abstracts with Programs, v. 14, no. 4, p. 214.

Morton, D. M., Matti, J. C. and Tinsley, J. C., 1982. Quaternary history of the Cucamonga Fault Zone, southern Califonria: Geological Society of America, Abstracts with Programs, v. 14, no. 4, p. 218.

Tinsley, J. C., Matti, J. C. and McFadden, L. D., (eds.), 1982, Late Quaternary pedogenesis and alluvial chronologies of the Los Angeles and San Gabriel Mountains areas, southern California and Holocene faulting and alluvial stratigraphy within the Cucamonga Fault Zone: a preliminary view. Guidebook, Field Trip 12, Geological Society of America Cordilleran Section Meeting, Anaheim, CA 1982.

U.S. Geological Survey staff (J. I. Ziony, coordinator), 1982, Seismic zonation of the Los Angeles region--a progress report: Proceedings of the 3rd International Earthquake Microzonation Conference, June 28-July 1, 1982, Seattle, WA.

Table 1. Diagnostic Profile Characteristics for Alluvial Soils of the San Gabriel Mountains Chronosequence

Stage	Typical Profile	Epipedon Type	Epipedon Thickness	Epipedon Hue,Value	B Horizon 1/ Thickness	B Horizon 1/ Reddest Hue, Chroma 1/	Characteristic Cobble Weathering Stage 2/ Leucocratic	Characteristic Cobble Weathering Stage 2/ Mafic
S7	A - Cn to A - Cox - Cn	Ochric	0-50	10YR,3	0	10YR,4	1	1-2
S6	A - AC - Cox - Cn	Ochric or Mollic	26-92	10YR,3	0	10YR,4	1-2	2
S5	A - AC - Cox - Cn to A - Bt - Cox	Mollic	17-128	10YR,3	0-128	7.5YR,6	2-3	3-4
S4	A - B2t - B3 - Cox	Ochric or Mollic	6-80	10YR,3	155-425	5YR,4	3-4	3-4
S3	A - B2t - B3 - Cox	Ochric	1-20	5YR,5	163-223	5YR,6	3-4	4
S2	A- B2t - B3 - Cox	Ochric	2-8	5YR,3	208-469	2.5YR,8	4	4
S1	B2t - B3 - Cox	--	--	--	458	10R,8	4	4

1/ If no B Horizon is present, the reddest values for hue and chroma pertain to the Cox horizon.
2/ Cobble weathering stages:

Cobble weathering stages described for most profiles constitute a semiquantitative field technique to indicate the relative variations in weathering of grains greater than 2mm in diameter; the technique is employed in making comparisons among different profiles and within any given profile. The weathering stages are classified as follows:

Stage 1: Clast is essentially unweathered except for minor surface pitting or incipient oxidation rinds; when struck, rings sharply to the blow of a hammer.

Stage 2: Clast is slightly weathered and is characterized by incipient to moderate surface pitting, fracturing, and moderately thick (greater than 1-2 mm) oxidation rinds; yields moderate ring to blow of a hammer.

Stage 3: Clast is substantially weathered, surface may be highly pitted, and stongly fractured; ferruginous material may line fracture planes; moderate thick oxidation rinds may be present, and many mafic minerals and some feldspar grains may be strongly altered. The clast can be broken with difficulty by hand and has a dull sound to the blow of a hammer.

Stage 4: Clast is very strongly weathered and can be easily disaggregated by hand into a grus that consists of grains resistant to weathering. The clast emits a very dull sound when struck with a hammer.

U.S.G.S./Alaska Divison of Geological Surveys Cooperative Earthquake Hazards Project; Geotechnical Soils Investigations, Upper Cook Inlet, Alaska

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Investigations

The Upper Cook Inlet area of sourth-central Alaska, including the Municipality of Anchorage, is the most populous area of the State and sustained considerable damage and loss of life during the 1964 Prince William Sound Earthquake. Much of the resultant destruction was attribute to massive ground failure of Quaternary soils. Subsequent to the investigations conducted in the years immediately following the earthquake, very little additional research has been conducted on the seismic hazards of 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) I have initiated and continue to maintain a data bank system for subsurface engineering and geologic information obtained from trenches and boreholes by municipal, state and federal agencies, and by industry. Presently, the information is being stored in its original report format with a Kardex catalogue file for data scope and acquisition reference. Several thousand sites are now on file for the areas of Anchorage, Eagle River, Eklutna, Peters Creek, Palmer, and Wasilla. Efforts are underway to transfer the data to a computer-based retrieval system.

(2) I have documented an hypothesis which suggests that discrete geologic facies exist in the Bootlegger Cove Formation, that these facies vary in their engineering characteristics based upon difffering geologic histories and modern ambient conditions, and that these resultant engineering geologic facies may be characterized in terms of static and dynamic behaviour for earthquake hazard assessment. The Government Hill area of Anchorage was used as a model area. Seven engineering geologic facies were identified and mapped in three

dimensions, each having distinct field and laboratory parametric characteristics. One facies was found to be moderately to highly sensitive and two others are susceptible to liquefaction. The results of this study are presently in final review as a series of USGS I-series maps and a USGS Bulletin.

(3) Based upon the success of the above study, a detailed engineering geology mapping project of southwest Anchorage (including the International Airport and Turnagain Heights landslide area) has been completed. This project includes a colored engineering geologic map (1:10,000 scale), geologic cross-sections, structure contour and isopach maps of the Bootlegger Cove Formation, and a computer-digitized modeling program plotting subsurface soils units. The results are in review for Alaska DGGS publication.

(4) A geotechnical study of a high-rise building site in downtown Anchorage has been completed. The study focuses on the Bootlegger Cove Formation and includes: (a) a series of deep geotechnical stratigraphic boreholes, (b) a laboratory program of static engineering tests on core samples, (c) resonant column dynamic tests, (d) cyclic triaxial dynmanic tests, and (e) down-hole in situ shear wave velocity measurements. Independant runs of the SHAKE soil-structure interaction program were made before and after the dynamic testing. Multiple publications are in preparation.

(5) During April, 1982, the Electric Cone Penetration Testing System (Ertec CPT) was brought to Alaska and utilized at selected sites in the vacinity of the Turnagain Heights, L Street, and 4th Avenue landslides. The CPT data is being processed to characterize the pre-defined Bottlegger Cove Formation facies in order to better assess liquefaction potential, sensitive clays, and to correlate with existing SPT data, geotechnical logs, and static laboratory testing results. The CPT system was also used to characterize stratigraphic units in tidal flats (Anchorage Port and the head of Knik Arm) and tidal floodplain deposits of the Knik River.

(6) Bedrock and surficial geologic mapping has been initiated 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 faults, believed to be splays of that system have been mapped both transecting McHugh Complex (Jurassic/Cretaceous) bedrock and late Quaternary glacial/periglacial surficial deposits. The final draft geologic maps are in preparation.

Geothermal Seismo-tectonic Studies

9930-02097

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Investigations

1. St. Helens seismic zone (SHZ) studies. Seismicity continues in the Elk Lake section of the SHZ. Earthquakes with magnitudes greater than 2.5 are being analyzed as they occur, in an effort to monitor possible changes in the Elk Lake area. Possible changes that could be detected include rotation of the fault planes on focal mechanisms, a change in the distribution of earthquakes (clustering in a small volume), and changes in the b-value.

2. Olympic Peninsula-Washington Coast Range seismicity. The Olympic Peninsula subnet of the University of Washington statewide network continues to record low rates of local seismicity. Focal mechanisms for small magnitude (2+) earthquakes on the Olympic Peninsula continue to be routinely calculated. As with the SHZ studies, the contemporary data is now being compared with the pre-1980 data as this investigation moves to the reporting phase.

3. Crustal structure studies on the Olympic Peninsula have advanced to the stage of ray-tracing and the development of velocity models. Analysis is focused on the Canadian refraction data recorded during the summer of 1980 and on data acquired from an onshore-offshore refraction profile shot across the Washington margin south of the Olympic Mountains.

4. A teleseismic P-delay study, initiated in 1981, is nearing completion. Teleseismic residuals are being used in an effort to constrain the geometry of the subducting Juan de Fuca plate beneath the North American plate.

Results

1. The St. Helens seismic zone (SHZ) has been interpreted as a crustal fault zone 90 km long that is capable of generating a large magnitude, shallow earthquake if the entire zone (90 km long) were to fail at one time. At the northern end of this seismic zone (about 15 km north of the Cowlitz River), a large area of western Washington has been seismically quiet above the magnitude 3.0 level since 1977. The quiet area makes it difficult to determine if the SHZ continues northward into southern Puget Sound. The direction of the axis of maximum compression inferred from

focal mechanisms along the SHZ, in consistant with models of on-going oblique subduction of the Juan de Fuca plate beneath the North American plate. This tectonic framework raises the possibility of a large magnitude, subduction earthquake beneath the Pacific Northwest coast. Neither the possibility of a large crustal earthquake not a major subduction event are part of the current earthquake assessment for the Puget Sound basin. Our results suggest that earthquake hazards should be re-assessed in western Washington.

2. On March 1, 1982, the largest earthquake in the continuing Elk Lake aftershock sequence occurred. This event, magnitude 4.1 was located directly beneath the mainshock at a depth of 11 km (mainshock depth was 6.5 km). Since March 1 all magnitude 2+ events in the Elk Lake area have been deep between depths of 9 and 12 km. Focal mechanisms for activity since March 1 continues to be dominated by north-south strike-slip, but with a larger thrust component than that observed for earlier earthquakes.

3. Teleseismic P-wave delays across western Washington and northern Oregon appear to have a significant sub-crustal component that is overprinted by the crustal component. When the crustal component is subtracted from different approach azimuths, the resulting delay pattern is consistant with the hypothesis of a subducting high velocity slab. Because the delays are smaller in the southern half of western Washington, we suggest that the dip of the subducting plate may be greater here than under Puget Sound.

Reports

Grant, W. C., Weaver, C. S., and Zollweg, J. E., 1981. The February 14, 1981 Elk Lake, Washington earthquake and its aftershock sequence (abs.): EOS, Transaction of the American Geophysical Union, v. 62, 968.

Weaver, C. S., and Smith, S. W., 1981, The St. Helens seismic zone: A major crustal fault zone in western Washington (abs.): EOS, Transactions of the American Geophysical Union, v. 62, 966.

Michaelson, C. A., and Weaver, C. S., 1981, Teleseismic P-wave residual studies in Washington and northern Oregon (abs.): EOS, Transactions of the American Geophysical Union, v. 62, 1089

Weaver, C. S., Green, S. M., and Iyer, H. M., 1982, Seismicity of mount Hood and structure as determined from teleseismic P-wave delay studies: Journal of Geophysical Research, 87, 2782-2792.

Weaver, C. S., and Smith, S. W., 1982, Regional tectonic and earthquake hazard implications of a crustal seismic zone in Southwestern Washington (Director's approval pending, to be submitted to the Journal of Geophysical Research).

Tectonic Tilt Measurements Using Lake Levels

9-9950-02396

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Investigations

Work continues to re-occupy sites established for simultaneous lake-level measurements across large lakes for the purpose of monitoring surface tilt in tectonically active areas. Lakes monitored by this project are in southern Alaska, Utah, Montana, and this year, sites were established on Reelfoot Lake, Tennessee.

Reference benchmarks were established at 5 shoreline sites on Reelfoot Lake in January, 1982 (see Figure 1). Water levels were recorded simultaneously for at least one day at 4 sites. High winds and freezing lake conditions prevented longer recordings and limits the initial referencing of level between sites to $\pm$ 15mm. Rates of late Holocene uplift (including coseismic deformation of the 1811-12 earthquakes)are of the order of 10 m/2000 yrs (Hamilton and Russ, 1981). These rates and current seismicity suggest that contemporary tilt across the lake might be detectable within 2 to 5 years.

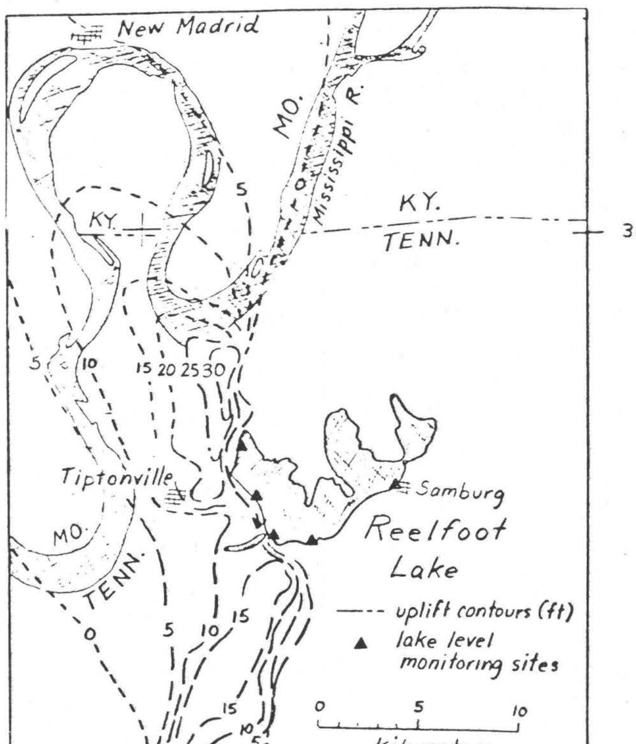

Figure 1. Lake level monitoring sites established on Reelfoot Lake, Tennessee, January, 1981. Dashed lines are equal-uplift contours (in feet) of the "Lake County uplift" as reconstructed by D. P. Russ and reported in Hamilton, R.M., and Russ, D.P., 1981, Seismotectonics of the New Madrid Region: in Proceedings of Conference XIII, Evaluation of regional seismic hazards and risk, U. S. Geological Survey Open-file Report 81-437, p.55-73.

Results

No new results

Reports

No reports

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 and R. F. Yerkes). Phase data from merged CIT-USC-USGS files for 1973 checked for completeness and consistency against Santa Barbara station records (not normally included with CIT or USGS data). Examined C. F. Richter's professional notes, extracted and coded for computer entry unpublished data on mainshock and aftershocks of 1933 Long Beach sequence. About 5000 seismograms for period May 1927 to March 1932 from Santa Barbara station filmed.

2. Fault map (Yerkes). Continued monitoring field and related investigations on active faults, deformation rates, age-dating of Quaternary deposits for 1:250,000 summary map.

3. Summary Professional Paper report on earthquakes hazards of southern CA region (Yerkes and Williams). Prepared draft of introductory chapter on seismotectonic setting. Prepared map and data table on historic damaging (MM 7) earthquakes and their damage patterns.

4. April 1981 "Lompoc" rupture (Yerkes, Ellsworth, Tinsley). Continued preparation of journal report on new surface fault and microearthquake (see GSA Abs. with Programs, vol. 13-7, p. 586, 1981).

5. W. Transverse Ranges structure (Yerkes). Revised structure contour map of top basement on basis of isostatic residual gravity model of Griscom and Grafft (GSA Abs. with Programs, v. 14-4, p. 168, 1982), which indicates that no Paleogene section is present beneath middle Miocene volcanics of western Santa Monica Mountains and that Miocene and younger strata in the deep Ventura basin-Santa Barbara Channel structural trough (which coincides with a -68 mg low) rest on young oceanic crust veneered by attenuated older sediments over a 10-km upward protrusion of the mantle.

6. Late Cenozoic ashes (Sarna-Wojcicki). Nine separate ashes in stratigraphic succession are now identified in the composite marine section of the Ventura Avenue and South Mountain anticlines, central Ventura basin. The section represents continuous deposition during the interval 1.9 to 0.6 my. Three of the ashes (Lava Creek, 0.6 my; Bishop, 0.73 my; and Huckleberry Ridge, 1.9 my) are correlated with chemical equivalents in the pluvial section of Pleistocene Lake Tecopa in southeast CA, thus correlating marine-nonmarine sequences and reconciling the provincial marine invertebrate fossil chronology and continental vertebrate chronology of southern CA. Cooperation with J. W. Hillhouse, USGS MP, has identified a normal-to-reverse polarity transition in

the Ventura Anticline section several meters below the Bishop ash (0.73 my). The transition must represent the Brunhes-Matayama reversal, commonly found below the Bishop ash at many localities in the western U. S. Samples from below the Bailey ash (1.2 my) in the Ventura Anticline west of the Ventura River have reversed polarity, suggesting that this part of the section is 1.2-1.7 my old.

Reports

Lajoie,, K. R., and Sarna-Wojcicki, A. M., 1982, Late Quaternary coastal tectonics in the central and western Transverse Ranges, southern California (Abs.): Geological Society America Abstracts with Programs, vol. 14-4, p. 179.

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Earthquake Hazards
Puget Sound, Washington

9540-02197

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Investigations:

1. Complete mapping of surficial deposits in the northwest and southeast corners of the Seattle 1:100,000 map area, specifically the Uncas, Center, Redmond, Kirkland, Issaquah, and Mercer Island 7½ minute Quadrangles. Incorporate mapping with previous work to produce a surficial geologic map of the Seattle 1:100,000 map area, as background for studies of seismic ground response and liquifaction potential on a regional scale.

2. Prepare maps portraying the depth distribution of bedrock, Holocene alluvium, and certain poorly consolidated glaciofluvial and glaciolacustrine Quaternary deposits in the Seattle 1:100,000 map area for purposes of providing background geologic information for interpreting variations in earthquake induced ground shaking , assessment of liquifaction potential, and guiding location of instrumentation for measuring strong ground motion.

3. Compile and interpret available subsurface stratigraphic and structural data from early Tertiary rocks penetrated by exploratory oil wells in the Puget Lowland for the purpose of documenting mismatches of facies or age across major geophysical (primarily gravity and aeromagnetic) lineations in the Puget Lowland, as a supplement to a previous seismotectonic study (Gower and Yount, in press) that was based mainly on the surface distribution of early Tertiary rocks.

Results

1. Surficial mapping in the central portion of the Seattle 1:100,000 map area confirms the existence of at least two glacial drift complexes lying beneath the extensive blanket of recessional and advance glacial outwash deposits and till of the latest (Vashon) glaciation. One particular well-sorted loose sand unit deposited in proglacial lacustrine and outwash train environments in front of the advancing Vashon glacier is very extensive throughout the middle and eastern thirds of the map area. This unit, termed the Colvos Sand in Kitsap County and the Esperance Sand in King County, has long been recognized as being susceptible to landsliding and liquifaction problems, especially where it is water saturated near its lower contact with underlying impermeable glaciolacustrine clays.

2. Compilation of measures of the thickness of the Quaternary section throughout the Seattle 1:100,000 map area, derived mainly from geotechnical borings, water well logs, oil well logs, and multichannel seismic reflection profiles, demonstrates that the major structural basins in the Seattle area are also the sites of the thickest Quaternary sections. Further, the Quaternary section appears to thin over a prominent structural arch (Feature H, Gower and Yount, in press), suggesting that tectonic processes at basin margins and along these structural features have been active throughout the Quaternary.

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Regional Syntheses of Earthquake Hazards in Southern California

9940-03012

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Investigations

1. Studies focused on analysis of the geologic and geophysical character of late Quaternary faults of the Los Angeles region as determined from published and unpublished sources and from limited field investigations. We concentrated on obtaining: (a) quantitative data on offsets of deposits younger than about 500,000 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. More than 100 faults with evidence of late Quaternary activity were identified. Data files were compiled for each fault summarizing information on its geometry, age of latest displacement, style and amount of offset during late Quaternary time, seismicity, and evidence for geologic constraints on recurrence. Compilation began of a regional map that will delineate, at 1:250,000 scale, fault strands with historical, Holocene, or late Quaternary surface offset. The assembled data base currently is being used to prepare a summary report on the fault hazards of the Los Angeles region.

Although quantitative measurements of late Quaternary offset currently are available for about half of these faults, less than a quarter of the faults displace deposits that are sufficiently well dated to provide reliable estimates of slip or separation. At present, well-constrained estimates of slip exist only for the San Andreas fault (20-30 mm/yr), the Clark strand of the San Jacinto fault zone (8-12 mm/yr), and the Cleghorn fault (2 mm/yr). Rates of vertical separation determined for some of the major late Quaternary faults of the Transverse Ranges suggest that most of these faults are characterized by rates of about 1 mm/yr or less, except for the Sierra Madre and Cucamonga faults which appear to have rates of separation of about 1 to 3 mm/yr. Estimated rates of vertical separation derived for faults of the Newport-Inglewood Zone, which is considered to be a dominantly strike-slip system, range as high as 0.6 mm/yr and imply that the actual slip rate for the zone is considerably higher.

2. Contributors to the proposed professional paper presented their preliminary conclusions regarding characterization of the fault, ground shaking, and ground failure hazards for the Los Angeles region. These ideas and data were assembled in a brief paper for the Third International Earthquake Microzonation Conference in June 1982.

Reports

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Pennsylvania Seismic Monitoring Network
(Northeastern United States Seismic Network)

14-08-0001-19248

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Investigations

1. to operate a regional seismic network centered in Pennsylvania capable of monitoring local seismic activity and that in surrounding areas,

2. to collect base-line data on the spatial and temporal distribution of seismic events,

3. to identify and distinguish local earthquakes from quarry blasts,

4. to calibrate the region with regard to travel-time and amplitude anomalies and establish regional travel-time curves,

5. to interpret seismicity patterns and focal mechanisms for Pennsylvania and surrounding areas in terms of regional controlling structures and tectonic stresses,

6. to work co-operatively with operators of adjacent networks in the Northeast to establish overall patterns of seismicity.

Results

Baseline data on the spatial and temporal distribution of seismic events is obtained from a 13 station fixed network of short-period vertical 1-Hz seismometers deployed in Pennsylvania and surrounding areas as shown in Figure 1 and Table 1. Portable instruments are used to provide additional data for selected regional areas of interest. In addition, digital data from the upgraded DWWSSN station SCP are being used to analyze spectral characteristics of crustal phases from regional quarry explosions and earthquakes. During the past year several large quarry explosions were timed and used to calibrate crustal phase travel-times for sources in the south-central portion of the network.

From combined use of seismic observations and other observational evidence such as gravity and magnetic field interpretations, geologic mapping, and remote sensing (e.g. LANDSAT) we have found that old continental areas, including in particular the northeastern U.S., appear to be characterized by major crustal blocks with dimensions typically on the order of 100 km on a side. Further, it can be demonstrated that in Pennsylvania the crustal fractures associated with these blocks have been in existence since late Precambrian or early for the zone is considerably higher.

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Paleozoic time and that before Ordovician time significant NW trending lateral offsets (60-100 km) took place between adjacent blocks in this region. Block boundaries remain today as zones of weakness in the crust in this region. Variations in crustal structure among these blocks can be significant, particularly in the relative thickness of the 'granitic' layer and the intermediate layer. Superimposed on this structural fabric may be a major decollement thrust sheet that is ubiquitous along the entire East Coast and which may play a significant role in shallow earthquake activity. While there is some indication that these major blocks and their boundaries are spatially correlated with observed seismicity patterns in the Northeast, definitive tectonic interpretations suffer from lack of information on the details of lateral variations in crustal structure and especially the uncertain depth of focus of earthquakes.

A small regional earthquake having an average Lg body-wave magnitude (m_{bLg}) of 2.6 occurred on February 3, 1982 (origin time: 04:28:16.3 U.T.) near Jennerstown, Pennsylvania (epicentral coordinates: 40.21°N x 79.05°W), roughly 24 km north of Somerset, Pennsylvania. The event was observed and recorded at all azimuths and epicentral distances less than 4° by seismic network stations in Pennsylvania, Virginia, West Virginia, and Ohio. The maximum modified Mercalli intensity for this earthquake is IV. An isoseismal map of the region, based on numerous, reliable felt reports and ground reconnaissance, displays a NE-SW elliptical felt area approximately 16 km^2 in extent. The epicenter location is situated in the central portion of the felt area. Because of a rapid intensity fall-off with distance and felt and sound reports at the epicenter, the source depth is inferred to be very shallow (less than 2 km). This earthquake is significant for Pennsylvania seismicity because it occurred in a previously aseismic portion of SW Pennsylvania, but close to the NW-trending Pittsburgh-Washington lineament, a major structural (block) boundary. The earthquake could be related to this zone of crustal weakness. Within the source region itself, there are small local faults, type of fault slip unknown, trending NW-SE. No recent fault movement has been observed on these faults. There is active coal mining to a depth of approximately 300 m in the immediate source area, possibly suggesting a relationship between tectonic stress release and instability induced from mining activities.

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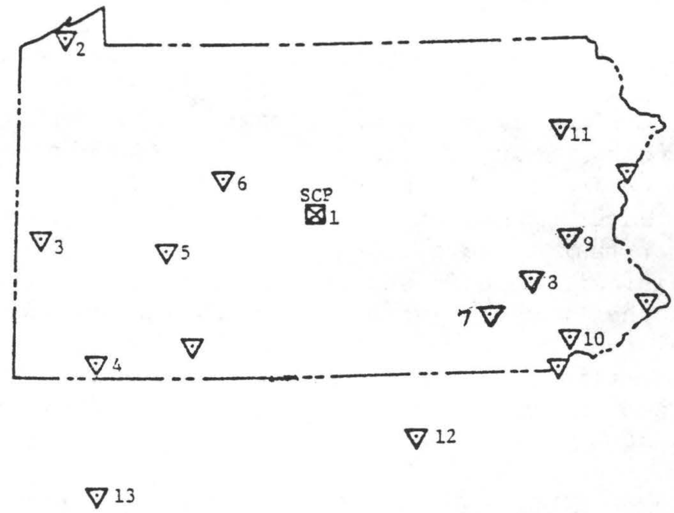

Figure 1. Map showing locations of the Pennsylvania Seismic Monitoring Network. Data from each numbered station is transmitted via telephone line to a central recording site at Penn State's main campus at State College, Pennsylvania (boxed X in the center). Unnumbered stations are candidates for possible future installations. See Table 1 for co-ordinates.

TABLE 1

Pennsylvania Seismic Monitoring Network Stations

Sta	Campus Site	Station Location: Lat (deg N)	Long (deg W)	Elev (m)	Local Faculty Contact
3	Beaver, PSU	40.70	80.33	305	Prof. John Ciciarelli
2	Behrend, PSU	42.13	79.98	229	Prof. Eva Tucker
6	DuBois, PSU	41.13	78.75	427	Prof. John Vargas
4	Fayette, PSU	39.93	79.67	335	Prof. Peter Ostrander
5	*Indiana State College	40.62	79.06	396	Prof. Fred Park
8	*Kutztown State College	40.52	75.78	152	Prof. Madin Varma
9	Lehigh University	40.60	75.37	116	Prof. Ken Kodama
7	Millersville State College	39.98	76.37	104	Prof. Chas. Scharnberger
11	*Scranton, PSU	41.45	75.62	287	---
1	*University Park PSU	40.80	77.87	352	Prof. Shelton Alexander
10	West Chester State College	39.95	75.58	128	Prof. Allen Johnson
	Other Sites				Local Contact
13	Greenbank, W. Va.	32.43	79.85	866	Dr. Richard Allenby
12	* Ellicott City, Md.	39.26	76.88	153	Dr. Richard Allenby

* 3-component station

TRENCHING THE ROSE CANYON FAULT ZONE, SAN DIEGO, CALIFORNIA

U.S. Geological Survey Contract No. 14-08-0001-19824

by

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A trench was excavated, logged, and the geology interpreted across the mapped projection of the Rose Canyon Fault zone in the La Jolla area of the City of San Diego, California. The trench was extended for approximately 70 meters across the mapped projection of the Rose Canyon Fault. Inspection and analysis of the trench exposures indicated that the fault is located within a zone 3 meters wide that separates the Cretaceous Point Loma and Eocene Ardath Shale.

The main shear of the fault is approximately 23 cm wide, strikes N 18° W and dips 70° southwest. A second shear, about 5 to 12 cm in width and striking about N 20° W and dipping 60 to 80° northeast, is located 1.8 meters north of the main shear. The rake of striations along the 3-meter-wide fault zone dips at angles greater than 80°, suggesting a mainly vertical component of displacement.

The main shear is overlain by an unfaulted Middle to Late Pleistocene deposit estimated to be approximately 75,000 to 128,000 years old. The secondary shear has an apparent vertical stratigraphic separation of 2.5 to 3 meters in the Middle to Late Pleistocene deposits; a residual soil and colluvial deposit dated as approximately 1,140±75 years old showed geologic evidence for no displacement. Careful logging of the geologic features indicates that the strike and dip of the secondary shear in the Middle to Late Pleistocene deposits coincide with the strike and dip of the bedding of the Ardath Shale which underlies the Middle to Late Pleistocene deposits. Such an association does not discount tectonic faulting but suggests alternate hypotheses for their development such as displacement due to adjustment along bedding planes within the Ardath Shale, consolidation of the younger sediments, or a combination of the two.

Based upon our examinations and those of others of fault exposures along the Rose Canyon Fault, we concluded that the Rose Canyon Fault along the northern side of Mount Soledad is mainly an en-echelon series of oblique reverse faults.

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.

2. Examination of some characteristics of the New Brunswick earthquake of January 9, 1982 was undertaken.

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.

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

4. 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.

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 no 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.

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Central and Eastern U.S. Tectonics

9730-03399
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Investigations

1. M. F. Kane is analyzing the gravity anomalies of the eastern United States in terms of mantle and crustal structure. He is developing a structural model that incorporates post-basin compressional deformation with the McKenzie stretching model for sedimentary basins. Support studies are being made on the effect of filtering of anomalies computed for ideal sources.

2. T. G. Hildenbrand is continuing the study of basement features of the midcontinent region using both gravity and magnetic data. He is also examining the correlation of gravity and terrain features for the conterminous United States.

3. R. W. Simpson, Jr. is analyzing the gravity and geologic data in terms of the crustal structure along the seismicity trend that extends from the Gulf of St. Lawrence to the Mississsippi embayment.

4. Hildenbrand, Simpson and Kane together with R. H. Godson are collaborating in the production and interpretation of a series of gravity and terrain maps for the conterminous United States.

Results

1. Kane has developed an extension of the McKenzie sedimentary-basin stretching model which incorporates a concept of compressional deformation that follows the rifting and sedimentary basin phase. The idea originates from a conclusion in a recent paper on the evolution of the Mississippi embayment (Kane and others, 1981) that the central part of the underlying rift graben is a principal zone of weakness. This conclusion is coupled with the observation that many of the earth's sedimentary basins exhibit positive central structural features (the west Texas and North Sea basins, for example) as well as central linear gravity and/or magnetic anomalies. The nature of the uplift commonly appears to be reverse, that is, the faults which bound the uplifted central feature appear to dip inward beneath it. Alternatively the uplift may be an asymmetric one in which failure takes place principally along one edge of the central feature so that the central feature and one flanking basin are raised up and shifted laterally over the other flanking basin.

The structural model of the previous paragraph is the basis of suggesting that the linear gravity highs of the Peidmont region of the southern Appalchians and those of the Green Mountain-Sutton Mountain-Long Mountain axis of the northern Appalachians are expressions of exhumed rift systems that once underlay continental shelves. In this context the Green-Sutton-Long system of anomalies would represent the shelf region of the early Paleozoic North American continent north of New York whereas the Peidmont system would represent that of a continent that approached from the east and collided with North America in middle Paleozoic time. This construct fits well with earlier interpretation of the continental shelf rift system that underlies the Appalachian basin (forming the early Paleozoic North American shelf south of New York) and of the suture that extends from Alabama to eastern Maine.

Filtering of calculated anomalies for ideal sources show that the residual (short wavelength) field is not greatly distorted if the wavelengths of the removed field are at least twice those of the residual field. Examination of the 250 km residual and regional U.S. gravity maps shows that the wavelengths of the high-amplitude anomalies of the regional field are at least twice those of the residual field. This indicates that there is a natural separation in the dominant wavelengths of the Bouguer gravity field and would explain the apparent coherency of the gravity patterns of the residual map and the very different appearance of the complementary 250 km residual and regional maps.

2. Hildenbrand is examining correlations between gravity and terrane features at different wavelengths. There are some promising associations of the distribution of seismicity with certain aspects of the correlations, but no clear relation has emerged as yet. Detailed truck-mounted magnetometer profiles have been used to refine estimates of the location of the southeast edge of the Mississippi Valley graben. Amplitude spectra of the gravity fields are being calculated and analyzed. Preliminary results indicate that there may be a window in the spectra centered near 200 km.

3. Simpson is developing a model of the interior continental seismicity in which the series of seismicity centers extending from the Gulf of St. Lawrence to the Mississippi embayment are linked by a system of rift elements. A common property of the three centers of largest seismic activity, Malbaie Bay, Massena-Cornwall, and New Madrid, is that all show a linear band of seismicity in lowlands flanking topographic-structural highs--Laurentian Highlands, Adirondacks and St. Francis mountains respectively. The centers of seismicity may indicate mega-asperities which are linked by a seismic movement along conveniently aligned intermediate rift structures. The topographic highlands may be areas of crustal thickening caused by thrusting.

4. More than ten presentations of the wavelength-filtered gravity maps have been made since the beginning of the year to a wide variety of audiences. There is a general consensus that the maps offer a new synoptic view of the general structure of the crust and mantle of the central part of the North American continent as well as insights into structures in many specific areas. Among the latter are expressions of magmatic arcs and other features related to the plate subducted beneath the western United States, evidence of plate-margin rifts and a subduction zone in the eastern United States, sharply delineated zones exhibiting characteristic trends and distinctive anomalies in the central United States, and evidence of both mantle and crustal structure that supports the McKenzie stretching model as an explanation for thick deposits of sedimentary strata. We are expediting dissemination of these maps by release of slides, Open-File reports, and Geophysical Investigation maps in response to many requests for the data.

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Quaternary Stratigraphy and Bedrock Structural Framework of Giles County, Virginia

9510-02463

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Investigations

1. Studies of surficial deposits by Hugh Mills have been essentially completed; reports on these deposits have been prepared and are under review.

2. Bedrock has been mapped and studied in selected areas in and adjacent to Giles County, and a bedrock map, which will encompass the area affected by the current seismic activity, is being compiled for publication at a scale of 1:125,000. The Giles map will be based on the new mapping in combination with previous published and unpublished maps.

Results

1. New River terraces were studied by means of mapping, topographic analysis, and weathering profiles. No effects clearly attributable to neotectonic activity have been found. The terraces are unpaired, however, and a statistical analysis of their elevations shows that they are more abundant at certain elevations. Weathering studies suggest that terrace concentrations are related to relative stream stability during Pleistocene interglacial stages.

2. Analysis of boulder streams in the Mountain Lake area of Giles County has resulted in classification of these deposits into three types, based on fabric and other properties, which are related to mechanisms of origin. Two types are associated with frost heave and catastrophic flooding; deposits of the third type are probably produced by gravity transport. These are probably produced in part by seismic shaking. This may be confirmed by comparison of distribution and density with nearby seismically quiet areas.

3. Bedrock mapping and compilation of existing maps and other data show no direct effects of current seismicity. However, certain topographic features in and near Giles County are parallel to and near a vertical projection of the deep-seated Giles County seismogenic zone; these features, currently under study, may be related to neotectonic activity; they may represent structures of Central Appalachian trend overridden by structures of southern trend. Minor structures (larger than outcrop-scale) are more common than shown previously.

Reports

Wagner, J. R., and Mills, H. H., 1982, Mineral analysis of New River Terrace deposits between Radford and Pearisburg, Virginia (abstract): Geological Society of America, Abstracts with Programs, v. 14, no. 1&2, p. 93.

Northeastern U.S. Seismicity and Tectonics

9510-02388

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Investigations

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

2. Evaluation of exposures of faulted glacial pavement in southeastern New York as evidence for neotectonic activity.

3. Trenching of glacial Lake Passaic deposits on Ramapo fault with Byron Stone.

4. Development of a Seismo-tectonic model for Ramapo seismic zone and the Lower Hudson River Valley that is testable by seismic reflection profiling.

5. Core drilling in the northern Newark Basin.

Results

1. Ratcliffe has extended the mapping of Triassic-like brittle faults in the central Hudson River Valley area, northward to near Copake, New York. These zones of faults are spatially associated with exposures of faulted glacially polished surfaces (see below).

2. Exposures of faulted glacially polished pavement (20,000-16,000 years old) are spatially associated with zones of brittle faulting such as the Chatham fault and other block faults bounding outliers or horsts of Proterozoic Y basement gneiss in the aseismic area of Dutchess and Columbia County. Seven new and three previously identified (Oliver and others, 1970) exposures of faulted glacial pavement have been studied. In all instances the dominant faulting is southeast side-up reverse faulting with multiple faults, each with 0.5 to 0.4 cm vertical net slip indicated. The close spatial association of faulted glacial surfaces with zones of brittle faulting could suggest reactivation of these faults in the past 20,000 years. Analysis of exposures of these faults shows that they contain open brittle fractures, suitable for producing the observed offsets by expansion of ice and frost wedging. This is the preferred interpretation for these features. The spatial association of the faulted glacial pavement with zones of brittle faulting is therefore attributable to the presence of fractures suitable for frost wedging rather than localized neotectonic reactivation of old faults.

3. A trench dug in Pleistocene deltaic deposits near the ancient shoreline of glacial Lake Passaic (10,000-12,000 years old) revealed numerous faults along the up dip projection of the Ramapo fault as determined from core drilling in bedrock. Numerous southeast dipping vertical and northwest dipping high angle faults show predominant reverse movement with throws up to 2 cm. Analysis of the faults by Byron Stone and N. Ratcliffe indicate that the numerous faults terminate downward against bedding and are thus intrastratal. We conclude that the faults observed are compaction, syndepositional faults rather than tectonic in origin.

4. A seismo-tectonic model for the Ramapo seismic zone and Lower Hudson River Valley area suggests that current seismicity here is controlled by the structure of Proterozoic Y basement gneiss. Where this basement forms shallow level thrust sheets or is deeply buried no seismicity occurs, where highly faulted basement rocks are exposed near the surface recurrent earthquakes do occur. Plans for reflection profile traversing the seismic and aseismic areas in southeastern New York to test this hypothesis are being developed.

5. Core drilling in the northern part of the Newark Basin of New York has shown that basalt and diabase of the Palisades Sill is continuous in the subsurface with the Ladentown lava flows near the west margin of the Newark Basin. These results confirm that no major faults can exist within the Newark Basin and that Palisades Sill erupted as a fissure flow in Lower Jurassic time.

Reports

Ratcliffe, N. M., Armstrong, R. L., Mose, D. G., Seneschal, Ronald, Williams, Neil, and Baiamonte, Matthew, 1982, Emplacement history and tectonic significance of the Cortlandt complex, related plutons and dike swarms in the Taconide zone of southeastern New York based on K-Ar and Rb-Sr investigations: American Journal of Science, v. 282, p. 358-390.

Ratcliffe, N. M., 1982, Results of core drilling of the Ramapo fault at Sky Meadow Road, Rockland County, N.Y., and assessment of evidence for reactivation to product current seismicity, U.S. Geological Survey Miscellaneous Investigations Map, MI-1401.

Ratcliffe, N. M., 1982, Tectonic vs. non-tectonic origin of faulted glacially polished surfaces in the Lower Hudson River Valley area, N.Y., [abs.], Geological Society of America Abstracts with Programs, v. 14, nos. 1 and 2, p. 76.

Mississippi Valley Seismotectonics

9950-01504

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Investigations

1. Processing and interpretation of seismic reflection data recorded by the R/V Neecho on the Mississippi River was continued. To date, 72 km of line have been processed, representing about one-half of the total profile.

2. Detailed analysis of Vibroseis® reflection profiles to identify and characterize pre-Quaternary faults was continued. Small-scale magnetic anomalies and zones of abundant bedrock fractures were also investigated to determine their relationship to the faulting.

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

4. Work continued on radiometric age-dating of igneous rock cuttings from wells in the Mississippi Embayment. This study is a cooperative effort with J. Obradovich of the Branch of Isotope Geology and is being done to determine the igneous history of the embayment area.

5. An investigation was begun to determine the relationship, if any, of major northwest-trending gravity anomalies (lows) to the occurrence and distribution of seismicity and geologic structures.

Results

1. Interpretation of part of the Mississippi River boat reflection profiles has resulted in the identification of a number of previously undetected normal and reverse faults. The faults displace sediments of Paleozoic, late Mesozoic, and Cenozoic age. The largest measured vertical displacement is about 60 m and occurs on a northeast-striking fault that closely parallels a straight reach of the Mississippi River northeast of Osceola, Arkansas. Detailed analysis of the reflection data indicates that the contact between the Tertiary sediments and Quaternary river alluvium is clearly seen on the profile at about 0.06 sec (two-way travel time). Thus, for the first time, using a geophysical technique, a large area of the Mississippi Embayment can be readily examined for the presence of Quaternary faults.

2. A detailed analysis of Vibroseis® reflection profiles from the Mississippi Embayment shows that there is a strong correlation between zones where the reflector from the Paleozoic bedrock surface is poorly defined or absent and areas of abundant microearthquakes. It is hypothesized that abundant fracturing and, perhaps, faulting over many millions of years has so shattered and disrupted the Paleozoic bedrock surface in these areas that the Vibroseis®

seismic energy is scattered, resulting in poor phase coherence and poorly developed reflections. Modern earthquakes are occurring on reactivated faults in these areas of intense structural disruption.

3. A preliminary investigation of published geologic data suggests that there are strong geologic relationships in Arkansas, Missouri, and Tennessee between northwest-trending linear gravity lows (as expressed on a high-pass filtered 125 km wavelength residual map) and faults, fractures, uplifts, lithologic variations, and geomorphic features. One of the gravity lows is 50 km wide and extends from southeastern Missouri to southeastern Iowa where it intersects the Central North America Rift System at the location of a possible ancient transform fault. The bulk of the evidence suggests that this gravity low is a long-standing zone of upper crustal weakness that has had a profound influence on the tectonic evolution of the rocks within it. Where it intersects the Mississippi Embayment, the low coincides with a major shift in the trend of microearthquakes, being subparallel to the gravity low within the anomaly, and parallel to the rift axis outside of the anomaly. This zone of intersection is also the location of the Lake County uplift. Perhaps one reason for the localization of significant earthquake activity in the New Madrid area is that this region is the site where two major zones of upper crustal weakness cross--the Reelfoot rift and the northwest-trending gravity low.

Reports

Crone, A. J., Russ, D. P., and Barnhard, T. P., 1982, Map of exploratory trench across the Cottonwood Grove fault, Lake County, northwestern Tennessee: U.S. Geological Survey Open-file Report 82-399, 10 p, 1 pl.

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Trenching Studies of the San Andreas Fault Bordering Western Antelope Valley, Southern California

14-08-001-18200

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Investigations

Backhoe trenches were dug across the main zone of active faulting and within landslide deposits offset along the fault. The objectives were to obtain radiometric dates for prehistoric earthquakes, and for determining the average late Holocene slip rate and recurrence interval for the central part of the "Big Bend" of the San Andreas.

Results

Very high late Holocene slip rates of about 4.5 to 5cm/yr are indicated, together with evidence that the Big Bend reach of the fault is characterized by earthquakes recurring about every 140 to 170 years on average that are very similar in extent and magnitude to the great earthquake of 1857.

The results in more detail are as follows: Total fault offset of a large landslide across the San Andreas was determined from a steep and relatively straight gully leading down the landslide axis. The gully intersects the fault almost at right angles and has been offset 44 ± 3m. This value is supported by an offset of 46.5 ± 3m on another similar gully which meets the fault at a more oblique angle. The age of the landslide was obtained by a ^{14}C date on tiny fragments of charcoal found dispersed throughout the deposit. These were collected from the lower part of a backhoe trench dug in the prominent toe of the landslide and provided an age of 1065 ± 60BP(UW-631). Charcoal collected in the same way from a second trench dug in another part of the landslide toe gave an age of 895 ± 55BP(UW-632); however, while contributing to confidence in the age of the landslide, because some parts of this trench were disturbed by rodent burrowing this date is considered somewhat less reliable than the 1065 ± 60BP date from the first trench.

Using the 1065 ± 60BP date,(after dendrochronological correction, Stuiver, 1982), and the 44m offset value, gives an average slip rate for the past 1000 years of about 5cm/yr. This figure is a best estimate value. Because of the statistical uncertainty in the ^{14}C date and the measurement uncertainty in the gully offset, this slip rate could be at least 1cm/yr too high or too low.

This is the highest late Holocene slip rate recognized on the San Andreas (Sieh, pers. comm. 1982) but it is consistent with other results from this study and earlier fieldwork:

a) Measurements of the margins and crest of another large landslide toe offset along the fault give a figure of about 120 ± 10m total displacement. A minimum age for this landslide was obtained from the base of a succession of ponded sediments filling a single well defined closed depression at the toe of the landslide. The depression, which had been formed by offset along the main trace of the fault, was trenched and two separate samples of charcoal fragments were collected from a silty clay bed at its base. These samples produced ^{14}C dates of 2370±120BP(USGS-667) and 2010±80BP (UCLA-2080A).

In order to use these figures to calculate a suggested slip rate it is assumed that the closed depression was initiated by the first faulting event following the landslide and that the ponded sediments began to fill the depression soon afterwards. With these assumptions the offset produced by at least one faulting event, needed to initiate the depression, must be subtracted from the total displacement. A typical faulting event appears to be 7m or so (see under b) below), giving a total "post depression" displacement of about 113±10m. Using the oldest of the two ^{14}C dates, 2370±120BP corrected dendrochronologically (Ralph and others, 1973), gives a best estimate maximum average slip rate for the past 2500 years of about 4.8cm/yr. Once again, the statistical and measurement uncertainties mean that this figure should be expressed as 4.8±1cm/yr.

b) A compilation of measurements made on offset and deflected stream channels in a detailed study of about 30kms of the fault in this area, strongly indicate that displacement in at least the past three earthquakes has been rather uniform at about 7-7.5m per event. At a proposed slip rate of 4.5-5cm/yr the recurrence interval of large faulting events is therefore about 140-170 years.

c) Radiometric dates from a trench straddling the zone of active faulting indicate that the pre 1857 faulting event was similar in extent of rupture to that of 1857 and occurred within the general range of the proposed recurrence interval.

The dates were obtained from charcoal fragments found within cross sectional exposures of a conspicuous "collapse fissure" (Clark, 1972) developed at the fault trace which broke in the pre 1857 earthquake. Two samples were collected for dating. One from a concentration of charcoal at the bottom of the fissure gave an age of 220±40BP(UW-622), and another from higher in the fissure filling on the opposite wall of the trench gave an age of 210±60BP(UW-623). ^{13}C values were determined for both samples and fractionation corrections made. In light of the following considerations these dates are believed to represent a good estimate of the actual time of the earthquake:

(1) The collapse fissure was most probably formed fairly soon after the earthquake occurred. With storm runoff entering the still-open fault fracture, undermining the walls which then collapse to create a fissure as described by Clark (1972).
(2) The concentration of charcoal fragments at the bottom of the fissure indicates that they wereincorporated very soon after the fissure was formed.
(3) The fissure was filled with a uniform silty sand suggesting relatively rapid filling.
(4) The closeness in age of the two separate charcoal samples provides a good measure of confidence in the date.
(5) The charcoal fragments themselves were extraordinarily abundant,

unusually large and often rather angular and delicate in shape. An interpretation of these characteristics leads to the view that the charcoal was formed only a short time before incorporation in the fissure and had not been present during earlier runoff episodes which would have transported the bulk of it out of the area.

(6) The frequency of prehistoric forest fires in this area (R.J.Vogl, Dept. Biology, California State University Los Angeles, written comm. 1981) and the exponentially diminishing quantity of older inner heartwood compared to younger outer sapwood, lead to the conclusion that on average a single charcoal fragment will have a relatively neglible "initial" ^{14}C age produced by "contamination" from very old heartwood. Actually it seems reasonable to fully discount this "too old" influence against the "too young" influence resulting from the delay in creating the fissure and incorporating the charcoal following the fault rupture itself.

Before applying the dendrochronological correction to all the ^{14}C dates in this report the plus or minus figures of one standard deviation (1σ)were doubled to 2σ in order to significantly reduce the uncertainty in the date produced by counting statistics at the laboratory. Thus the date from the bottom of the fissure becomes 220±80BP before referring it to the tree ring calibration curve of Stuiver (1982). This high precision curve indicates a corrected date of 1660±30AD(±2σ). However, because of a marked increase in atmospheric ^{14}C levels in the early eighteenth century the corrected date could also be $1765\pm^{4}_{45}$AD(±2σ); a post 1769 date being excluded on historical grounds. For convenience the alternative date will be expressed as 1745±25AD.

These dates for the pre 1857 faulting event correlate quite well with those obtained by Kerry Sieh at the south end of the Big Bend and by Thom Davis at the north end, and clearly show that this event broke through the entire Big Bend of the fault in a similar fashion to the fault rupture of 1857.

When all the forgoing results are combined a picture is presented of high late Holocene slip rates in the central Big Bend of about 4.5-5cm/yr, with recurrence of fairly uniform "1857 type" faulting events producing offsets of some 7-7.5m about every 140-170 years.

These conclusions appear to be substantiated by correlating the information from this study with the faulting record determined at Pallett Creek (Sieh, written comm. 1981) as indicated by the table on the following page.

Correlation of this study with the faulting record at Pallett Creek

PALLETT CREEK FAULTING EVENTS (DATES AD$\pm 2\sigma$)	SUGGESTED CORRELATIONS WITH THIS STUDY (DATES AD$\pm 2\sigma$)	SUGGESTED CUMULATIVE OFFSET OF LANDSLIDE AT 7-7.5m/FAULTING EVENT
935±86	965±185 (Age of landslide now offset 44±3m, most probably triggered by faulting event)	0
1013±90	-	7-7.5
1080±65	-	14-15
1350±50	-	21-22.5
1550±70	-	28-30
1720±50	1660±30 or 1745±25	35-37.5
1857*	1857	42-45m

* Average recurrence interval of last 7 faulting events at Pallett Creek = 155 years. Average recurrence interval determined in this study = 140-170 years.

Reports

Rust, D. J., 1982, Radiocarbon dates for the most recent large prehistoric earthquake and for late Holocene slip rates: San Andreas fault in part of the Transverse Ranges north of Los Angeles: Geol. Soc. of America Abstracts with Programs, v. 14, no. 4, p. 229.

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Ralph, E. K., Michael, H.N., and Han, M. C., 1973, Radiocarbon dates and reality: Applied Science Center for Archaeology, Newsletter, v.9, no. 1, p. 1-20.

Stuiver, M., 1982,A high-precision calibration of the AD radiocarbon time scale: Radiocarbon, v. 24, no. 1, p. 1-26.

Glacial Lake Passaic

9510-02724

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Investigations

The project continued in FY'82 to include detailed mapping of the late-Wisconsinan terminal moraine in glacial Lake Passaic and reconnaissance mapping north of the terminal moraine. Cores of lacustrine sediments south of the deltas within the moraine and a core of sediments within the moraine were analysed and correlated to a proximal distal transect. Drill holes were cased and geophysical logs were obtained. Shallow seismic profiling across the Great Swamp basin was completed.

Results

1. Mapping near the Late Wisconsinan terminal moraine in the Chatham 7.5' quadrangle delimited glacial till, glaciolacustrine sediments of glacial Lake Passaic, and soils and colluvial deposits that underlie and overlie the Late Wisconsinan glacial sediments.

2. A core obtained from the moraine at Niles Park, Madison, NJ, showed sequence at the ice-margin. Cores along a transect parallel and proximal to the moraine allowed for correlation of stratigraphic units. Correlation was aided by geophysical logging by Dick Walker (WRD, USGS, Trenton, N.J.). The ice-margin position was pinpointed including the southwestern limit of subsurface till.

3. Post-glacial crustal rebound has tilted to the lake basin up to the north-northeast. The slope of the lake water plane is about 0.65 m/km, based on the altitude of a delta topset/foreset contact at Pequannock, the altitude of the Moggy Hollow spillway, and an assumed topset/foreset contact altitude of 355' at Summit.

4. Soils shows vertical trends similar to dated, older soils south of the glacial border, chiefly, increase of 2:1-layer vermiculite near the surface. The clay-size fraction of varves, by contrast, exhibit a mineralogically immature suite of illite, feldspar, and quartz.

FY'82 target activities planned for the Summer of 1982 include:

1. Detailed mapping of surficial geology in Bernardsville, Morristown and Pompton Plains quadrangles.

2. Synthesis of subsurface data, including detailed cross sections of subsurface units using geophysical logs and seismic reflectors for correlation.

3. Palynology and paleomagnetic studies of cores from north of the terminal moraine will continue.

4. Peat samples from bogs that overlie the lacustrine silt-clay facies both southwest and northeast of the moraine will be submitted for ^{14}C dating.

5. Clay mineralogy and soil geochemistry of pre- and post-late Wisconsinan soils will be studied.

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

14-08-0001-19842

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Investigations

1. Eleven additional radiocarbon age-dates have been obtained for samples collected from trenches across the Wasatch fault at the North Creek site using accelerator mass spectrometry techniques. Sample analysis was conducted by Dr. A. B. Tucker (San Jose State University) using an existing MP Tandem Van de Graaff accelerator at Chalk River Nuclear Laboratories, Ontario, Canada.

2. Detailed geologic studies including mapping of the late Quaternary deposits, topographic profiling of displaced geomorphic surfaces, and excavation of test pits, have been conducted along the East Cache fault.

Results

1. Radiocarbon age-dates obtained for the suite of North Creek samples using the accelerator mass spectrometry technique are in general agreement with age-dates measured using conventional beta counting techniques and with ages estimated based on the relative stratigraphic positions of the samples (Table 1). These age-dates, some of which were obtained for samples too small to be dated by conventional methods, support previous estimates for recency and intervals of time between individual surface faulting earthquakes at this site (Hanson and others, 1981; Swan and others, 1981).

2. The East Cache fault lies parallel to the Wasatch fault zone. The fault extends in a north-south direction for a distance of about 70 km from the latitude of Brigham City, Utah, to Preston, Idaho, passing immediately east of Logan, Utah. At the golf course on the north side of the river near the mouth of Logan Canyon, there are two west facing scarps that are less than 2 m-high on a post-Provo strath terrace. Minor backtilting occurs on the downthrown side of the eastern scarp. On projection of these scarps to the north, two test pits were excavated across a subtle break in slope near the

base of a scarp immediately below the Bonneville shoreline. The test pits were located between Logan and Green Canyon in an area that has not been affected by landslides. The Bonneville age sediments exposed in both test pits are displaced by numerous small faults. To the south of the Logan River, the fault scarp crosses extensive landslides developed in Bonneville late deposits. The geologic mapping and data from the test pits provide evidence that there has been only one surface faulting event post recession below the Provo shoreline (approximately 12,000 years B.P.).

Reconnaissance along the northern Wasatch fault zone indicates that there is a significant decrease in Holocene fault activity from approximately the latitude of Brigham City north to the northern end of the Wellsville Range (Swan and others, 1981). There are a number of faults subparallel to the Wasatch fault zone north of the latitude of Brigham City, including the Hansel Valley fault, the East Cache fault, and the Bear Valley fault, that have experienced late Pleistocene and/or Holocene faulting. It appears that the Holocene deformation in north-central Utah is distributed across a wide zone that includes all of these faults.

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Hanson, K. L., Schwartz, D. P., and Swan, F. H., III, 1981, Recurrence of surface faulting along the Wasatch fault zone near Nephi, Utah: Geological Survey of America Abstracts with Programs, v. 13, no. 7, p. 469.

Swan, F. H., III, Hanson, K. L., and Schwartz, D. P., 1981, Study of earthquake recurrence intervals on the Wasatch fault zone, Utah, in Summaries of Technical Reports, v. XII, National Earthquake Hazards Reduction Program: U.S. Geological Survey Open-File Report 81-833, p. 106-109.

SAMPLE NO.	LOCATION	SAMPLE DESCRIPTION	AGE-DATE		COMMENTS
			Conventional (^{14}C yr B.P.)	Accelerator (^{14}C yr B.P.)	
	NORTH CREEK SITE				
WC-12-80-2	Trench NC-1	detrital charcoal—From buried organic-rich soil developed on scarp-derived colluvium or alluvium		300±300	Decayed wood and the soil fraction from this deposit yielded conventional radiocarbon dates of modern and 130±95 ^{14}C yr B.P., respectively. All the age-dates obtained for this deposit appear to be too young and probably reflect some contamination by younger material.
WC-12-80-3	Trench NC-1A	soil—Buried organic-rich soil developed on North Creek alluvium	2180±80	4500±300	The age-date obtained by accelerator mass spectrometry for this soil sample is in agreement with the age-date obtained for the underlying parent deposit (sample WC-12-80-11). The younger conventional age-date probably reflects contamination by younger carbonaceous material.
WC-12-80-4	Trench NC-1A	detrital charcoal—From burn layer at the base of an historical mudflow		250±300	The historical age assigned to the mudflow is based on the presence of nails and pieces of metal associated with the burn layer at the base of the unit.
WC-12-80-5	Trench NC-2	detrital charcoal—From sandy silt alluvium	1350±70	1550±300	
WC-12-80-6	Trench NC-3	detrital charcoal—From buried soil developed on faulted alluvium	1110±60	700±250	These age-dates provide a maximum limiting age for the most recent faulting event.
WC-12-80-7 7u	Trench NC-3	soil—Buried organic-rich soil developed on colluvium derived from the fault scarp subsequent to the second most recent surface faulting event	3640±75	1700±300 3850±400	Samples 7 and 7u were obtained from the same bulk soil sample; sample WC-12-80-9, which consists of detrital charcoal, is also from the same soil. The older dates obtained for this unit most likely represent a minimum age for the underlying scarp-derived colluvium on which the soil is developed.
WC-12-80-8	Trench NC-3	detrital charcoal—From buried soil within alluvium		1200±300	The age-date obtained for this sample is consistent with age-dates from stratigraphically older and younger deposits.
WC-12-80-9	Trench NC-3	detrital charcoal—From same deposit as sample WC-12-80-7		1350±250	
WC-12-80-10	Trench NC-3	detrital charcoal—From unfaulted mudflow deposit		0±300	
WC-12-80-11	North Creek Site stream cut	detrital charcoal—From North Creek alluvial fan deposit	4580 (1)	4000±400	

NOTE: (1) Bucknam, 1978

TABLE 1 SUMMARY OF AGE-DATING RESULTS

Structural Framework of Eastern United States Seismic Zones

9950-02653

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Investigations

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. 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. With Bollinger, continued preparation of a manuscript describing seismicity in and near Giles County and making structural interpretations of the seismicity. The manuscript awaits Director's approval in the form of an open-file report of about 200 pages. It will then be returned to TRU to be edited for a Professional Paper. A short summary awaits Director's approval, and will be submitted to Science to direct users to the open-file report. See Results 1 and 3 and Reports 1 and 2.

2. Analysis of stratigraphic data to seek evidence of Devonian tectonism at the Allegheny Front in Maryland, West Virginia, and Virginia. See Result 2 and Report 3.

3. Interpretation of inferred stress orientations on and near the Giles County seismogenic zone (GCSZ). See Result 4.

4. Dropping plans to search large areas of the East systematically for sand blows (see Semi-annual Technical Report for first half of FY81). The work would be worthwhile, but other committments leave no time for it. Fortunately, L. Seeber (Lamont-Doherty Geological Observatory), P. Talwani (University of South Carolina), and others have expressed interest in doing such work.

Results

1. As reported earlier, the structure most likely to be responsible for the GCSZ is a sub-thrust, Iapetan normal fault reactivated in today's compressional stress field. This conclusion allows posing of three questions as guides for future work, and suggestions of ways to answer them.

a. Is there really a fault or fault zone down there? This question could be most conclusively answered with a carefully designed reflection experiment. Less direct but also less expensive approaches could involve modeling of basement structure with maps of various derivatives of digitized gravity, aeromagnetic, and terrain data, and investigating whether rocks exposed above the seismogenic zone are usually high fractured, as recorded by intensities of systematic joints, nonsystematic joints, and lineaments inferred from aerial photographs and Landsat images.

b. Is the GCSZ unique, or are there other reactivated or reactivatable Iapetan normal faults in the East? Analysis of digitized terrain and drainage elevations over large areas might detect unusual vertical motions at or near the seismogenic zone (F. McKeown, oral and written communications, 1981 and 1982). Any such geomorphic signature could then be sought elsewhere. Also, large, cross-trend basement structures may focus seismic release of stress on the Giles County area. Any such structures would probably require geophysical detection and documentation.

c. Where else might Iapetan normal faults occur? The large gravity gradient that runs the length of the Appalachians is widely regarded as the southeastern edge of relatively intact North American cratonic crust that survived Iapetan rifting; to the southeast lie suspect terranes. Reflection profiles across modern passive continental margins may allow construction of a probability distribution, which would allow estimation of the probability of finding an Iapetan normal fault at any specified distance northwest of the half-amplitude of the gravity gradient. Preliminary perusal of some published reflection profiles, of the distribution of Mesozoic fault-bounded basins in the eastern U.S., and of other data allows the speculation that the seismicity around Knoxville, Tennessee, may occur on a similarly reactivated Iapetan normal fault.

2. J. Dennison (University of North Carolina) and coworkers have published 18 measured stratigraphic sections through Devonian strata exposed on the Allegheny Front in Maryland, West Virginia, and Virginia. In West Virginia, several of the intervals between pairs of adjacent measured sections contain statistically significant numbers of terminations of thin mapped units. The same intervals also contain intersections of the Front with large, independently mapped structural lineaments. Thus apparently the Petersburg, Fairmont-Rowlesburg, and perhaps Bartow lineaments were structurally active in middle and late Devonian time. Bathymetry distorted by that activity would have affected dispersal patterns of the clastic sediment that formed most of the Devonian sequence. It is not known whether that tectonism reflected detached or basement deformation. However the three lineaments extend westward into what may be an east-trending arm of the Rome trough that R. Shumaker and A. Donaldson (West Virginia University) infer to have been an active graben in Devonian time. These findings were presented at the joint meeting of the Northeastern and Southeastern sections of the GSA in March, 1982.

3. The relative ages of central and southern Appalachian thrusting have long been uncertain. Various workers have mapped interference structures in the Valley and Ridge province where the central and southern Appalachians interfinger, but results are conflicting. Such conflicts are to be expected, given the known complexities of deformation sequences that can occur in single

fold-and-thrust belts. However compilation and interpretation of published data on Pennsylvanian stratigraphy and coal composition, and of unpublished data on small solution structures mapped by S. Dean (University of Toledo, written and oral communications, 1981) and B. Kulander (Wright State University), allow the conclusion that stresses and molasse attributable to southern Appalachian thrusting reached the vicinity of Giles County and adjacent West Virginia slightly before stresses and molasse from central Appalachian thrusting (respectively, in early and middle Pennsylvanian time). However thrusting in the 2 provinces may also have overlapped in time for much of its history. These findings were presented at a Penrose Conference on orogenic timing in May, 1981.

4. Results concerning inferred stress orientations on and near the GCSZ were presented at the meeting of the Eastern Section of the SSA in October, 1981. The abstract is in press in Earthquake Notes.

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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 emphasis is currently on (a) establishing a better constrained uplift history for the San Bernardino Mountains, and (b) elucidating the nature and modes of deformation acting on the northern range front. Our longer term goals are to (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 Arrastre Canyon. In this Summary Report we will present the results of our detailed mapping between Deep Creek Flood Control Basin and Arrastre Canyon. The area between Silverwood Lake and the Deep Creek Flood Control Basin was discussed in detail in our first Summary Report (Volume XII).

Results

1. The Ord Mountains are underlain by a ~600-meter-thick section of interbedded low-grade marble, schist, phyllite, calc-silicate, and quartzite of probable Paleozoic miogeoclinal affinity (P.M. Sadler, pers. comm., R.L. Coffman, 1980). Pre-Cretaceous(?) syenite and hornblend-diorite bodies intrude these metasediments. A very different, higher-grade section of of coarse-grained quartzite, pelitic granofels, and biotite-sillimanite gneiss (R.E. Powell, pers. comm) is in steep tectonic contact with the lower-grade metasediments in sec 8,9 R3W T3N. Bedrock south and east of the Ord Mountains is dominantly Cretaceous(?) biotite- and hornblende-bearing quartz-monzonite (Miller and Morton, 1980; R.L. Coffman, 1980). A deeply weathered erosion surface, developed on this bedrock complex, is tentatively correlated with the extensive late Tertiary surface developed atop most of the San Bernardino Mountains (Oberlander, 1972).

The volcanogenic eastern facies of the Crowder Formation is not exposed north of the Deep Creek Flood Control Basin. Locally-derived clasts within the eastern facies of the Crowder Formation suggest that the Ord Mountains and Pinnacles existed as positive areas at the time of Crowder deposition. We infer that any Crowder Formation deposited north of the Deep Creek Dam has been buried beneath the Mojave River and "Victorville Fan" sediments.

Extensive exposures of fluvial sands and gravels north of the Deep Creek Dam and east of the Mojave River contain clasts derived from the western San Bernardino and Ord Mountains, but no Pelona Schist. These fluvial sediments were deposited by a major drainage system peripheral to the Victorville Fan, following the late-Pliocene uplift of the western San Bernardino Mountains and are probably correlative with the Shoemaker Gravel or Old Alluvium of the Victorville Fan. The lack of Pelona Schist clasts requires that deposition occurred prior to the excavation of Pelona-bearing units in Summit Valley (⩾500,000 years ago). Soil development is consistent with this age estimate. A prominant linear ridge in the Marianas area of Apple Valley (sec 13, 14,22 R3W T4N) is underlain by river deposits that probably represent a correlative west-flowing tributary drainage fed by streams along the north flank of the San Bernardino Mountains to the east.

Pleistocene and Holocene alluvial fans overlie the fluvial deposits on the west flank of the Ord Mountains. The oldest and highest fans are graded to the level of the Old Alluvium capping the Victorville Fan and are therefore ⩾500,000 years old. Younger alluvial fans, along with correlative terrace deposits containing Pelona Schist, clearly postdate the down-cutting of Summit Valley, making them ⩽500,000 years in age. Moderate soil development tends to support a lesser age; terrace height is consistent with the height of Qtl in Summit Valley (⩽100,000 years old).

2. Uplift of the Ord Mountains occurred along a single zone of NNE-trending, med/high-angle reverse faulting that can be followed from Grass Valley to Arrastre Canyon. In the vicinity of Grass Valley, warping replaces faulting as the dominant mode of range-front deformation. Several right-lateral steps in the NNE-trending system are due to EW-trending, N-block-down high-angle tear faults.

The reverse fault system displaces the oldest alluvial fan surfaces (⩾500,000 years old) up to 70 meters vertically along a prominant scarp on the west flank of the Ord Mountains. Reverse faults just northeast of Deep Creek Dam (sec 7 R3W T3N), in contrast, appear to be overlain by undisturbed old alluvial fan deposits. We therefore conclude that displacement of the older fans represents only the latest period of fault activity and that most of the displacement on the reverse faults probably occurred prior to the deposition of the old fans. This view is supported by the geometry of segmented older alluvial fans and their steep talus-mantled contact with bedrock which both suggest a linearly receding mountain front. Moreover, the mid-Pleistocene fluvial deposits are truncated and sharply folded, and the flat geomorphic surface and deep soil profile capping them is deformed.

There has been no significant lateral component of motion on the Ord Mountain frontal faults; clasts within the alluvial fan deposits can all be traced to the drainage basin immediately upstream.

We found no evidence for more than one episode of neotectonic deformation in the Ord Mountains block in marked contrast to the Silverwood Lake area.

3. There is no compelling evidence for Holocene activity on the north frontal fault system between the Deep Creek Flood Control Basin and Arrastre Canyon. The prominant scarps along the west flank of the Ord Mountains are underlain by carbonate-cemented, monolithologic marble fanglomerates which are highly resistant to erosion. The cones of active alluvial fans along the scarp are not cut by range-front faults. These small fans are probably Holocene based on lack of soil development, size and preservation of delicate surface features. An older, moderately weathered surface that is graded to the Qtl Mojave River terrace level (⩽100,000 years old) also appears to be undisturbed at the fault line (sec 5, R3W T3N). We conclude that scarps developed in the unusually resistant marble-clast fanglomerates of the Ord Mountains may be latest-Pleistocene or older.

Frontal faulting in the Ord Mountains may have begun in the early Pleistocene; vertical displacement was largely complete by the time of deposition of the old alluvial fans (≥500,000 years ago). Although there is no evidence to constrain the onset of frontal faulting in the Ord Mountain block, it probably accompanied the change to strike-slip faulting in the Silverwood Lake area.

Maximum cumulative vertical displacement on the Ord Mountain frontal fault zone since the mid-Pleistocene cannot be greater than 400 m, as this is the difference in elevation between the high flat spur crests and the mid-Pleistocene fluvial deposits which contain clasts from, and were confined by, the Ord Mountains. Cumulative displacement since mid-Pleistocene cannot be less the 70 m, since this is the maximum height of scarps in the old alluvial fan deposits. Since both the fluvial deposits and the older alluvial fans are conservatively estimated to be at least 500,000 years old, we calculate a maximum uplift rate of ~0.8 mm/yr (400 m/500,000 years). Since the older alluvial fan deposits were graded to the Victorville Fan level they cannot be older than the maximum proposed age for the Harold Formation (the oldest Victorville Fan deposit) of 1 my (Weldon et al, 1981). We can therefore calculate a minimum uplift rate of ~0.07 mm/yr (70 m/1 my).

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Regional and Local Hazards Mapping in the Eastern Great Basin

9950-01738

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Investigations

1. Study the paleoseismicity of the East Cache and Bear Lake faults, Utah and Idaho.

2. Measure geodetic strain across the Hurricane Cliffs northeast of Cedar City, Utah.

3. Study the distribution and age of late Quaternary faulting in unconsolidated sediments of the Elko 1° x 2° quadrange, Nevada.

4. Analyze the geometry of basins and basin-bounding structures along the Wasatch front.

5. Analyze subsurface data from the Great Basin to improve understanding of the geometry and evolution of basins and their bounding structures.

Results

1. Preliminary field studies of the East Cache and Bear Lake faults, Utah and Idaho by A. J. Crone show a) geomorphic evidence for surface faulting of possible Holocene age on the East Cache fault is restricted to a 5 km segment west of Logan, and b) a 20 km segment of the Bear Lake fault in the UT-ID border area has at least 1 m of normal surface offset resulting from a faulting event of mid to late Holocene age.

2. Resurvey in October 1981 of an eight-station trilateration network installed across the Hurricane Cliffs 10 km NE of Cedar City in October 1977 by the National Mapping Divison, U.S. Geological Survey indicates a maximum position shift of about 39 mm over a distance of about 3 km within the network. Excellent exposures of numerous faults within and adjacent to the network may provide a basis faor evaluating the relationship between the large strain signature and fossil fault slip.

3. Field study by T. Barnhard and R. Dodge of six main zones of fault scarps in unconsolidated sediments in the Elko 1° x 2° quadrangle, Nevada failed to reveal positive geomorphic evidence of Holocene surface displacement. Two fault zones west of the Ruby Mountains-East Humbolt Range block contain geomorphic evidence of recurrent late Quaternary surface offset and the last offset event on one of them may be of Holocene age. A compound scarp 15 km long extends from the west flank of the southern Ruby Mountains across Huntington Valley to the Daimond Mountains. Profile data indicate its last

displacement predates the Bonneville shoreline scarp (ca 15000-14000 years old, Scott, 1981). A compound scarp about 13 km long extends along the west flank of the East Humbolt and northernmost Ruby Mountains. Profile data place weak constraints on the age of last displacement as approximately at the Pleistocene-Holocene age boundary. Profile data from four other major scarp zones in Butte, Independence, Ruby and Lamoille Valleys indicate the last faulting event to be of late Pleistocene age.

4. An analysis of gravity, geology, and earthquake data of a 200 km wide zone along the Wasatch fault zone between 39° and 42°15'N by M. L. Zoback shows 1) a poor correlation between earthquake epicenters and surface faults or major buried fault zones, 2) basin-fill sediments exceed 3 km in thickness locally, 3) minimum vertical offsets across major normal fault zones vary between 3 and 5+ km, 4) most major faults are down-to-the west but several major down-to-the east faults that can be identified from gravity data serve to complicate the structural picture, 5) some basin and range blocks terminate against east-west-trending transverse fault- or warp-controlled structures some of which are inherited from prebasin-range structures, 6) some transverse structures are apparently dormant and do not serve to segment the Wasatch fault or other major faults, and 7) the current least principal stress throughout much of the region is oriented east-west to west-southwest--east-northeast representing an approximately 30° counterclockwise departure from that which characterizes most of the remainder of the Basin and range province.

5. Basin-range faulting is a late-stage structural development in a long and complex history of extensional tectonism in the great Basin (Zoback, Anderson, and Thompson, 1981). An extensive review of subsurface data (mainly seismic reflection data) indicates that the relatively young basin-range events involve a wide variety of fault geometries and processes ranging from displacement on steep, deeply penetrating planar normal faults to shallow detachment faults and associated listric or planar faults. Some basins form as relatively simple asymmetric sags associated with displacements on one or more steep, deeply penetrating basin-bounding faults. Such basins probably formed over directly subjacent zones of deep extension. Other basins form by block rotation associated with deeply penetrating listric faults and still others as pull-apart features above shallow detachment faults. Where detachment faults are involved, deep extension is probably located large lateral distances from sites of surface faulting. Some basins evolve from complex features characterized by subbasins and transverse structures to relatively simple broad features that shape the modern landscape. The diversity of structures involved in basin-range faulting has important implications for earthquake hazards assessments and resource appraisals. The diversity precludes generalization and requires basin-specific subsurface data before the fault geometry or faulting process can be characterized.

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Surface Faulting Studies

9940-02677

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Investigations

The investigations were focused on the study of rupture fraction (surface rupture length/total fault length) and statistical data related to surface faulting, in collaboration with J. J. Lienkaemper.

Results

The study of rupture fraction included the search for geologic literature and other data pertinent to surface ruptures in Bulgaria, Turkey (7 faulting events), China, and Mongolia. Landsat imagery covering the fault systems on which the 1957 and 1967 Mongolian faulting occurred was studied, for comparison with geologic maps and imagery interpretations that have been done by others. Compilation on a common base map of geologic data from 8 sources for the 1967 Mongolian faulting showed almost 8 versions of the fault pattern. The results of the landsat study may have to be the principal basis for estimating total length of the fault zone on which the rupture occurred, unless the detailed information requested from Mongolian geologists is received.

Estimates of errors in reported surface fault displacement and rupture length were completed for well-documented historic faulting. In connection with this study, J. J. Lienkaemper determined the magnitudes and errors in magnitude for six events. Plots were prepared relating earthquake magnitude to surface rupture length and displacement, and surface displacement to surface rupture length, using newly developed data on those parameters. The magnitude-length plot for all types of faults has a curvature which was not expected. To test whether saturation of the 20-second surface wave magnitude produced the curvature, we calculated and plotted moment-magnitudes for all events for which seismic moments are available, but no important change resulted. The limited size of the data set may be the cause of the problem, and we are examining that possibility as well as several others. The plot of surface displacement as a function of surface rupture length shows considerable scatter but suggests a linear relation up to a surface rupture length of about 100 km, beyond which the surface displacement increases more slowly.

Reports

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ACTIVITY OF THE CENTRAL REACH OF THE SANTA YNEZ FAULT

Contract Number: 14-08-0001-19787
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Detailed geologic mapping of the Santa Ynez fault was conducted for the purpose of identifying sites for geologic trenching (Figure 1). Mapping within an 8 to 10 km corridor extending eastward from the east end of Lake Cachuma yielded two localities at which branches of the fault in bedrock could be accurately projected beneath nearby Quaternary alluvium. Access and related logistical limitations prevented further investigation of one of the two sites. Very detailed geologic mapping, paleontologic studies and extensive geologic trenching at the second site area (0.3 km^2 study area) revealed stratigraphic and structural relationships heretofore unknown by geologists studying this area (Figure 2).

Identification and interpretation of macro- and microfauna collected from natural and trench exposures, detailed examination and logging of 450m of trench exposures, and soil stratigraphic/ geomorphic analyses yielded the following observations and allowed the following interpretations:

1. The fault zone is 290m wide and consists of seven bedrock faults;

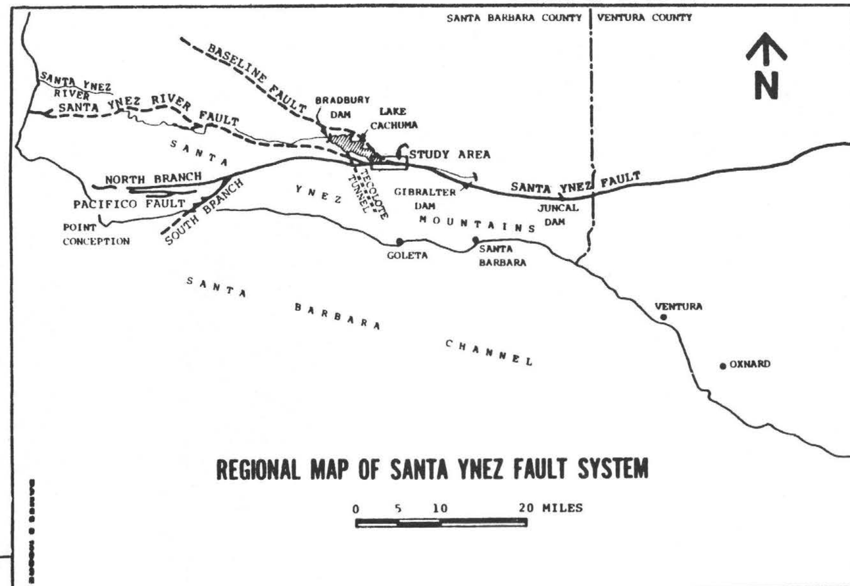
2. Holocene alluvial deposits are displaced along one of the southerly branches at the fault (Figure 2). (Age assignment of deposits based on correlation of site soils to dated soils in Ventura basin.);

3. Late Quaternary alluvial deposits are displaced along the southernmost fault branch;

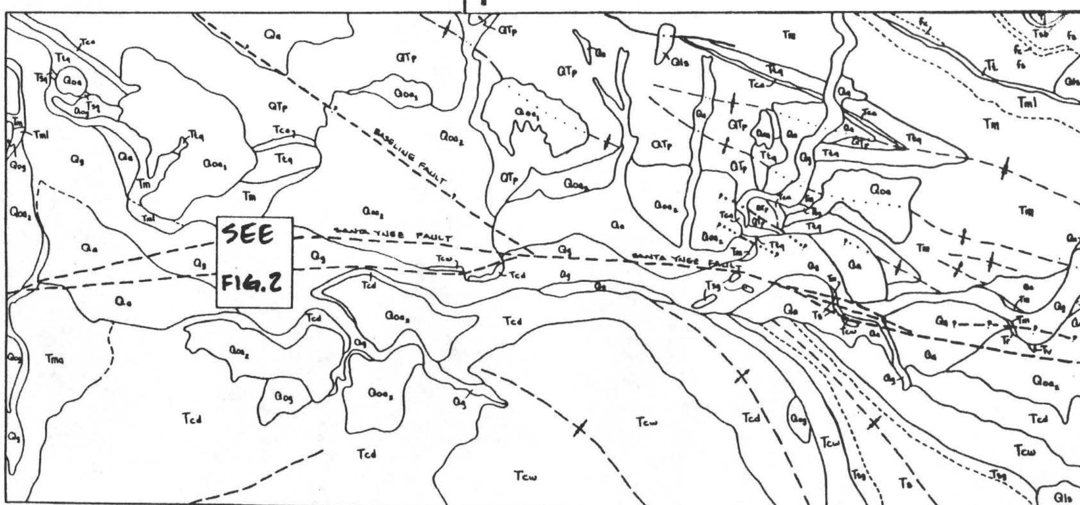
4. Eocene Coldwater and Gaviota Formations and Oligocene Sespe Formation are fault-bounded wedges lying between the Eocene Cozy Dell Formation to the south and the Upper Miocene Monterey Formation to the north. Prior to this study, the Gaviota Formation north of the crest of the Santa Ynez Mountains was thought to extend no further east than the

Refugio Pass area (approximately 32 km west of the study area).

Questions of whether the observed Holocene displacement represents multiple events and, if so, the magnitude, direction and timing of each slip event remain to be answered.



REGIONAL MAP OF SANTA YNEZ FAULT SYSTEM



MODIFIED AFTER DIBBLEE (1966) AND COSS (1980)

AGE			FORMATION	LITHOLOGY	THICKNESS	DESCRIPTION
QUATERNARY	RECENT		ALLUVIUM (N)		0-50'	Gravel, sand, silt
	PLEISTOCENE	Upper	OLDER ALLUVIUM (N)		0-100'	Gravel, sand
			FANGLOMERATE (N)		0-200'	Boulder gravel
	?	Lower ?	PASO ROBLES (N)		2500'	Light gray cobble gravel; shale, pebble gravel, pebbly gray clay, silt and sand
TERTIARY	PLIOCENE	Upper	CAREAGA		0-270'	White to yellow sand
	?	Lower	TEQUEPIS		0-900'	Fine white sand, locally tuffaceous
	MIOCENE		SISQUOC		0-900'	White silty diatomite
		Upper	MONTEREY		1300'-2500'	Hard laminate platy to fissile siliceous shale; Soft fissile to ellipsoidal shale; occasional lenses of sandstone
		Middle	TEMBLOR		0-600'	Buff sandstone; locally bentonitic
		Lower	RINCON		0-1000'	Gray clay shale; local sandstone
	?	?	VAQUEROS		0-600'	Greenish buff sandstone
	OLIGOCENE		SESPE		0-2000'	Gray to buff sandstone; Green to red clays, silts; Basal red to gray conglomerate
	?	?	GAVIOTA		0-1000'	Buff sandstone
	EOCENE		COLDWATER		0-1500'	Buff arkosic sandstone
		Upper	COZY DELL		0-1200'	Gray clay shale
		?	MATILIJA		0-800'	Buff arkosic sandstone
		Middle ?	JUNCAL		0-1500'	Gray clay shale and siltstone
CRETACEOUS			SIERRA BLANCA		0-20'	White sandy limestone
		Lower	ESPADA		2000'	Dark green-brown carbonaceous shale and thin interbeds of green-brown fine sandstone
?						CONTACT NOT EXPOSED
CRETACEOUS OR UPPER JURASSIC ?			FRANCISCAN		2000'	Dark green-gray sandstone or graywacke; sheared gray-black clay shale; varicolored chert

MODIFIED AFTER DIBBLEE (1966)

- Qg STREAM CHANNEL GRAVEL AND SAND
- Qa ALLUVIUM
- Qls LANDSLIDE DEBRIS
- OLDER SURFICIAL DEPOSITS:
  - Qoa UNDIVIDED
  - Qoa_2 YOUNGER, LOWER GRAVEL
  - Qoa_1 OLDER, HIGHER GRAVEL
- QTp PASO ROBLES FORMATION
- Tca CAREAGA SANDSTONE
- Ttq TEQUEPIS SANDSTONE
- Tsq SISQUOC FORMATION
- MONTEREY FORMATION:
  - Tmu UPPER
  - Tml LOWER
- Tt TEMBLOR SANDSTONE
- Tr RINCON FORMATION
- Tv VAQUEROS SANDSTONE
- Ts SESPE FORMATION
- Tsg BASAL CONGLOMERATE
- Tcw COLDWATER SANDSTONE
- Tcd COZY DELL FORMATION
- Tma MATILIJA SANDSTONE
- Tj JUNCAL FORMATION
- Tsb SIERRA BLANCA LIMESTONE
- FRANCISCAN FORMATION:
  - Fs SANDSTONE AND SHALE
  - Fc CHERT

N

EXPLANATION

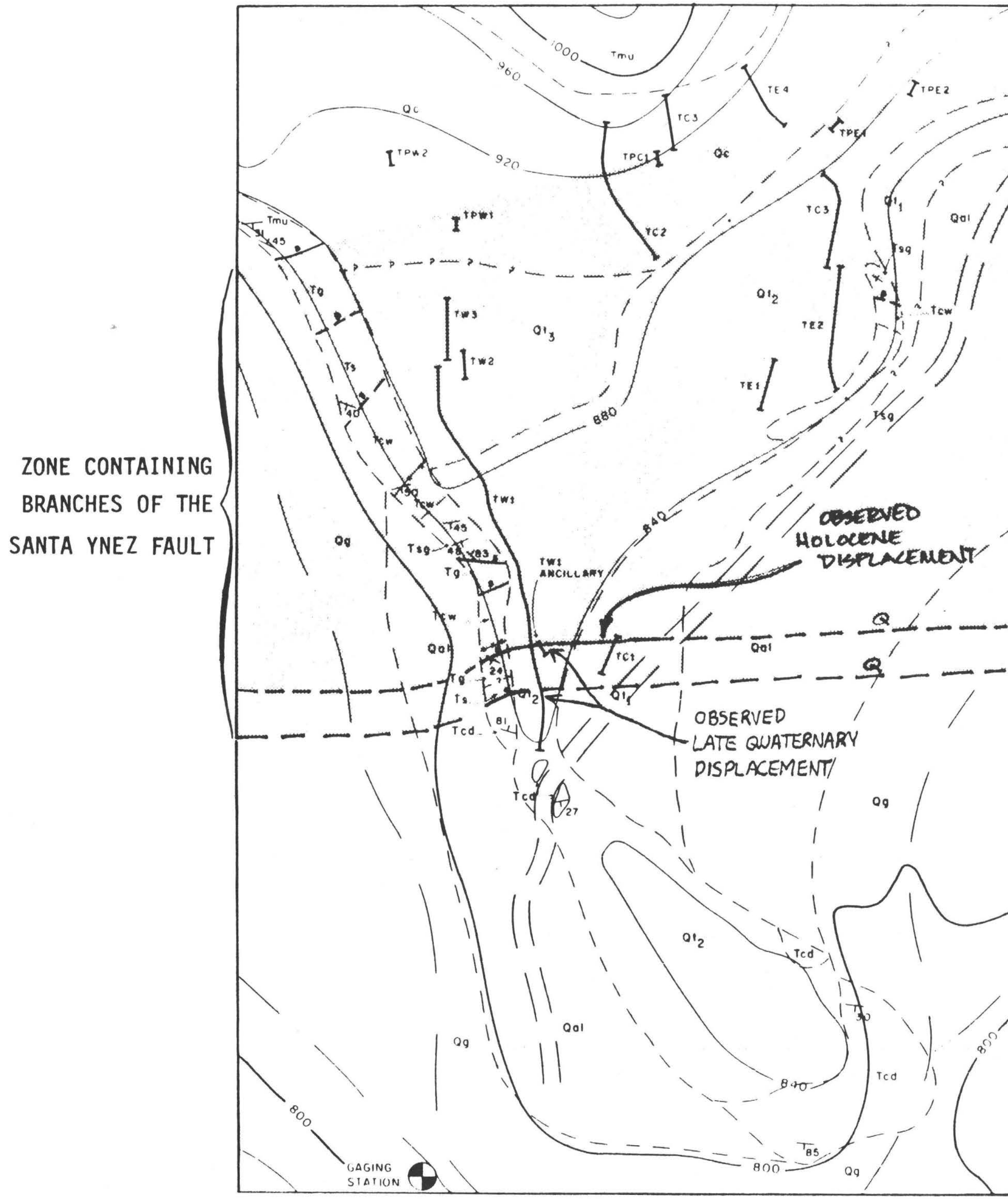
- D/U FAULT SHOWING RELATIVE MOVEMENT DASHED WHERE INFERRED, DOTTED WHERE CONCEALED
- SYNCLINE, ANTICLINE: DASHED WHERE INFERRED, DOTTED WHERE CONCEALED
- CONTACT, DASHED WHERE APPROXIMATED
- STRIKE AND DIP OF BEDDING

GENERALIZED GEOLOGIC MAP OF STUDY AREA

GENERALIZED STRATIGRAPHIC COLUMN

Dames & Moore

FIGURE 1



EXPLANATION

- QUATERNARY FAULT, DASHED WHERE INFERRED
- BEDROCK FAULT, DASHED WHERE INFERRED
- CONTACT, DASHED WHERE APPROXIMATE
- FOSSILIFEROUS MARKER BED WITHIN THE COLDWATER FORMATION.
- 45 STRIKE AND DIP OF BEDDING
- STRIKE AND DIP OF VERTICAL BEDDING.
- TW4 BACKHOE TRENCH
- TPC2 TEST PIT

	Qg	RECENT STREAM GRAVELS
	Qal	RECENT FLOOD PLAIN DEPOSITS
Qc	Qt_1	
	Qt_2	STREAM TERRACE DEPOSITS COLLUVIUM
	Qt_3	
	Tmu	MONTEREY FORMATION- UPPER
	Ts	SESPE FORMATION
	Tg	GAVIOTA FORMATION
	Tcw	COLDWATER FORMATION
	Tcd	COZY DELL FORMATION

SCALE 1:2000

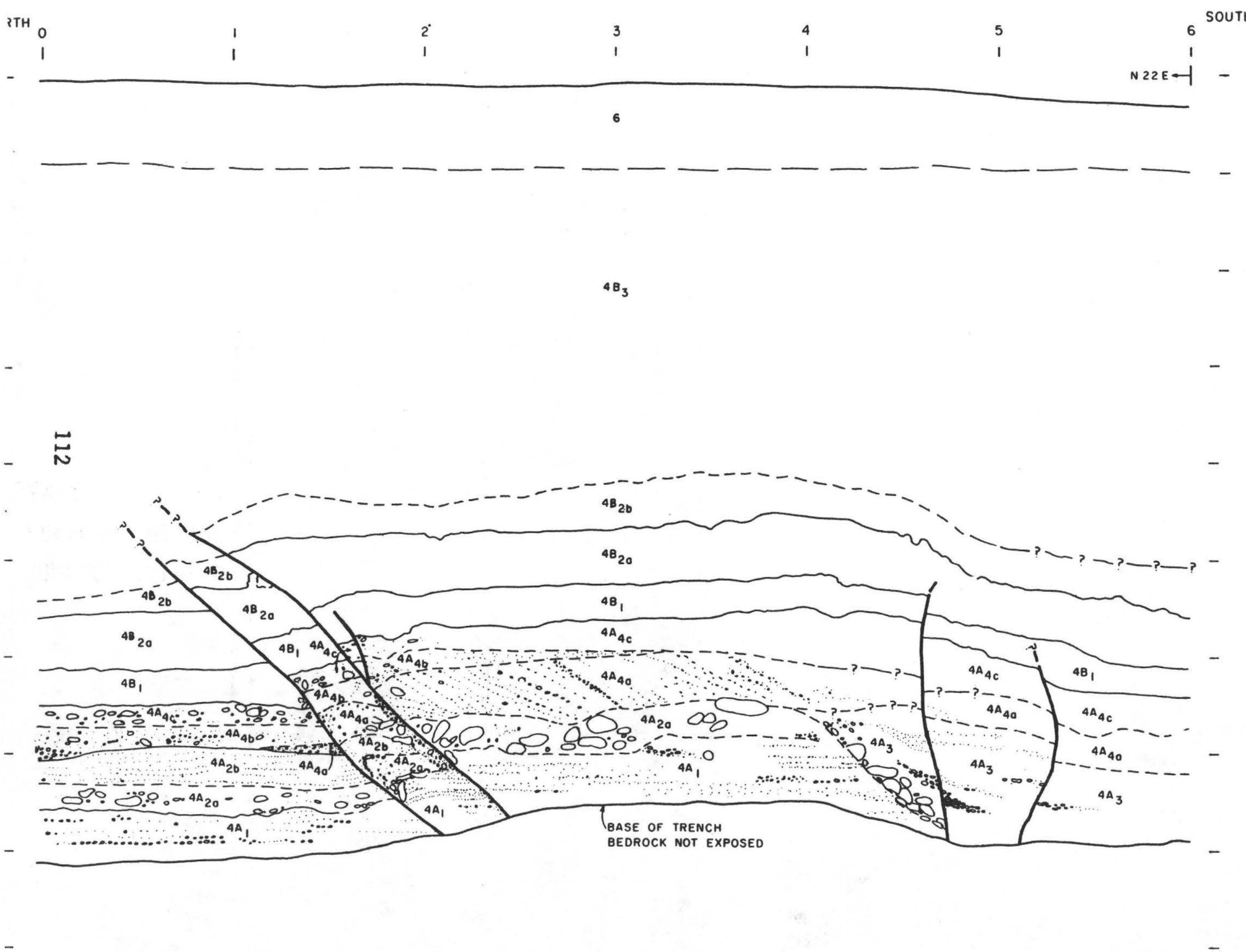
0 25 50 75 100 METERS

0 100 200 300 400 FEET

N

FIGURE 2
LOCAL SURFICIAL GEOLOGY

Dames & Moore



EXPLANATION

- CONTACT, SHARP
- CONTACT, APPROXIMAIELY LOCATED
- CONTACT, GRADATIONAL
- SHEAR, DASHED WHERE INDISTINCT
- BEDDING PLANE
- FRACTURE
- ...ATION (MAY OR MAY NOT BE ...SOCIATED WITH BEDROCK STRUCTURES)
- ...ULT, DASHED WHERE INDISTINCT
- ...BBLE AND COBBLE CONCENTRATION
- WELL LAMINATED SAND AND GRANULES
- BOULDER ZONE
- N 40 W 20 S — STRIKE AND DIP OF BEDDING, SHEAR, FAULT
- K — INFILLED ANIMAL BURROW (KROTVINA)
- 10+00 — STATION NUMBERS; INDICATES DISTANCE IN METERS FROM ZERO REFERENCE.

UNIT DESCRIPTION

QUATERNARY

- $4A_1$ GRAY BROWN, LAMINATED FINE GRAVELLY VERY COARSE SAND.
- $4A_{2a}$ GRAY BROWN POORLY LAMINATED FINE TO COARSE GRAVEL WITH SILTY MEDIUM TO COARSE SAND MATRIX.
- $4A_{2b}$ LIGHT BROWN LOOSE LAMINATED MEDIUM TO VERY COARSE SAND.
- $4A_3$ LIGHT GRAY-BROWN LAMINATED COARSE SANDY FINE GRAVEL TO FINE GRAVELLY COARSE SAND. CONTAINS DISTINCT LENSES OF SANDSTONE PEBBLES AND COBBLES, AND MONTEREY SHALE GRANULES.
- $4A_{4a}$ LIGHT GRAY-BROWN CROSS LAMINATED GRANULE TO SMALL PEBBLE GRAVEL.
- $4A_{4b}$ LIGHT GRAY-BROWN, MODERATELY LAMINATED TO MASSIVE PEBBLY COARSE SAND TO COARSE SANDY PEBBLE GRAVEL.
- $4A_{4c}$ LIGHT GRAY-TAN POORLY INDURATED MASSIVE VERY SILTY FINE TO MEDIUM GRAVELLY FINE SAND.
- $4B_1$ TAN MASSIVE MODERATELY INDURATED SILT.
- $4B_{2a}$ LIGHT BROWN GENERALLY MASSIVE VERY FINE SAND.
- $4B_{2b}$ LITHOLOGICALLY EQUAL TO $4B_1$.
- $4B_3$ LIGHT BROWN MASSIVE VERY FINE SANDY SILT.
- 6 LIGHT GRAY-BROWN SILT WITH SOME FINE SAND AND MINOR ORGANIC MATERIAL.

DETAILED GEOLOGIC LOG
TRENCH TC1
EAST WALL

SCALE

0 100 cm

FIGURE 3

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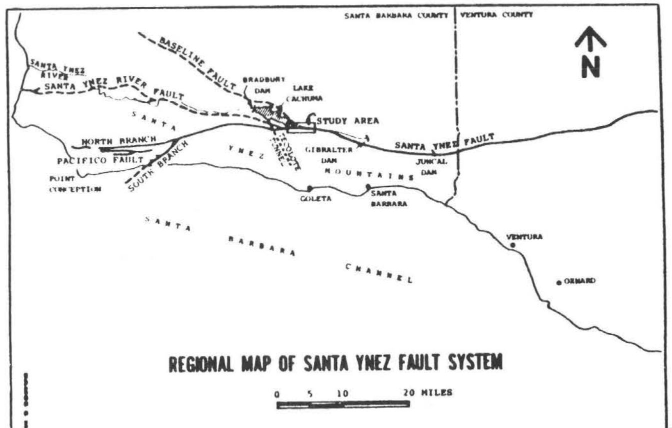

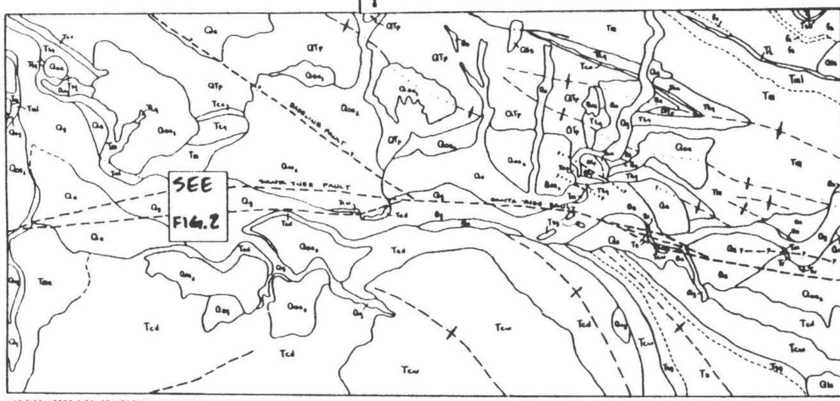

AGE			FORMATION	LITHOLOGY	THICKNESS	DESCRIPTION
QUATERNARY	RECENT		ALLUVIUM (H)		0-30'	Gravel, sand, silt
	PLEISTOCENE	Upper	OLDER ALLUVIUM (H)		0-100'	Gravel, sand
			FANGLOMERATE (H)		0-200'	Boulder gravel
		Lower	PASO ROBLES (H)		2500'	Light gray cobble gravel, shale, pebble gravel, pebbly gray clay, silt and sand
TERTIARY	PLIOCENE	Upper	CAREAGA		0-270'	White to yellow sand
		Lower	TEQUEPIS		0-500'	Fine white sand, locally tuffaceous
			SISQUOC		0-900'	White silty diatomite
	MIOCENE	Upper	MONTEREY		1500'-2500'	Hard laminate platy to friable siliceous shale; Soft friable to ellipsoidal shale, occasional lenses of sandstone
		Middle	TEMBLOR		0-900'	Buff sandstone, locally bentonitic
		Lower	RINCON		0-1000'	Gray clay shale, local sandstone
			VAQUEROS		0-600'	Greenish buff sandstone
	OLIGOCENE		SESPE		0-2000'	Gray to buff sandstone, Green to red clays, silts, Basal red to gray conglomerate
	EOCENE	Upper	GAVIOTA		0-1000'	Buff sandstone
			COLDWATER		0-1500'	Buff arkosic sandstone
			COZY DELL		0-1200'	Gray clay shale
			MATILIJA		0-800'	Buff arkosic sandstone
		Middle ?	JUNCAL		0-1500'	Gray clay shale and siltstone
CRETACEOUS		Lower	SIERRA BLANCA		0-20	White sandy limestone
			ESPADA		2000'	Dark green-brown carbonaceous shale and thin interbeds of green-brown fine sandstone
						CONTACT NOT EXPOSED
CRETACEOUS OR UPPER JURASSIC ?			FRANCISCAN		2000'	Dark green-gray sandstone or graywacke, sheared gray-black clay shale; varicolored chert

MODIFIED AFTER DIBBLEE (1966)

Qg STREAM CHANNEL GRAVEL AND SAND
Qa ALLUVIUM
Qls LANDSLIDE DEBRIS
OLDER SURFICIAL DEPOSITS.
Qoa UNDIVIDED
Qog YOUNGER, LOWER GRAVEL
Qoo OLDER, HIGHER GRAVEL
QTp PASO ROBLES FORMATION

Tca CAREAGA SANDSTONE
Ttq TEQUEPIS SANDSTONE
Tsq SISQUOC FORMATION
MONTEREY FORMATION
Tmu UPPER
Tml LOWER
Tt TEMBLOR SANDSTONE
Tr RINCON FORMATION

Tv VAQUEROS SANDSTONE
Ts SESPE FORMATION
Tsg BASAL CONGLOMERATE
Tcw COLDWATER SANDSTONE
Tcd COZY DELL FORMATION
Tma MATILIJA SANDSTONE
Tj JUNCAL FORMATION

Tsb SIERRA BLANCA LIMESTONE
FRANCISCAN FORMATION
Fs SANDSTONE AND SHALE
Fc CHERT

EXPLANATION

D/U FAULT SHOWING RELATIVE MOVEMENT DASHED WHERE INFERRED, DOTTED WHERE CONCEALED

SYNCLINE / ANTICLINE — DASHED WHERE INFERRED, DOTTED WHERE CONCEALED

CONTACT, DASHED WHERE APPROXIMATED

STRIKE AND DIP OF BEDDING

GENERALIZED GEOLOGIC MAP OF STUDY AREA

GENERALIZED STRATIGRAPHIC COLUMN

Dames & Moore

FIGURE 1

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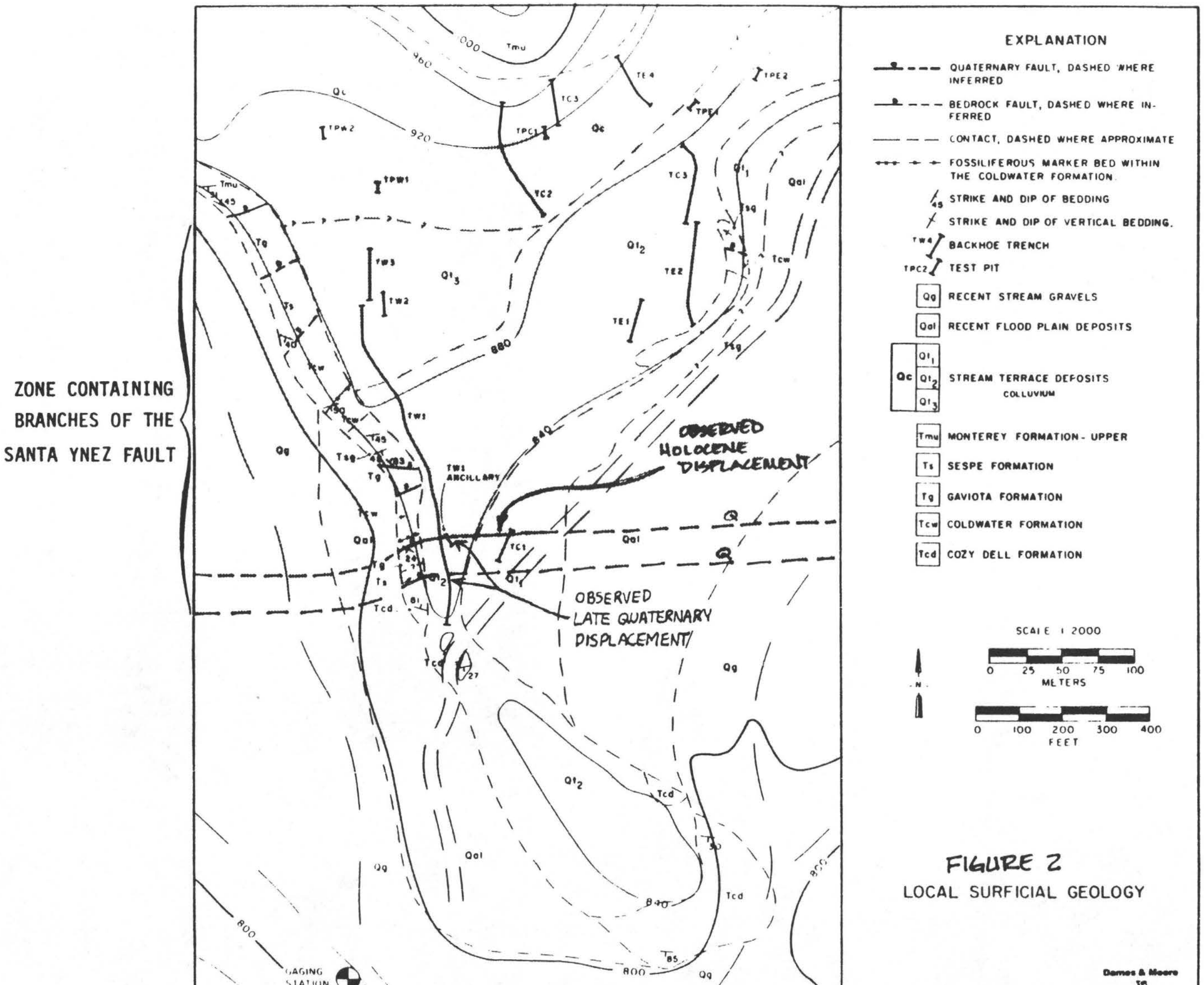

FIGURE 2
LOCAL SURFICIAL GEOLOGY

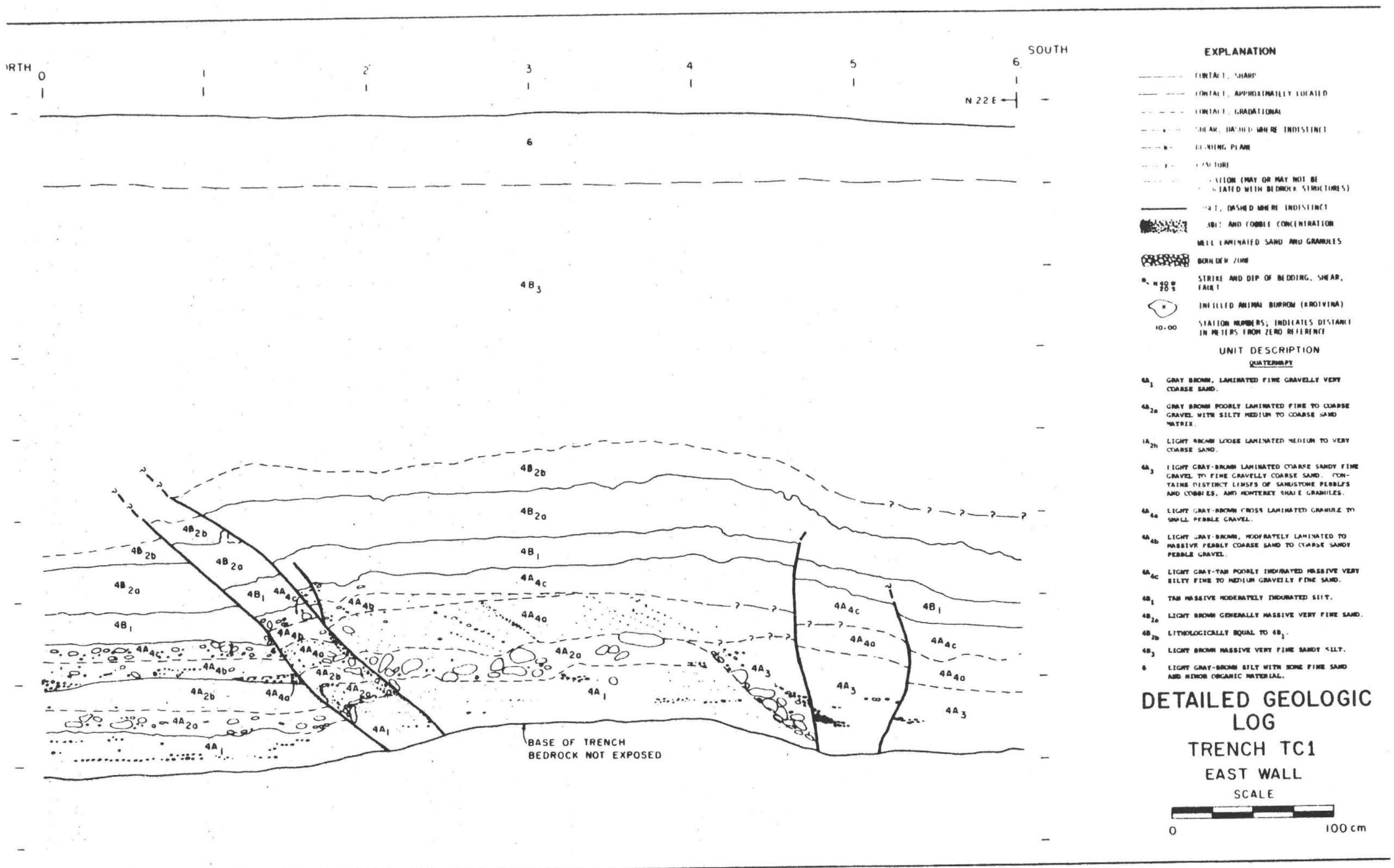
NORTH
SOUTH
0
1
2
3
4
5
6
N 22 E
6
4B3
4B2b
4B2a
4B1
4A4c
4A4a
4A4b
4A2a
4A2b
4A3
4A1
BASE OF TRENCH
BEDROCK NOT EXPOSED
EXPLANATION
INFILLED ANIMAL BURROW (KROTOVINA)
STATION NUMBERS; INDICATES DISTANCE IN METERS FROM ZERO REFERENCE
UNIT DESCRIPTION
QUATERNARY
4A1 GRAY BROWN, LAMINATED FINE GRAVELLY VERY COARSE SAND.
4A2a GRAY BROWN POORLY LAMINATED FINE TO COARSE GRAVEL WITH SILTY MEDIUM TO COARSE SAND MATRIX.
4A2b LIGHT BROWN LOOSE LAMINATED MEDIUM TO VERY COARSE SAND.
4A3 LIGHT GRAY-BROWN LAMINATED COARSE SANDY FINE GRAVEL TO FINE GRAVELLY COARSE SAND. CONTAINS DISTINCT LENSES OF SANDSTONE PEBBLES AND COBBLES, AND MONTEREY SHALE GRANULES.
4A4a LIGHT GRAY-BROWN CROSS LAMINATED GRANULE TO SMALL PEBBLE GRAVEL.
4A4b LIGHT GRAY-BROWN, MODERATELY LAMINATED TO MASSIVE PEBBLY COARSE SAND TO COARSE SANDY PEBBLE GRAVEL.
4A4c LIGHT GRAY-TAN POORLY INDURATED MASSIVE VERY SILTY FINE TO MEDIUM GRAVELLY FINE SAND.
4B1 TAN MASSIVE MODERATELY INDURATED SILT.
4B2a LIGHT BROWN GENERALLY MASSIVE VERY FINE SAND.
4B2b LITHOLOGICALLY EQUAL TO 4B1.
4B3 LIGHT BROWN MASSIVE VERY FINE SANDY SILT.
6 LIGHT GRAY-BROWN SILT WITH SOME FINE SAND AND MINOR ORGANIC MATERIAL.
DETAILED GEOLOGIC LOG
TRENCH TC1
EAST WALL
SCALE
0
100 cm

FIGURE 3

ACTIVITY AND EARTHQUAKE POTENTIAL OF THE PALOS VERDES FAULT

Contract Number: 14-08-0001-19786
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Investigations

Overview:

The regional and local fault geometry and displacement history of the Palos Verdes fault are being evaluated using geological, geophysical and seismological techniques. The deformation history of the fault, including the length and inferred recency of faulting along individual fault segments, is being studied in areas of the San Pedro shelf and outer margin where a well-developed late Pleistocene-Holocene chronostratigraphic sequence is present. Based on comparison of fault behavior on the various segments through time and inferred fault displacement parameters associated with discrete displacement events, we will attempt to estimate long-term slip rates for the fault zone and the frequency of occurrence and size of potentially damaging earthquakes on the Palos Verdes fault.

Specific Investigations:

1. Late 19th and early 20th century topographic maps and late 1920's vintage pre-development aerial photographs are being evaluated for evidence regarding fault locations and any information that may allow inference regarding nature and amounts of displacements along the fault.

2. First order horizontal and vertical (geodetic) survey nets transecting the onshore fault trace are being analyzed for evidence of distortion that may be attributed to fault movement.

3. Subsurface lithologic data from drillers and geologists logs and historic water level measurements from approximately 100 water wells are being analyzed for evidence regarding fault locations, stratigraphic discontinuities in late Quaternary age strata across the fault, and potential water table variations across the fault. Two basic methods are

being utilized to delineate stratigraphic and water level discontinuities: (1) drillers logs and geologic logs are being examined and correlated stratigraphically; and (2) selected synoptic water level measurements by the LACFCD and California DWR are being plotted and water levels in the major water bearing zones contoured.

4. A late Quaternary seismic stratigraphic sequence analysis was completed for two detailed study areas along the Palos Verdes fault zone: (1) the outer Los Angeles Harbor area, and (2) the outer San Pedro margin area. Correlation of these stratigraphic sequences with bore hole information has been established in the outer margin and tentatively established in the harbor area.

5. A late Quaternary geologic map of the outer Los Angeles Harbor area (scale 1:2,400) has been completed.

6. Preliminary geologic maps of the outer San Pedro margin area (1:2,400 to 1:6,000) have been revised.

7. A Palos Verdes fault zone strip map (1:24,000) across the San Pedro shelf and upper slope is nearing completion.

8. Detailed late Quaternary cross-sections across the Palos Verdes fault zone in the outer San Pedro margin area have been constructed. Regional sections along the zone between the harbor and outer margin are in progress.

Results

1. Analysis and interpretation of old topographic maps and pre-development aerial photographs revealed several closed depressions along the northeast margin of the Palos Verdes Hills in the vicinity of the fault. No systematic alignment of depressions is evident, and their tectonic significance is unknown. Tectonic geomorphic features commonly associated with moderately to highly active strike-slip fault zones are not recognized along the onshore fault trace.

2. Analysis of results of first order levelling surveys by the County of Los Angeles, Long Beach Harbor Department, Los Angeles Department of Public Works, and Department of Oil Properties does not reveal evidence of distortion of survey nets that may be attributed to fault movement. Distortion of regional survey nets is interpreted to result from oil field subsidence associated with hydrocarbon fluid withdrawal in the Wilmington oil field and subsequent rebound resulting from fluid injection and repressurization of the field. Interpretation of isopleths of rebound suggest that subsidence and rebound in the area may be structurally controlled to the southwest by the Palos Verdes fault, but tectonic movement is not implied.

3. The late Quaternary stratigraphy of the inner San Pedro shelf and the outer Los Angeles Harbor area can be subdivided into three seismic stratigraphic sequences that are correlated with the "Holocene" Gaspur Aquifer mapped by Zielbauer et al. (1962). Designated as Units GI, GII and GIII (youngest to oldest), these sequences are interpreted as a nested set of upward fining channel-fill deposits. Boundaries between the three units are unconformities. The base of Unit GIII is a pronounced angular unconformity.

   Reflectors within GI sub-Units IA and IB display moderate apparent amplitudes and high continuity with many narrow cycles and are correlated with the fine grained upper Gaspur of Zielbauer et al. The general external geometry of these units is that of channel-fill sequences.

   The mid-Gaspur unit (GII) is a transitional sequence. Reflection character is less continuous than that of Units IA and IB and more continuous than the underlying unit (GIII). The short, discontinuous, low to moderate amplitude reflectors of Unit GIII suggest a coarser grained unit similar to the sand and gravel-rich lower Gaspur of Zielbauer et al.

   A late Quaternary geologic map of these units, isopachs of units GIA and GIB, and detailed sections have been completed over the projected trace of the Palos Verdes fault zone. There is no evidence that the base of either Unit GI or GII is cut by the fault. However, the base of GIII, the major unconformity below the Gaspur, is apparently offset.

   To the west of Reservation Point, uplift of the Palos Verdes block has controlled the edge of these channel-fill sequences. Because the channel-fill units lap-out to the west against the uplift, it is not possible to discern Holocene fault activity in this area.

4. Along the outer margin of the San Pedro shelf, a complete marine Holocene-middle Quaternary record is preserved within the down-dropped block of the Wilmington Graben of Junger and Wagner (1977). These units wedge-out or are truncated towards the Palos Verdes fault and uplift. Within this area, four mapable late Pleistocene-Holocene seismic stratigraphic sequences have been established. The basal sequence, designated as LP-1, is only preserved on the slope. The three Holocene units are mapped over the entire outer margin study area east of the Palos Verdes uplift.

   Detailed cross-sections along high resolution profiles suggest that the Palos Verdes fault zone has experienced episodic surface or near-surface displacements during the late Pleistocene-Holocene. Portions of segments of the fault display evidence of latest Holocene activity, but this activity is not continous along entire segments or along the zone. Other fault segments display evidence of activity during the latest Pleistocene or early Holocene. Deeper upper and mid-Quaternary units record a similar history of fault activity, but with less resolution.

The lengths of fault segments that ruptured the key reflective horizons or unit boundaries are being mapped. Few exceed several kilometers in length, and most are less than one kilometer long.

5. The regional (1:24,000) strip map of the Palos Verdes fault zone generally supports the interpretations of Rudat (1980). Faulting along the zone is not continuous, but rather distributed along a broad zone of en-echelon faults.

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Zielbauer, E.J., Kues, H.A., Burnham, W.L., and Keene, A.G., 1962, Coastal basins barrier and replenishment investigation, Dominguez Gap barrier project geologic investigation: Unpub. report by the Los Angeles County Flood Control District, 29 p.

ESTIMATION OF SEISMIC GROUND MOTION IN UTAH

14-08-001-19825

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Attenuation of MM Intensity in Northern Utah has been examined by the U.S. Geological Survey (1976). For this study we have used the attenuation equation suggested by the U. S. Geological Survey

$$I_o - I = 4 \log_{10} (R/h) \qquad - (1)$$

where I_o is the maximum MM Intensity at the epicenter, I is MM Intensity, R is hypocentral distance and h is focal depth. This intensity relationship was based on median distances to various intensity levels observed in two earthquakes. One of the problems in dealing with intensity data is the bias introduced by the use of isoseismal plots rather than station information directly. This bias was demonstrated by Bollinger (1977) using data from the Charleston earthquake and was also shown using data from the 1971 San Fernando earthquake by Donovan (1978). Where isoseismal curves have been drawn in a consistent manner the magnitude of this bias effect has been found to be between one half and a full intensity unit and is approximately constant throughout the entire distance range beyond the immediate epicentral region (10 to 20 Kilometers).

By recognizing that the bias exists we are forced to acknowledge an additional problem. This is the different bases that have been used by different investigators in developing Intensity attenuation relationships. Most use isoseismal data directly (Nuttli, 1981) while others are based on site Intensity values (McGuire, 1978). These differences prevent the direct comparison of possible ground motion levels in different seismic areas. With an almost constant bias effect it is still possible to compare relative attenuation rates between different seismic areas. An example of this comparison is shown in Figure 1 where data from across the United States are compared. In this figure attenuation curves are shown for an epicentral MM Intensity IX event using the equations of Nuttli for the Central US, McGuire for the eastern US, equation 1 for northern Utah and direct data from the San Fernando event complied by Donovan. These plots show some distinct trends and also raise major questions.

Although equation 1 is based on data from only 2 earthquakes it suggests that attenuation in Utah may be more rapid than in other parts of the United States. This is in contradiction to the results of Evernden (1975) who stated that attenuation in the Mountain states is less than that in California and more than that in Central and Eastern states. Griscom & Arabasz (1979) using Wood-Anderson data suggest that the Richter & Gutenburg correction curves for California are directly applicable for local earthquakes in Utah.

The epicentral Intensity of the February 9, 1971 San Fernando earthquake was at least X so the data shown on Figure 1 confirms the more rapid epicentral attenuation in California than for all other regions. Figure 1 also shows a trend which was not expected. After the rapid initial attenuation of Intensity within 10 kilometers of the epicenter the rate of attenuation at greater distances in the San Fernando event was approximately equal to and possibly lower than that proposed by Nuttli for the Central United States.

Further investigation of the attenuation of ground motion in Northern Utah and the estimation of ground motion levels is continuing using aftershock data recorded by King and Hays (1977) in combination with the application of the seismic source model of Brune (1970) by the McGuire & Hanks (1980).

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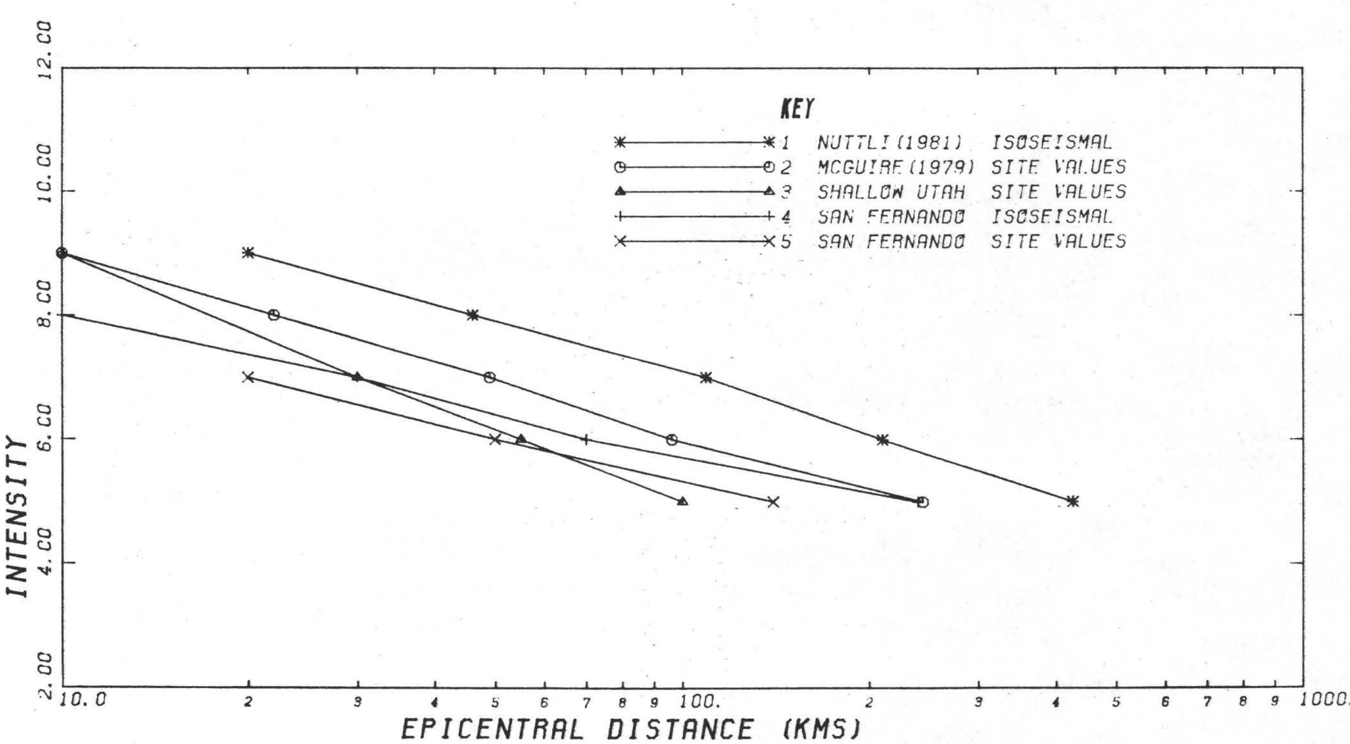

REGIONAL INTENSITY ATTENUATION EQUATIONS ACROSS THE UNITED STATES
CURVES BASED ON ISOSEISMAL LINES OR SITE VALUES AS NOTED (MMI = IX)

FIGURE

Tectonics of Central and Northern California

9950-01290

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Investigations

1. Tectonics of accretion of the North Fork and other terranes of the Klamath Mountains and Coast Ranges of California: in collaboration with D. L. Jones and C. D. Blome.

2. Relations between seismicity and carbon dioxide discharges: in collaboration with Ivan Barnes.

3. Paleomagnetic orientation of Permian and related strata of the eastern Klamath Mountains: in collaboration with E. A. Mankinen and C. S. Gromme.

Results

1. Tectonic complexity of the North Fork terrane in the central Klamath Mountains is indicated by radiolarian cherts that are interbedded with other oceanic volcanic and sedimentary strata. The cherts are found to contain radiolarians that range in age from Early Permian to Late(?) Jurassic. Permian chert is found at only a few localities and contains radiolarians previously known only from Japan. Upper Triassic chert is predominant and contains undescribed early and middle Karnian radiolarians similar to those from the Elkhorn Ridge Argillite in east-central Oregon and the Cache Creek Group of British Columbia. Much contains a late Karnian to middle Norian radiolarian fauna that also has been recognized in Baja California, Oregon, British Columbia, Alaska, and Japan. Chert of Early or Middle Jurassic age is abundant in the North Fork terrane at the latitude of Hayfork and north of Yreka and contains radiolarian faunal assemblages characterized by distinctive and short-ranging forms. The most exciting discovery was radiolarians that may be the youngest to be found in the North Fork terrane. These are distinct forms that are known to occur in only the Upper Jurassic (Tithonian). This age suggests major disruption of the deep-marine environment and final suturing of the North Fork terrane to the central metamorphic belt during the Late Jurassic or earliest Cretaceous, and documents the remarkable rapidity of some major tectonic events. The suturing must have been virtually contemporaneous with deposition of the oldest part of the Great Valley sequence and occurred shortly before Lower Cretaceous (Hauterivian) beds of the Great Valley sequence covered the suture at the south end of the Klamath Mountains province.

2. Late Paleozoic and Mesozoic strata of the eastern Klamath terrane crop out in west-facing concentric arcuate belts and "young" eastward. Cores of Permian to Jurassic volcanic and sedimentary strata were drilled in the northern part of the eastern Klamath terrane where the trend of the formations is north-northeast. Preliminary results of paleomagnetic measurement on these cores indicate large clockwise rotation of the Permian volcanic strata but significantly smaller rotation of the Jurassic strata. Permian volcanic rocks were also cored at the middle latitude of the eastern Klamath terrane, but these rocks seem to have rotated much less than the Permian rocks to the north. These preliminary findings seem to indicate that the eastern Klamath terrane did not rotate as a rigid block, and that the arcuate distribution of the Permian rocks is the result of oroclinal bending. Our previous paleomagnetic investigations have shown that any post-Cretaceous rotation of the Klamath Mountains has been either small or negligible.

Reports

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Coastal Tectonics, Western U. S.

9940-01623

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Investigations

1. Continued mapping and dating late Quaternary tectonically deformed marine terraces and deposits at several coastal sites in western U. S. with emphasis on Santa Barbara, Ventura and Los Angeles Counties, CA. (Lajoie, McCrory, Mathieson and Ponti).

2. Quantified soils data in Antelope Valley, southern California as a means of dating tectonically deformed alluvial fan deposits (Ponti).

3. Continued installing on U.S.G.S. computer the geotechnical data base for ground motion studies in the Los Angeles basin (Vivrette and Ponti in cooperation with Tinsley).

4. Obtained chemical data from new fumerole on South Santa Ynez fault (William Evans WRD) in Santa Barbara County.

5. Completed ^{14}C dating of lacustrine deposits in Mono Basin, California that provide stratigraphic control for tectonic, climatic and tephra studies in the western Great Basin (with Steve Robinson).

Results

1. Several sequences of marine terraces along the coastline east of Point Conception (Santa Barbara County) fit a constant uplift model that is based on the Bloom and others (1974) sea level curve as a variable datum. These results are consistent with correlations based on independent paleontological and amino-acid dating techniques. The uplift rate of 0.4 m/ka at Cojo Canyon indicates the $\sim$55 m terrace near Point Conception was cut on the 200 ka highstand of sea level and was reoccupied by the 124 ka (5e) highstand. Three terraces tentatively dated at 83, 104 and 124 ka BP are highest near Alegria Canyon, where each is offset across the South Santa Ynez fault, and slope gently to the east and west along the coastline.

2. The emergent marine terraces mapped by Bradley (1978) in Santa Cruz County also fit the constant uplift model. The 83 ka age (paleontology and amino-acid data) of Davenport terrace yields an uplift rate of 0.35 m/ka and 124 ka for the successively higher Highway 1 and Cement terraces. The age estimates of these and even higher terraces in this area are consistent with estimates derived from numerical analyses of topographic profiles using the diffusion equation (Tom Hanks).

3. The existence of a pervasive and uniform sequence of apparently synchronous deposits throughout the Antelope Valley, (western Mojave Desert) indicates that major aggradational episodes are controlled by regional climatic change (Ponti). Physical properties and numerical indices such as in-situ V_S, soil development indices and dry density cluster tightly within each stratigraphic/geomorphic unit and can be used for correlation and numerical age dating. Many of these units are tectonicaly deformed. Therefore, this control may yield information on rates of tectonic deformation along the San Andreas and Garlock faults.

4. Chemical and isotopic data (William Evans) indicate the gases discharging from the new fumerole 100 m from the South Santa Ynez fault (Santa Barbara County) are heated air and meteoric water (71°C-78°C) which indicates the heat source may be fairly shallow. Las Cruces spring (35°C) which is also associated with the Santa Ynez fault several kilometers to the east, emits large quantities of methane and, therefore, may tap a deeper heat source. Unconfirmed reports by local property owners in this area suggest warm springs in Agua Caliente Canyon were shut off during an earthquake in the 1800's. There are no thermal springs in Agua Caliente Canyon today.

5. ^{14}C dates on lacustrine deposits in Mono Basin (eastern California) provide detailed age control for the late Pleistocene lake-level fluctuation curve of Mono lake, which is based on stratigraphic and geomorphic data. The most significant result from these data is that Mono Lake rose to a very brief highstand about 12-13 ka BP. This highstand most likely records a wet climatic pulse throughout the Great Basin near the end of Pleistocene time. Strandlines and fluvial deposits associated with this pulse are useful markers for tectonic studies in this region. In Lundy Canyon (NW Mono Basin) fluvial deposits most likely associated with this pulse are offset (normal displacement) about 24 m across the Sierran range-front fault.

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Paleomagnetic Stratigraphy of the Saugus Formation Los Angeles County, California

14-08-0001-20514

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We have begun a magnetostratigraphic study of the Plio-Pleistocene Saugus Formation of the east Ventura basin (Figure 1). The primary objective of our investigation is to identify dated magnetozones and geomagnetic reversal boundaries for the purpose of more accurate age determination of the Saugus in this area. This would enable one: to make correlations with other age-calibrated sections of Saugus near the coast; to determine average sedimentation rates and possibly detect changes of deposition with time; and to identify rates of displacement, uplift, and rotation associated with the major faults cutting the Saugus.

We have selected sections along the transmission line and the Santa Clara River for establishing our reference magnetostratigraphic column (Figure 2). The former is a well exposed unfaulted homocline with beds dipping about 50° to the north-northeast (Winterer and Durham, 1962). It is also relatively straightforward to correlate the transmission line section with the Santa Clara River section, which exposes yet younger beds of the Saugus Formation dipping more gently to the northeast.

The preliminary paleomagnetic results from our reconnaissance sampling are highly encouraging. Sites were selected at interbeds of the finer-grained sediments (siltstone, sandy siltstone, and silty sandstone), which are typically between 0.5 and 5 m thick. At each site three independently oriented hand samples were obtained. In the laboratory we cut two specimens from each hand sample, and at least one specimen from each site was demagnetized in progressively increasing alternating fields (AF), up to between 400 and 1000 Oersted, to isolate the primary remanence and to determine the blanket alternating fields for demagnetizing the remaining specimens at each site. At least four blanket AF levels were used for each specimen of every site. Figure 3 shows the behavior of two specimens during progressive AF demagnetization. The directions of both normal and reversely magnetized specimens are well clustered, suggesting that both contain only minor components of secondary remanence. The initial increase of the normalized intensity curve of the reversely polarized specimen is rather typical, indicating the overprinting influence of the present-day normal field. Figure 4 shows the stable directions (after AF demagnetization to 300 Oe) of all six specimens of the above two sites before and after bedding correction. The fact that the mean site directions prior to bedding corrections are clearly distinct from the mean Quaternary and the present field supports the interpretation that the stable direction is indeed primary. Table 1 summarizes all the existing paleomagnetic results available for our Saugus sites at the present time. The sites listed in Table 1 are not necessarily in the correct stratigraphic position. An asterisk next to the site designation denotes that AF cleaning has not yet been completed. At present, it appears that all sites (with the possible exception of T.L.-22) will yield polarity information and that the data of many sites are of sufficient quality for obtaining paleomagnetic directions. The sampled sites (Figure 2) are predominantly of reversed polarity (12 out of 14). However, site S-6, which is stratigraphically youngest, is of normal polarity.

For sites justifying calculations of paleomagnetic directions the data were analyzed in two ways: (1) each specimen was assigned equal weight (upper line); and (2) we combined the data for specimens from each oriented sample (lower line), thereby halving the number of independent vectors. The two methods yield essentially identical directions, in all cases estimates for the precision parameter, k, increased when N was halved. The radius of the 95 percent cone of confidence, α_{95}, increased or remained unchanged as N decreased. Only in one case did the α_{95} decrease. Interestingly, these preliminary results suggest an average clockwise rotation of about 23° for sites of the transmission line and Santa Clara River sections. Though very preliminary, these results suggest extremely rapid rotation of the Saugus Formation in this area.

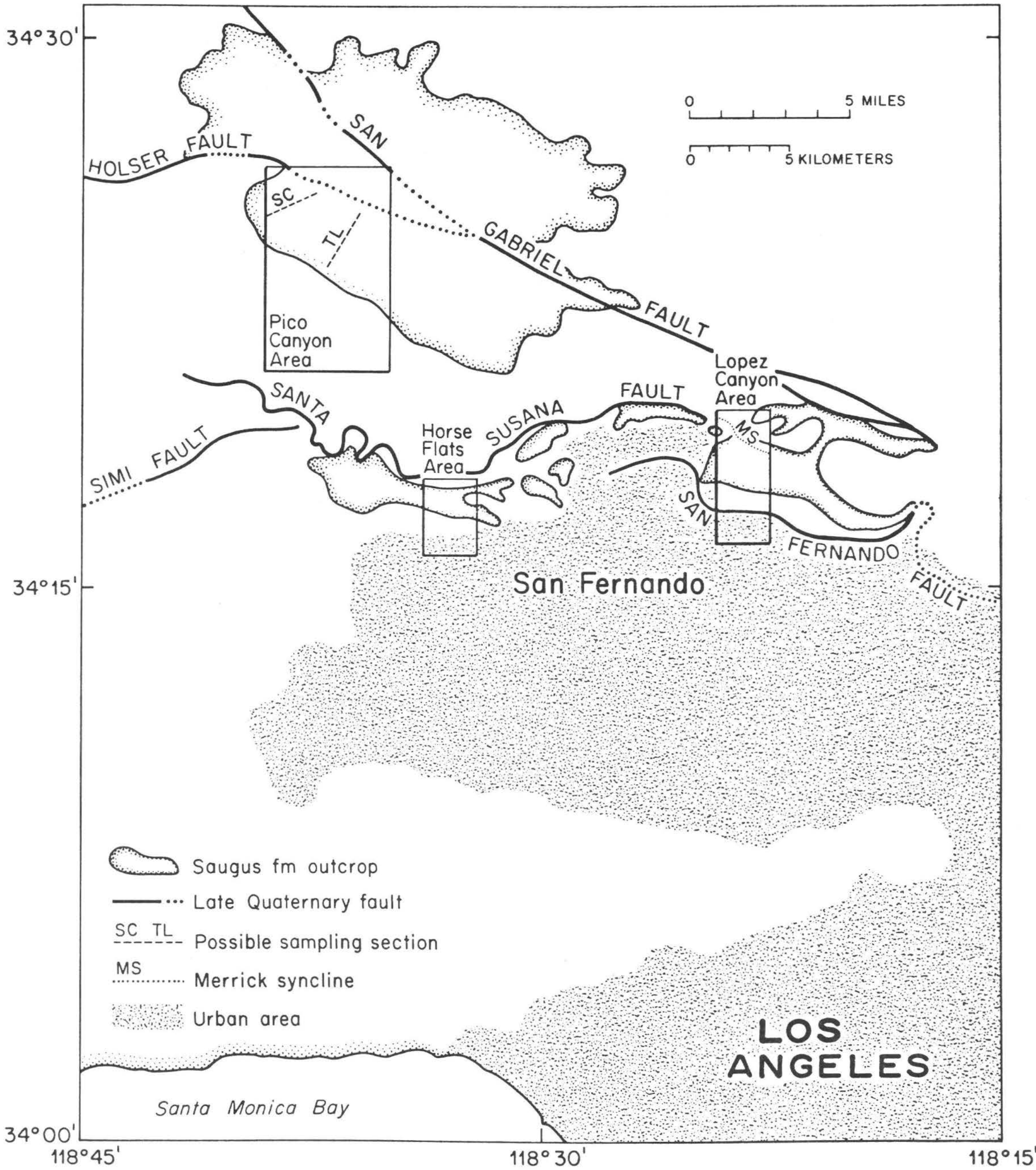


Figure 1. Location of Saugus outcrops in East Ventura basin. The Saugus is cut by several faults with known potential for ground rupture (e.g., San Gabriel, Holser, Santa Susana, San Fernando faults). The rectangles enclose the sections, where we plan to do detailed magnetostratigraphic studies. Figures 3, 4 and 5 represent more detailed geologic maps of the areas enclosed by the rectangles. (SC = Santa Clara Section; TL = Transmission Line Section; MS = Merrick Syncline). Adapted from "Geologic Map of the San Gabriel Mountains, California", 1:250,000, by W.G. Bruer, California Division of Mines and Geology Bull. 196, 1975.

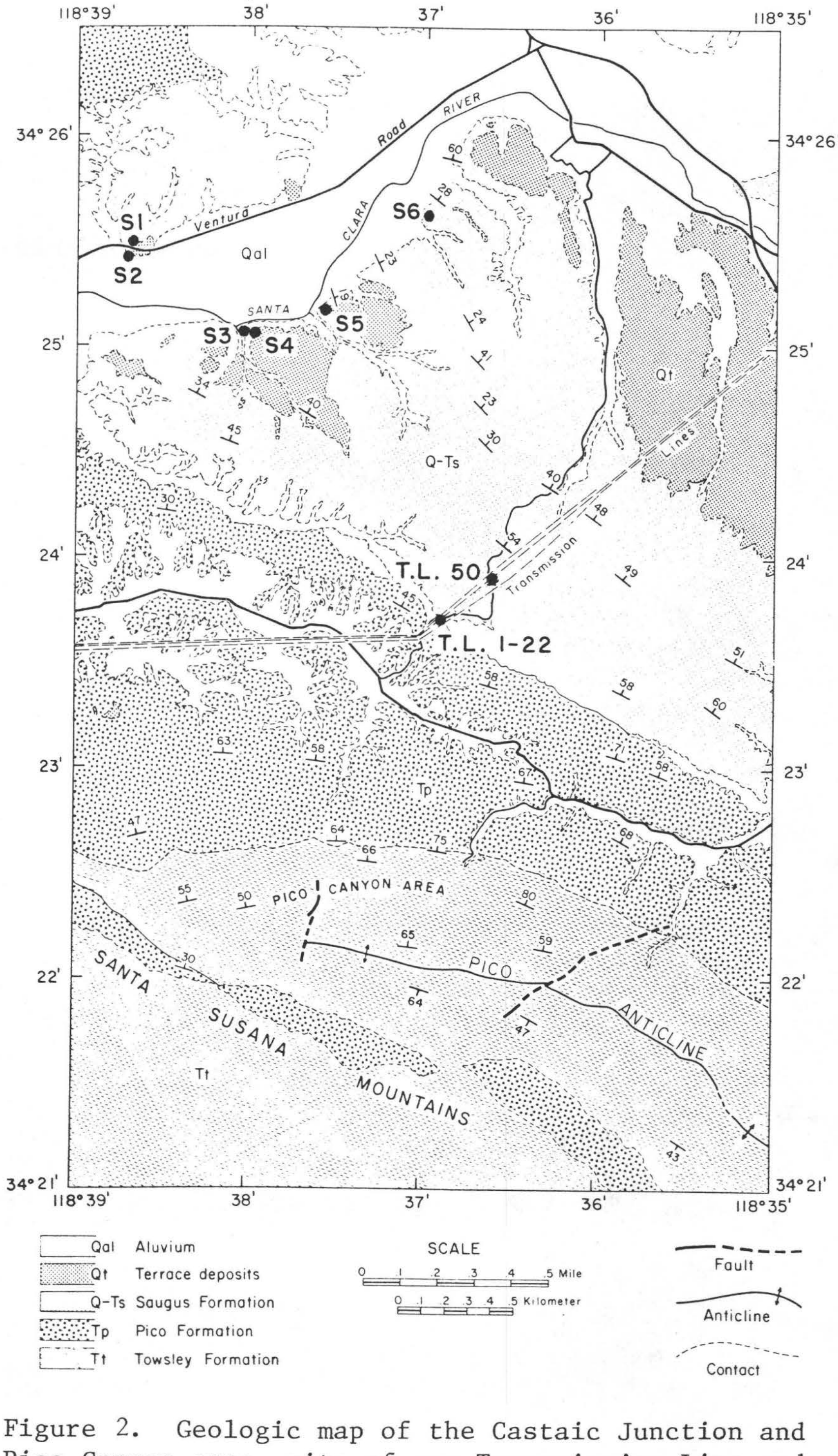
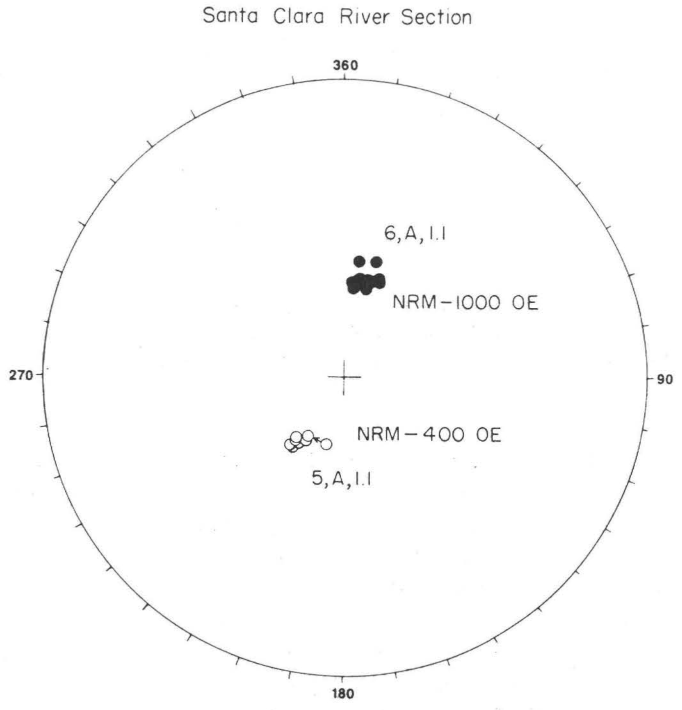


Figure 2. Geologic map of the Castaic Junction and Pico Canyon area, site of our Transmission Line and Santa Clara River sections. Redrawn from "Geologic Map of part of the Ventura Basin, Los Angeles County, California", 1:24,000, Winterer and Durham (1962). (See also figure 2 for location)



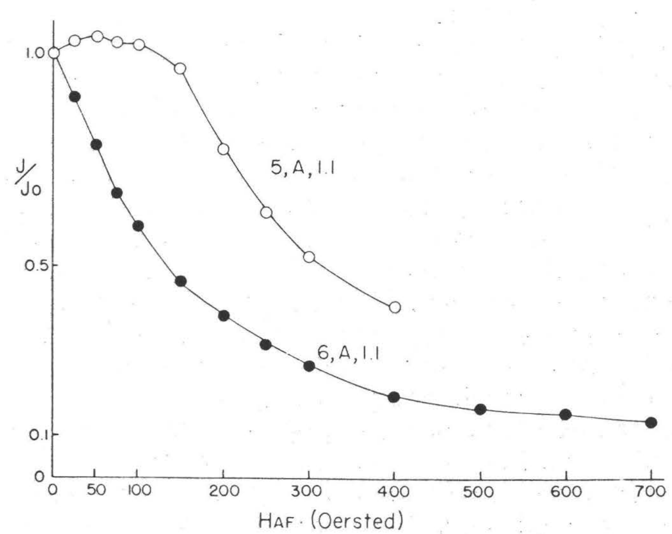


Figure 3. Behavior of the remanence vectors during progressive AF demagnetization of two specimens from a normal and a reversed site of the Santa Clara River Section. Closed (open) circles designate lower (upper) hemisphere inclinations.

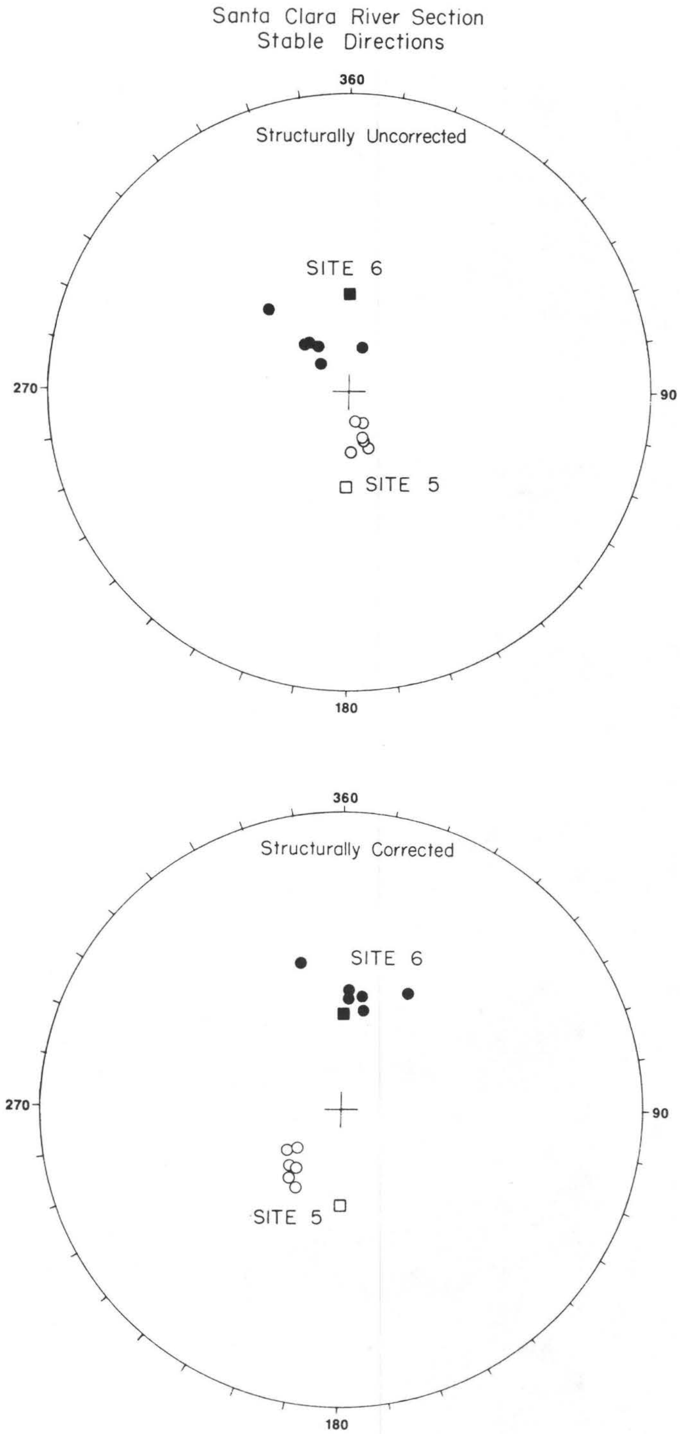


Figure 4. Stable remanence directions (after 300 Oe 'cleaning') of all specimens from sites S-5 and S-6 of the Santa Clara River Section before and after corrections for bedding attitudes: Closed (open) circles designate lower (upper) hemisphere inclinations. Squares represent the expected average remanence directions of the geocentric axial dipole.

TABLE 1: SUMMARY OF PALEOMAGNETIC RESULTS FROM SAUGUS FORMATION

		Uncorrected for Bedding				Corrected for Bedding				AF Demag for Stable
Site No.	N(n)	Dec	Inc	k	α_{95}	Dec	Inc	k	α_{95}	Remanence (Oe)
S - 6	6(6)	324	68	41	11	006	47	41	11	Ave of
	3(3)	327	67	136	11	006	46	220	8	200, 300, 400
S - 5	6(6)	168	-72	233	4	222	-63	242	4	Ave of
	3(3)	166	-71	295	7	220	-64	285	7	200, 300, 400
S - 4 *	5(6)					REVERSED				
S - 3	4(4)	180	-64	156	7	216	-56	157	7	300
	2(2)	179	-64	1394	-	217	-55	1405	-	
S -2 *	6(6)	212	-40	13	19	182	-65	13	19	
	3(3)	212	-39	17	31	176	-63	15	33	
S - 1	6(6)	176	-49	142	6	222	-55	143	6	300
	3(3)	176	-49	804	4	221	-55	841	4	
TL - 50*	6(7)					REVERSED				
TL - 22*	4(6)					NORMAL				
	2(6)					?				
TL - 21	6(6)	39	-59	116	6	196	-70	116	6	400
	3(3)	39	-59	104	12	196	-70	101	12	
TL - 20*	6(6)					REVERSED				
TL - 19	6(6)	31	-61	64	8	198	-69	136	6	400
	3(3)	39	-60	242	8	196	-69	230	8	
TL - 3*	5(6)					REVERSED				
TL - 2*	4(6)					REVERSED				
TL - 1	6(6)	16	-73	42	10	217	-56	42	11	400
	3(3)	16	-72	44	19	216	-55	79	14	

* AF "cleaning" is not yet complete

N(n) Number of specimens or samples used in the calculations (Number of specimens or samples measured)

k Best estimate of precision parameter of Fisher distribution

α_{95} Radius of 95 percent confidence interval of mean direction

MAGNETOSTRATIGRAPHIC INVESTIGATION OF LATE NEOGENE DEPOSITS IN THE ATLANTIC COASTAL PLAIN WITH APPLICATION TO DATING TECTONIC DEFORMATION IN THE CENTRAL AND SOUTHEASTERN UNITED STATES

14-08-0001-19746

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Investigations

1. Extend the magnetostratigraphy in the Neogene of the Atlantic Coastal Plain where the approximate age of sediments has been established using invertebrate fossils, radiometric dates, and amino acid enantiomeric ratios.

2. Refine the record of paleomagnetic secular variation for the Pleistocene in the northeastern United States for application to dating tectonic deformation associated with the Ramapo Fault System (New Jersey and New York).

3. Date Paleogene sediments in the Atlantic and Gulf Coastal Plains using the paleomagnetic polarity time scale that is keyed to the marine faunal record.

Results

1. Paleomagnetic samples from the Canepatch and Waccamaw formations along the Intracoastal Waterway in South Carolina confirm the paleomagnetic polarity previously assigned to the deposits: Canepatch has normal polarity (younger than 0.73 my); Waccamaw has reversed polarity (older than 0.73 my)(Liddicoat and Opdyke, 1981).

Samples of the Great Bridge and Chowan River formations from quarries near Portsmouth, Virginia, confirm the age of the deposits as established by stratigraphic position and analyses of mollusks (Blackwelder, 1981). The Great Bridge Formation records normal paleomagnetic polarity following alternating field (a.f.) demagnetization, and is assigned to the Brunhes Normal Chron (Present-0.73 my). The underlying Chowan River Formation records reversed paleomagnetic polarity, which is consistent with the late Pliocene age assigned to the deposit (Blackwelder, 1981). These findings will permit refinement of the paleontologic record in the central Atlantic Coastal Plain using planktonic foraminifers and nannofossils.

2. Previously, we used a 30-meter core (Shelby tube taken in September 1980) from Pleistocene Lake Passaic (New Jersey) to assess the varved sediment for a paleomagnetic investigation of secular variation (Reimer, et al., 1981).

The agreement of paleomagnetic directions from three depths (4.6, 16.9, and 23.0 meters) gave us encouragement that a means of correlating and dating stratigraphy in the vicinity of the Ramapo Fault might result if additional cores are obtained (Liddicoat and Opdyke, 1981). The coring in August 1981 using a Swedish foil sampler did not result in the desired cores (foils broke before full penetration because the sediment is too stiff). However, the paleomagnetic data from a portion of one of those cores (GS-1) near the Great Swamp Wildlife Headquarters (40°42'30"N, 285°30'E) bolsters our belief that a detailed record of secular variation can be eventually compiled. As part of that assessment, we used paired specimens (1.2-cc cylinders) from ten consecutive varves that span 12 cm, and a string of nine larger specimens (4.7-cc cylinders) over 15 cm in the upper meter of the core. Throughout, the data for a.f. demagnetization are acceptably reproducible, and the ability to identically orient specimens is the critical factor.

3. Paleomagnetic samples from the 40-meter Putney Mill core (New Kent County, Virginia, split spoon) were analyzed as a feasibility study for additional coring in the outer Atlantic Coastal Plain. The data for four specimens following a.f. demagnetization and a shelf test identify reversed polarity near 20-meter depth and normal polarity near 40-meter depth. The findings suggested that paleomagnetism might be used as a chronologic tool in paleontologic investigations of the Paleogene in the Atlantic and Gulf Coastal Plains.

In the expanded investigation, the two most promising localities of exposed Paleogene sediments in Virginia and Maryland occur along the Pamunkey River and Chesapeake Bay (Calvert Cliffs), respectively. Although stratigraphic succession is easily traced along strike, the primary magnetization is obliterated by weathering or is too weak to be measured because of an unsuitable lithology (diatomite). A better opportunity is presented in samples from several long cores that are being rotary drilled near Glouchester, Virginia, by the State of Virginia in cooperation with the USGS Water Resources Division. Analysis of back-to-back samples at approximately 30-meter intervals to the Cretaceous/Tertiary boundary (215 meters) is in progress. Among the objectives is an accurate interpretation of temporal and spatial relationships between sedimentary deposits of marine, marginal marine, and non-marine origin.

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Soil Dating Techniques, Western Region
9540-02192

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Investigations

Purpose: Establish data base for soil chronosequences and conduct fundamental research on the potential of soils as correlation and dating tools for Quaternary surficial deposits in the western United States.

Strategy: Fourteen numerically dated soil chronosequences (table 2) from varied climatic and geologic environments have been sampled and are currently being analysed to determine 1) which soil properies are the most useful indicators of soil age, and 2) how rates of soil development vary in different environments. Analyses preformed by the Dept. of Land, Air, and Water Resources (Univ. of Calif. at Davis) and the U.S.G.S include bulk and extractive chemistry, bulk density, particle size, and mineralogy.

Personnel: M. N. Machette, J. W. Harden, E. M. Taylor, M. C. Reheis, R. M. Burke (all U.S.G.S.); M. J. Singer, A. J. Busacca, and P. Janitzky (all Univ. of Calif., Davis), and M. L. Gillam (Univ. of Colo., Boulder).

Major investigations of the previous six months include:

1. Completed paper that compares soil development in four different climatic regimes through a quantitative field-based index. (Harden and Taylor)
2. Completed manuscript describing the morphology, age, and rate of accumulation of $CaCO_3$ in calcic soils of the southwestern U.S. This paper shows potential uses of calcic soil development in correlating and estimating the age of Quaternary deposits. (Machette)
3. Completed a preliminary draft of laboratory manual describing the chemical, mineralogical, and physical analyses of samples collected from the 14 soil chronosequences of this study. (Singer, Busacca, and Janitzky)
4. Started analysis of Santa Cruz, Ano Nuevo, Animas River, Rock Creek, and Big Horn Basin chronosequences (table 2). (Singer, Janitzky, Gillam, and Reheis)
5. Continuéd laboratory analyses of Honcut, Ventura, and Beaver chronosequences (table 2). (Singer, Busacca, Janitzky, and Machette)

Results

1. Our sampling of soil chronosequences has been completed with the Santa Cruz chronosequence. These samples are currently being analyzed and most lab data should be complete by the end of FY 82. The data is stored by unique USGS number in MULTICS which allows us to access and compare up to thirty chemical, physical, or field properties simultaneously with the MINITAB statistical package. The computer data bank contains over 10,000 analyses for 1000 samples from 175 soil profiles in the western United States.

2. The computer data management system was used to compare development of soils from four areas with different soil moisture regimes. Taylor and Harden (1982) found that the rates of soil development in Merced and Ventura, Calif., Las Cruces, N.M. , and central Penn. are generally compariable when measured by the Soil Development Index of Harden (in press). This use of the index is encouraging and was the topic of much discussion at the recent GSA meeting.

3. Machette completed a study of calcic soils from the southwestern United States. The ages of these soils range from Holocene and latest Pleistocene for incipient Stage I carbonate to thick, indurated Stage IV calcretes of Pliocene to Miocene age (Machette, 1982). Differences in rates of $CaCO_3$ accumulation in calcic soils are mainly a response to the amounts of effective precipitation and influx of airborne $CaCO_3$ and Ca++ dissolved in rainfall (see table 1). Calcic soils are a potential dating tool for Holocene through middle(?) Pleistocene age deposits in widespread parts of the semiarid and arid southwestern U.S.

4. We have identifed soil properties useful as age determinates (fig. 1) in our preliminary investigations of soil chronosequences in the western United States (see table 2). These properties enable one to make quantitative estimates of soil age and is a potential tool in studies of earthquake hazards, earth surface processes, and basic Quaternary stratigraphy.

```
SOIL PARAMETER                        RANGE IN USEFULNESS AS AN AGE DETERMINATE
-------------------------------------------------------------------------------
Soil thickness                        ========================================
Stratification                        ==========================
Soil structure                        ============================
Field melanization                    =======================
Rubification                                         =========================
Dry, moist consistence                                 ====================
Clay films                                                ====================
Total texture                                             ====================
Percent clay                                              ====================
Mineral etching                                         ========================
C organic; N total                    ========================
pH, H exchangeable                    ====================
Base saturation                       ===================               =======
Extractable Fe                              ==================================
Mg total (all size fractions)         ============================
Ca total (all size fractions)                          =======================
Fe and Ti total (fine fractions)                            ==================
Na total (sand & fine fractions)                               ===============
Si/Al total (sand fractions)                    ==============================
-------------------------------------------------------------------------------
                                       10^2    10^3    10^4    10^5    10^6    10^7
                                                     Age, in years
```

Fig. 1. Schematic diagram of the usefulness of soil properties in geologic studies, based on the maximum property development in the Merced area. (Revised from Harden and Marchand, 1977, fig. 8.)

Table 1. Age, maximum stage of carbonate morphology, secondary carbonate content (CS), and average rate of secondary carbonate accumulation ($R\bar{x}$) in relict soils of four regions of the southwestern United States. [From Machette, 1982.]

Area: Geomorphic Surface	Age (m.y.)	Stage	CS, g/cm^2 $\bar{x}$	CS, g/cm^2 range	$R\bar{x}$, in g/cm^2 per 1000 yr
Beaver, Utah: Last Chance Bench	0.5	III+	71	64-78	0.14 ± 0.01
Albuquerque, New Mexico: Llano de Albuquerque	.5	III	110	98-114	$.22\pm0.02$
Las Cruces, New Mexico: Lower La Mesa	.5	IV	129	120-137	$.26\pm0.02$
Roswell-Carlsbad, New Mexico: Mescalero	.5	V-	257	229-307	$.51\pm0.06$

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Table 2. **SUMMARY OF SOIL CHRONOSEQUENCES BEING INVESTIGATED BY THE SOIL DATING TECHNIQUES PROJECT (9540-02192) OF THE U.S. GEOLOGICAL SURVEY.**

Chronosequence	Age range	Climate	Provenance[1] Texture[2]	Number of units	Number of profiles	Number of samples	Present status[3]	MAJOR INVESTIGATORS Chronosequence geology	Soil sampling
1. Sierra Nevada Foothills, CA.	9k-600k	Mediterranean MAT 60^{o}F, MAP 32"	mv psgr	5	12	40	9	Marchand	Harden and Marchand
2. Merced River, CA.	0-3m.y.	Mediterranean MAT 62^{o}F, MAP 12"	gr sa	9	22	154	7-9	Marchand and Harden	Harden, Marchand and others
3. Dry Creek, CA.	0-1m.y.	Mediterranean MAT 62^{o}F, MAP 12"	m,a si,sa	8	9	51	7	Marchand and Harden	Harden, Marchand, and others
4. Front Range, CO.	0-10k	Highland MAT 25^{o}F, MAP 30-35"	gr psbo,sa	4	8	25	7	Birkeland, Burke, and Harden	Birkeland, Burke, and Harden
5. Palisades, CA. (no USGS funds)	0-10k	Highland Tundra MAT 25^{o}F, MAP 35"	gr psbo,sa	3	7	23	5	Burke and Birkeland	Burke and Birkeland
6. Cowlitz River, WA.	0-1.5 m.y.	Marine West Coast MAT 52^{o}F, MAP 47"	a si/cogr	9	12	80	7	Bethel, Dethier, and Harden	Bethel, Dethier, Marchand, Ugolini
7. Ventura	0-85k	Coastal Mediter. MAT 60^{o}F, MAP 15"	cogr si/psgr	4	7	53	7	Lajoie, Marchand, Sarna-Wojcicki, and Burke	Harden and Marchand
8. Ano Nuevo, CA.	0-320k	Mediterranean to West Coast Marine MAT 56^{o}F, MAP 37"	psgr s2	4	6	58	4	Burke, Marchand, and Webb	Harden, Burke, and Taylor
9. Santa Cruz, CA.	0-1m.y.	Marine West Coast to Coastal Mediter. MAT 56^{o}F, MAP 37"	gr sa	9	9	77	4	Burke, Bradley, and Curry	Harden, Burke, Busacca, Reheis, Taylor, Machette
10. Honcut Creek, CA.	0-3m.y.	Mediterranean MAT 62^{o}F, MAP 21"	a,mv,gr si,cogr	9	19	112	7-8	Busacca and Singer	Busacca and Singer
11. Beaver basin, Utah	0-500k	Contin. Subarctic MAT 48^{o}F, MAP 12-16"	r,a cogr,sa	5	22	100	5	Machette	Machette
12. Rock Creek, SW Montana	0-600k	Contin. Subarctic MAT 42^{o}F, MAP 16-22"	gr,s2 cogr	7	19	150	4-7	Reheis	Reheis
13. Big Horn Basin, Wyoming	0-600k	Contin. Subarctic MAT 45^{o}F, MAP 7"	s3,s4 psgr	7	9	60	5-7	Reheis	Reheis
14. Animas River, Durango, CO. to to Farmington, NM.	0-1.5. m.y.(?)	Contin. Subarctic to Contin. Semiarid MAT 46^{o} to 51^{o}F, MAP 18" to 8"	mixed si/cogr	11	nd	nd	4-5	Scott and Gillam	Gillam

1/ Provenance: gr = granitic; a = andesitic; r = rhyolitic; b = basaltic; m = metamorphic (slate, schist); mv = metavolcanic; s2 = sedimentary (fairly stable mineralogy); s3 = sedimentary (relatively stable mineralogy, s4 = sedimentary (unstable mineralogy).

2/ Texture: si = silty; sa = sandy; gr = gravelly; co = cobbly; bo = bouldery; ps = poorly sorted.

3/ Status: 1 = reconnaissance, 2 = area selection, 3 = site selection, 4 = sampling and description, 5 = conventional soil analysis, 6 = neutron activation and (or) X-ray fluorescence, 7 = data interpretation, 8 = report writing, 9 = report published.

Quaternary Dating and Neotectonics
9530-01559

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Investigations

1. Synthesized soils data for surficial deposits of different compositions and different ages in areas adjacent to the Wasatch fault (R. R. Shroba).

2. Synthesized stratigraphic and sedimentological data for age and origin of Quaternary gravel deposits, basin and range of southeastern Idaho (K. L. Pierce and W. E. Scott).

3. Trenched possible fault scarps on alluvial fans near Raft River geothermal plant, Idaho to investigate their age and origin (K. L. Pierce).

4. Completed compilation of map (scale 1:125,000) showing Quaternary deposits and faults, and fault-scarp morphological data for the Rio Grande Rift of Colorado. Continued development of diffusion-equation model for fault-scarp degradation with time (S. M. Colman).

5. Began background work and inquiries for a collection of papers on rates or rock weathering (S. M. Colman).

6. Prepared linework for a series of seven maps (scale 1:250,000) showing Pliocene and Quaternary faults in the Rio Grande Rift in New Mexico and western Texas. These maps show fault locations, amounts of displacement, ages of faulted deposits, and recency of fault movement. Also included is scarp morphology data for 32 of the more prominent Quaternary faults of the rift. Started compilation of Neotectonic map of the Rio Grande rift at one million scale. This map will show faults in four age catagories: Pliocene and early Pleistocene, middle Pleistocene, late Pleistocene, and Holocene. Also shown are Miocene and older rocks, Pliocene-Quaternary sediments, and Pliocene-Quaternary volcanics (M. N. Machette)

Results

1. The age of deposits along the Wasatch front, many of which are locally faulted, can now be estimated by soil studies. Soils in various parent materials have been quantitatively characterized by field and laboratory parameters for ages of about 2,000-4,000 yrs, 4,000-6,000 yrs, 8,000-10,000 yrs, 11,000-20,000 yrs, and >100,000 yrs (R. R. Shroba, investigation no. 1).

2. The extensive gravel deposits in the Basin and Range of SE Idaho are the most useful local datum for studying Quaternary faulting. Soils, carbonate coats on stones, carbon-14 dating, and relations to local glacial deposits indicate that well-washed, clast supported gravels are of Pleistocene age and were deposited under conditions with much greater runoff than present. In Holocene time, deposition has been limited to rubbly deposits at fan heads below steep mountain valleys and to fine-grained sediment along axial drainages. (K. L. Pierce and W. E. Scott, investigation no. 2 and in press).

3. Two scarps about 5 m high cutting alluvial fans on the western side of the Raft River valley and look like normal fault scarps, but trenches across these features show that they are not. The contact between a unit of unfaulted bouldery alluvium and the underlying Salt Lake(?) Formation dips 4^o for 50 m across the structurally disturbed zone, whereas the fan-surface gradient is 1.5^o, indicating that tilting accounts for two thirds the topographic releif. Three vertical filled fissures cutting the Salt Lake(?) Formation that were exposed in the bottom of the trench discharged groundwater into the trench. They are apparently responsible for lines of darker vegetation apparent on the aerial photographs. Thickening of the loess towards the tops of the scarps accounts for the remainder of their topographic relief. The age of these structures is middle Quaternary or older as indicated by unaffected units in both the upper part of the trenches and along strike to the north. These trench exposures favor interpretation of the structurally disturbed zone as related to extension above a subhorizontal fault rather than as related to a high-angle fault cutting basement rocks (K. L. Pierce, investigation no. 3 and Williams and others, in press).

4. The map of the Rio Grande rift of Colorado (scale 1:125,000) is the first map of the entire length of the structure that focuses on Quaternary faults and deposits. The map clearly shows the pattern of young faulting along the fronts of the Sawatch and Sangre de Cristo ranges, and portrays the morphologic data for the fault scarps. Computer analysis of the scarp morphology data using a diffusion-equation model suggests that many of the faults have had similar histories (S. M. Colman, investigation no. 4).

5. Analyses of fault scarp morphology for 32 of the more prominent Quaternary faults of the Rio Grande rift in New Mexico and western Texas have been collected. The final data set consists of about 250 scarp profiles. Estimates of ages of most recent movement for these faults is based on comparisons with the morphometric data collected along the La Jencia fault in central New Mexico. The following two segments of the La Jencia fault are here used for calibration:

1) Segment C (~5,000 yrs old): $\theta = 7.8 + 20.2 (\log Hs)$, and
2) Segment D (~15,000 yrs old): $\theta = 3.8 + 21.0 (\log Hs)$.

Scarp slope angle (θ) and scarp height (Hs or Hm for mutliple event scarps are used to quantitatively define the degraded nature of fault scarps. In the following examples of morphometric data for fault scarps (figs. 1-4), those scarps with data sets lying above the upper dashed line (5K) are considered to be Holocene, those between the two dashed lines (5K and 15K) are considered to be Holocene or latest Pleistocene, and those below the lower dashed line are considered to late Pleistocene or older (middle? Pleistocene). Solid circles indicate total scarp height measurements; open circles indicate partial scarp heights related to the most recent surface rupture (M. N. Machette, investigation no. 6).

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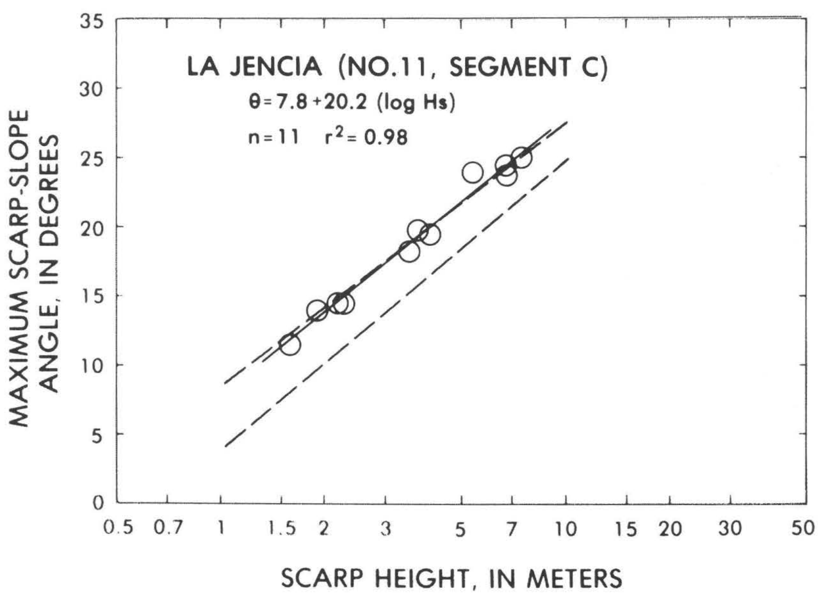

Figure 1. Scarp morphlogy data for segment C, La Jencia fault, central New Mexico. Scarps are 1.5-7 m high, the products of a single Holocene rupture event. Age estimate fo 5,000 yrs B.P. comes from quantitative accessment of soils development in faulted and unfaulted materials along the fault.

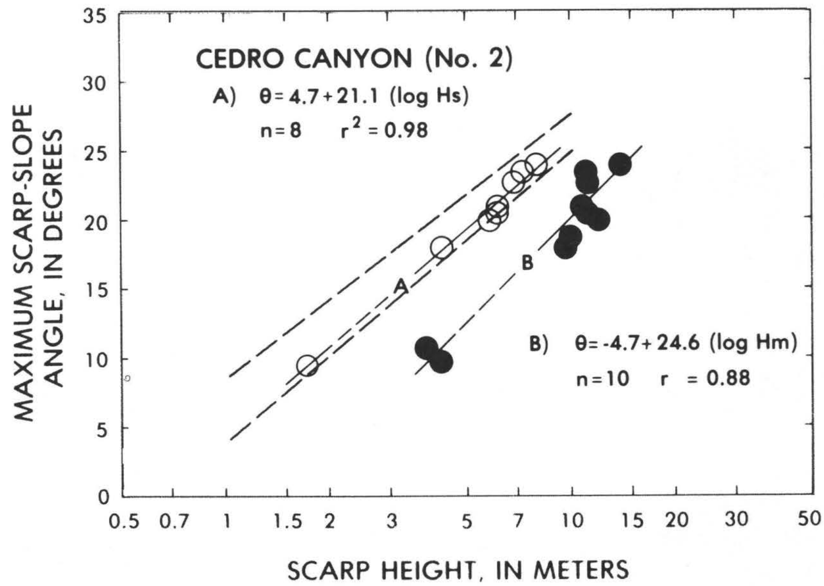

Figure 2. Data for the Cedro Canyon fault, located about five km south of Costilla, New Mexico. Most recent movement of this recurrent fault occurred in the latest Pleistocene (it does not cut Holocene alluvium). Black circles are total scarp height (multiple movements), whereas open circles indicate partial scarp heights related to latest faulting.

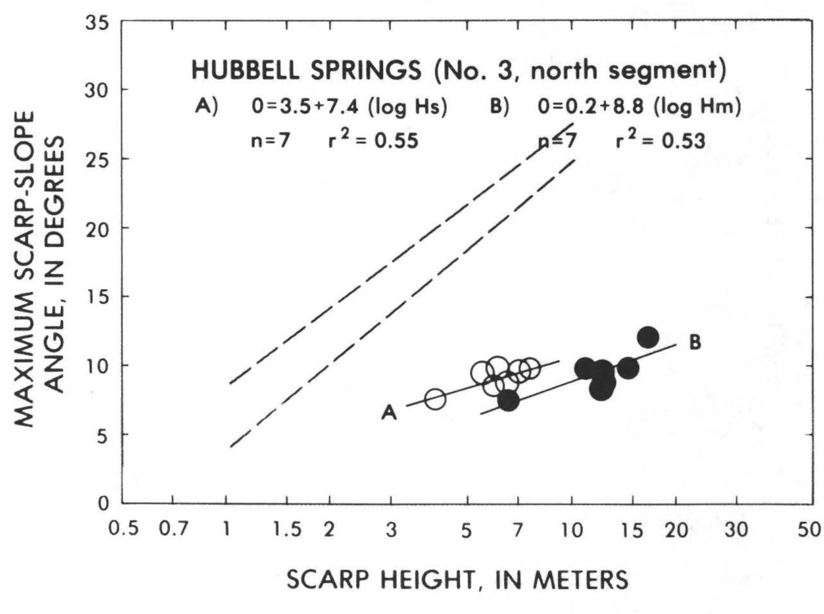

Figure 3. Scarp morphology data for the northern segment of the Hubbell Springs fault, located 20 km east of Belen, New Mexico. Eariler reported as Holocene, our evidence suggests that the most recent movement occured in late Pleistocene (or eariler). Latest Pleistocene deposits are not displaced along this segment of the fault (symbols are same as in fig.

Neogene Micromammal Biochronologies

9590-02708

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Investigations

The purpose of this project is to develop late Neogene-Quaternary biochronologies for rapidly-evolving small mammals in order to increase the ability of paleontology to date non-marine sediments. The biochronology of the microtine rodents has been completed and enables the age determination of sediments that are 5 m.y. old or younger in temperate to arctic regions around the northern hemisphere with an accuracy comparable to K/Ar dates of volcanic rocks. The neotomyine and sigmodontine rodents, also rapidly evolving lineages but with a warm temperate to tropical habitat preference, are now under study. These new biochronologies will extend the usefulness of micromammals into southernmost United States and Mexico, areas where microtine rodents are very rare except during the glacial episodes of the Pleistocene. These rodents of current study are exclusively North American, however, and will be of little value in dating Old World deposits. The microtine rodents remain the single most useful mammalian group for intercontinental correlation during the last 5 m.y.

It should be noted that micromammals have proven, during the course of this research, to be much more abundant in non-marine sediments than large mammals. Most of the micromammal localities found have few or no large fossil mammals, although large mammal localities usually have micromammals in them. Micromammals appear to occur in specific depositional environments and their discovery requires trained collectors because of this environmental preference (or preservation) and because of their small size. Guidelines for collecting are being formulated but at present the field geologist usually has neither the time nor the guidelines for finding micromammals.

As much as possible, the work of this project has been directed toward areas of tectonic interest in the hope of providing data of use to other studies, as well as to those of the project. Personnel during the first half of FY 1982 have included the project chief and Anne H. Walton, Museum Technician.

Results

In the first half of FY 1982 the following results have been obtained. It is to be noted that these are largely in southern areas where attention has been concentrated in developing the new micromammal biochronologies.

1. Uplift of the San Bernadino Mountains, California. Deposits in the San Timoteo Badlands, south of the San Bernadino Mountains, record the first appearance in this area of debris derived from the rising Transverse Ranges source area to the north along the San Andreas Fault (Morton and Matti,

9540-01616). The Mount Eden fauna occurs in this part of the section and has been known for 60 years as being of late Hemphillian age (about 7-5 m.y.b.p.). Interest has been expressed in a more precise date, and the application of the developing neotomyine rodent biochronology has indicated an age of between 5.0 and 5.4 m.y.b.p. for this change in source area. Earlier work, based upon the microtine rodent biochronology, had indicated that deposition derived from the Transverse Ranges continued in the San Timoteo structural block at least until about 1.2 m.y. ago before deformation halted deposition in the area.

To the north of the San Bernadino Mountains, near Lucerne Valley on the Mojave Block, the Old Woman Sandstone also records the first appearance of debris from the Transverse Ranges; the formation was subsequently overthrust from the south. Two poor faunas are known from the Old Woamn Sandstone in that part of the section underlying the earliest clasts derived from the San Bernadino Mountains. Use of the developing neotomyine rodent biochronology indicates that these faunas are between 2.5 and 3.0 m.y. old.

Farther west along the San Andreas Fault near Palmdale, the Harold Formation, previously considered younger than 400,000 years, is now known to be between 800,000 and 1,000,000 years old on the basis of the developing neotomyine rodent biochronology.

2. Elsinor Fault Zone, California. Coincident with biochronologic studies, two localities within the Elsinor Fault Zone have shed light on the age of the deposits involved in this structure. From known localities near the town of Radec and in the Temecula Arkose (presumably the middle part), neotomyine rodents have been collected which indicate an age of about 4.6 m.y. Earlier studies of the large mammals from this region had suggested an age of between 2 and 3 m.y. Near the town of Murrieta, to the northwest of Radec along the fault zone, microtine and neotomyine rodents from a locality in the "unnamed sandstone and conglomerate formation," overlying the Temecula Arkose, indicate a correlation with oxygen isotope stage 16 and an age of about 600,000 years.

3. Rio Grande Trench, New Mexico. In a reconnaissance of deposits in the southern part of the Rio Grande rift zone of New Mexico, the oldest known deposits of the Sierra Ladrones Formation (extended) were found near Truth or Consequences and are dated by micromammal biochronologies at 4.0 m.y.b.p. This date is in agreement with basalt dates in the lower part of the formation near Socorro, far to the north. Younger faunas and ashes are known from the Truth or Consequences area southward to El Paso (Machette, in Pierce 9530-01559) which extend into deposits as young as 600,000 years. The youngest deformed deposits in the northern part of the trench (San Luis Valley, Colorado) had earlier been dated by microtine biochronology as spanning at least the time between 800,000 and 600,000 years b.p. Micromammals have not been looked for elsewhere in the Rio Grande Rift except in rocks in the 14 to 7 m.y. age range in the northern part of New Mexico. Field plans for FY 1982 are centered on the discovery of other micromammal localities in the southern part of the trench in New Mexico.

4. Beaver, Utah. Although the age of the deposits in the Beaver Basin are well established by tephrochronology (Izett 9530-02169) and correlated by stratigraphic studies (Pierce 9530-01559), the micromammal fauna presents

some interesting contrasts with localities off of the Colorado Plateau to the west in adjacent Nevada and to the south in central Arizona. These faunas of the same age, as determined by micromammal biochronology and that lie beyond the Colorado Plateau to the south and west, lack some of the distinctive microtine rodents from the Beaver fauna, and the Beaver fauna lacks several distinctive neotomyine rodents found west and south of the Plateau. The Beaver fauna, instead, is similar to faunas found as far north as Thayne and Jackson Hole, Wyoming. Faunal provincialism, because of differing elevations between the Colorado Plateau and the adjacent Basin and Range of 2.0 to 2.5 m.y. ago, seems evident and raises the possibility of detecting changes of elevations of sedimentary basins through recognition of vertically-zoned faunal provincialism.

5. Elk Hills, California. On Naval Petroleum Reserve No. 1, the youngest sediments involved in the first upwarping of the Elk Hills anticline contain micromammals (both neotomyine and sigmodontine rodents) which indicate deposition about 2.1 m.y. ago. These beds subsequently were upwarped, beveled, and overlain by fluvial gravels that are as yet undated and that were themselves subsequently upwarped to produce and present total structural relief.

6. Gubik Formation, Alaskan North Slope. At two localities southeast of Point Barrow, marine mammals from a basal unit of the Gubik Formation indicate great differences in age. These indications are based upon the known biochronology of these marine mammals as calibrated around the Northern Hemisphere by micromammal biochronology. At one locality the basal marine unit of the Gubik is within 200,000 years of being 2 m.y. old; at the second, the basal(?) marine unit is most likely only about 120,000 years old. Dating is through micromammal chronology as correlated to the oxygen isotope records of the deep sea cores. Formerly, all Gubik deposits were thought to be middle to late Pleistocene, and the depositional picture seems a good bit more complex with the recognition of such extreme age variation within the formation.

7. Tautavel Man, southern France. Evaluation of the microtine rodents and other fossil mammals from la Caune de l'Arago, in Roussillion, southernmost France, strongly indicates a correlation with oxygen isotope stage 8, peaking about 260,000 years ago, although stage 10, peaking about 100,000 years earlier, cannot be ruled out at present. The near coincidence of this date to that determined by Kvenvolden (9830-01996) through amino acid analysis in the second Semi-Annual Technical Report of FY 1981 (Vol. XIII) is encouraging.

8. Homo erectus, Israel. The microtine rodent biochronology is worldwide in the Northern Hemisphere, as has been indicated. In reviewing the microtine fauna from 'Ubeidiya, Israel, it was noted that the age of "slightly more than 700,000 years b.p." usually given for this locality was impossible and was based upon the dogma that man evolved in Africa. Thus, extra-African records had to be younger. The microtine rodents indicated an age of 2.0 m.y. with probably less than 100,000 years margin of error on either side of this date. A review of the faunal history of Africa, Israel and the Levant, Europe, and western Asia clearly indicated that the other mammalian elements of 'Ubeidiya also indicated approximately this age. The presumed *Homo erectus* from the 'Ubeidiya fauna is at least one million years older

than is generally believed and half a million years older than the earliest record of Homo erectus, the first universally recognized man, in Africa. At present, there is no evidence that man evolved in Africa.

Reports

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Repenning, C. A. In press. Pleistocene mammalian faunas: climate and evolution (for the proceedings of the Third International Theriological Congress to be held in Helsinki, August, 1982) (Director's approval granted, 13 ms. pages).

Repenning, C. A., and Fejfar, O. In press. 'Ubeidiya, Israel: closer to Eden (Director's approval granted but not yet sent to *Nature*, 17 ms. pages).

Basement Tectonic Framework Studies
Southern Sierra Nevada, California

9950-01291

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Investigations

1. Petrographic study and preliminary write-ups of the data on some granitic units near the Kern Canyon fault zone.

2. Revision following technical reviews of the Professional Paper manuscript dealing with possible correlations of basement rock units across the San Andreas and San Gregorio-Hosgri fault zone.

Results

The basement rock data from the southernmost Sierra Nevada have been re-assessed in the light of recent emphasis on tectono-stratigraphic terranes along the western continental margin of North America. Several discrete terranes (structural elements) have been defined in the southernmost Sierra Nevada that are relatively homogeneous with regard to metamorphic framework rocks, granitic intrusive rocks, and initital strontium ratios. Some of the terranes are separated by major structural breaks, others are not.

The most distinctive terrane is dominated by dark gneissic rocks, amphibolite, and greenschist of probable oceanic affinity judging by initial strontium ratios of 0.703 to 0.704. Sparse and somewhat equivocal radiometric age dates suggest that at least part of this terrane is about 160 m.y. old. This age suggests contemporaneity with the Coast Range ophiolitic terrane as well as with some ophiolitic scraps along the western foothills of the Sierra Nevada to the north.

In sharp contrast are three dominantly granitic terranes with minor amounts of chiefly quartzo-feldspathic and calcareous metasedimentary framework rocks. Initial strontium ratios of 0.707 to 0.708 in all three terranes indicate continental crust. Sparse radiometric age dates suggest that the granitic rocks in all three terranes are Cretaceous. Less is known of the probable age of the metamorphic framework rocks, but rubidium-strontium data suggest the possibility of a Jurassic age for minor metavolcanic layers in the Bean Canyon Formation in the terrane southeast of the Garlock fault. Two of the three granitic terranes are separated from the main Sierra Nevada massif by major structural breaks (Garlock and Pastoria fault zones).

Of special interest is a "transitional" terrane that is dominated by the tonalite of Bear Valley Springs. Initial strontium ratios of about 0.705 suggest an environment at the margin between oceanic and continental crust for this terrane. Only the transitional terrane and one of the previously mentioned granitic terranes is now tied directly to the Sierra Nevada batholith. The two structurally separated granitic terranes are probably only displaced tens of kilometers from their original position in the batholithic belt. The oceanic terrane, on the other hand, may be a widely travelled terrane that was accreted to the continental margin sometime in the Jurassic or early Cretaceous.

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 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, M.J. Woodward, J.L. Slate, and J.R. Rivera, 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, and R.F. Yerkes, BEG; Santa Clara (del sur) River basin, with Gerry Treiman, CDM&G; Los Angeles basin, with T.H. McCulloh, BO&GR; Anza-Borrego area, with George Miller, Imperial Valley College; Lake Tecopa area, with J.W. Hillhouse, BP&RS).

   b) Central California (San Joaquin Valley, with J.A. Bartow and W.R. Lettis, BWRG; Mono Basin, with K.R. Lajoie)

   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, BEG&M).

   d) Western Nevada (with J.O. Davis, Desert Research Institute, Reno, Nev.).

   e) Central and eastern Washington (with Susan Shipley, BWRG, and R.B. Waitt, Cascade Volcano Observatory).

2) Completed through Director's approval report on Holocene volcanism in the conterminous U. S. and role of silicic volcanic ashes in correlation of latest Pleistocene and Holocene deposits (for 1982 INQUA Congress; with D.E. Champion, BP&RS, and J.O. Davis, Nevada Archeological Survey, Reno, Nev.).

3) Completed, through review stage, study on hazards to nuclear reactors from volcanic ash erupted in the Pacific Northwest of the U. S. (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, BWRG).

Results

1) We correlate an ash bed exposed in the upper part of a thick sequence of ancient lake beds in Mohawk Valley, northeastern California, with the Rockland ash bed. The Rockland ash bed is a widespread marker bed found at many localities in northern California and western Nevada. In a previous study, we obtained an age of 0.45 ±0.08 m.y. by the fission-track methods on zircons obtained from samples of this ash exposed south of San Francisco. This ash has also been dated as 0.45 ±0.30 m.y. by the K-Ar method (Gilbert, 1969), on samples collected near Manton, in northeastern California, near the eruptive source of this ash. This correlation establishes the mid-Plesitocene age of that part of the Mohawk lake beds that contains the ash. Another ash, identified as the Dibekulewe ash bed, has been found in these lake beds in the same area, but its age relative to the Rockland ash bed could not be deduced on the basis of local stratigraphy (with S.A. Mathieson, C.E. Meyer, and M.J. Woodward).

2) The Rockland and Dibekulewe ash layers have been identified in stratigraphic context, however, near Mexican Dam, south of Carson City, western Nevada, where the Rockland ash layer overlies the Dibekulewe ash layer (with J.O. Davis, C.E. Meyer, and M.J. Woodward).

3) The Dibekulewe ash bed has been tentatively identified from an exposure near Oreanna, in west-central Nevada, where it is found in the Paiute Formation. At this locality, according to J.O. Davis, the Dibekulewe ash bed is stratigraphically above the Lava Creek ash bed, dated elsewhere by others at 0.6 m.y. (the latter ash bed has been previously referred to as the Pearlette type O ash). Thus, if the correlation of the Dibekulewe ash bed is confirmed, its age is between 0.45 and 0.6 m.y. Thus, the upper part of the Mohawk Lake beds probably span an interval of about 0.45 to 0.6 m.y. (item 1) (study in cooperation with J.O. Davis).

4) We have identified the Putah Tuff Member of the Tehama Fm. in the subsurface of the Sacramento Valley near Orland, from a bore-hole sample obtained at about 440 m below the surface. We identify another tuff, about 10 m higher in the same bore hole, as the Nomlaki Tuff Memeber of the Tehama Formation, dated by others at 3.4 m.y. by the K-Ar method, an age identical to that obtained previously by others on the Putah Tuff Memeber. Exposures of the Putah Tuff Member are restricted to the southwestern flank of the Sacramento Valley, while exposures of the Nomlaki Tuff Member, to the northwestern and northeastern flanks, and nowhere have the two tuffs been exposed together. The Nomlaki Tuff is widespread, and has been identified by us as far south as the Los Angeles basin in both surface exposures and in the subsurface, in the Repetto beds. Identification of the two tuffs in close stratigraphic proximity within the core establishes for the first time their relative ages, and supports their similar radiometric ages (with C.E. Meyer and M.J. Woodward).

5) Results of energy-dispersive X-ray fluorescence analysis of glass of several superposed silicic ash layers in Wilson Creek, north of Mono Lake, California, indicate that glass chemical compositions of these ash layers are sufficiently distinctive that they can be identified by their chemical signatures, and correlated among several outcrop localities within Mono basin. These ashes were erupted from the Mono Craters over a period of about 35,000 to 7,000 radiocarbon yr B.P. (K.R. Lajoie). We are currently working on correlating the Wilson Creek ashes to near-source tephra units exposed near the Mono Craters, as well as to several localities in western Nevada.

6) Stratigraphy, thickness, and grain size of the ash layer formed by the May 18, 1980 eruption of Mount St. Helens, has been studied to monitor changes that have taken place over the last two years as a consequence of erosion and redeposition. At many downwind locations, the original three-fold and two-fold stratigraphy has been little modified since initial deposition, except for compaction of as much as 45 percent over the May 18, 1980, thicknesses. At other localities, the ash lobe axis has been shifted as a consequence of reworking by wind. In several small, closed basins, a considerable thickening of the May 18 air-fall layer has been observed, a consequence of local reworking. At such sites, the original air-fall stratigraphy is preserved beneath a massive, poorly-stratified layer of reworked ash. These observations are being applied to studies of stratigraphy of pre-historic tephra layers, in order to estimate the original thicknesses and the magnitudes of the associated eruptions (study by Susan Shipley, BWRG).

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Mathieson, S. A., and Sarna-Wojcicki, A. M., 1982, Ash layer in Mohawk Valley, Plumas County, California, correlated with the 0.45 m.y.-old Rockland ash--implications for the glacial and lacustrine history of the region, in Geological Society of America Abstracts with Programs, v. 14, no. 4, p. 184.

Sarna-Wojcicki, A. M., and Yerkes, R. F., 1982, Comment on article by R. S. Yeats on "low-shake faults of the Ventura basin, California," in Cooper, J. D., ed., neotectonics in Southern California, volume and guidebook for 78th Annual meeting, Cordilleran Section, Geological Society of America, Field Trip 3, p. 43-51.

Salton Trough Tectonics and Quaternary Faulting

9940-01292
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Investigations

1. Short base-line leveling across the San Jacinto fault zone and the San Andreas fault.

2. Trenching of the Imperial fault at the United States-Mexico border.

3. Mapping of Quaternary structure along the Superstition Hills and Superstition Mountain faults.

Results

1. Four of five short-base leveling lines across two strands of the San Jacinto fault zone southeast of Anza show elevation changes that are insignificant for a 17 month period. However, the fifth line, at the Coyote Creek fault 14 km southeast of Anza, showed a cumulative uplift of 5 mm over a line length of 0.34 km in 377 days, equivalent to a west-southwestward component of tilt of about 15 microradians. By 519 days, the overall tilt decreased to 10 microradians, but elevations near the fault trace had continued to increase. A similar pattern of deformation was observed across the Imperial fault in early 1979 before the Imperial Valley earthquake.

An east-west 0.58 km-long leveling line across the San Andreas fault at North Shore, in 497 days, recorded an uplift of 13.4 mm, equivalent to a westward component of tilt of 23 microradians. The tilt has accumulated irregularly in time. The direction of tilt, here as well as across the Coyote Creek fault, agrees with the sense of the relative vertical component of past fault movement indicated by geologic or geomorphic evidence. Groundwater pumping may be affecting the North Shore elevation changes but not those at Middle Willows.

2. Trenches supplementary to those cut in 1977 provide new data on the right-lateral displacement of several layers of deltaic and lacustrine sediments that are transected by the Imperial fault. One marker layer, radiocarbon dated at about 710 $\pm$ 57 years BP, overlies another that has been offset by an amount that matches the 1940 fault slip. Apparent pre-1940 deformation found in one excavation is spurious. For the usually seismically quiet and noncreeping central segment of the fault where the 1940 movement was greatest, these data limit the recurrence time for displacement to greater than 700 years. The historic surface displacements north of this part of the fault, in 1979, 1940, and possibly in 1915, suggest that more than ten 1970-type earthquakes might recur before the central locked section of the fault will move again. This result is so surprising that the age of the charcoal-bearing layer must be investigated further.

3. Field work for the Superstition Hills fault is completed. Southeast of the part of the fault that has shown right-lateral creep several times in the last three decades, a 1 km extension of the fault has been discovered. Fresh cracks found only in this segment in January 1982 suggest that this part of the fault also moves intermittently by creep.

Field work along the Superstition Mountain fault is 10 percent complete.

Reports

Sharp, R. V., 1981, Displacement on tectonic ruptures in the San Fernando earthquake of February 9, 1971: discussion and some implications: U. S. Geological Survey Open-File Report 81-668.

Burford, R. O., and Sharp, R. V., 1982, Slip on the Hayward and Calaveras faults determined from offset power lines [abs.]: Proceedings, Conference on Bay Area Earthquake Hazards.

Sharp, R. V., Lienkaemper, J. J., and Rymer, M. J., 1982, Surface displacement on the Imperial and Superstition Hills faults triggered by the 26 April 1981 Westmorland, California earthquake: Seismological Society of America Earthquake Notes, v. 53, no. 1, p. 12-13, and U. S. Geological Survey Open-File Report 82-282.

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Clark, M. M., in press, Map showing recently active breaks along the San Andreas and associated faults between Salton Sea and Whitewater River - Mission Creek, California: U. S. Geological Survey Miscellaneous Geologic Investigations Map (scale 1:24,000).

Clark, M. M., Yount, J. C., Vaughan, P. R., and Zepeda, R. L., in press, Map showing surface ruptures associated with the Mammoth Lakes, California, earthquake of May 1980: U. S. Geological Survey Miscellaneous Field Investigations Map MF-1396 (scale 1:24,000).

Detailed Geologic Studies, Central San Andreas Fault Zone

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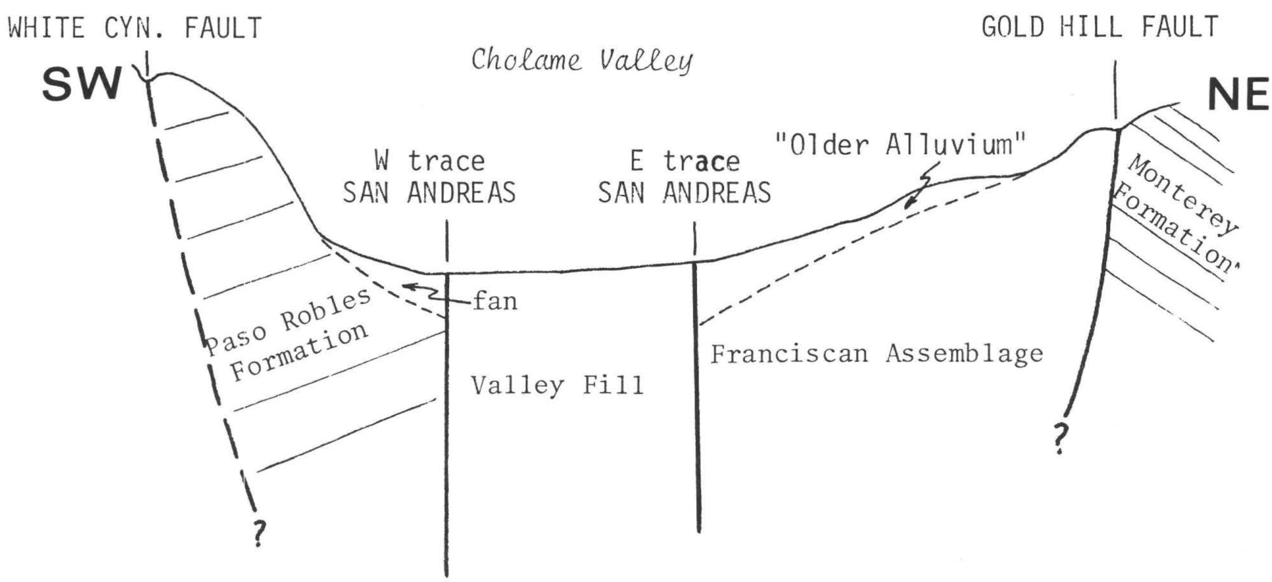
Investigations

Detailed geologic investigations of surficial and bedrock deposits in and adjacent to the central section of the San Andreas fault zone.

Results

1. The study of fault relationships in the Cholame Valley area has delineated the San Andreas fault zone between two boundary faults the "White Canyon" fault to the southwest of the zone and the Gold Hill fault to the northeast. The Gold Hill fault is a high-angle reverse fault that brings Franciscan Assemblage ophiolite in contact with Miocene and younger rocks. The "White Canyon" fault appears to be a high angle fault but is confined to the Pliocene Paso Robles Formation and its style of movement is not yet known. Below is a sketch of inferred relationships.



A part of this project is to examine possible trenching sites that will yield recurrence interval or slip rate information. One site in the Cholame Hills 7 1/2" Quadrangle about 2 mi SSE of Parkfield was identified. The site is a valley beheaded by the San Andreas Fault and closed by a shutter ridge. The valley will be examined using portable exploration seismic equipment to determine depth of fill and rough geometry of the hill.

2. The relationship of subsidiary faults northeast of the main trace of the San Andreas fault zone with the main trace along Mustang Ridge, Monterey County, was investigated by M. J. Rymer. Mapping of faults was based on offset lithologies, soil contrasts, aligned vegetation; and the presence of sag ponds, springs, benches, trenches, and notches, along with other geomorphic, vegetational, and physical criteria. Most of these features along subsidiary faults suggests geologic youthfulness of movement on the faults. Comparison of alinement-array measurements by Burford and Harsh (1980), short-range distance measurements by Lisowski and Prescott (1981), and geologic mapping by Rymer (1981) suggests that the subsidiary faults are presently active. Both the alinement array and the short-range network cross the main trace in the same area, but the latter is shown also to cross two subsidiary faults. Slip rate across the fault zone, as determined by the alinement array is 17 ± 1 mm/yr, and by short-range distance measurement is 29 ± 3 mm/yr. This latter rate approximates the regional average for the San Andreas fault zone. The difference in slip rates determined by these two methods is about 12 mm/yr, and probably occurs on the normal or dextral oblique-slip subsidiary faults. The subsidiary faults are present in the fault zone for about 7 km approximately centered on Monarch Peak. Their inferred current activity makes the tectonic picture near Monarch Peak anomalous for the creeping section of the San Andreas. Another feature of this part of the fault zone is a localized concentration of seismicity that may be associated with the inferred activity on the subsidiary faults.

3. Geologic field studies of the San Andreas Fault zone in the Bickmore Canyon 7 1/2 minute quadrangle are continuing by J. A. Perkins. The San Andreas Fault forms a continuous main trace throughout the study area that offsets three Holocene (?) terraces present along the San Benito River. Emphasis is currently placed on determining offset and ages of these terraces, as a result of lateral (and vertical) movement of the San Andreas fault. Plane table surveying of the terraces is approximately 70 percent complete. Additional datable material (carbon) was collected from the oldest terrace, and submitted for ^{14}C analysis. A search for datable material of the two younger terraces has thus far been negative.

4. A comparison was made, by Perkins and Sims, of the fracture patterns developed in strike-slip shear zones to those found within the San Andreas Transform System (SATS), within California. The SATS was subdivided into three regions, a northern (37^{o}-40^{o} N. Lat.), central (35^{o}-37^{o} N. Lat.), and southern (33^{o}-35^{o} N. Lat.) region. A detailed and general comparison was made between fracture patterns developed in experimental strike-slip shear zone models to those found within the three regions of the SATS. The general analysis consists of comparison of over 60 major fractures found within the three regions of the SATS to those developed in experimental models. The detailed analysis consists of the comparison of approximately 2,000 fractures of all sizes found within the three regions, to those developed in experimental models. These comparisons suggest that the fracture pattern found within the central region of the SATS is in good agreement with that predicted by experimental models. The fracture pattern found within the southern region is in significant variance with strike-slip models. The southern region is anomalous in that the percentage of rupture length of R-fractures in the southern region is < 1/2 that prediced by strike-slip models, there is also a > 5 X increment in fractures other than R-R' and P-P' types, and there is a significant increase in large magnitude P' and R'.

Reports

Sharp, R. V., Lienkaemper, J. J., and Rymer, M. J., 1982, Surface displacement on the Imperial and Superstition Hills faults triggered by the 26 April 1981 Westmorland, California, earthquake: U.S. Geological Survey Open-File report 82-282, 33 p.

Sharp, R. V., Lienkaemper, J. J., and Rymer, M. J., 1982, Surface displacement on the Imperial and Superstition Hills faults triggered by the 26 April 1981 Westmorland, California, earthquake [abs.]: Earthquake Notes, v. 13, p. 12-13.

Rymer, M. J., Lisowski, M., and Burford, R. O., 1982, The case of the missing 12 mm/yr offset near Monarch Peak, central section of the San Andreas fault zone, and its tectonic implications [abs.]: Earthquake Notes, v. 13, p. 11.

Quaternary Reference Core, Clear Lake, California
9950-02394

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Investigations

1. Sedimentological and stratigraphic studies of cores CL-80-1 and CL-80-2 from Clear Lake, California.

2. Varve thickness as a paleoclimatic indicator (J. A. Perkins and J. P. Sims).

Results

1. I had a discussion with Milan Pavich (Eastern Regional Geology) about using ^{10}Be analysis of the sediments from the Clear Lake Core CL-80-1. We decided to select about 10 samples to examine the ^{10}Be equilibrium in Clear Lake. The rest of the project is being wrapped up and is now in the report writing stage. No further investigations are being conducted or are contemplated on the Clear Lake cores.

2. The thickness of varves in sediments of Skilak Lake, Alaska, are correlated with the mean annual temperature ($r = 0.574$), inversely correlated with the mean annual cumulative snowfall ($r = -0.794$, and not correlated with the mean annual precipitation ($r = 0.202$) of the southern Alaska climatological division for the years 1907-1934 A.D. Varve thickness in Skilak Lake is sensitive to annual temperature and snowfall because Skilak Glacier, the dominant source of sediment for Skilak Lake, is sensititve to these climatic parameters. Trends of varve thickness are well correlated with trends of mean annual cumulative snowfall ($r = -0.902$) of the southern Alaska climatological division and with trends of mean annual temperature of the southern ($r = 0.831$) and northern ($r = 0.786$) Alaska climatological divisions. Trends of varve thickness also correlated with trends of annual temperature in Seattle and North Head, Washington ($r = 0.632$ and 0.850, respectively). Comparisons of trends of varve thickness to trends of annual temperature in California, Oregon, and Washington suggest no widespread regional correlation.

Climatic reconstructions for the period 1700-1906 A.D., on the basis of varve thickness in Skilak Lake, utilize equations derived from the regression of series of climatological data on series of varve thickness. Reconstructions of trends of mean annual cumulative snowfall in the southern Alaska climatological division suggests that snowfall during the 1700's and 1800's was much greater than that during the early and mid-1900's. The periods 1770-1790 and 1880-1906 show marked decreases in the mean annual snowfall. Reconstructed trends of the annual temperature of the northern and southern Alaska climatological divisions suggest that annual temperatures during the 1700's and 1800's were lower than those of the early and mid-1900's. Two periods of relatively high annual temperatures coincide with the periods of low annual snowfall thus determined. Reconstruction of trends of annual snowfall and annual temperature on the basis of tree-ring data and fluctuations of glaciers supports the proposal that reconstruction of climatic parameters on the basis of varve thickness is a valid technique.

Reports

Sims, J. D., 1982, Granulamotery of core CL-73-4, Clear Lake, California: U. S. Geological Survey Open-File Report 82-70, 5 p.

Perkins, J. A., and Sims, J. D., in press, Correlation of varve thickness to climatic parameters and paleoclimatic reconstruction: Quaternary Research.

Perkins, J. A., and Sims, J. D., in press, Paleoclimatic reconstruction based on varve thickness, Skilak Lake, Alaska: Science, v.

Rymer, M. J., and Sims, J. D., 1982, Lake sediment evidence for early deglaciation of the Hidden Lake area, Kenai Peninsula, Alaska: Geology, v. 10.

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 in the Stillwater "Seismic Gap" to see if the gap is characterized by different recurrence intervals than the adjacent fault zones that broke in 1915 and 1954. Faults in the gap may be more permanently locked, or they may be nearing a rupture point.

3. Repeated measurements of erosion nets established on selected fault scarps to determine rate, pattern, and processes of erosion of scarps.

Results

The abundance, size and distribution of pre-Holocene and Holocene fault scarps is similar in the areas of the Stillwater seismic gap and the 1915 and 1954 earthquakes. Displacements on the faults bounding the Stillwater Range within the seismic gap area clearly were in increments sufficient to generate large earthquakes in the past. The faults in the gap, thus, do not appear to be more permanently locked on a long-term basis than are those in areas of the 1915 and 1954 earthquakes.

Overall height and uplift rates of range blocks is similar throughout the zone of consideration, so that blocks within the Stillwater seismic gap have been displaced for approximately 10 m.y. at rates that average 0.2-0.4 mm/yr, similar to those rates in the 1915 and 1954 earthquake areas. On the basis of this uplift rate, the average recurrence interval for large earthquakes (M 7) is estimated to be approximately 3,000 to 7,000 years within the area of consideration.

The central Nevada-eastern California seismic belt has been the site of large-scale surface faulting events every few years to few decades over the past 150 years. The pattern of occurrence of events is one of incremental filling of the length of the belt. If that pattern of belt-filling continues, the Stillwater gap is a likely site for future major faulting. No evidence from the study of fault scarps rules against this possibility.

Long average recurrence intervals which characterize recurrence on individual fault segments in the region coupled with a belt-filling sequence of activity over a few centuries suggest the following overall pattern of strain release by faulting in the Great Basin Province. After a burst of large-scale faulting in one localized belt or area, similar bursts may occur in other belts or areas in some unknown sequence, with activity returning to the original belt or area only after thousands of years.

Reports

Wallace, R. E., 1982, Fault scarp analysis in paleoseismology [Abs.]: AGU Spring Meeting, Philadelpnia, PA, May 31 - June 4, 1982.

Wallace, R. E., 1982, Paleoseismicity--a guide a seismic zonation [Abs.]: Third International Conference on Microzonation, Seattle, Washington, June 1982.

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

Physical Constraints on Source of Ground Motion

9940-01915

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Investigations

1. Analysis of digital ground motion records from the 1980 Mammoth Lakes, California, earthquake sequence.

Results

1. Ratios of source spectra have been determined for seven aftershocks occurring at nearly the same location. Absolute spectra and apparent stress are undetermined, although the spectral ratios are consistent with constant apparent stress.

I attempted to apply Aki's coda analysis method to find source spectra, but found that it is not valid in this case. The assumption that the coda consists of body waves scattered from inhomogeneities distributed randomly, but uniformly, throughout the volume is not consistent with the three observable functions: 1) direct S-wave spectrum, 2) coda spectrum, and 3) coda decay. My preferred interpretation is that scattering arises primarily from irregular topography at the surface.

The best determination of the source spectrum is the ground motion spectrum from a short window at the S-wave arrival. However, these direct S-wave spectra are cut off rather abruptly at high frequency by what appears to be an attenuation, not a source, effect. The high-frequency fall-off depends on the station, but not on the event.

National Strong Motion Data Center

9940-02085

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1. Investigations

The National Strong Motion Data center provides investigators with a convenient, state-of-the-art tool for studies of earthquake sources, wave propagation, ground response, and strong motion. Projects hosted include field investigations of major earthquakes, routine processing of records from permanent installations, and studies of synthetic earthquake sources.

Incoming field data is transferred to on-line disk storage from several digital playback units (through parallel and serial interfaces and custom cartridge tape units), from in-house digitizers (through cards or IBM-compatible floppy disks), and from outside sources (on 9-track magnetic tape).

Using familiar, industry standard Fortran techniques, real and synthetic data are analyzed, with output printed on terminals and line-printers, or displayed on Tektronix graphics terminals and Versatec or CalComp plotters.

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

The current system supports up to 14 simultaneous users and has delivered from 8 to 12 CPU hours a day during this six month period, roughly 1/2 from 8 a.m. to 6 p.m., and 1/2 overnight.

Hardware:

Two editing and two editing/graphics terminals were installed for use with the new Office VAX-11/780.

There is now approximately 500,000 words of core memory. Conversion of the memory system from core to MOS (semiconductor) has been ordered to improve overall system throughput and reduce add-on memory costs.

The existing 300 lines-per-minute printer was modified to print both upper and lower case, at a reduced rate of 240 lines-per-minute.

Two DR11-W DMA parallel interfaces were installed, and work has begun to modify a locally developed high-speed interface to Tektronix 4014-1 terminals to be compatible with the DR11-W.

A KMC11-A microprocessor was installed to offload DECnet low-level protocol processing for RS-232 lines to local and remote LSI-11 microcomputers.

An LSI-11/23 microcomputer system was purchased to begin building a field deployable system for locating and plotting aftershock sequences on-site, with hardware compatible with the existing PDP-11/70 and the capability to run existing programs without modification.

A DR11-C parallel interface was installed on the PDP-11/70 to be compatible with the LSI-11/23 DRV11 parallel interface for playback of DR100 digital event recorder data.

Application software:

Tinker--A general purpose program to do routine analysis such as filtering and sepctra of digital data from event recorders. Modified to read DR100 data files with either real or integer data.

System software:

MTDup--Duplicates magnetic tapes. Enhanced to allow skipping past end-of-tape marks for salvage of overwritten tapes, use standard MCR command line processing, and allow selective partial copying to another tape with verification.

Tapelook--Examines magnetic tapes and displays the density and format. The formatting of labelled tape contents has been improved.

MTExport--Produces magnetic tapes for export. Enhanced to increase buffer size for reading larger input tape blocks, use standard MCR command line processing, and allow user to specify output record blocking.

FXR--Memory parity error fixer. Improved to eliminate unneeded error log entries and recover from parity errors discovered in Read-Only regions.

DVD--Dissociate virtual disk. Modified to allow a privileged user to unconditionally break the connection between a virtual disk and its associated file.

Plotting libraries--Enhancements were made to add new features or improve overall convenience for users, including automatic serialization of post-processors, automatic cleanup on task abort, deletion of intermediate files used for Versatec plotting, and migration of the locally written CalComp-style plotting package to the Office VAX-11/780.

User library--New subroutines included task abort notification from Fortran, enhanced MCR command line processing from Fortran, and access to FCS primitives from Fortran.

A console log entry is made for completed plot jobs and print jobs.

DECnet/M-Plus V1 was installed with a 1 million bits-per-second link to the new Office VAX-11/780 for file transfers, remote file access, and remote terminal access.

PDP-11 Fortran-77 was installed as the default system Fortran compiler.

Data:

A limited amount of digital data was collected for aftershocks of the January 9, 1982, earthquake in New Brunswick, Canada.

Miscellaneous

All the computer equipment was relocated to accommodate installation of the new Office VAX-11/780 computer.

A substantial amount of technical assistance was given to the Chinese visitors and local USGS technical specialists involved in the U.S.-China Exchange Program.

3. Reports

Reducing the size of a Fortran Program, 1981 Fall DECUS U.S. Symposium, December 7-11, 1981.

Chairperson, RSX Mag Tape Panel, 1981 Fall DECUS U.S. Symposium, December 7-11, 1981.

National Strong Motion Data Center Technical Notes:

DECNET Summary
Program DR100
Program DR11K
Program EPIMAP
Program HINV
Program HPLT
Program INVERT03
Program MADIG
Program MOMENT
Program TINKER
Fortran Cross Reference Utility
Abort Command Trapper
Virtual Disks

Nonlinear Soil Response at Imperial Valley Recording Sites

9550-03390

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Investigations

(1). Examined wave velocity profiles and cone penetration records for the assemblage of soil profiles at strong motion recording stations in Imperial Valley, California.

(2). Experimented with various analytical procedures for the development of an inverse technique for assessing bedrock base motion from surface strong motion recordings. Such a technique is particularly important in areas of thick sedimentary fill in order to improve analytical capabilities in modeling site response and predicting damaging ground motion.

Results

(1). Preliminary results indicated that cone and standard penetration readings did not correlate very well with the shear wave velocity profiles at Stations 6 and 7 of the El Centro Array. Wave velocity profiles at other stations are needed for further correlation.

(2). Use of the method of characteristics on base motion synthesis has a rather serious drawback. The method iterates the stress component of soil layers and is not effective in considering the yield condition using an inverse process.

Reports

Chen, A. T. F., 1981, MULAP3 -- A multi-linear analysis program for ground motion studies of horizontally layered systems: Report No. USGS-GD-82-001, NTIS No. PB82-160425, 49 pages.

Interpretation Of Historical Earthquakes In Arizona

14-08-0001-18396

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Investigations

An accurate catalog of historic earthquakes is an essential initial step in the evaluation of seismic risk. Prior to this study, a thorough compilation of Arizona earthquake data did not exist. The objectives of this study were to search for original source material, to document earthquakes felt in Arizona prior to 1980 and to organize these data for further analysis. These goals were met through collection of Arizona felt reports for specific events from national and state archives, local historical societies and published scientific literature. In addition, instrumental data for Arizona earthquakes from International Seismological Summary Bulletins, USGS publications (Earthquake Data Reports and Preliminary Determination of Epicenters) and original station logs were used to verify event times and locations. Copies of some Tucson seismograms were re-evaluated.

Analysis of the data included rating of maximum intensities, assignment of epicenter locations and verification of origin times, isoseismal contouring for events with maximum intensity V or greater, attenuation studies for the May 3, 1887 earthquake in Sonora, and deletion of previously published events for which there is no evidence that epicenters or effects occurred in Arizona.

Results

Seismic activity has occurred throughout Arizona. However, more frequent activity and the moderate-to-high intensities (≥VI) and magnitudes (≥4.0) are concentrated in three regions: north-central Arizona, southeast Arizona, and the extreme southwest corner near Yuma. Nearly 350 epicenters in Arizona with magnitudes > 2.5 or minimum intensities II-III were documented and analyzed. Of these events, approximately 40 exceeded intensity V or magnitude 4.0. In addition, several hundred earthquakes were reported in the Lake Mead vicinity, an area of frequent low-level seismicity that is partially related to reservoir fluctuations. At least 125 earthquakes with epicenters out of state have been felt in Arizona, twenty-six of which have caused effects rated intensity VI or greater.

Although the earthquake catalog resulting from this study represents a significant improvement over previous efforts, further work is still necessary to provide the detailed data base required for seismic risk analyses. Recommendations include detailed geomorphic analysis of young scarps throughout the state, correlation of seismicity with Quaternary faulting and deformation, estimation of magnitudes for all Arizona earthquakes and determination of both recurrence relationships and maximum earthquake size. Establishment of a seismic monitoring network for Arizona is also needed. Additional seismograph stations would ensure capability to detect moderate (≥4.0) and minor (<4.0) earthquakes in the state or in neighboring Sonora. Ultimately, seismotectonic source zones must be delineated, based on results of these suggested endeavors.

Reports

DuBois, S. M., and Sbar, M. L., 1980, The 1887 earthquake in Sonora: Analysis of regional ground shaking and ground failure, Abstract: USGS conference on evaluation of regional seismic hazards and risk, Santa Fe, August 25-27.

_____, 1981, The 1887 earthquake in Sonora: Analysis of regional ground shaking and ground failure: Proceedings of the USGS conference on evaluation of regional seismic hazards and risk, Santa Fe, August 25-27, USGS Open File Report, 81-437, p. 124-136.

DuBois, S. M., and Smith, A. W., 1980a, Earthquakes causing damage in Arizona; in Fieldnotes: Arizona Bureau of Geol. and Min. Tech., v. 10, n. 3, p. 4-6, 12.

_____, 1980b, The 1887 earthquake in San Bernardino Valley, Sonora: historic accounts and intensity patterns in Arizona: Arizona Bureau of Geol. and Min. Tech., Special Paper 3, 112 p.

DuBois, S. M., Sbar, M. L., and Nowak, T. A., 1981, Interpretation of historical earthquakes in Arizona: Final report to USGS under contract 14-08-0001-18396.

DuBois, S. M., Smith, A. W., Nye, N. K., and Nowak, T. A., Arizona earthquakes, 1776-1980, in preparation: Arizona Bureau of Geol. and Min. Tech., Bulletin 193, incl. map, scale 1:1,000,000.

Sbar, M. L., DuBois, S. M., and Bull, W. B., 1980, Preliminary assessment of seismic hazard in Arizona: Abstract, Annual Seismological Society of America meeting, Seattle, Earthquake Notes, v. 50, n. 4, p. 6.

Sbar, M. L., DuBois, S. M., and Natali, S. G., 1981, Analysis of the 1887 Northern Sonora earthquake and a microearthquake study of the epicentral region: Abstract, Geological Society of America sectional meeting, Hermosillo, Mexico, 1980, GSA Abstracts, v. 13, p. 104-105.

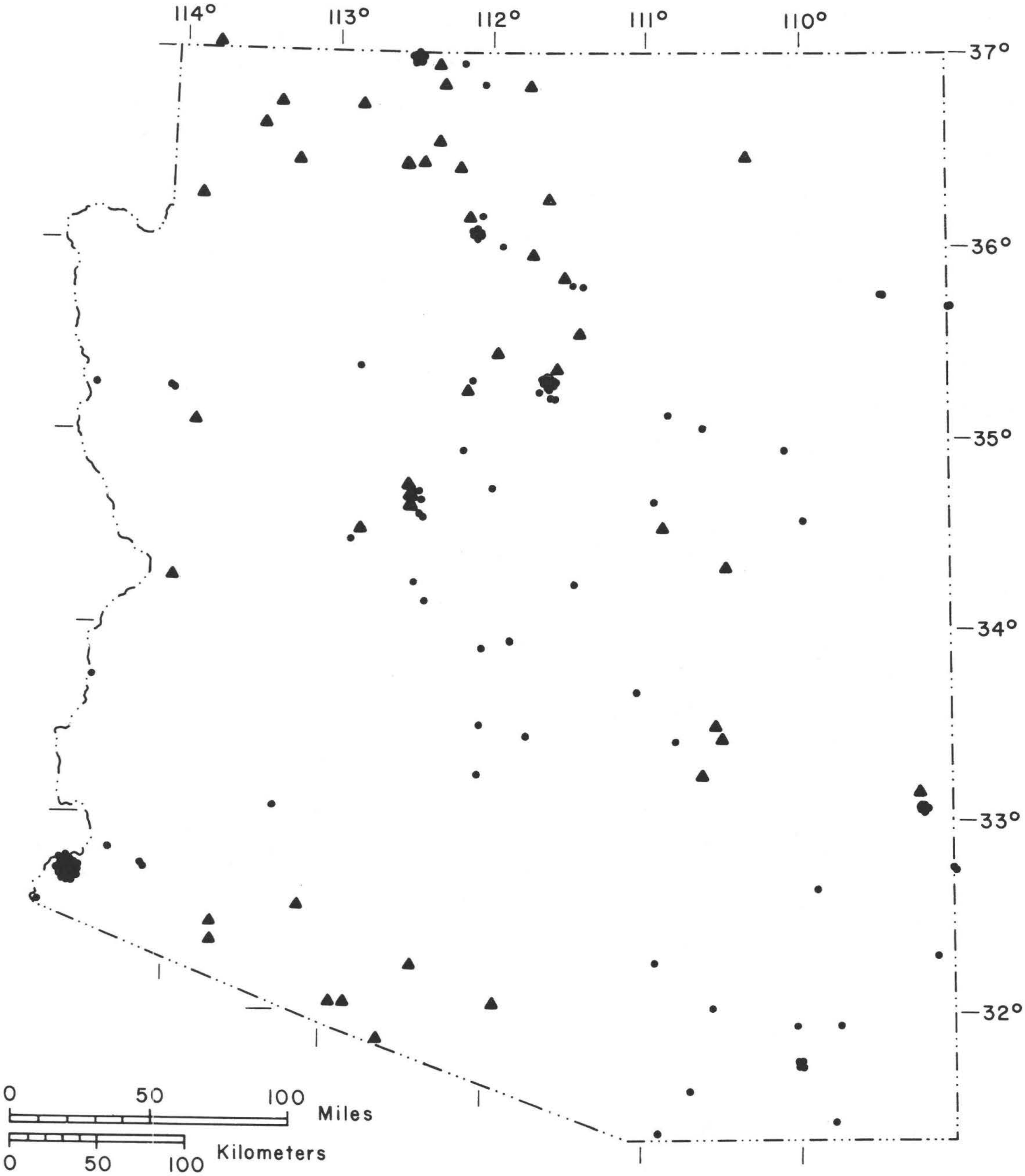

Figure 1. Historical epicenters in Arizona, 1830-1980. A ▲ denotes epicenters which were instrumentally derived and assigned magnitudes. A • designates epicenters determined from felt reports, given maximum intensity ratings. Specific intensities and magnitudes are not shown. Range of intensities: III-VIII; range of magnitudes: 3.0-5.9. Excluded are hundreds of minor earthquakes felt in the vicinity of Lake Mead and all earthquakes with magnitudes < 3.0 not reported felt.

Hybrid Ray-Mode Method for Synthetic Seismology
14-08-0001-19107
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This report summarizes progress and accomplishments during the period from March 11, 1981 to March 10, 1982.

During the preceding reporting period, the hybrid ray-mode method has been applied to study two-dimensional SH motion in a two-layer half space consisting of a homogeneous sediment above a homogeneous semi-infinite bedrock. The source was located in the bedrock. Numerical calculations demonstrated the effectiveness of the hybrid scheme for this configuration. These results were presented in a manuscript that has been published recently.[1]

The analysis was extended subsequently to source locations in the sediment. In this case, one excites a far richer variety of ordinary ray arrivals (trapped and leaky), as well as refraction arrivals (lateral rays) excited by the critically incident ordinary ray. Moreover, the collective treatment of multiply reflected arricals leads to stronger excitation of trapped modes and leaky modes than when the source is located in the bedrock.

We have carried out the required analysis, patterned after the one pursued in reference 1, but with the necessary modifications introduced by the different source location. As in reference 1, this had led to alternative frequency domain representations of the observed motion in terms of a) plane wave spectral integrals, b) normal and leaky modes, c) generalized ordinary and lateral rays, d) high-frequency asymptotic approximations for the ordinary and lateral ray fields, and e) hybrid ray-mode combinations. The analysis has also been performed by the Poisson summation method (see reference 1), which has the advantage of being applicable to more complicated environments wherein rigorous solutions fail but asymptotic ray methods can be employed effectively.[2] The conclusions may be summarized as follows. The hybrid method again quantifies the truncation effect of an incomplete ray series by expressing the omitted rays collectively in terms of guided (trapped and leaky) modes plus a remainder that can be interpreted as a "collective ray," with a weighted amplitude. This interpretation applies to multiply reflected ordinary rays as well as to multiply reflected lateral rays. In the former case, truncation of the ordinary ray series gives rise to a uniquely specified number of trapped and leaky modes and corresponding trapped and leaky collective rays, whereas truncation of the multiply reflected refraction arrivals (lateral rays) is quantified as a collective lateral ray. Lateral rays appear only if totally reflected ordinary rays are retained in the original ray series. The characterization of the remainder fields as "collective" rays or modes emerges from a general study of ray-mode equivalences that is under investigation. Thus, the hybrid form of the motion u due to an SH line source within the sediment, observed at the earth's surface, is found to be given by (see Appendix I):

$$u = \sum_{j=1}^{2} u_j \tag{1}$$

$$u_j = \sum_{\ell=1}^{L} \bar{G}_\ell + \sum_{\ell=\check{\ell}}^{L} \check{G}_\ell \, U(\mathrm{Re}\, w_\ell - w_b) + \sum_{M_1}^{M_2} G_m$$

$$+ \sum_{\hat{M}_1}^{\hat{M}_2} \hat{G}_m + \frac{1}{2} \bar{Q}_{L+1} \bar{G}_{L+1} + \frac{1}{2} \check{Q}_{L+1} \check{G}_{L+1} \, U(\mathrm{Re}\, w_{L+1} - w_b) \tag{2}$$

where U is the Heaviside unit function. Here, the index j represents the two ray species corresponding to upward and downward departure directions at the source. For simplicity of notation, this index has not been included on the right-hand side of (2), it being understood that all quantities (L, $M_{1,2}$, $\hat{M}_{1,2}$, $\bar{G}_L$, $\check{G}_L$, G_m $\hat{G}_m$) may have different forms appropriate to j =1 or j = 2. $\bar{G}_\ell$, $\check{G}_\ell$, G_m, and $\hat{G}_m$ represent ordinary (trapped or leaky) ray fields, lateral ray fields, trapped modes and leaky modes, respectively, with ray or modal (eigen) angles w_ℓ and w_m measured from the vertical, while $\bar{Q}_L$ and $\check{Q}_L$ represent the amplitudes of the collective ordinary and lateral ray contributions, respectively. w_b denotes the critical incidence angle at the sediment-bedrock interface . (see Figures 5 and 6 of Appendix I). The ordinary ray fields are defined over laterally shifted paths that account for the phase variation, with direction of incidence, of the sediment-bedrock reflection coefficient. This leads to complex incidence angles for leaky rays. Omission of the lateral shift would yield an incorrect dispersion equation when the ray fields are summed collectively into guided modes. The number of rays L and the number of trapped modes (M_2 - M_1+1) and leaky modes ($\hat{M}_2$-$\hat{M}_1$ + 1) are related in that the modes fill the angular spectrum interval left vacant by rays, and vice versa. It may be noted that the representation in (1) and (2) could be generalized by having more than one angular interval filled with rays or modes.

The most interesting conclusion from this study is that even the multiply reflected refraction arrivals, when these are significant, can be summed into collective form. Numerical calculations remain to be performed to assess how these contributions emerge on hybrid time-domain synthetic seismograms.

The hybrid analysis has been generalized further to accommodate a vertically inhomogeneous sediment. By asymptotic approximations of the WKB type, we have derived results for general profiles provided that these change slowly over an interval equal to the local wavelength. This analysis is quite similar to one performed previously for an underwater sound channel.[3,4] Due to continuous refraction attributable to the velocity profile in the sediment, there now exist also ray and mode categories which do not interact with the sediment bottom. The hybrid ray-mode expression for the SH motion then has a form similar to (1) and (2) provided that the surface guided rays and modes are included. Again, the resulting formulation is exact if all wave functions or integrals are retained intact. When high-frequency asymptotic approximations are employed, the resulting ray approximations fail in transition regions near the critically reflected ray, the glancing ray, and the caustics of the surface reflected rays. To correct for these failures of asymptotic ray theory, one has several options which are being explored for a specific analytical profile selected to simulate data taken in the Imperial Valley[2].

The analysis has been completed (see Appendix II) and numerical studies are in progress to assess the feasibility of replacing non-legitimate transitional ray fields by a group of modes and remainders. Conclusions from calculations for the model profile are expected to provide guidance on how to deal with more general environments, including those with lateral inhomogenities, for which asymptotic ray theory provides an effective analytical tool.[2]

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Theoretical and Empirical Studies of Strong Ground Motion

14-08-0001-19835

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OBJECTIVE

The principal objective of this investigation is to use theoretical and computational techniques to derive guidelines for scaling strong ground motion for the effects of distance, depth and earth structure. These guidelines should be compatible with and provide for the extrapolation of existing strong ground motion data. The study will include the behavior of peak ground acceleration (PGA) Local Magnitude (M_L) and response spectra with distance and source depth. The project will also include studies of the effects on non-planar structure on modeled strong ground motion.

MAJOR ACCOMPLISHMENTS

A. Response Spectra Scaling

In previous investigations (Hadley et al., 1982), a set of Green's functions have been computed for a southern California velocity model. The adequacy of these functions to accurately model observations in the distance range 5-90 km has been validated through a comparison with simulated peak ground acceleration (zero period constraint) and by M_L ($\sim$1 sec constraint). The simulated PGA curves are in very good agreement with the empirical results of Campbell (1981). The simulated M_L curves indicated a systematic dip of $\sim$0.2 M_L units at about 20 km and an increase of $\sim$0.1-0.2 units between 50-90 km. This result has been observationally confirmed by Jennings and Kanamori (1982). The good agreement between the observed and simulated data has encouraged us to extend the study to the behavior of the response spectra as a function of source depth and epicentral distance.

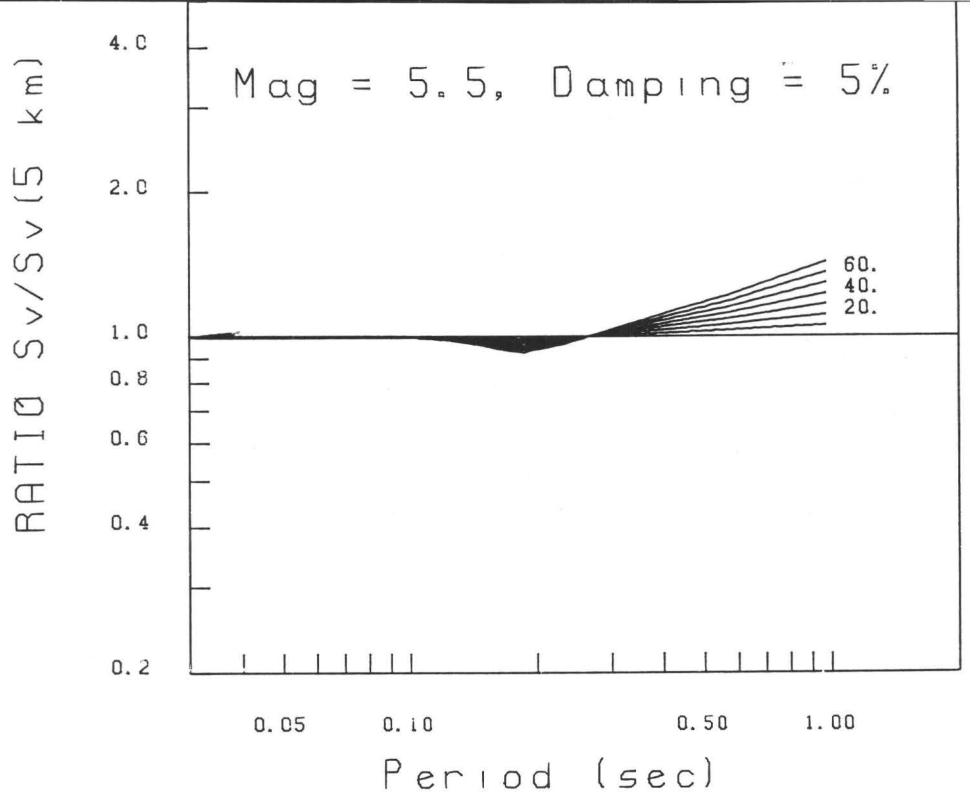
In the near-field of small earthquakes (M_L $\sim$4-5), these simulations show that the effects of source depth (2.5 km vs. 11 km) can introduce a factor of $\sim$3 variation in the response spectrum. The amplitude variation is reduced to about a factor of 2 at epicentral distances of 40-70 km. These results suggest that, independent of variations in dynamic stress drop, the effects of source depth introduce considerable dispersion in the observation of strong ground motion. As the magnitude of the simulated event increases, and the rupture extends over a wider depth zone, the dispersion in the simulations is reduced.

Several empirical methods are currently used to routinely develop response spectra. These include scaling a normalized spectra by PGA and period-by-period regression analysis. The adequacy of scaling a normalized spectra and possible constraints on the regression analysis can be obtained through a study of simulated response spectra as a function of magnitude and distance. Response spectra have been calculated from the simulated accelerograms, magnitude 5.5 and 6.5, for the distance range 5 to 70 km. As we are primarily interested in variations with distance in the shape of the response spectra, we have reduced the derived spectra to a common zero period acceleration (ZPA) and have normalized the smoothed spectra by the spectra at 5 km. Figure 1 shows a very smoothed and generalized summary of the resulting normalized spectra. For both magnitudes, the effects of increasing distance is to move the turning point of the dynamic amplification ramp to larger periods and to systematically increase the longer period level, relative to the ZPA, of the response spectra. These results suggest that scaling a normalized spectral shape by PGA, without consideration for changes in the shape of the spectra with distance, may be inaccurate.

B. Tabas Earthquake

The original strong-ground motion recordings of the near-field accelerations produced by the Tabas Earthquake are currently in Iran. Political considerations suggest that these records may not be available to the community for some time. Because near field data from large earthquakes are extremely rare, we have made a special effort to transform a Xerox copy of one record into useful time histories. Time marks on the record were used to correct for down-the-record distortions introduced by the copying process. Similar corrections could not be made for distortions in the perpendicular direction. Both horizontal components could be laboriously traced for the entirety of the record. The vertical time history was not recoverable.

The ENE dipping thrust fault discontinuously ruptured the surface for 85 km along a NNW trend. The accelerograph was located on alluvium approximately 3 km NNW from the north end of the surface rupture. The proximity of surface faulting, and the trigger-S time of 4.2 S, indicates that the fault rupture propagated towards the station for a distance of 30-40 km. The corrected horizontal peak ground accelerations are 0.78 g and 0.83g. The quality of the record and the high frequency character prohibited determining the maximum vertical acceleration. However, the maximum was at least as large as 0.88g. The duration of strong shaking (>10% of PGA) was 23S. Because of the long period noise that may be present due to the copying process, the records were processed with a low frequency cut-off of 0.25 Hz. The integrated peak velocities are 63.3 and 68.3 cm/s and the peak displacements are 16.6 and 18.3 cm, respectively.



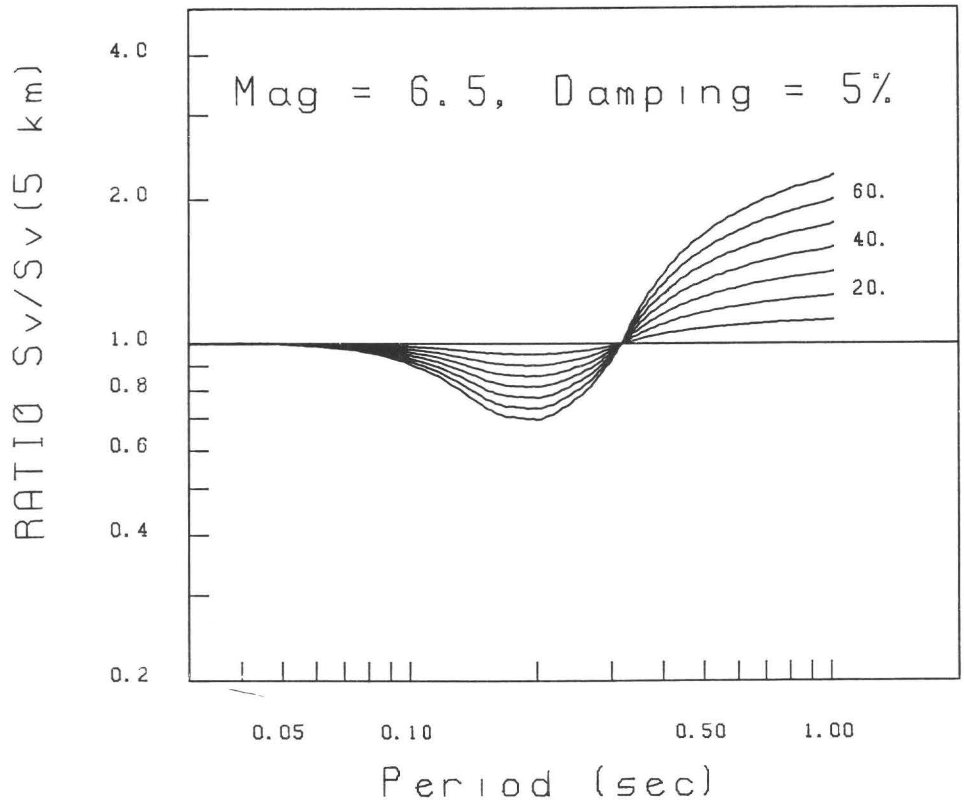


Figure 1. Variation in the shape of the response spectra, derived from simulated accelerograms, as a function of distance, 10-70 km. For each distance the smoothed spectra were reduced to a constant ZPA and normalized by the spectra at 5 km. These curves represent a smoothed and generalized summary of the modeling.

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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 predictive maps of strong ground motion.

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

Results

1a. Development of predictive equations for peak horizontal acceleration, velocity, and response spectra in terms of moment magnitude, distance, and geologic site conditions.

1b. Surveying and data analysis for P and S velocity at seventeen 100-foot drill holes at strong-motion sites.

2. Completion of the report of the Zonation Subcommittee of the Seismology Committee of the Structural Engineers Association of Northern California. The report, largely written by R. B. Matthiesen, is concerned with revision of the building codes.

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Seismological Field Investigations

9950-01539

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Investigations

1. Seismotectonic study of the New Madrid, Missouri region.

2. Puerto Rico seismicity study--regional investigation of the seismicity on and near the island of Puerto Rico.

3. Denver aftershock study--local investigation of the earthquake sequence of March-April, 1981.

Results

1. The predominate feature in the pattern of seismicity in the upper Mississippi Valley is a prominant northeast-trending alignment of epicenters which is offset to the northwest by approximately 20 km in the area between Ridgley, Tennessee and New Madrid, Missouri. Within this offset zone is an area of fairly concentrated, low-magnitude seismicity that trends to the north-northwest. The geology and tectonics of this offset zone are not well understood; therefore, it was anticipated that a closely spaced network of portable seismographs might provide sufficient earthquake data to help define the causative structure(s) of this ongoing seismic activity.

During the month of August, 1981, a cooperative field study (USGS, St. Louis University, and the University of Wisconsin) was conducted in the above described offset zone. Forty-six earthquakes ($M < 1.5$) have been located from data obtained by the USGS - St. Louis University instruments (see Figure 1). Data from the University of Wisconsin have not been made available.

2. Historical records document the occurrence of damaging earthquakes in the vicinity of Puerto Rico dating back to 1540 and include intensity MM (Modified Mercalli) VII-IX earthquakes in 1867 and 1918. Also, earthquake catalogs of events located instrumentally in this century show that Puerto Rico and surrounding region have continued to exhibit moderate amounts of seismic activity. However, the historical accounts and the instrumental earthquake catalogs list only the macroseismic events. These data are far too inaccurate to estimate recurrence rates or to identify seismogenic sources that may be associated with previously mapped geologic structures or geophysical trends. This problem is further compounded by a complex and sometimes conflicting body of geologic and geophysical information relating to the Greater Antilles. For many years Caribbean geologists and geophysicists have attempted to reconcile these data, and, as a result, some relatively self-consistent theories have emerged. It should now be possible to consider these theories in light of

data available from seismograph networks located in the northeastern Caribbean.

The Puerto Rico seismic program was designed to evaluate current levels of seismicity on and near Puerto Rico. The program was a cooperative effort between the Puerto Rico Electric Power Authority (formerly the Puerto Rico Water Resources Authority) and the USGS. The results of this study were determined from data recorded by a permanent 15-station seismograph network installed on the island of Puerto Rico, Isla Mona, and Isla Desecheo (see Dart and others, 1980, for a description of the network and techniques used for data reduction and analysis).

Conclusions that may be drawn thus far from this investigation are:

1. The seismicity of the island of Puerto Rico is characterized by numerous small magnitude, shallow (< 50 km) earthquakes, suggesting a relationship to pre-existing zones of weakness, such as elements of the Great Northern and Southern fault zones. Larger magnitude earthquakes tend to occur to the north in the Puerto Rico Trench zone and to the west in the Mona Passage.
2. An inclined seismic zone (Schell and Tarr, 1978) dips southward from the Puerto Rico Trench to depths of about 135 km under Puerto Rico, implying the presence of a lithospheric plate.
3. Composite focal mechanism solutions from earthquakes within 10 shallow crustal areas suggest that the Puerto Rico island block is being subjected to a horizontal maximum compressive stress trending north to northeast implying that a significant component of convergence exists between the North American and Caribbean plates.

3. The Denver earthquake sequence of March-April, 1981, was monitored by a network of four permanent and eight portable seismographs. In addition to the principal shock (M_b = 4.3) on April 2, six microaftershocks (M < 2) that occurred during the subsequent two-week period were recorded by an adequate number of stations to be located. Five of these six events had epicenters within the most active area of the 1967-1968 Rocky Mountain Arsenal (RMA) sequence. A composite focal mechanism solution favored west-northwest reverse faulting as opposed to northwest-trending normal faulting reported for the 1967-1968 RMA episode.

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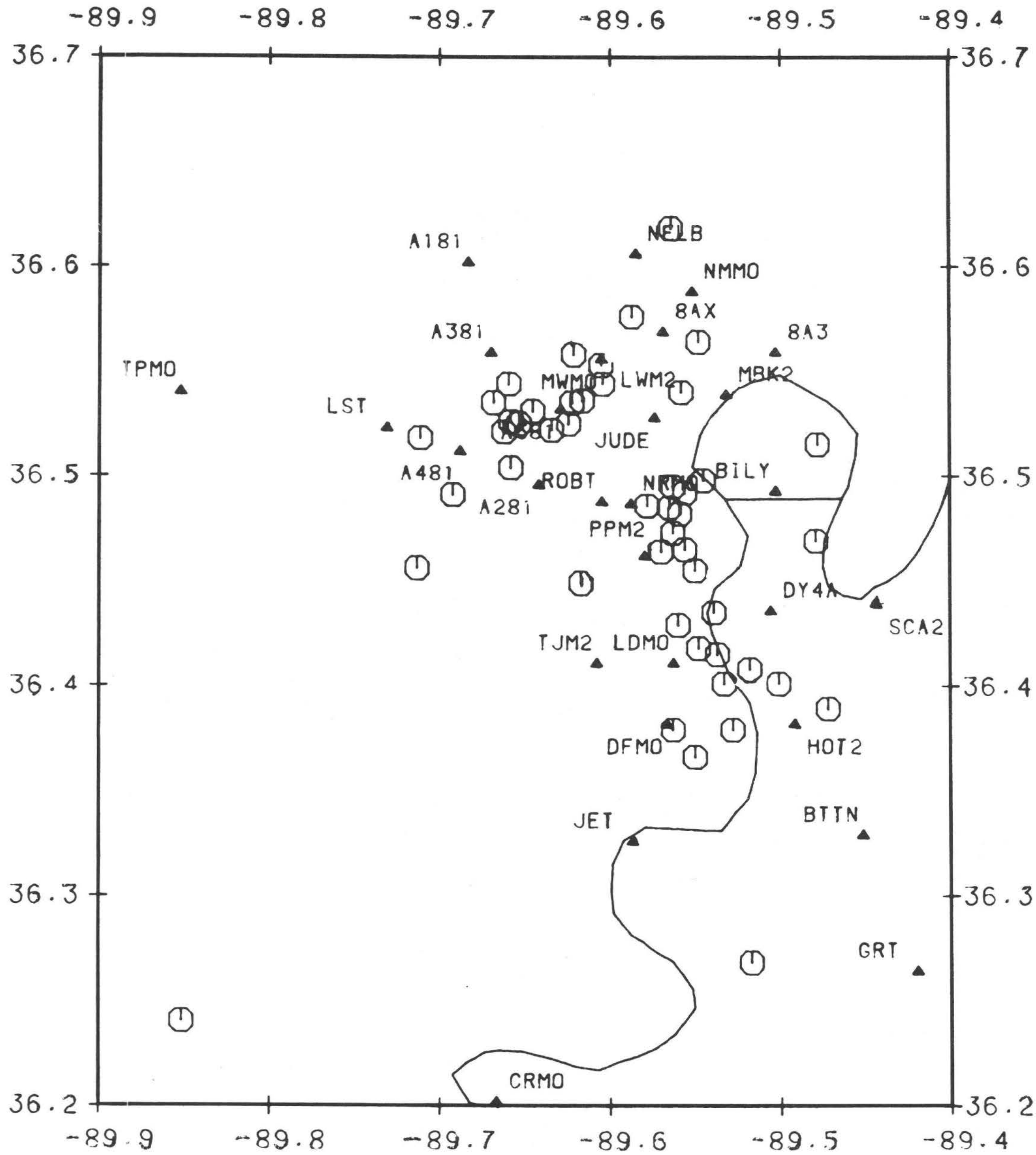

Figure 1.--Microearthquake epicenters within the zone-August, 1981. Seismograph stations are denoted by solid triangles; epicenter locations are indicated by open octagons.

Post-Earthquake Shaking Effects and Fault Creep

9940-03027

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Investigations

1. The effects of the magnitude 5.9 earthquake of 30 September 1981 at Mammoth Lakes, California were investigated in the field. Earthquake cracks were examined and seven post-earthquake creepmeters which were installed the previous year were examined for changes.

2. The systematic use of disturbance in food stores was further developed as a reliable technique for seismic intensity studies.

3. Study of the seismic intensity effects of the 1906 earthquake continued.

4. Several features across the Hayward fault in Hayward and Fremont which were measured by the writer in 1968 were carefully remeasured to determine the average fault creep rate for the past 14 years.

Results

1. The creepmeters on the earthquake cracks at Mammoth Lakes did not show significant changes (more than several millimeters) in the 30 September 1981 earthquake.

2. The food-store disturbance technique of seismic intensity study was successful in showing the separate disturbances in the different Mammoth Lakes earthquakes and aftershocks of the past two years.

3. Local 1906 newspaper descriptions show that there was much more damage in the Oakland area than has been previously reported, including collapse of thirteen buildings and major ground failure.

4. The survey measurements show that the average rate of creep slip on the Hayward fault for the past 14 years has been approximately 4.5 mm/yr, which is 20% less than in the pre-1968 time period. The reasons for this decrease are not known. Adjacent creepmeters show that the fault creep has been continuous during this time period.

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Strong Ground Motion Prediction in Realistic Earth Structures

9940-03010

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Investigations

1. Calculation of theoretical ground motions in the Los Angeles basin caused by a hypothetical magnitude 6.5 earthquake on the Newport-Inglewood fault.

2. Forward modeling of the local and teleseismic ground motion data from the 1979 Imperial Valley, California, earthquake.

3. Development of both time- and frequency- domain inversion methods for inference of subsurface fault slip distribution from observed ground motions, with applications to the 1979 Imperial Valley earthquake.

4. Development and verification of a new method for calculating complete theoretical seismograms in media with arbitrary variation of velocity and attenuation with depth.

5. Development of an improved method for calculating theoretical ground motions in the near-field of an extended earthquake source.

6. Cross-correlation analysis of ground motions observed on the El Centro Differential Accelerometer Array (EDA) during the 1979 Imperial Valley earthquake.

7. Observation and processing of 3-component digital recordings of aftershocks of the 1982 New Brunswick, Canada, earthquake.

Results

1. Los Angeles ground motions: 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.

2. Imperial Valley Forward Modeling: Hartzell and Helmberger (1982) obtained a distribution of slip on the Imperial fault by forward modeling of the strong-ground motion displacement records. This model has been used to calculate the long-period teleseismic P and SH waves (Hartzell and Heaton, 1982). The synthetics were compared with the observations for 19 P waves and 10 SH waves. P wave amplitudes match very well. Ignoring nodal stations, the SH amplitudes are also acceptable. The long-period synthetics are not sensitive to the fine scale details of the slip distribution, but they do indicate that the moment of 5.0×10^{25} dyne-cm, obtained by modeling the strong-motion records, is accurate and also that the gross distribution of slip is correct. The Hartzell and Helmberger (1982) model uses a vertical, strike-slip fault. Forward modeling of the teleseismics has been used to investigate the dip on the Imperial fault. While fault dips of 85^{o}W and 85^{o}E do equally well in explaining the long-period teleseismic data, a dip as small as 75^{o} violates long period first motion data. Thus, the long period data suggests that the fault is nearly vertical with variations of plus or minus 5^{o} along its length. This contradicts the evidence for fault dip presented by Fuis and others based on a local refraction survey. Investigation of the teleseismic short-period P waves is presently under way. The short-period P waves have emergent first arrivals with about 6 sec of initial low amplitudes. These initial arrivals may be interpreted as small amplitude slip occurring before the main rupture. Similar indications are also obtained from a study of the strong-motion data. It has been suggested that the Hartzell and Helmberger (1982) model, with its patches of larger dislocations, would violate the teleseismic short-periods by predicting amplitudes that are too large. However, modeling has shown that the synthetic short-period amplitudes are about correct or smaller than the observations.

Initial modeling has been done of the geodetic measurements taken across the Imperial fault by Ron Mason (Imperial College, London). These data indicate a rapid decrease in the amount of slip on the fault north of Interstate 8. The slip distribution of Hartzell and Helmberger (1982) has been used to calculate the distribution of surface displacements by an analytic calculation in a half space. A very similar pattern is obtained to that in the data, but the magnitudes are substantially smaller. The calculation has been repeated for a layered half space using 3-D finite elements with similar results. These calculations suggest that the geodetic measurements, which were taken over a period of several months, express the migration of larger co-seismic slip at depth toward the surface.

3. Time domain inversion: A least squares inversion is being used to solve the over-determined system $Ax = b$; where A is the matrix of synthetics for predetermined sections or subfaults of the Imperial fault, x is the vector of weights associated with the subfaults, and b is the vector of observation records. The elements of the solution vector x are constrained to be positive using a computer algorithm given by Lawson and Hanson (1974). Besides the positivity constraint, it is also important to add stability by the method of ridge regression or damped least squares, so that the actual problem being solved is:

$$\begin{bmatrix} A \\ \lambda F \end{bmatrix} x = \begin{bmatrix} b \\ \lambda d \end{bmatrix}$$

If F is equal to I, the identity matrix, and d = 0, then the solution which fits the data and also minimizes the moment is found. This requirement has been found to be very useful in eliminating erroneous, poorly resolved slip beneath and north of the El Centro strong-motion array stations. Different functional expressions are being explored for F and d to futher stabilize the solution. The effects of the size of the subfaults are also being investigated.

The approach we have taken calls for first specifying the fault geometry and timing. By timing we mean the hypocenter, origin time, and rupture velocity. The least squares inversion is then run for this configuration. Next, the fault geometry and/or timing is changed and the inversion is run again. By this procedure we hope to investigate the resolvability of both the near and far-field data.

4. Frequency domain inversion: In collaboration with Edward Leaver (University of Utah), we have successfully applied the frequency domain inversion method of Spudich to infer slip distributions on a fault from observed ground motions in a test example using synthetic data in a wholespace. This method has advantages over time-domain methods in that it is not necessary to break the fault into discrete subfaults and less computation effort is required to invert data in identical frequency bands. However, positivity constraints cannot easily be imposed in this approach.

5. Complete theoretical seismograms: In collaboration with Dr. Uri Ascher (University of British Columbia), we (Ascher and Spudich, 1981) have written a computer code which uses a collocation method to calculate complete theoretical seismograms in laterally homogeneous earth models with arbitrary variation of velocity and Q with depth. This method allows group and phase velocity windowing of the theoretical seismograms, and calculates all body waves, surface waves, leaky modes, and near-field terms if the windows are set properly. This method has been verified against three other methods.

6. Calculation of extended source seismograms: We have improved our frequency-domain method for calculation of ground motions near extended earthquake sources (Spudich, 1981) to include the dip-slip component of motion as well as the strike-slip component. We can now calculate theoretical ground motions from arbitrary kinematic rupture models on dipping faults in laterally homogeneous earth models with arbitrary non-attenuating velocity profiles. This method is more accurate than our previous method due to a more rigorous algorithm for Greens function interpolation.

7. Differential array analysis: We (Cranswick and Spudich, 1981, and Spudich and Cranswick, 1982) have applied cross-correlation analysis methods to the ground motions recorded at EDA during the 1979 Imperial Valley earthquake. Preliminary results suggest that the apparent velocity of arrivals along the array rose from about 10 km/s during the initial motion to infinity about 5s later. From this a rupture velocity of 2.4-2.5 km/s may be inferred for the Imperial Valley earthquake.

8. New Brunswick aftershocks: In conjunction with the Canadian Department of Energy, Mines and Resources, three digital event recorders equipped with force-balance accelerometers and three digital recorders with velocity transducers were installed in the epicentral region of the New Brunswick,

Canada, M_b 5.9 earthquake of January 9, 1982, one week after the mainshcok (Sembera et al., 1982, Cranswick, et al., 1982, Cranswick and Mueller, 1982). Between January 15 and January 22, 98 three-component digital records were obtained. The largest event recorded was the January 17 magnitude 3.5 aftershock. All recorded events occurred within 10 km of the instruments, and peak accelerations exceeding 0.05 g on both horizontal and vertical components were recorded.

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Earthquake Hazards Maps, Mt. Rose NE and Reno NW 7 1/2-Minute Quadrangles, Nevada

14-08-0001-19823

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Goals

The goals of this study were to develop earthquake hazard maps for the Mt. Rose NE and Reno NW quadrangles, western Nevada. These maps provide information for planners, developers, and the public on 1) the suspected response of geologic units to seismic shaking, and 2) the location and recency of movement for faults in these quadrangles.

Investigation

In order to assess the earthquake hazards, the following tasks were completed:

1) Collection, review, and compilation of existing geotechnical data from federal, state, and local sources.
2) Measurement of seismic velocities to aid in determination of ground shaking characteristics.
3) Measurement of *in situ* density for those geologic units lacking bulk density information.
4) Preparation of depth-to-groundwater maps for use in determining liquefaction potential.
5) Categorization of the seismic response of geologic units according to rigidity products (product of shear wave velocity and bulk density) and depth to groundwater.
6) Trenching of youthful faults to examine the stratigraphy and determine the age of last movement.

The geologic maps of Mt. Rose NE (Bonham and others, in progress) and Reno NW (Soeller and Nielsen, 1980) provided the bases from which the earthquake hazard maps were derived. Soil maps by the Soil Conservation Service (Mt. Rose NE, 1977; Reno NW, in progress) were used to supplement the stratigraphic information and age-relationships shown on the geologic maps.

Results

Geologic units in the Mt. Rose NE and Reno NW quadrangles were grouped into 5 categories (I-V) according to their potential for ground shaking and liquefaction during earthquakes. Based on 1) rigidity products as indicators of the severity of shaking, and 2) depth to groundwater, indicative of saturation and possible liquefaction, the geologic units were categorized as follows:

Category I - Greatest severity of shaking, possible severe liquefaction. Includes unconsolidated Holocene and late Pleistocene deposits of low rigidity such as lacustrine and alluvial fan deposits in Mt. Rose NE and playa, forebeach and lake sediments in Reno NW, where the depth to groundwater is less than 3 meters.

Category II - Moderate severity of shaking, may be subject to liquefaction. Includes unconsolidated Pleistocene deposits of moderate rigidity such as the older alluvium and glacial outwash in Mt. Rose NE and floodplain, beach, and older alluvium in Reno NW, where the depth to groundwater is less than 10 meters.

Category III - Moderate severity of shaking. Includes early Pleistocene unconsolidated to moderately indurated alluvial fan deposits of moderately high rigidity in both quadrangles, as well as Pleistocene glacial outwash and Tertiary sandstone in Mt. Rose NE and Tertiary lacustrine and basin-fill deposits in Reno NW, where the depth to groundwater is greater than 10 meters.

Category IV - Least severity of shaking. Underlain by bedrock. Includes massive, relatively unaltered volcanic, granitic, and metamorphic bedrock areas in both quadrangles.

Category V - Variable severity of shaking. Includes isolated alluvial deposits over bedrock in both quadrangles, landslide deposits and hydrothermally altered volcanic bedrock in Mt. Rose NE, and highly weathered granitic bedrock in Reno NW. These units cannot be assigned to Categories I to IV, but may exhibit properties of any one of these categories.

Stratigraphic studies supplemented by trenching indicated that the extensive faulting in Mt. Rose NE quadrangle is predominately early to mid-Pleistocene in age in the alluvium and possibly older in bedrock areas; however, fault movement within the last 2,000 to 3,000 years was apparent in trenches across the Sierra Nevada Frontal Fault Zone which separates the eastern Sierras from the Great Basin in the western half of the quadrangle.

A single fault with apparent Holocene movement displaces delta sands in the west-central part of Reno NW quadrangle. The remaining range-bounding faults and faults in Tertiary basin-fill are considered to be pre-Holocene and, in some cases, pre-Pleistocene. Faulting of Mesozoic bedrock is pre-Pleistocene; however, recent movements are not precluded.

Publications

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Development of General Earthquake Observation Systems

9940-03009

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Investigations

This project will develop a low power, wide dynamic range, portable, digital recording system. The system is software based for easy use in a wide variety of applications. The system will have an RS 232 interface for communication through a modem.

Results

Testing and modifications have been completed on all hardware. All the circuit boards have been converted to P.C. and debugged. Three production units havv been assembled and testing is in progress. All of the essential software has been completed and is being tested. Several units will be field tested in June.

Aftershock Investigations and Geotechnical Studies

9940-02089

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Investigations

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

2. 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:

New Brunswick, Canada	January 1982	Earthquake aftershocks
Imperial Valley, CA	February 1982	Nevada Test Site Sources
Microearthquake monitoring	January 1982	San Francisco Peninsula

1b. E. D. Sembera assisted in the preparations for the new GEOS recording systems.

2a. The Nimbus system was adapted to downhole shear wave measurement so that tape utilization was improved and false triggering is prevented. G. Maxwell and A. Walters have developed a data transfer procedure to allow Nimbus data to be transferred into the Branch computer. A. Walters is adapting some of his programs for use in processing the numbers data.

2b. A direct comparison of the S.I.E. and Nimbus systems was conducted at the Coyote Lake Dam site. That data is in the process of reduction.

UTAH STATE UNIVERSITY, LOGAN, UTAH

Development of a Liquefaction Potential Map for Salt Lake County, Utah

Contract No. 14-08-0001-19910

by

Loren R. Anderson[1]

Jeffrey R. Keaton[2]

Introduction

A liquefaction potential map is being prepared for Salt Lake County, Utah. Subsurface data from the files of private consulting firms and state and local agencies have been collected and compiled in the form of a Soil Data Map. This data will be supplemented with data from a drilling and sampling program that is still to be carried out. The existing data that has been collected shows that liquefiable deposits are present in many parts of Salt Lake County, Utah.

Ground surface acceleration required to induce liquefaction have been computed for all sites where existing subsurface data was available. These ground surface accelerations are referred to as "critical accelerations". The liquefaction potential for each site will be classified as high, moderate, low or very low depending on the probability of exceeding the "critical acceleration" in 100 years.

Methodology

An evaluation of liquefaction potential at a given sity by current state of the art methods involves comparing the predicted cyclic stress ratio (τ/σ_o') that would be induced by a given design earthquake with the cyclic stress ratio required to induce liquefaction. The predicted cyclic stress ratio can be computed using response analysis techniques or by a simplified procedure based on rigid body theory modified to account for the flexibility of the soil profile (Seed, 1979). The simplified theory for computing the cyclic stress ratio induced by an earthquake is given by Equation 1.

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$$\frac{\tau_{av}}{\sigma_o'} = 0.65 \frac{a_{max}}{g} \left(\frac{\sigma_o}{\sigma_o'}\right) r_d$$

where, a_{max} = maximum acceleration at ground surface

σ_o = total overburden pressure on sand layer under consideration

σ_o' = initial effective overburden pressure on sand layer under consideration

r_d = a stress reduction factor varying from a value of 1 at the ground surface to a value of 0.9 at a depth of about 30 ft.

The cyclic stress ratio required to cause liquefaction can be evaluated by an emperical relationship between some insitu property of the soil and the cyclic stress ratio required to cause liquefaction. Seed, Mori and Chan (1977) have developed an emperical relationship between the cyclic stress ratio required to cause liquefaction and the standard penetration resistance of the soil.

Seed, (1979) points out that the factors that tend to influence liquefaction susceptibility, such as relative density, age of the deposit, seismic history and soil structure, also tend to influence the standard penetration resistance in a like manner. Although the standard penetration test has its shortcomings, if used properly and with judgement it provides a convenient and rapid method of evaluating the insitu characteristics of sand. The standard penetration test also provides a convenient method to utilize existing data in evaluating liquefaction potential because in the past the most common method to obtain samples of sand has been the standard penetration test.

Qualitative descriptions of the liquefaction potential in the Salt Lake County study area will be assigned on the basis of the probability that the computed values of critical acceleration would be exceeded during a 100-year time period. The critical acceleration for a given location is defined as the lowest value of maximum ground surface acceleration required to induce liquefaction.

The standard penetration test data from soil borings in conjunction with Eq. 1 and the standard penetration - cyclic stress ratio relationship by Seed, Mori and Chan (1977, Fig. 11) are used to compute the critical acceleration at all boring locations. Equation 1 can be solved for the critical acceleration and stated as:

$$(a_{max})_c = \left(\frac{\tau_{av}}{\sigma_o'}\right) \left(\frac{\sigma_o'}{\sigma_o}\right) \left(\frac{1}{0.65\ r_d}\right)$$

where, $(a_{max})_c$ = critical acceleration (ground surface acceleration required to induce liquefaction at a given site)

$\left(\frac{\tau_{av}}{\sigma_o'}\right)$ = cyclic stress ratio required to cause liquefaction at the given site and obtained from the standard penetration resistance and Seed, Mori and Chan (1977, Fig. 11).

σ_o = total overburden pressure at the point where the standard penetration resistance is measured

σ_o' = effective overburden at the point where the standard penetration resistance is measured

Judgement is required in assigning critical acceleration values. Generally more than one boring log is available for a given site and many standard penetration values are reported for each boring. Therefore, several critical acceleration values are computed for each boring at each site. A value considered to be representative of the critical acceleration is then assigned to the site. In assigning this representative value, consideration is given to consistancy within and between borings, to the soil type and to the limitations of the standard penetration test. A single low critical acceleration vlaue at a site is not considered representative if it is not consistant with other critical acceleration values at the site and in the general area.

A two-step procedure is used to develop the Liquefaction Potential Map. Contours are first drawn on the basis of the critical acceleration values and used to divide the study area into preliminary zones of high, moderate, low and very low liquefaction potential. The contours represent the critical accelerations that have exceedance probabilities of 50, 10 and 5 percent in 100 years.

After the liquefaction potential zones are initially identified from the critical acceleration contours, they are adjusted to reflect the geology of the area. This adjustment is particularly important because boring data and critical acceleration values are available only at selected locations and do not necessarily reflect specific geologic features such as the locations of stream beds and the distribution of sediments.

Results

The results of this study will be presented on for maps (USGS 7½ minute quadrangle maps reduced by 50%).

1) Soil Data and Ground Water Map
2) Critical Acceleration and Ground Slope Map
3) Selected Geologic Data Map
4) Liquefaction Potential Map

The liquefaction map will identify areas of high, moderate, low and very low liquefaction potential.

This method was used to develop a liquefaction potential map for Davis County, Utah (Anderson et. al, 1982).

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UTAH STATE UNIVERSITY, LOGAN, UTAH

Development of a Liquefaction Potential Map for Davis County, Utah

Contract No. 14-08-0001-19127

by

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and

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As part of the U.S. Geological Survey's Earthquake Hazard Reduction program a "Liquefaction Potential Map" has been prepared for Davis County, Utah. Liquefaction potential was evaluated from existing subsurface data and from a supplementary subsurface investigation performed as one of the tasks in this study. All of the data used in this study are summarized on base maps of the study area.

For this regional assessment, *liquefaction* implies *liquefaction-induced ground failure*. The liquefaction potential is classified as high, moderate, low and very low depending on the probability that a critical acceleration will be exceeded in 100 years. The critical acceleration for a given location is defined as the lowest value of the maximum ground surface acceleration required to induce liquefaction. The categories of high, moderate, low and very low correspond to probabilities of exceeding the critical acceleration in the ranges of greater than 50 percent, 10 to 50 percent, 5 to 10 percent and less than 5 percent, respectively.

The Liquefaction Potential Map on Plates 4A and 4B of the final report shows that for a significant portion of Davis County the probability of exceeding the critical acceleration in 100 years is greater than 50 percent. Hence, liquefaction induced ground failure is a significant seismic hazard.

Ground slope information, as well as the subsurface conditions documented on the Soils and Ground Water Data Map, can be used in combination with the Liquefaction Potential Map as a means of assessing the type of ground failure likely to occur. Three slope zones have been identified from the characteristic failure modes induced by liquefaction during historic earthquakes (Youd, 1981, personal communication).

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At slope gradients less than about 0.5 percent, loss of bearing capacity is the type of ground failure most likely to be induced by soil liquefaction. Stratified soil conditions, which exist in Davis County, provide vertical confinement for liquefiable layers and may tend to reduce the probability of bearing capacity failures. Buildings imposing light loads on the subsurface soils may not be affected by loss of bearing capacity during an earthquake. Heavy buildings, on the other hand, might be severely affected. Additionally, during earthquakes, heavy buildings subjected to movement from deformation of the subsurface soils might cause damage to adjacent lightly-loaded structures.

Buried tanks, even those full of water or gasoline, could "float" to the surface if the soils surrounding them were to liquefy. For this to happen, however, the tanks would have to be buried in very thick deposits of sand. The stratified nature of the soils in Davis County generally tends to reduce the likelihood of this type of failure.

Slope gradients ranging from about 0.5 percent to about 5.0 percent tend to fail by lateral spread processes as a results of soil liquefaction. Evidence exists in Davis County for five large lateral spread landslides. Consequently, it appears that these kinds of failures have occured in response to earthquakes within the past few thousand years.

Lateral spread landslides present the greatest concern because of the potential consequences. A small amount of movement can do a great deal of damage. Lifelines (buried utilities) are particularly vulnerable. A large amount of Davis County falls within the slope range characterized by lateral spread landslides induced by soil liquefaction.

Slopes steeper than about 5 percent tend to fail as flow slides if the mass of soil comprising the slope liquefies. In Davis County, the stratified nature of the geologic materials suggests that flow-type failures are likely to be relatively rare. Instead, translational landslides or lateral spreads are likely to results from liquefaction on slopes steeper than about 5 percent.

In some places in the county granular soils were found to be relatively loose but not saturated. Unsaturated soils are not susceptible to liquefaction; however, these soils are noted because ground water conditions could change. These soils would be susceptible to liquefaction if they were to become saturated. Areas where unsaturated, relatively loose granular soils were found are identified as "potential susceptibility" by open triangle symbols on the Ground Slope and Critical Acceleration Map.

It should be emphasized that perched ground water. is equal to true ground water with respect to soil liquefaction. Saturated granular material is the chief concern, the source of the saturation is immaterial.

The results of our research on the liquefaction potential of Davis County lead us to conclude that lateral spread landsliding is the type of ground failure most likely to accompany soil liquefaction. The probability of extensive damage due to this type of ground failure is very high. All types of structures could be damaged by liquefaction-induced ground failure; lifelines are especially susceptible to damage.

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 waves. The method is reliable and rapid enough to be employed for real-time tsunami warning purposes when on-line seismographic data become available. During this reporting period, we tested the method for many large ($M_s \geq 6.5$) earthquakes, and investigated the use of Love waves.

Results

In our previous report, we reported the results of the test on large earthquakes in 1980. In Figure 1, we show the mechanism diagrams for these events. In most cases, reasonably accurate solutions were obtained. However, when the mechanism has a large amount of oblique slip component, the solution is somewhat ambiguous.

We also tested the method using Love waves. Large numbers of Love-wave records obtained at SRO and ASRO stations for the November 8, 1980, Eureka, California earthquake, and the May 25, 1980, Mammoth Lakes earthquakes were used for this purpose. Our results show that use of Love waves is very effective for increasing the stability and quality of the solution. The results of these investigations have been written in papers listed below.

Reports

Kanamori, H. and J. W. Given, Use of long-period surface waves for fast evaluation of earthquake source parameters, Phys. Earth Planet. Interiors, 27, 8-31, 1981.

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Lay, T., J. W. Given, and H. Kanamori, Long-period mechanism of the November 8, 1980, Eureka, California earthquake, Bull. Seism. Soc.

Am., in press, 1982.

Given, J. W., T. C. Wallace, and H. Kanamori, Teleseismic analysis of the 1980 Mammoth Lakes earthquake sequence, submitted to Bull. Seismol. Soc. Am., 1982.

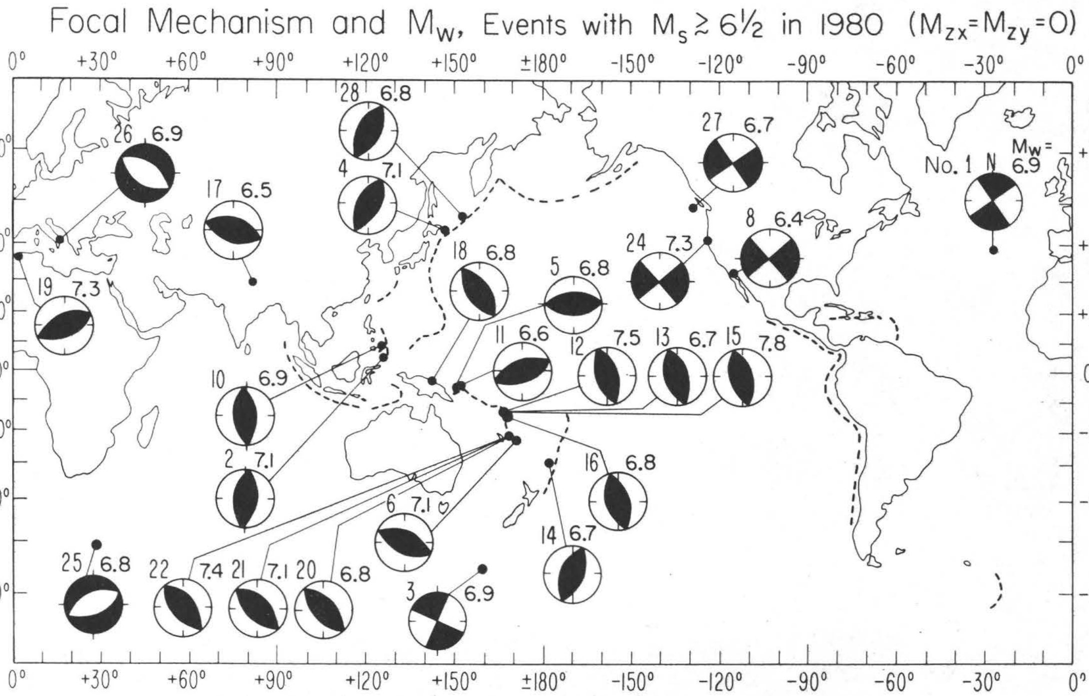

Fig. 1. Focal mechanism (lower focal hemisphere, dark and blank quadrants correspond to the compressional and dilatational first motion, respectively), and M_w of large ($M_s \geq 6.5$ shallow earthquakes in 1980. The major double couple of the source moment tensor obtained by inversion with the constraints $M_{zx}= M_{zy}= 0$ is shown. These constraints are equivalent to constraining the mechanism to either pure strike slip on a vertical plane or pure dip slip on a plane dipping 45°. (For the list of the events, see the Tables in the previous report).

Seismic Slope Stability

9550-03391

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Investigations

1. Mapped probabilities of seismic shaking from a postulated earthquake exceeding threshold values for slope failure.
2. Evaluated landslide susceptibility in the Santa Monica Mountains due to a postulated M 6.5 earthquake on the Newport-Inglewood fault.
3. Continued analyzing pore-pressure recordings from saturated lake sediments during the May 1980 Mammoth Lakes, California earthquake sequence.
4. Revised the paper "Landslides caused by earthquakes," which integrates data on landslides from numerous historical earthquakes.

Results

1. We have prepared a map of the probability that seismic shaking from a postulated M 6.5 earthquake on the northern part of the Newport-Inglewood fault would be severe enough to trigger slope failures on susceptible slopes. We have estimated minimum values of shaking intensity for slope failures as follows: A) for shallow (<3m) rock or soil falls on steep ($>35^{o}$) slopes, shaking of sufficient intensity and duration to cause a slope with a critical acceleration, $Ac \leq 0.05$ g, to be displaced >2 cm; B) for deeper seated slumps and block glides, shaking sufficient for a slope with $Ac \leq 0.05$ to be displaced >10 cm. Previously developed correlations between predicted block displacements (from the Newmark seismic stability analysis) and Arias Intensity (Ia) indicate that these threshold displacement values for rock/soil falls and slump/block-glides correspond approximately to Ia = 0.28 m/s and Ia = 0.50 m/s, respectively.

For a postulated M 6.5 event on the northern 30 km of the Newport-Inglewood fault zone, the map predicts:
A) Deep-seated slumps and/or block glides in the Baldwin Hills and the southern slope of the central Santa Monica range, and possibly in the northeastern half of the Palo Verdes Hills; and,
B) Rock/soil falls in the steep canyons of the Santa Monica range from Malibu east to Griffith Park, along the sea cliffs from Pt. Dume to Pacific Palisades, along the sea cliffs of the Palo Verdes Peninsula, and possibly in the Verdugo range and the western San Gabriel Mountains.

2. Studies of the engineering characteristics of the rocks and soils in the eastern Santa Monica Mountains, the Baldwin Hills, the Verdugo Mountains, and adjacent areas indicate that virtually all rocks and soils present are susceptible to earthquake-induced landslides on slopes steeper than 50^{o}. Most of the failures in a postulated M 6.5 event on the Newport-Inglewood fault will probably be shallow falls and slides. Units with widely spaced fractures, such as parts of the Topanga Canyon and Tuna Canyon formations will be especially hazardous. Deep-seated failures such as slumps and block slides

will be most prevalent in less indurated rocks such as in the Modelo Formation, shaly parts of the Topanga Canyon Formation, and other units that have been unstable in the past.

3. Preliminary analysis of pore-water pressure records from aftershocks of the Mammoth Lakes earthquake sequence, performed in collaboration with Gerald Mavko, indicates that dynamic pore-water pressures in the saturated sediments of Convict Lake can be predicted from the strong-motion acceleration records using an elastic model. Of the aftershocks for which we have both acceleration and pore-pressure recordings, shear strains are of the order of 10^{-4} or less.

Reports

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Evaluation of Liquefaction Susceptibility in the San Diego, California Urban Area

14-08-0001-19110

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Investigations

A study has been conducted to provide a regional assessment of liquefaction susceptibility in the San Diego urban area. Geologic units have been identified and mapped. Logs of borings made for numerous projects in the San Diego area were examined to aid in this mapping. Data from the borings on ground water levels and the engineering characteristics of the deposits, including penetration resistances (blow counts) and grain size characteristics, were compiled. Blow count data were statistically analyzed. Published correlation relating liquefaction susceptibility to penetration resistance (Seed, 1979; Seed and Idriss, 1981) and to geologic age and mode of deposition (Youd and Perkins, 1978) were then used to rate the liquefaction susceptibility of the deposits.

Results

For this study, ten geologic units have been identified and mapped. The estimated horizontal and vertical extent of these geologic units is shown in seventeen maps and thirty-eight cross sections. Liquefaction susceptibility ratings for the units are summarized in Table 1. Included in Table 1 are: susceptibility ratings based on the correlations of Youd and Perkins (1978); the medians, means, and ranges of penetration resistance (blow count) values obtained for each unit from the statistical analyses; and the susceptibility ratings assigned in this study using this information. The liquefaction susceptibility of non-hydraulic fill (Qhf) is not addressed in Table 1 due to the wide range of characteristics for this unit and the fact that the unit is generally located above the ground water table.

The liquefaction susceptibility of the geologic units has been quantified by using the blow count data and the correlation between cyclic stress ratio required to cause liquefaction, earthquake magnitude, and blow count presented by Seed (1979) and Seed and Idriss (1981). In Figure 1, the median, mean and range of blow count values for six of the geologic units are superimposed on this correlation. It can be seen in this figure that the cyclic stress ratio required to cause liquefaction varies substantially between the Holocene units (hydraulic fill, fluvial and estuarine deposits) and the Pleistocene units (littoral, estuarine and undifferentiated).

The cyclic stress ratio shown in Figure 1 can be related to peak ground acceleration using the simplified procedure of Seed and Idriss (1971). Assuming a groundwater table at a depth of 10 feet, the typical average depth for the study area, the peak ground acceleration (g's) is approximately equal to 1.1 to 1.2 times the cyclic stress ratio for soil deposits in the depth range 20 to 50 feet below ground surface. Thus, Figure 1 can be used to obtain a preliminary indication of the relationship between peak ground acceleration required to cause liquefaction, and earthquake magnitude for the different geologic units.

Reports

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Youd, T. L. and Perkins, D. M. (1978), "Mapping Liquefaction-Induced Ground Failure Potential," Journal of the Geotechnical Engineering Division, ASCE, Vol. 104, No. GT4, Proceedings Paper 13659, April, pp. 433-446.

TABLE 1

LIQUEFACTION SUSCEPTIBILITY OF GEOLOGIC UNITS

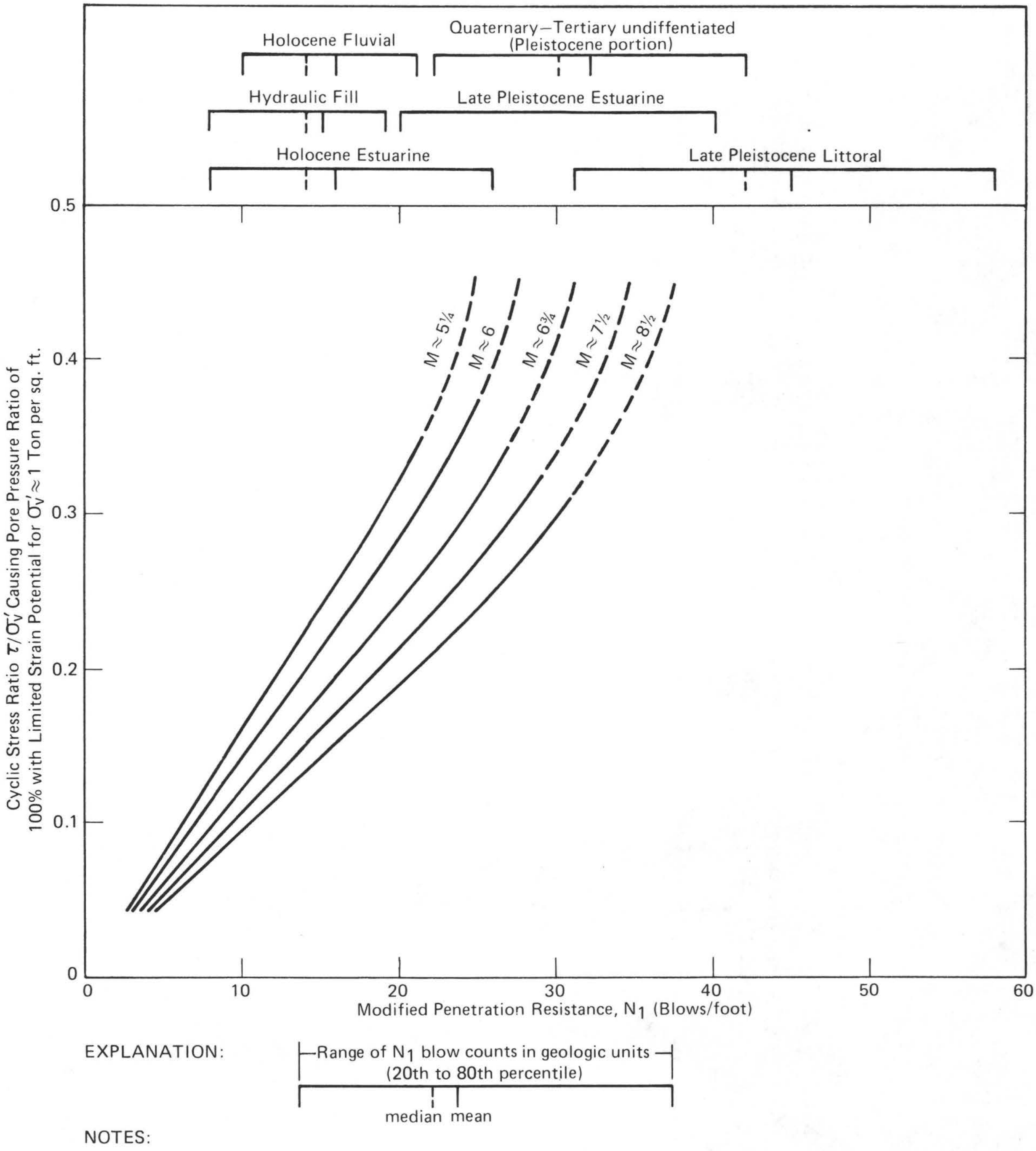
Geologic Units	Liquefaction Susceptibility Based On Youd and Perkins (1978)*	Number of Blow Count Values	Normalized Blow Count, N_1 (Blows/Foot)			Assigned Liquefaction Susceptibility Rating
			Median	Mean	Range**	
Hydraulic Fill (Qhf')	Very high	102	14	15	8-19	Moderate to high
Holocene Fluvial (Qhfl)	High to very high	56	14	16	10-21	Moderate to high
Holocene Estuarine (Qhe)	Moderate to high	78	14	16	8-26	Moderate to high
Holocene Littoral (Qhl)	Low to moderate	-	-	-	-	Low to moderate
Late Pleistocene Fluvial (Qplfl)	Low	-	-	-	-	Low
Late Pleistocene Estuarine (Qple)	Low	23	-	-	20-40***	Low
Late Pleistocene Littoral (Qpll)	Very low	69	42	45	31-58	Very low
Quaternary-Tertiary and Quaternary-Late Cretaceous undifferentiated (QTu and QKu) (Pleistocene portions)	Very low to low	162	30	32	22-42****	Very low to low

* Based on deposits with the groundwater table less than about 30 feet below the ground surface. The highest ratings for the three Holocene units correspond to sediments less than 500 years old; in the present study, it was not possible to separate these very young deposits from older Holocene deposits.

** Reported range is from the 20th to the 80th percentile of cumulative distribution curves of blow count values.

*** Range is based on a limited data set.

**** Blow counts for this unit include data from silty and clayey sands which tend to be lower than those for cleaner sands. Blow counts in all other units are for cleaner sands (SP and SP-SM).



NOTES:

1) Range for Late Pleistocene Estuarine deposits is based on a limited data set

2) Blow count values for Quaternary—Tertiary undifferentiated deposits tend to be too low because they include data from clayey and silty sands as well as cleaner sands

3) Correlation between τ/σ_v', N_1, and M is from Seed and Idriss (1981)

Fig. 1 — Comparison of Blow Counts in Geologic Units with Correlation for Liquefaction Potential

Liquefaction Investigations

9550-01629

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Investigations

1. Compilation continued on liquefaction potential maps for the Los Angeles Basin area of California.

2. Evaluated liquefaction hazards in the eastern San Francisco Bay area, California.

3. Continued compilation of data from subsurface investigations at sites where liquefaction has occurred during recent earthquakes.

4. Ordered equipment to permanently instrument a site for measurement of ground motion and pore-water pressure response associated with the generation of liquefaction during possible future earthquakes.

Results

Ground failures generated by liquefaction have been a major cause of damage in the eastern San Francisco Bay area during past earthquakes. During the 1906 San Francisco earthquake, ground failures severed pipelines, disrupted roads and railroads, fractured or distorted buildings, and disturbed the ground surface at many localities. Areas that liquefied were primarily along rivers and creeks, marginal to bays, and in poorly compacted sand fills; these same areas are likely to undergo liquefaction again during future earthquakes. Other areas likely to contain susceptible sediment are saturated Holocene alluvial and estuarine deposits; these deposits were delineated on a susceptibility map for part of Alameda County. Likelihood of shaking intense enough to cause liquefaction in highly susceptible sediment (liquefaction opportunity) is greatest in the area between San Francisco Bay and the Amador and San Ramon Valleys, where liquefaction could be generated by large earthquakes on the San Andreas and San Gregorio faults and moderate to large events on the Hayward, Calaveras, Concord, and Green Valley faults. On the basis of the historical record, opportunity for liquefaction in that area occurs about once every 40 years. East of the San Ramon and Amador Valleys, opportunity decreases to an average of once every 100 to 200 years at the west margin of the San Joaquin Valley, where large earthquakes on the San Andreas fault are the primary generators of liquefaction. Thus, areas of the east bay with the highest potential for liquefaction (combination of high susceptibility and high opportunity) are those underlain by sandy Holocene alluvial and estaurine deposits and poorly compacted sand fills in the plains bordering San Francisco and San Pablo Bays and in the San Ramon and Amador Valleys.

Reports

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Youd, T.L., Wilson, R.C., and Schuster, R.L., 1981, Stability of blockage in North Fork Toutle River, in Lipman, P.W, and Mullineausx, D.R., eds., The 1980 Eruptions of Mount St. Helens, Washington: U.S. Geological Survey Professional Paper 1250, p. 821-828.

Earthquake Hazard Analysis For Commercial Buildings in Memphis

14-08-0001-19829
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Investigations

The major objective of this project is to present a methodology used to evaluate loss from predicted ground motion. The approach is demonstrated on commercial buildings in Memphis, Tennessee. The emphasis is placed on local characteritics of the commercial structures in the region. From the listing of all commercial buildings, the structures representative to the region have been selected and likely structural and nonstructural damage was evaluated.

The evaluation of seismic strength was carried out on the basis of selected structures listed in Table 1. The buildings were on site examined by the project team. Then, a more detailed analysis was performed to determine the seismic strength of five structures: two low-rise and three medium high ones. Analysis is based on the available technical drawings.

For each building considered, a representative bent was selected, and moment capacities were calculated for all members in the frame. Inertia masses were calculated and apportioned, using the building plans, photographs and observations. Mode shapes, frequencies, periods, and base shear equivalent masses were calculated using a Stodola iteration procedure.

The equivalent lateral forces were calculated for four design earthquakes. Two were given in terms of response spectra: Imperial Valley, (El Centro) California (1940) and Kern County, California, (1952); the other two were specified by the codes: UBC 1979 edition (zone 3) and BOCA 1981 edition (zone 2).

Moments and shear forces due to earthquake were compared to resistance of the structure.

Table 1, Selected Commercial Buildings

Identification	Number of Stories	Year of Construction	Type of Structure	Remarks
A	3	before 1897	mason ry walls, timber joists.	originally 2 storie
B	4	before 1900	mason ry	cast iron front
C	3	1930's	reinforced concrete frame	
D	4	1926	reinforced concrete frame	
E	8 & 6	about 1881	mixed; steel frame, cast iron columns, timber frame	numerous additions,
F	9	1906	steel frame mason ry walls	numerous changes
G	12	1906	reinforced concrete frame	
H	13	1923	steel frame	
I	9	1920's	reinforced concrete columns and slabs (no beams)	
J	11	1921	reinforced concrete frame	U shaped
K	18	1901	steel frame mason ry walls	Annex added 1937
L	19	1909	steel frame	
M	29	1929	steel frame	U shaped
N	31	1969	steel frame	

Results

The site examination of existing commercial buildings in Memphis revealed a surprisingly good quality of design and workmanship. A very limited degree of deterioration was observed.

Seismic analysis showed that the examined buildings, in general, satisfy the requirements of the BOCA code (1981 edition), zone 2. However the columns, especially exterior ones, do not satisfy the requirements of the UBC code (1979 edition), Zone 3.

Table 3, Ratios of Load Resistance for Beam C-B

Floor Level	Earthquake			
	Imperial Valley	Kern County	UBC	BOCA
4	.70	.48	.44	.33
3	.61	.39	.33	.20
2	.90	.51	.44	.41
1	.73	.42	.33	.21

Table 4, Ratios of Load to Resistance for Column A

Floor Level	Earthquake			
	Imperial Valley	Kern County	UBC	BOCA
4	.92	.46	.38	.15
3	2.03	1.02	.72	.31
2	3.22	1.61	1.15	.49
1	3.07	1.53	1.14	.49

Table 5, Ratios of Load to Resistance for Column B

Floor Level	Earthquake			
	Imperial Valley	Kern County	UBC	BOCA
4	2.74	1.37	1.12	.44
3	4.65	2.33	1.72	.72
2	5.10	2.75	2.01	.86
1	3.13	1.57	1.16	.50

For example a building with a reinforced concrete frame is considered, Fig. 1. The results of calculations are summarized in Tables 2 to 5.

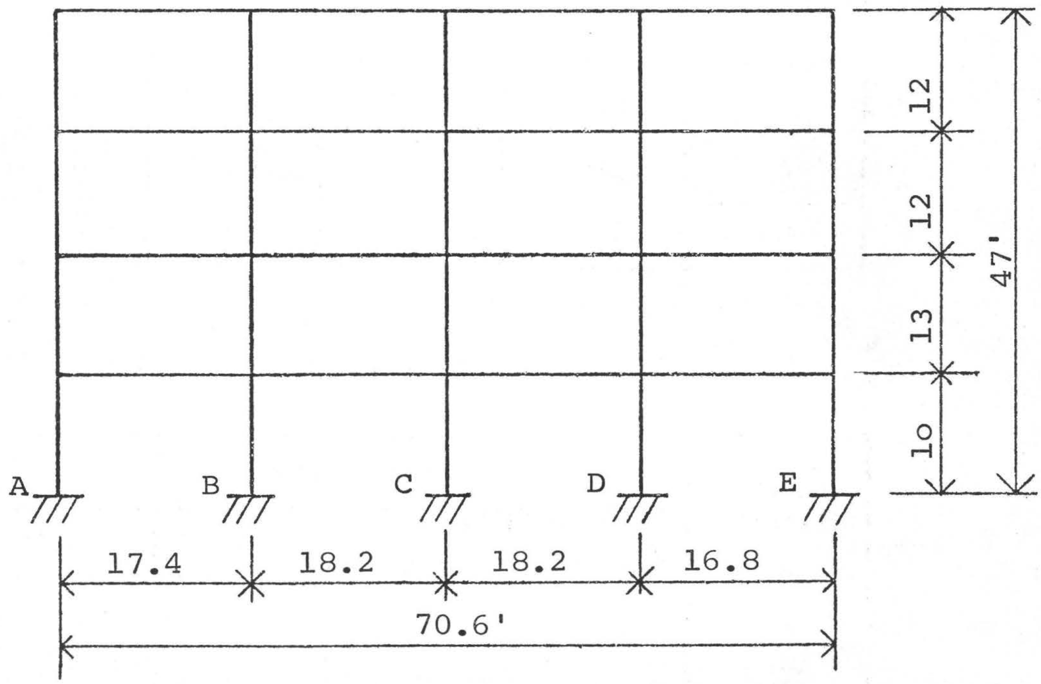

Fig. 1 Frame of the Reinforced Concrete Building

Table 2, Ratios of Load to Resistance for Beam A-B

Floor Level	Earthquake			
	Imperial Valley	Kern County	UBC	BOCA
4	1.33	.80	.70	.44
3	1.16	.64	.53	.28
2	1.76	.94	.72	.38
1	1.24	.67	.52	.24

Creep and Strain Studies in Southern California

Contract No. 14-08-0001-19269

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Investigations

This semi-annual report summary covers the six-month period from 1 October 1981 to 31 March 1982. The contract's purpose is to maintain and 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.--This has been a period of relative inactivity in the Imperial Valley. Continuously recording creepmeters at HARRIS ROAD, ROSS ROAD, HEBER ROAD, and TUTTLE RANCH were each serviced once during the reporting period, and no significant creep episodes were noted. Similarly, resurveys of alignment arrays at HIGHWAY 80, WORTHINGTON ROAD, ALL AMERICAN CANAL, SUPERSTITION HILLS, and KEYSTONE ROAD, as well as resurveys of nail-file arrays at ROSS ROAD, ANDERHOLT ROAD, and WORTHINGTON ROAD, revealed no large movements. The dial-gauge-reading creepmeter at SUPERSTITION HILLS was also read, and it, too, revealed no movement during the reporting period.

Coachella Valley.--Alignment arrays at INDIO HILLS and RED CANYON were each resurveyed once during the reporting period, with no significant changes. Likewise, the dial-gauge-reading creepmeter at NORTH SHORE and the continuously recording creepmeter at MECCA BEACH (serviced twice) showed no significant changes. This segment of the San Andreas fault in the Coachella Valley has shown surprising episodic creep over the past ten years, as discussed in the previous semi-annual report summary, but nothing significant appears to have happened during the current reporting period. Because this segment of the fault also represents a marked seismic gap, it is the object of special attention.

Other areas.--Alignment arrays farther northwest along the San Andreas fault are normally resurveyed annually, as are those along the Garlock fault. Arrays at UNA LAKE, PALLETT CREEK, CAJON PASS, and WATERMAN CANYON, all across the San Andreas fault, were resurveyed during this reporting period, with no significant changes observed.

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 has concentrated on:

1. Waveform studies of preshocks of the 1971 San Fernando earthquake.
2. Seismicity near the Anza gap, Southern California.
3. Reformatting of the CEDAR phase data into an easily accessible format.

Results

1. Waveform studies of preshocks of the 1971 San Fernando earthquake.

In our previous study, we found that the preshocks of the 1979 Imperial Valley earthquake have remarkably similar waveforms over the entire record length (~30 sec), with an average correlation between seismograms of consecutive events of 0.74.

We made a similar analysis for the 1971 San Fernando earthquake. Ishida and Kanamori [1978] collected Wood-Anderson seismograms recorded at Pasadena for all $M_L < 3$ events which occurred within 15 km of the epicenter of the 1971 San Fernando earthquake (Δ~40 km) during the period 1961-1971. Master event locations for this region show diffuse seismicity from 1961-1964, quiescence from 1965-1968, and clustering near the eventual hypocenter from 1969-1970. This pattern was confirmed by visual inspection of the waveforms, although Ishida and Kanamori note that it is much more obvious on the EW component than on the NS component. We applied our cross-correlation test to the hand-digitized records of Ishida and Kanamori. The results are shown in Fig. 1. Because of digitization noise and because only ~9-11 seconds of record had a large enough amplitude to be digitized in most cases, these cross-correlations are not as reliable as those performed with CEDAR data. Nevertheless, Fig. 1 confirms the observations of Ishida and Kanamori that the events during 1961-1964 exhibit a greater variety of waveforms than those during 1969-1970, at least on the EW component. On the EW records, the last four events before the mainshock have very high cross-correlations (~0.75) as do the first three events in 1961.

Cross-correlations between other pairs of consecutive events are all < 0.6. This suggests that tight clustering of hypocenters does not occur very often, even if such clustering is not limited to the time period immediately before large earthquakes. Hence, comparison of waveforms may be a useful tool for monitoring stress conditions along faults.

2. Seismicity near the Anza gap, Southern California.

We investigated the seismicity near the Anza gap using the CEDAR data. The aftershock activity of the February 25, 1980 ($M_L = 5.5$) has more or less died down, and the activity in the gap remains low as of February, 1982.

Reports and Publications

Walck, M. C. and J. B. Minster, Relative array analysis of upper mantle velocity variations in Southern California, J. Geophys. Res., 87, 1757-1772, 1982.

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, submitted to J. Geophys. Res., 1982.

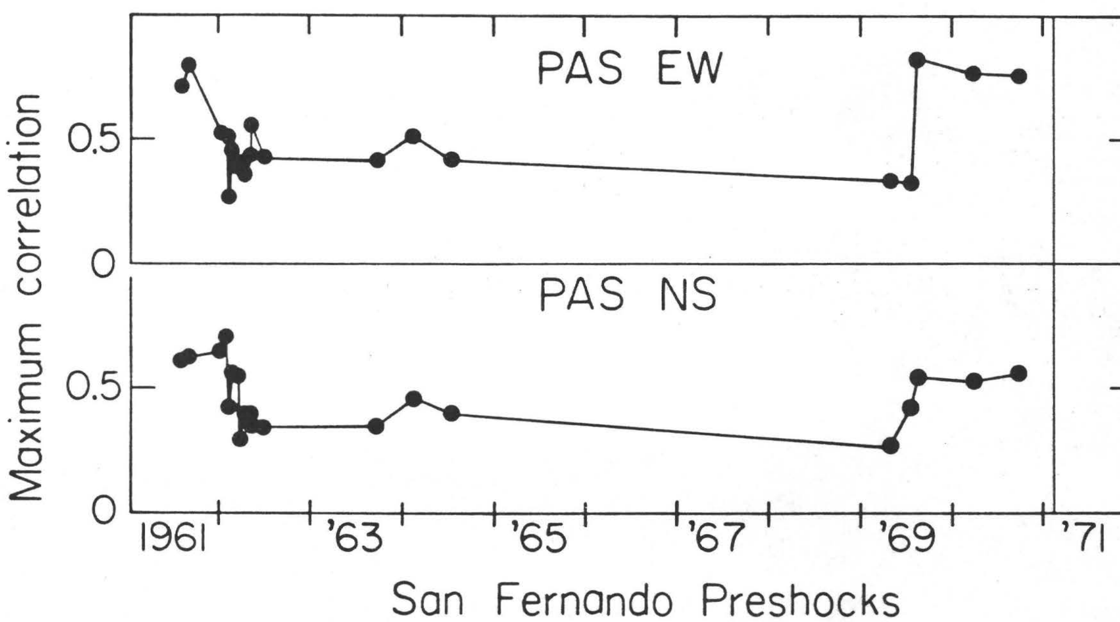

Fig. 1. Maximum cross-correlation between seismograms of consecutive events within a 15 km radius of the epicenter of the 1971 San Fernando earthquake, plotted as a function of time. Seismograms are shown in Figs. 2 and 3 of Ishida and Kanamori [1978]. 9-11 sec of record was used in most cases, beginning with the S-wave. Seismograms were recorded on Wood-Anderson torsion instruments located at Pasadena ($\Delta \sim 40$ km).

On-Line Seismic Processing

9970-02940

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Investigations and Results

During the reporting period we have again worked at improvements on the existing (Real Time) picker without major changes in the system hardware. Jim Ellis identified failure modes which explained most of the system problems, and was able to remedy these problems with minor field changes in wiring and replacement of IC's. As a result, our estimated mean time between failures (MTBF) for soft failures of the Menlo Park RTP has increased from 2-3 weeks to something over two months. This estimate is hazy because there have been no failures since the changes were made.

The RTP's measure of coda length of an observed events was changed to conform to the "hand-pick" standard of 1 cm amplitude on 16 mm film image, and the measured magnitudes are now in satisfactory agreement with Calnet hand picks up to a magnitude of about 3.5. We are continuing work on other magnitude rating schemes, but this will allow us to use RTP data in the usual way in Calnet analysis.

As of early October about 1/3 of all Calnet phase cards processed are from the RTP. This proportion will increase as more of the Calnet stations go on the RTP and as we gain more experience in using the output.

The RTP software has been modified to provide a daily report on observed status of the seismic net as seen by the system. This report is generated each morning during the quiet time at 5:00 a.m. and includes for each station the observed values of discriminator offset and average background seismic noise. The reports have proved to be of considerable value to the technicians maintaining the seismic telemetry system, since these critical parameters can be checked at a glance and maintenance activity planned accordingly.

The 120 station RTP for the University of Washington has been delivered and is operating satisfactorily.

No major changes have been made in the Real Time Processor (RTP) system during this period. A system has been built for the Hawaii

Volcano Observatory and is now undergoing final tests before delivery. Work is progressing on hardware required to expand the Menlo Park R.T.P. to capacity of 500 stations to accomodate all telemetry lines brought in here.

A careful review of automatic picker operating principles was made and several areas of possible improvement of the pickers were identified. I expect to gain a measureable improvement in software performance as a result.

Carbon-Fiber Strainmeter Studies near Palmdale, California - Instrument Construction, Data Reduction and Interpretation/Correlation with Other Geophysical Instruments

14-08-0001-19790

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Investigations

1. Data from 4 carbon fiber extensometers at Dalton Canyon and Bouquet reservoir continue to be analysed.

2. Four additional extensometers were installed at three new sites. All the sites are underground tunnels varying in depth and length from 10 m to 150 m.

3. Instruments for a further two sites await final site preparation.

4. Satellite telemetry has been added to four of the instruments.

Results

1. Instrument parameters are listed in the Table below.

2. No anomalous strain signals were observed during 1981. Thermo-elastic and hydraulic noise occur in the data superimposed on strain rates of a few microstrain/year.

Location	Azimuth	Length	latitude	longitude	start date	telemetry
Jackson	155	20 m	34°30.9'	118°17.6'	Dec. 1981	-
	45	20 m				
Bouquet	109	27 m	34°35.7'	118°22.8'	Dec. 1978	x
	79	20 m				x
Dalton	55	58 m	34°10'	117°50'	Dec. 1979	-
	162	30.5 m				
Three Sisters	150	20 m	34°40.5'	118°22.6'	Dec. 1981	x
Aqueduct	51	20 m	34°32.0'	118°31.2'	Dec. 1981	x
Monte Christo	10	20 m	34°21.2'	118°05.3'	-	-
Big Horn	45	20 m	34°21.5'	118°22.2'	-	-
	135					

Fault Slip Measurements

9960-02943

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Investigations

Fault creep monitoring along the San Andreas fault in central California and along the active strike-slip faults in the San Francisco Bay Area was continued. Investigations of historic slip rates on the Hayward fault in Fremont and on the Calaveras fault in Sunol Valley were undertaken by analyzing the measured fault offsets of 1924 and younger powerline-tower alinements.

Design work on the proposed development of a deep reference strainmeter system has been started. The first step in the development work is to design and test a 30-meter inverted-pendulum, carbon-fiber tiltmeter.

Results

Repeated measurements of 3 alinement arrays established in 1968 across the Hayward fault at San Pablo and Fremont and across the Calaveras fault at Coyote Lake have been analyzed to determine long-term, local slip rates. The long-term averages were about 6 mm/a and 9 mm/a on the Hayward fault at San Pablo and Fremont, respectively, as of mid-1980, and about 11 mm/a on the Calaveras fault at Coyote Lake prior to the August, 1979 Coyote Lake earthquake of magnitude 5.9. Following this event, the local slip rate increased abruptly and has since decayed in a logarithmic manner (afterslip). Surveys of an array established in 1973 across the Concord fault in Concord have been analyzed to determine a long-term, average rate of about 4 mm/a.

The consistent right-lateral offsets of powerlines at the Calaveras fault in Sunol Valley indicate a long-term average slip rate of about 3.5 mm/a since 1924. This result is in close agreement with a 2.9-mm/a rate independently determined by repeated, precise geodetic surveys of the adjacent Veras network conducted since 1965. The variations in offsets of powerlines of significantly different ages suggest that an increase in local slip rate from <1 mm/a to >4 mm/a may have occurred between 1939 and 1944. The low rate before 1939 and the increased rate after 1944 which decayed to 2.9 mm/a by 1965 may be related to the occurrence of a local sequence of moderate earthquakes in 1943.

Possible temporal variations in slip rate, if any, on the Hayward fault in Fremont remain unresolved. However, a reliable measurement of the right-lateral offset of the 1924 Hetch Hetchy power line at the Hayward fault determines a long-term average slip rate of 10 $\pm$ 1 mm/a.

A design for a proto-type float and sensor assembly for the deep-reference tiltmeter component has been completed. Pending review of an outside consultant engineer, a modification of the prototype design may be manufactured in the near future. The design depends upon the workability of a resin-coated carbon fiber as the elastic suspension line between float/sensor assembly and the anchor point (deep reference) at the bottom of the drill hole. Stability tests for the carbon fiber have been proposed as a cooperative effort by Roger Bilham and Keith Evans at Lamont.

Reports

Harsh, P.W., and R.O. Burford, 1982, Fault slip determined by alinement array measurements in the east bay region, presented at Conference on Earthquake Hazards in the Eastern San Francisco Bay Area, Calif. State Univ., Hayward, March 24-27, 1982.

Burford, R.O., and R.V. Sharp, 1982, Slip on the Hayward and Calaveras faults determined from offset power lines, presented at Conference on Earthquake Hazards in the Eastern San Francisco Bay Area, Calif. State Univ., Hayward, March 24-27, 1982.

Remote Monitoring of Source Parameters for Seismic Precursors

9920-02383

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Investigations

1. Monitoring changes in source parameters before large earthquakes using teleseismic data. The rupture characteristics of 4 moderate-sized ($5.4 \leq m_b \leq 6.1$) earthquakes that encircled the eventual rupture zone of the Miyagi-Oki earthquake of June 12, 1978, over a period of 2 years before the mainshock were studied using digital data from the GDSN.

2. Broadband analysis of large earthquakes. We are evaluating the utility of exploiting broadband waveforms recorded by the GDSN to analyze the rupture process of large earthquakes (magnitude ≥7.0).

Results

1. Monitoring changes in source parameters before large earthquakes using teleseismic data. Static and dynamic source parameters of four earthquakes preceding the Miyagi-Oki earthquake of June 12, 1978, have been obtained. 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.

2. Broadband analysis of large earthquakes. We are examining the rupture process of the large (M_s 7.8) Samoa earthquake of 1 September 1981. By using broadband records of displacement and velocity, the depth of the initial nucleation and a preliminary description of the rupture process have been obtained.

Reports

Harvey, D., and Choy, G. L., 1982, Broadband deconvolution of GDSN data: Geophysical Journal of the Royal Astronomical Society, in press.

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, submitted.

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.

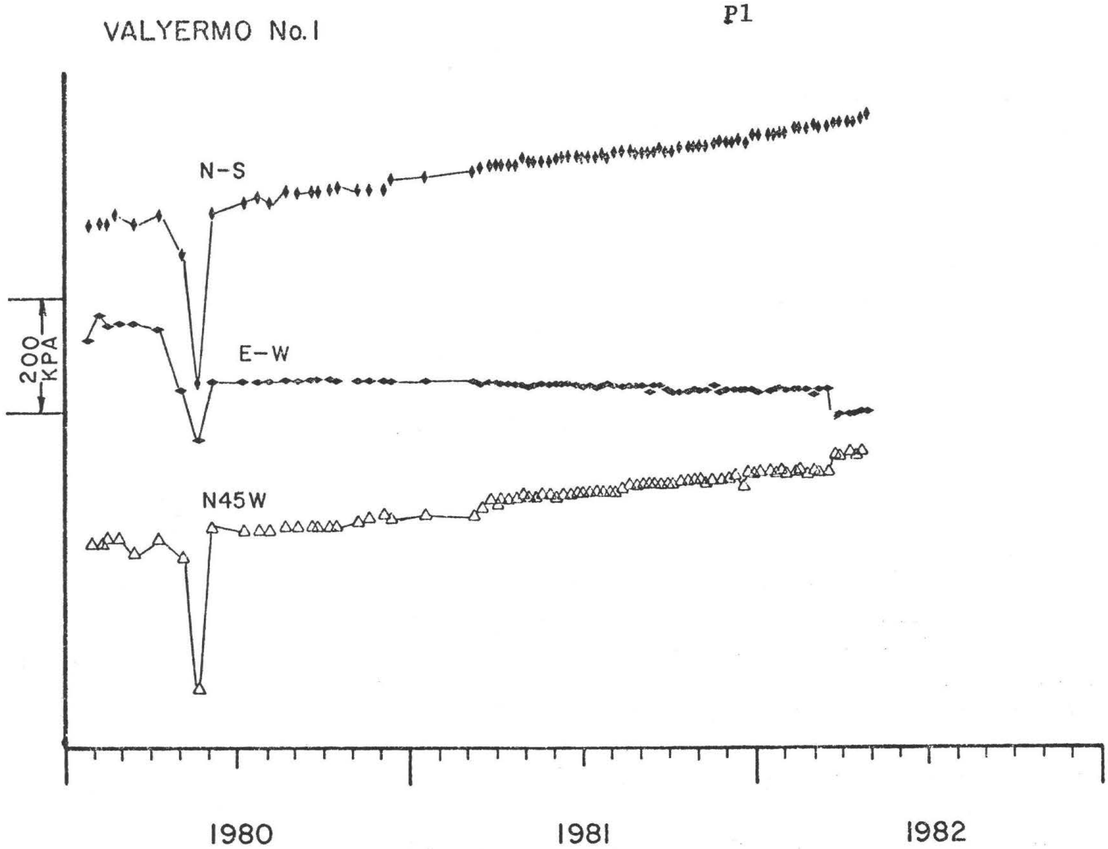
Reports

Clark, Bruce R., 1981, Long-Term Changes in Southern California Stressmeter Net: EOS, Trans. Am. Geoph. Union, v. 62, p. 1052.

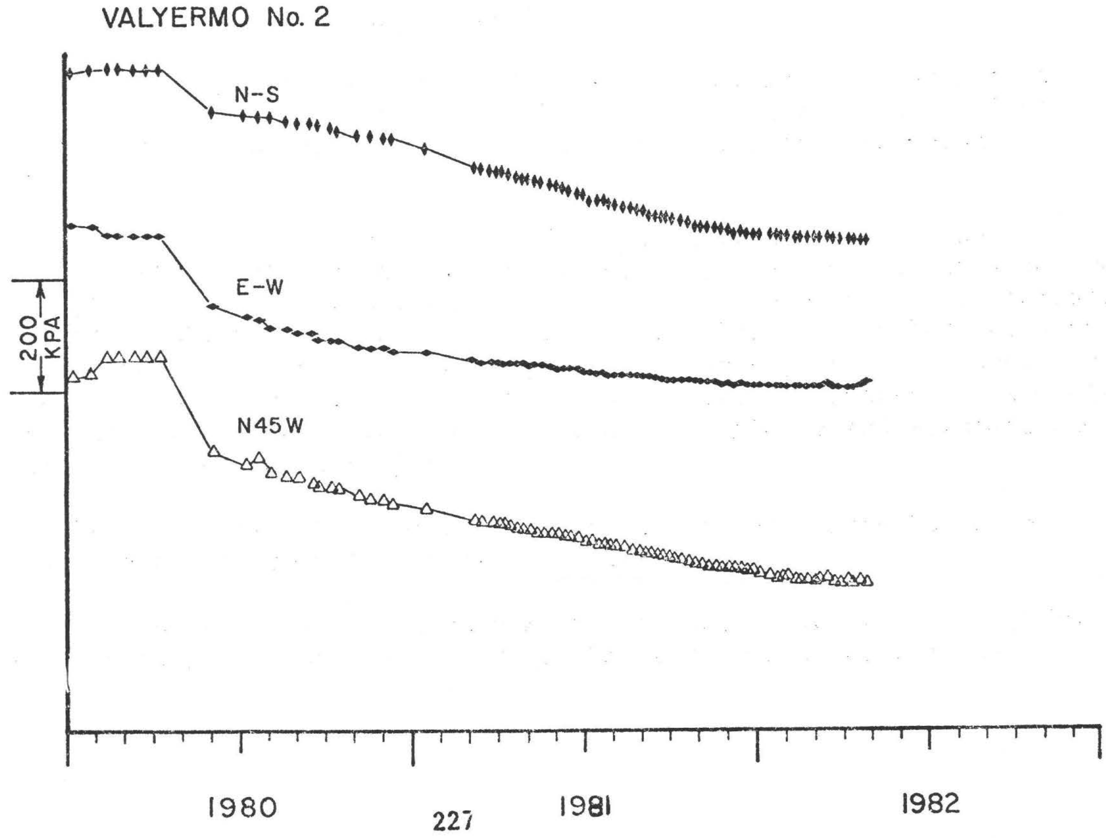
------, 1982, Monitoring Changes of Stress along Active Faults in Southern California: Jour. Geoph. Research, in press.

Figure 1

P1

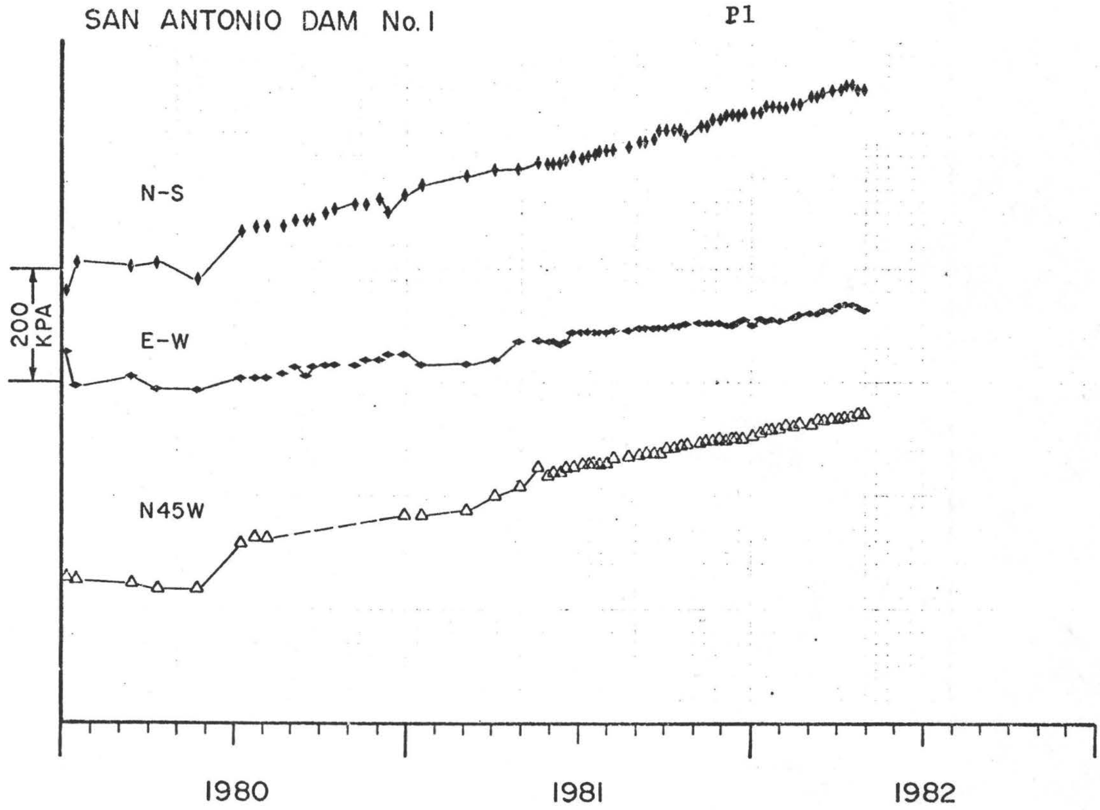


VALYERMO No.1
N-S
E-W
N45W
200 KPA
1980
1981
1982

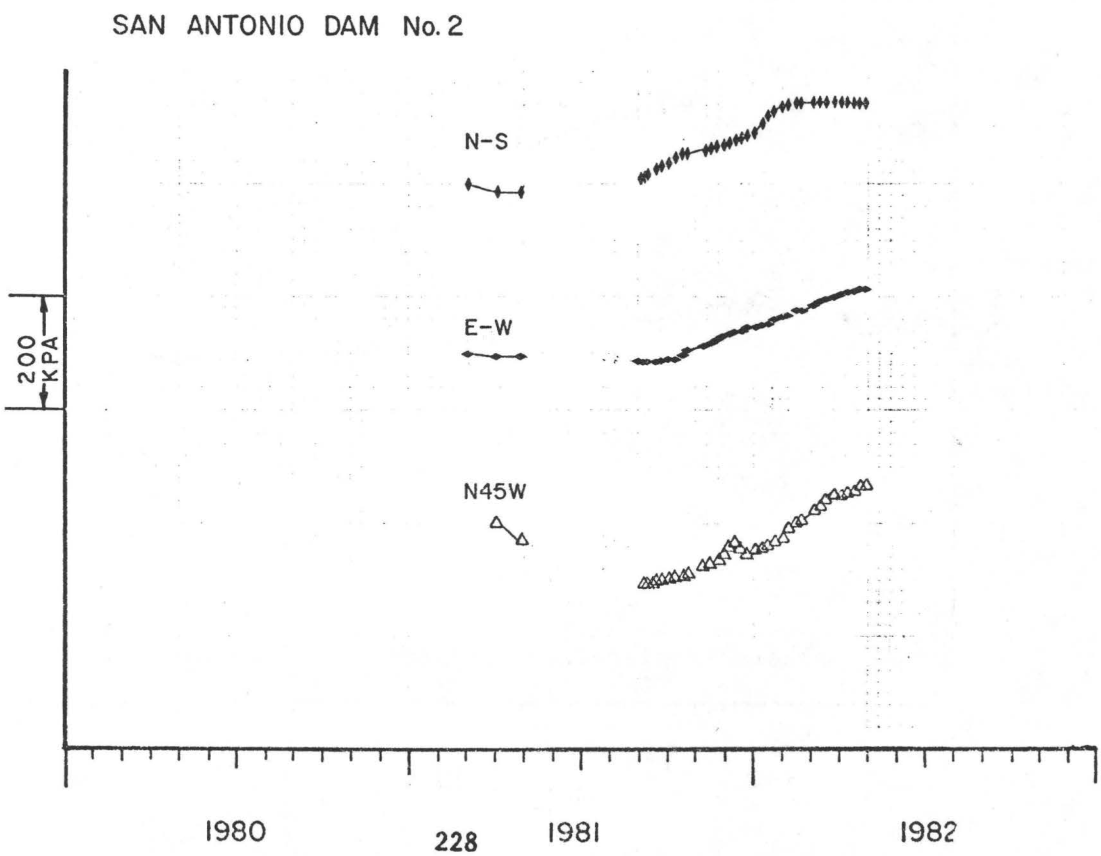


VALYERMO No. 2
N-S
E-W
N45W
200 KPA
1980
1981
1982

Figure 2



SAN ANTONIO DAM No. 1
P1
N-S
200 KPA
E-W
N45W
1980
1981
1982



SAN ANTONIO DAM No. 2
N-S
200 KPA
E-W
N45W
1980
1981
1982

Central California Network Processing

9930-01160

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Investigations

Signals from 300 stations of the multipurpose Central 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. Summary catalogs of earthquakes located by the network from 1969 through December 1977 have been published. Preliminary results for January 1978 through June 1980 are accessible in various forms, and work on completing and publishing the summary catalogs for these years has high priority but is proceeding slowly. Results for July through December 1980 and May to December 1981 are being finalized.

2. Routine analysis of the network data has been transferred from the MULTICS system to the PDP 11/70 computer under the UNIX system. Processing procedures have been revised to include the merging of P-phase data provided by the real-time picker system developed by Rex Allen and Jim Ellis. The addition of these data has substantially decreased the amount of time required to process earthquakes to catalog quality. On a daily processing basis emphasis is placed on completing, to catalog quality, each

day's earthquake. This approach to the processing was initiated in May 1981 and has been reasonably successful.

3. A compilation of USGS and University of Nevada (Reno) earthquake location data was undertaken for the years 1980 and 1981 for California State. Preliminary epicentral maps of these data are presented in Fig. 1. These data are believed to be complete at the $M \geq 1.5$ for the region west of the Sierra Nevada crest to the Pacific Ocean and north of San Luis Obispo to the Cape Mendocino area. The remaining territory, So. California and the east side of the Sierra Nevada, is believed complete to $M \geq 2.2$. These data have been compiled with the assistance of Carl Johnson (USGS-CIT) and Allan Ryall (Univ. of Nevada at Reno).

4. A detailed study of the seismicity of the San Andreas Fault System north of San Francisco Bay has been started using CALNET data acquired since January 1980. Two distinct regions are evident; north of 40° N. latitude and 38° N. to 40° N. latitude. In the northern region, the epicenters are randomly distributed except for a small clustering of events approximately 25 km off Cape Mendocino. Focal depths in this northern region range from 10 to 35 km; the deepest events are between 50 and 60 km. These earthquakes outline a 20° - 25° SE - dipping Benioff zone, (Fig. 3a) representing subduction of the Gorda plate. Southward to lat. 38° N., in the southern region, the pattern of seimicity consists of two N. 30° W.-trending zones that parallel an essentially aseismic San Andreas fault (Fig. 2); all focal depths within this region are shallower than 18 km (Fig. 3b). The western zone coincides with the Rodgers Creek-Maacama faults whereas the eastern zone of seismicity coincides with the Green Valley-Bartlett Springs faults. Geologic mapping of these faults in the northern San Andreas fault system has revealed abundant evidence for repeated displacement during the Holocene. Fault creep is locally occurring at a rate of several millimeters per year on the Maacama and Green Valley faults.

5. On May 29, 1980 (0338 UTC), an earthquake of $m_b = 5.1$ (NEIS) occurred off the south-central California coast within the Hosgri fault system, approximately 40 km SSW of San Luis Obispo and 30 km west of Santa Maria. Many small aftershocks, generally too small to be located, followed in the next few days; magnitude (coda) 2.6 aftershocks occurred on May 31 (0919 UTC). The main shock was well recorded at 245 stations of the central and southern California seismic networks. Timing errors are believed to be no larger than 0.02 s. A hypocentral location of latitude 34°56.11'N., longitude 120°46.74'W., and depth of 8.9 km was determined from 45 P-wave arrivals at stations within 150 km of the epicenter by means of program HYPO71. The standard-error estimates of 1.4 km and 1.8 km for location and depth, respectively, appear to be unrealistically

small. The epicentral location ranges over about 6 km in a NE-SW direction as the maximum distance to stations included in the solution ranges from 100 to 200 km. Thus, a more realistic estimate of error in epicentral location is about 3 km. With the location given above, P-wave first motions were used to determine a focal mechanism. The focal-plane solution indicates reverse faulting on a fault plane that strikes N. 62° W. and dips either 22° NE. or 68° SW. The T- and P-axes strike N. 26° W. and S. 25° W., and plunge 66° and 24°, respectively.

Reports

Cockerham, R. S., and Eaton, J. P., The Point Sal, California, Earthquake of May 29, 1980, Earthquake Notes v. 53, no. 1, p. 51, 1982.

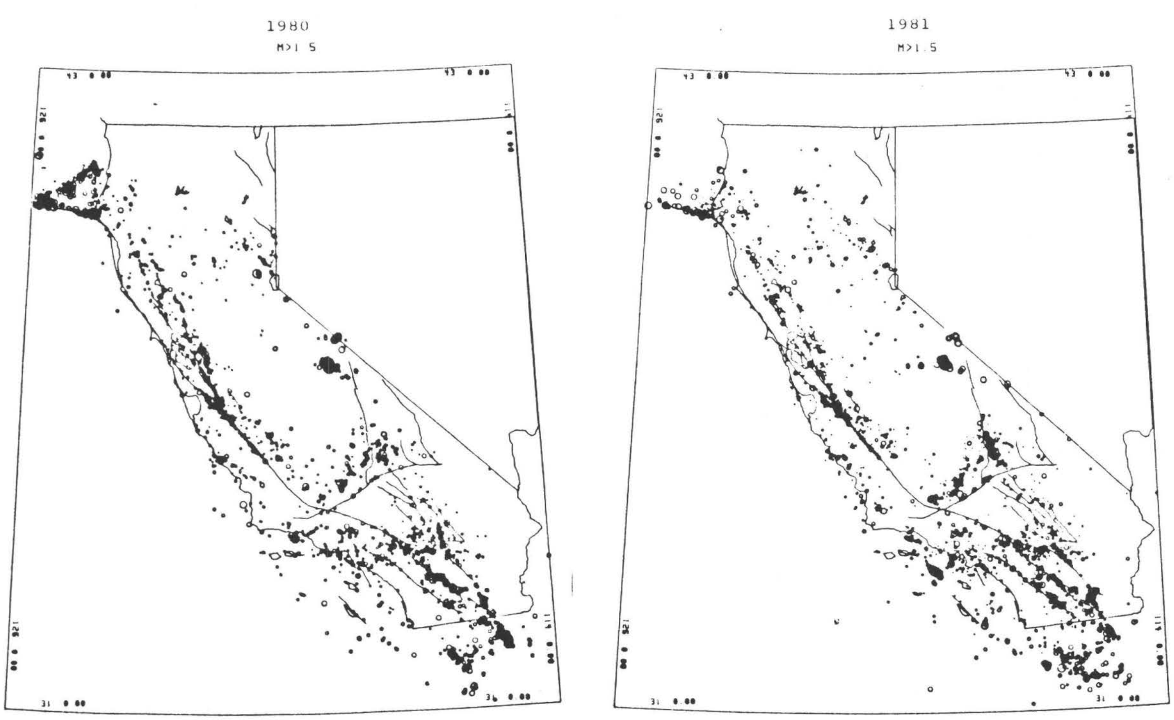

FIGURE 1

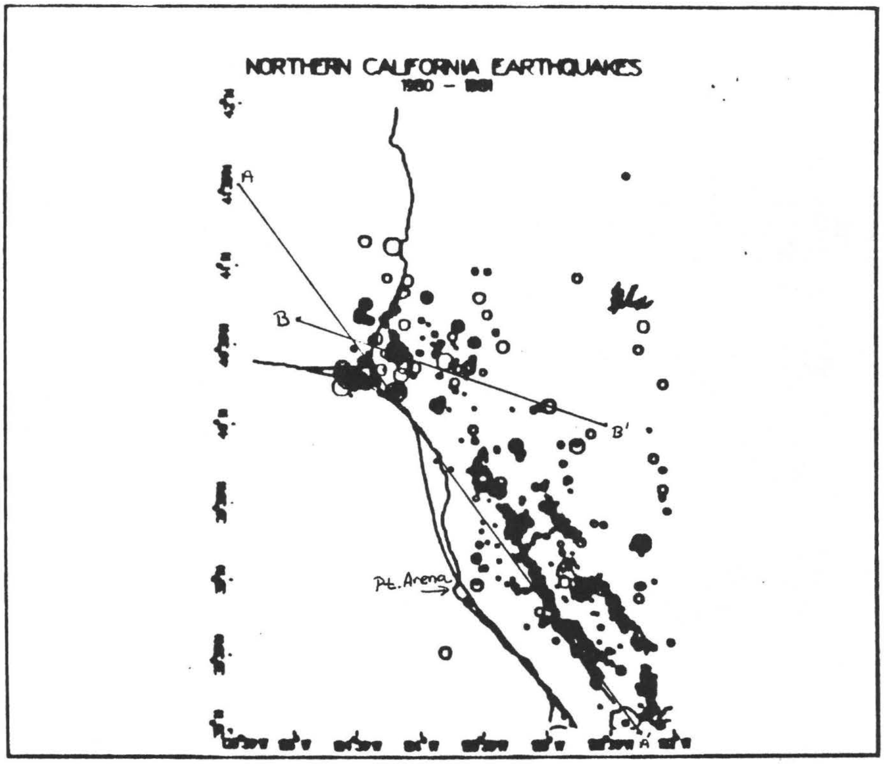

FIGURE 2

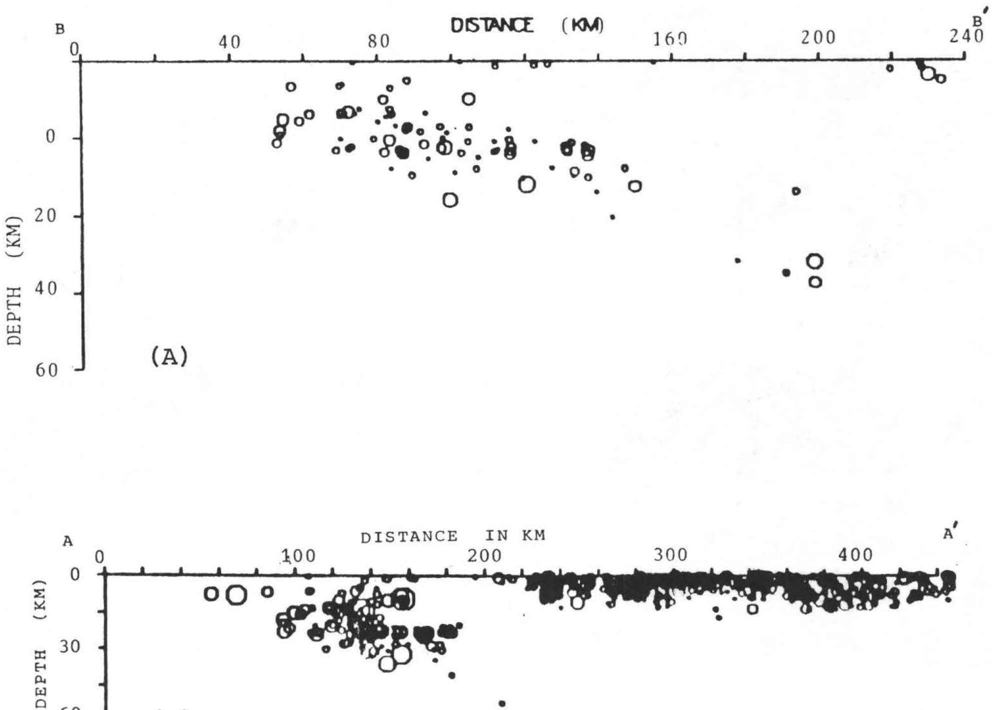

FIGURE 3

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. The knowledge gained from these and other studies should improve our ability to assess the results of the real-time earthquake monitoring system that is now in routine use.

Results

1. Precisely located earthquake hypocenters and well-constrained focal mechanism solutions in the eastern San Francisco Bay region from 1969 to 1980 show a close association with many recently active faults. The principal faults, including the Hayward, Calaveras, Concord, and Greenville faults, can be readily identified on the basis of prominent alignments of hypocenters and correlative focal mechanism fault planes that lie beneath the surficial expressions of these faults. Seismic activity also is widely distributed throughout the region from the east shore of San Francisco Bay to the west edge of the San Joaquin Valley. This distributed activity strongly suggests the presence of at least two major subsurface faults that lack a clear surficial expression. In other areas, the absence of a clear pattern suggests a volumetrically distributed strain-release mechanism.

2. Our study of the historic record of moderate-to-large magnitude earthquakes (M 5.5+) suggests that the cyclic accumulation of elastic strain in the crust and its release in great earthquakes

modulates the regional pattern of seismicity within the San Andreas fault system (see reference to Ellsworth, et, al., 1981 cited in the previous report). The space-time distribution of moderate-to-large magnitude earthquakes observed in California generally conforms to the same stages of the seismic cycle recognized by Fedotov (1968) and Mogi (1981) in the subduction zones of the Western Pacific. This cycle consists of an extended period of relative seismic quiescence following a great earthquake, followed by a period of increased activity that leads to the cycle-controlling earthquake and its foreshocks and aftershocks. At present, we consider the evidence for a seismic cycle in California to be supportive rather than decisive.

Application of the seismic cycle hypothesis in a predictive mode suggests that while a great earthquake is not likely to occur for several decades on the northern segment, which last ruptured in 1906, that region is entering a period when moderate-to-large earthquakes will be more frequent than they have been in the three quarters-century following that event. The likelihood of a major earthquake is considered to be much higher along the southern half of the south-central segment and along the southern segment of the San Andreas fault, where we tentatively identify an active stage of the cycle. Independent data on the south-central segment also supports this assessment. The meaning recurrence time for prehistoric great earthquakes at one site of 140 years (Sieh, 1978) can be taken to imply that there is a 50% chance that this segment of the fault will rupture in a large event within the next 30 years. In contrast to our rising expectations of potentially damaging events in northern and southern California, all of the available evidence suggests that the central creeping segment of the San Andreas fault will not produce a major earthquake in the near future, if ever.

3. Aftershock locations and focal mechanisms for the August 6, 1979 Coyote Lake earthquake indicate that fault displacement involved movement on a 25-km-long complex network of preexisting faults. The gross pattern of aftershock hypocenters describes two overlapping nearly vertical planar sheets separated by a 2-km right step near latitude 37° N., with some diffuse activity concentrated between the sheets within the overlap zone. Virtually all the focal-mechanism solutions indicate strike-slip motion and generally parallel the trend of the two main zones except within the overlap zone. In the overlap zone the mechanisms are rotated an average of about 15° clockwise, in good agreement with the fault-interaction model of Segall and Pollard. Detailed examination of hypocenters and focal mechanisms within the northern planar zone suggests that this zone possesses a fine-scale structure dominated by left-step imbrication.

The distribution of aftershocks within the entire zone of faulting is highly clustered in space and time. Very few aftershocks locate within about 5 km of the main shock, at the north end of the northern planar zone. The dimension of this quiet zone agrees reasonably well with body-wave estimates of the source dimension of the main shock. Initiation of activity on the southern planar zone some 5 hours after the main shock suggests that slip was triggered by stress redistribution from the main shock. Similar interactions are apparent on smaller scales as well. These observations suggest that the fault structure is geometrically complex and that the displacements on its component surfaces, together with the resulting local stress perturbations, form a self-interacting system.

4. Daily monitoring of seismicity with the Real-Time Picker (RTP) has been in routine operation for the past 12 months. Phase arrival time data transferred from the RTP to the UNIX 11/70 computer are used to produce a daily log of earthquakes in central and northern California. Earthquakes that locate in selected study zones (including San Juan Bautista) are further processed with specialized crustal velocity models. The resulting high-precision relocations are examined on a daily basis for changes in the background activity pattern.

5. The earthquake catalog for 1977 is now complete. Open-file reports for the entire year have been published, and the fourth quarter report will be released in early FY82. Verification of the network data for the 1978 catalog has begun.

Reports

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Ellsworth, W. L., Olson, J. A., Shijo, L. N., and Marks, S. M., 1982, Seismicity and Active faults in the eastern San Francisco Bay Region, in Proceedings of Conference on earthquake hazards in the eastern San Francisco Bay Area. March 24-27, 1982: California Division of Mines and Geology, Special Publication, 10 ms.

McLaren, M., Farrell, D., Shijo, L., and Bakun, W., 1981, Source Parameters of Microearthquakes near San Juan Bautista, California [abs.]: EOS, Transactions, American Geophysical Union v. 62, p. 958.

Reasenberg, P., and Ellsworth, W. L., The 1979 Coyote Lake, California, earthquakes: a geometrically complex self-interacting fault system [abs.]: Earthquake Notes, 53, No. 1, pp. 50-51, (1982).

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Moths, B. L., Lindh, A. G., Ellsworth, W. L., and Fluty, L., Comparison between the seismicity of the San Juan Bautista and Parkfield regions, California, [abs.]: EOS, Trans. Amer, Geophy. Union, 62, pp. 958 (1981).

Theodolite Measurements of Creep Rates on San Francisco Bay Region Faults

Contract No. 14-08-0001-19767

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(415) 469-1204

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 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:

Seal Cove fault - 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 several months our measurements indicate a slight left lateral movement of about one millimeter.

San Andreas fault - Since March 1980, our site on the San Andreas fault in South San Francisco shows a net of 2.7 millimeters of right lateral slip. This indicates that the fault is creeping at a rate of about 1.5 millimeters per year in the San Francisco area.

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 and mid-December 1981.

At our site in San Ramon, the Calaveras fault has shown virtually no movement in the nine 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, the fault has moved a net of about two millimeters in a right lateral sense. However, large variations in the amounts and directions of movement from one measurement day to another suggest than seasonal and/or gravity-controlled mass movement effects might be influencing the results.

West Napa fault - During a little more than a year after beginning our measurements on the West Napa fault in Napa, the fault has moved a net of about four millimeters in a right lateral sense. Large variations between successive measurement days have also occurred here which may be nontectonic in origin. We lost about three months' data between August and November 1981 due to road resurfacing.

Hayward fault - We presently have five measurement sites along the 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. Subsequently, the fault has moved only about an additional five millimeters right laterally in the next 20 months in Fremont and seven millimeters in the next 17 months in Union City. Both sites again showed a tendency for left lateral movement near the end of 1980 - beginning of 1981, though of a smaller amount than for 1979. 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. At both sites the Hayward fault moved a net of about five millimeters right laterally during the next 16 months.

At our northernmost site along the Hayward fault in San Pablo, there was a net of about three and one-half millimeters of right lateral movement in the year following our first measurement in August 1980.

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, probably the first significant movement on this fault in the past two decades. One of the sites shows additional right lateral movement of a few millimeters whereas the other has been virtually locked for the past two years.

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 we measured a few millimeters of additional right lateral movement. We began our measurements at the more northwesterly site in May 1980. Our measurements indicate a few millimeters of left lateral slip in the past one and one-half years.

Much subsidence and mass movement creep are occurring inside and outside the Antioch fault zone and it is quite possible that these nontectonic movements are influencing our theodolite measurement results for this fault.

TECTONOMAGNETIC MEASUREMENTS IN THE SOUTH PACIFIC ISLANDS REGION

14-08-0001-17771

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Investigations:

1. This project has established, in the past two and a half years, a set of twenty-five automatic, microprocessor controlled tectonic monitoring stations in regions of very high seismicity in the South Pacific islands. Eleven sites have been set up in Vanuatu (New Hebrides Islands), six sites in the Solomon Islands, and eight sites in Papua New Guinea in the eastern region.

Each site is capable of operating up to eight sensors at the relatively low sample rates required for tectonic monitoring. Data (828 bits) are transmitted from the station every three hours and retrieved via satellite. In the event of satellite failure selected data is also recorded on a digital printer which has the capacity for one year's data. The stations are currently instrumented with quarter gamma proton precession magnetometers only. A series of five readings are taken in rapid succession every five minutes at each site (synchronously across the total array to ± 10 seconds) and an average produced for transmission or recording.

Location of the stations are shown in figures one and two. Clearly the array covers a zone of major tectonic activity. It is expected that at least one shallow earthquake with magnitude greater than 7 will be captured by the array in the next three years.

2. A data management system for the array is now in development allowing some preliminary presentation of results. The data stream is rich (approximately 25%) in station diagnostics, which increases confidence in the data set. Potential malfunctions can be identified before catastrophic failure of the station occurs.

Results:

1. Raw data for the New Hebrides array is now available for the period May 1980 to the present. The northern stations were established in May 1981 so that only five months of data is available on these sites. Three day running means of the New Hebrides set of data are shown in composite figure three.

2. A series of instantaneous differences has been taken over selected pairs of stations in the array. A typical result is shown in figure four where five day running means for some New Hebrides data pairs is presented. An arbitrary reference line for each station pair has been added to emphasise any secular variation terms. A ten nanotesla scale reading is shown.

3. A preliminary examination of the standard deviation of hour averages of differences between various stations has revealed that the strong dependence on station separation reported for the Californian data (Johnston, Mueller and Keller, Vol. 12, Summaries of Technical Reports) is not obvious in this data. Figure five shows typical values for this array where hour average standard deviations were taken over a three day interval for all stations. This study is not yet complete, but even across the total array aperture (approximately 1800 km) it appears that an expectation value of 1.3 ±0.3 nT is appropriate. This contrasts strongly with the value of 0.097 ±0.02 per km. separation revealed in the Californian array. It is possible that the California data is dominated by cultural noise.

4. Figure five also indicates the high quality of the data set. Simple hour averages of station differences are typically stable to much better than one nanotesla. Better processing will provide resolution considerably below 0.5 nT.

5. A number of significant earthquakes have occurred in the Vanuatu region during 1980-1981. Most of these occurred well north of the array - Santa Cruz (Ms >7.5), Meru Lava (Ms ≈6.8), and in a sequence of moderate events in the Southern Vanuatu region in October 1980. On July 15, 1981 the P.D.E. catalogue shows an event at 17.29°S 167.59°E with magnitude, Ms = 7.1. The event is marked on figure one. According to local seismologists the event has magnitude significantly smaller than this (≈6.0). No clear precursory signals were observed for this event which was about 90 km. from the nearest stations. Stations at Lamen Bay and Lamap show departures from normal behaviour over the period from March 1981 to June 1981. The significance of these records is presently under examination.

6. Detailed data for the northern section of the array will be presented in the next Technical Report.

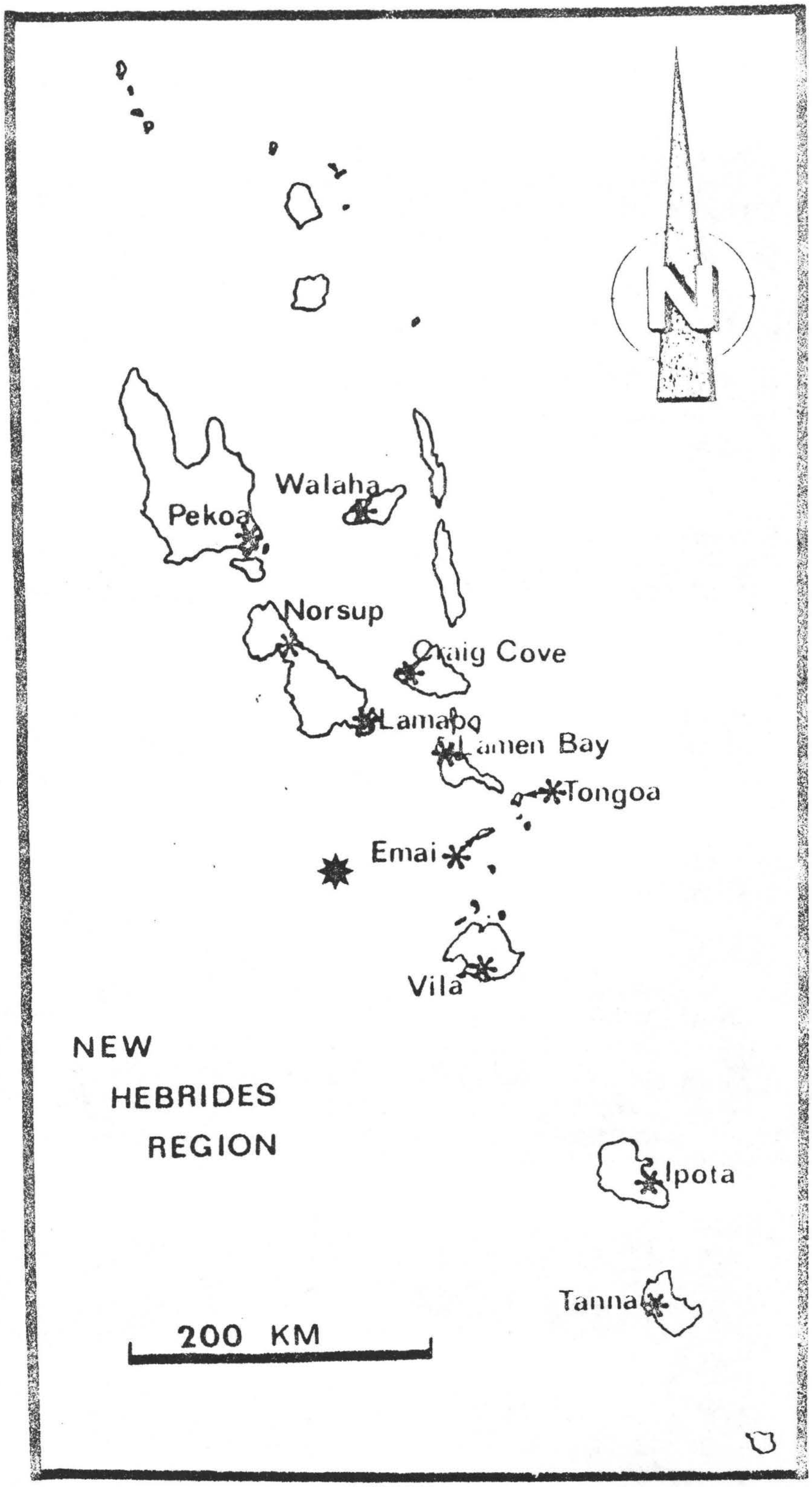

Figure One. Station locations Vanuatu (New Hebrides Islands.)

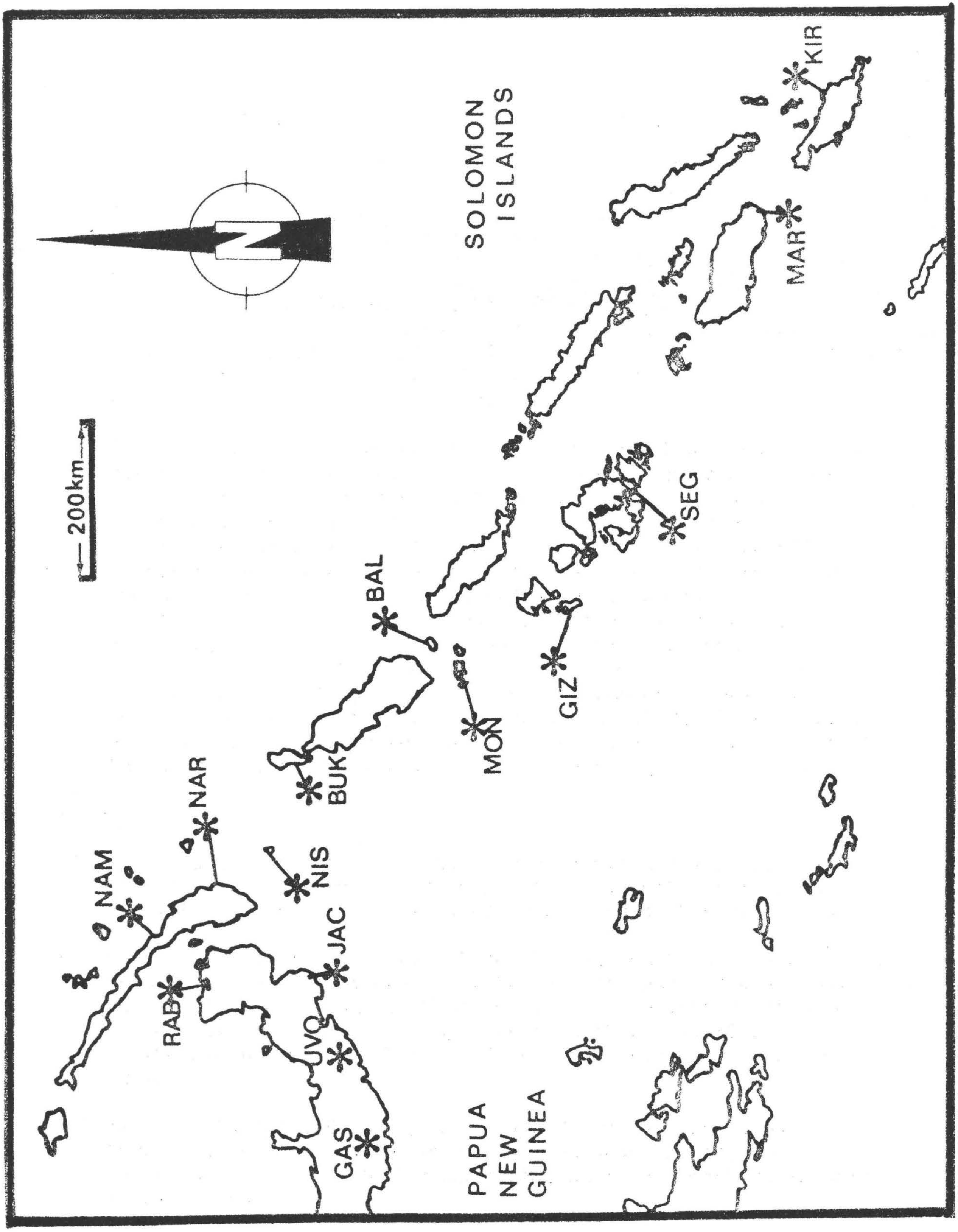

Figure Two. Station locations Solomons & Papua New-Guinea.

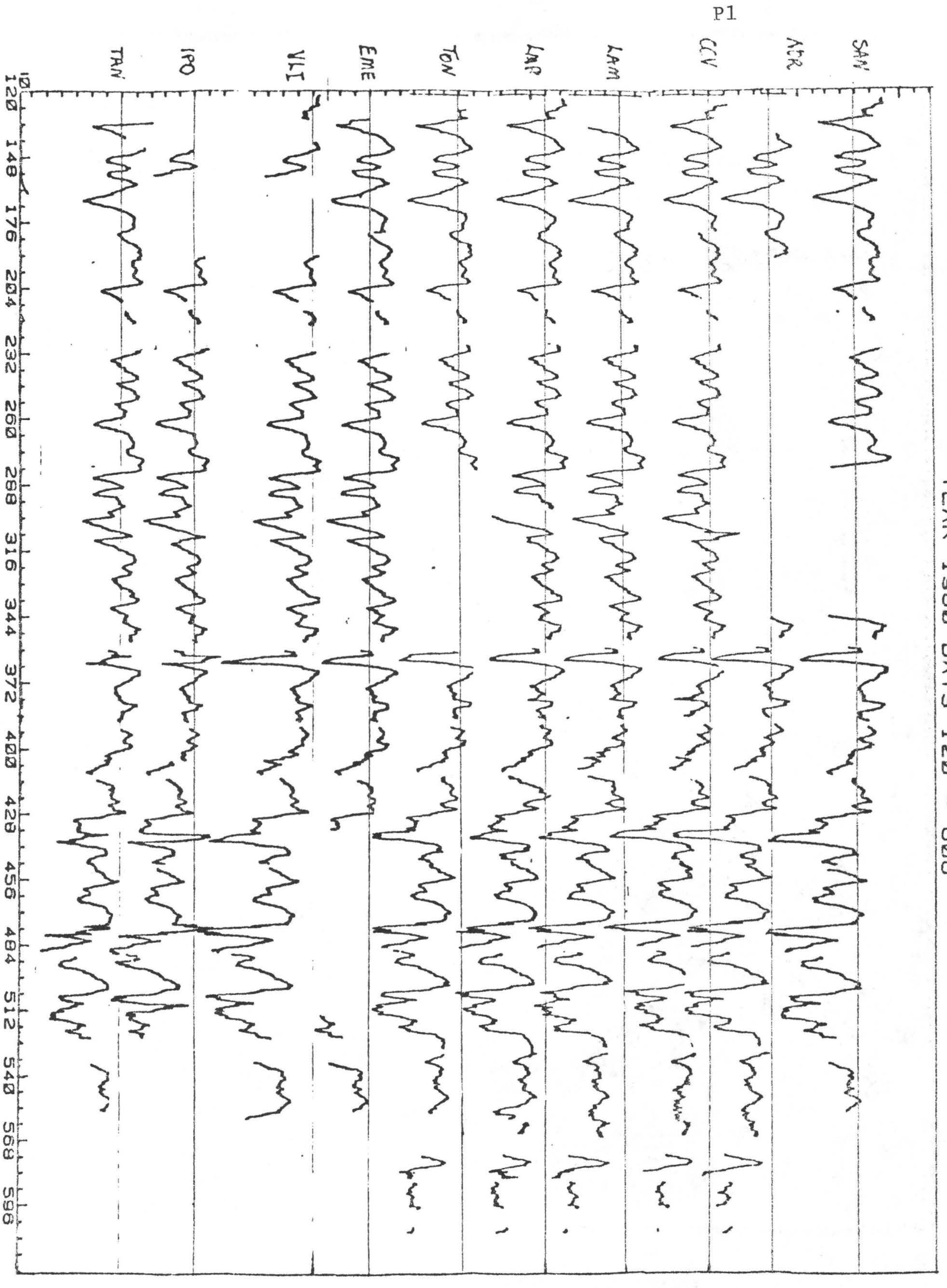

Figure Three. Three day running means of individual station data.

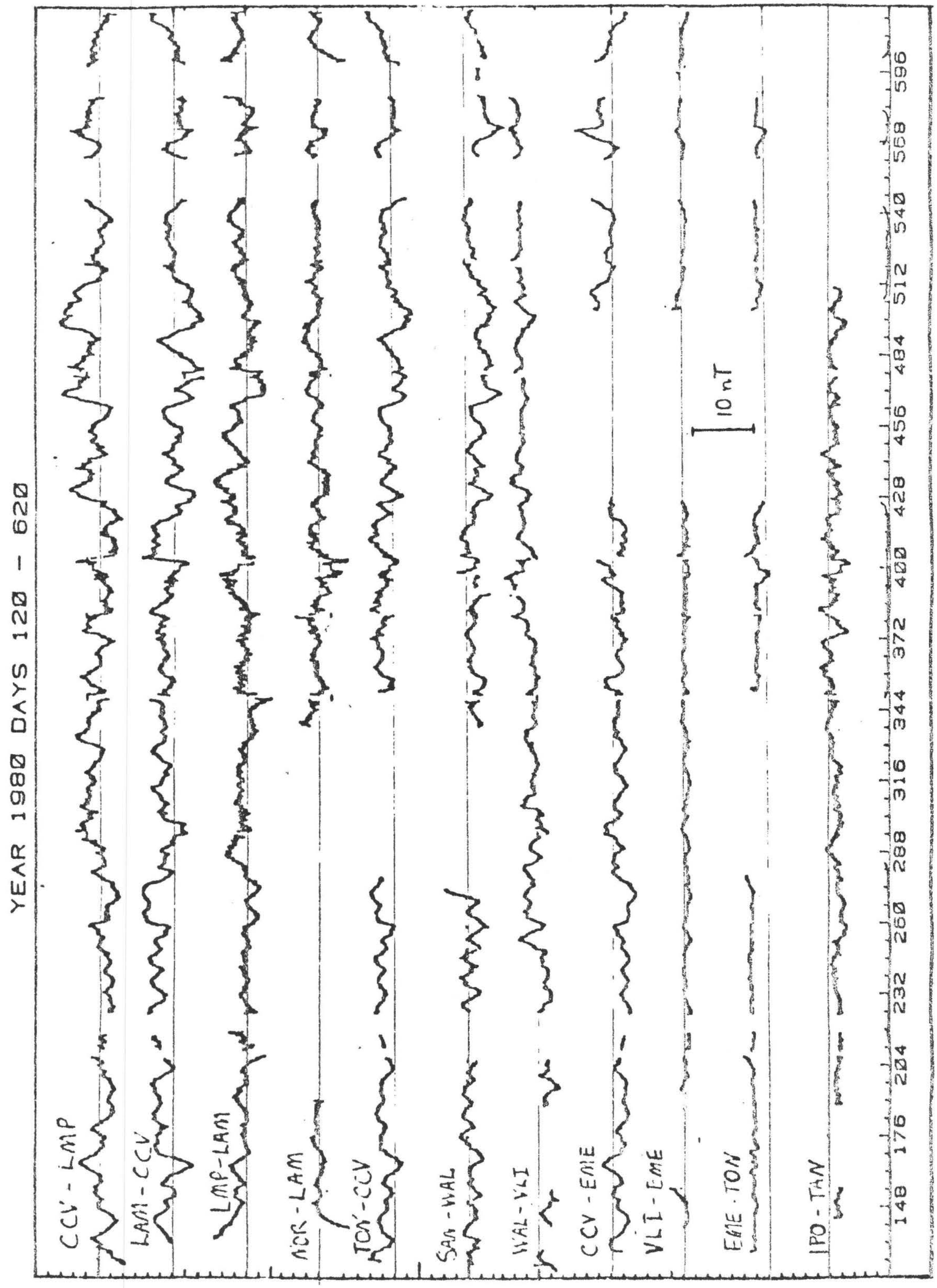

Figure Four. Representative Station differences in the New Hebrides array.

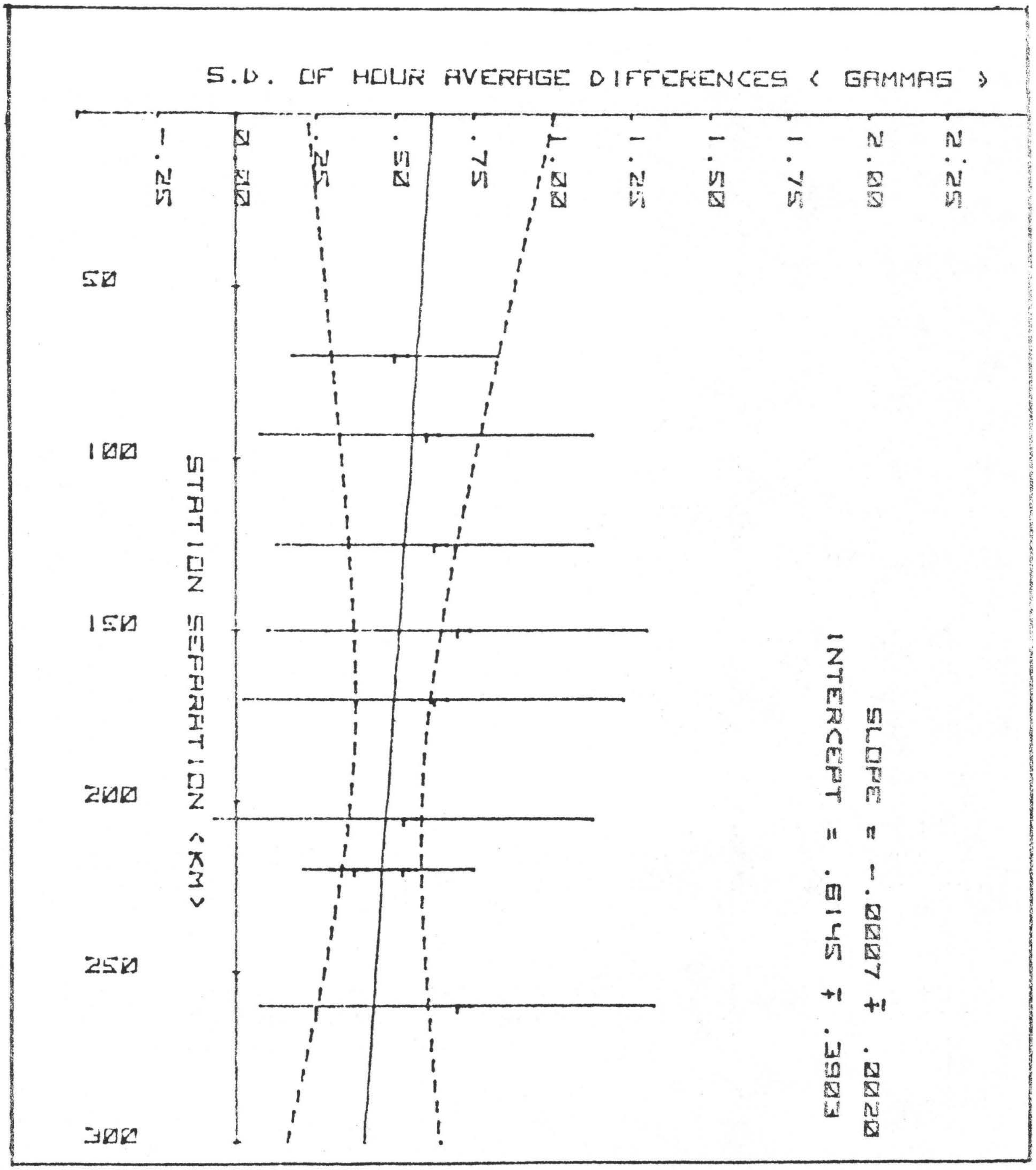

Figure Five. Expectation values for standard deviation of hourly data in the New Hebrides region as a function of station separation.

Central California Network Operations

9970-01891

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Investigations

1. Maintenance and recording of 400 seismograph stations, located in Northern California and Oregon. The area covered is approximately 101,000 square miles. Recording of 20 tiltmeters, 8 strain meters, and 18 creepmeter sites.

Results

1. The Stanwick Corporation, under contract 14-08-0001-1945 is responsible for the installation and maintenance of all seismic stations in Central California. U. S. Geological Survey has reacquired inside maintenance of low frequency digital recording equipment; building and final testing of J402 VCO/AMP units.

2. To date, 20 solar systems are operational at seismic sites using radio signal transmission. Additionally, a solar DC to DC converter (J600-5) has been tested for use in both summing amplifiers and VCO's. This unit permits the seismic VCO, summing amplifier, and radio to be powered by a solar panel, and a 12 v storage battery.

3. Approximately 48 VCO frequency changes were made in the field due to consolidation of telco lines.

4. Reduced film speed on all develocorders from 60cm/sec to 30cm/sec. This has reduced film consumption in half.

5. New seismic stations installed:
   - 1 new station in Oroville area
   - 1 new station in Calaveras area
   - 1 new station in San Jose area
   - 2 new stations in Napa Net area
   - 2 new stations in Bear Valley area
   - 3 new stations in Parkfield area.

6. Reconditioned 1 develocorder for HVO. Reconditioned and installed an additional develocorder at Menlo Park.

7. Began installation of new telemetry terminal at Caltech. Completed installation of following: 100 telco terminal inputs; jack field; AGC inputs; 360 discriminator inputs.

8. Completed building and final testing of 50 J402 VCO's units.

Interaction of Earthquakes

9940-02676

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John, Lord Boatwright

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The purpose of the project is to examine the cause-and-effect relationships that may exist between the larger members of the Oroville aftershock set. Specifically, we are interested in the manner by which one of the larger aftershocks may have conditioned the occurrence (in time and space), size, and source parameters of subsequent earthquakes. Following the first 48 hours after the mainshock (Aug 1, 1975; $M_L = 5.7$), almost all of the larger ($M_L \geq 4.0$) aftershocks occurred on an northern extension of the mainshock fault plane. It is these events that are especially well-recorded by the strong-motion accelerographs deployed for aftershock recording. With one exception these $M_L \geq 4.0$ aftershocks migrate to the north as time progresses from August 3 to the end of September. Of the seven $M_L \geq 4.0$ earthquakes that occurred in the northern sector from Aug 3 to Sept 27, five had a_{rms} stress drops very close to 100 bars; the remaining two had a_{rms} stress drops about twice as large. These two events (0350 Aug 6 and 2234 Sept 27) are also distinguished by especially enriched aftershock sequences of their own relative to the other five $M_L \geq 4.0$ aftershocks.

November 20, 1981

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, 1981 to September 30, 1981.

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 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 eight data logging (TIM) units have been maintained on site and TIM units have been prepared for five additional sites and will be installed shortly.

Stations currently in operation:

SITE LOCATION	TYPE of MEASUREMENTS	PRINCIPAL INVESTIGATOR
Anza (AZ)	water well	Lamar/Merifield
Caltech campus (RO)	tilt	T. Ahrens
Hollister (HO)	tellurics	T.A. Madden
Kresge Lab. (KR)	tilt,gravimeter	Test site
Lake Hughes (LH)	tilt	L. Teng, T. Ahrens
Palmdale (PD)	tellurics	T.A. Madden
Palmdale (PM)	water well,baro. pressure	Lamar/Merifield
Valyermo (VY)	water well	Lamar/Merifield

Stations to be installed:

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/Marifield
Valyermo (PC)	water well	Lamar/Marifield

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.

DEEPWELL MONITORING ALONG THE SOUTHERN SAN ANDREAS FAULT

14-08-0001-19759

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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 variously 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 on a minicomputer. In addition to instrumenting only deep, favorably located wells, our emphasis has been on minimizing instrumental noise while achieving high sensitivity.

RESULTS

Figures 1 and 2 are representative data sets for November and December, 1981 (hourly averages based on 10 minutes sampling intervals), for four deep wells: Anaverde (1000'), Fairmont (700'); Chief Paduke (1200') and Crystallaire (2600').

The quality of these data and the correlation across the array are readily apparent. Clearly seen is the response of each well to the solid earth tides. It is possible that the S_2 solar diurnal atmospheric tide is also imbedded in the well response, but we have reason to believe that it would be extremely small, since the diurnal atmospheric pressure variation, which is significantly larger, seems to produce only a subtle response in water level at best. The three to six day (and longer) fluctuations in atmospheric pressure, however, have a profound effect on well water level, suggesting a clear frequency dependence. The correlations of water level with these longer term barometric pressure changes are extremely good, and demonstrate the absolute necessity in removing these effects from the data in order to search for secular strain or earthquake related effects.

Based on visual correlations, we do not see any unusual behavior in the data sets over the past year that we can reasonably attribute to fault/earthquake related activity; this conclusion was also reached and presented by us at the fall southern California earthquake prediction meeting at Caltech. However, some recent "spikes" in our data are not fully explained. First, a series of rapid increases in water level followed by a transient decay are seen on the Chief Paduke record. At this time we surmise that, because all of these are associated with periods of rainfall and we have found water on the floor of our security box where the casing terminates, the spikes represent water introduced down the casing from the surface. We have recently modified our box to prevent this problem.

Second, a spike with rapid increase and subsequent rapid increase in water level appears on the Crystallaire data on November 13, 1981. Interestingly, this event correlates almost to the minute with a M 1.8 earthquake, the epicenter of which was located by Caltech virtually at the Crystallaire site (onset of anomaly 05:00-05:30 local time; Earthquake 05:25 local time; duration of anomaly 10 hrs.). There is nothing about the character of this anomaly, however, that would suggest that it is related to a strain event; but at this time we have no alternative explanation.

It is clear from the current data that the problems of long term stability and performance of the downhole/digital recording packages have been largely if not completely solved. Future data will be reliable and easy to analyze by computer. New field practices which we are introducing during tape recovery will insure that timing errors do not exceed ± 1 min, in contrast to the ± 15 min we presently have. This will permit better resolution of anomalies vis-a-vis seismic events.

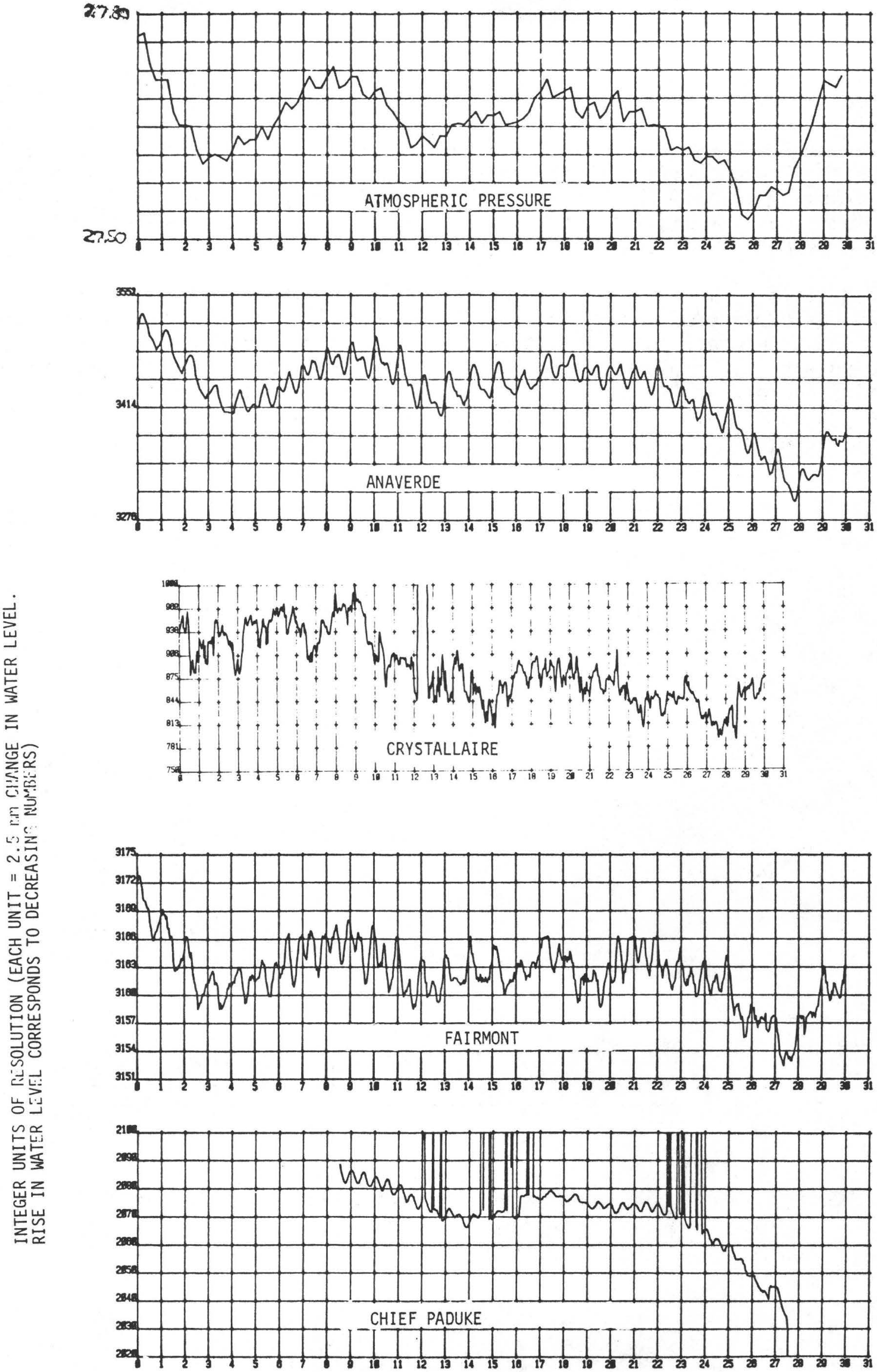

FIGURE 1. NOVEMBER, 1981 WATER LEVEL RESPONSE FROM FOUR TYPICAL PALMDALE WEL

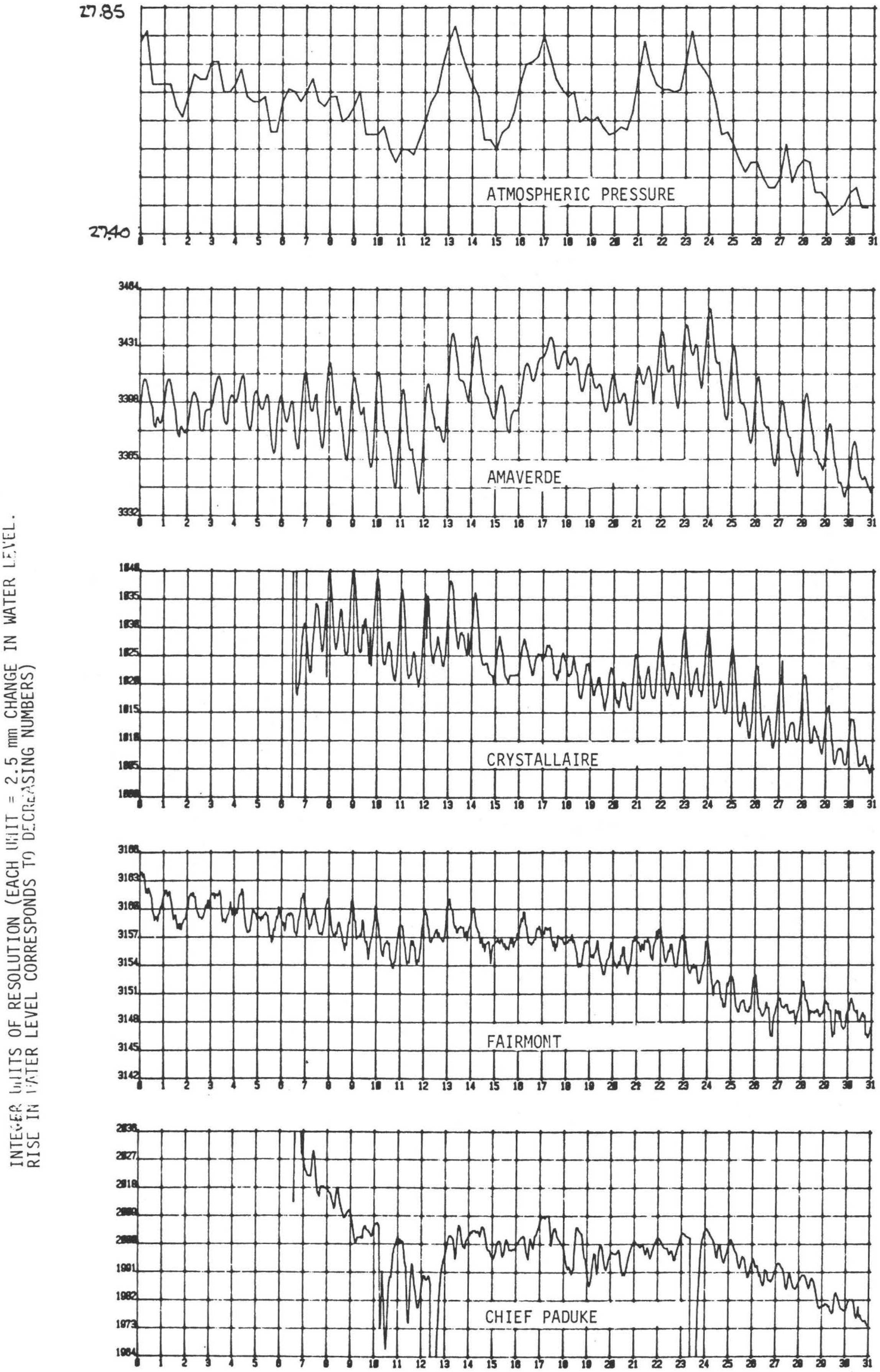

FIGURE 2. DECEMBER, 1981 WATER LEVEL RESPONSE FROM FOUR TYPICAL PALMDALE WELLS

A MULTI-PURPOSE CRUSTAL STRAIN OBSERVATORY, DALTON TUNNEL COMPLEX, SAN GABRIEL MOUNTAINS

#14-08-0001-19263

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SUMMARY

The strainmeters, operated in conjunction with Roger Bilham of the Lamont-Doherty Geological Observatory, were installed in July, 1980 and recorded continuously until electronic failure during a lightning storm in October, 1981. The electronics were replaced in December, 1981 with units compatible with the southern California strainmeter net (joint Lamont/USC project in earthquake prediction program, U.S.G.S. Contract #14-08-0001-19760 to Bilham and Leary).

The strain data from Dalton from 1981 are shown in Figure 1 with the strain records for the other operational strainmeter pair in southern California, at Bouquet Reservoir. Solid earth tides are filtered from these data. There is a good degree of tracking between the instrument pairs except for a large excursion in July-August. The origin of the excursion is not known. Generally, however, drift and deterioration in carbon fiber performance leads to an apparent compression. The LVDT displacement sensor frequency did not change in this interval. The failure of the displacement arm null positioning circuitry earlier in the year may have caused a none-null displacement arm position to be the preferred equilibrium position; however, again, the direction of such drift tends to be towards apparent compression. No unusual surface effects - temperatures, precipitation or groundwater - were recorded.

The effect of groundwater may possibly be seen in the hump in the 60° instrument and the parallel drop off in both instruments occurring in February, the period following the first major rainfall of the season (Figure 1). A slight hump in the 60° instrument during March may reflect rainfall in late February. The shallower Bouquet instruments appear to register the results of the rain more quickly. It is interesting to note that while there appears to be an initial response to rainfall, increasing rain does not lead to an increasing effect. This suggests that rainwater transmits seasonal surface temperature changes rapidly into the surficial ground mass.

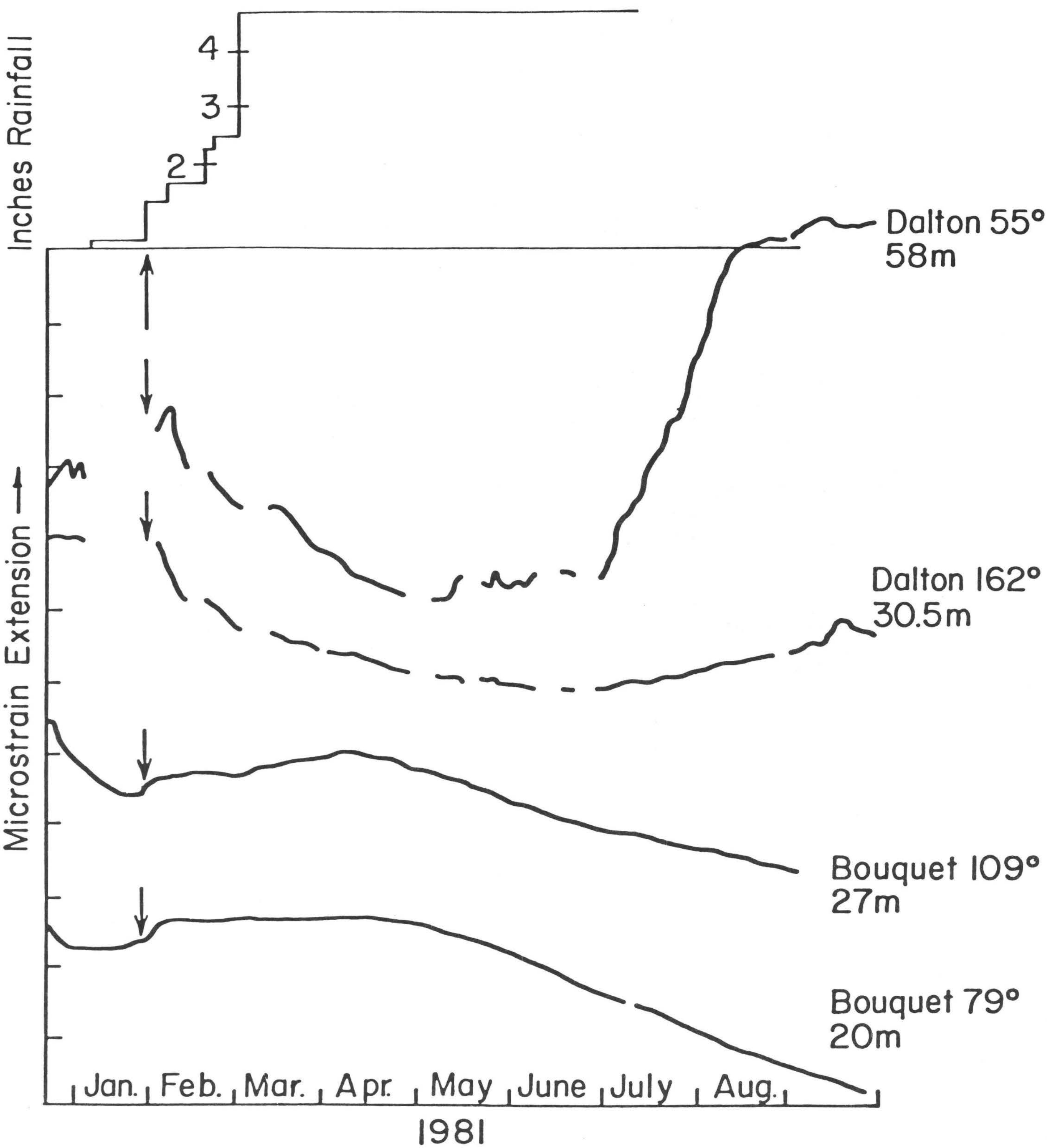

FIGURE 1. Carbon fiber strainmeter data for 1981 at Dalton Tunnel and Bouquet Reservoir, with regional rainfall plotted above. Arrows denote correlation between first seasonal rainfall and small extensions on all strainmeters.

A MULTI-PURPOSE CRUSTAL STRAIN OBSERVATORY, DALTON TUNNEL COMPLEX, SAN GABRIEL MOUNTAINS

#14-08-0001-19263

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1) The strain and short baseline tilt instruments continued to function throughout the year. The U.S.C. water level tiltmeter end stations proved difficult to balance and ultimately were rejected for a simpler and more sensitive device.

2) Two independent measuring efforts joined the Dalton complex. U.S.C. constructed a 20 station dry tilt array for Arthur Sylvester (U.C.S.B.), and Bruce Clark (Leighton and Associates) installed two 70 meter deep borehole stress-sensors.

3) The thermal stability of the tunnel complex was improved from circa ± .05°C daily variation to $\lesssim$ ± .01°C daily variation with the construction of a heavy door in a cinderblock frame 10 feet from the tunnel entrance.

Southern California Repeat Gravity Studies

9730-03074

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Investigations

1. Conducted eighth reoccupation of southern California secondary reference station network and selected parts of the general precision gravity network.

2. Investigated 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

Yearly or half-yearly repeated measurements show large correlated changes in gravity, elevation, and strain along the San Andreas fault in southern California during the 1977-1982 period (figure 1). Precise gravity surveys indicate changes as large as 25 μGal between surveys six months apart. Repeated leveling surveys reported by W. Thatcher and R. S. Stein show that annual changes of as much as 100 mm occurred over 40-100 km long base lines. Areal strain surveys by J. C. Savage reveal that coherent changes of 1-2 ppm occurred over much of southern California during 1978-1980. Based on plots of strain change and elevation change versus gravity change, the various quantities are related by approximately -0.01 ppm/mm and -0.2 μGal/mm. Although some doubts may exist concerning the precision of each of these measurement systems, the rather good agreement among them argues that the changes reflect true crustal deformation.

The style of deformation revealed by the data is that of rapid aseismic fluctuations during which uplift is accompanied by gravity decrease and areal compression whereas subsidence is associated with gravity increase and areal dilitation. That deformation of this style occurred during the past five years has implications for many of the deformation monitor programs being conducted in southern California. The short-period nature of the deformation suggests that measurements of various parameters must be nearly coincident in time if the relationships between them are to be accurately portrayed. Also, the potential influence of short-period fluctuations must be considered when interpretating the results of measurements that require extended periods of time to perform. For example, changes in relative elevation determined by repeated level surveys between widely separated points could reflect both intersurvey and intrasurvey movements.

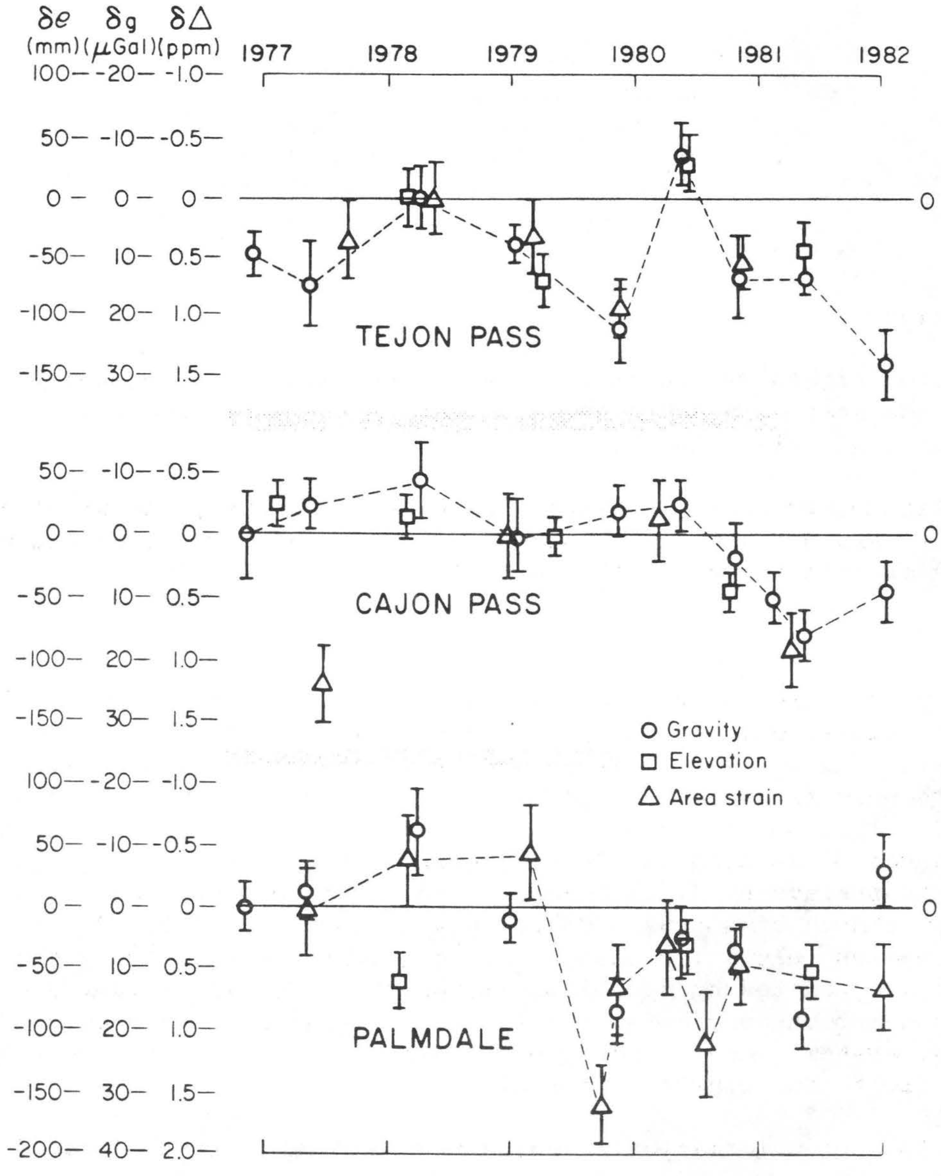

Fig. 1. Time histories of gravity, elevation and strain at three locations in southern California. Gravity is relative to Riverside, California. Elevation is relative to Glendale, California for the Tejon Pass and Palmdale data, and relative to Colton for the Cajon Pass data. Strain is from local networks. Error bars represent one standard deviation on either side of the plotted points for the elevation and strain data and one standard error for the gravity data.

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 radio-controlled trigger system for the Seismic Cassette Recorders (SCR) has been developed. Several of the production units have been tested and are working well. The full system including base station transmitter, repeater and 100 receiver/trigger units will be field tested in June. These radio triggers are also soon to be used for triggering event recorder and for turning on remote telemetry. Meanwhile 20 new SCRs have been under construction which when complete will bring the total to 120 recorders. Maintenance and some field operation of the Seismic Cassette Recorder system and its playback equipment has been provided through several field programs.

During this period the relocation of Calnet recording and playback equipment necessitated by the installation of several new computers was completed. This included the reestablishment of Eclipse tape digitizing, tape dubbing and tape hard-copy playback operations. The new computers also required the installation of new terminal lines. The total number of 4-wire lines has been increased from 30 to 85. The interface of a Tustin A/D converter to the Calnet PDP-11/34 event digitizer has been modified and debugged and is now in operation with 144 channels.

A DC/DC power converter has been developed and produced which now allows seismic VCO/preamp units that are located at sites where solar panels are used to power radios to also use solar power. A new VCO frequency stabilizer which has four times the resolution of the previous one has been designed and is currently being developed. Sixty new VCO/preamp units and 40 new discriminators have been tuned calibrated and installed. Alignment and repair of 110 radio transmitter and receivers and calibration of 100 seismometers has been completed.

Southern California Cooperative Seismic Network

9930-01174

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Investigations

1. Routine processing using stations of the southern California cooperative seismic network were continued for the period October 1981 through March 1982. Routine analysis includes the timing of phases, event location and preliminary catalog production using the newly developed CUSP analysis system. Overall activity has apparently decreased markedly during the reporting interval and no events exceeded a magnitude of 5.0. There were 10 events with a local magnitude of at least 4.0.

2. We are proceeding with the developments 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 catalogued 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. Progress in this program is presently at nearly a standstill due to a decrease in staffing.

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 anamalous 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 apparent departures from background seismicity levels. Particular efforts were directed at completing the analysis of the Westmoreland swarm (26 April, 1981; M_L = 5.7), understanding the tectonic implication of the Indian Wells Valley swarm (February-March, 1982; M_L = 4.2, 4.3, 4.5, 4.0). Background and structural studies using master-event techniques were conducted near Anza in the San Jacinto fault zone, as well

as the region of complex faulting associated with the San Andreas fault zone east of San Bernadino.

Results

1. A swarm of earthquakes occurring in Indian Wells Valley near Ridgecrest, California resulted in field monitoring and increased network coverage following a general increase in seismicity in the vicinity of the southern Owen's Valley. The swarm with 4 events exceeding a magnitude of 4.0 (4.2, 4.3, 4.5, 4.0) was most active during February and March with the period of most intense activity occurring on March 7, 1982. This sequence represents a continued progressive migration of activity in a southeasterly direction along the trend of the Little Lake fault following a similar sequence in April 1981. Focal mechanisms are generally consistent with right-lateral motion on a northwest trending, vertical fault. A possible correlation with activity in the Coso geothermal area has been noted and is the subject of continued enhanced monitoring efforts.

2. A detailed three-dimensional analysis of 963 events associated with the Westmoreland swarm (26 April, 1981) has led to considerable insight into the active tectonic processes associated with Imperial Valley swarm activity more generally. Foreshock activity outlined an inverted pyramid in the shallow crust with mainshock rupture occurring on an east-northeast buried fault as evidenced by focal mechanisms and aftershock distributions. The hypocenter of the largest events (M_L = 5.7) occurred on a fault roughly 2 km south of and parallel to that associated with primary rupture. The zone of activity extending from the Imperial fault near El Centro to the San Andreas on the eastern shore of the Salton Sea (Brawley seismic zone) appears to be the locus of oblique spreading between the two major faults mentioned.

3. An ongoing study of seismicity in the San Jacinto fault zone southeast of Anza shows that background activity occurs in a diffuse zone. However, master event relocations of a M_L = 5.5 earthquake and its aftershocks reveal previously unrecognized structure. Focal mechanisms and three-dimensional relationships of the aftershocks indicate that they occurred on a planar structure dipping about 70^o to the northeast. This plane is most reasonably associated with the Coyote Creek fault suggesting that it, rather then the Clark fault, is the dominant structural feature in the area at present. Further study is directed at clarifying the dynamic relationships between faults in this area.

Reports

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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.

Results

The PDP11-70 UNIX system has continued to operate smoothly, and performs a large amount of computing for program projects. Some current statistics:

184	registered users
1733	directories
36962	files
490099	1024-byte disk storage blocks used
110	logins per weekday
34	different users per weekday

Recent events of particular importance include:

Hardware. An One *dz-11* terminal multiplexor has been replaced by an *Able dh/dm*, adding 8 new terminal ports. This gives us a total of 56 ports, 48 of which are of the efficient direct-memory-access (DMA) type. These include direct connections to the VAX-11/780 and low-frequency PDP-11/44 computers (see below).

UNIX Operating System. UNIX has been modified to enforce disk-usage quotas. This feature enables system administrators to control the amount of disk space used by different projects and reduces the liklihood of the available physical storage capacity becoming exhausted.

Software. In addition, the following software additions and changes have been made:

** *VMS networking.* Users can now connect to the new VAX/VMS system through UNIX and to transfer files from one machine to the other. Currently, only a limited number of terminals are connected directly to the VAX, so this program makes the VAX much more accessible to prediction-program computer users.

** *Pack and Compact.* These programs compact disk files so they occupy 30-70% less space than they otherwise would. They has proven especially useful to the Calnet project, which uses many large files in its routine processing.

** *Geoplot.* A package for plotting maps, offering a choice of 29 different projections, has been added to Geoplot.

** *Berknet* This networking system, developed at the University of California, is now running, allowing communication, file transfer and remote program execution between the PDP-11/70 and the low-frequency PDP-11/44 UNIX system.

Variable Rupture Mode of Seismic Gaps and the Relation to Foreshock-Mainshock-Aftershock 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 includes: (1) Study of an earthquake sequence in 1980 in a seismic gap near the Loyalty Is., New Hebrides. (2) Study of an earthquake sequence in 1980 in a seismic gap near the Santa Cruz Is. (3) Review of the mechanical properties of various subduction zones.

Results

1. Loyalty Islands Sequence

The Loyalty Islands sequence in 1980 occurred in the middle of a seismic gap of category 2 (Nishenko and McCann, 1981), and is considered to be one of the successful cases of prediction. We made a preliminary study to investigate how the stress built up in this gap to cause the event.

Figure 1 shows the locations of the major events in this sequence together with the mechanism and the seismic moment which are determined by the method described by Kanamori and Given (1981). The dotted curve in Figure 1 shows "the immediate aftershock area". One anomalous feature associated with this sequence is expansion of the aftershock area into a very large area (2×10^4) during the 10-day period after the mainshock. This activity includes a large number of events along the trench axis. This type of expansion of the aftershock area seems to be very common for events in the New Hebrides (Isacks et al. 1981; Cardwell et al., 1981).

If we assume that the slip at the time of the main shock took place over the "immediate aftershock area", the amount of slip there can be estimated from the seismic moments to be about 3 m. Since the repeat time of major earthquakes in this region is about 40 years (McCann et al., 1979), a seismic slip rate is estimated to be 7.5 cm/year which is comparable (within a factor of 2) to the rate of plate motion in this region. This agreement indicates that the slip in this zone is more or less seismic.

2. Santa Cruz Islands Sequence

This sequence occurred within a region which had been assigned a low 6 seismic potential, and points to some difficulties in identifying gaps for relatively small (in this case M_s = 7.9) events. We examine the level of seismicity in this region by using a contour-map of earthquake energy release. Briefly, we first calculate the energy release from each earthquake by using an appropriate magnitude-energy relation (e.g., $\log E = 1.5 M_s + 11.8$), average it per unit area (e.g., 10^2 km^2) and time, and then contour it on a map. Despite the uncertainty in the magnitude and the magnitude-energy relation, this method provides an objective and useful tool for mapping spatio-temporal variations of seismicity.

With this method of mapping, we found that the energy release in the zone from 11.5°S to 16° had been very high during this period (more than one M_s = 6 events per 100 km^2 in 20 years) suggesting that the assignment of 6 to this general area is reasonable. However, it is clear that the epicentral area of the M_s = 7.9 event of the 1980 sequence indicates a relatively low-energy level suggesting that this zone could have been identified as a high-potential seismic gap for a moderate earthquake.

Although identification of a gap by this method alone would not be very easy, particularly before the fact, the method is useful for detecting a small gap in the relatively high background activity. We plan to apply this method to other seismic zones to obtain a better picture of spatio-temporal energy release pattern.

Reports and References

Lay, T., H. Kanamori, and L. Ruff, The asperity model and the nature of large subduction zone earthquake occurrence, in press, Earthquake Prediction Research, 1982.

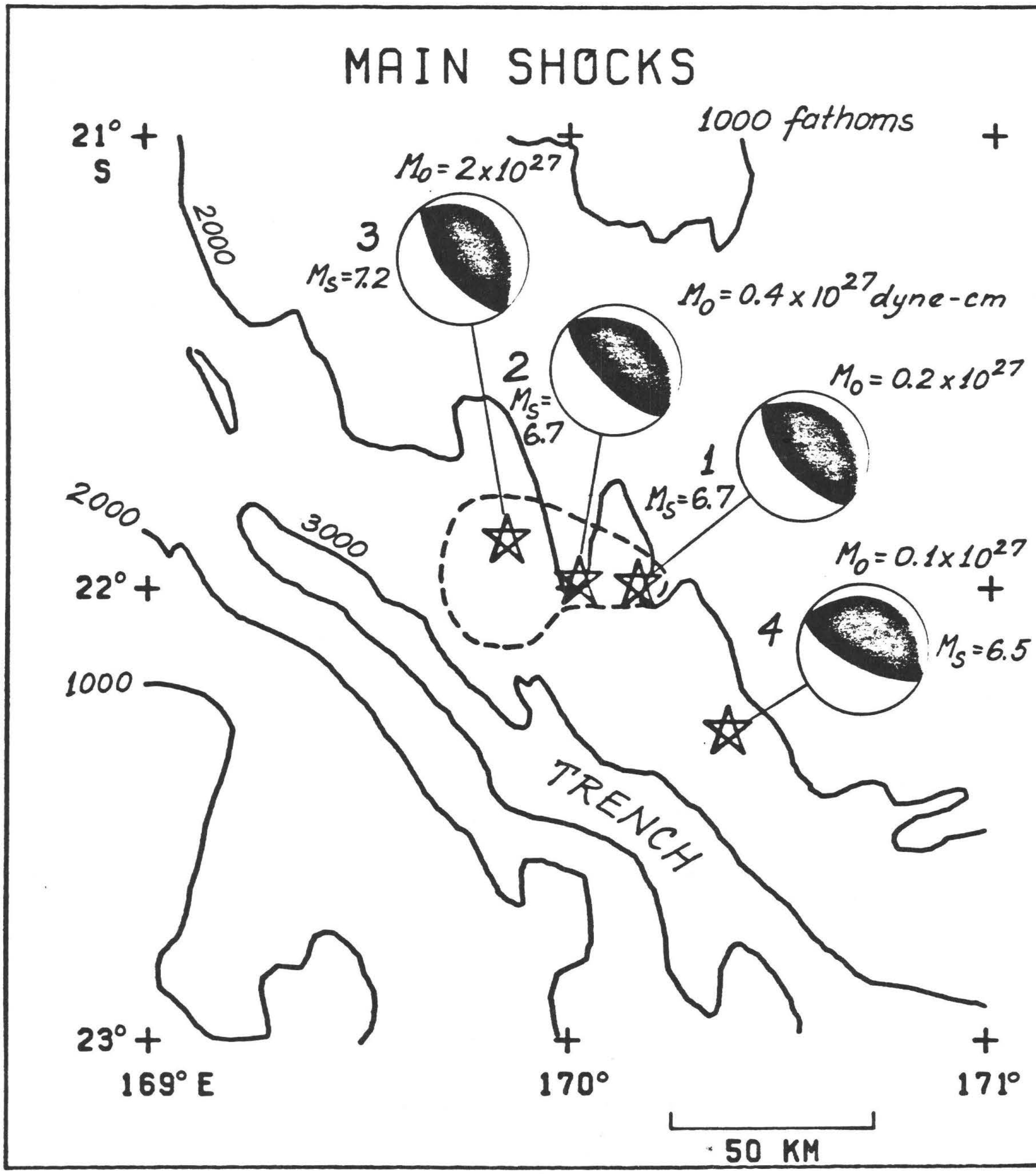

Figure 1. Larger earthquakes of the 1980 Loyalty Islands sequence. Event 1, Oct. 24, 3^h25^m, $M_s = 6.7$; Event 2, Oct. 25, 7^h00^m, $M_s = 6.7$; Event 3, Oct. 25, 11^h00^m, $M_s = 7.2$; Event 4, Oct. 25, 16^h20^m, $M_s = 6.5$.

Seismicity Studies for Earthquake Prediction in Southern California Using a Mobile Seismographic Array

14-08-0001-19266
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This final report covers the 3-month period from October 1, 1981 to December 31, 1981. It was decided that the California Institute of Technology was going to terminate this project, and Dr. Karen McNally was to take over the project from the University of California at Santa Cruz. In order to facilitate smooth transfer, we requested no cost extension of this project to December 31, 1981, which was approved by the U. S. Geological Survey.

Under these circumstances, we did not conduct a major research project during this time period. We maintained our trailer network near Palmdale to avoid any data gap during this transition.

The most recent results of our research projects supported by this contract, have been summarized in our Semi-Annual Technical Report for the period 1 April 1981 to 30 September 1981.

During this 3-month period, we made focal mechanism determinations for 10 events which occurred in 1981 in our study area.

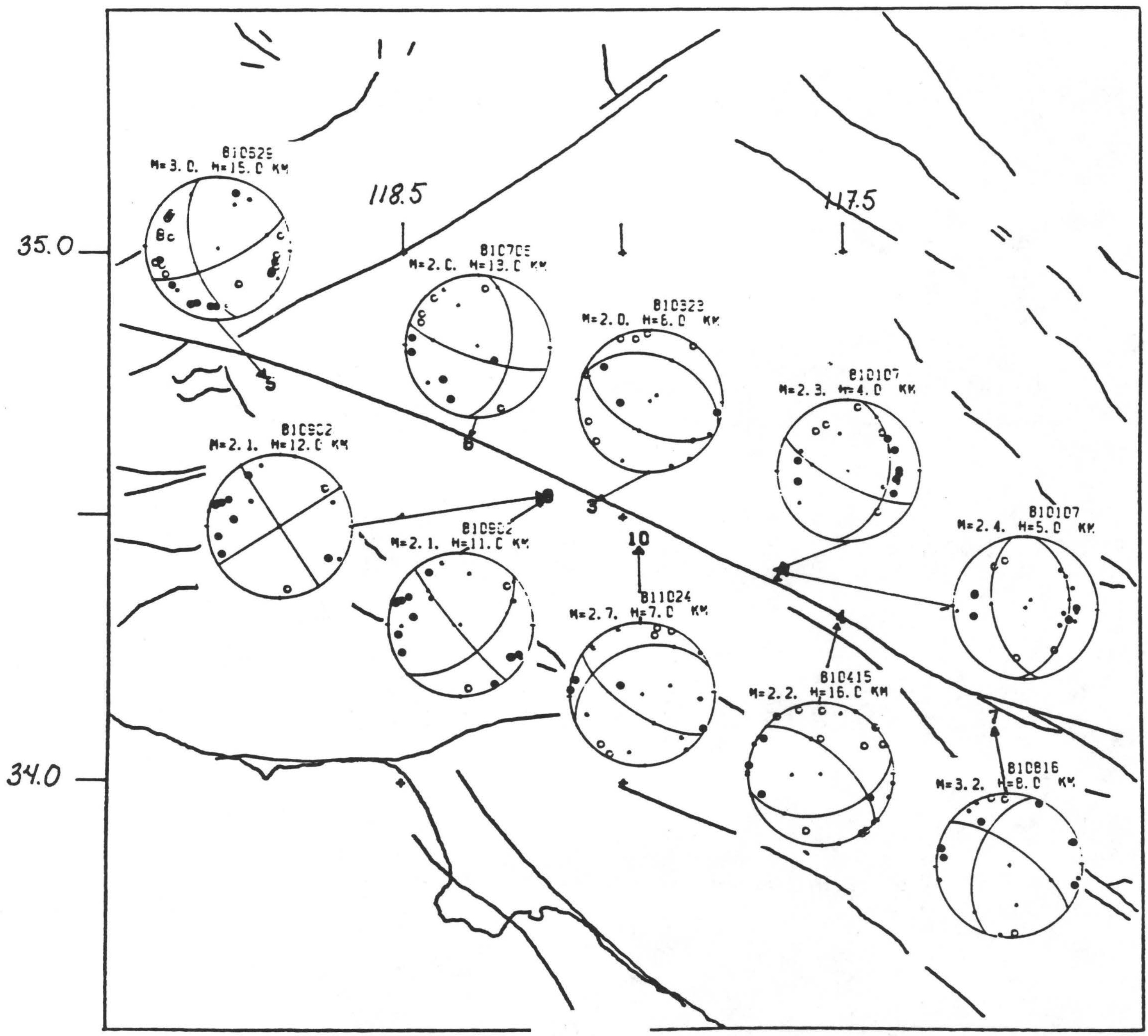
From P-wave first motions, preliminary focal mechanisms were determined for 10 events for $M_L \geq 2.0$ which occurred in 1981. These events are listed in Table 1 and focal mechanisms are shown in Figure 1. First-motion data from the CEDAR (Caltech Earthquake Detection and Recording) system were supplemented by readings from the mobile trailer array. The focal mechanisms determined for 8 of the 10 events are consistent with a significant component of strike-slip faulting.

Also, we made substantial revision of the paper by J. Sauber et al. (1982) which was attached to the Semi-Annual Report. Here we attach the final revised version of the manuscript.

TABLE 1

Event No.	Date	Time (HR:MIN)	Magnitude (M_L)	Latitude	Longitude	Depth
1	810107	06:40	2.4	34 23.89	117 38.78	5.0
2	810107	06:58	2.3	34 23.79	117 39.51	4.0
3	810323	16:06	2.0	34 31.36	118 04.76	8.0
4	810415	23:24	2.2	34 18.86	117 29.85	16.0
5	810629	05:59	3.0	34 45.18	118 48.16	15.0
6	810706	09:18	2.0	34 38.39	118 29.89	13.0
7	810816	11:23	3.2	34 07.13	117 10.20	8.0
8	810902	11:58	2.1	34 32.63	118 10.50	12.0
9	810902	14:17	2.1	34 32.75	118 10.58	11.0
10	811024	19:10	2.7	34 27.47	117 59.06	7.0

Figure 1. Lower hemisphere P-wave focal mechanisms. M = local magnitude. H = is depth of hypocenter in km. (0) indicates dilatation. (●) indicates compression.



Seismicity Studies for Earthquake Prediction in Southern California Using a Mobile Seismograph Array

14-08-0001-19266

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Seven seismograph trailers are being used to monitor spatial-temporal variation in locations and mechanisms of small earthquakes in southern California, especially near the Palmdale area, where anomalous changes in radon gas emissions, strain rate and seismicity were observed recently. A portable array of seismographs was operated in and around in the seismically quiet portion of the San Jacinto fault near Anza, California, during the spring and again in the summer of 1981. The records obtained by these field surveys together with those obtained from permanent stations are being analyzed in an attempt to understand physical processes leading to an earthquake. Long-term seismicity patterns (since 1932) in southern California, and detection capability of the permanent array, form the basis for selecting special areas for field studies.

Earthquake Mechanisms and Patterns in Seismic Activity near Palmdale, California

To understand better the relationship between seismicity and temporal changes in crustal deformation of the "big bend region" of the San Andreas fault, we have compared the spatial-temporal patterns and fault mechanisms of small earthquakes with the recent (since 1976) temporal changes in horizontal strain observed near Palmdale, Calfornia. Epicenters of all earthquakes located by the California Institute of Technology for Oct. 1, 1975-Oct. 31, 1981 which occurred along and adjacent to the San Andreas fault from 50 km south of Cajon Pass to Tejon Pass are shown in Figure 1. To summarize the patterns of seismicity in time and in space for this time period, the microearthquakes were projected onto a line parallel to the San Andreas fault (Figure 2). The activity of small earthquakes along the entire big bend of the San Andreas fault increased in November, 1976, concurrent with the initiation of an earthquake swarm at Juniper Hills. This activity then decreased abruptly to the northwest and southeast of Juniper Hills during the beginning of 1979. This drop in activity occurred around the time that rapid crustal dilation was observed on the U.S.G.S. Palmdale trilateration network. In November, 1980, earthquake activity along the big bend returned to the higher level observed previously, concurrent with an episode of crustal compression. This increased level of activity has been maintained through Oct. 1981, with the highest activity being concentrated in the area from Palmdale to Cajon Pass.

The results of the focal mechanism study of events from Nov. 1976-Dec.

1980 suggest a possible relationship between temporal changes in strains measured at the surface and the mechanism of faulting at the depths of local earthquakes (5 to 13 km). During the time period (1976-1978) when N-S compression was reported on the Palmdale trilateration network (Savage, 1981, personal communication) the earthquake mechanism is predominantly thrust type on E-W striking planes. In contrast, around the time when an increased rate of E-W extension was observed, particularly in the early part of 1979, the type of faulting is predominantly strike-slip.

Preliminary focal mechanisms from 3 recent events (two on Sept. 2 and one on Oct. 24, 1981) in the Palmdale and Juniper Hills area show similar strike-slip type fault mechanisms.

The State of Stress near the Anza Seismic Gap San Jacinto Fault zone, Southern California

During the spring and again in the summer of 1981 a portable array of seismographs was operated in and around the seismically quiescent portion of the San Jacinto fault near Anza, California. The data obtained from the portable array along with data from the C.I.T. catalog was used to determine P-wave first-motion focal mechanisms. The results of the focal mechanism study and examination of the local geology were used to infer the state of stress in this area.

The fault geometries, types of faults, amounts and ages of fault displacement, topographic features, seismicity, and earthquake source mechanisms in the area of the San Jacinto fault zone near Anza, suggest that considerable fault-normal compression as well as fault-parallel right-slip characterize the stress regime locally.

The San Jacinto fault zone narrows from 11 km wide across the Buck Ridge, San Jacinto, and Coyote Creek faults to 1.5 km wide near Anza. All of these faults show many kilometers of total offset and also geomorphic evidence of recent activity. The uplifted Coyote Ridge block and several shallow thrust faults oriented parallel to segments of the right-slip fault are evidence of the compressive forces in the area of this fault zone constriction. Seismicity maps show a 22 km long quiet section of the fault zone, the Anza seismic gap.

Earthquake source mechanisms for small earthquakes in the Anza area indicate that the axes of maximum compression in the block SW of the San Jacinto fault and NW of the termination of the Coyote Creek fault are rotated up to 40° clockwise with respect to the regional compression axis as determined by strain calculations (Savage *et al.* 1981). The composite source mechanisms for several earthquake in the crustal block very near the locked segment indicate maximum compression directed normal to the San Jacinto fault.

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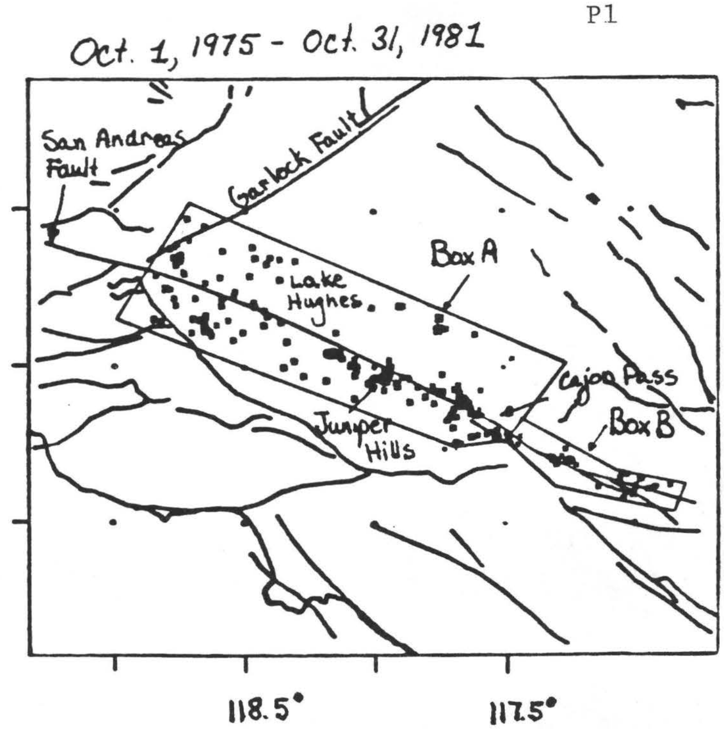

Figure 1. Earthquakes located by Caltech from Oct. 1, 1975 to Oct. 31, 1981. Boxes A and B indicate the area used for the time/distance projection.

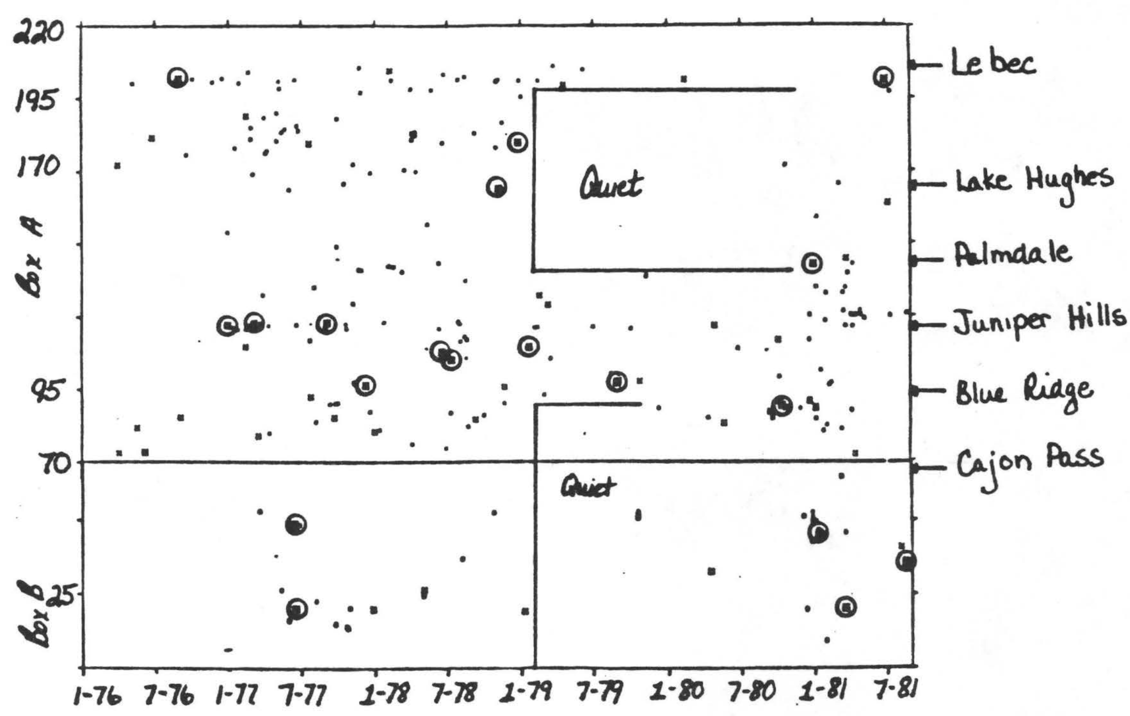

Figure 2. Time/distance plot of seismicity for Oct. 1, 1975 to Oct. 31, 1981. The vertical, dashed line represents the initiation of the Juniper Hills swarm. (✱) indicates events of $M_L \geq 2.5$.

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

14-08-0001-19272

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Recent Seismicity.

803 local earthquakes were located by the Adak seismographic network for the year 1981 (Figure 1). In general, the most active sources are the same as in previous years. Five earthquakes with m_b 5 or greater occurred within the network in the eight months from July, 1981 through February 1982. Of special interest is the continued concentration of larger earthquakes in the region SW2. Since July, 1980 four events with m_b 4.6 and greater, with gradually increasing magnitudes, have occurred in almost the same place, at a depth of about 38 km. The 'b'-value in this source is distinctly lower, about 0.7, than that in most of the Adak seismic zone. We have identified SW2 as a place for special study with regard to the identification of precursors and we are alert to the possibility of continued strong activity there. We are also watching the Adak Canyon region with special attention because it continues to be very inactive for events strong enough to be located teleseismically. It was the site of two magnitude 7 events in 1971.

A systematic program of revision of the Adak earthquake catalog has been undertaken. Random and systematic location errors have been eliminated as far as possible and the format of the stored data modified to make the entire catalog uniform in this regard. The catalog has also been carefully compared with the NOAA Hypocenter Data File in the search for any missing events (large earthquakes are sometimes not located routinely by the local network because S-waves are unreadable on the clipped seismograms). 15 such events were found and all but one of these have been located with network data and added to the Adak catalog. This revised catalog provides a clear picture of the area of high-quality locations covered by the network (Figure 2).

Research on Foreshocks.

Foreshocks offer hope as precursors to larger events in the Adak zone, but it is necessary to make a systematic study of how commonly they occur. The Adak catalog has been processed for foreshocks in two ways. In one, the number of events preceding a mainshock (defined as m_b 4.5 or greater) in specified time intervals before the mainshock is counted and the counts combined to provide a histogram for all mainshocks. This analysis showed no clear peaks that would indicate a systematic occurrence of foreshocks at a particular time before a mainshock. The second analysis was based on the distribution of interevent times, in an effort to find evidence for systematically shorter interevent times for either single events or clusters of events before a mainshock. The results are not definitive, but there is some indication of single event foreshocks within distances of about 20 km of the mainshocks. Neither of these approaches, which use only the part of the catalog for which detection is thought to be complete, can detect the small magnitude foreshocks which have been found for a few cases by *ad hoc* studies.

A Shallow-Focus Swarm Possibly Related to Volcanism.

The investigation of recent shallow back-arc activity has been completed. Hypocenter locations and focal mechanisms for the events have been carefully determined. This was the first study undertaken in which standard P first-motion distributions for individual events, objective compositing of first-motion data and amplitude ratios were all used to determine focal mechanisms. All types of focal mechanisms, strike-slip, normal and reverse faulting, are found among these events,. Clearly, a complex stress pattern associated with the inhomogeneous upper layers under the volcanic arc controls these small earthquakes. Although the volcano Adagdak seems to play a role in concentrating the activity, and volcanic processes may contribute to the stress field, there is no evidence that the swarm was related directly to movement of magma in the volcano or to imminent activity of this dormant volcano.

Focal Mechanisms in the Southwest Regions.

The computerized compositing method developed under this program has been applied to the search for precursory focal mechanism changes in seven regions south of Adak Island. Although the method has worked well for sorting the observed first-motion polarity patterns, no precursory changes in focal mechanisms associated with any of the larger events during the study interval were detected. A pattern of first motions different from the usual one was seen during a six-month period in the region designated 'S', but no large event occurred there. Although the technique is certainly capable of searching out changes in the pattern of first-motion polarities recorded by the network, it cannot be depended on to detect small changes in fault-plane orientation.

Intermediate Depth Earthquakes, North Island, New Zealand.

A cooperative effort to study the seismotectonics of intermediate depth earthquakes under the North Island of New Zealand has been undertaken with the Department of Geology and Geophysics of the University of Minnesota. Our part is the determination of focal mechanisms by the analysis of the amplitude ratio data provided by the New Zealand network. This research is providing a chance to become familiar with data from another subduction zone and to gain further experience with the use of the amplitude ratio technique. Focal mechanisms for 12 events out of 179 for which data were provided by Prof. Harold Mooney have been done. The big problems are considerable uncertainties in the locations of the hypocenters, especially depths, and the sparsity of amplitude data for many of the events. The results so far confirm the results of other studies that both strike-slip and thrust faulting are seen among these earthquakes.

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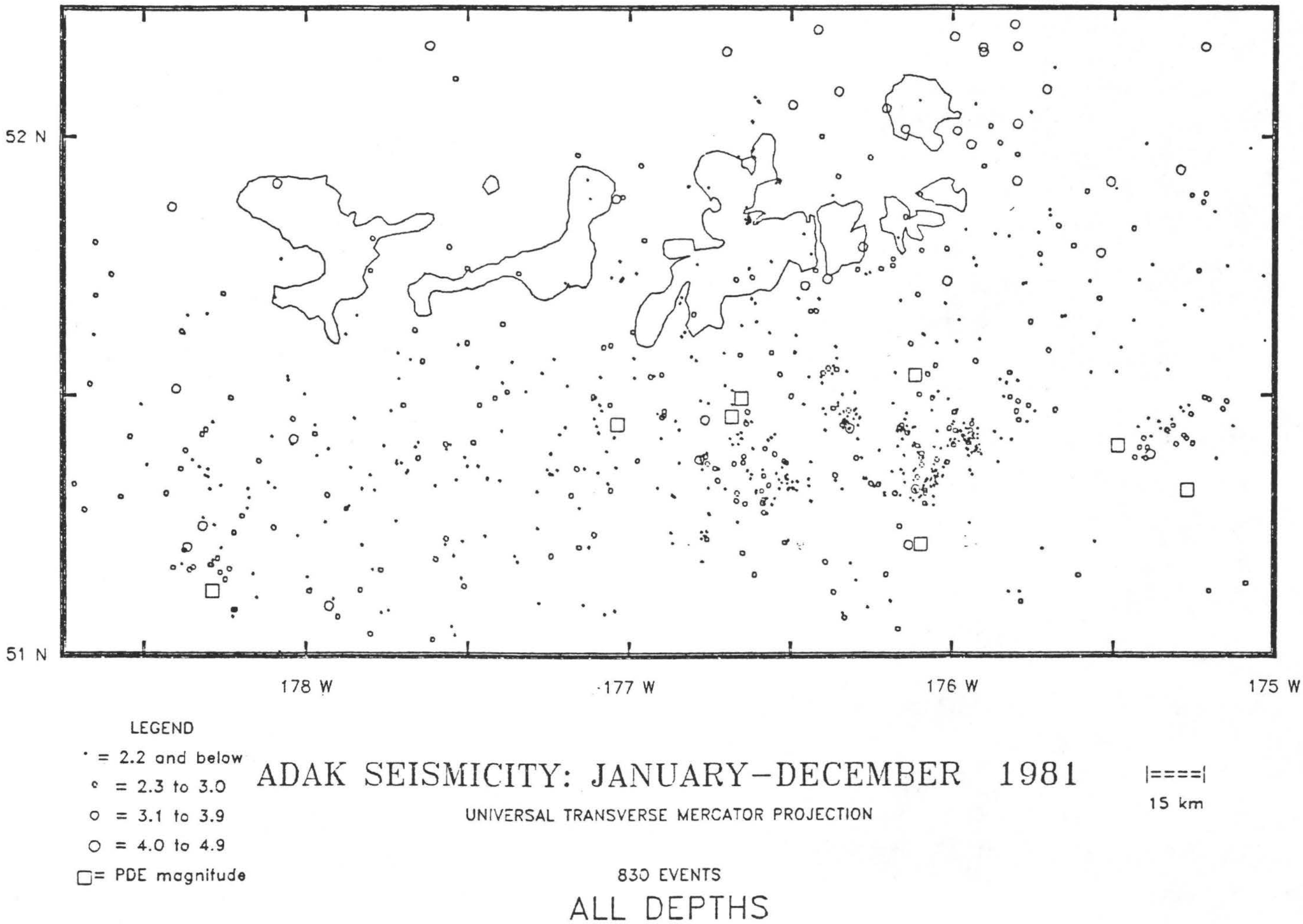

Figure 1: Map of seismicity near Adak which occurred during 1981. All epicenters were determined from Adak network data. Events marked with squares are those for which a teleseismic body-wave magnitude has been determined by the USGS; all other events are shown with symbols which indicate the duration 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.

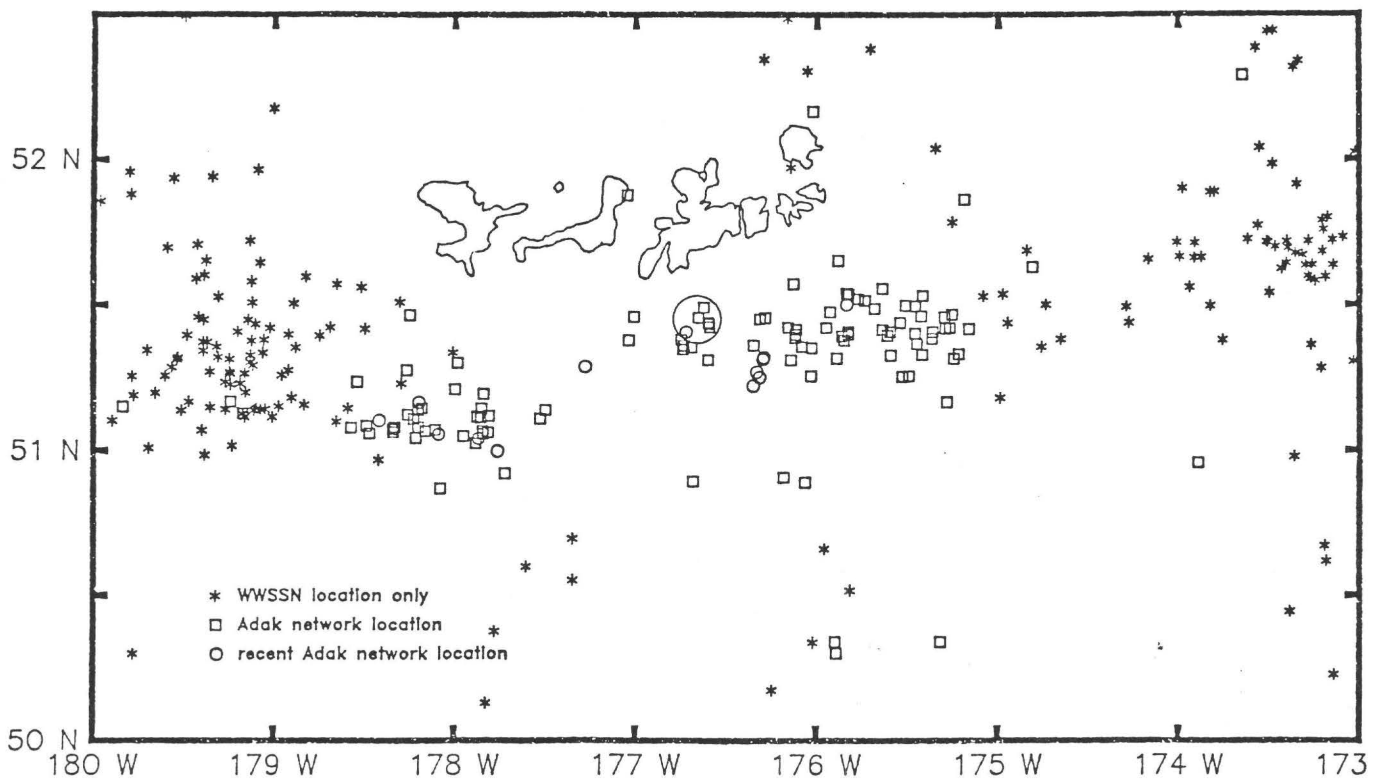

Figure 2: Map of teleseismically located earthquakes in the Central Aleutian Island arc from Aug, 1974 to Dec., 1981. Asterisks are hypocenters of earthquakes located *only* by the World Wide Standard Seismograph Network (WWSSN), squares are Adak Seismograph Network (ASN) locations of earthquakes located by *both* the WWSSN and the ASN, and circles are ASN locations of earthquakes added to the catalog during the recent revision. A circle is drawn around a series of 5 m_b 4.5–5.0 earthquakes in the SW2 subregion.

CARBON FIBER STRAINMETER STUDIES NEAR PALMDALE, CALIFORNIA

14-08-0001-19760

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The southern California carbon fiber strainmeter network (Figure 1) began in 1978 with an installation at Bouquet Reservoir (BQ) as an independent USC/ Lamont observational program. Two additional instruments were installed at Dalton Tunnel (DT) in 1980.

During the spring and summer of this past year, we located six additional suitable tunnel sites in the San Gabriel Mountains (AQ, TS, JK, MC, BH and NS in Figure 1) and built instrument piers and security doors in AQ, TS, JK and MC. Lamont placed instruments (July, 1981) and electronics (December, 1981) in the prepared sites. The strain history of the established sites for 1981 (BQ and DT) are shown in Figure 2. Figure 3 shows a three-site (BQ, TS, and AQ) composite of initial network data, and Figure 4 the performance of the Bouquet instrument compared with the Piñon Flat (PFO) laser strainmeters.

The carbon fiber strainmeter as developed by Bilham from the original Bilham-King design has an instantaneous sensitivity 10^{-10} and an instrumental stability of 10^{-9} - 10^{-8}/year (see, for instance, Figure 2 for 250 days and strain record for the 162° instrument at DT). The pier installation procedures appear to have overcome significant problems of pier stability; the Caltech bubble tiltmeter placed on the main pier at Dalton Tunnel (DT) has operated for 18 months, with a stability on the order of the solid earth tide.

It is difficult to know a priori the level of noise a given site will generate (aside from the obvious trend towards noise suppression with a deeper instrument location). Site generated noise is likely to exceed instrument noise and solid earth tidal signals in shallow tunnel sites available for use in the San Gabriel Mountains (see, for instance, the strain-rainfall correlation at the DT and BQ sites (Figure 2)). For these reasons, an inexpensive instrument capable of wide distribution is desirable. Poor sites can be discriminated against or eliminated and intrasite correlations can be used to strengthen data interpretation. For example, the simultaneous strain data in Figure 3, while preliminary and of limited duration, illustrate the power of the network concept. The two sites south of the San Andreas fault, AQ and BQ, have a clear short term anti-correlation while the TS site north of the fault appears independent of the BQ and AQ sites. Whether this is of fundamental importance cannot be decided on the basis of this initial two weeks of data, but it is an intriguing result. As additional data is collected, the effects of daily and seasonal temperature, rainwater, groundwater and regional strain can be sorted out. Note that a strainmeter network allows site intercomparisons to define the size and importance of signals and noise, whereas a single instrument or site requires distinctly ad hoc interpretation.

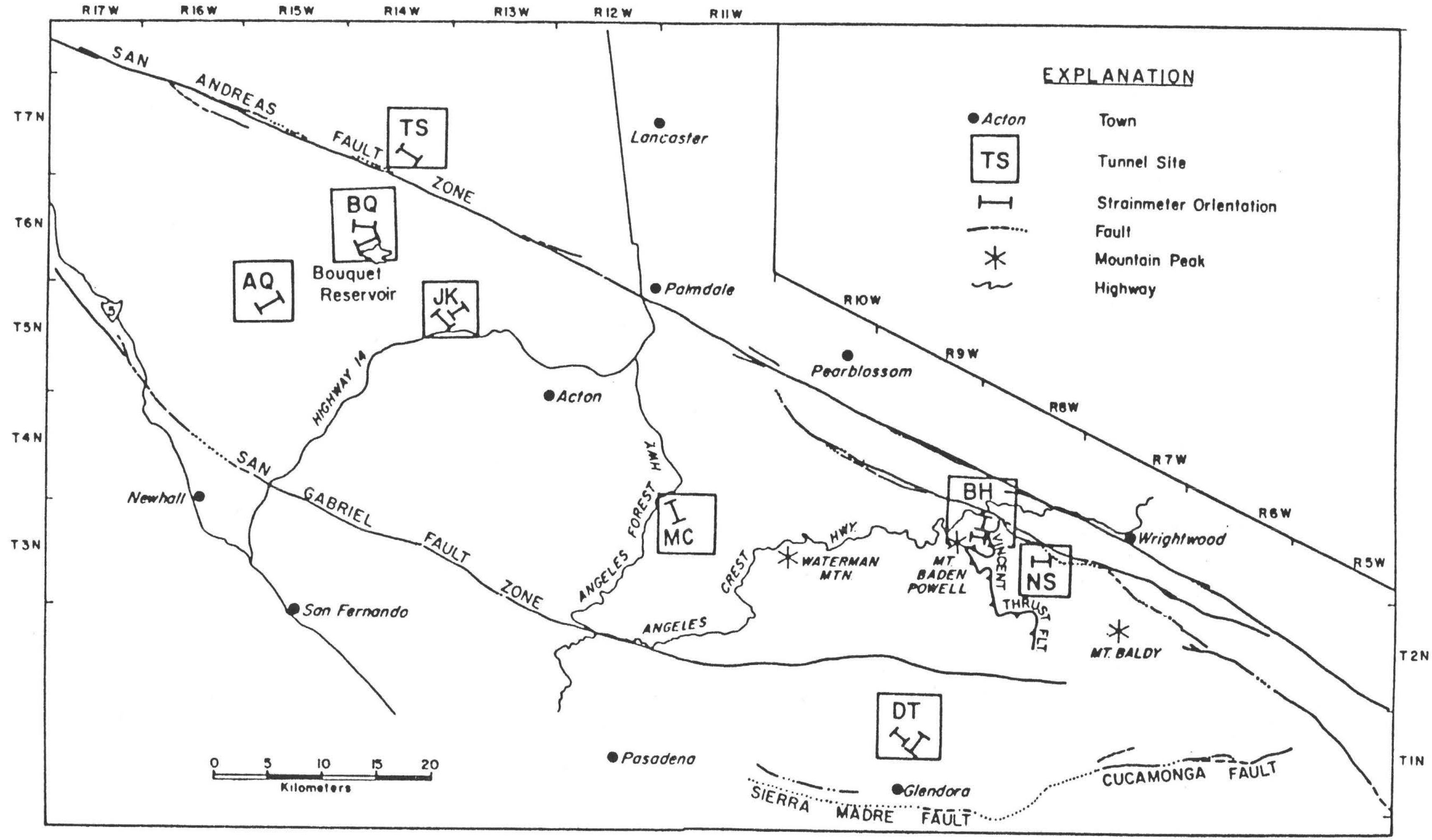

Figure 1. Location map for carbon fiber strainmeter array in San Gabriel Mountains of southern California.

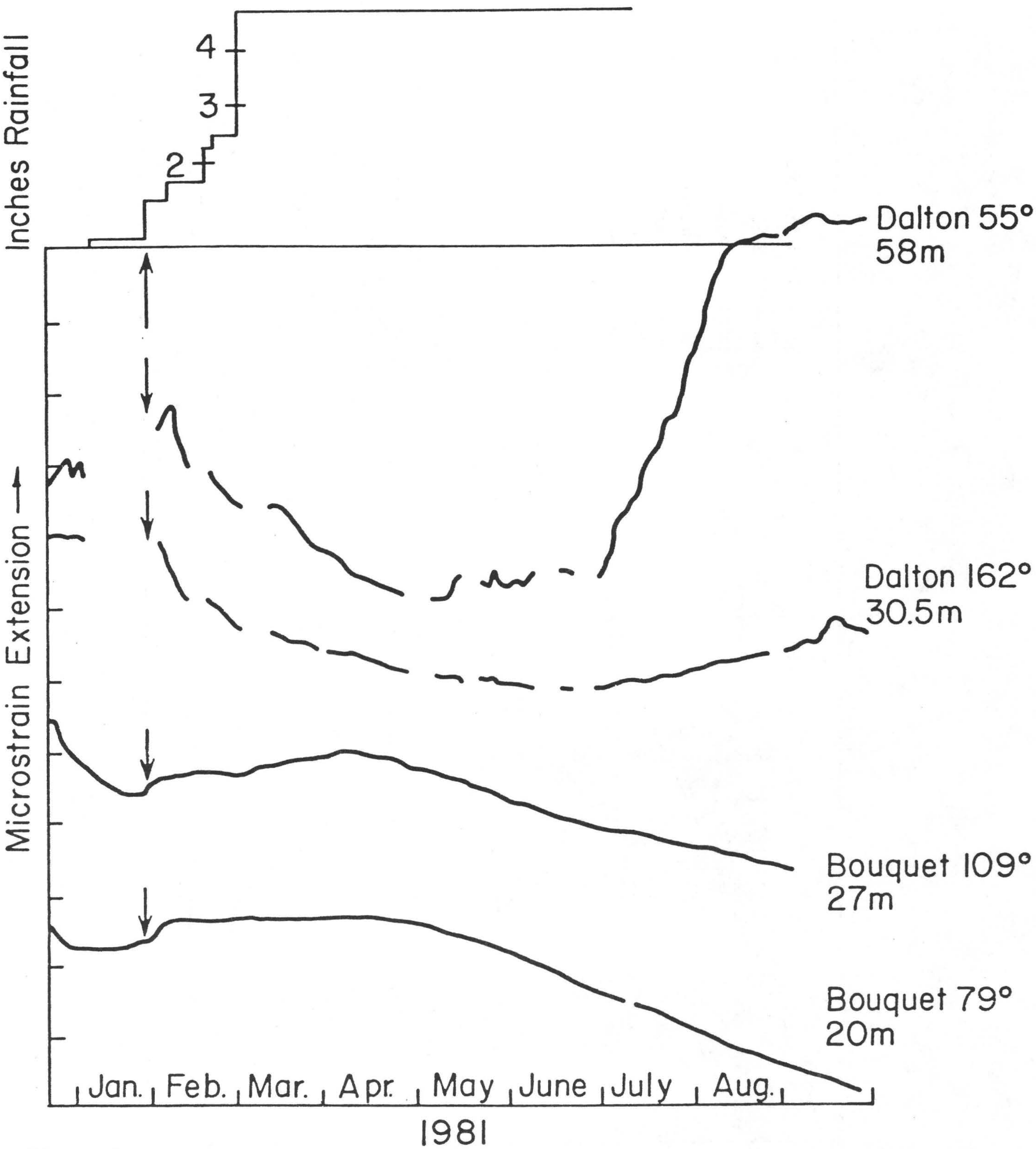

Figure 2. Strainmeter data for the network elements active in 1981, with regional rainfall. Bouquet site is BQ and Dalton site is DT on Figure 1. Numbers below strainmeter names are the instrument lengths in meters. Arrows point to correlation between season's first substantial rainfall and small extensions registered on all four instruments.

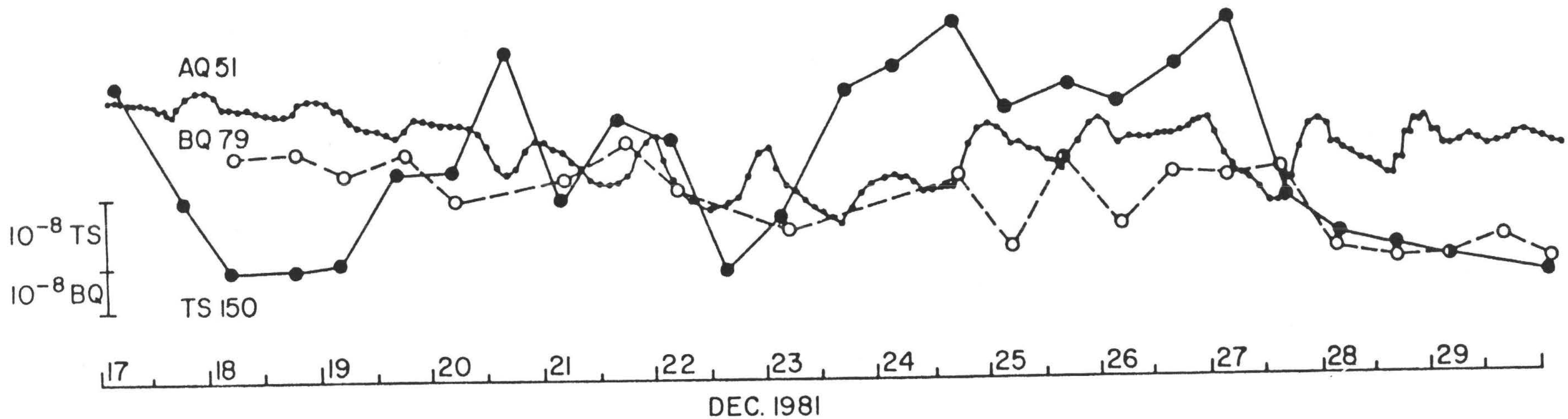

Figure 3. Initial data from sites BQ, AQ, and TS strainmeters in southern California.

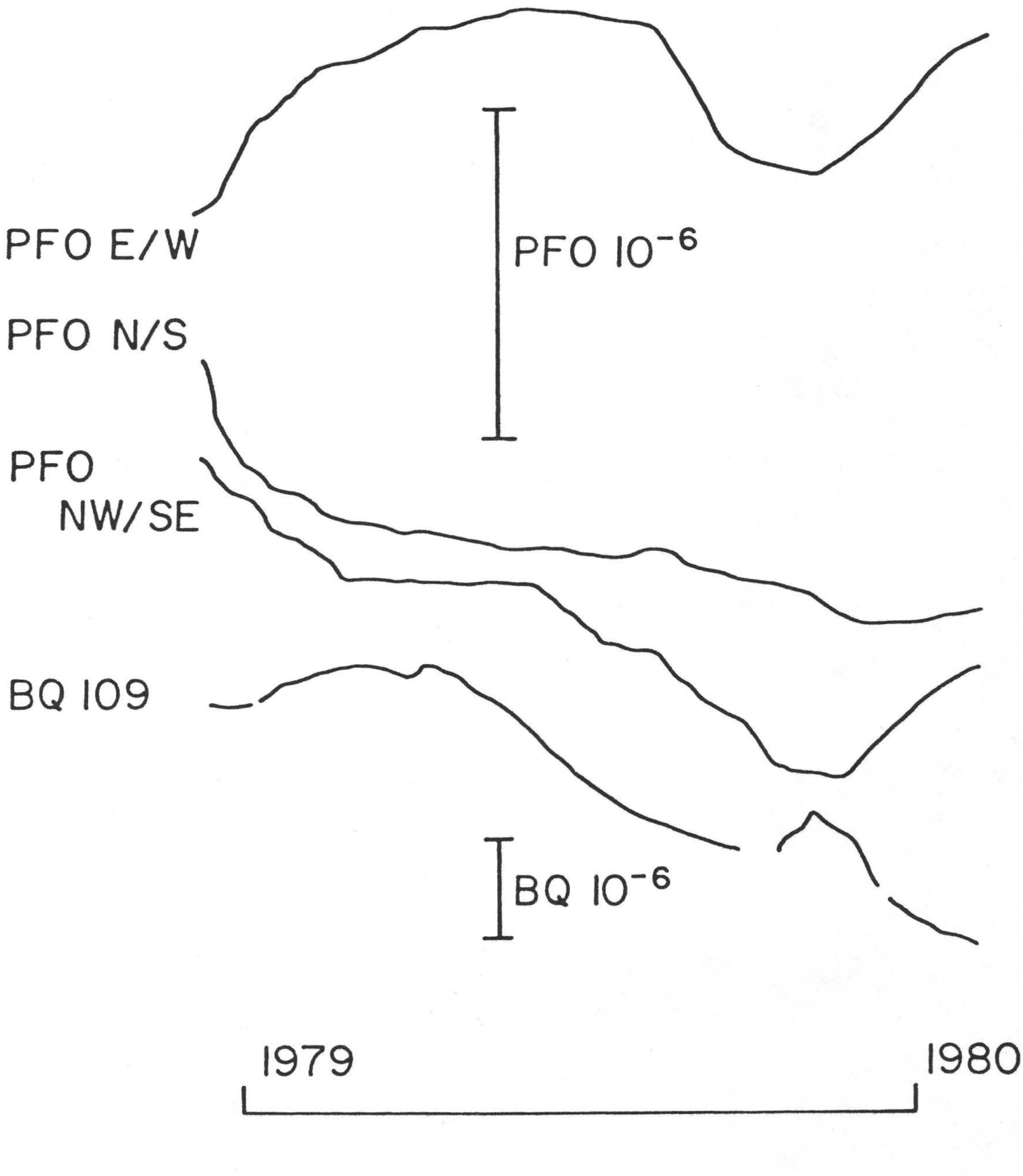

Figure 4. Comparison of strain measured during 1979 by the carbon fiber instrument at Bouquet Reservoir (27 meters long) and the laser strainmeters at Piñon Flat Observatory (PFO).

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. Seismicity and tectonics of the San Luis Reservoir area were studied by precise location of earthquake hypocenters and determination of focal mechanisms.

2. Local Hermite interpolation was combined with solution of 3-dimensional ray equation.

Results

1. Earthquakes in the San Luis Reservoir, Central California, were relocated for the purpose of better understanding seismic hazards to the San Luis Dam. This work was a joint research with R. LaForge of Bureau of Reclamation. Earthquakes recorded by a temporary network operated around the San Luis Reservoir by the USGS in 1974 and an M_L 3.7 shock recorded by the current California Department of Water Resources local network in 1981 Comprise the set of master events with which earthquakes from 1969 through 1980 were precisely relocated. Epicenters generally moved to the south and west after the relocation, and many events appear to be associated with the Ortigalita fault. Seismicity decreases from south to north along this fault, and clustering of earthquakes occurs where the fault strike changes. Seismicity is also concentrated in the vicinity where the Ortigalita fault and sub-parallel faults intersect the San Luis Reservoir. Focal mechanism analysis shows predominant strike-slip faulting. However, complex faulting was found where the Ortigalita fault takes a right step. The observed focal mechanisms agree with Dave Hill's theory on block tectonics. Details of this work may be found in LaForge and Lee (1982).

2. A major difficulty in 3-dimensional seismic ray tracing is how to represent the seismic velocity in a discrete model and compute seismic velocity and its spatial derivatives anywhere in the model. By using a

variable mesh for the velocity model and by constructing Hermite polynomials from local tensor product splines, we were able to overcome the interpolation problem. Six 3-dimensional ray tracing problems with known analytic solutions were tested. The results indicate that we can obtain numerical solutions with prescribed accuracy. In particular, we studied the Maxwell fish eye problem, where the velocity is given by

$$V(x, y, z) = 1 + x^2 + y^2 + z^2.$$

Reports

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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. It consists of the following 4 sub-projects:

1. WWNSS Seismogram Library

All WWNSS Seismograms are kept up-to-date and properly filed. This library is the only one in the western United States and serves seismologists from Alaska to southern California.

2. OES Library Room

A small, non-circulating library of mostly journals and books concerning earthquakes and related topics is being maintained in Building 8 of USGS, Menlo Park.

3. Current Earthquake Literature (CEL) Database

The CEL database is being maintained and kept-to-date. At present, about 10,000 articles (reports, reprints, and preprints) have been indexed and a copy kept on file in the OES Library Room. The 1981 Annual and 1982 Quarterly indexes are being distributed on schedule.

4. Historical Seismograms Filming Project

This is an international project to film historical seismograms of the world in order to preserve and make easy access of seismograms recorded before 1964. So far, about 300,000 seismograms from U.S. seismic stations have been filmed, and plans are being made now to film oversea stations. This project belongs to the International Association of Seismology and Physics of the Earth (IASPEI), and is jointly sponsored by the USGS, NOAA, World Data Center, UNESCO, and many national and local groups. At present, W.H.K. Lee is the Chairman of a joint IASPEI/UNESCO working group for this project.

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University of California, Los Angeles
Contract #14-08-0001-17686

Can Animals Predict Earthquakes? A Search for Correlations Between Changes in the Activity Patterns of Captive Fossorial Rodents and Subsequent Seismic Events

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Durward D. Skiles, Co-Principal Investigator*
Page Hayden, Research Associate

This project is an experimental investigation of the possibility that certain animals may behave in unusual ways immediately prior to nearby earthquakes. To that end we have accomplished the following.

1. We have established two monitoring facilities within seismically active regions. One facility is located on the Big Morongo Wildlife Reserve in San Bernardino County, California. The other is located in Stone Canyon, San Benito County, California.

2. We are continuously monitoring (a) the daily and long term activity of small rodents under controlled conditions of light and temperature, and (b) the daily and seasonal activity of small rodents in artificial burrow systems buried in the ground and exposed to the natural environment.

3. We have obtained long term activity records from about 50 animals including one species of kangaroo rat and three species of pocket mice. We have established baseline patterns of animal activity in the absence of seismic events, and determined correlations between some apparent anomalies in activity patterns and non-earthquake related parameters such as temperature, rainfall, humidity, insolation, barometric pressure, and atmospheric electrostatic fields.

4. Our primary objective has been to determine whether any correlations exist between changes or anomalies in the activity of test animals and subsequent seismic events. Unfortunately most seismic activity experienced at both study sites during

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the 3 year study period has been of low magnitude or with distant epicenters. One of the best earthquakes intercepted at Stone Canyon was a magnitude 4.2 event which occurred about 15 km NW of the study site on 14 August 1981. The greatest seismic activity intercepted at Morongo Valley was an earthquake swarm which commenced on 15 March 1979. It consisted of one event of magnitude 5.2, six events of magnitudes from 4.0 to 4.9, and 36 events of magnitudes 3.0 to 3.9. The epicenter of the swarm was located about 30 km NNW of our study site.

In both the Stone Canyon and Morongo Valley incidents our data could be interpreted to show that some of the test animals did indeed behave differently prior to the seismic events, but the argument is tenuous and as good correlations can be made with non-earthquake related parameters.

It is clear, from a casual examination of the data collected at both study sites over the entire course of this study, that there is no clear evidence that test animals exhibited any consistent, easily recognizable, unusual behavior prior to nearby small earthquakes. However, because of the nature and location of the seismic events detected, no conclusion whatsoever can be drawn regarding large or moderate earthquakes. Our data have not been fully reduced. Subtle precursory anomalies might be revealed by time series or other in depth analyses which were programmed to be undertaken in FY 1982. It is doubtful, however, that the final stages of data analysis can be completed without continued support from the USGS.

Parkfield Prediction Experiment

9930-02098

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Investigations

One view of what is meant by the phrase "earthquake prediction" is the specification of the time, place, and magnitude of a future earthquake, with some statement of the uncertainity associated with the estimates. In practice most workers in the field have actually thought in terms of a progression from long-term prediction, in which time and place are specified imprecisely, to medium-term prediction, in which the estimate is narrowed in space and time, to a short-term prediction in which a specific time and fault are indicated. These ideas have recently been cast in a probabilistic framework (Utsu, 1978; Lindh, 1980; Aki, 1981) in which the estimated probability of an earthquake at a given site varies with time, increasing for instance, if specific "earthquake precursors" are noted in an area. Thus while popular usage has focused on short-term prediction, in particular the specification to within days of the time of occurrence of a future earthquake, research has all along been directed toward a broader range of problems.

Similarly the term "earthquake hazard assessment" has been taken to imply the identification of recently active faults as "possible" or "probable" sites for future damaging earthquakes, sometimes with estimates of the largest credible or likely event included. In fact a program in which a fault can only be designated "active" on the basis of any Holocene activity, with no estimation of the frequency (or probability) of a damaging earthquake, can only lead over the long term to a more and more cluttered hazards map, and eventually to a situation in which most sites are "hazardous". This is of little practical value since real world judgments need to be made on the basis of relative risk. In practice estimates of the likelihood of a destructive earthquake are often made, or implied, and in actual fact the distinction between "hazards assessment" and "long-term earthquake prediction" was never particularly clear.

I believe one step forward we are now taking, is in moving from qualitative assessments of earthquake hazards, involving terms like "active faults", "less active", "inactive", "maximum credible", etc.; to quantitative assessments like "2% change of a M 8 event on this fault, this year". As I will attempt to illustrate below, I believe we are now in a position to begin to assign such annual probabilities on a routine basis. If we were to make such an effort a high priority, within a relatively short time they might come to mean something. I believe we tend to underestimate the impact such estimates might have over the long run, if it was clear that while they represented only our current best guesses, we stood behind them, and would direct our efforts to refining the models, and improving the data on which they were based.

From a broad societal perspective, the problem of earthquake hazard reduction is to some degree one of resource allocation; there is only so much concrete, rebar, and structural steel to distribute amongst the required structures, and only so many sites on which to build them. It is a fixed-sum game in which the task is to minimize the integrated seismic risk within the constraints of economic reality. Maps of active faults, whether they are based on seismic or geologic evidence, tend to contain only bad news. Even worse they usually include a disclaimer, implied or explicit, that because of poor exposure, inadequate station coverage, etc, more faults may exist than are shown, implying that more work will probably make things worse. The story is told that during an NRC hearing on a license application, one of the judges interrupted the proceedings to say that he ".....hoped that he would only have one-handed geologists to deal with in the future, because he was tired of hearing again and again 'and on the other hand'..."!

Yet for real world problems it is in a certain sense only relative risk that matters. So long as our input to these problems is largely qualitative, I believe there is a tendency for decision makers to view us as just another natural hazard to be dealt with; and leave the engineers to deal with the seismic risk as best they can after the fact.

Over the long run I believe quantitative estimates of the probabilities of given earthquakes on given faults (or within a given region) will change the nature of our imput to these problems. Quantitative maps explicitly contain good news along with the bad, safer sites along with more hazardous. And quantitative estimates of the probability of a given level of ground motion, even a specific design earthquake, can be dealt with directly by engineers (and insurance actuaries) in comparing costs of various designs, and at different sites.

The difference, I believe, potentially lies in the quality of the input we have to real world problems, and the point at which we have it.

The difficulty is, of course, that we are all too painfully aware of the tentative nature of our models, the inadequacy of our data in most cases, and loathe to mislead anyone by making too definite statements about relative levels, or the character, of seismic risk. The other side of the coin, however, is that everytime a politician, planner, engineer or builder makes a site selection, or sets structural standards, he implicitly does make such a judgement, usually without knowing the limitations of the data or the models, and without the benefit of the "subjective understanding" that comes from working in a field. In the end our data are no more ambiguous, and our theories no more half-baked, than those used routinely by designers and engineers, and probably less so than those politicians and planners have to rely on. The price of a "real" place at the table would likely be a "real" share of the blame when things go wrong; but of course we'll probably get that anyway, even if we don't have any "real" input at the time the decisions are made.

Seismic Studies of Block Tectonics

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Investigations

1. Focal mechanisms of earthquakes of the east San Francisco Bay region.

2. Continuation of seismic refraction studies of the Sierra Nevada using the 1980 Mammoth Lakes earthquakes.

Results

1. Focal mechanisms were determined for 25 earthquakes that occurred throughout the San Francisco Bay region between 1976 and 1981; 15 of these earthquakes had magnitudes greater than 3.5, and so a large number of stations could be included. Between 50 and 200 first motions were used in each fault-plane solution. The orientations of principal focal planes for the earthquakes generally agree with the local orientations of the mapped fault traces; exceptions include the nodal plane for one event on the southern section of the Hayward fault that is rotated more than 40° clockwise relative to the mapped fault-trace orientation. For more than half of the earthquakes studied, clear fault-plane solutions could be modeled from mapped first-motion patterns only by assuming that some rays underwent lateral refraction. A simple model, consisting of a uniform velocity contrast across a vertical fault plane, is sufficient to explain the anomalous first-motion data. All the earthquakes on the San Andreas fault between San Juan Bautista and Bear Valley show laterally refracted first arrivals that can be explained by the presence of higher velocity rock southwest of the fault, consistent with the result by McNally and McEvilly (1977). More than half the earthquakes on the Calaveras fault show refracted first arrivals consistent with higher ($<$ 1%) velocity material to the northeast of the fault. First-motion patterns from the two earthquakes on the Sargent fault show

refractions corresponding to faster velocity material to the northeast. No lateral refraction was evident for events on the Hayward fault.

2. Events from the May-June 1980 Mammoth Lakes, California, earthquake sequence were used as sources for a seismic-refraction study of the upper-crustal structure of the Sierra Nevada and its western foothills. The earthquakes used in this study were located using temporary stations deployed by the U.S. Geological Survey and local permanent stations operated by the University of Nevada, Reno. Travel times from a total of 14 earthquakes, with depths from 1 to 11 km, were used. For the refraction study, six portable smoked-drum seismographs were deployed over a distance of 140 km at 10 sites along a line extending west-southwest of the Mammoth Lakes events, roughly perpendicular to the axis of the Sierra Nevada. In addition, a portable magnetic-tape seismograph was set up at Edison Lake, approximately midway between the earthquakes and the closest smoked-drum recorder. Modeling of this unreversed refraction data shows evidence of a strong vertical velocity variation in the shallow crust, which is modeled as a (4.0 km/sec) weathered zone with thickness 2.3 km laying over a 5.6 km/sec layer extending to 8.5 km, and a 6.0 km/sec layer below 8.5 km. At distances of 50 to 100 km an apparent velocity of 6.5 km/sec $\pm$ 0.2 km/sec is observed, indicating a refractor at 13 km depth. The westermost three stations (> 90 km), which lie in the Great Valley, indicate an apparent velocity of 5.6 $\pm$ .1 km/s. This apparent velocity may be modeled by a 5^o wedge of sediment with a velocity of 2.5 km/s that thickens to the west over a shallow structure otherwise similar to that inferred under the Sierra. The results of this study are most consistent with models by Eaton (1966) and Bateman and Eaton (1967).

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Geodetic Strain Monitoring

9960-02156

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Investigations

1. A portable two-color laser geodimeter (terrameter) is being employed in high-resolution trilateration surveys in selected areas of the San Andreas fault system.

2. 18-km of level lines in the vicinity of Pearblossom, California, and within a two-color trilateration network, are releveled twice per year to first-order standards.

3. A suite of measurements of _in situ_ stress, obtained using the hydro-frac technique, is the basis of an elastic analysis of the state of stress in the Mojave Desert adjacent to the San Andreas fault.

4. A cooperative program was initiated in late 1980 with Dr. Larry Slater of the University of Colorado, CIRES, to observe crustal deformation using his two-color laser ranging system operated from an observatory near Pearblossom, California.

Results

1. Monitoring of the Pearblossom network (Figure 1) for changes in line length continued and the results of the updated strain analysis are shown in Figure 1. The most notable strain change is an abrupt dilation of the network of about 0.8 μstrain followed by nearly as much contraction during the next month. This dilational episode, which began in the first part of March, 1982, is primarily associated with an extension parallel to the San Andreas fault; whereas, a similar, though smaller, dilational episode in December, 1980, was due more to the normal strain component (Figure 2). Another noteworthy feature is the apparent acceleration in the rate of right-lateral shear strain accumulation during the third quarter of 1981. In addition to the Pearblossom network, weekly monitoring of the Palmdale network (20 lines), northwest of the town of Palmdale, and the Buttes network (13 lines), about 30 km northeast of Pearblossom, commenced recently.

2. Three medium-aperature (approximately 3 km) levelling networks have now been measured twice. The tilts inferred by comparing the levelling

in 1982.1 to that in 1981.6 are not significantly different from zero based on our estimate of 2 μrad for the standard deviation of the measurements.

3. The elastic analysis of the *in situ* stress measurements was completed as well as a report of the results. In addition to the results reported previously, we find that if the strength of the San Andreas fault zone limits the regional state of deviatoric stress then the inferred coefficient of the friction for this zone is about 0.45. Furthermore, on the basis of a tectonic model involving a locked fault extending from the surface downward to 22 km, inferred from trilateration measurements of the strain accumulation, the *in situ* stress data imply that the total fault slip below the locked portion is less than 13 m; a more comprehensive set of stress observations would permit the estimation of a better lower bound on accumulated slip at depth.

4. Joint measurements of baselines in the Pearblossom network were made with the new terrameter and the CIRES two-color instrument from August, 1981, until early February, 1982, to avoid any discontinuities in the geodetic data due to an instrument change. Then on 9 February 1982 our program of collaboration ended when the CIRES equipment was transported to central California in preparation for a new two-color measurement project near San Juan Bautista.

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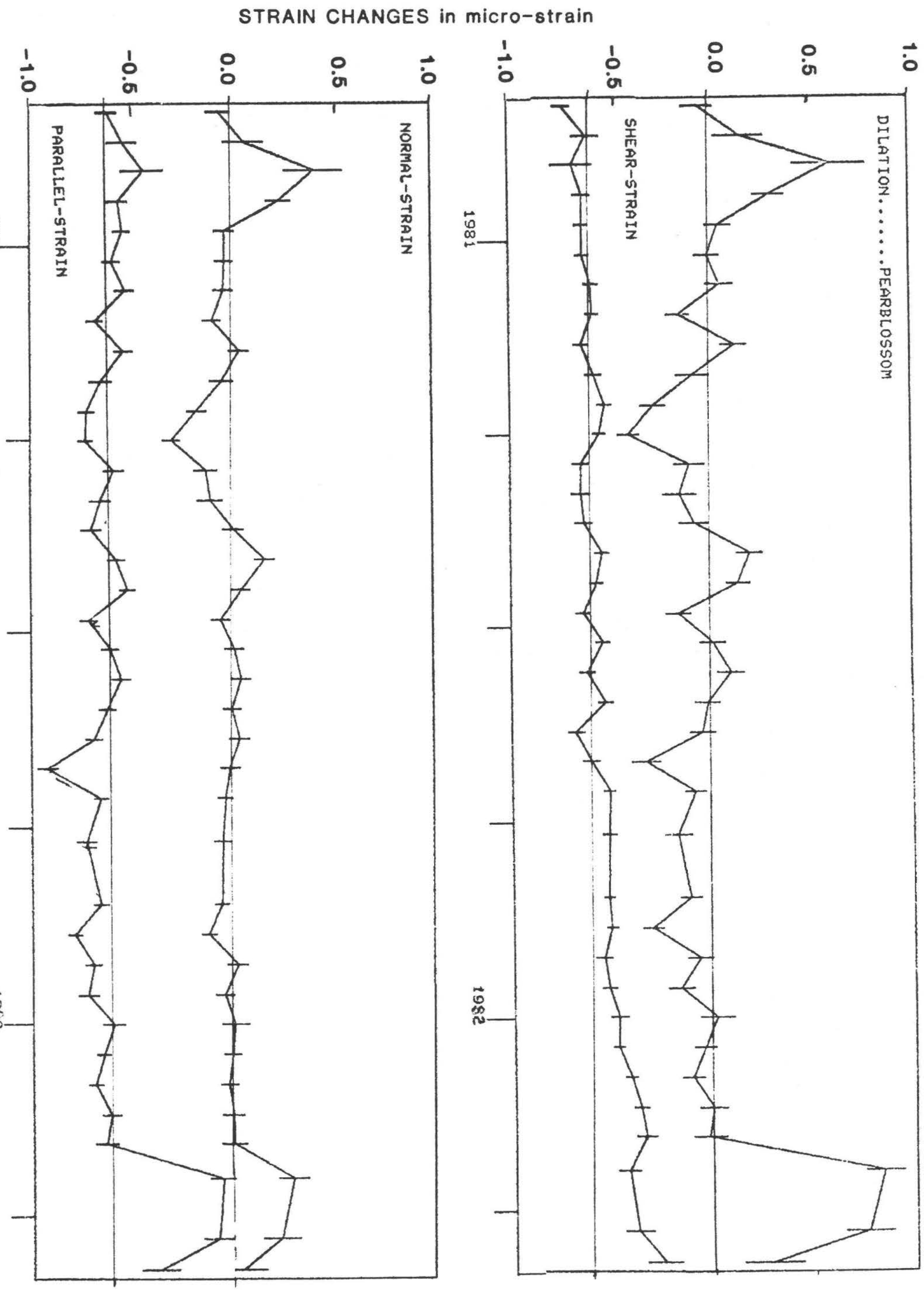

Figure 2 - Strain changes as a function of time that have been inferred from the repeated line-length measurements of the Pearblossom network.

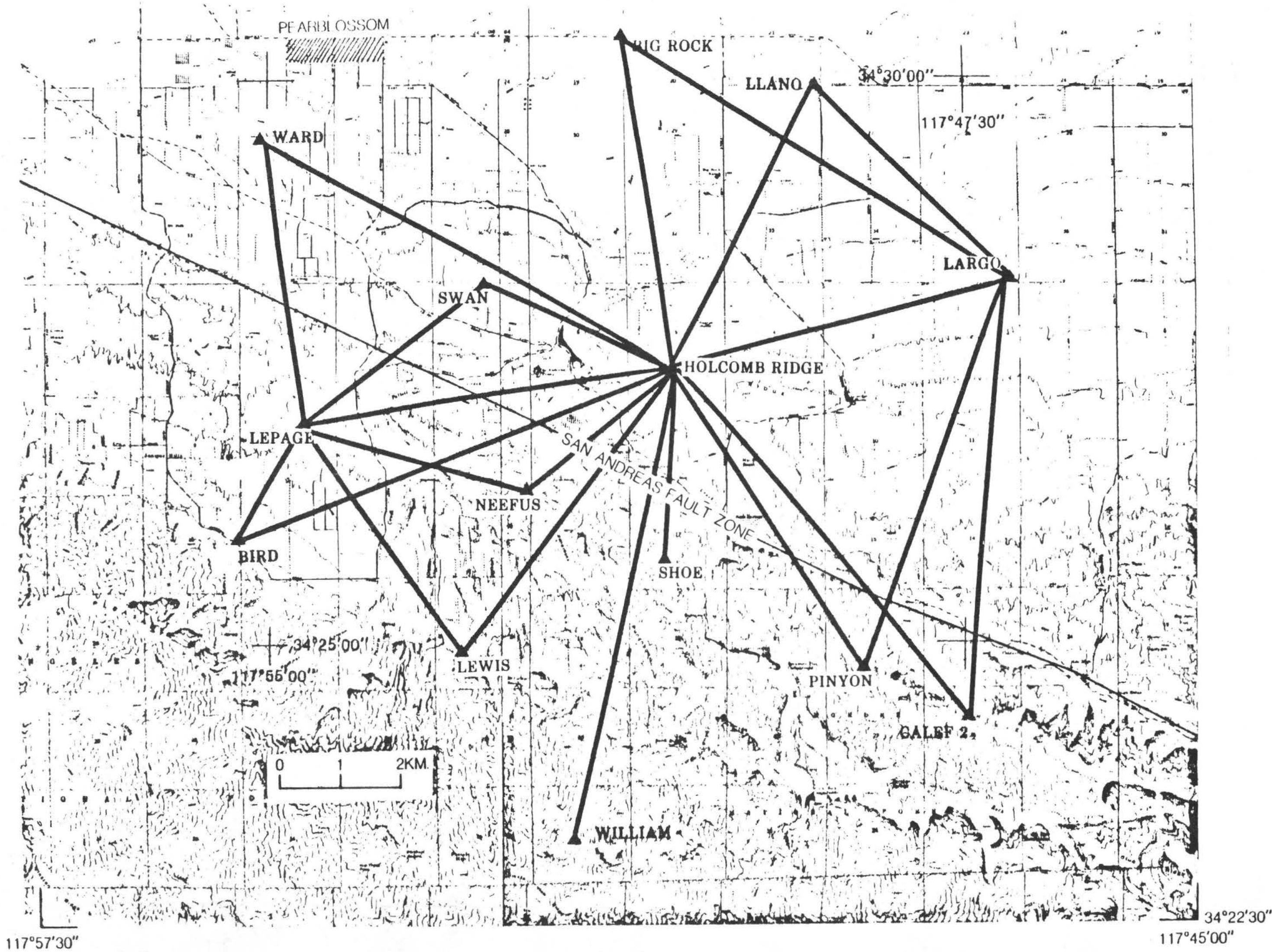

Figure 1 - A map showing the baselines in the Pearblossom network. The baselines that extend from Holcomb Ridge have been repeatedly measured since November 1980. Measurements on the remaining baselines have only commenced recently.

Variable Rupture of Seismic Gaps and the Relation to Foreshock-Mainshock-Aftershock Sequences

14-08-0001-19265

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Investigations

Research supported wholly or in part by this contract during the six-month reporting period includes: (1) Analysis of seismic rupture patterns in Oaxaca, Mexico. (2) Investigation of seismicity pattern before the Acapulco, Mexico earthquake (M_s = 7.5) of July 25, 1957. (3) Study of variable rupture mode of the subduction zone along the Ecuador-Colombia coast. (4) Study of an earthquake sequence in 1980 in a seismic gap near the Loyalty Is., New Hebrides. (5) Application of the seismic-gap method to the seismicity of Costa Rica. (6) Representation of seismicity data in 3-D, via advances in computer graphics.

Results

1. The results of our study on the Middle American Trench were reported in our previous report. During this reporting period, we completed a paper on the project, and it has been accepted for publication (see Tajima and McNally (1981) in the reference list).

2. Preliminary relocation of events with mb $\geq$ 4.0 occurring during the time period of 1950 through 1956 near Acapulco, Mexico, shows a zone of relative seismic quiescence in which the Acapulco earthquake (Ms = 7.5) of 28 July, 1957 took place. This result is consistent with previous studies of seismicity patterns before large earthquakes (Ms > 7.0) due to the subduction of the Cocos plate beneath the North America plate along the coast of Mexico. This result together with the study of the source parameters of the 1957 Acapulco earthquake may be used as a first step toward evaluating the seismic potential of a present seismic gap in the same region (see Gonzalez and McNally (1981) in the reference list).

3. Most of the results of our study on the Colombia-Ecuador region are summarized in our previous report. During this reporting period, we examined some of the seismograms for the 1906 earthquake to infer the focal mechanism, and rupture direction. We completed a paper which has been submitted to Bull. Seismol. Soc. Am. (see Kanamori and McNally (1981) in the reference list).

4. We investigated four large earthquakes which occurred in a seismic gap of category 2 (McCann et al., 1979) near the Loyalty Is. in the New Hebrides. At 3:25 on Oct. 24, 1980, an event with M_S = 6.7 initiated the sequence. Three events, M_S = 6.7, 7.2, and 6.5 followed this event on the

next day. The mechanisms of all four events are almost pure thrust on a plane dipping 20^{o} and striking parallel to the local strike of the New Hebrides trench. The first-day aftershocks indicate an initial rupture zone of about 2,000 km^2 which is consistent with the estimated seismic moment of 3 x 10^{27} dyne-cm. During the next two days, the aftershock activity expanded to an area of 10,000 to 20,000 km^2. This pattern suggests that the initial rupture zone represents a zone of increased strength (i.e., asperity), and the stress change due to failure of this asperity subsequently migrated outward. During the 2 year period before the main event, seismicity in the initial rupture zone had been very low except near the point where the main shock sequence initiated. A very tight clustering of activity occurred there (see Vidale and Kanamori (1981) in the reference list).

5. Patterns of seismic energy release in small and moderate earthquakes since 1965 have been studied for the NW, central, and SE zones of Costa Rica. Recently large earthquakes have occurred in the NW region (1978, M_s = 7.0) and SE region (1979, M_s = 6.4; M_s = 6.5); the previous seismic history indicates that the central region may now be considered a "seismic gap". Patterns of seismic quiescence ($m_b \geq 3.8$) followed by a resumption in activity have preceded the last three moderate ($m_b \geq 5.2$ earthquakes in the central region. A seismic quiescence has occurred again in 1978-79, followed by a renewal of activity. These observations suggest the possibility of a future moderate earthquake ($m_b \geq 5.2$) in the central region. Based on the temporal patterns of the quiescent periods, the renewal of activity and the occurence of the "mainshocks", a computed total range of time for the forthcoming event would be estimated between Februrary 1979 and July 1982 (see Guendel and McNally (1981) in the reference list).

6. We made a preliminary study on the use of 3-D presentations of data taken from several different earthquake catalogues. This technique can help an individual who seeks to master, ab initio, the information contained in a given catalogue. For the person who has already conducted a careful seismicity study, the technique also helps in communicating the results rapidly to a wider audience.

Our method entails viewing a CRT via reflection in a mirror of rapidly oscillating curvature. Timing, of the (2-D) CRT display, is computer-conrolled so that each earthquake location appears to come from the appropriate distance away from the mirror. With no eye strain, one thus views a 3-D display of seismicity. (see Anderson et al. (1981) in the reference list).

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Crustal Strain

9960-01187

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Investigations

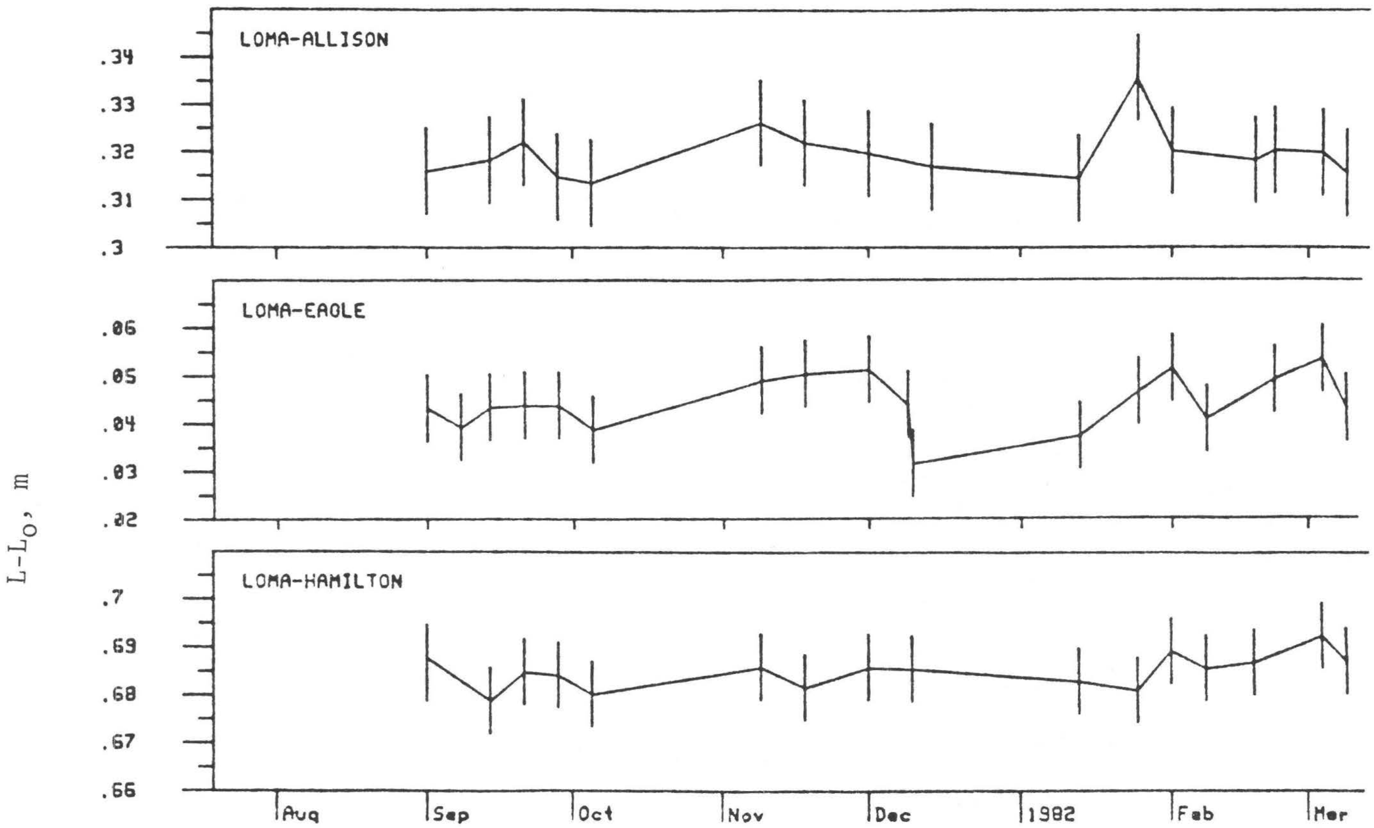
The principal subject of investigation was the analysis of deformation in a number of tectonically active areas in the Western United States.

Results

1. Strain accumulation along Hayward and Calaveras faults. A number of small survey networks, 2 km or less in diameter, located along the Hayward and Calaveras faults, have been measured occasionally since 1965. These observations imply a surface slip rate on the Hayward fault at Fremont, Hayward, Berkeley, and Richmond of about 6 mm/yr. On the Calaveras fault, north of Hayward-Calaveras fault junction, surface slip rates have only been determined from four data sets. Three give a rate of 3 mm/yr. We annually measure 32 longer lines (10-30 km) in the East Bay. Observations of these lines extend back to 1977 for most and to 1970 for some of the lines. The observed creep rates and the data for the longer East Bay lines provide constraints on the amount and location of deeper slip on the Hayward and Calaveras faults. After correcting for line length changes produced by fault slip, strain accumulation was calculated. The shear strain rate parallel to East Bay faults is 0.07 $\pm$ 0.02 μstrain/yr, a rate well below that of other areas along the San Andreas fault system, suggesting that creep is relieving a large part of the strain in this area.

2. Coyote Lake earthquake afterslip. Periodic measurements of three small-aperture (2 km) trilateration networks on the Calaveras fault, near the epicenter of the Coyote Lake earthquake (M_L = 5.7 $\pm$ 0.2, August 6, 1979), are used to deduce preseismic, coseismic, and postseismic right-lateral surface slip. The networks are located along the 21 km long rupture zone; Ruby Canyon is 5 km south of the main shock, San Felipe 5 km north of the southern limit of aftershocks, and Silva is near the southern limit of aftershocks. The Ruby Canyon network was first surveyed in 1978, with no additional surveys before the earthquake. Coseismic slip was 5 $\pm$ 5 mm and afterslip totaled 98 $\pm$ 5 mm by December 1980. Secular surface slip in the San Felipe network for seven years before the earthquake averaged 13 $\pm$ 2 mm/yr with no significant variation. Coseismic fault slip was 14 $\pm$ 5 mm, and afterslip totaled 85 $\pm$ 5 mm by November 1980. Secular surface slip in the Silva network averaged 10 $\pm$ 2 mm/yr for four years before the earthquake, and the sum of coseismic slip and postseismic afterslip was 60 $\pm$ 10 mm by December 1980.

3. <u>Loma Prieta Monitor Net</u>. In September 1981 we began frequent (weekly when possible) measuring of three lines (lengths 43, 31, and 31 km) near the San Andreas fault at San Jose, California. Mercury barometers are permanently installed at each end of the lines for pressure measurements. Temperature and humidity are measured by flying a light plane along the line while ranging. Data for all three lines are shown in the figure. For two of the lines only one point deviates from the mean by more than one standard deviation. For the third line no point does.



4. <u>Model predictions of relation between gravity, elevation change and dilatation</u>. Rundle (1978) and Walsh and Rice (1979) have shown that the change in the vertical component of gravity is proportional to uplift for a spherical source of dilatation and for slip on an infinitely long dip-slip fault. In the first case no free-air gravity anomaly is produced and in the second case no Bouguer gravity anomaly. Gravity anomalies due to other dislocation sources in three dimensions are as follows: For strike-slip faulting the ratio of the gravity change to uplift depends upon position; however, the gravity change contours are roughly similar to those corresponding to a zero free-air gravity anomaly. Nor is the ratio constant for dip-slip faulting except for the two special cases of dip slip on a vertical fault and horizontal slip on a horizontal fault, neither of which produce a Bouguer anomaly. The Bouguer anomaly produced by a horizontal crack is the same as would be produced had the material

within the crack been mined out without deforming the solid. If the horizontal crack were filled with material of density equal to the host rock (a good approximation to sill formation), no Bouguer anomaly is produced. For cracks of other inclinations the ratio of gravity change to uplift is not constant. Thus, dilatancy, in general, does not correspond to the absence of a free-air anomaly as might be suggested by the special case of a spherical source of dilatation. For two-dimensional models a cylindrical source of dilatation produces no free-air gravity anomaly, dip-slip faulting produces no Bouguer anomaly, and open cracks produce a Bouguer anomaly equal to that which would be produced had the materials within the crack been mined out without deforming the solid. A two-dimensional crack filled with material of density equal to that of the host rock would produce no Bouguer anomaly. Jachens et al. (1982) have reported temporal changes in gravity, elevation, and areal strain along the San Andreas fault in southern California such that the Bouguer anomaly apparently remains unchanged and the uplift-to-strain ratio is about -100 km. Several dislocation mechanisms are proposed that fulfill these constraints, but these mechanisms appear to be rather contrived and are not regarded as satisfactory explanations.

5. Southern California Monitor Net. In early May a Geodolite Monitoring Program was initiated at five sites along the San Andreas fault in southern California. The intention is to measure three lines, each of about 20 km length, at each site biweekly. An airplane will be flown along the lines at the time of ranging to measure refractivity. The sites are located near Indio, Cajon Pass, Gorman, Taft, and Cholame. A pilot study (see figure) in northern California of such monitoring indicates that changes of about 0.5 μstrain between successive surveys can be detected.

6. Elsinore, San Jacinto, and San Andreas faults strain profile. A profile of the strain accumulation rate along a line trending N50°E across the subparallel Elsinore, San Jacinto, and San Andreas faults near Palm Springs, California, has been constructed from trilateration surveys in the 1973-81 interval. The strain accumulation is principally right-lateral shear across a vertical plane parallel to fault strike (N40°W). The strain rate profile for that component exhibits two clearly resolved maxima, one centered on the San Jacinto fault (γ_{max} = 0.35 ± 0.02 μrad/a) and the other on the San Andreas fault in the Coachella Valley (γ_{max} = 0.40 ± 0.02 μrad/a); no maximum is associated with the Elsinore fault. The implication is clearly that slip at depth on both the San Andreas and San Jacinto faults is loading the shallower sections of the faults, and eventually rupture can be expected on both.

7. Tehachapi-Palmdale shear strain. The Tehachapi and Palmdale trilateration networks are both located along the San Andreas fault near its intersection with the Garlock fault. The Palmdale net spans a region about 10 km wide along the fault, while the Tehachapi net spans a region about 75 km wide along the fault. Shear strain rates obtained from these nets differ significantly (Table). However if the Tehachapi net is subdivided into two regions, one near the San Andreas fault and one more distant, the San Andreas region strain rate agrees with Palmdale while the other region indicates a

lower rate (Table). The strain in this area decreases away from the San Andreas fault. If this decrease is interpreted in terms of slip at depth beneath a locked layer on the San Andreas fault, the ratio of slip to depth is about 1 mm/yr/km and is well constrained but the values of the two parameters individually are poorly constrained.

TABLE. Maximum right-lateral shear strain rates.

	γ(μrad/a)	ψ(deg CWFN)
TRILATERATION NETWORKS:		
Tehachapi, 1973-80	0.21 ± 0.02	126 ± 03
Palmdale, 1971-80	0.36 ± 0.02	118 ± 02
San Andreas Region, Tehachapi, 1973-80	0.34 ± 0.02	119 ± 02
Garlock Region, Tehachapi, 1973-80	0.17 ± 0.04	144 ± 05

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A Crustal Deformation Observatory Near the San Andreas Fault in Central California

14-08-0001-19300

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Investigations

A site near San Juan Bautista has been selected for the Crustal Deformation Observatory. The observatory will utilize both the multiwavelength EDM instrument and the new 2-fluid tiltmeter. We will be able to collect both horizontal and vertical deformation data simultaneously to high precision.

A multiwavelength EDM monitoring program was begun near Palmdale in Southern California during October 1980 and concluded in February 1982 using the University of Colorado instrument. Rapid changes in strain had been monitored by Savage et. al. (1981) in the region and one of the goals of our multiwavelength EDM effort was to provide a more detailed picture of this deformation. We also wished to establish a high precision geodetic data base as early as possible with the expectation that other, commercially available multiwavelength EDM instruments would be available in the near future to continue the effort when the University of Colorado instrument was moved to the San Juan Bautista site. This Southern California monitoring program is a cooperative effort between the University of Colorado and the U.S. Geological Survey.

Results

The construction of the multiwavelength EDM observatory building near San Juan Bautista is complete. The instrument has been installed in the rotating turrent of the observatory building. Approximately 10 retro-reflector sites are being permitted and permanent reflectors are being located at these sites. The reflectors will be located at distances ranging between 2 and 8 km from the central observatory building.

Within the multiwavelength EDM array is located the 2-fluid tiltmeter installation. The tiltmeter installation is complete and tests and initial data collection has been underway for approximately 6 months. The tiltmeter is composed of 2 legs joined in the shape of an 'L', one leg is 243 meters in length and the other is 193 meters. Figure 1 presents some of the vertical displacement data collected with the 2-fluid tiltmeter during a recent evaluation test. The duration of the test was approximately 15 days. The upper two curves show the single fluid relative height measurements. Peak-to-peak variations as large as 9 millimeters are evident and are due in large part to daily variations in temperature (fluid temperatures in the end reservoirs were varied by as much as 30°C). The upper two curves are the result that one abtains with a single-fluid, filled tube, tiltmeter approximately 300 meters in length and installed with elevation differences along the leg of approximately 10 meters. The lower curve is the result of the two-fluid technique. The peak-to-peak variations have been reduced to 2 millimeters and the long-term stability is considerably improved. We are hopeful that the short-term variations seen in Figure 1 can be reduced by another order of magnitude in the near future.

We installed a precise geodetic network along the San Andreas fault near Pearblossom, California in October 1980. The network is within the region frequently referred to as the 'Palmdale Uplift' and consisted of 13 lines radiating from a central benchmark. The lines range in length from 3.2 km to 8.1 km and were generally measured twice each week. Figure 2 shows the strain components as a function of time that were calculated from the multiwavelength EDM data collected over the 15 month effort. A coordinate system aligned with the local trace of the San Andreas fault was used. The long-term linear strain rates are as follows:

$\dot{\varepsilon}_{nn} = + 0.00 \pm 0.02$ microstrain/a (perpendicular to fault)

$\dot{\varepsilon}_{pp} = - 0.10 \pm 0.01$ microstrain/a (parallel to fault)

$\dot{\varepsilon}_{np} = + 0.16 \pm 0.01$ microstrain/a (right lateral shear)

The above strain rates were calculated from a model that assumed homogeneous strain and no fault slip. Both of these assumptions appear to be justified. Plots of the strain components as a function of time (Figure 2) reveal that each behave differently. The right lateral shear component shows a monotonic increase with time with none of the data points departing significantly from the secular trend line fitted to the entire data set. The perpendicular strain component has a secular rate of zero but this component shows large departures from the trend line. Variations as large as 0.7 microstrain occur over periods of a few months. The parallel strain component also shows some fluctuations from its secular trend although they are considerably smaller than those shown by the perpendicular component.

Largely because of the improved time resolution and increased precision, compared to previous efforts, the current results indicate that the strain field in the vicinity of Pearblossom, California has more temporal structure than was formerly appreciated.

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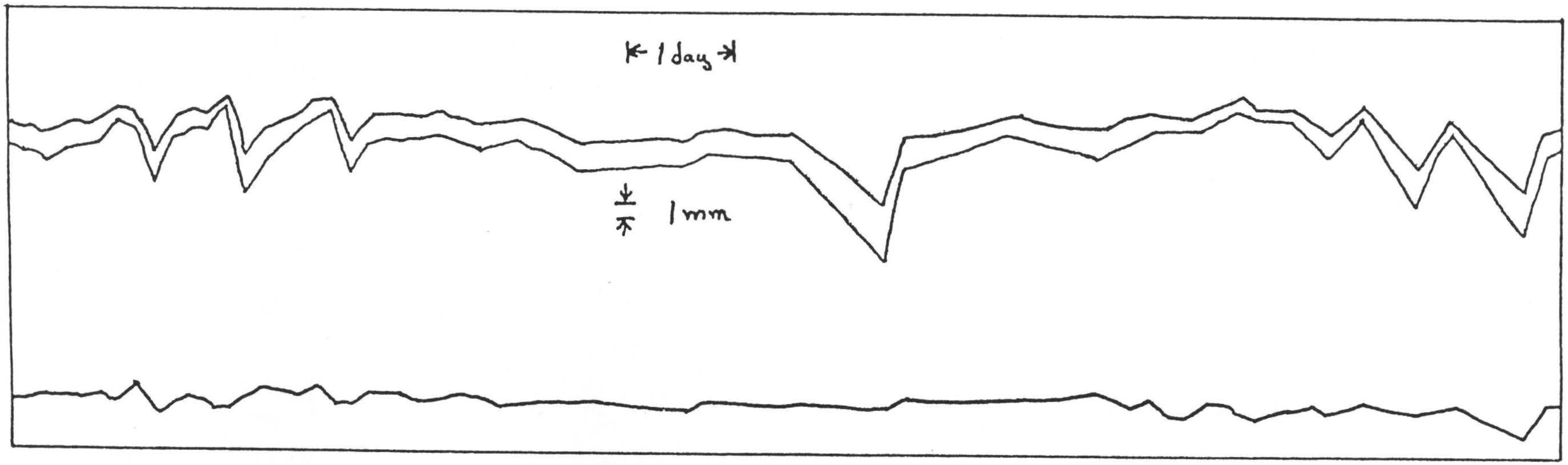

Figure 1. The two curves at the top of this drawing show the thermally induced relative height changes for the two fluids used in the tiltmeter at San Juan Bautista. The maximum thermal error in this figure is approximately 9 mm (apparent tilt of approx. 30 microradians). The lower curve is the two fluid corrected result, the maximum variation is approximately 2 mm.

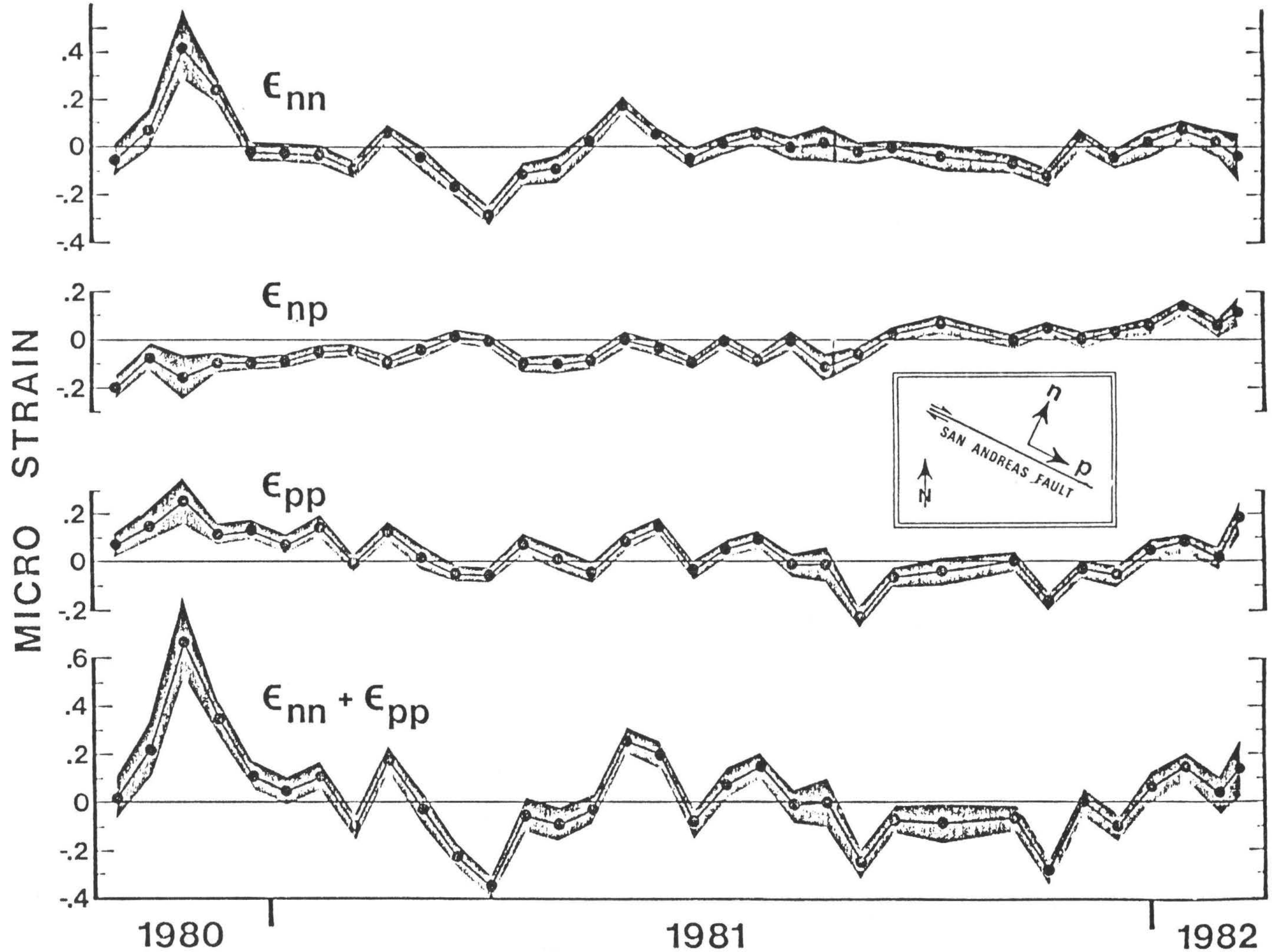

Figure 2. Strain components (tensor) as a function of time. Shading indicates uncertainty.

Crustal Deformation Observatory
Part G

14-08-0001-19758

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Investigations

This effort consists of a portion of the initial field testing and evaluation of a new 2-fluid, long-baseline 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 and techniques 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.

Results

New thermally-stable monuments have been constructed and installed at the Pinon Flat site. The connecting fluid and air tubes have been installed and filled in a shallow trench (approximately 1 meter deep) between the monuments and small protective above-ground shelters are located around the monuments. We will begin measurements using the 2-fluid tiltmeter at Pinon Flat Observatory within a few weeks.

Initial field tests of the instrument in central California revealed daily variations in relative height measurements as large as 1-2 centimeters. These variations have been traced to several causes, some of which have been eliminated. Current measurement variations are reduced to approximately 2 millimeters peak-to-peak. Figure 1 shows the results of a 15 day test. The upper two curves show the single fluid relative height measurements. Peak-to-peak variations as large as 9 millimeters are evident and are due in large part to daily variations in temperature (fluid temperatures in the end reservoirs varied as much as 30°C). The upper two curves are the result that one abtains with a single-fluid, filled tube, tiltmeter approximately 300 meters in length. The lower curve is the result of the two-fluid technique. The peak-to-peak variations have been reduced to 2 millimeters and the long-term stability is considerably improved.

We are hopeful that the short-term variations seen in Figure 1 can be reduced by another order of magnitude in the near future.

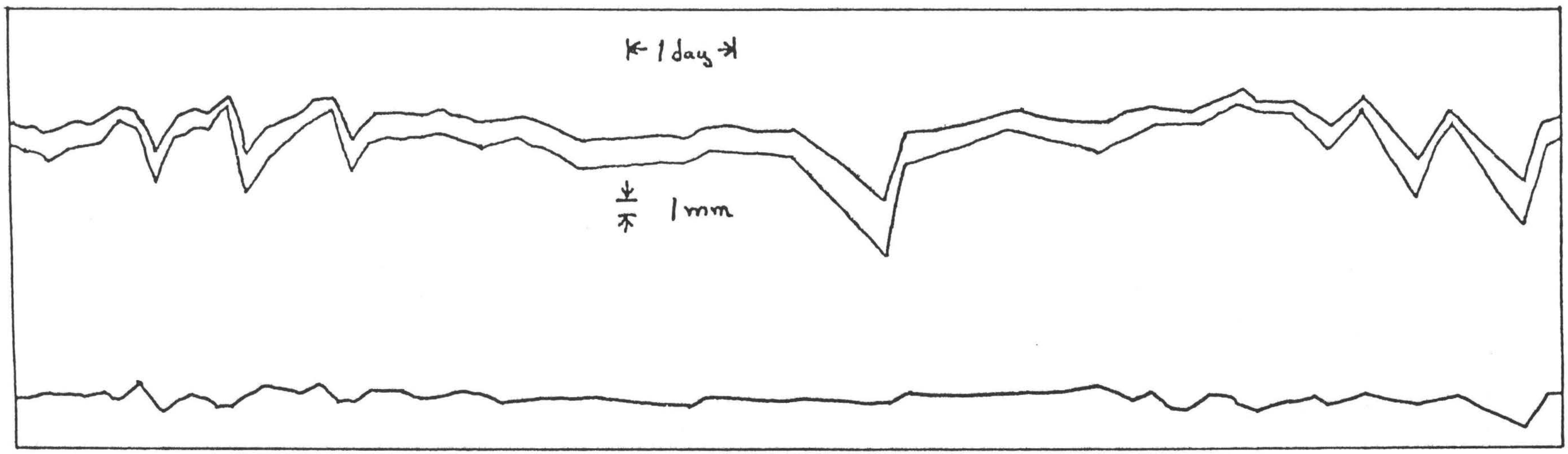

Figure 12. The two curves at the top of this drawing show the thermally induced relative height changes for the two fluids used in the tiltmeter at San Juan Bautista. The maximum thermal error in this figure is approximately 9 mm (apparent tilt of approx. 30 microradians). The lower curve is the two fluid corrected result, the maximum variation is approximately 2 mm.

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. An analysis of the cause-and-effect relationship between magma chamber inflation, crustal uplift and the occurrence of 3 magnitude 7 earthquakes on the Izu Peninsula, central Japan.

2. Stimulated by the above analysis, an assessment of the potential general importance of triggering processes in earthquake occurrence and its implications for earthquake prediction research.

Results

1. A close spatial and temporal association between three aseismic uplift episodes and subsequent large ($M \simeq 7$) earthquakes on the Izu peninsula, Japan, suggests a causal relation. Quaternary geology as well as studies by other workers indicates a volcanic origin for the observed uplift, and we use a simple inflation model constrained by leveling data to compute the expected increments in normal and shear stress across faults that ruptured in the earthquakes. Using a Mohr-Coulomb criterion, we find that, in two cases out of three, stress changes induced by inflation are in the correct sense to trigger failure. Although changes are no more than a few bars, they represent the equivalent of several decades to a century of secular stress buildup (W. Thatcher and J.C. Savage).

2. Observational evidence leaves little doubt that transient and episodic aseismic crustal movements occur in major seismic belts, and a convincing case can be made that some of these have induced stress changes which triggered large earthquakes. Observed episodic movements can represent the equivalent of a decade or more of steady strain buildup, suggesting the importance of triggering in regions of high earthquake potential such as category 1 seismic gaps. These observations further suggest a monitoring strategy more focused on episodic deformation and emphasizing a probabilistic rather than deterministic approach to earthquake prediction (W. Thatcher).

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, submitted.

Thatcher, W., Seismic triggering and earthquake prediction, 1982, Nature, submitted.

Thatcher, W., Seismic triggering and earthquake prediction, 1982, EOS, 63, in press.

Thatcher, W., and T. Matsuda, 1981, Quaternary and modern crustal movements in the Tokai district, central Honshu, Japan, J. Geophys. Res., 86, 9237-9247.

Thatcher, W., and J.B. Rundle, 1981, A viscoelastic model for periodically recurring earthquakes in subduction zones, EOS, 62, 1031.

Thatcher, W., and J.C. Savage, 1982, Triggering of large earthquakes by magma chamber inflation, Izu Peninsula, Japan, Geology, submitted.

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. Two unreversed profiles were recorded using energy from quarry blasts. One line was run between Los Altos and Davenport, California and the other between San Luis Reservoir and Llanada, California.

Telemetry Networks. The small seismic network near China Lake was expanded in cooperation with the U.S. Navy in response to the increased seismic activity in the region. A major reorganization of the telephone line telmetry has been accomplished resulting in a 25% savings in the telemetry costs.

Portable Networks. Nine 5-day recorders were operated in the Parkfield, Coalinga, California area for a period of 3 months.

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.

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.

3. Participation in the collection and basic reduction of refraction data in the Central Valley of California and the Santa Cruz Mountains.

Results

Unraveling the tectonics of California is a complex and varied problem. One aspect that we are concentrating on is to try to understand the source and nature of intraplate intrusion such as near the Geysers, north of San Francisco, and Long Valley. A review of all techniques used to locate magma shows that seismic reflection has the most potential followed by seismic refraction including special techniques such as fan shooting. An integration of geologic and geophysical data suggest that large crustal intrusions exist in the western United States at depths as shallow as 5 or 6 km, that these intrusions take several million years to both be emplaced and to cool, that the hottest magma may be near the top of the intrusive, and that the best place to develop magma energy is to find a large intrusive before a Caldera has formed. A summary paper targetted for science is in preparation.

Ocean lithosphere can be formed simply by splitting the lithosphere under extension and allowing the underlying mantle material to rise and adjust in terms of chemical phase relations, temperature, and density. Thus convection currents are not needed. A paper on this is being written. Looking at a ridge crest in such a way provides a different way to interpret the effects on California tectonics of overriding a ridge crest.

Report

Ward, P. L., Iyer, H. M., 1981, Finding large, dullable magma bodies in the United States (invited abstract): American Geophysical Union, Fall Meeting.

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 twenty stations in Central America to study the Ms 6.0 earthquake on January 12, 1982. This very shallow earthquake occurred at a major offset in the Quaternary volcanic chain on a previously unknown fault and caused Mod. Mercalli intensity VIII damage near the epicenter.

Results

1. The "Catalog of Damaging earthquakes in Guatemala" at this time contains 95 events since 1525 and appears virtually complete since 1660-that is a rate of about one damage-causing earthquake every five years!

A significant result of this historical work is the documentation of an apparent "seismic cycle" for the 1816 magnitude 8 earthquake on the left-lateral Chixoy-Polochic Fault. The historic record shows eight damaging earthquakes between 1700 and 1816 compared to only possibly one or two damaging earthquakes between 1821 and 1981 for the vicinity of this fault.

2. Aftershocks were located and a focal mechanism obtained for the Ms 6.0 January 12, 1982 earthquake by combining data from local networks. The results show a left-lateral strike-slip fault striking NE, i.e. perpendicular to the Quaternary volcanic chain. This mechanism is virtually identical to the 1972 Managua earthquake which also occurred at a major offset in the volcanic chain. Taken

together these data may indicate that offsets in active volcanic chains are mechanically similar to the transform faults of mid-ocean ridge systems.

Reports

White, R. A., 1982, Historical earthquakes and the diffuse Caribbean-North American Plate boundary in Guatemala: Earthquake Notes, v. 53, p. 81.

Harlow, D., Yuan A., and McNutt, S., 1982, Seismicity and Eruptive Activity of Fuego Volcano, Guatamala February 1975 - January 1977: [abs.] accepted: EOS, transactions, American Geophysical Union.

Red River Fault Study, Yunnan Province, China

Contract No. 14-08-0001-19271

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(213-356-6904)

Investigations

This study is being carried out under the Protocol between the State Seismological Bureau of the People's Republic of China and the National Science Foundation and the U. S. Geological Survey for scientific and technical cooperation in earthquake studies. The principal Chinese investigators on this project are Zhang Buchun of the State Seismological Bureau and Han Yuan and Zhu Chengnan of the Seismological Bureau of Yunnan Province. Reported herein is progress between 1 October 1981 and 31 March 1982, the final period of the contract.

Results

During the reporting period, a 90-page manuscript resulting from our joint field work along the Red River fault in 1981 was completed and submitted to our Chinese co-authors for their modification and approval. Figure 1 shows the area in which field work took place, primarily in the segment between Xiaguan and Atu.

Field studies confirm that the Red River fault of southernmost China is a major regional seismotectonic feature. Although history records no large earthquakes resulting from slippage along the principal 500-km-long trace of the fault, youthful landforms and disruptions of young sedimentary rocks indicate that it has generated large earthquakes during the Pleistocene and Holocene epochs. Thus it is a prime candidate for producing such events in the future, although probably much more infrequently than many other worldwide active fault systems.

The Red River fault trends northwestward from Viet Nam into Yunnan Province, China, controlling the course of the Red River (Fig. 1). It is the northeasternmost of several large right-lateral faults on the east flank of the Himalayan syntaxial bend. For 500 km northwest from the Viet Nam border to Xiaguan, slippage along the fault has been primarily right-lateral. Offsets of drainages are abundant along this segment, as are other geomorphic indicators of youthful faulting. Offsets range in size from 4 m to 5-1/2 km and record activity throughout much if not all of the Quaternary period, including the Holocene epoch.

In its central 170 km the fault comprises two active branches--the range-front and mid-valley branches. The former demarcates the northeast base of the Ailaoshan Range and, at least locally, has an appreciable component of vertical slip. The mid-valley branch traverses principally a deeply dissected Cenozoic valley fill northeast of the range-front fault and has undergone almost pure lateral slip. Offsets along the range-front branch diminish toward the southeast, whereas those along the nearby mid-valley branch diminish northwestward. The net effect is that the total offset across both branches is uniform.

The Red River and its major tributaries appear to have experienced about 5-1/2 km of right slip since the beginning of a major episode of incision that continues to the present day. Using a maximum credible rate of incision, we estimate a maximum average fault slip rate of about 7 mm/yr. At this long-term rate of slip, the smallest offsets observed along the fault (4 to 9 m) would occur no more frequently than every 500 to 1,200 years on the average. This is consistent with the historical record of fault dormancy for at least the past 300 years.

North of the Red River fault is a very large seismic region laced by numerous faults of north and northwesterly trends, between Xiaguan and Lijiang (Fig. 1). Several of these faults display clear evidence of youthful normal faulting, and several appear to have left-slip components as well. These faults, as well as the Red River fault itself, are accomodating east-west crustal extension and north-south shortening.

Manuscript completed

Allen, C. R., Gillespie, A. R., Han Yuan, Sieh, K. E., Zhang Buchun, and Zhu Chengnan, Quaternary activity of the Red River fault, Yunnan Province, China: 48 p., 42 figs., 1 pl.

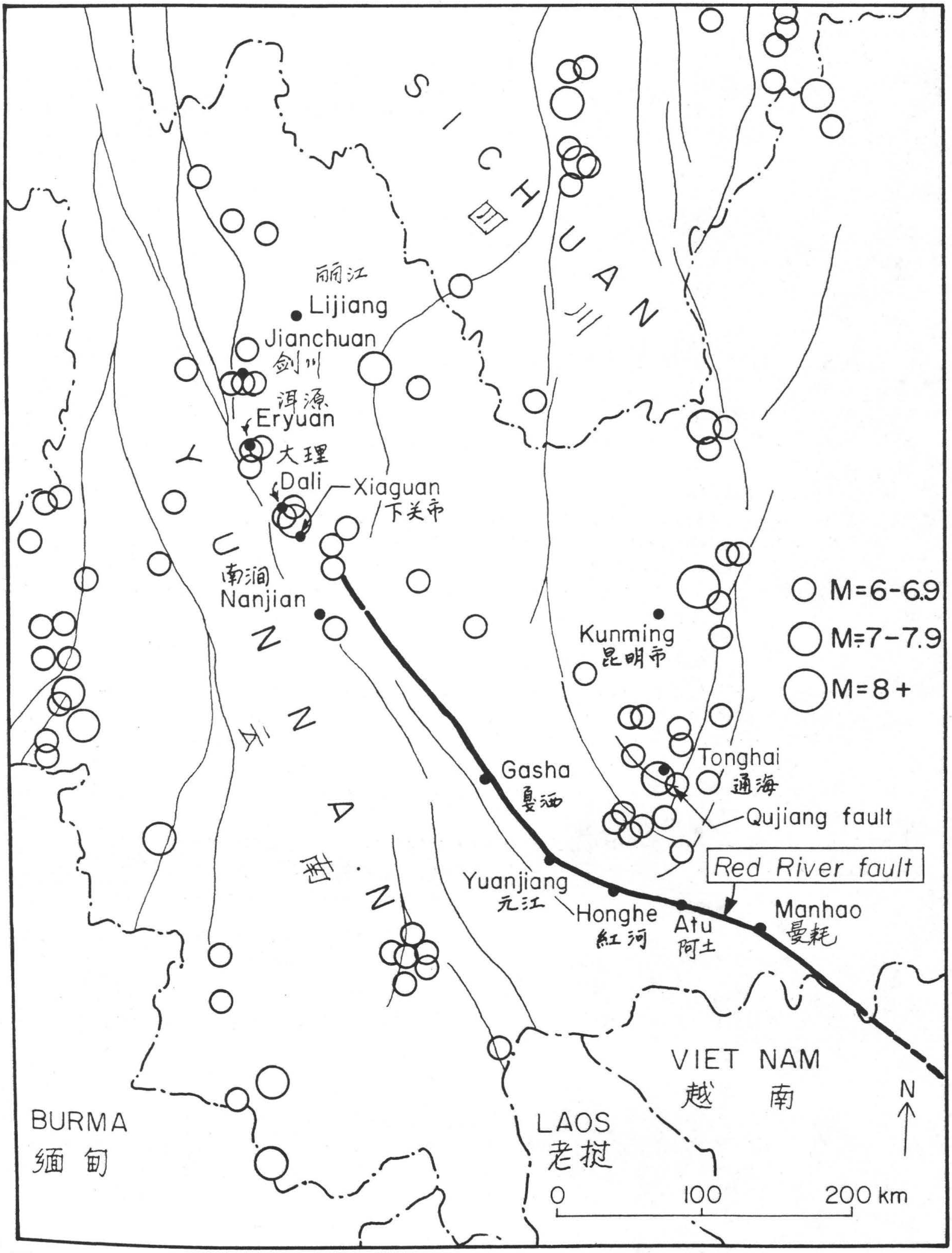

Fig. 1.--Index map of parts of Yunnan and Sichuan Provinces, China, showing Red River fault and epicenters of major reported earthquakes from 780 to 1976. Thin lines represent other mapped faults.

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 November 1980 to October 1981 from geothermal wells in Iceland. Discrete radon samples are being collected weekly from nine stations in the Southern Iceland Seismic Zone (SISZ) and two stations in the Northern Iceland-Tjörnes Fracture Zone (TFZ) to determine the potential for earthquake prediction. We also monitor volume ratio of gas to water, wellhead temperature and chloride content of the water to enable us to constrain the possible mechanism involved in radon anomalies. One continuous radon meter installed by LDGO in 1980 is operated in the Southern Iceland Seismic Zone.

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.

A drastic increase in radon concentration in fumarole gas was observed at the presently active Krafla caldera volcano throughout 1981 reaching values about four times the average level of the period 1978-1980.

Reports

Einarsson, P., Bjornsson, S., Foulger, G.R., Stefansson, R. and Skaftadottir, Th. (1981). Seismicity pattern in the South-Iceland Seismic Zone. In: Earthquake Prediction - An International Review, Maurice Ewing Series 4, 141-151. Amer. Geophys. Union

Hauksson, E., Goddard, J.G. (1981). Radon earthquake precursor studies in Iceland, J. Geophys. Res., 86, 7037-7054.

Hauksson, E. (1981). Radon content of groundwater as an earthquake precursor: Evaluation of worldwide data and physical basis. J. Geophys. Res. 86, 9397-9410.

Hauksson, E. (1981). Episodic rifting and volcanism at Krafla in North Iceland: Radon (222) emission from fumaroles near Leirhnjúkur. J. Geophys. Res. 86, 11806-11814.

Crustal Deformation Measurements near Yakataga, Gulf of Alaska and the Shumagin Islands, Alaska Peninsula

14-08-0001-19745

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Investigations

1. Sea level provides an approximate datum against which relative vertical motions above the Benioff zone in the Shumagin Islands and the coastline in Yakataga may be monitored. The stability of the sea surface as a function of time determines the threshold of detectability of vertical tectonic movements. Five sea level monitors were installed in the coastal regions of the two seismic gaps investigated. The instruments have a vertical resolution of 1 mm and a range of more than 5 m. Sea level from a pressure transducer installed on a rocky foreshore near the low tide level is integrated for 12 minutes and transmitted via the GOES satellite every 3 hours together with atmospheric pressure and sea water temperature.
2. Nine short levelling lines in the Shumagin Islands and one in Yakataga were remeasured in 1981 in a continued search for tilt indicative of seismic imminence.
3. Five 17 m long water-filled carbon fiber strainmeters were operated at three locations in the Yakataga seismic gap in order to record short term precursors should they occur.

Results

1. Figure 1 shows data received from the Shumagin array of three gauges in a line normal to the trench axis corrected only for the direct effect of atmospheric pressure on the sea water sensor. Figure 2 shows smoothed differences between the three gauges during the same period of time. A power spectrum of sea tilt derived from any two of the gauges (40 km apart) indicates that on time scales up to several months the sea is flat to better than a microradian at all frequencies other than harmonics of the oceanic tides (Figure 3). Empirical correction for wind stress and pressure gradient may reduce the noise levels further.
2. Sea level at Pirate Cove (Popof Island) and at Simeonof Harbour shows little evidence of change (± 5 cm) in a comparison of 1976 and 1981 data (Figure 4).
3. Levelling data during the same period (Figure 5) indicate that a tilt rate (down) to the southeast of 0.9 microradians/year appears to have reversed in 1978 and changed to a rate of 2.2 microradians/year to the northwest. The equivalence of the 1976 and 1981 sea level datums is consistent with the levelling data.
4. An attempt to model the observed deformation as slow slip on the Benioff zone below the Shumagins requires a 100 km portion of the seismic zone to have slipped 20 cm aseismically. This represents

less than 5% of the available inferred slip budget for a future Shumagin earthquake. Other explanations for the data are possible.

5. Strainmeters in the Yakataga gap are characterized by a 10^{-5} annual signal of presumed thermal origin. Periods of low noise are interrupted by the passage of storm fronts from East to West across the seismic gap. During intense storm conditions the strain data are unuseable (5% of year). At other times strain rates are of the order of 10^{-7}/week. The secular strain rate is of the order of 10^{-6}/year.
6. The load strain tide varies in amplitude from 10^{-7} to 10^{-6} strain according to proximity to the coastline. The coastal tide and the strain tide have been examined to test the possibility of monitoring the temporal stability of elastic parameters in the region. The instruments are very sensitive to near-surface conditions and it appears unlikely that useful data can be obtained.
7. A vibratory pile driver was tested in the Yakataga region. The device enables us to implant bench marks or strainmeter/tiltmeter end mounts in unconsolidated materials without drilling machinery. The device uses a 4 HP engine and weighs about 50 kg. The rate of penetration of 1 1/2" O.D. water pipe in sand and gravel varied from 30 mm/s to 1 mm/s. The depth of penetration in our preliminary tests was limited by bedrock at 4 m.

Reports

Beavan, J., Bilham, R., and Hurst, K., Installation of sea-level monitors to detect vertical motion and tilt in Alaskan seismic gaps, EOS, Trans. Am. Geophys. Un., vol. 62, p. 1053.

Beavan, J., The Shumagin Islands levelling network, Internal Report, Lamont-Doherty Geological Observatory, March 1982.

Bilham, R., and Beavan, J., 1980, Strain measurements in the Yakataga seismic gap, EOS, Trans. Am. Geophys. Un., vol. 61, p. 1030.

Bilham, R., 1981, Delays in the onset times of near-surface strain and tilt precursors to earthquakes, Earthquake Prediction - An International Review, Maurice Ewing Series, vol. 4, edited by D. W. Simpson and P. G. Richards, AGU, Washington, D.C.

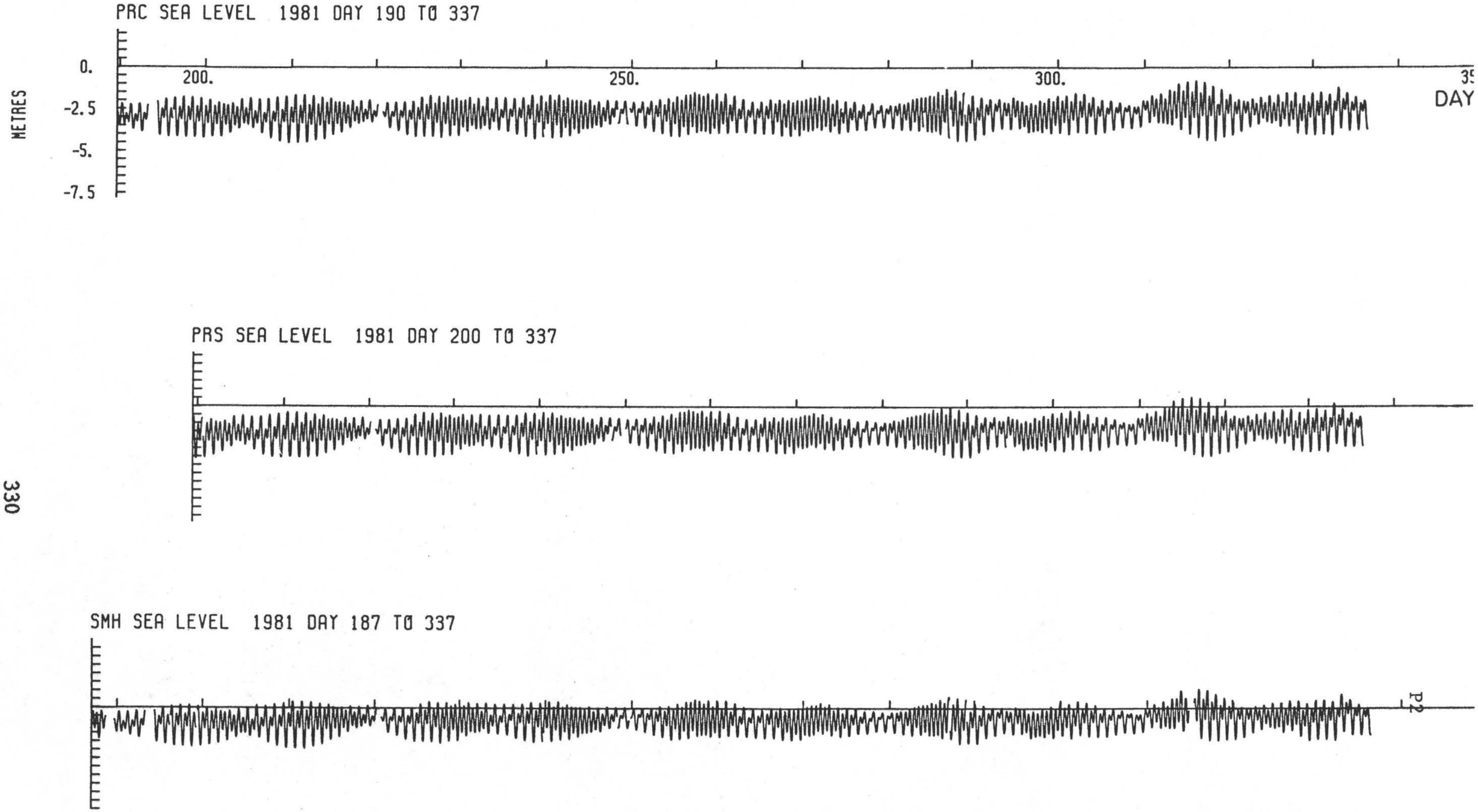

Figure 1: Sea level recorded in the Shumagin Islands by the Lamont gauges between July and December 1981. Time is in days from the beginning of 1981. PRC = Pirate Cove, Popof Island; PRS = Pirate Shake, Nagai; SMH = Simeonof Harbour.

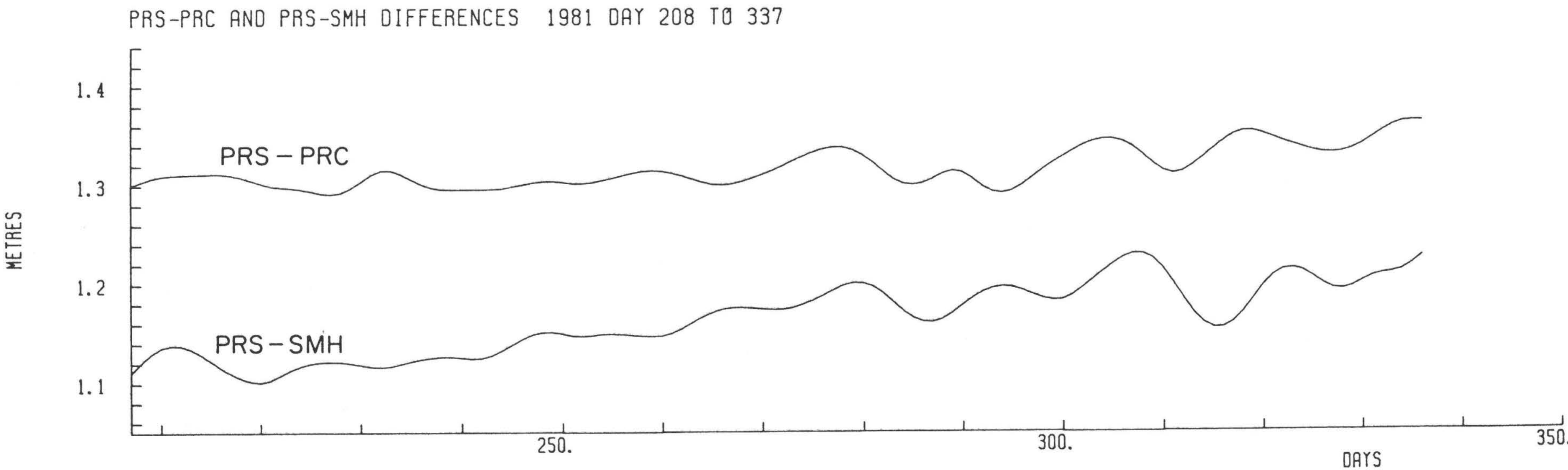

Figure 2: Low-pass filtered differences between adjacent gauges during August-November 1981. The gauges agree to within 10 cm at all periods.

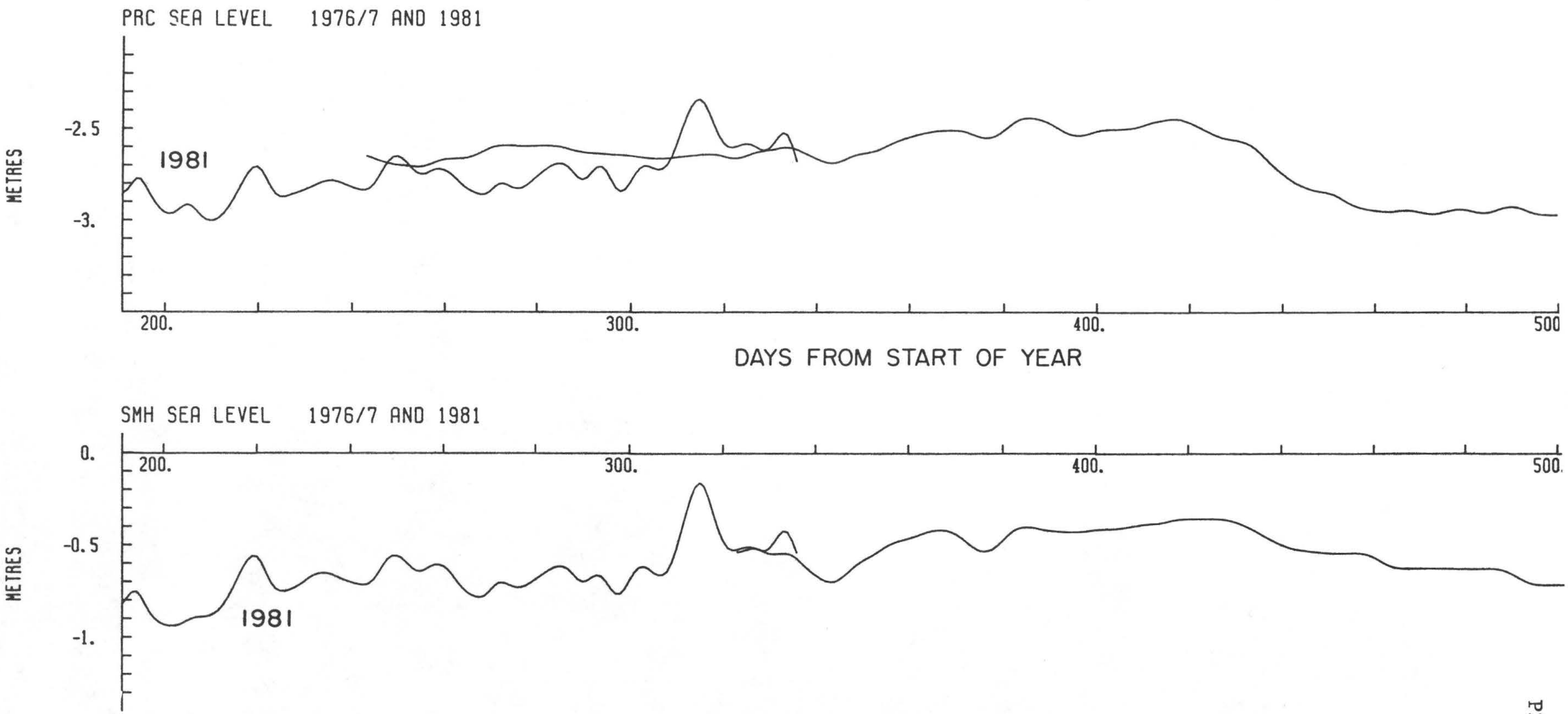

Figure 3: Comparison of sea level at Pirate Cove (PRC) and Simeonof (SMH) measured in 1976/77 and 1981. The 1976 and 1981 instruments were tied to the same bedrock benchmarks. The 1981 data have been low pass filtered with a 10 day cutoff. The 1976 data are smoother because they were recorded by an instrument incorporating severe hydraulic filtering. The data are plotted against days since the start of the year in order to reduce the effects of the 20 cm annual term which is visible in the data. Evidently, no gross changes of land level have occured since 1976.

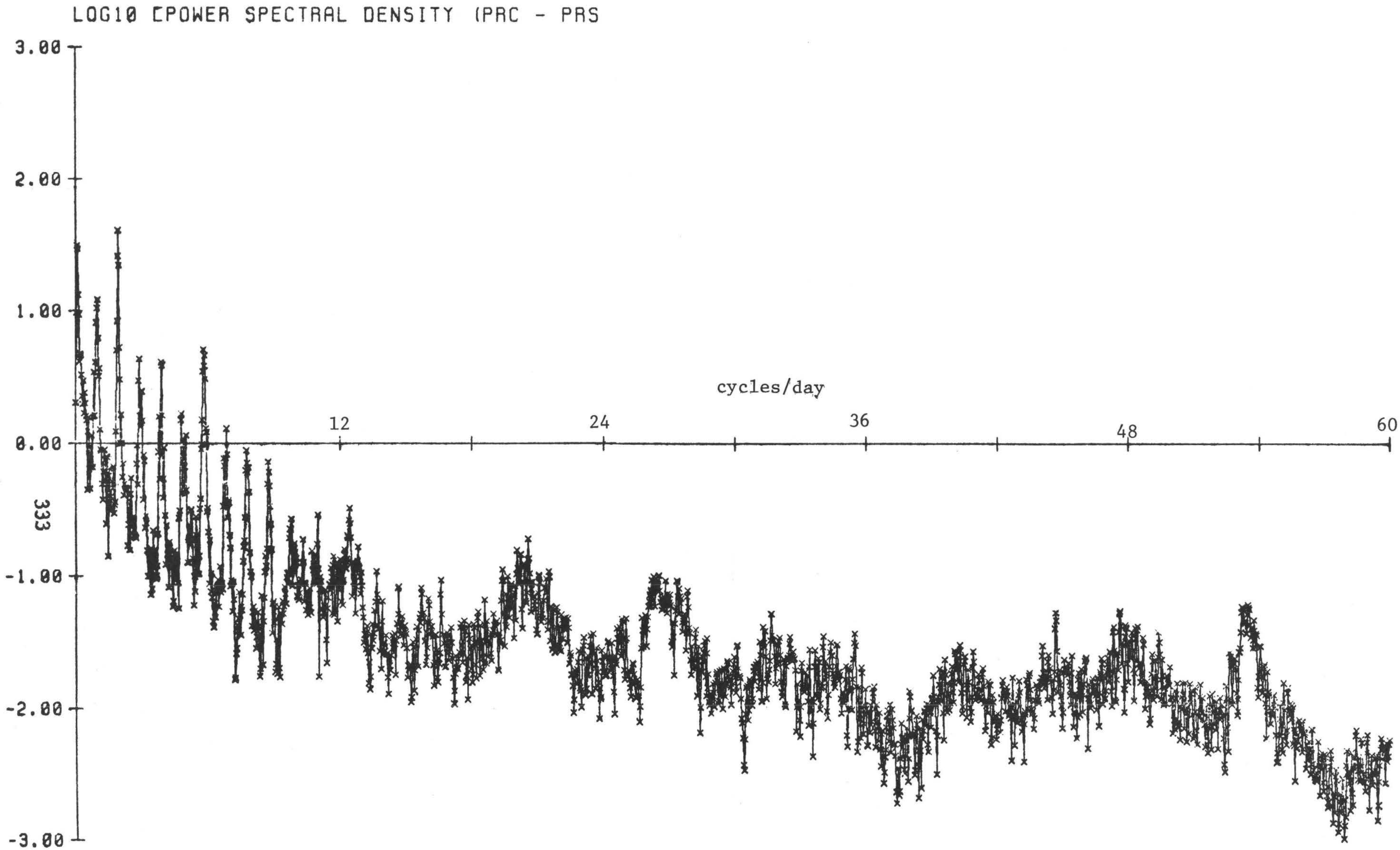

Figure 4: Power spectrum of sea surface slope between PRC and PRS (40 km NW separation). The zero axis corresponds to an RMS slope of one microradian. Spectral peaks at subharmonics of one cycle per day result from non-linear interactions between oceanic tides and the shallow sea floor around the Shumagin Islands. RMS sea slope noise at periods shorter than two hours is of the order 3×10^{-7} except for seiches near each tide gauge.

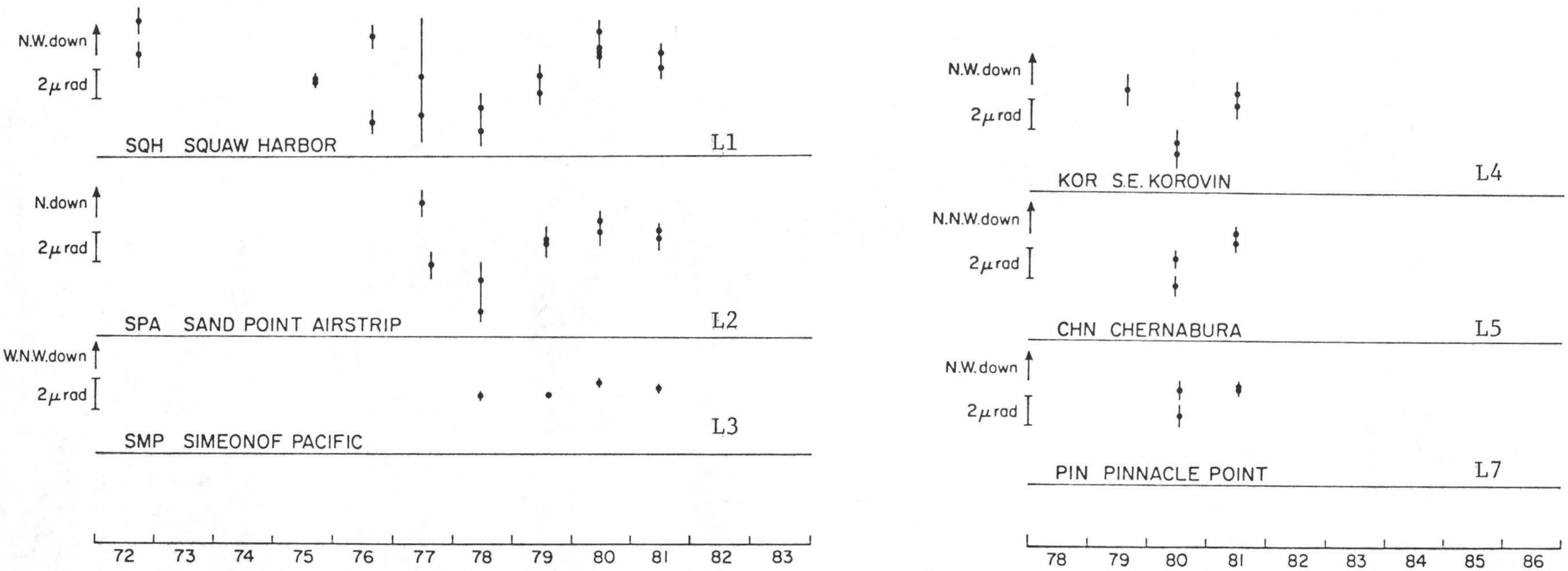

Figure 5: Data from those level lines in the Shumagins that have been levelled at least twice. The two dots each year represent forward and backward runs of levelling. The error bars are $\pm$ 1 standard deviation based on variations in multiple readings of each station rod from each tripod position. Note particularly the 0.9 $\pm$ 0.3 μrad/year down towards the Aleutian trench between 1972 and 1978 on line L1 (SQH). The tilt apparently reverses (2.2 $\pm$ 1.0 μrad/year) between 1978 and 1980. The L1 data are corroborated by those from line L2 which is about 10 km away. The other, more distant, lines tell a different story, but none of these have as complete a history as L1 and L2.

TILT MEASUREMENTS IN THE NEW HEBRIDES ISLAND ARC:
SEARCH FOR ASEISMIC DEFORMATION RELATED TO EARTHQUAKE GENERATION
IN A MAJOR ZONE OF LITHOSPHERE SUBDUCTION

Report prepared by B.L. Isacks, Principal Investigator,
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14-08-0001-18350

Seven earthquakes with magnitude Ms $\geq$ 6 occurred in the Vanuatu (formerly New Hebrides) islands during the period April, 1981 through September, 1981. These events continue the arcwide episode of large, shallow earthquakes that began in 1980. In the northern part of the arc one event with a magnitude Ms=6.9 occurred in April 1981 in the Torres islands. In the southern part of the arc one event with magnitude Ms=7.0 occurred in July 1981 near Matthew Island and four other events with magnitudes Ms=6.2, 6.1, 6.6, and 6.0 occurred in July and September, 1981 near the location of the October 1980 mainshock.

In the central Vanuatu islands a large earthquake with magnitude Ms=7.0 occurred on July 15, 1981 in the center of the Cornell/ORSTOM network of seismograph and tiltmeter instrumentation. The local seismograph network was working well and recorded a complete sequence of foreshocks and aftershocks. The mainshock was an interplate, thrust-type earthquake which occurred near three previous interplate, thrust-type earthquakes on 1 September 1978 (Ms=5.9), 17 August 1979 (Ms=6.1), and 26 August 1979 (Ms=6.0). Months before the event, swarms of smaller-magnitude (M=3-5) earthquakes occurred near the perimeter of the zone which was to rupture during the mainshock. The mainshock was preceeded a few days before by a distinct cluster of small-magnitude foreshocks which occurred near the eventual epicenter of the mainshock. However, no clear precursory signals were detected by the tiltmeters. Detailed analysis of this event will be presented in the next technical report.

The space-time analysis of the seismicity of the entire Vanuatu arc using data from the PDE bulletins has continued to be updated. The July 1981 event occurred in a segment of the arc which has been more active than any other part of the arc during the past 20 years. No precursory anomaly was recognized in the rate of occurrence of earthquakes in the epicentral region of the July 1981 earthquake in the central Vanuatu islands.

Most of the local tiltmeter instrumentation was working well during the 1981 mainshock. In particular, repairs to the long-baseline, water-tube tiltmeter were completed in May 1981 and the instrument ran continuously before, during, and after the July 1981 mainshock. Aside from some growth on the probe tip of the north component of the long-baseline tiltmeter, the system has run trouble-free for almost nine months and its long-term stabilty is encouraging.

Tilt, Strain, and Magnetic Measurements

9960-02114

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Investigations

1. To investigate the mechanics of failure of crustal materials using deephole strainmeters, tiltmeters and arrays of absolute magnetometers.

2. To investigate real-time records of these and other parameters for indications of incipient failure of the earth's crust.

Results

1. Three Carnegie dilatometers have been installed since early 1981 at distances of 3 km, 17 km and 35 km from the San Andreas/San Jacinto fault intersection near Palmdale, California. At an installation depth of 200 m, the strain noise spectra are consistent with those obtained from long-baseline laser strain meters (from 0.01 to 10 c.p.d.). Thermoelastic or meteorological contamination is not evident at the 10^{-9} strain level. Comparison of data from U.S.G.S. 2-color laser strain array and the one instrument within this array indicates similar long-term rates but the dilatometer is more than an order of magnitude quieter at periods of days to months. Calculated coseismic offsets for the M 5.1 Santa Barbara Island earthquake (100 km distant) are less than 10^{-10} strain. The predicted coseismic strains were at the limit of resolution; no offsets were observed.

2. Magnetic transients have been identified in data from Japan, USSR, China and U.S.A. which appear related to:

1) Moderate to large local earthquakes
2) Episodes of crustal uplift and subsidence
3) Volcanic activity
4) Dam loading

The model dependent stress sensitivities from these observations are, on the average, 0.3 nT/bar. At the present measurement precision of 0.2 nT, field perturbations have not been observed to occur with either changes in fault creep, or earthquakes with $M_L < 4.0$. This is consistent with expectations from physical models of these events. At least an order-of-magnitude improvement in the present measurement precision appears necessary in order to capture details of moderate magnitude earthquakes. Local magnetic fields in the sub-nano tesla range are more critically dependent on local site response than any other factor. However, little knowledge of the magnetic and electrical induction characteristics in the complex geologic environments near active faults presently exists.

3. The crustal tilt rate obtained by linear regression on differential lake level measurements in San Andreas Lake near San Francisco from 1978 to 1981 is 0.7 ± 0.4 μrad/a down to the north.

4. Three prototype deep-hole differential strainmeter installations have been designed and are partly installed in the three holes containing volume strainmeters in the Mojave Desert near Palmdale. These instruments should provide independent estimates of dilatational strain at depths of 100 to 200 m. Pore pressure and temperature data will also be obtained in these holes.

5. Four portable recording magnetometers have been constructed to the original U.S.G.S. design and will be sent to China as part of the U.S.-China Exchange Program.

6. Sites which had been selected in the San Juan Bautista area for five Carnegie Dilatometers are being drilled by Dennis Styles of the Stress Measurement Project and logged by Tom Urban. The first dilatometer in this area was installed in April, 1982.

7. An analysis of differential proton magnetometer data indicated a standard deviation that varies with site preparation of $\sigma = aL+b$ where $a = 0.097 \pm 0.02$, $b = 0.003 \pm 0.001$ and L is the site separation kilometers. At separations of a few meters in seismically and culturally quiet sites, the precision approaches the theoretical instrument limitation of 0.1 nT at a 0.25 nT sensitivity and 0.05 nT sensitivity.

Reports

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Johnston, M.J.S., Linde, A., Sacks, I. and Myren, D., 1982, Borehole dilatometer strain array - Preliminary results from the Mojave Desert, Trans. A.G.U. 62, 1924.

Byerlee, J., Lockner, D. and Johnston, M.J.S., 1982, A mechanism for earthquake lights, Trans. A.G.U. 62, 1970.

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.

4. Soil-gas radon content was monitored at about 100 sites in California. This work will be discontinued shortly because of lack of funds.

Results

Pulselike water-level changes of large amplitudes (more than 1m) and short durations (several days) were recorded at two shallow water wells along the Hayward fault in Oakland, CA. Some of these changes occurred in a dry season, and cannot be attributed to rainfall or unusual pumping activities. One of such changes was accompanied by large changes in water chemistry. One possible mechanism for the observed water-level changes is elastic or inelastic deformation of the aquifers caused by fault creep events.

Report

King, C.-Y., Presser, T., Evans, W.C., and Husk, R.H., Anomalous water-level and water-chemistry changes in two Oakland, California, wells and their possible relation to earthquakes (abs.), Earthquake Notes, v. 53, no. 1, p. 58.

Water-Level Monitoring Along San Andreas and San Jacinto Faults, Southern California, During First Half of Fiscal Year 1982

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Contract No. 14-08-0001-19253

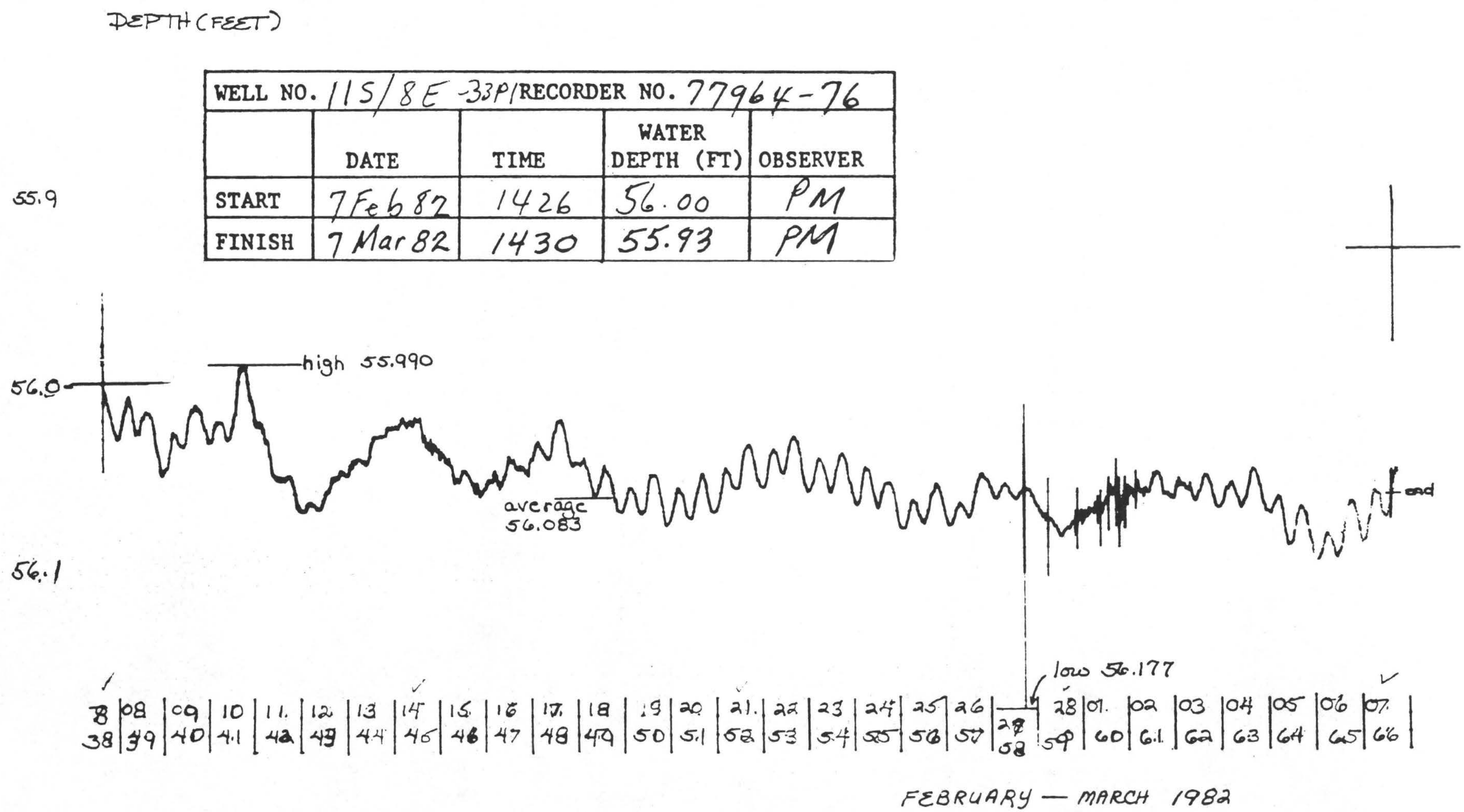
Water levels in over thirty wells along the San Andreas and San Jacinto fault zones were monitored during the current reporting period. Water levels in seven wells and barometric pressure at two wells were monitored by the Caltech Remote Observatory Support System (CROSS). Another ten wells were monitored continuously with Stevens Type F recorders, two being 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.

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. Installation of equipment to monitor water temperature and conductivity in three wells and barometric pressure in a third well is planned.

No earthquakes of M3.2 or greater occurred in the past twelve months within 13 miles (20 km) of an observation well along the Palmdale-Valyermo segment of the San Andreas fault.

A M4.5 event occurred 22 March 1982 in the Ocotillo Wells area. The epicenter was about 8 miles (13 km) southwest of well 11S/8E-33P1. The continuous records for the periods prior to, and at the time of, the event are shown in Figures 1 and 2. Sizable earthquakes commonly appear as spikes on the records; this event appears as an extremely small tick mark (ca. 0100 hours). The short-term water-level fluctuations correlate with barometric changes except that, from 27 February to 3 March 1982, anomalous spikes and high-frequency fluctuations appear on the record. Nothing like this has appeared on records for this well during the past two years of continuous recording. One other well (11S/6E-1C1) in Borrego Springs showed similar high-frequency fluctuations during the spring and summer of 1980. This activity was not followed by a significant earthquake. Our best explanation for this type of water-level fluctuation is that it is due to gas bubbling up the well. Such behavior may or may not precede earthquakes.

Eight other earthquakes of M3.3 to 3.9 occurred within 13 miles (20 km) of one or more of the six observation wells with continuous recorders along the San Jacinto fault zone. Neither the long-term hydrographs nor continuous records show any variations which are interpreted as precursors to these earthquakes.



WELL NO. 11S/8E-33P1	RECORDER NO. 77964-76			
	DATE	TIME	WATER DEPTH (FT)	OBSERVER
START	7 Feb 82	1426	56.00	PM
FINISH	7 Mar 82	1430	55.93	PM

Fig. 1 - Stevens water-level record for days 38-66 (7 Feb. - 7 March 1982) well 11S/8E-33P1, Ocotillo Wells.

DEPTH (FEET)

WELL NO. 11S/8E-33P1 RECORDER NO. 77984-76

	DATE	TIME	WATER DEPTH(FT)	OBSERVER
START	7 Mar 82	1430	55.93	PM
FINISH	7 Apr 82	1220	55.98	WC

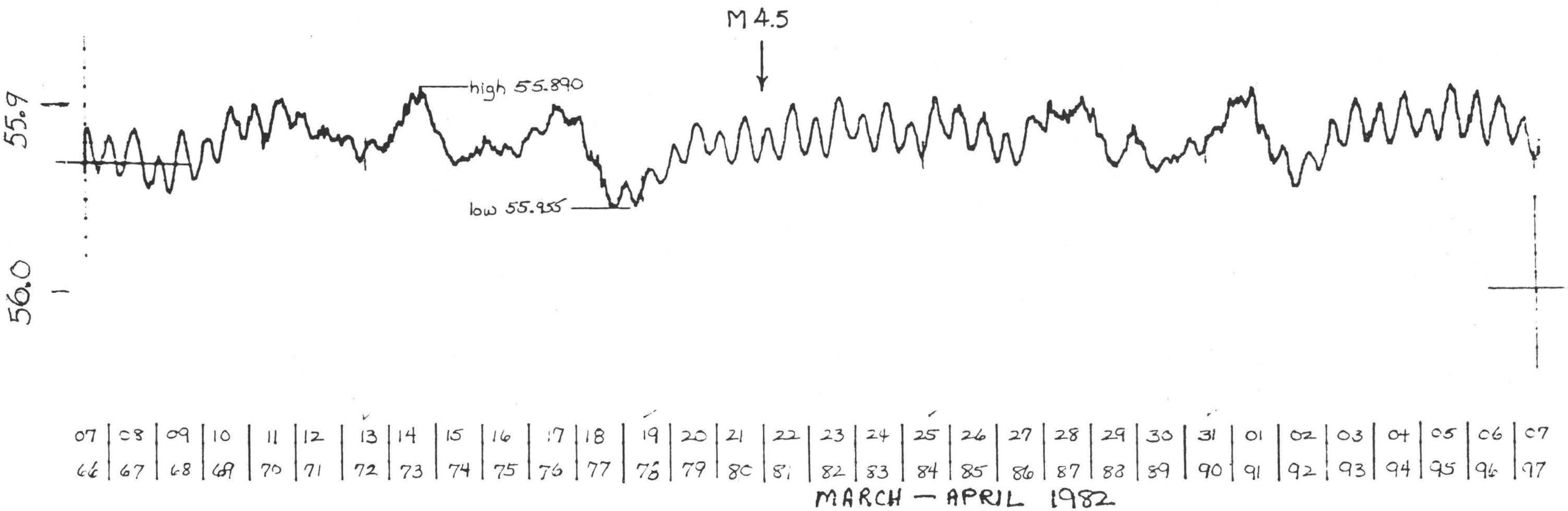


Fig. 2 - Stevens water-level record for days 66-97 (7 March - 7 April 1982) for well 11S/8E-33P1, Ocotillo Wells.

Air-gun Seismic Velocity Measurements in the San Andreas Fault Zone

9960-02413

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Investigations

1. Traveltime variations of a 19.2 Hz surface wave over a 600 m baseline have been determined over several 12-hour periods in fractured granitic rocks at Libby Ranch 2 km west of the San Andreas Fault near Hollister, CA, in order to measure the seismic velocity stress sensitivity, V^{-1} $(\partial V/\partial \sigma)$, under the solid-earth tidal stress loading. The generation, detection, and recording of the seismic waves, and the method of data reduction have been described previously (Liu, 1982). The 12-hour measuring period is chosen between 6 p.m. and 6 a.m. local time so as to avoid the daytime cultural noises which reduce significantly the seismic signal-to-noise ratio. The seismic velocity dependence on tidal stress and other extraneous factors can be established after the data from a sufficient number of 12-hour period runs have been obtained and analyzed.

2. Laboratory measurement of rock internal friction. For a detailed discussion of the results of this investigation, refer to Internal Friction in Rocks, 9960-01490.

Results

There is an apparent correlation between the traveltime and solid-earth tide strain variations for data gathered in the dry season of 1981 (Figure 1). No such correlation was detected for data collected in the wet season of 1982 (Figure 2) which suggests that the water table position and/or the moisture content in the unsaturated zone between the ground surface and the water table influence the stress dependence of surface wave traveltime. The field traveltime measurements will be continued into the dry season of 1982 in order to see if the apparent correlation between the traveltime and solid-earth tidal strain variations is reproduced.

Reference

Liu, H.-P.,1982, Air-gun seismic velocity and attenuation measurements in the San Andreas fault zone, in Summaries of Technical Reports, Vol. XIII, U.S.G.S. open-file report 82-65, p. 341.

Report

Liu, H.-P., and Peselnick, L., Investigations of internal friction in fused quartz, steel, lucite and westerly granite from 0.01 to 1.0 Hz at 10^{-8} to 10^{-7} strain amplitude, submitted to J. Geophys. Res.

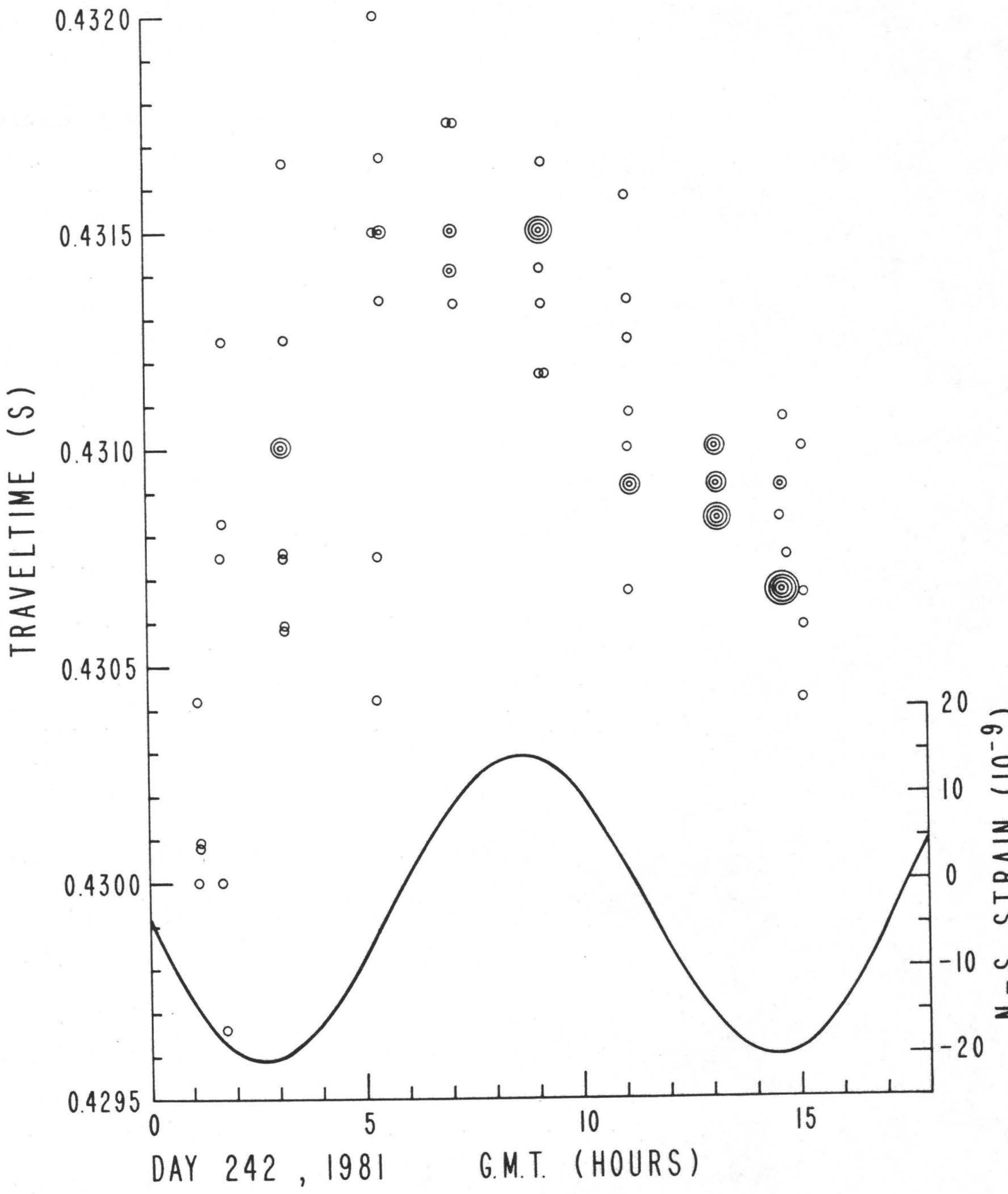

Figure 1. Surface wave traveltime data (circles) and theoretical N-S strain component (solid line). Each circle represents a single measurement. Concentric circles indicate several measurements with the same traveltime value.

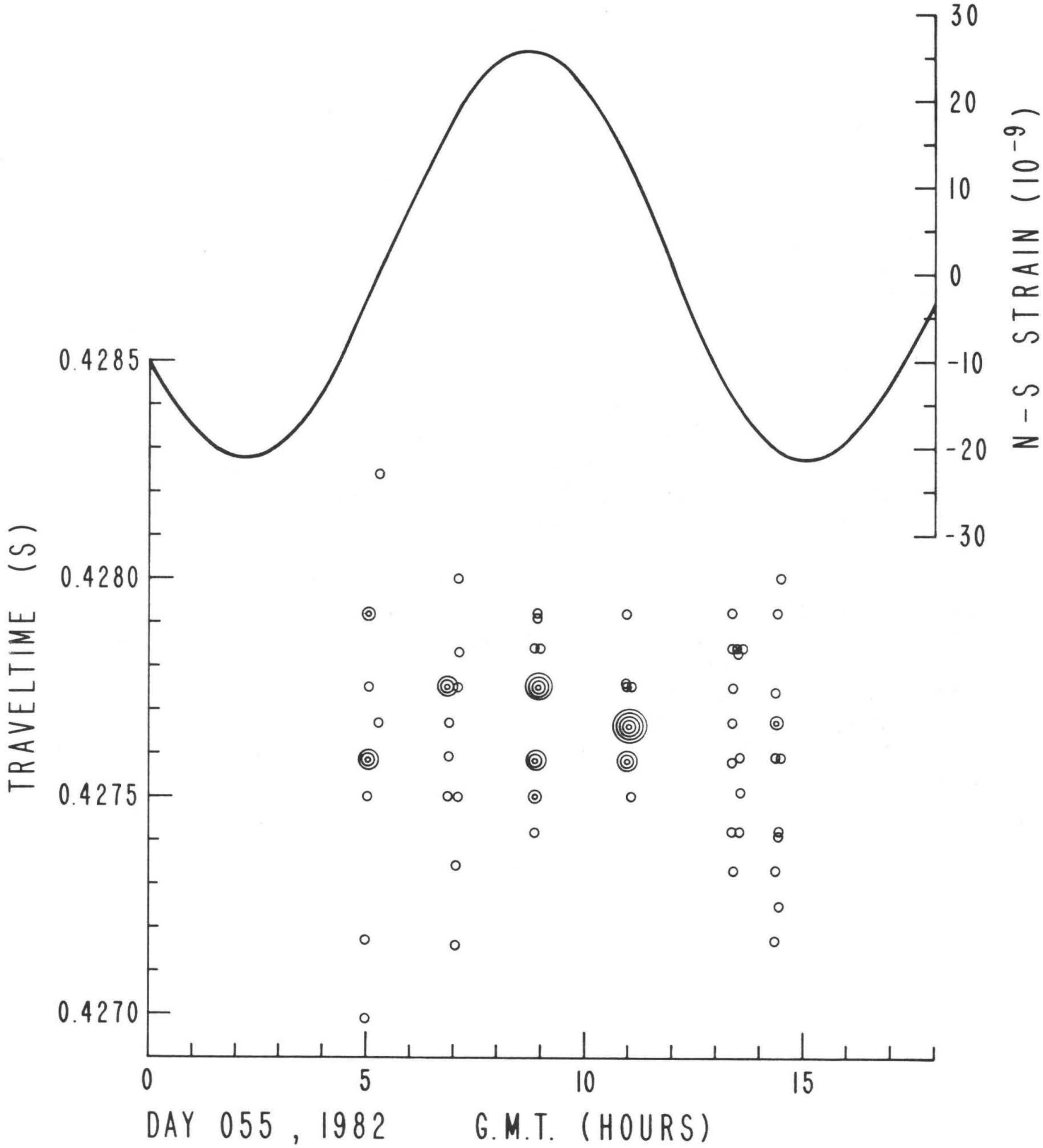

Figure 2. Surface wave traveltime data (circles) and theoretical N-S strain component (solid line).

High Sensitivity Monitoring of Resistivity and Self Potential Variations in the Palmdale and Hollister Areas for Earthquake Prediction Studies

Contract No. 14-08-001-19249

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Based on a detailed analysis of the information content of telluric arrays (LaTorraca, 1981), we are restructuring our data analysis and are presently reanalyzing our entire data collection. The outcome of this analysis will be telluric tensor eigenstates from various segments of the array which can be compared to the eigenstates of various resistivity models of the region. A sensitivity analysis of the models will allow us to relate observed changes in the tensors to resistivity variations. Figures 2 and 3 show results of a preliminary step in the data analysis in which individual dipoles are related to two other dipoles used as the reference pair. Some noise editing has been used in this step. The earlier indication that drifts of the order of a few tenths of a percent per year were occurring in Hollister is reaffirmed. A drift is also seen on one tensor component of dipole B in Palmdale. The significance of these changes are not known at present.

The array recording arrangement has also been reorganized. Tensor cancellations are no longer being recorded, but rather individual dipoles. This involves some loss of sensitivity, but the original arrangement was designed for analog recording, and digital recording recovers much of this sensitivity. The advantages are twofold: firstly the effect of a telephone line outage is now confined to a small subset of the recorded channels, and secondly the calibration procedures are greatly simplified and the calibrations will be more stable.

References

LaTorraca, G.A., 1981. Differential tellurics with applications to mineral exploration and crustal resistivity monitoring. Ph.D. thesis, M.I.T., Department of Earth and Planetary Sciences.


W
D
B
ST
E
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C
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A
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P
Hollister Telluric Array
20 STATUTE MILES
0 5 10 15 20 25 30 KILOMETERS
CONTOUR INTERVAL 200 FEET
DOTTED LINES REPRESENT 100 FOOT CONTOURS
DATUM IS MEAN SEA LEVEL
DEPTH CURVES IN FEET—DATUM IS MEAN LOWER LOW WATER
SALINAS
Bakersfield
KERN COUNTY
Mojave
Barstow
Lancaster
Palmdale
Victorville
LOS ANGELES COUNTY
VENTURA COUNTY
Santa Barbara
Oxnard
Ventura
Fp
Po
Go
A
Lc
B
Pd
C
Cs
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Pb
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Su
F
Az
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0 10 20 30 40 50 km
Palmdale Telluric Array

Fig 1

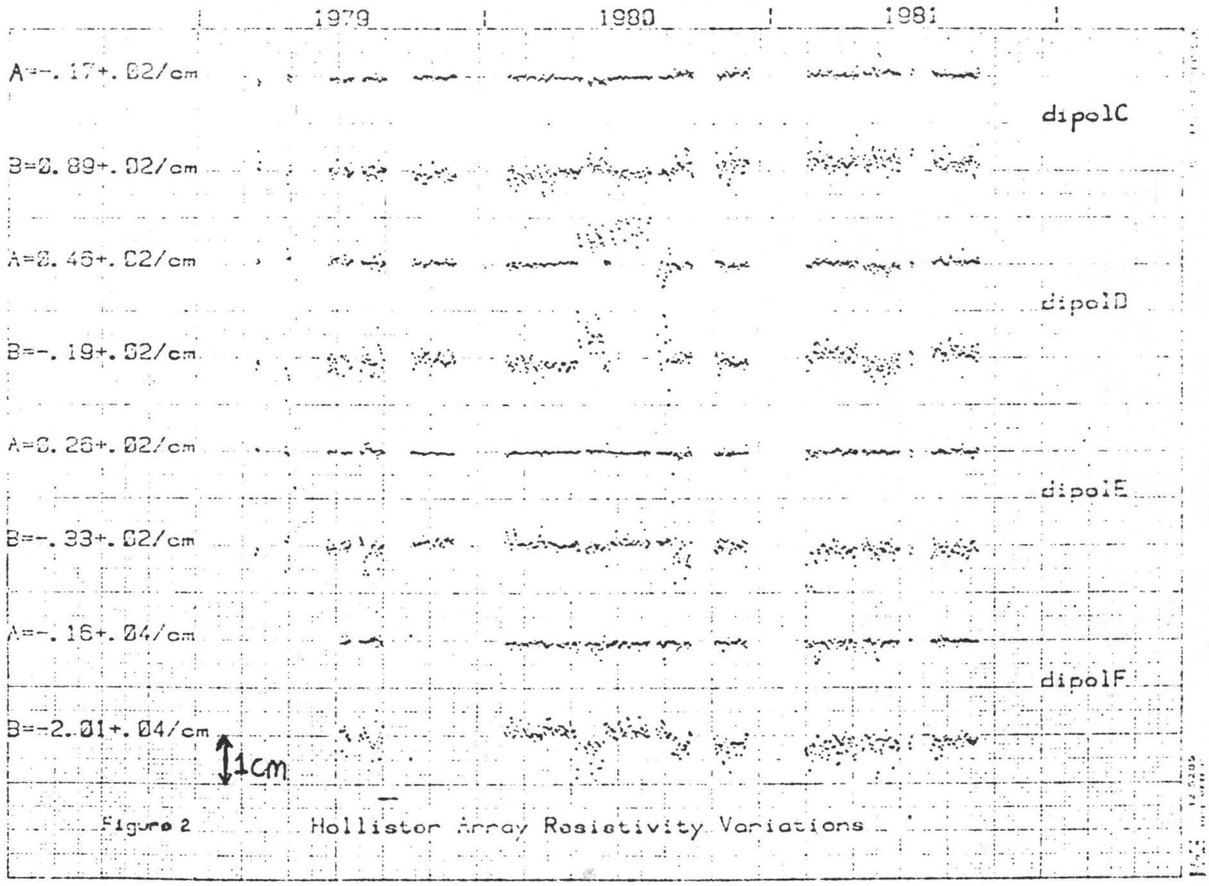

Figure 2 Hollister Array Resistivity Variations

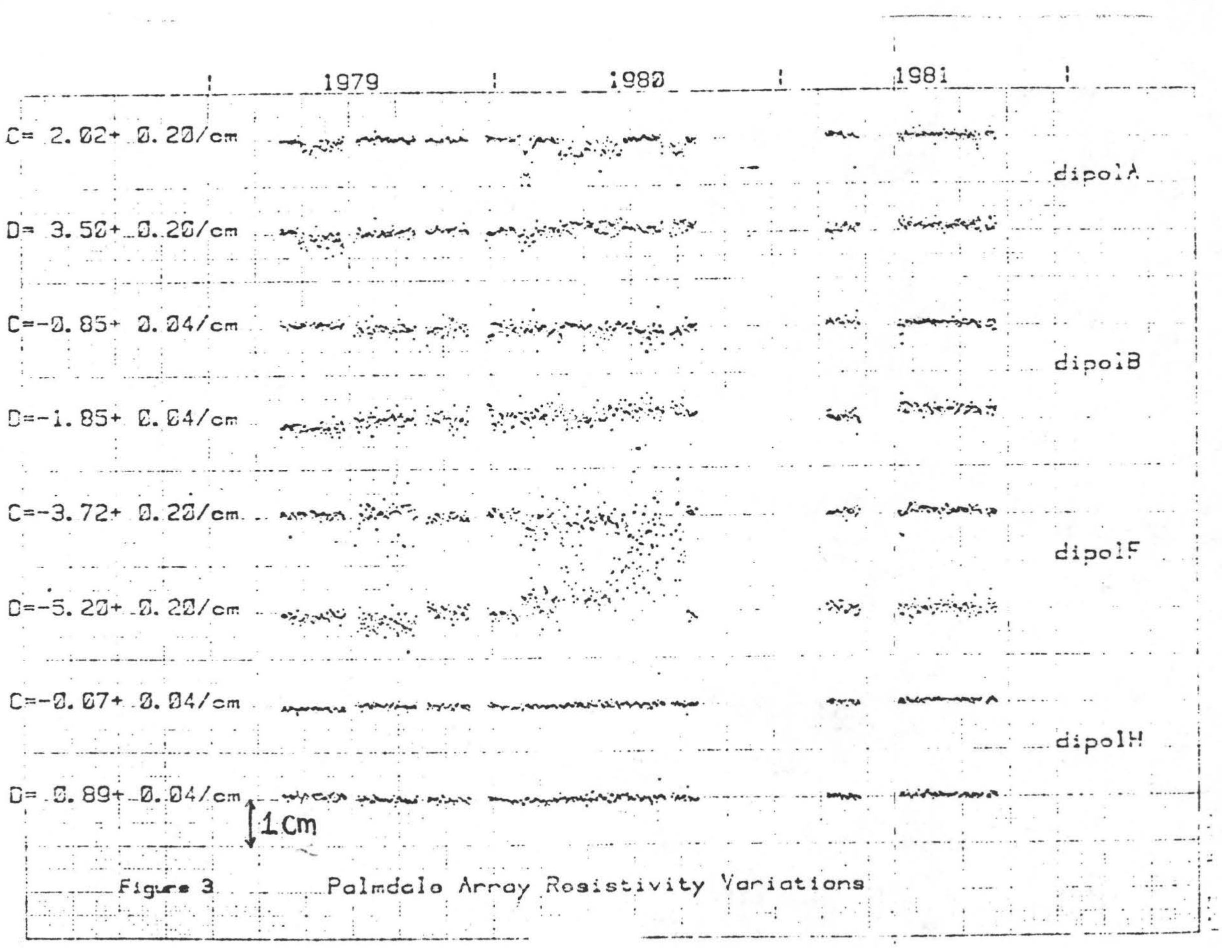

Figure 3 Palmdale Array Resistivity Variations

A SEARCH FOR PRECURSORY SEISMIC VELOCITY ANOMALIES NEAR PALMDALE, CALIFORNIA OVER FIXED BASELINES

#14-08-0001-19262

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SUMMARY

Seismic refraction profiles across and along the San Andreas fault zone near Palmdale, California, were used to establish propagation paths for several phases whose travel times are being monitored for earthquake precursors. The profiles were generated using an airgun submerged in Bouquet Reservoir, together with surface and borehole geophone receivers. Source signal stacking, coupled with the noise reduction provided by the downhole receivers, provided data of sufficient quality to measure the ray parameters of the phases. Using the ray parameters and surface travel-time curves, velocity structures parallel and transverse to the fault zone have been constructed. Two of the observed phases are confined to the upper portions of the crustal structure, which was found to differ across the fault. A third phase is consistent with a reflection from a depth of approximately 10 km. Two later arrivals are suggestive of reflections from depths of 21 and 27 km.

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.

3. Continued studies on the effects of rainfall and ground water on creep observations.

Results

1. Currently 39 extension creepmeters operate; 25 of the 39 have on-site strip chart recorders; and 19 of the 25 are telemetered to Menlo Park.

2. Fault creep data from all 39 U.S.G.S. creepmeter sites on the San Andreas, Hayward, and Calaveras faults have been updated (through March, 1982) and stored in digital form (1 sample/day). A report of all data from recently operating creepmeters was accepted for publication.

3. Slip records produced at creepmeter sites along the San Andreas Fault in central California include many examples of response to rainfall. Records from four U.S. Geological Survey creepmeters were analyzed in an effort to separate creep signals from those of seismicity and of rainfall. Onset times of episodic movements called creep events were compared with origin times of local earthquakes and with onset times of rainfall. Seismicity apparently affected long-term creep rates, but did not have a consistent immediate influence on creep events. Rainfall appeared to affect long-term creep rate somewhat, and its immediate influence on creep events was ambiguous. Rainfall was then compared statistically on an annual basis to total creep, number of creep events, number of local magnitude 2+ earthquakes, and total amount of episodic movement. With the equation used, no significant numerical correlation could be shown to exist between rainfall and any of the variables. Although no statistical correlation could be demonstrated, records from the four instruments did show varying responses to rainfall. It is also suggested that the dry part of the rainfall cycle introduces a delay into the onset of creep events.

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. (in press).

Mavko, G., Evidence of coherent fault slip in central California (abstract), EOS, 62, 1052, 1981.

Schulz, S.S., R.O. Burford, and B. Mavko, Influence of rainfall on creepmeter records (abstract), EOS, 62, 1052, 1981.

In-Situ Seismic Wave Velocity Monitoring

14-08-0001-19251

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Investigations

We have continued to monitor 1) first arrival travel times on nine paths crossing or adjacent to the San Andreas fault in central California, and 2) down-hole travel times in boreholes at all but one of the sites, to account for near-surface seasonal variations. The measurements are made with a VIBROSEIS (TM) system. Measurements from October through March were made at erratic intervals, first as a response to funding uncertainties and later due to greater than normal winter rainfall. After the winter rains end in mid-April, measurements will be made on all paths at 1-2 week intervals.

Results

The two figures show first arrival travel-time data corrected for near-surface variations. The stabilization after mid-1981, especially evident in Figure 1, is due to elimination of system instabilities. The 1-2 msec oscillations prior to this time are probably spurious. The west (W) receiver site in the Stone Canyon array is the one remaining site with no borehole geophone installation. Thus the increase in travel time in the past winter on the top three traces in Figure 2 is undoubtedly due to the near-surface seasonal changes under this site. Overall, the removal of seasonal variations, which can amount to 6-8 msec, appears to be effective. We estimate at this point that a change of 1 msec is clearly significant.

Regular monitoring of deep crustal reflections in the Bear Valley region, with the aid of a new amplifier/filter package with much improved noise rejection capability, was begun in April, 1982.

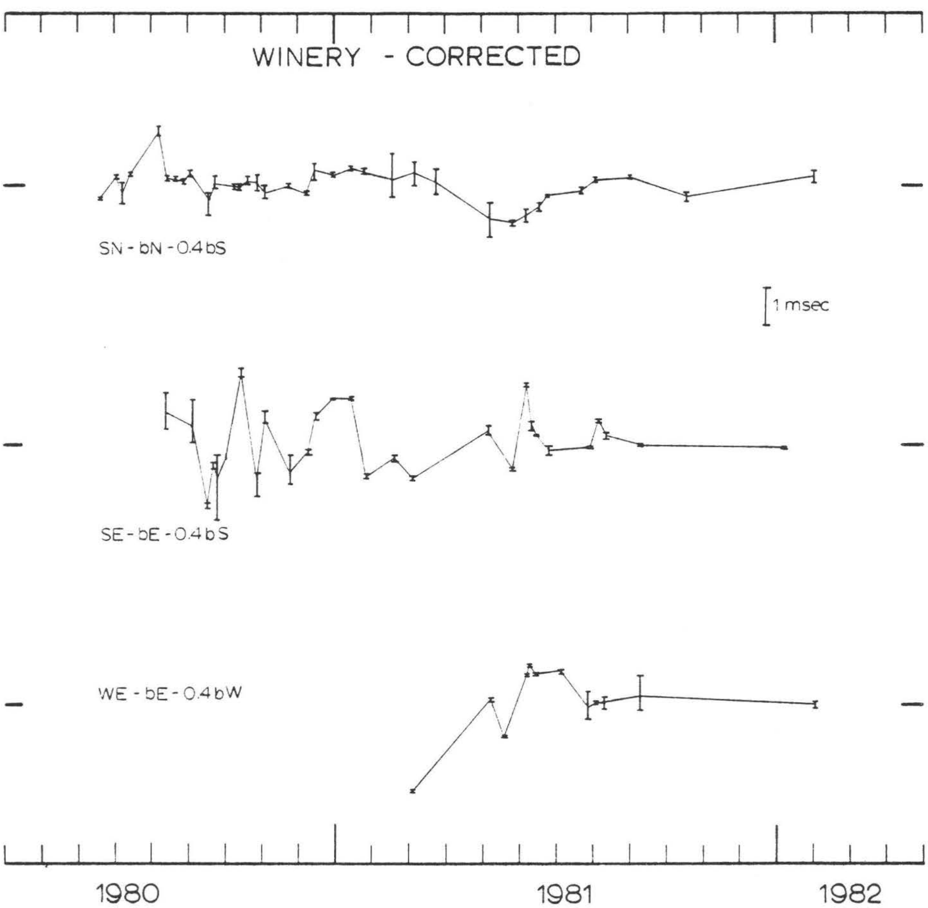

Figure 1. First arrival travel times for the three paths of the Winery array, corrected for near-surface changes. Brackets indicate scatter in several repeated measurements.

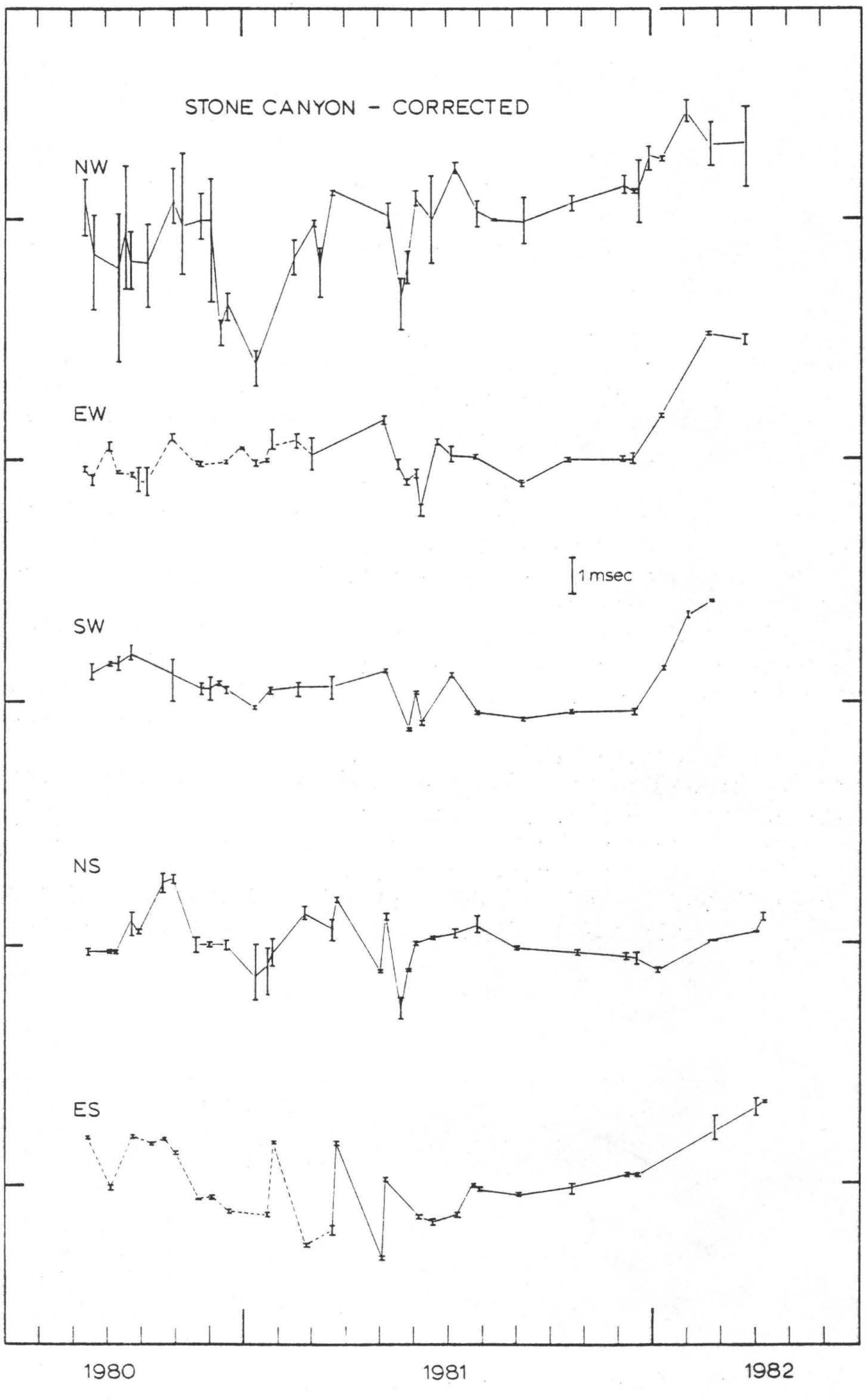

Figure 2. First arrival travel times for paths in the Stone Canyon array. The top three data sets are corrected only for near-surface changes at the vibrator sites. Dashed lines show when there was no borehole measurement at the east (E) vibrator site.

Experimental Tilt and Strain Instrumentation

9960-01801

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Investigations

1. Project investigators dismantled all but 12 of the shallow-borehole tiltmeter stations in central California and all but 4 in southern California. The total number of operating tiltmeters prior to this reduction was 56. The sites that were retained were those that have demonstrated the best stability and reliability. This reduction in the size of the tiltmeter networks represents a revision of experimental strategy coming from the results of a number of experiments and tests, including a cluster of tiltmeters near Parkfield, California, that established the capabilities and limitations of short-baseline instruments installed in shallow boreholes. Those results are currently being written up.

2. Coincident with the reduction in size of the tiltmeter networks, the Stanwick maintenance contract for low-frequency instrumentation was terminated and maintenance responsibilities were returned to the projects. Project personnel have been conducting maintenance visits and dealing with the many problems caused by the catastrophic winter rains.

3. In addition to the maintenance of tiltmeter and strainmeter sites, project personnel have undertaken redesign of the satellite interface system and the lake-level monitor system. Design and development of a deep-borehole tiltmeter and vertical wire strainmeter are also underway. Project personnel have participated in the installation, operation and maintenance of the Carnegie volumetric strainmeters. For details of the deep-borehole instrumentation projects the reader is referred to the report for Malcolm Johnston's project.

4. Project investigators took an active part in the initial activities of the Prediction Working Group by preparing data plots and coordinating the collection and posting of data for review.

Results

On 15 January 1981, at 1247 UTC, an earthquake (M_L = 4.6) occurred with epicenter in Halls Valley south of the Calaveras Reservoir. In the month preceding this earthquake a tiltmeter near Mt. Hamilton, 7.8 km southeast of the epicenter, recorded several tilt signals that closely resembled signals observed on other tiltmeters at the time of nearby surface creep events. Five such signals occurred during this time period, culminating in a signal of 8.2 μradian maximum amplitude on 8 January 1981. These creep-event-like tilt signals also resemble the tilt events that preceded a pair of earthquakes (M_L = 4.2, 0014 UTC and M_L = 3.9, 0018 UTC, both on 29 August 1978) with epicenters in Halls Valley about 2 to 3 km southeast of the 15 January epicenter. An earthquake (M_L = 4.5) on 8 May 1979, with epicenter 3 km south of the Mt. Hamilton tiltmeter, near Panochita Hill, was not preceded by observable tilt events.

These observations, along with cumulative seismic moment information, suggest that the Halls Valley section of the Calaveras fault, roughly between Mt. Hamilton Road and Panochita Hill, may be creeping episodically throughout the seismogenic depth range. A localized region of right-lateral shear, that is subject to diminished normal stress resulting from right-lateral slip on either side, may border this creeping section of the fault at its northwest limit. The 8 May 1979 epicenter, near the southwest limit of the creeping section, may indicate a localized region of right-lateral shear that is locked to right-lateral slip from the southeast, but into which slip may propagate from the adjacent creeping section to the northwest. A bend in the fault may cause this localized region to be subject to increased normal stress in response to right-lateral slip to the southeast and diminished normal stress in response to right-lateral slip along the creeping section of the fault to the northwest. Creep events at depth between these points may be an integral part of a loading/unloading mechanism for the transfer of strain energy between these two fault patches. These results were presented at the Conference on Earthquake Hazards in the Eastern San Francisco Bay Area held in March, 1982.

Report

Dvorak, J., Okamura, A., Mortensen, C. and Johnston, M., 1981, Summary of electronic tilt studies - Mount St. Helens, 1980: U.S. Geological Survey Professional Paper no. 1250.

Biological Premonitors of Earthquakes: A Validation Study

14-08-0001-19112

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The goal of this project is to test the long-held, popular belief that many types of animals behave unusually just before earthquakes, presumably in response to one or more precursors. To this end, a network of volunteer observers of animal behavior has been set up in selected seismic regions of California. The key feature of the reporting protocol adopted is that each volunteer is asked to report on a "hot line" all observed instances of unusual animal behavior. Only reports received before an earthquake are considered to be positive evidence in support of the hypothesis under test.

By July 3, 1981, 154 new observers had joined the network, bringing the total processed since the project was initiated in 1978 to 1751. Of this number, 1407 were active observers during the first six months of 1981. Most of them are concentrated in southern Humboldt County; the San Francisco Bay area, north to Santa Rosa and south to Santa Cruz and Hollister; the northern Los Angeles area, particularly around San Fernando; and the San Diego area. During this time there were 28 earthquakes in California with a preliminary magnitude of at least 4.0, one of which had a magnitude of at least 5.0. A total of 881 hot line reports were received.

Graphical display of the 1981 data revealed that none of the earthquakes of $M \geq 4.0$ fell well within the observer network but six on the fringes of the network appeared visually to be preceded by a relatively large number of reports. A computer-programmed statistical model and analysis procedure created for quantitatively correlating earthquakes and observer reports was applied to these six candidates. These significant correlations were found:

DATE	TIME (PST)	LOCATION	MAG.	PROB.
1/15/81	04:48	10 mi ESE Milpitas	4.6	.0018
1/27/81	14:11	2 mi S A æmas	4.0	.0001
3/3/81	02:45	2 mi NE Fremont	4.3	< .00005

Together with the 4 events for which significant probabilities were found during 1980 (using the same parametric values in the analytic model) these findings are interpreted as strongly favoring the hypothesis that anomalous animal behavior precedes at least some earthquakes.

Most routine network operations are automated, including maintenance of records of the performance of each observer, the mailing of additional logs, praise and delinquency notices, and the preparation of weekly and monthly management and statistical reports. A cadre of non-observer volunteers in the Menlo Park area handle other non-automatable features.

Electrical Conductivity Structure of the San Andreas Fault in Central California

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In this report we present the results of an electromagnetic induction experiment aimed at investigating the electrical conductivity structure of a section of the San Andreas Fault in central California. This location is about 18 km southeast of the city of Hollister and encompasses a section of the fault which runs adjacent to the Gabilan Mountains, one of the coastal ranges of central California.

The experiment consists of using a grounded electric dipole as a source to excite electric and magnetic fields which are measured at ground level at a series of sites running roughly perpendicular to the strike of the fault. The spatial and frequency dependence of the fields yield information about the conductivity structure. In particular a simple one-dimensional magnetotelluric analysis is applied to the data at each site. Apparent resistivities are calculated from the observed fields and fit to theoretical two-layer magnetotelluric sounding curves. The resulting two-layer models are combined to give a two-dimensional profile of the conductivity in the vicinity of the fault zone.

The results indicate a large contrast in conductivity across the fault, conductivity values being much higher on the northeast side. There is also evidence of a conducting layer at depth on the southwest side. The large contrast in conductivity seen at the surface is expected on the basis of the geology of the area. Sedimentary rocks such as the Franciscan complex are found on the northeast side of the fault and are characteristically better conductors than the granite rocks found in the Gabilan Mountains on the southwest side. The observation of conducting material at depth on the southwest side of the fault correlates with the results of seismic and gravity surveys in the area. Results of a gravity survey indicate the presence of a pocket of low density rocks beneath the eastern rim of the Gabilans. The depth to these rocks is comparable to the depth to the conducting layer. Farther from the fault zone to the southwest, seismic studies indicate a seismic velocity discontinuity at nearly the same depth as the discontinuity in electrical conductivity.

Helium Monitoring for Earthquake Prediction

9440-01376E

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Denver Federal Center
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Investigations

Monitoring continued of the soil-gas helium concentrations from the permanent stations established along the San Andreas Fault between Stone Canyon and San Benito, CA.

Results

The seasonal pattern continued with increasing helium concentrations for the fall and winter months. Several probes emplaced to a depth of 4 and 5 meters revealed the same seasonal pattern and concentration variations as the probes at a 2-m depth. The extremely wet winter season of 1981 to 1982 is reflected by the helium concentrations that greatly exceed those for the same period the previous two years (figure 1). One permanent station, our number 10, is located in a low-lying area and is particularly sensitive to precipitation events. It often shows helium increases of several hundred parts per billion for several weeks following heavy rains. Figure 2 shows the same plot as figure 1 except that the data from station 10 has been excluded from the averages. The general trends persist but the "run-away" helium increases of the last few months is greatly moderated. Now that nearly 3 years worth of data has been gathered, new statistical methods of evaluating the variations in helium concentrations will be tested. Although the extremely high soil moisture concentrations add to the difficulty of separating helium decreases from the background fluctuations, correlations of helium decreases to seismic activity continue. Most notable is the December 12, 1981 earthquake of 3.9 magnitude with the epicenter very near San Juan Bautista, CA.

Report

Reimer, G. M., 1981, Soil gas helium variations related to seismic activity: EOS, Transactions of the American Geophysical Union, v. 62, p. 962.

HELIUM SOIL-GAS CONCENTRATIONS NEAR HOLLISTER, CA.

3-POINT MOVING AVERAGE THROUGH 82096.

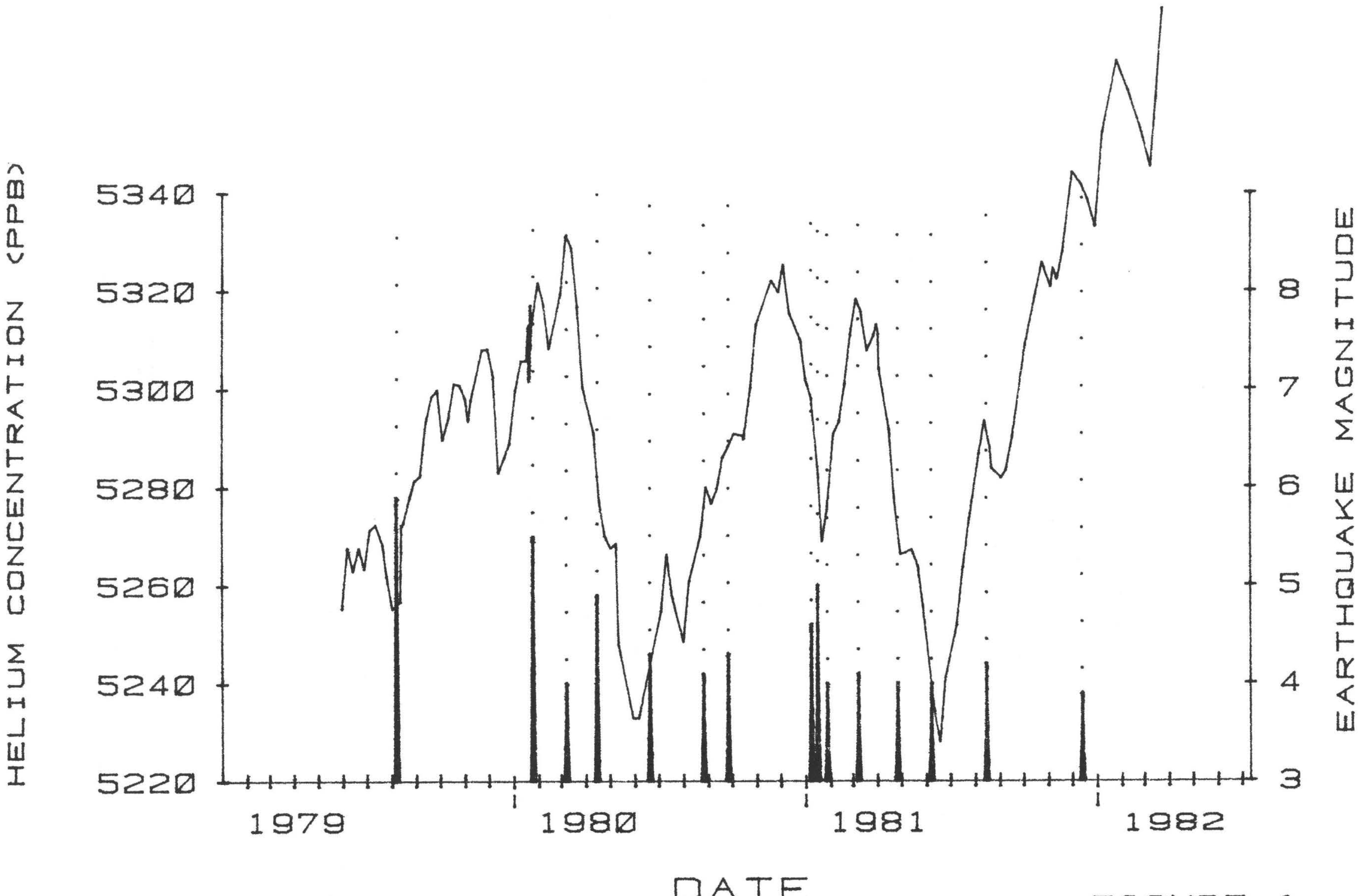

FIGURE 1.

HELIUM SOIL-GAS CONCENTRATIONS NEAR HOLLISTER. CA.

3-POINT MOVING AVERAGE THROUGH 82096.

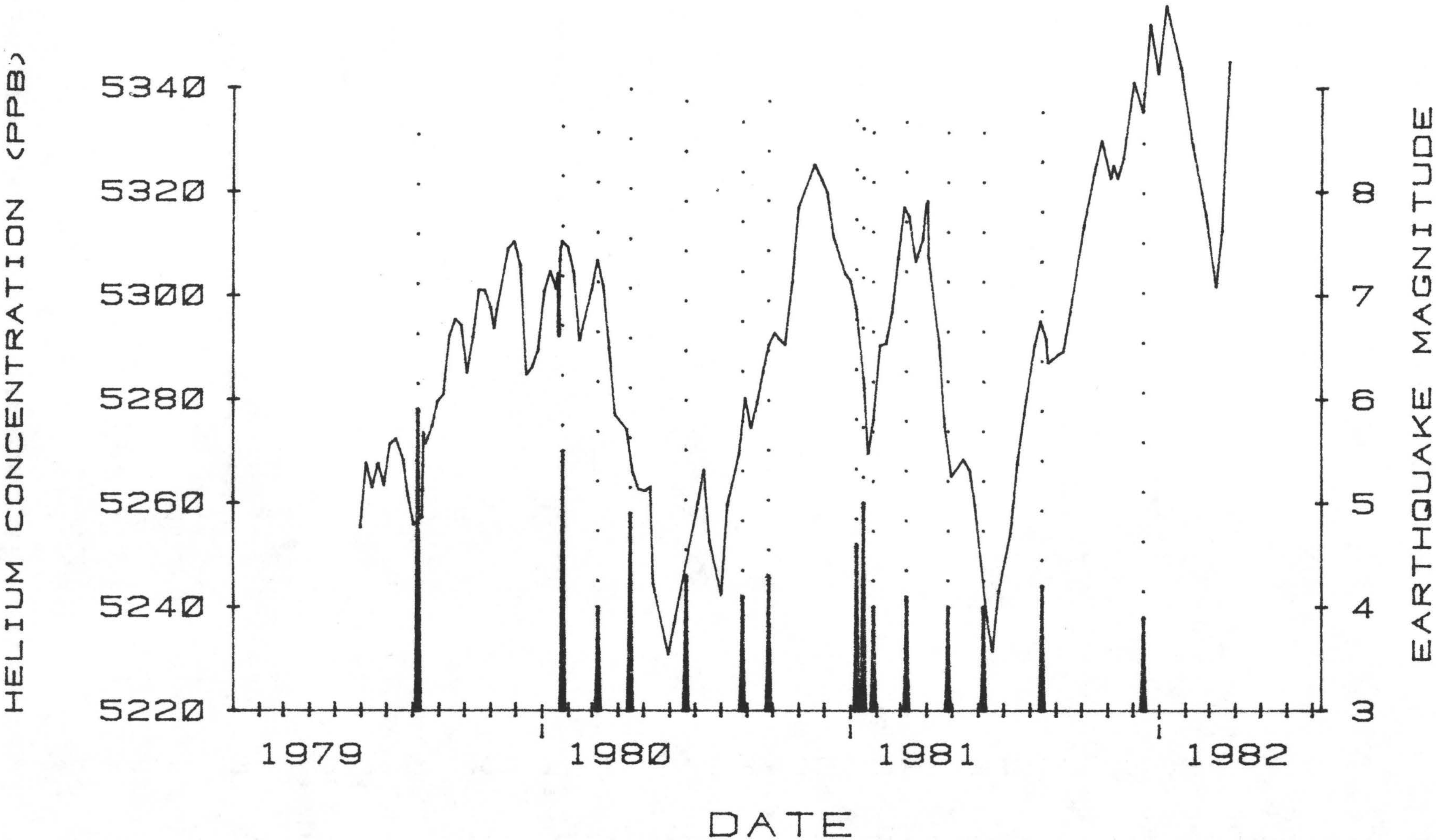

FIGURE 2.

HYDROGEN MONITORING

9710-02773

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Investigations

Hydrogen gas can be generated by the reaction of ferrous silicates with water at a depth where temperature is higher than about 300°C. At least several bars of H_2 pressure should exist at a depth of 10 km in an ophiolitic crust. Because H_2 is extremely mobile and relatively non-reactive once formed, it should ascend to the surface easily from such a depth, if an incipient fracture developes along a tectonic fault zone. We hope to examine if anomalous emission of hydrogen indeed relates to the development of such a fracture by monitoring hydrogen continuously along the major seismogenic faults in California.

We have operated six H_2 monitoring stations along the San Andreas and Calaveras faults since July 1981. They are located at Carr Ranch, Parkfield, Slack Canyon, Melendy Ranch, Wright Road, and Shore Road. An index map was provided in the previous report. The first 4 sations use a solar panel to power an air pump to supply oxygen to the H_2 sensor, which is a small H_2/O_2 fuel cell and generates a voltage proportional to the H_2 concentration. We recently added a catalytic H_2 scrubber and an isolation amplifier to improve the signal/noise ratio of these stations. The last 2 stations use bottled oxygen to operate the sensor. The voltage outputs of the H_2 sensors are telemetered to Menlo Park via the digital telemetry network maintained by the Branch of Network Operations, OES. Recently we have completed the task of transferrring the H_2 data from Menlo Park to our microcomputer system in Reston via phone and processing the raw data for optimum interpretation of the data.

Results

In contrast to the preceding 6 months, during which only one anomalous H_2 degassing event was observed (July 24, 1981), a series of major degassing events were observed during this reporting period at the Shore Road and Wright Road stations and less major events at other locations starting in mid-November, 1981. Some of the events took place at two or possibly more locations concurrently. What did these anomalous H_2 degassing events signify in terms of seismicity, tectonic movements, or surface-related phenomena such as regional barometric changes are being investigated currently.

In order to eliminate the diurnal barametric effect (i.e., orographic wind effect), all the valid data obtained in each Julian day (upto 144 data points per day) have been averaged and chronologically plotted for the six stations between October 1981 and March 1982. To show the concurrency of some of the degassing events, the daily averaged values from three stations (Shore Road, Wright Road, and Melendy Ranch) are compositly shown for the month of November 1981 (Fig. A), January 1982 (Fig. B), and February 1982 (Fig. C). These three stations showed anomalous degassing events most frequently among the six stations during this reporting period. Because we consider the pattern of changes in H_2 concentration rather than the absolute values important, the absolute magnitude of the H_2 concentration is not uniform in the composit diagrams.

On November 14, 1981, an anomalous H_2 degassing took place at the shore Road station for the first time since July 24, 1981. Another degassing peak energed on November 17, 1981. This event was also detected simultaneously at the Wright Road station, 8.6 km to the SE (Fig. A).

A large degassing event started on January 20, 1982, at both Shore Road and Wright Road. The event ended on January 22 at Shore Road and on January 24 at Wright Road (Fig. B).

An apparent 3-station-wide degassing event, which involved the Melendy Ranch station, took place on February 14, 1982 (Fig. C). As Melendy Ranch is on the San Andreas fault and Shore Road and Wright Road are on the Calaveras fault, and as there are other anomalous degassing events at Melendy Ranch in February 1982, the concurrency of the Feb. 14 event could be merely concidental. But the overall increases in the frequency of anomalous degassing events at all these stations since mid-November, 1981, is real. The distance between Shore Road and Melendy Ranch is over 45 km. If the degassing event of Feb. 14 truly covered the distance and started on the same day, the implication is profound.

A reasonabale model to explain such a multi-station degassing event appears to be either (1) the source of hydrogen is very deep, if it is a point source, or (2) the source of hydrogen is regional and the development of a fracture, which permits the escape of the pent-up hydrogen, extends over tens of kilometers.

References:

For detailed explanation of the hydrogen sensor used in this investigation, see the following:

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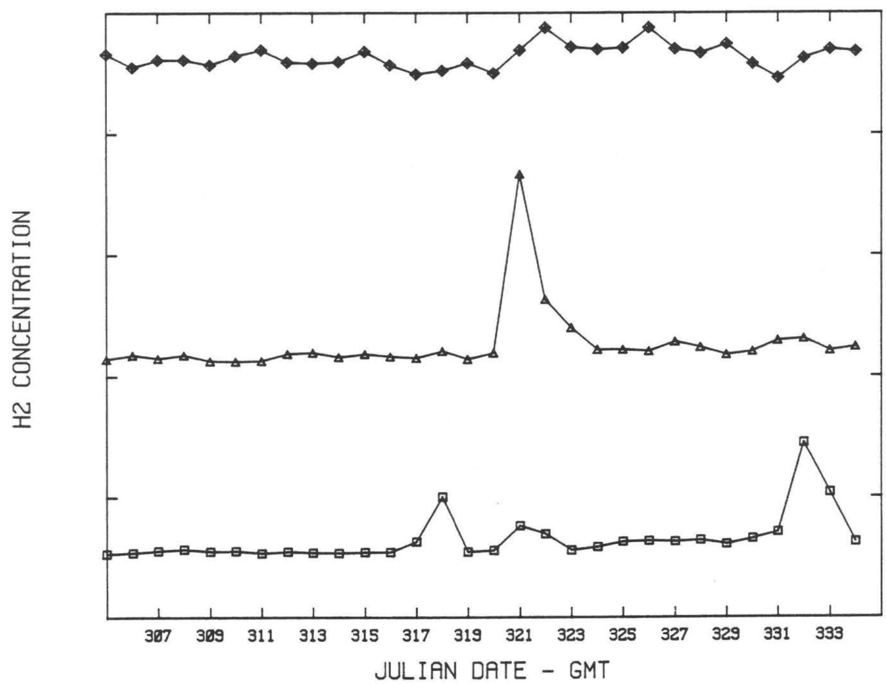
Figure Captions.

Fig. A Daily average concentration of hydrogen along seismogenic faults in California in November 1981. The hydrogen concentration scale is not uniform for the three stations. The symbols are: △ for the Shore Road station, □ for the Wright Road station, and ◆ for the Melendy Ranch station.

Fig. B Daily average concentration of hydrogen along seismogenic faults in California in January 1982. For symbols see Fig. A.

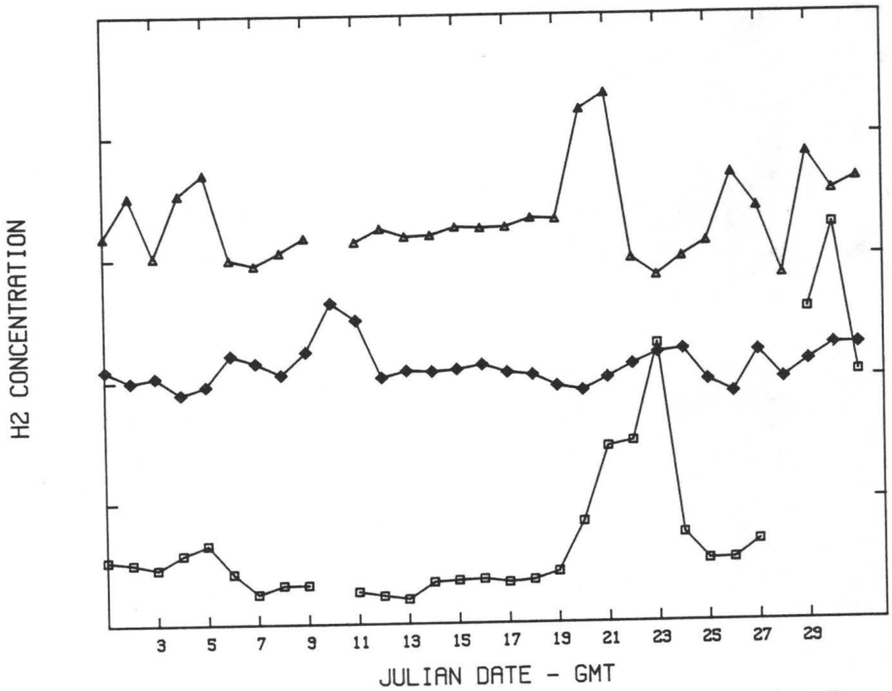
Fig. C. Daily average concentration of hydrogen along seismogenic faults in California in February 1982. For symbols see Fig. A.

(Fig. A)



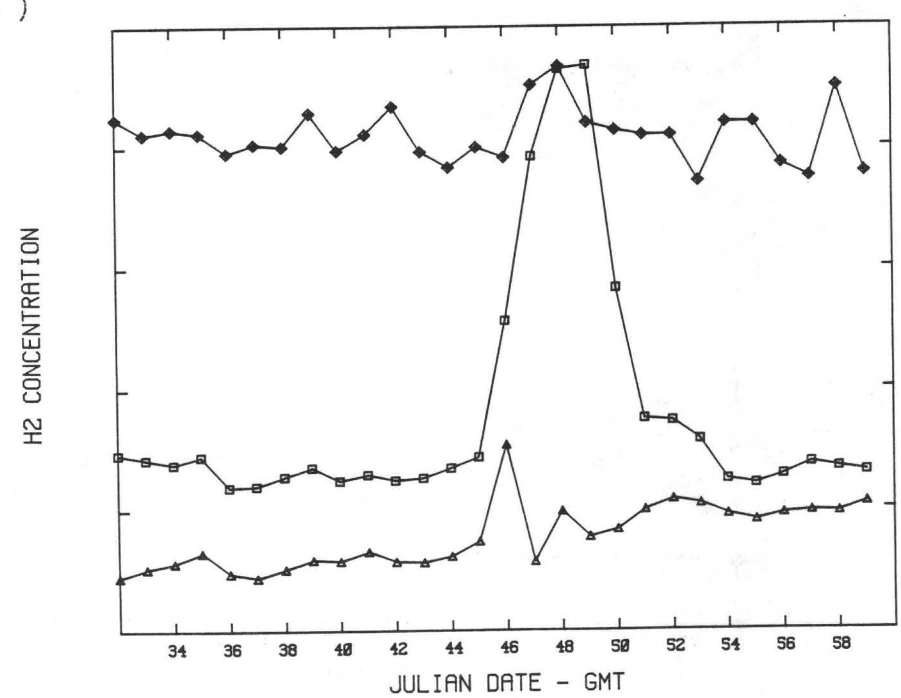
COMBINED STATION HYDROGEN DATA - 11/81

(Fig. B)

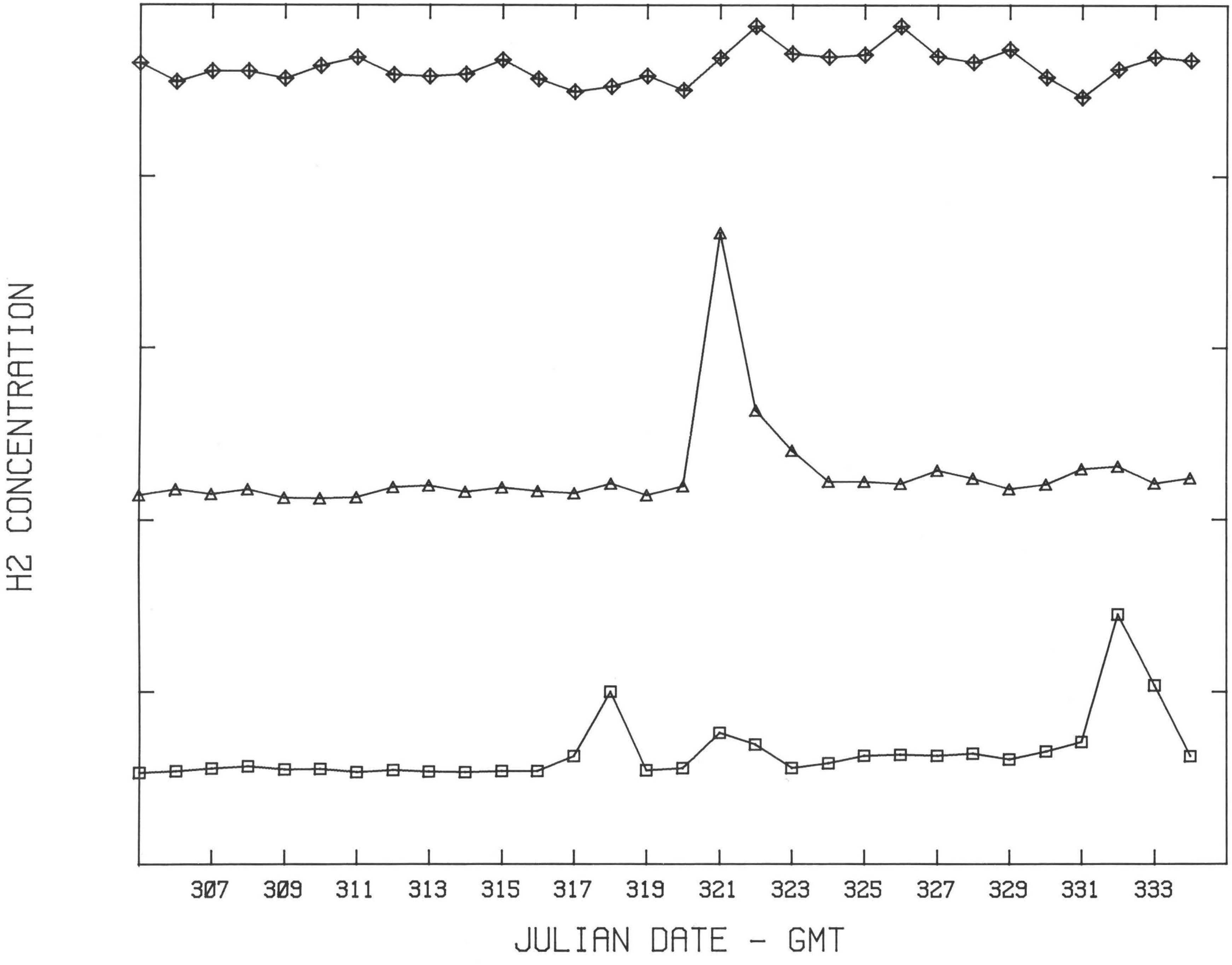


COMBINED STATION HYDROGEN DATA - 1/82

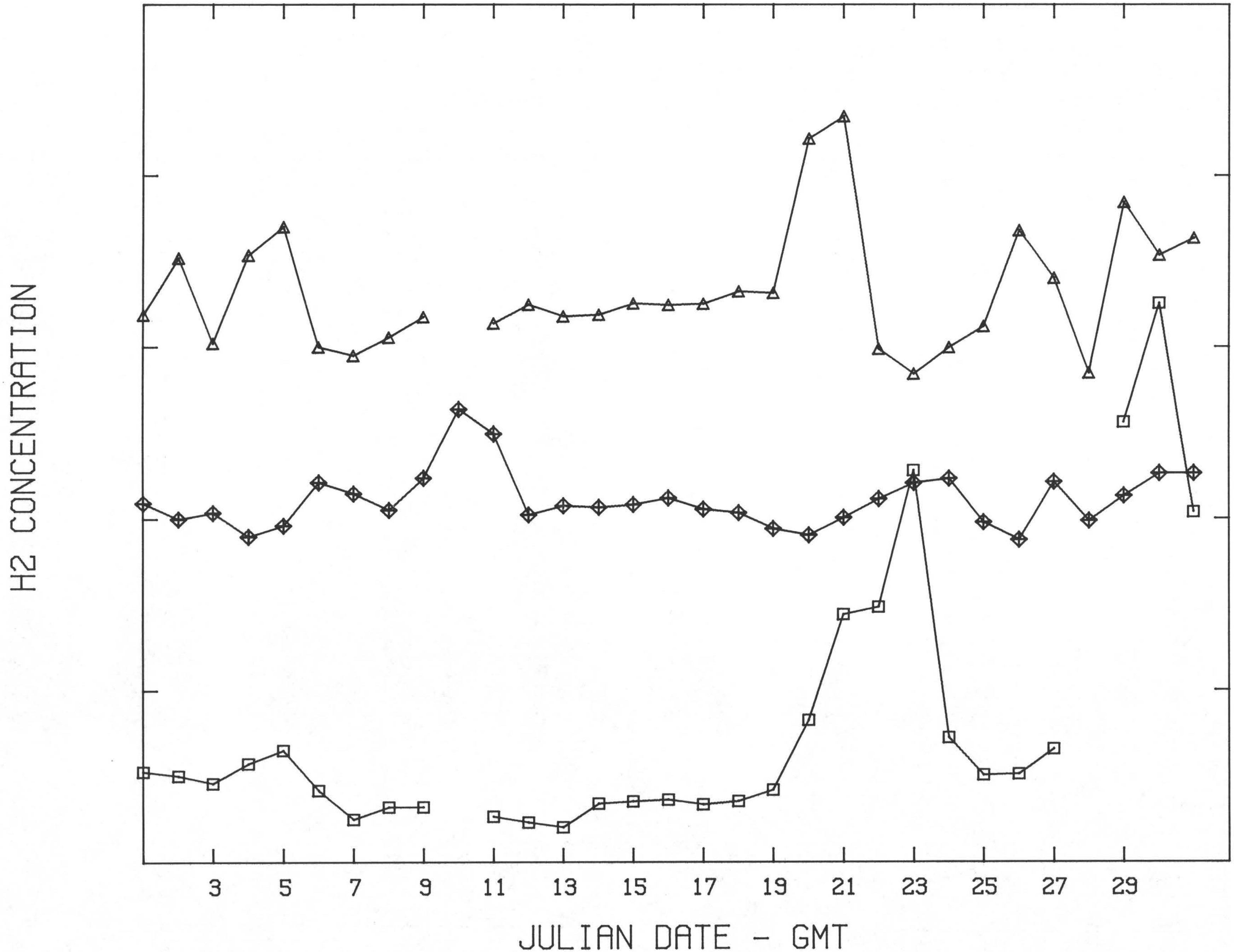
(Fig. C)



COMBINED STATION HYDROGEN DATA - 2/82

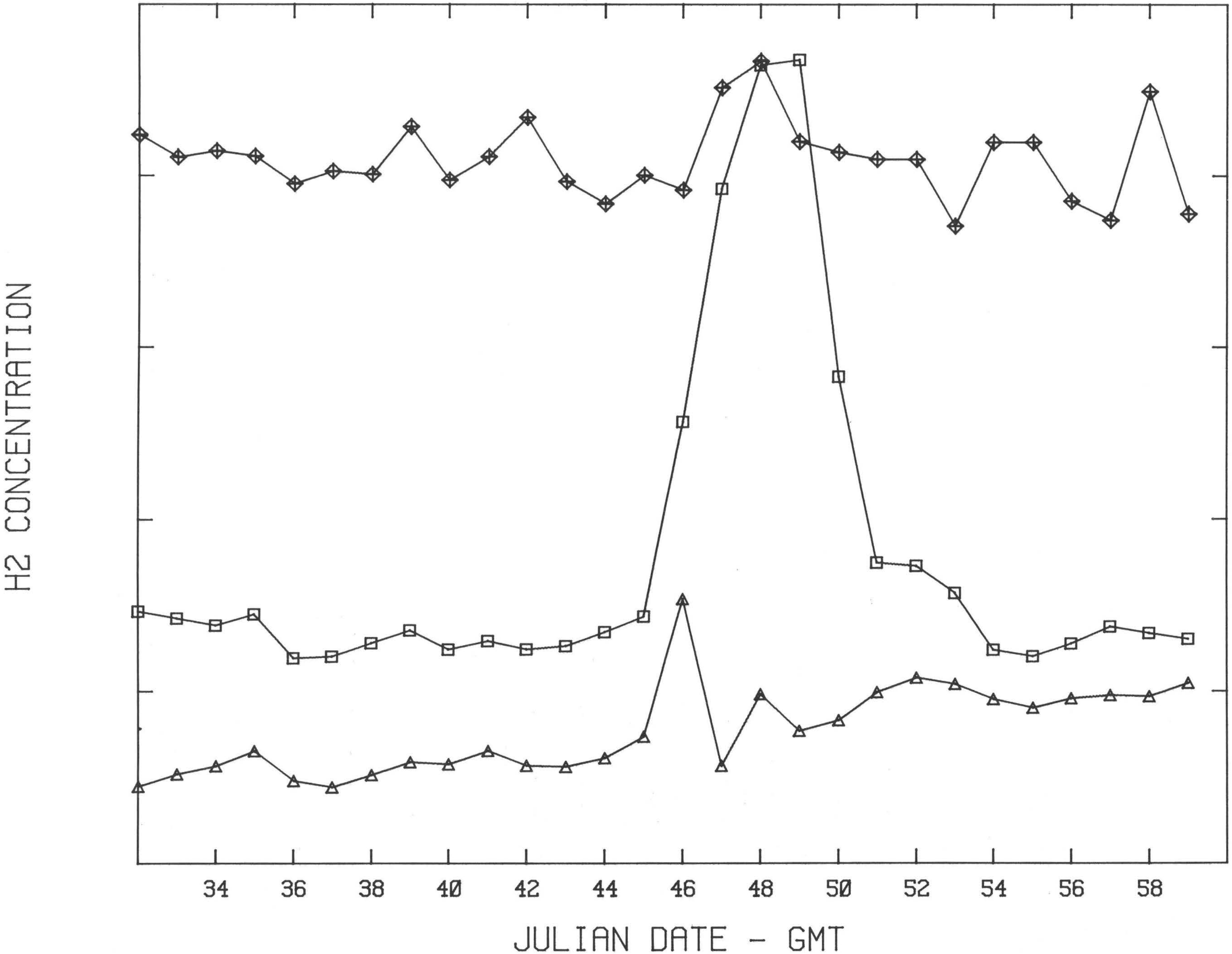


COMBINED STATION HYDROGEN DATA - 11/81



COMBINED STATION HYDROGEN DATA - 1/82

P2



COMBINED STATION HYDROGEN DATA - 2/82

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 FY81, our efforts were devoted mainly to (1) the analysis of data from the radon-thoron monitoring network, (2) completion of upgraded software for the fully automatic analysis of data from the network, (3) the installation of a VAX-750 computer which now is used for much of the automated analysis, (4) an expanded program of geochemical characterization of the sites at which radon is monitored, (5) the analysis of hydrogen and helium data from the Pacoima site, (6) completion of site work at Ft. Tejon, (7) field work associated with the development of three new sites in Riverside County, (8) the installation of additional gas analysis equipment at the Lake Hughes, Kresge, and Lytle Creek sites, and (9) visits to research institutions and geochemical monitoring sites in the Peoples' Republic of China.

RESULTS

Many of the stations on the network recorded anomalous radon spectra during FY81. This was particularly true of those stations located on the frontal faults of the Transverse Ranges during the first half of FY81, and of stations located near the San Andreas fault during the second half of FY81. A qualitative correlation was observed between the character of the radon data at these sites and geodetic measurements of strain and strain rates in the Transverse Ranges. For the past two years rapid changes in strain of considerable magnitude have been measured in the vicinity of Palmdale. It appears that during those times when the strain has been predominantly compressional, fluctuations in the radon levels have been relatively small. At times when the strain has appeared to be tensional large fluctuations in radon level have been noted. It appears that the regional strain event which began about two years ago is continuing, and is responsible for the increased level of seismicity in the region.

During the latter part of FY81 significant changes were observed in the radon data from our network. Large increases in radon were recorded beginning in August at Lake Hughes and Lytle Creek, while at Sky Forest a corresponding decrease was noted. Many of the frontal fault stations which previously were quite noisy became quite during this period. In addition to the general increase in average radon level, both the Lake Hughes and Lytle Creek stations began to record correlated fluctuations starting in September. These were found to be phase correlated with barometric pressure. Gas analyses revealed that both boreholes were releasing substantial amounts of CO_2, which appears to be the carrier for radon. The cause of the large increase in CO_2 at these two sites is not yet understood. Radon data from the network are shown in figures 1 and 2.

In collaboration with visiting scientists from the China, an expanded program of hydrogeological field work and geochemical analysis has been undertaken with the aim of determining hydrological and geochemical profiles of existing and future monitoring sites. Water samples were taken from all of the boreholes on the network both before and after the 1980-81 rainy season. Geochemical and radiological analyses of these samples have been completed. Additional sampling now is being carried out in the vicinity of Lake Hughes and Lytle Creek to provide more information relating to the anomalies at these locations.

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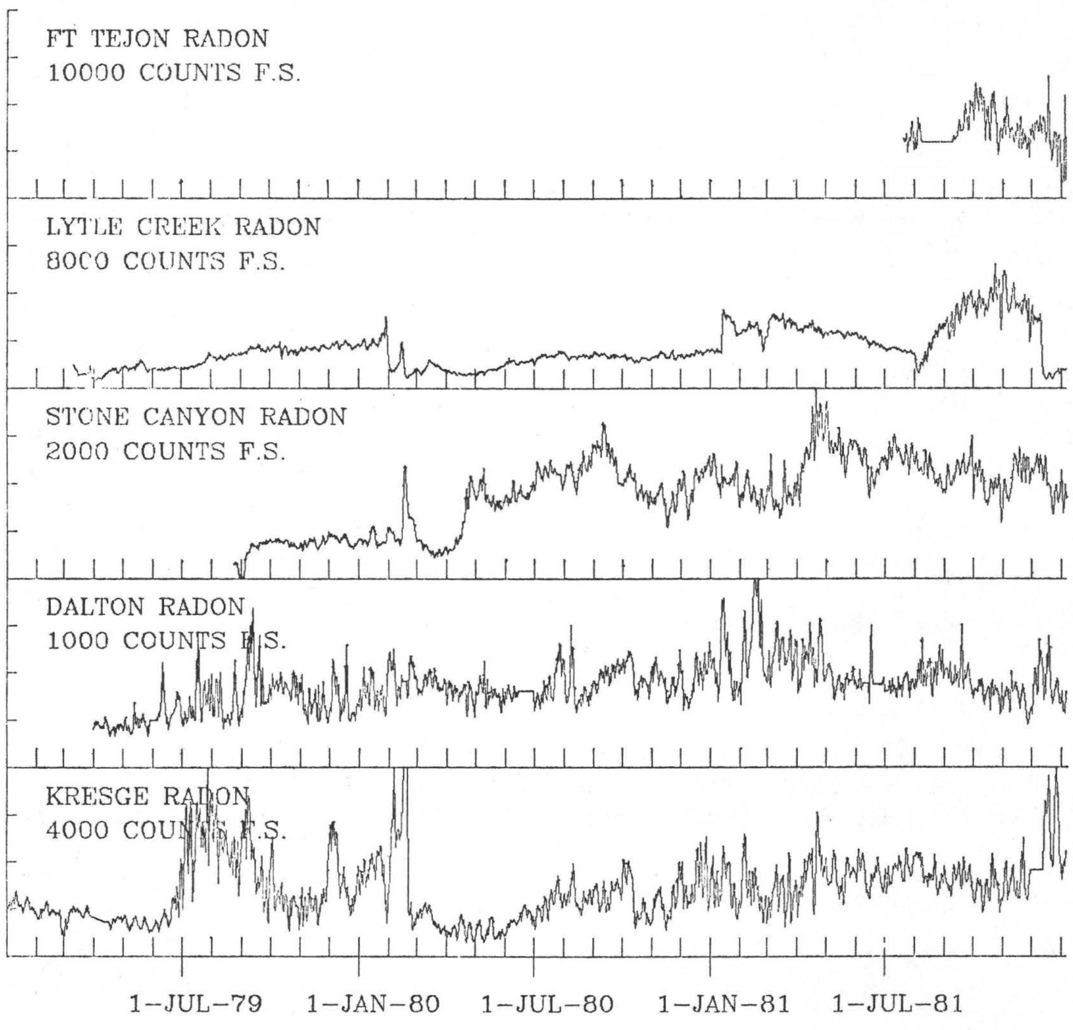
FT TEJON RADON
10000 COUNTS F.S.
LYTLE CREEK RADON
8000 COUNTS F.S.
STONE CANYON RADON
2000 COUNTS F.S.
DALTON RADON
1000 COUNTS F.S.
KRESGE RADON
4000 COUNTS F.S.
1-JUL-79
1-JAN-80
1-JUL-80
1-JAN-81
1-JUL-81

Fig. 1

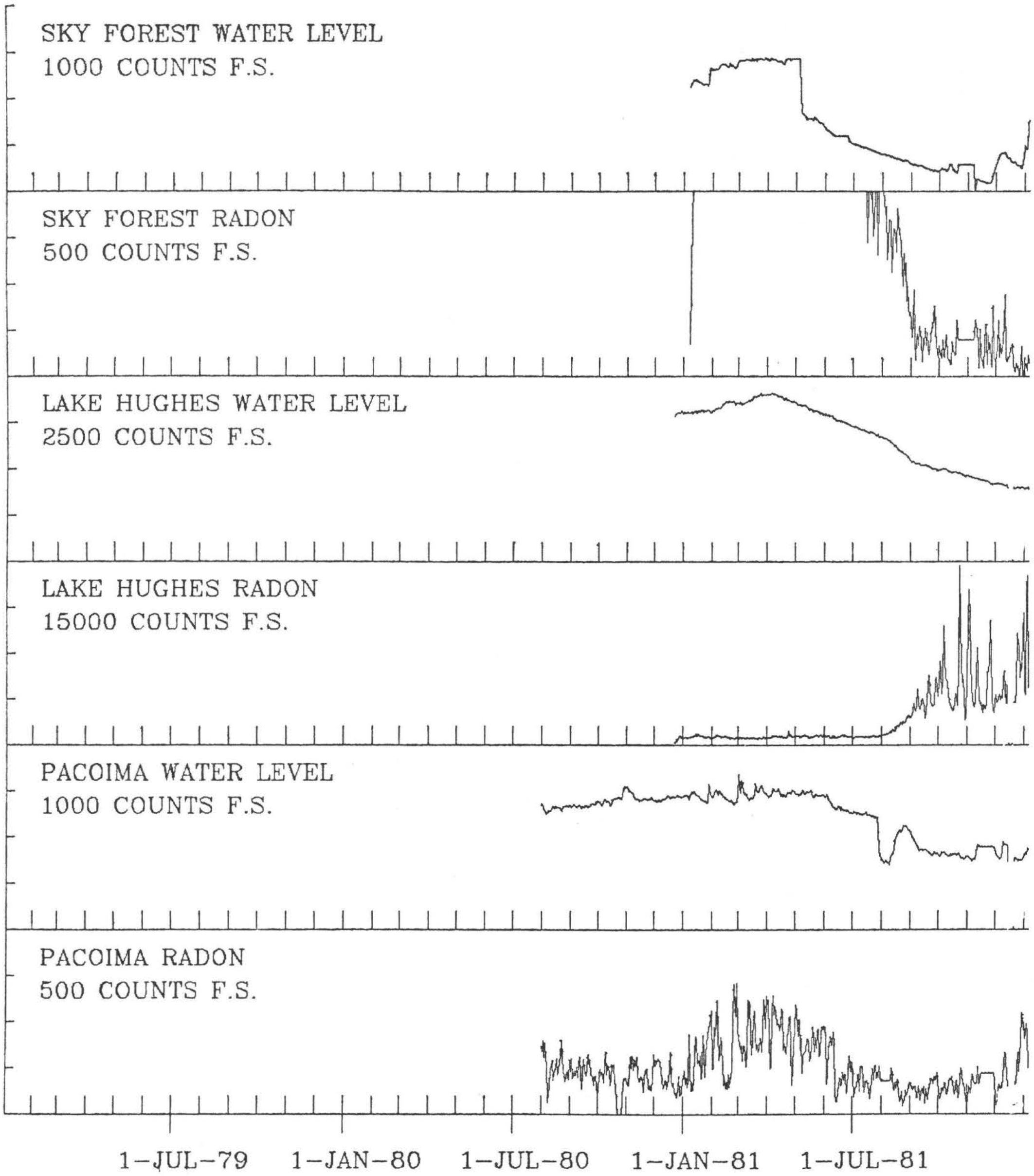
SKY FOREST WATER LEVEL
1000 COUNTS F.S.
SKY FOREST RADON
500 COUNTS F.S.
LAKE HUGHES WATER LEVEL
2500 COUNTS F.S.
LAKE HUGHES RADON
15000 COUNTS F.S.
PACOIMA WATER LEVEL
1000 COUNTS F.S.
PACOIMA RADON
500 COUNTS F.S.
1-JUL-79
1-JAN-80
1-JUL-80
1-JAN-81
1-JUL-81

Fig. 2

GROUNDWATER RADON AND CHEMISTRY STUDIES FOR EARTHQUAKE PRECURSORS

#14-08-0001-19264

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SUMMARY

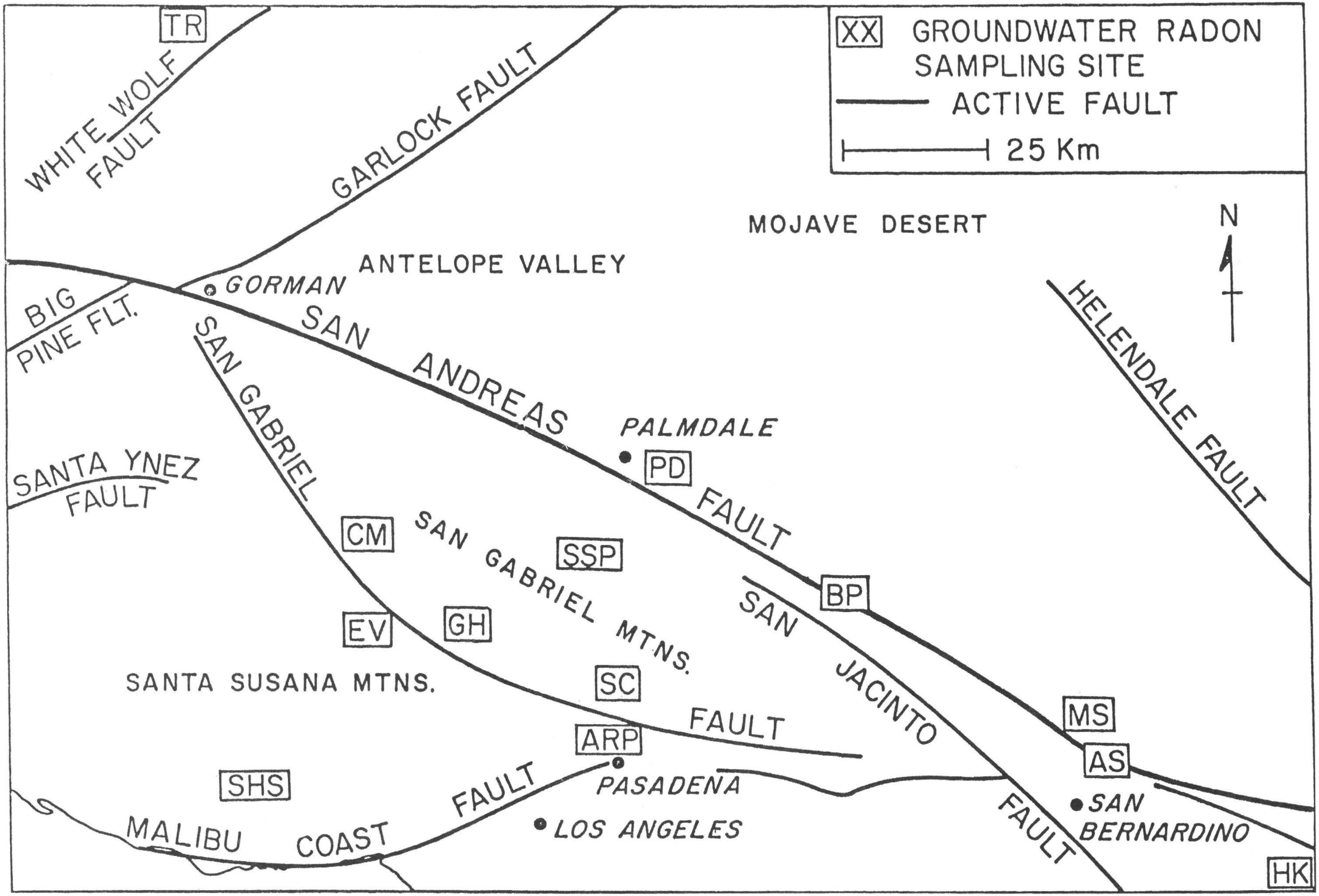
The University of Southern California is monitoring groundwater radon content at 13 sites (Figures 1) in the Central Transverse Ranges of southern California. In addition, methane, helium and other gases are being monitored at four sites. Radon monitoring has been underway since 1974, while monitoring of methane began in the spring and summer of 1981. Helium measurements began in the fall of 1981.

During the past six months we note the following:

1) Groundwater radon at the Arp well in the San Gabriel mountain foothills near Altadena has shown cyclical behavior for several years; low radon in winter, high radon in summer. This pattern seems to be continuing except for a brief period of high radon levels in the fall of 1981.

2) Groundwater radon at the three Arrowhead (AS) sites (1,2, and 3), on the San Andreas fault, show no anomalous behavior during the period.

3) Groundwater radon content at several sites (Arp, Big Pines (BP), Eternal Valley (EV), Glen Haven (GH), Switzer Camp (SC) and Seminole Hot Springs (SHS) showed unusual behavior (both high and low measurements) during the fall of 1981 and in late March-early April, 1982. The latter anomalies (also seen on water level measurements) were probably related to the abnormal weather in southern California during the period. We have no explanation for the fall anomalous measurements at this time.



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
SAN GABRIEL
HELENDALE FAULT
PALMDALE
PD
SANTA YNEZ FAULT
CM
SAN GABRIEL MTNS.
SSP
BP
SAN JACINTO FAULT
EV
GH
SANTA SUSANA MTNS.
SC
FAULT
MS
ARP
AS
SHS
PASADENA
SAN BERNARDINO
MALIBU COAST FAULT
LOS ANGELES
HK

FIGURE 1.

A STUDY OF TECTONOMAGNETIC METHODS AND INSTRUMENTS

14-08-0001-19140

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Investigations

This project is focused on the development and use of noise reduction techniques and improved instrumentation to enhance our ability to detect magnetic events associated with earthquakes.

Results

1) Development of self-calibrating rubidium magnetometers (SCRs) accurate to 0.01 nT rms.

2) Demonstration of local and SCR instrument noise levels not exceeding 0.002 nT for periods ranging up to several hours.

3) Identification of noise which correlates to variations in vector field components and the development of techniques for removing it.

4) Development and demonstration of a scalar noise reduction technique which produced a residual of 0.03 nT for one month of 12 km baseline SCR differences in a non-seismic zone.

5) Identification of noise generated by ocean tidal effects in USGS data from California.

6) Testing of USGS proton magnetometers (0.25 and 0.125 nT least count) using SCRs as a standard at sites in California and Colorado.

7) Deployment of SCRs at two sites near the San Andreas Fault in central California, to obtain high accuracy data in a seismic zone. Comparison with USGS proton data shows that increased instrument sensitivity can improve the coseismic event detection threshold by an order of magnitude or more (Fig. 1).

Reports

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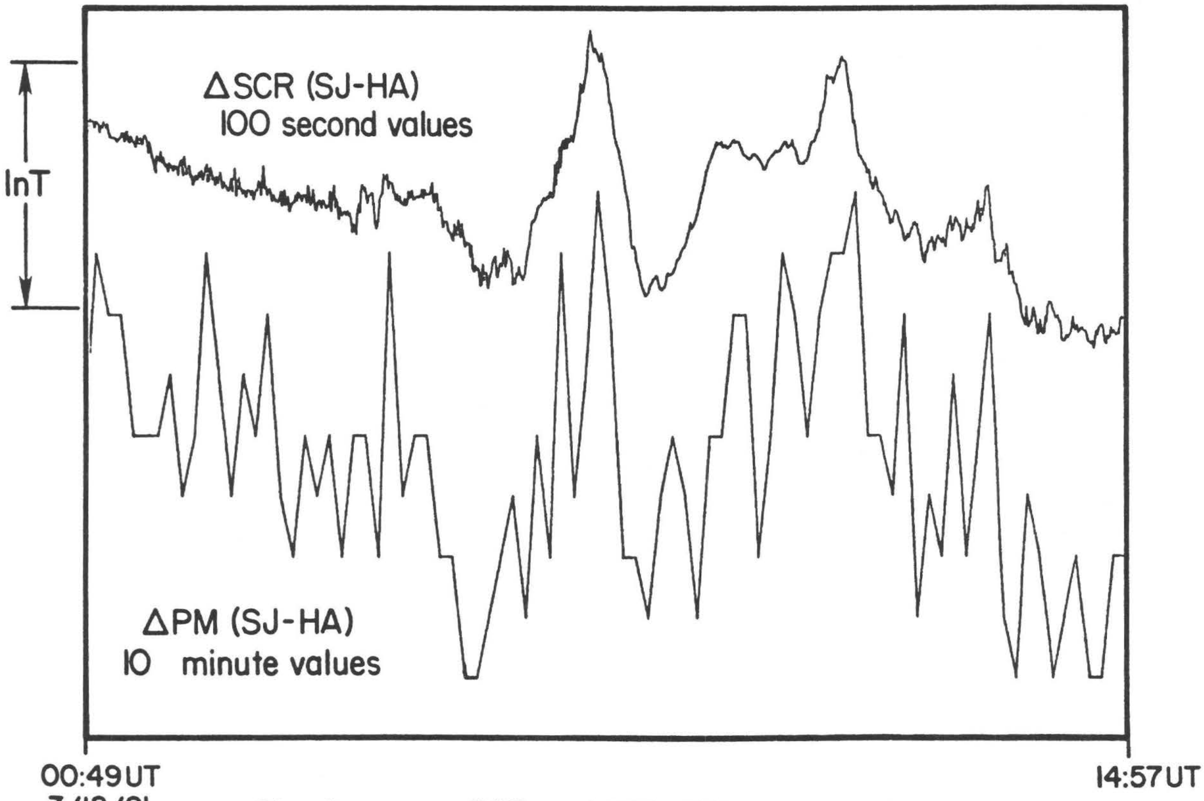
FIGURE 1



Simultaneous SCR and PM differences at San Juan Batista (SJ) and Harris Ranch (HA)

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, Holland (1922, 1934, 1966) and Tacubaya, Mexico (1934 and 1966) were obtained to test the support for the "time-predictable earthquake recurrence model" obtained from an analysis of seismograms recorded at Berkeley, California.

2. Seismic moments for earthquakes along the central section of the San Andreas fault system in California were obtained in order to calibrate the CALNET duration with the seismic moments.

Results

At the present time, work is underway on these topics but only tentative results are available.

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Rock Mechanics

9960-01179

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Investigations

Laboratory experiments are being carried out to study the physical properties of rocks at elevated confining pressure, pore pressure and temperature. The goal is to obtain data that will help us to determine what causes earthquakes and can we predict or control them.

Results

We have studied the shear deformation of simulated faults under triaxial conditions, with a one mm thickness of crushed Westerly Granite fault gouge. Experiments were conducted under drained conditions, either nominally dry or with constant 2 MPa pore pressure. While holding confining pressure constant at either 30 or 300 MPa, the axial strain rate was varied over four orders of magnitude from 10^{-7}/sec to 10^{-4}/sec, corresponding to sliding velocities ranging from 0.72 x 10^{-7} mm/sec to 0.72 x 10^{-4} mm/sec. The frictional stress level was proportional to the logarithm of strain rate. At 300 MPa confining pressure, an increase of one order of magnitude strain rate raised the frictional stress 2.5 percent. To test the generality of the strain rate strengthening effect, experiments were also conducted in which the strain rates were decreased in steps. Consistent results were obtained: A decrease in strain rate of one order of magnitude lowered the stress level 2.5 percent. With identical samples under 30 MPa confining pressure, the results were similar to those at 300 MPa. One order of magnitude increasing steps of strain rate elevated the frictional stress level approximately 2 percent, while one order of magnitude decreasing steps of strain rate lowered the frictional stress level 2 percent. Thus, at both moderate (30 MPa) and elevated (300 MPa) confining pressures, increased strain rates elevated the frictional stress level and decreased strain rates lowered the frictional stress level. This suggests that in situ frictional strength may be significantly less than that measured under relatively rapid strain rates in laboratory simulations.

Reports

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Mechanics of Earthquake Faulting

9960-01182

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Investigations

1. Study the effects of loading and fault roughness on dynamic source parameters of stick-slip events generated on laboratory large-scale model faults.

Results

Propagating crack or dislocation models of the earthquake source indicate that predicted strong ground motions and high-frequency signals are highly dependent on the earthquake rupture velocity. Another important parameter in such earthquake source models is the energy required to create newly faulted material in the source region, which is referred to as the apparent fracture energy or the energy release rate. High-speed records of shear strains and slip velocities along a 2-m-long model fault in a block of Sierra white granite (V_p = 4.2 km/s; V_s = 3 km/s) clearly show the propagation of the shear failure zone associated with stick-slip failures generated on the fault. The data, taken at intervals of 5 μs/sample, also provide detailed resolution of the motions and deformations along the fault and show displacement weakening at the onset of sliding as the failure passes by the instrumented sites.

Experiments have been performed with two different prepared roughnesses of the simulated fault. Apparent fracture energy of events generated on both the rough and the smooth faults increases with increasing normal stress and the events on the rougher fault are characterized by larger fracture energies than those of the smoother fault (Figure 1). Apparent rupture velocities of the stick-slip events were calculated from arrival times of the rupture front at the different gage locations. Representative rupture velocities of events generated on the rougher fault (roughness, 80 μm) range from 0.8 to 1.8 km/s. The sliding distance required for the fault strength to drop from the maximum to residual value, d_r, is 30 μm. Corresponding values for apparent rupture velocity and d_r for the smoother fault (0.2 μm) are 2.5 to 5.1 km/s and 3 μm, respectively. Minimum dimension, L_c, for an unstable rupture to nucleate is proportional to d_r and (normal stress)$^{-1}$. These rupture velocity measurements when scaled by L_c suggest that at fault lengths close to the nucleation dimension, rupture velocity increases with increasing fault length (Figure 2).

Reports

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Report prepared by P. G. Okubo.

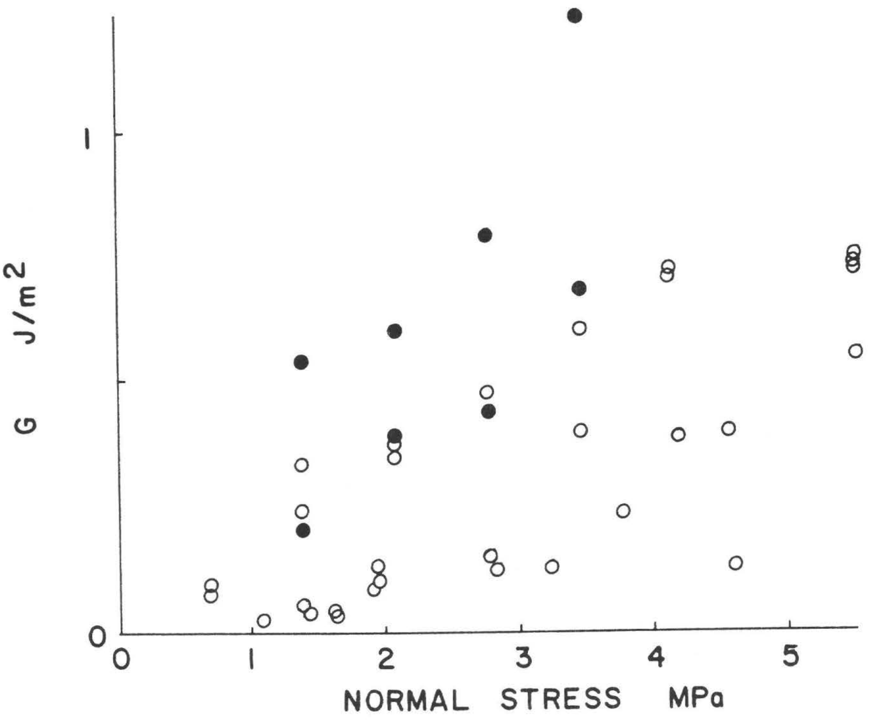

Figure 1: Apparent fracture energies, G, of stick-slip events as a function of normal stress. Solid symbols represent events generated on rough fault; open symbols represent events generated on smooth fault.

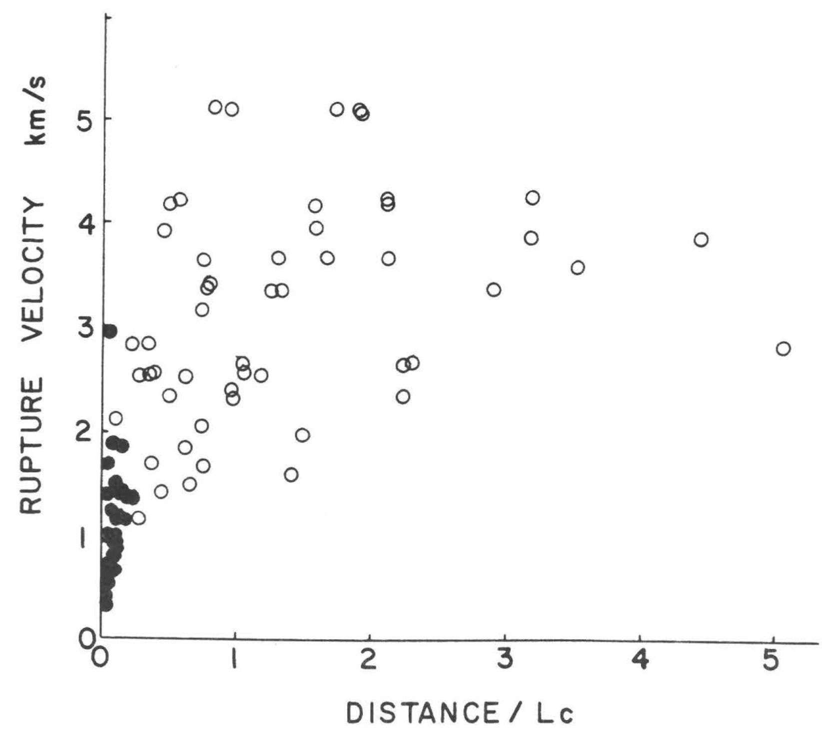

Figure 2: Apparent rupture velocities as a function of propagation distance normalized by critical crack length, L_C. Open symbols represent data from smooth fault; closed symbols represent data from rough fault. The apparent supersonic rupture velocities are probably spurious because the rupture front may propagate oblique to the strain gage array, especially at small L_C.

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 is being spent on bringing up the programs on the DEC 11/70 and VAX computers. Individual prediction files will be restored if needed for evaluation.

3. The probability program could be expanded to calculate the changing probability of a quake as precursory phenomena are noted. The equations would be based on Bayes Law and require the random probability of an earthquake in a region and estimates of the probabilities that precursors precede earthquakes and non-earthquakes.

4. Because the project budget can only cover salary and computer charges, item 3 above and any prediction scoring or evaluation has been impossible. Predictions received can only be dated and filed.

Reports

No reports were published during this period.

Earthquakes and the Statistics of Crustal Heterogeneity

9930-03008

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Investigations

The size of an earthquake is determined by the processes that stop rupture growth, namely propagation into a region of either great strength or low stress. Therefore, earthquake statistics must depend on the statistical distribution of stress and mechanical properties in the earth, a subject about which we are almost totally ignorant.

The most powerful tool for studying the small-scale mechanical properties of the earth is the scattering of seismic waves. Scattered waves are, in addition, of direct interest because they profoundly effect local seismograms, distorting our view of earthquake sources, and because earthquake coda lengths are routinely used to determine earthquake magnitudes.

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

A paper on using linear-programming methods to analyze earthquake focal mechanisms has been completed and submitted to the Geophysical Journal of the Royal Astronomical Society. These methods are much more efficient than techniques previously available, and, more importantly, yield explicit bounds on the uncertainty of the derived mechanisms. Furthermore, they can use both polarity (e.g. first-motion) and amplitude data, thus greatly improving our ability to resolve earthquake mechanisms. Techniques for inverting data from suites of earthquakes to obtain stress orientation are currently being investigated.

A theoretical analysis has been completed of the scattering of seismic waves in media with anisotropically-distributed inhomogeneities. Such a theory is needed to understand the propagation of local earthquake waves in stratified and foliated crustal rocks. Several interesting results have emerged:

(1) The effect of a statistically anisotropic heterogeneity distribution is to multiply the scattering patterns by an angular factor which is the three-dimensional Fourier transform of the correlation function of the heterogeneities, evaluated at the vector difference between the incident and scattered wavenumber vectors.

(2) At low frequencies, the Fourier transform term is independent of direction, so the amplitudes of scattered waves are proportional to the fourth power of frequency (Rayleigh scattering) and independent of the distribution of the heterogeneities. The angular distribution of scattering depends only on the wave types involved and can be rather complicated. It is strongest for S-to-S scattering and weakest for P-to-P scattering, with the P-to-S and S-to-P cases being intermediate.

(3) For wavelengths comparable to the dimensions of the heterogeneities, resonance effects occur. For a "quasi-layered" medium, the Fourier transform factor tends to concentrate scattered power in the directions of "reflection" and "refraction" from the "layering".

(4) At high frequencies P-to-S and S-to-P scattering disappear. P-to-P and S-to-S scattering persist, but are concentrated strongly into the forward direction, where they interfere with the direct wave and produce fluctuations in its phase and amplitude. S-to-S scattering remains much stronger than P-to-P.

(5) If the distributions of the heterogeneities in elasticity and density are independent, forward and backward scattering are equally strong. Pronounced back-scattering, thought to be important in the generation of local earthquake coda waves, only occurs when the different types of inhomogeneities are correlated.

A paper based on these results was presented at the April, 1982 meeting of the Seismological Society of America, in Anaheim, California.

Large Scale Laboratory Contained Fracture Experiment

9960-02941

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Investigations

1. Determination of source parameters during unstable sliding on a fault.

2. Producing contained fracture events by altering the stress field along the fault.

3. Measuring heat generated during unstable sliding on a fault and relating this to the total energy released during sliding.

Results

1. Unstable stick-slip events have been confined to a portion of a finely ground, 40- by 200-cm simulated fault in a granite sample by selectively injecting water onto the ends of the stressed fault. Source parameters of eight confined events generated at normal stresses between 0.7 and 4.1 MPa have been measured. Dynamic stress drops increased from 0.06 to 0.38 MPa with increasing normal stress such that the ratio of stress drop to normal stress is about 0.09. Fractional shear stress drops of these events are approximately 0.2 MPa. Total fault slip measured at the center of the slipped portion ranged from 8.5 to 38.9 μm. The maximum relative slip velocities at the same location ranged from 2.5 to 34.7 cm/s and slip velocity increased with increasing dynamic stress drop. The successful containment of stick-slip failures in the laboratory as demonstrated by these experiments now permits experimental investigation of problems pertinent to the effects that control the size of earthquakelike failures. Such problems range from the question of how seismic energy is radiated from the fault during different stages of rupture, including the stopping stages, to the question of how the stable sliding induced by pore-fluid manipulation can be used to relieve stresses along active faults in the Earth. With these experimental procedures, we can also study the behavior of faults in simulated seismic gap regions and begin to understand the mechanics that ultimately lead to unstable failure within a seismic gap.

2. Frictional heating of a simulated fault was measured during unstable sliding at normal stresses up to 6.41 MPa. The heat generated during slip was proportional to total energy released and accounted for 94 $\pm$ 2%

of the total work. This implies a seismic efficiency of 4 to 8 percent. If these results are extended to earthquake-size events, they confirm theoretical arguments that for even moderate earthquakes, temperatures in the fault zone could rise hundreds of degrees and thermo-mechanical effects could be important.

Reports

Okubo, P.G., J.H. Dieterich and D.A. Lockner, Rupture velocities and fault roughness, Seism. Soc. of Amer. Annual Meeting, April 1982.

Lockner, D.A., P.G. Okubo and J.H. Dieterich, Containment of stick-slip failures on a simulated fault by pore fluid injection, submitted to Geophys. Res. Lett.

Lockner, D.A. and P.G. Okubo, Measurements of frictional heating in granite, submitted to J. Geophys. Res.

Theoretical Mechanics of Earthquake Precursors

9960-02115

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Investigations

Studied strain-induced pore pressure changes in a seismically active region.

Results

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. The theoretical relation between P and the solid dilatation Θ assuming elastic deformation is derived to be:

$$P = \frac{K_f(K_o-K)}{\phi(K_o-K_f)}\Theta$$

where K_f, K_o, and K are the bulk moduli of the fluid, the mineral grains, and the saturated composite respectively, and ϕ is the porosity.

The above relation is approximately satisfied by the data. Superimposed, however, is a slight frequency-dependent, inelastic effect due to the fluid motion. With increasing frequency (over the range 3 hz-50 hz) the ratio P/Θ decreases, indicating grain-scale pore-pore pressure gradients and flow, rather than large scale Biot flow.

Bounds on Lower Crustal Rheology

9960-02414

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Investigations

1. The isostatic gravity map for northern California calculated by the U.S. Geological Survey (Roberts et al., 1981) on the assumption of Airy compensation reveals a residual correlation between gravity and topography. Admittance calculations which determine the correlation between gravity and topography as a function of wavelength were performed to investigate whether the isostatic residuals were due to

   a) incorrect surface density value
   b) incorrect assumption for compensation depth
   c) departures from local compensation.

2. The origin of the Hawaiian swell, a teardrop-shaped depth anomaly encompassing the Hawaiian islands, has been hotly debated. One theory holds that the swell is a dynamic feature maintained by convecting currents in the mantle. A competing hypothesis proposes that the swell results from thermal expansion of oceanic lithosphere reheated by the Hawaiian hot spot. The most important piece of evidence cited in support of the former contention is the fact that the flexural rigidity of the oceanic lithosphere in the Hawaiian region is similar to that found elsewhere in the oceans for crust of equivalent age without a depth anomaly. The exponential dependence of rock strength on temperature predicts that reheated crust should have a lower rigidity. A one-dimensional thermal history calculation was performed to determine the effect of thermal rejuvenation of flexural rigidity.

Results

1. The admittance estimates at wavelengths less than 50 km suggest that the mafic and metamorphosed units in the Klamath Mountains are about 130 kg/m^3 more dense than the standard Bouguer reduction density of 2670 kg/m^3. The longer wavelength response requires some differences in the nature of isostatic compensation for features in eastern versus western sections of northern California. Although interpretation of the data is nonunique, a plausible explanation for the variation in compensation is that the Klamath Mountains are rootless structures supported by the low but nonzero rigidity of the underlying Gorda plate, while the Cascades are compensated by much shallower, low-density material within the North American plate.

2. Thermal history calculations reveal that the magnitude of the flexural rigidity of the oceanic lithosphere in the Hawaii region and its variation down the island chain is consistent with reheating of the lithosphere as long as the process initially only involves the lower half of an 80-100 km-thick oceanic lithosphere. Since this reheating model is also consistent with the heat flow data in the area, lithospheric reheating remains a viable model for explaining the Hawaiian swell.

Reports

McNutt, M.K., Tectonic zonation in northern California: Evidence from gravity anomalies, EOS Trans Amer. Geophys. Union, 62, 1032, 1981.

Menard, H.W. and M.K. McNutt, Aprons, moats, arches, swells, and guyot relief, EOS Trans Amer. Geophys. Union, 62, 1028, 1981.

Menard, H.W. and M.K. McNutt, Evidence for and consequences of thermal rejuvenation, J. Geophys. Res., in press, 1982.

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Probabilistic Approach in Earthquake Forecasting

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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 600 reported precursors, including the negative observations, have been compiled in 11 categories with 44 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 44 subcategories of precursory phenomena, 13 with 10 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:

- The precursors which show no recognizable scaling pattern against the magnitude of the eventual main shock. Examples of this group are foreshocks and precursory tilt.

- The precursors which show clear scaling with magnitude. These include seismic velocity ratio (V_p/V_s), duration of seismic quiescence, and, to some degree, the variation of b-value.

- The precursors which display clustering of precursory times around a mean value, which differs for different precursors from a few weeks to a few years. Examples include the earth current anomalies (mean precursory time about two weeks), strain (few months), radon concentration (few months), and the enhancement of seismicity (few years) only reported for larger earthquakes.

- The precursors with bimodal patterns of precursory times such as resistivity and leveling changes and the occurrence of microseismicity.

As an initial step in applying some of these results to the premonitory observations in southern California, we have analyzed the variation of seismicity in this region over the last half-century, using the Caltech Data File, at several magnitude levels. In addition, we have examined the variation of the regional b-value in comparison to its long-range base value by applying the method of locally weighted regression. The same method was tested for application to other problems requiring data reduction such as radon emission time histories. We are currently pursuing further analysis of the worldwide precursory data by applying the method of multiple regression to identify the influence of distance on the lead time and the amplitude of precursory signal. Other effects being examined include those of regional tectonics and source type. We are further examining the seismicity pattern of southern California at more refined levels for smaller subdivisions of the region, on the basis of recently suggested physiographic units (Allen (1981) personal communication) and eventually individual active faults of the area.

Internal Friction and Modulus Dispersion in Rocks at Seismic Frequencies

9960-01490

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Investigations

1. Internal friction in rocks at seismic frequencies and strain amplitudes.

2. Elastic properties of rocks.

Results

1. Direct stress-strain method for determining internal friction (Q^{-1}). Laboratory and theoretical investigations of the direct stress-strain method at 0.01 to 1.0 Hz and 10^{-8} to 10^{-7} strain amplitude were completed. A manuscript was prepared. Sample interfaces were identified as an important source of systematic error in the determination of Q^{-1}. Preparation of optically polished and clean surfaces are required to reduce errors in phase angle to 5 X 10^{-4} radians. For air-dried Westerly granite Q^{-1} is less than 2 X 10^{-3}, and is independent of frequency for uniaxial compression at atmospheric pressure and 25°C.

2. Elastic properties of rocks: (a) The determination of quasi-static Young's modulus of rocks at small strain (10^{-8}). Equipment modifications were made which reduce error resulting from bending of the apparatus frame. A piezoelectric transducer ($LiNbO_3$) was used to calibrate the displacement in the sample; however, a large systematic error in the strain remains to be identified.

(b) The manuscript "Differential path phase comparison method for determining pressure derivatives of elastic constants of solids" was revised and resubmitted to J. Geophys. Res.

Reports

H.-P. Liu and L. Peselnick, Investigations of internal friction in fused-quartz, steel, Lucite and Westerly Granite from 0.01 to 1.0 Hz at 10^{-8} to 10^{-7} strain amplitude. Approved by Director.

Mechanics of Geologic Structures Associated with Faulting

9960-02112

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Investigations

1. Field mapping and thin section investigation of strike-slip faults in granitic rocks of the Sierra Nevada. Mechanical analysis of their formation.

2. Field mapping and thin section investigation of joints in granitic rock of the Sierra Nevada. Mechanical analysis of their formation and inference of the state of stress and fracture toughness.

3. Investigation of the geometry of strike-slip and normal faults, and the nature of geometric discontinuities along fault zones (with Atilla Aydin).

4. Microscopic investigation of deformation structures within a strike-slip fault (with Y.-N. He and Steve Kirby).

Results

1. A steeply dipping joint set, striking N10^o-20^{o}E, was studied in the Mt. Givens granodiorite, central Sierra Nevada, to clarify the mechanics of fracture and joint formation in granitic rocks. Individual joints consist of numerous sub-parallel, planar segments. The lengths of joints range from meters to nearly one hundred meters, with shorter joints more abundant than longer ones. Between mapped joints are found small cracks with lengths of several centimeters, which parallel the larger joints. These cracks provide a link between grain scale microcracks and macroscopic joints.

   Examination of markers in outcrop and thin section demonstrates that relative displacements are dominantly normal to the joint surfaces, and that joints formed in response to an extensional deformation. The measured extensional strain accommodated by joints is on the order of 1-5 x 10^{-4}. A few joints in the area exhibit small strike-slip offsets, which resulted from a later superimposed shear. A method for determining an upper bound on the tensile stress responsible for initiating joint growth is developed. The method requires knowledge of the extensional strain accommodated by joint dilation, and the spatial density of joints, both of which can be determined by field observations. Calculations based on observations of joints in the Florence Lake area indicate relative tensile stresses (average remote stress plus internal fluid pressure) of less than 10 ± 6 MPa and 26 ± MPa at two outcrops. These values are compatible with existing data from laboratory uniaxial tension experiments.

2. Air-photo lineaments in the southern Mount Abbot quadrangle of the Sierra Nevada, California, U.S.A. form three transitional domains: the southwest domain dominated by NNE trending lineaments; the central domain of transitional NE to ENE trending lineaments; and the northeastern domain of NE trending lineaments. Detailed fracture mapping was conducted in outcrops between lineaments in the southwestern and central domains. Within each domain centimeter-long cracks, outcrop-scale fractures and photo-lineaments parallel one another. In the southwestern domain, the small cracks and outcrop fractures are found to be joints, and the lineaments are joint zones. In the central domain, many of the outcrop fractures are small left-lateral faults, and many of the lineaments are left-lateral fault zones. Detailed field and thin-section observations demonstrate that all fractures in the study area initially formed as opening fractures, i.e. joints. The faults developed as a later shear deformation concentrated on the pre-existing joint set. There appear to be no characteristics for differentiating lineaments that are fault zones from those that are joint zones on aerial photographs of this region. Yet, detailed mapping of a small area, combined with reconnaissance investigation, is apparently sufficient to characterize the types of fractures present within a lineament domain.

Reports

Segall, P., and Pollard, D.D., 1981, Nucleation and growth of strike-slip faults in granite, Sierra Nevada, California: (abstract) Amer. Geophys. Union Trans., v. 62, p. 1037-1038.

Segall, P., and Pollard, D.D., (in press), From joints and faults to photo-lineaments: Proc. Fourth International Conf. on Basement Tectonics.

Segall, P., and Pollard, D.D., (in press), The process of joint formation in granitic rock near Florence Lake, Sierra Nevada, California: Geol. Soc. Amer. Bull.

He, Y.-N., Kirby, S.H., and Segall, P., 1981, Deformation microstructures within a strike-slip fault in granodiorite: (abstract) Amer. Geophys. Union Trans., v. 62, p. 1030.

FUNDAMENTAL STUDIES ON FAULT MECHANICS AND EARTHQUAKE PRECURSORY PROCESSES

14-08-0001-19793

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Investigations

Studies carried out under this project have been a continuation of basic studies on pre-instability deformations and slip motions in earthquake fault zones, particularly as these may relate to the generation of detectable precursors. They have been grouped in the following way:

1. Tectonic scale stressing and rupture at plate boundaries, asthenospheric coupling, and relation to seismicity patterns.
2. Fault instability in relation to constitutive descriptions for frictional slip.
3. Electrical phenomena preceding rupture processes.

Results

1.1 The model for great earthquake rupture process along tectonic plate boundary has been developed and analyzed. In the model it is assumed that the generation process of a great earthquake along a plate boundary can be described as the quasi-static growth of a slipped zone, starting from some depth at plate boundary where plates are almost decoupled and fast creep occurs. The deformation front, modelled by a crack, progresses upward along the plate boundary, culminating in the great earthquake rupturing the most shallow parts of boundary segment. The model deals with quasi-static crack growth along some segment of plate boundary and is able to predict time dependence of slip on the fault in dependence 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 at critical fracture energy, characterized by a bell-shaped curve as proposed by Stuart and Mavko (1979)), rupture length, and relaxation time of the asthenosphere. In the model transmission of stress in the lithosphere-asthenosphere system is treated with the use of general plane stress theory and thickness-averaged values of all considered variables in the lithosphere, and coupling to the viscoelastic asthenosphere is obtained with the use of generalized Elsasser model (as proposed by Rice, 1980). This coupling stabilizes the progression of slipping front after reaching a first instability, after which self-driven progress of the ruptured zone occurs, until the system reaches the final dynamic instability point corresponding to a great earthquake.

A first estimate of time dependence of slip on the fault during the whole seismic cycle has been computed for different ranges of parameters affecting the model. In the range of assumed values it has been found that the precursory period (i.e. time between first instability point and final dynamic instability of the system) could range from 1 to 5 years. It has been also found, that with other parameters equal, a longer precursor period is associated with a longer rupture, which appears to be consistent with seismological observations.

As the outgrowth of this work a paper by Li and Rice has been submitted for presentation at U.S. National Congress of Applied Mechanics, Cornell University, June 1982, and two papers have been prepared in a draft form.

1.2 The large-scale response of an elastic lithosphere riding on a visco-elastic asthenosphere to periodic slip at a transform or subduction-type plate boundary has been described by an appropriate limit cycle solution for the generalized Elsasser type plate model introduced and analyzed previously by Rice (1980) and Lehner et al. (1981). The periodic behavior of displacements and stress, their decay away from the plate boundary, and a resolution into co-seismic and post-seismic stress alterations have been obtained, and their dependence on plate velocity, recurrence time, and a characteristic relaxation time investigated. Post-seismic stress alterations of equal sign as co-seismic stress jumps appear gradually at distances beyond one lithosphere thickness and become progressively more important than the latter. They are followed by a much slower post-seismic stress recovery, extending typically over 80% of the cycle length. The results of this study (Lehner and Li, 1982) should provide aid in interpreting data from monitoring stations with a view on discovering potential long term precursory trends.

1.3 The modelling described in the previous paragraphs has been also generalized to cover strength/friction inhomogeneities of the plate boundary (Dmowska and Li, 1982). Different strength-depth dependences have been introduced for different x-coordinates along the rupturing segment, each x-slice being treated in a manner based on the "line-spring" concept for part-through cracks in plates introduced by Rice and Levy (1972). This approach allowed for introducing horizontal asperities, blocking the upward progression of slip zone and being either local higher strength regions or areas of currently higher strength due to a local slowdown of a basically rate-dependent frictional response. In this work the progression of slip is interpreted by either seismic slip in the form of small earthquakes (background seismicity) or aseismic slip, caused by creep processes along some parts of the fault. The blocking of the slip region by one or more asperities is interpreted in terms of a seismicity gap, observed before many great earthquakes, accompanied by higher small earthquake seismicity appearing at one or both ends of seismic gap zone and interpreted in terms of the model as associated with partial entrance of a slip zone into an asperity region, especially at the ends of the asperity, where high stress concentration occurs and where slip events could be associated with local higher stress drops. Numerical results show that the advance of the slip front is rapid (per unit remote load increase or unit time increase) at depth, reflecting the low fracture energy and fast creep conditions at the base of the lithosphere. The slip front generally slows as it encounters the brittle seismogenic layer. Parts of the slip front that come in contact with the asperities tend to proceed slower relative to the portions outside the asperities. This is due to the requirement of higher local stress for the slip front to push through the stronger areas on the fault surface, so the asperities act as stress concentrators.

2.1 The following paragraph is the abstract of a recent summary paper by Rice and Ruina (1982) that establishes general linearized stability conditions for steady frictional slipping:

"The shear resistance of slipping surfaces at fixed normal stress is given by $\tau = \tau(V,\text{state})$. Here V = slip velocity, dependence on "state" is equivalent to functional dependence on prior V(t), and $\partial\tau(V,\text{state})/\partial V > 0$. We establish linear stability conditions for steady slip states ($V(t), \tau(t)$ constant). For single degree of freedom elastic or viscoelastic dynamical systems instability occurs, if at all, by a flutter mode when the spring stiffness (or appropriate viscoelastic generalization) reduces to a critical value. Similar conclusions are reached for slipping continua with spatially periodic perturbations along their interface, and in this case the existence of propagating frictional creep waves is established at critical conditions".

The stability analysis is carried out by linearizing the functional dependence of $\tau(t)$ on $V(t')$, $-\infty < t' \leq t$, about the value τ_{ss} [$= \tau_{ss}(V)$] for steady-state slip at speed $V = V_o$. This has the form (with $V(t) = V_o + \dot{x}(t), |\dot{x}(t)| \ll V_o$, and $\dot{x}(t) = 0$ for $t < 0$):

$$\tau(t) = \tau_{ss} + f\dot{x}(t) - \int_o^t h(t-t')\dot{x}(t')dt'$$

where

$$f \equiv \partial\tau(V,\text{state})/\partial V > 0 \ , \quad f - \int_o^\infty h(t)dt \equiv d\tau_{ss}(V)/dV < 0 \ ,$$

the derivative being evaluated in steady state with $V = V_o$. As mentioned in the above abstract, among other problems we have considered the steady sliding of a one degree of freedom system with mass m and elastic spring stiffness k per unit area of slip surface. This system can be represented as a rigid block that is dragged along a surface by a spring, of which one end is attached to the block and the other is moved at constant speed V_o. In this case (as in all others considered) instability occurs by a "flutter" mode of circular frequency β at critical conditions given by

$$\int_o^\infty \cos\beta t\, h(t)dt = f \ ,$$

and the sliding system is stable only if

$$k \geq k_{cr} \equiv m\beta^2 + \beta\int_o^\infty \sin\beta t\, h(t)dt.$$

All problems examined correspond to bifurcations (as stiffness, like k, is reduced) of the Hopf type, such that the underlying non-linear constitutive structure allows finite amplitude periodic oscillations in $V(t)-V_o$ in some small neighborhood of k_{cr} with either: (i) $k < k_{cr}$, in which case the periodic oscillations are stable, i.e., limit cycles; (ii) $k = k_{cr}$; or (iii) $k > k_{cr}$, in which case the periodic oscillations are unstable.

2.2 A reasonably full non-linear analysis of slip instability has been possible in one simple case, discussed in summary paper by Gu, Rice and Ruina (1982), the abstract follows:

"Motion of a spring and massless-block (with a surface of frictional contact) is found numerically and analytically. The friction force is assumed to depend additively on $A\ell n$(slip rate) and a state variable which hunts the value $-B\ell n$(slip rate), (A,B constants with $B > A > 0$). This law is based on features of experiments of Dieterich (1979) and Ruina (1980) valid over a range of slip speeds. Constant slip rate motion near steady state goes from stable to unstable with decreasing spring stiffness k. At neutral linear stability finite oscillations are observed. Sufficiently large perturbations cause instability for all finite k. The results imply that "stick-slip" is possible even in systems for which steady sliding is stable and that physical manifestation of quasistatic oscillations depends delicately on material properties".

The constitutive law is of the one-state-variable type, and is sensible for $V > 0$ only:

$$\tau = C + A\ln(V/V_1) + \theta\ , \quad d\theta/dt = -(V/L)[\theta + B\ln(V/V_1)]\ .$$

Here A, B, C, V_1, and L are positive constants with $A < B$. In the notation of the linear stability analysis described in 1.1 above, h(t) is proportional to $\exp(-V_o t/L)$, $f = A$ and $\int_o^\infty h(t)dt = B$. The flutter frequency of the linear stability analysis at critical conditions and the critical spring stiffness (with $m = 0$) are

$$\beta = (V_o/L)[(B-A)/A]^{1/2}\ , \quad k_{cr} = (B-A)/L\ .$$

The non-linear analysis of this case shows that the Hopf bifurcation into a periodic orbit is of type (ii) above. Further, we have succeeded in explicity constructing periodic orbits (in a τ versus θ plane) for the simple one-degree-of-freedom system described in 1.1. As mentioned in the abstract, this periodic orbit becomes unstable at sufficiently large amplitude, as do all orbits with $k > k_{cr}$,

3. No new work has been done on electrical phenomena preceding rupture processes in the period of this report, however the paper by Dmowska and Stopinski on electrical resistivity changes of rocks before and during rockbursts in a copper mine in Poland has been accepted for publication in "Pure and Applied Geophysics" in July 1981 pending revisions which are still underway.

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THEORETICAL STUDIES OF RUPTURE PROCESSES IN GEOLOGICAL MATERIAL

14-08-0001-19850

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Summary of Accomplishments

During the six month period May 21, 1981 to December 1, 1981 we have continued work in two areas of the proposed studies: effects of dilatant hardening on the development of incipient shear rupture and 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. Approximate and perturbation solutions of this problem are being investigated in order to clarify some aspects of the approach to instability that were not resolved sufficiently by our finite difference solution and to obtain a method that is less expensive and more suitable for application to complex geometries than a direct numerical approach. One approach we are examining is a perturbation expansion in the small parameter $\dot{U}h/c$ where h is the height of the layer and c is the diffusivity. The zeroth order solution ($\dot{U}h/c = o$) corresponds to homogeneous deformation in each sublayer and a uniform value of the pore pressure throughout the layer. Although this solution is valid for most of the deformation history, it breaks down when the weakened sublayer nears the peak in its stress strain curve. Corrections to the zeroth order solution necessitate the introduction of a boundary layer at the interface between the sublayers. A second approach idealizes the deformation in each sublayer as homogeneous and assumes that the fluid mass flux between the sublayers is proportional to the difference in the pore fluid pressures. This approach leads to a set of coupled nonlinear first order differential equations. The homogeneous solution of the linearized version of these equations changes from exponentially decaying to exponentially growing in time when the weakened sublayer passes the peak of its drained stress strain curve. This feature is consistent with the linearized stability analysis by Rice (JGR, 80, 1531-1536, 1975) of the exact layer equations and gives some confidence in the ability of the approximate equations to describe instability.

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.

In Situ Stress Measurements

9960-01184

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Investigations

The efforts of this project were devoted to a wide variety of investigations. These activities and those planned for the remainder of this fiscal year are displayed on the attached chart. In October and November we drilled three holes at San Juan Bautista for the emplacement of the Carnegie dilatometers. In November we instrumented the deep borehole at Hi Vista, near Palmdale, California, to record water level for a period of 20 days and gathered data for comparison with data from other water wells in California. Joe Svitek, Steve Hickman, and Dan Moos went to Panama to install measuring instruments on the GLOMAR CHALLENGER, the research vessel used for deep sea drilling, to make in situ measurements. In November and December we made stress measurements and televiewer logs in a 5,000 ft borehole on Yucca Mountain at the Nevada Test Site. In January and February we drilled a deep hole at Oroville, California, which successfully penetrated an active fault zone that had surface ruptured during the 1975 Oroville earth- quake. In February, March, and April we planned and executed stress measure- ments and televiewer logs in a 5,000 ft borehole drilled in Auburn, New York. In March and April we logged three drill holes in Pinon Flat that were prepared for installation of Sachs meters. In April and May we returned to San Juan Bautista to assist with the installation of the Sachs meters at that site and we are currently planning to return to Oroville to finish the measurements started there. Also during this period, research continued on the development of the televiewer systems that offer great promise for obtaining additional information from the televiewer logs, and a new 12-channel ultrasonic logging tool from Simplec Co. is being developed for use in our holes that was purchased with funding from the deep sea drilling experimental program.

Results

We are continually gaining experience in solving the problems of drilling holes in rocks near active fault zones. Although this experience does not translate into results we believe we are making progress in the operational aspects of these problems which will pay dividends in the future, both in the economics of drilling holes and installing instruments, and, more importantly, in understanding the physical properties of the rocks in which the instruments are installed. We are gradually improving the equipment and techniques needed for deep stress measurements. We have successfully made measurements at a depth of 5,000 ft and from this experience we are making design changes in our instrumentation which hopefully will permit us to make stress measurements to at least 10,000 ft. Data from the experiments conducted in the first six months of this year have been analyzed in a preliminary manner. Important results from these experiments include:

1. After some difficulty a deep fracture at 1950 ft in the Hi Vista drill hole was isolated and water level monitoring showed a large tidal fluctuation of fluid pressure in this fracture zone. The amplitude of this fluctuation exceeds 10 cm and corresponds almost exactly to the predicted volumetric tidal strain. The drift during the 20-day period is less than 3 cm or 1/3 of the tidal amplitude. Thus, it appears that this well and others like it could be one of the most sensitive measures of volumetric strain changes over periods of several months.

2. On Yucca Mountain at the Nevada Test Site there were three important discoveries. The well had been hydrofraced by the drilling fluid producing long fractures that indicate a maximum compressional stress about N10°W. Televiewer logs show long vertical features that are apparently related to borehole ellipticity and are oriented at 90° to the drilling-induced hydrofractures. While this feature is more prominently displayed in the logs from the Yucca Mountain hole than in any other hole we have investigated, it suggests that the televiewer has the potential of determining stress direction from hole ellipticity. Finally, the least principal stress in this hole is much less than the vertical stress, suggesting that the rocks on Yucca Mountain are close to the point of normal faulting.

3. At Oroville we successfully drilled through an active fault zone. After drilling to a depth of about 1,500 ft the rocks in this fault zone collapsed into the borehole and temporarily prevented us from working below about 1,100 ft where the fault zone intersects the borehole. As in other places where we have intersected fault zones, the zone is obviously not a single plain but involves a zone of crushing at least 30 m in thickness and consists of multiple fracture plains within this zone of fractured rock.

Reports

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01184 Field Projects Calendar

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Oct    Nov    Dec    Jan    Feb   Mar   Apr   May   Jun    Jul   Aug   Sep   Oct
_________________________________________________________________________________

 SJB                                      SJB
-----I                                 I-------I

       HV
     I____I

         PA
       I----I

           NTS                                                                 NTS
        I------I                                                              I---

                         Oroville                Oroville
                     I-------------I            I--------I

                               New York
                             I-----------I

                                    PF
                                  I----I

                                                      Hfd
                                                     I---I

                                                               Hi Vista
                                                          I---------------I
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HV Hi Vista
PA Panama
PF Pinon Flat
Hfd Hanford

Fault Zone Structures

9930-01725

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Investigations

1. Earthquake hazards and crustal structure in the northern Mississippi Embayment, central United States.

2. Detailed crustal studies in and near fault zones of central and southern California in support of strong ground motion studies.

3. Edited, made changes, and wrote additional sections for the Saudi Arabian profile final report.

4. Prepared a proposal in conjunction with Dr. Robert Kovach of Stanford University for a semi-permanent seismic network in Jordan to survey the microseismic activity in the region of the Dead Sea rift. Outlined the project goals (understanding the geologic structures, geothermal prospects, assessing seismic risk; instrument maintenance and data analysis training for Jordanians), the instrument system design, construction, and installation, and the plans for instrument operation and data analysis.

Results

The Mississippi Embayment has received considerable attention during the past decade. The focus of this attention has centered on the New Madrid seismic zone, where in 1811 and 1912, the most devistating earthquakes on the continent occured, in an area adjacent to the stable craton. The largest of these shocks had an estimated modified Mercalli intensity of XII and an estimated felt area (intensity V) of 2,500,00 km^2 (Nullti, 1973). The extremely large felt area, and extensive damage from the 1811-1812 shocks was primarily due to the great thickness of loosely consolidated sediments in the embayment (Nuttli, 1973). Recently there has been concern, in light of population increases, and the possibility of nuclear plant construction; that a recurrent series of equal magnitude would be extremely destructive. Recent seismic studies in the embayment have gained considerable information regarding the cause of this seismicity. Plots of epicenters from recent earthquakes in the New Madrid area have revealed a roughly linear zone of seismicity which extends south of New Madrid, and follows a course approximately parallel with the Mississippi River (Nuttli, 1979; Hermann, 1980).

In September, 1980, we conducted a detailed seismic refraction investigation in the northern Mississippi Embayment. The experiment was designed to obtain a number of overlapping, reversed profiles along the assumed axis of the rift and to obtain information about the areal distribution of the velocities in the northern Embayment. In order to achieve that design, a total of 34 shots were fired from nine shotpoints along an axial line, a flank line, and four cross lines arranged perpendicular and diagonal to the axial line (fig. 2). The seismic data were recorded on analog tape by 100 portable seismographs deployed along the profiles. The data were digitized in the field and record sections plotted in order to monitor the quality of the recorded data.

The crustal structure of the Embayment has been shown to consist of six primary layers. The first four layers can be identified lithologically, based on regional surface and borehole data as loosely consolidated Cenozoic and Mesozoic rocks (1.8 km/s), Paleozoic dolomitic and carbonate rocks (5.95 km/s), poorly metamorphosed sedimentary rocks (4.9 km/s low velocity layer) and crystalline upper crustal rocks (6.2 km/s). The lower two layers corresponde geologically to metamorphic lower crust (6.6 km/s) and modified lower crust (7.3 km/s).

Two of the layers are of particular importance to the interpretation of the Embayment as a continental rift. The sediments of the low velocity layer must be older than the overlying Early Paleozoic sedimentary rocks and we interpret them to be the graben sediments within the late Precambrian rift outlined by aeromagnetic and gravity data (Hildenbrand et al., 1977; Kane et al., 1981). The 7.3 km/s lower crustal layer is interpreted as a mixture of mantle derived material and normal lower crustal material (6.6 km/s). This layer is discussed by previous workers and is interpreted as a product of a rift event (Ervin and McGinnss, 1975), but the present work has identified it's three-dimensional structure. The layer forms a dome in the northern Embayment beneath the Rellfoot basin (fig. 1) and dips gently to the east and west, rapidly to the southwest. If the dome is identified as the product of Precambrian mantle plume, the Embayment may be viewed as an arm of a triple junction, the other arms going through the Rome trough and Illinois basin. This suggested location of the mantle plume differs from the southern Mississippi location proposed by Burke and Dewey (1973).

2. The Santa Clara Valley and the southern Santa Cruz mountains of west central California were chosen as the site of a seismic refraction investigation in July 1980 because the region lies to the west of the portion of the Calaveras fault that ruptured in the magnitude 6.4 Coyote Lake earthquake in August 1979 (Lee el at., 1979; figure 1). Continuing investigations of foreshocks and aftershocks of that earthquake indicate strong lateral velocity variations in the epicentral region (figure 1); we provide some details concerning those variations. In addition, five strong ground motion instruments located in the Santa Clara Valley near the city of Gilroy wrote records of the main shock and its aftershocks (Brady et al., 1981). Preliminary interpretation of these accelerograms indicates that the velocity structure of the valley has a significant effect on the seismograms (Spudich and Angstman, 1980). We here describe the shallow structure of the valley in the vicinity of Gilroy, California.

Two seismic refraction profiles were recorded in the Santa Clara Valley. The data indicate that the valley is wedge-shaped in cross-section with the basement dipping 10^o to the east. The alluvial fill of the valley has a maximum thickness of 1.5 km and has an average compressional-wave velocity of 2.3 km/s. The top of the basement has a velocity of 4.3 km/s; the velocity reaches 6.0 km/s at a depth of 2 km. The Calaveras fault zone, located due east of the valley, was crossed by a short, unreversed profile. It appears to be characterized by a low velocity (V_p = 2.7 km/s) to depth of 2.5 km. The southern Santa Cruz Mountain profile indicates a 4.6 km/s near-surface refractor and a layer with a velocity of 6/1 km/s at 2 km depth. Thus, considered together, the similarity in velocity structure determined from the two profiles indicates that the Franciscan rocks of the Santa Cruz Mountains continue beneath the valley.

Reports

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Healy, J. H., Mooney, W. D., Blank, H. R., Gettings, M. E., Kohler, W. M., Lamson, R. J., and Leone, L. E., 1982, Saudi Arabian seismic deep-refraction profile: final project report, U.S. Geological Survey Open-File Report USGS-OF-02-37, 255 pp.

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 California, Arizona, and Nevada. Sites were selected for FY 82 drilling.

2. Heat flow and tectonics of Alaska: Work was completed on Prudhoe Bay, and additional thermal conductivity data were obtained from NPR-A.

3. Thermal studies related to nuclear waste isolation: Temperature logs and additional thermal conductivity data were obtained from the Yucca Mountain site, Nevada, and the Paradox Basin in SE Utah. Interpretive studies of both regions continued. Geothermal input was provided for the Basin-and-Range working group's site-screening activities.

4. Equipment development. Laboratory testing of temperature-monitoring equipment continued. Logging capability is being extended to depths of greater than 4 km.

Results:

1. Heat flow and tectonics of the western United States: Heat-flow calculations on the Mojave-Sonoran Desert - Mexican Highland regions of the Basin and Range province are nearing completion, and interpretive work is under way. A report documenting thermal studies in the California Cascades has been released (Open-File 82-150). The main finding of this study to date is that the expected thermal anomaly across the high cascades is concealed (at least in the upper few hundred meters) by regional groundwater circulation with discharge at low enthalpy from springs. A similar situation exists around the San Francisco volcanic field in Arizona.

2. Heat flow and tectonics of Alaska: The geothermal regime at Prudhoe Bay has been analyzed in a manuscript submitted to JGR. A general model of the area yields the heat flow, recent climatic change and a means of predicting the depth of offshore permafrost and post-Pleistocene transgression rates for the Arctic Ocean shoreline. A manuscript on permafrost distribution on the Alaskan Arctic slope was submitted for a USGS professional paper. It contains an analysis of geothermal data from 25 oil exploration wells which were kept open for measurements of equilibrium temperatures. Both depth of permafrost and temperature gradients vary laterally. The results of conductivity studies presently under way will determine the extent to which these variations are the result of corresponding variations in heat flow in the sedimentary basin.

3. <u>Thermal studies related to nuclear waste isolation</u>: Analysis of thermal data from 60 wells in and adjacent to the Nevada Test Site indicates a Basin-and-Range thermal regime perturbed by both local and regional groundwater flow. Heat-flow studies at two sites in the Paradox Basin, southeastern Utah, indicate normal heat flow with little evidence for vertical water movement locally.

4. <u>Equipment development</u>: We are conducting long-term (a few months) downhole tests of our precision (10^{-4} °C) temperature-monitoring system, and incorporating refinements to increase long-term stability.

<u>Reports</u>:

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Active Seismology in Fault Zones

9930-02102

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Investigations

1. Collection and analysis of seismic refraction data in central California: Livermore Valley, Great Valley, Diablo Range, Santa Clara Valley, Gabilan Range, and Santa Cruz Mtns. (with A. Walter).

2. Analysis of seismic refraction data from the Mojave Desert, southern California (G. S. Fuis and A. Walter).

3. Analysis of refraction data from the Mississippi embayment (with A. Walter, W. Lutter, A. Ginzberg, D. Peters, and M. Andrews).

4. Continued development of hardware and software systems for analysis of seismic refraction data (with G. Fuis, W. Kohler and A. Walter).

5. Continued analysis of wave propagation problems (with D. P. Hill and G. S. Fuis).

Results

1. Considerable progress has been made in the determination of the 2- and 3- dimensional velocity structure of the crust in central California. These investigations, carried out with the active support of several projects within the USGS have revealed that there is a resolvable difference in the crustal velocity structure on either side of the San Andreas fault. Below the sediments and weathered zone, the upper crust (3-8 km) of the Diablo Range has an average velocity of 5.5 km/s while in the Gabilan Range the average velocity is 6.1 km/s. In the middle crust (8-17 km) the Diablo Range has an average velocity of 6.1 km/s, while it is 6.3 km/s in the Gabilan Range. In the lower crust (17-29 km) the average velocity in the Diablo Range is 6.9 km/s while it is 6.5 km/s in the Gabilan Range. These contrasts in velocity with depth are indicative

of compositional differences between the two ranges. We concluded that the Diablo Range most likely consists of metagraywacke to a depth of 17 km, and a gabboic material below this depth. The Gabilan Range consists of granitic material to a depth of 17 km of metagranite (gneiss) in the lower crust, but it is possible that some gabbroic rocks are also present.

Newly recorded profiles are currently undergoing analysis. Profiles 1 and 2 run across and along the Great Valley, respectively, and were designed to provide information concerning the basement structure there and its relationship to the flanking Diablo and Sierra blocks.

2. Seismic-refraction profiles and geophysical studies in wells (1 km deep) have begun to shed light on relatively shallow crustal structure in the Mojave Desert, California. Deep (10 km) structure cannot be fully understood without understanding shallow structure, but inferences can be made.

1) Scattered alluvial basins as deep as 0.4 km are seen along a seismic-refraction profile from Rogers Dry Lake, in the western Mojave Desert, to Holcomb Ridge, in the San Andreas fault zone to the south (see index map in fig. 1) Sedimentary velocities range from 1.6 to about 2 km/s.

2) Granitic rocks exposed at the surface and underlying the alluvial basins can be modeled in two parts: a) an upper part 0.5 to about 3 km thick where velocity increases relatively rapidly with depths from 4.8 to 5.8 km/s; and b) a lower part where the velocity increases relatively slowly from 5.8 to at least 6.2 km/s at 10 km depth. Mapping of cracks in wells together with velocity logging and laboratory velocity studies indicate that the upper part of the granitic rocks is a region where cracks are closing rapidly with depths, and the lower part is a region where cracks are largely closed.

3) There is weak evidence for an intermediate crustal layer with a velocity of 6.8 to 7.0 km/s at about 20 km depth at least in the region southwest of Lake Mead, Nevada (Roller and Healy, 1963).

4) Mantle apparent velocities range from 7.6 to 8.6 km/s over most of the Majave Desert. In the eastern Mojave Desert a true velocity near 7.8 km/s is inferred from reversing traveltime branches from Nevada Test Site explosions and the October 15, 1979, Imperial Valley earthquake (fig. 2a). Higher and lower apparent velocities can be interpreted to indicate structure on the Moho discontinuity, namely an asymmetric ridge, or hinge, trending north-northwest roughly from the Coxcomb Mountains to the east end of the Garlock fault

3. See report for project 9930-01725, J. H. Healy and W. Mooney, Fault Zone Structures.

4. A major problem in any investigation that requires handling large amounts of data is creating a system that allows rapid and convenient access and display of data. To provide this ease of access we have implimented a number of improvements to our data processing/analysis system. 1) seismic sections with theoretical model times and amplitudes can now be plotted in a variety of formats on the National Strong Ground Motion PDP 11/70 computer. 2) a PDP 11/23 computer with hard and floppy disks has been added to allow for more rapid initial processing.

5. Near-surface seismic sources in deep sedimentary basins generate a family of multiple diving waves that are refracted upward by increasing P-wave velocity with depth and reflected downward by the free surface. The first three members of this family are represented by the direct P wave, the once-reflected PP wave, and the twice-reflected PPP wave. The whispering-gallery phase, P_W, is formed by the combination of waves that are reflected a progressively greater number of times and penetrate to progressively shallower depths beneath the free surface. Typical record sections from seismic-refraction profiles in the Imperial Valley of southern California and the Great Valley of central California show the P through PPP waves. The P-wave coda following the PPP wave becomes progressively more complex as P_W develops and terminates rather abruptly at the end of the whispering gallery phase. This family of diving P waves provides considerable leverage in resolving both the two-demensional velocity structure and the apparent Q in deep sedimentary basins.

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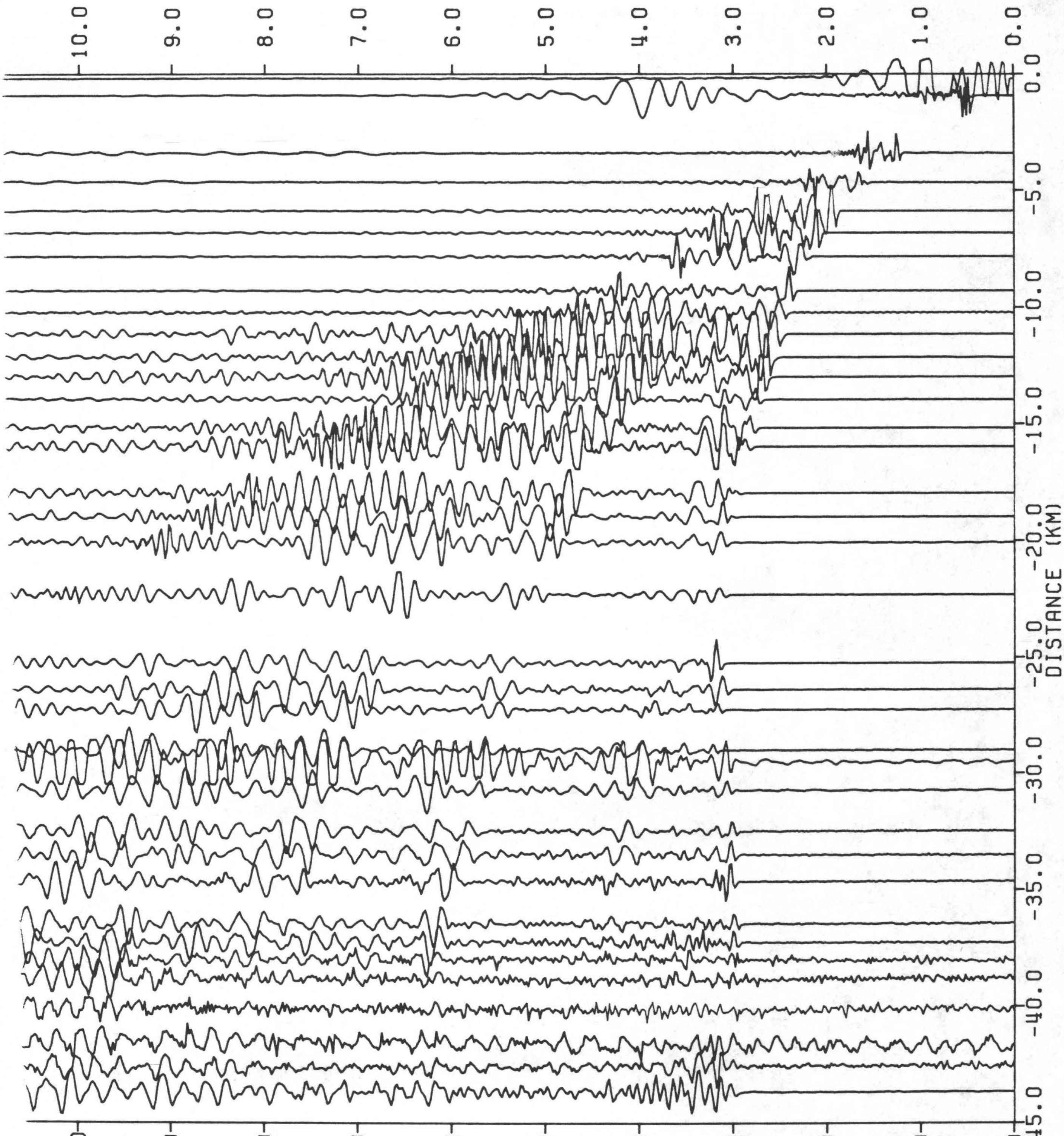

GREAT VALLEY LOS BANOS NORTH

Seismicity and Structure of the San Pablo Bay-Suisin Bay Seismic Gap from Calnet and Explosion Data

9930-02938

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Investigations

General investigation of the seismicity was continued, using plots of Calnet data.

Results

Major changes in seismicity occur in going from one side of the Gap to the other. Earthquake activity on the San Andreas Fault is low to the southeast (SE) and almost absent to northwest (NW). The Hayward Fault to the SE aligns with the Rodgers Creek Fault to the NW, and the Hayward Fault is more active. The Concord Fault to the SE is much more active than the Green Valley Fault to the NW, and the fault azimuth of the Green Valley Fault is about 20^{o} more northerly than that of the Concord Fault. There is no gap in the Antioch Fault just east of Suisin bay; it seems to terminate the Gap region.

Reports

None.

Worldwide Standardized Seismograph Network (WWSSN)

9920-01201

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Investigations

1. Technical and operational support was provided to the Worldwide Standardized Seismograph Network (WWSSN) as required and as funding and staffing permitted.

2. During this report period 228 modules and units and 372 separate items were shipped to 122 locations in support of the network. Forty-two stations were supplied with annual shipments of photographic supplies and emergency shipments were made to forty-one stations.

3. Training was given to Kathy Covert of the Topographical Division from 19 October 1981 to 30 October 1981. Kathy is wintering over at the South Pole and is responsible for the operation and maintenance of the WWSSN equipment located there. Training on the WWSSN and related equipment was also provided to one Raytheon Contract Technician during this period.

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: Continuously monitor U.S. seismicity using data recorded by the U.S. Seismic Network.

Worldwide 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 network will be complete by late summer.

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 exchnaged with both organizations.

Data Processing Section

9920-02217

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Investigations

1. Data processing for the Global Digital Seismograph Network - All of the digital data received from the global network is reviewed and checked for quality.

2. Network-Day Tape Program - All of the digital data received at the ASL is 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 presently being coded for use with the SRO and other digital recording systems. Secondary arrivals are also being detected.

Results

1. Data processing for the Global Digital Seismograph Network - During the past 6 months 358 digital tapes (169 SRO/ASRO and 189 DWWSSN) from the global network were edited, checked for quality, corrected when feasible, copied, and archived at the Albuquerque Seismological Laboratory.

The Sandia Corporation, Albuquerque, New Mexico, has established a Regional Seismic Test Network (RSTN) consisting of five stations. Station locations are: Cumberland Plateau, Tennessee (RSCP), Black Hills, South Dakota (RSSD), Adirondack, New York (RSNY), Red Lake, Ontario (RSON), and Yellow Knife, Northwest Territory (RSNT). All stations use borehole seismometers and transmit their data via satellite direct to Sandia Corporation, Albuquerque. We are working with Sandia software personnel to reformat and event detect these data and include it in the GDSN data base.

A GDSN Newsletter is being assembled which will contain pertinent information on the digital network including hardware problems, software availability, and general information on the status of the network. The first newsletter will be distributed in May 1982. Other editions will follow at fairly regular intervals.

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. Digital data from the RSTN program operated by the Sandia Corporation of Albuquerque, New Mexico, will be added to the network-day tapes in the relatively near future. These data must be event detected and reformatted prior to its inclusion. Most of this work has been completed, and the RSTN data should be available for the network-day tape program within the next 30 to 60 days.

3. Event Detection Program developed for the Global Digital Seismograph Network - Considerable revision was done with this program so it could be used to event detect the RSTN data recorded by the Sandia Corporation. We are now able to detect all short-period events with very few false alarms, even events that are almost buried in the background noise. In addition to detecting an event, the algorithm picks the direction of the first break and onset time, evaluates the pick, and estimates the period and amplitude of the signal. Coding is almost completed for the SRO field systems, and after the testing at the ASL should be installed by late summer. Additional subroutines have been written to pick later arrivals which they seem to do quite satisfactorily. A paper on this event detection program will be presented at the April meeting of the Seismological Society of America.

Reports

Murdock, J. N., and Jaksha, L, 1982, Preliminary estimate of the refractor velocity and the time terms of the Northern Basin and Range Province, Arizona: Earthquake Notes, v. 53, no. 1, p. 22-23.

Murdock, J. N., and Hutt, C. R., 1982, An event detector for digital short-period data: Earthquake Notes, v. 53, no. 1, p. 60-61.

Socorro Magma Bodies

9920-03379

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Goals

Study the relationship between earthquakes and injection of magma into the crust.

Investigations

The instrumentation network is being deployed.

Results

None.

Reports

None.

Albuquerque Observatory

9920-01260

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Investigations

1. Over the last 2 years we have compiled seismic data for a velocity model of the San Juan Basin, New Mexico. These data have been analyzed and the results are being prepared for publication as a part of a USGS professional paper.

2. Central Arizona Crustal Study - Results

a. Fifteen seismic stations were deployed between the Navajo/San Juan coal mines near Farmington, New Mexico, and the Jackpile uranium mine near Laguna, New Mexico, a distance of about 220 km. Shots recorded from the Navajo/San Juan mines yielded a Pg velocity of 6.1 km/s and the Jackpile shot gave a velocity of 5.9 km/s. The Navajo shot was also recorded at the Whitehorse Well, an oil test that bottomed in Precambrian granite after about 2.3 km of drilling. The shotline data combined with information from the drill hole suggest that the Phanerozoic section in the San Juan Basin is about 3 km thick and has a Pg velocity of about 3.2 km/s. The Pg velocity in the basement rocks is 6.0 km/s. A record section, compiled from the Navajo/San Juan shots suggests the presence of 2 clear reflectors beneath the basin. These reflectors, interpreted to be the Conrad and Mohorovicic discontinuities, seem to be at depths of 31 and 48 km.

A time-term study was done using 9 regional earthquakes and explosions recorded on the 8 station seismic network that monitors San Juan Basin seismicity. This analysis yielded a Pn velocity of 7.9 $\pm$ .15 km/s beneath the basin and Pn time-terms that range from near 4s for stations on bedrock to over 5s at stations on thick sections of sediments.

b. We have interpreted Pn arrivals on a shotline deployed between Globe, Arizona, and Parker Dam, Arizona. The energy sources used were MISERS BLUFF, a conventional device fired at Parker Dam, PANIR, a nuclear device fired at N.T.S., and quarry shots from Globe and Morenci. Our preliminary estimate of the Pn refractor velocity is 7.92 $\pm$ .04 km/s. The time terms suggest a 2°-3° dip eastward along the line from north of Phoenix to Globe.

Reports

Murdock, J. N., and Jaksha, L. H., 1982, Prelminary estimate of the refractor velocity and time terms of the Northern Basin and Range Province, Arizona (abs.): Earthquake Notes, v. 53, no. 1, p. 22.

Global Digital Network Operations

9920-02398

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Investigations

The Global Network Operations continued to provide technical and operational support to the SRO/ASRO/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.

The Raytheon O&M contract was reduced to one team leader and three technicians. Later, another technician resigned and a replacement was hired.

The software effort on the SRO event detector stopped in September 1981 due to resignation of programer. That effort has been started again and is still in progress.

The following station maintenance activity was accomplished:

ANMO - Albuquerque - SRO
One corrective maintenance visit was required to repair the ICS standby power system. Two additional visits were made for minor maintenance problems.

ANTO - Ankara, Turkey - SRO
Two maintenance visits were made during this period.

BCAO - Bangui, Central African Republic - SRO
One maintenance visit to replace borehole seismometer which was damaged by lightning. During the maintenance visit it was discovered the borehole armored cable was also damaged by lightning.

BOCO - Bogota, Colombia - SRO
No maintenance visit.

CHTO - Chiang Mai, Thailand - SRO
No maintenance visit. New standby power system and batteries placed on order for CHTO.

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
One maintenance visit was made.

SNZO - Wellington, New Zealand - SRO
No maintenance visit.

TATO - Taipei, Taiwan - SRO
No maintenance visit.

DWWSSN

ALQ - Albuquerque, New Mexico
Two maintenance visits were made.

TOL - Toledo, Spain
One maintenance visit was made.

Four DWWSSN installations were completed during this period:

SLR - Silverton, S. Africa
TOL - Toledo, Spain
COL - College, Alaska
JAS - Jamestown, California (remote DWWSSN installed)

ASL Repair Facility:

The DWWSSN system for BDF (Brasilia, Brazil) was tested and shipped. The DWWSSN system for KIP (Kipapa, Hawaii) is in testing phase at this time. The DWWSSN system for the Saudi Arabian project was assembled and tested. One borehole seismometer was tested and shipped to BCAO.

In addition, routine repair and testing of replaceable modules for SRO/DWWSSN systems took place as time permitted.

New addition completed on WWSSN building: Seismometer room set-up with work benches and test equipment. SRO programing system moved into new building and set-up for operation.

Results

Installation of the DWWSSN systems has expanded the digital network to a combined total of 26 SRO/ASRO/DWWSSN stations. This expansion has resulted in a much broader digital data base through the improved geographical coverage of the digital systems.

Global Seismograph Network Evaluation and Development

9920-02384

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Investigations

Peterson continued an analysis of the operating characteristics of the DWSSN system and completed documenting a design study for a global telemetered seismograph network. C. R. Hutt collaborated with J. Murdock in the development and evaluation of an event detector and worked with R. Ganse of NOAA in compiling a worldwide directory of digital seismograph stations. L. G. Holcomb continued an investigation of earth noise and began evaluation of a modified SRO borehole seismomenter.

Results

Calibration procedures used during the installation and daily operation of the DWWSSN systems were studied to determine the limits of accuracy and stability of the systems, especially with respect to seismometer period drift. Results indicate that, properly installed and operated, the DWWSSN systems will produce reliable, accurate data but that several of the systems are behaving erratically. Tests also reveal that critical operating parameters can be determined by least-squares fitting of the step response.

An event detector algorithm, developed by Murdock, has been successfully tested off line on a PDP 11/34. The detector is being used by Sandia Laboratories to edit RSTN data for the network-day tapes and is being coded for use on the SRO and ASRO field systems.

A joint NOAA/USGS effort to compile a directory of digital seismograph stations has been completed with a directory to be published in the near future. More than 100 digital stations and arrays have been identified.

During the past several years, a survey of the long-period data from several GDSN stations has been conducted to find time periods during which the 26 second microseismic storms occurred. This survey has yielded several storms of sufficient amplitude for detailed analysis. A preliminary analysis of the properties of 10 of these storms has been conducted during the past 6 months. This analysis confirms earlier predictions that the period of this microseismic peak is constant throughout all 10 storms and that the azimuths at all stations are also constant indicating a geographically fixed source region.

A KS 36000 borehole seismometer has been modified to extend the flat response to acceleration from .25 sec to 1500 sec. The seismometer has recently been delivered and is undergoing evaluation. Initial results are encouraging. The purpose of this test is to determine the feasibility of increasing the recorded bandwidth at SRO stations. Currently, the output of the seismometer is flat to acceleration from 1.0 sec to 50 sec.

Reports

Engdahl, E. R., Peterson, J., and Orsini, N. A., 1982, Global digital networks--current status and future directions (abs.): Earthquake Notes, v. 53, p. 59.

Ganse, R., and Hutt, C. R., 1982, Director of worldwide digital seismograph stations: World Data Center A for Solid Earth Geophysics Report series (in press).

Holcomb, L. G., 1982, Preliminary study of methods for upgrading USGS Antarctica seismological capability: U.S. Geological Survey Open-File Report 82-292, 40 p.

Murdock, J. N., and Hutt, C. R., 1982, An event detector for digital short-period data (abs.): Earthquake Notes, v. 53, p. 60.

Peterson, J., and Orsini, N. A., 1982, Design concepts for a global telemetered seismograph network: U.S. Geological Survey Open-File Report (in press).

Seismic Observatories

9920-01193

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Investigations

Recorded and provisionally interpreted seismological and geomagnetic data at observatories operated at Newport, Washington; Cayey, Puerto Rico; 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.

Seismic Review and Data Services

9920-01204

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Investigations and Results

The quality control and technical review were carrired out on 97,200 seismograms (540 station-months) generated by the Worldwide Standardized Seismograph Network (WWSSN). An additional seventy-five station-months of ASRO and SRO network analog seismograms were received on a current basis from the Seismological Laboratory in Albuquerque upon completion of the checking of the corresponding digital tapes, and the event picking programs. These records were channeled to NEIS for readings and control in the PDE programs.

Three hundred and eighty-six (386) station-months of original fiche seismogram copies were furnished on a special studies program monitored through this project.

A total of fifty-six WWSSN performance reports were sent out to the stations during this period. These reports cover the WWSSN station's instrumental and operational performance which includes timing precision, damping, magnification accuracy, noise problems, recording quality, and program cooperation. The overall operational quality and status of the WWSSN remains high and is probably better than at any other comparable period.

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) were removed from the 11/70 in June 1981 and are now being computed on the VAX. We continue to publish all earthquakes which have data available within 30 days of the earthquake. We are still having some improvements on rapid data flow from our foreign contributors, but in order to reach our goal of a faster PDE, we will need much faster reporting of seismic data from our contributors, both foreign and domestic.

These problems are still being worked on and slow but steady improvement is taking place. We continue to receive telegraphic data from the USSR on magnitude 6.5 or greater earthquakes and some damaging earthquakes with magnitudes less than 6.5. Data from the PR China via the American Embassy in Beijing is still being received, a total of four stations in time for the PDE and a total of 17 stations in time for the Monthly Listings.

The Monthly Listings of earthquakes is up to date. To date the Monthly Listings have been completed through November 1981 and have been mailed through October 1981. November is being printed. The Earthquake Data Reports (EDR) are computed through November 1981 and printed and mailed through August 1981. Fault plane solutions are being 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 are also being published in the Monthly Listing and EDR.

The modification of the program for entering seismic data on the BGS 11/70 is completed and operational. The program for producing the earthquake data report (EDR) on the VAX was completed and operational in February 1982. The Monthly Listings and EDR were re-formatted, reducing the number of pages about forty per cent.

We continue to provide services on recent earthquakes in response to the ever increasing demands from scientists, news media, and the general public.

Reports

Preliminary Determination of Epicenters (28 weekly publications--October 1981 to April 14--Numbers 37-81 through 12-82). Compilers: W. Leroy Irby, Reino Kangas, John Minsch, Waverly J. Person, William Schmieder.

Monthly Listings of Earthquakes and Earthquake Data Reports (EDR) (6 publications--June 1981 through November 1981). Earthquake Data Reports (EDR) -- 11 months--November 1980 through September 1981. Compilers: W. Leroy Irby, Reino Kangas, Willis Jacobs, John Minsch, Russell Needham, Waverly J. Person, Bruce Presgrave, William Schmieder.

Goals

A. Increase the routine use of SRO digital data.

B. Modify hypocenter relocation program (SEDAS)

   1. Additional phase travel-times (sP PCP, crustal phases).
   2. Local crustal models for U.S.
   3. Computation of routine USGS Moment Tensors and M_W Magnitudes.

C. Provide more rapid and comprehensive hypocenter locations to the government and the scientific community using our in-house computers.

   Provide more rapid notification of significant or damaging earthquakes to relief agencies, the press, the scientific community, and the general public.

   To receive more foreign data telegraphically on a weekly basis, including the USSR.

   Keep the Monthly Listings and Earthquake Data Reports up to date.

United States Earthquakes

9920-01222

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Investigations

1. Sixty-five earthquakes in 20 states were canvassed by a mail questionnaire for felt and damage data. Twenty-five of these occurred in California. The most significant earthquake for the period which was located in the United States was the January 19, 1982, UTC event in New Hampshire, located at 43.50°N, 71.60°W, depth 8 km, magnitude 4.4 mb and 4.5 mbLg. Two earthquakes in New Brunswick, Canada, on January 9 and 11, 1982, magnitude 5.7 and 5.1 mb, caused minor damage in northeastern Maine.

2. The United States earthquakes for the period October 1, 1981, to March 31, 1982, have been located and the hypocenters, magnitudes and maximum intensities have been published in the Preliminary Determination of Epicenters.

3. The seismicity maps for Iowa, Kansas, Nebraska, and Oklahoma have been printed at a scale of 1:1,000,000. The Texas map has been completed and is being printed. The data for Arizona, Colorado, Idaho, New Mexico, and Wyoming are in the process of being compiled.

Results

The maximum Modified Mercalli intensity of VI was evaluated for the New Hampshire earthquake of January 19, 1982. The most significant damage was reports of cracked chimneys and foundations in a few towns. The earthquakes were felt over most of New England and parts of southern Canada. The January 9 and 11 New Brunswick, Canada, earthquakes were evaluated at MM intensity VI in northeastern Maine along the Canadian border. These events caused damage such as cracked plaster, chimneys and house foundations as well as cracked streets and sidewalks in some areas. They were felt over most of New England as far west as eastern New York.

The United States earthquake data for October-December 1980 is being printed and the data for January-March 1981 is in TRU.

Reports

Stover, C. W., J. N. Minsch, P. K. Smith, and Person, W. J., 1981, Earthquakes in the United States, April-June 1980: U.S Geological Survey Circular 853-B, 53 p.

Minsch, J. N., Stover, C. W., Reagor, B. G., and Smith, P. K., 1981, Earthquakes in the United States, July-September 1980: U.S. Geological Survey Circular 853-C, 42 p.

Stover, C. W., Reagor, B. G., and Algermissen, S. T., 1981, Seismicity map of the State of Iowa: U.S. Geological Survey Miscellaneous Field Studies Map MF-1324.

Reagor, B. G., Stover, C. W., and Algermissen, S. T., 1981, Seismicity map of the State of Nebraska: U.S. Geological Survey Miscellaneous Field Studies Map MF-1350.

Stover, C. W., Reagor, G. B., and Algermissen, S. T., 1981, Seismicity map of the State of Maine: U.S. Geological Survey Miscellaneous Field Studies Map MF-1351.

Stover, C. W., Reagor, B. G., and Algermissen, S. T., 1981, Seismicity map of the State of Oklahoma: U.S. Geological Survey Miscellaneous Field Studies Map MF-1352.

Digital Data Analysis

9920-01788

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Investigations

1. Mantle Wave Magnitude. Develop methods for routine estimation of moment magnitude M_w from long-period surface (mantle) waves.

2. Moment Tensor Inversion. Develop methods for inverting body phase waveforms for the best point source description.

3. Computation of Free Oscillations. Develop practical methods for computing free oscillations of the Earth and combining them to construct synthetic seismograms.

4. Computation of Travel Times. Develop practical methods for computing body phase travel times directly from arbitrary, realistic Earth models.

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 a new NEIS publication containing detailed investigations of selected events.

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. Mantle Wave Magnitude. Appropriate software has been brought up on a branch minicomputer to implement this technique. The software has been tested on real data for the first special event report. More development is anticipated to enhance the robustness and automation of the method.

2. Moment Tensor Inversion. A journal article on the technique has been accepted for publication. The method has received more testing with real data. It is now being automated for routine use by the NEIS.

3. Computation of Free Oscillations. Work on a hybrid computational method is progressing. Initial work turned up several deficiences in one of the component algorithms which need to be resolved. General purpose software for generating synthetic seismograms by summation of normal modes has been brought up on a branch minicomputer.

4. Computation of Travel Times. A tau table method has been successfully implemented and is in the final stages of testing. A research note on applications of the method has been accepted for publication. A paper presenting the theory and numerics in detail is being prepared.

5. Network Day Tapes. The second revision of the software and documentation has been distributed. The first version handled network day tapes. The second version added capability for station tapes and old format network day tapes. A third revision is being prepared which handles network event tapes and corrects a few minor bugs and portability problems reported by the end users.

6. Special Event Reports. The first special event report on the 1 Sept. 1981 Tonga event is being prepared 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.

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. In all, 33 solutions were done for the calendar year 1981.

Reports

Sipkin, S. A., 1982, Estimation of earthquake source parameters from the inversion of waveform data: synthetic waveforms: PEPI, in press.

Buland, Ray, 1982, Towards locating earthquakes in a laterally heterogeneous medium: PEPI, in press.

Needham, R. E., Buland, R. P., Choy, G. L., Dewey, J. W., Engdahl, E. R., Sipkin, S. A., Spence, W. J., and Zirbes, M. D., 1982, Special Earthquake Report for the 01 September 1981 Samoa Islands Region Earthquake: Open-File Report, in preparation.

Earth Structure and its Effects upon Seismic Wave Propagation

9920-01736

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Investigations

1. Use of short-period waveforms to infer earth structure. Develop methods of generating synthetic waveforms that correctly incorporate the frequency dependent effects that arise from source directivity and the effects of 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.

3. Experiments with the GRF array. Perform technical comparisons of the SRO and Wielandt seismometers and the broadband data that they generate. Perform array experiments with the GRF array which digitally records broadband data on both horizontal and vertical component seismometers.

Results

1. Use of short-period waveforms to infer earth structure. Programs to synthesize seismograms by combining full wave theory with a causal rupture model to describe propagation and source effects have been converted to run on a local computer. 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 ±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 ($5.4 \leq m_b \leq 6.1$) earthquakes that encircled and preceded over a period of 2 years the eventual rupture zone of the Miyagi-Oki earthquake of 12 June 1978. The third event of the suite had a substantially higher stress drop than the first two events. Four months after the third event the mainshock occurred. We are also examining the rupture complexity of the large (M_s 7.8) Samoa earthquake of 1 September 1981.

3. Experiments with the GRF array. Data from this array have been examined and selected events stored on magnetic tape. Coherence of body waves across the array is found to be a function of frequency. Phase coherence is strong but amplitude coherence rapidly deteriorates with increasing frequency. Anisotropy in S-waves could be observed in broadband records of displacement.

Reports

Harvey, D., and Choy, G. L., 1982, Broadband deconvolution of GDSN data: Geophysical Journal of the Royal Astronomical Society, in press.

Choy, G. L., and Cormier, V. G., 1982, The structure of the inner core inferred from short-period and broadband GDSN data: Geophysical Journal of the Royal Astronomical Society, in press.

Choy, G. L., 1982, Experiments with SRO and GRF-array data: U.S. Geological Survey Open-File Report D-82-216, 40 p.

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, submitted.

Systems Engineering

9920-01262

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Investigations

1. Design, develop, and test microprocessor based seismic instrumentation.

2. Design, develop, procure, and test special electronic systems required by seismic facilities.

3. Design, develop, and test microprocessor/computer software programs for seismic instrumentation and seismic recording systems.

Results

1. The telemetered version of the DWWSSN Upgrade DRS System was installed for the Berkeley-Jamestown installation. The main control and recording unit was installed at the University of California at Berkeley's Seismic Station facility. The remote unit was installed at the Jamestown facility. A special remote controlled system current calibrator is part of the Jamestown remote equipment. Station operators at Berkeley can program 29 different calibrations and levels for step, daily sinewave, and full WWSSN frequency response type calibrations for short-period, intermediate-period, long-period and photo calibrations. The system was designed to operate over short distance 2400 baud telephone line circuits. Problems have developed because the distance and routing requirements of the telephone line circuits that cause 15 milliseconds absolute delay in the circuit. With a 50 millisecond time window for 20 samples per second short-period data, this 15 millisecond delay is too long for proper data transmission within the 50 millisecond time window. Studies are now being made for alternate data transmission schemes such as 4800 baud data rates.

2. The three component FDM short-period telemetry system for La Paz, Boliva, was designed and built. The remote unit of this system will be solar-powered and will use radio telemetry. This system has passed all system test-checkout requirements and is being prepared for shipment to La Paz.

3. Extensive modifications for the WWSSN Digital Recording System (DRS) type system for the Saudi Arabian Seismic Program are about completed. The modifications include: the WWSSN Berkeley-Jamestown Current Calibrator with on-site control instead of remote control, Systron-Donner Timing System instead of the WWSSN Digital Time System, new front control panel, and provisions for automatic changeover for the second tape recorder.

Seismicity and Tectonics

9920-01206

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Investigations

1. Peru Seismicity and Tectonics. Determine the space-time patterns of aftershocks of the October 3, 1974, Peru earthquake.

2. Mantle Structure Beneath the Rio Grande Rift. Use a 3-D, seismic ray tracing algorithm to invert a set of teleseismic P-wave delay data, with the objective of determining the maximum depth and degree of velocity anomaly in the upper mantle beneath the Rio Grande Rift.

Results

1. Peru Seismicity and Tectonics. The great (M_S 7.8, M_W = 8.1) Peru earthquake of October 3, 1974, and the major (M_S = 7.1) aftershock of November 9, 1974, have focal mechanisms that indicate virtually identical thrust faulting. The epicenters of these two earthquakes are separated by a 30-km-diameter cluster of aftershocks occurring throughout this 5-week interval. The November 9 earthquake at the south side of the cluster did not have a locatable subsidiary aftershock series, and after that shock there have been no teleseismically located earthquakes in the cluster zone. The aftershock series occurred in two separate spatial segments with aftershocks of one segment having distinctively different P-wave first-motions than aftershocks of the other segment. Except for activity in the main cluster, the two segments were alternately active, with each phase of one segment's activity accompanied by the general absence of aftershocks in the other segment. Five such temporal phases lasted for at least 2.3 days each, and all but one of these phases included aftershocks in the primary cluster. Extending updip and south from the main shock at the north side of the cluster is a large patch that is lacking in aftershocks and that surrounds the cluster. This inactive patch probably was destressed during the main shock rupture, whereas the aftershock cluster may map the location of a barrier that did not rupture during the main shock, leading to the occurrence of the earthquake 'twin' on November 9, 1974.

2. Mantle Structure Beneath the Rio Grande Rift. We have determined the resolution matrix for the 3-D seismic-ray-tracing inversion of a large set of teleseismic P-wave data taken at the Rio Grande Rift. We are now evaluating the degree of reliability of the inversion results, with particular attention to the low velocity zone at a depth interval of 90-130 km beneath a 150-km length of the Jemez shear zone.

Report

Spence, W., and C. J. Langer, 1982, Was a barrier involved with the 'twin' 1974 Peru earthquakes? (abstract): Earthquake Notes, v. 53, no. 1, p. 42.

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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OBSERVATIONS

1. Deformation in the Charleston S.C. Region

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. Displacement of unconformity surfaces is noted on seven contour maps along a line extending N 45° W from Charleston in Charleston and Dorchester Counties. Isopach maps constructed of intervals between the unconformities indicate faulting was active in Median Eocene time and more recently. Faulting may have occured earlier, but deep data is insufficient for proof. Growth faulting on the order of 100 feet displacement is shown for Base Lutetian-Base Priabonian and 50 feet for the Base Priabonian-Top Chattian intervals. 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 not supported in Charleston Medical Center nor adjacent Mount Pleasant holes.

Structure Contour, Isopach and Lithofacies maps are being prepared for South Carolina Department of Health and Environmental Control, Ground Water Protection Division through an Environmental and Protection Agency grant.

2. Expansion in Sea Level Change Curve for South Carolina

Archeologic and Holocene stratigraphic studies in the Georgetown and Beaufort regions 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 occuring between.

3. Archeologic and Holocene Stratigraphic Studies in Winyah Bay Area

Interriverine and coastal estuarine midden studies near and within Hobcaw Barony near Georgetown S.C. are progressing. Interriverine 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 similiar 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 (2. above). 2) The number of sites identified in the 1250-1750, 950-1050 and 250-350 clusters at Georgetown are significantly more than 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 occuring during the cluster intervals. The greater the change in sea level, the greater the number of interriverine sites.

Our present observations in Georgetown and in Charleston would indicate therefore that sea level changes in the Cooper River Valley 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 summary statement 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, and possibly, from present archeologic data sporadically in time.

CONCLUSIONS

1. A fault exists in the Charleston Region. The trace of the fault runs N 45 ^{o} W from Charleston in Charleston and Dorchester Counties. The fault appears hinged in the northwest, and is downthrown on its southwest side. The exact position of the fault is unknown but lies within a belt several miles in width as determined by deep well control in the region. Faulting began in the Lutetian and continued through Chattian and younger times sporadically. The movement is supported by structure contour and isopach maps in the Tertiary. Activity in the Quaternary is not supported nor negated from present data. Activity in the Holocene is supported by archeology and marsh stratigraphic studies, which also support the sense of the movement observed in the Tertiary. Present preliminary Holocene data suggests recent activity began about 1750 radiocarbon years B.P., and continues toward the present day. The activity is probably related to the Charleston Earthquake of 1886.

PUBLISHED INFORMATION

Abstracts

1. Boylan, D., Thunell, 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.

2. Howell, P., Colquhoun, D., and Padgett, G., (1982) Transgressive-regressive sedimentational sequences in Upper Cretaceous and Pa-

leocene deposits, Central South Carolina Coastal Plain, in program NE-SE Sections Geological Society of America Meetings, Washington D.C.

SUBMITTED INFORMATION

Abstracts

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., et al., Tectonic framework development and initial glacio-eustatic sea level change, East Georgia Embayment, U.S.A. to the Geological Society of America National Meeting, New Orleans, LA 1982

Theses (University of South Carolina)

1. Paul Howell, Surface and Subsurface Lithostratigraphy and depositional history of the Upper Cretaceous, Paleocene and Middle Eocene strata of the Coastal Plain of Updip Central South Carolina, Defended December 1981, to be submitted to Graduate School Summer 1982.

2. John Bishop, Lithostratigraphy and depositional history of Late Cretaceous to Oligocene sediments of the Coastal Plain of Western South Carolina, Defended February 1982, to be submitted to Graduate School Summer 1982.

3. Deborah Boylan, Stratigraphy, water depth, erosional unconformities and time of emplacement of the South Carolina Coastal Plain, Charleston to Hilton Head Island, to be defended, May 1982

Manuscripts

1. Van Nieuwenhuise, D.S., and Colquhoun, D.J., Contact relationships of the Black Mingo and Peedee Formations - the Cretaceous-Tertiary boundary in South Carolina, U.S.A., in press South Carolina Geology, S.C. Geol. Survey.

2. Van Nieuwenhuise, D.S., and Colquhoun, D.J., The Paleocene-Lower Eocene Black Mingo Group of the East Central Coastal Plain of South Carolina, submitted for review to J. Hazel (U.S.G.S.), G. Gohn (U.S.G.S.) and N. Olson (S.C. Geol. Surv.).

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 region was considered aseismic until the Shivaji Sagar reservoir was impounded in 1962. Several medium-sized earthquakes have occurred at Koyna since then, including a destructive earthquake of magnitude 6.0 in December 1967. The activity since then has averaged about 30 events per month, with a magnitude 4 or greater earthquake occurring every three months or so. The seismicity was considered to be on a decay curve until September 1980 when three earthquakes of magnitude close to 5.0 occurred. Thus, it appears as if there is still considerable scope for detailed work in the region.

During 1981, I visited the Koyna dam and the seismic observatories in the region under a UNDP Project, and was convinced that there is need to carry out high resolution seismicity studies there. However, in spite of considerable effort on the part of the collaborating Indian scientists, persmission to start the USGS project has so far not been given by the Government of India. Until the official approval is granted by the Indian government the work cannot be started.

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

In our previous studies, it was shown that the permeability of certain clay-rich San Andreas fault gouges is on the order of a nanodarcy under typical crustal conditions. It is of interest to know whether this is a unique property of clays, or whether non-clay gouges behave similarly, particularly since the extent of clay at depth is not known. For this reason, the permeability of four non-clay gouges from the San Andreas fault at Big Pines in southern California was studied at confining pressures up to 200 MPa. Each gouge was essentially a rock flour of fine sand to silt size particles, derived from various crystalline parent rocks. Clay development was minor (0-4% by weight). At 200 MPa confining pressure, granite gneiss and Pelona schist gouges had permeabilities of 0.57 and 1.07 nd respectively. A second granite gneiss gouge sample, and material from a thin shear zone within gneiss, had higher permeabilities, at 202 and 54.7 nd. The results of these experiments followed the relation

$$k^{1/3} = A - B\log P_e$$

where K is permeability, A and B are constants, and P_e is effective stress. Initially permeability of these gouges decreased more during shearing than the clay gouges. After 5 mm of axial displacement, two gouges which had lower permeabilities showed significant increases in permeability under saturated drained conditions. Friction and shear strength for these gouges are higher (up to 0.65 and 200 MPa) than for the clays. These results show that it is not necessary for clays to be present at depth in order to obtain low permeability conditions that may result in greater than lithostatic pore pressures and restricted fluid flow within a fault zone.

Reports

Shi, L., Morrow, C., Byerlee, J., 1981, Permeability and strength of non-clay gouges under high pressure and shear stress, EOS, v. 62, no. 45, p. 1037.

Moore, D., Morrow, C. and Byerlee, J., 1981, S_i0_2 precipitation accompanying fluid flow through granite held in a temperature gradient, 7th Workshop Geothermal Reservoir Engineering Stanford, Dec. 5-11.

Moore, D., Morrow C. and Byerlee, J., 1981, Chemical reactions accompanying fluid flow through granite held in a temperature gradient, Geol. Soc. Am. Abstracts with Programs, v. 13, no. 7, p. 514.

Brittle Tectonics and Reservoir-Induced Seismicity

9510-02389

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Investigations

1. Final analysis of cores from Monticello Reservoir drill holes #1 and #2 and Wateree Creek fault drill holes #1, #2, #3, and #4, was conducted to determine the best method of publication in regard to information from other field studies in the Monticello area.
2. Regional geologic mapping is underway at the Richard B. Russell Reservoir site prior to water empoundment to determine the nature and extent of brittle fracturing in the area.

Results

1. Analysis of the cores from the Monticello Reservoir area indicates that extensive brittle fracturing occurred in the area during the Late Paleozoic or early Mesozoic and was associated with the crystallization of zeolites and carbonates. The data collected are being published in conjunction with data collected by University of South Carolina geologists working in the same area. Several papers discussing basic data have been planned and one is presently in press.
2. Regional geologic mapping at the Richard B. Russell Reservoir site has provided preliminary evidence about the tectonic history of the area. Most prominent in this area is a zone of ductile shearing which is probably a portion of the Lowndesvillle-Middleton fault zone in nearby eastern Georgia. Several post-metamorphic faults have been mapped for short distances. They are characterized by brittle fractures along which biotite is altered to chlorite. Commonly these fractures are filled with quartz and(or) feldspar. The orientations of the late brittle faults are not coincident with the orientations of older ductile structures, and therefore probably reflect a change in stress after peak metamorphism. Although definitive evidence is not presently available, these faults most likely formed in Late Paleozoic or early Mesozoic time.

Reports

Secor, D. T., Jr., Peck, L. S., Pitcher, D. M., Prowell, D. C., Simpson, D. H., Smith, W. A., and Snoke, A. W., (in press), Geology of an area of induced seismic activity at Monticello Reservoir, South Carolina: Journal of Geophysical Research, (submitted 1982).

Self-Potential Measurements Near Dams

9780-02917

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Investigations

1. Construction and stability evaluation of $Pb-PbCl_2$ electrodes for self-potential measurements.

2. Selection of dam sites for self-potential field studies.

Results

$Pb-PbCl_2$ electrodes were constructed for use in field studies. The electrodes consist of a $PbCl_2$ coated Pb strip which is placed inside a PVC tube. A mixture of plaster of Paris, $PbCl_2$, NaCl, and water is placed around the metal strip inside the plastic tube. The metal strip is attached to a feed through in the top cap of the tube. An RTV seal isolates the metal junction between the Pb strip and the feed through from the active portion of the electrode. These electrodes have the following advantages: ease of construction, there is no electrolyte which must be periodically replaced, low noise and drift characteristics. Over a two month test period, drift voltages were less than 3 mV.

Three sites have been selected for making self-potential (SP) measurements at dams operated by the Denver Water Department. These include Gross Reservoir (concrete gravity arch dam in crystalline rock), Ralston Reservoir (earth filled dam resting on shale), and Dillon Reservoir (earth filled dam with grout curtain in sedimentary rock). These sites were chosen for the diversity of geology and construction types, as well as ease of access.

Reports

No reports have been written.

In Situ Stress Measurements

9960-01184

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Investigations

The efforts of this project were devoted to a wide variety of investigations. These activities and those planned for the remainder of this fiscal year are displayed on the attached chart. In October and November we drilled three holes at San Juan Bautista for the emplacement of the Carnegie dilatometers. In November we instrumented the deep borehole at Hi Vista, near Palmdale, California, to record water level for a period of 20 days and gathered data for comparison with data from other water wells in California. Joe Svitek, Steve Hickman, and Dan Moos went to Panama to install measuring instruments on the GLOMAR CHALLENGER, the research vessel used for deep sea drilling, to make in situ measurements. In November and December we made stress measurements and televiewer logs in a 5,000 ft borehole on Yucca Mountain at the Nevada Test Site. In January and February we drilled a deep hole at Oroville, California, which successfully penetrated an active fault zone that had surface ruptured during the 1975 Oroville earth- quake. In February, March, and April we planned and executed stress measure- ments and televiewer logs in a 5,000 ft borehole drilled in Auburn, New York. In March and April we logged three drill holes in Pinon Flat that were prepared for installation of Sachs meters. In April and May we returned to San Juan Bautista to assist with the installation of the Sachs meters at that site and we are currently planning to return to Oroville to finish the measurements started there. Also during this period, research continued on the development of the televiewer systems that offer great promise for obtaining additional information from the televiewer logs, and a new 12-channel ultrasonic logging tool from Simplec Co. is being developed for use in our holes that was purchased with funding from the deep sea drilling experimental program.

Results

We are continually gaining experience in solving the problems of drilling holes in rocks near active fault zones. Although this experience does not translate into results we believe we are making progress in the operational aspects of these problems which will pay dividends in the future, both in the economics of drilling holes and installing instruments, and, more importantly, in understanding the physical properties of the rocks in which the instruments are installed. We are gradually improving the equipment and techniques needed for deep stress measurements. We have successfully made measurements at a depth of 5,000 ft and from this experience we are making design changes in our instrumentation which hopefully will permit us to make stress measurements to at least 10,000 ft. Data from the experiments conducted in the first six months of this year have been analyzed in a preliminary manner. Important results from these experiments include:

1. After some difficulty a deep fracture at 1950 ft in the Hi Vista drill hole was isolated and water level monitoring showed a large tidal fluctuation of fluid pressure in this fracture zone. The amplitude of this fluctuation exceeds 10 cm and corresponds almost exactly to the predicted volumetric tidal strain. The drift during the 20-day period is less than 3 cm or 1/3 of the tidal amplitude. Thus, it appears that this well and others like it could be one of the most sensitive measures of volumetric strain changes over periods of several months.

2. On Yucca Mountain at the Nevada Test Site there were three important discoveries. The well had been hydrofraced by the drilling fluid producing long fractures that indicate a maximum compressional stress about N10°W. Televiewer logs show long vertical features that are apparently related to borehole ellipticity and are oriented at 90° to the drilling-induced hydrofractures. While this feature is more prominently displayed in the logs from the Yucca Mountain hole than in any other hole we have investigated, it suggests that the televiewer has the potential of determining stress direction from hole ellipticity. Finally, the least principal stress in this hole is much less than the vertical stress, suggesting that the rocks on Yucca Mountain are close to the point of normal faulting.

3. At Oroville we successfully drilled through an active fault zone. After drilling to a depth of about 1,500 ft the rocks in this fault zone collapsed into the borehole and temporarily prevented us from working below about 1,100 ft where the fault zone intersects the borehole. As in other places where we have intersected fault zones, the zone is obviously not a single plain but involves a zone of crushing at least 30 m in thickness and consists of multiple fracture plains within this zone of fractured rock.

Reports

Healy, J. H. and Urban, T. C., 1981, Drilling holes for earthquake prediction (abs.): EOS (American Geophysical Union Transactions), v. 62, no. 45, p. 1048.

Hickman, S., Healy, J., Zoback, M., and Svitek, J., 1981, Recent in situ stress measurements at depth in the western Mojave Desert (abs.): EOS (American Geophysical Union Transactions), v. 62, no. 45, p. 1048.

Hickman, S. and Zoback M., 1982, On the interpretation of hydraulic fracturing pressure-time data for in situ stress determination, in Workshop on Hydraulic Fracturing, U.S. National Committee on Rock Mechanics, Washington, D.C., in press.

Kohler, W. M. and Healy, J. H., 1981, The mechanism of anisotropic wave velocity in crystalline rocks of the Mojave Desert (abs.): EOS (American Geophysical Union Transactions), v. 62, no. 45, p. 961.

Moos, D. and Zoback M. D., 1982, In situ studies of seismic velocity in fractured crystalline rocks, submitted to Journal of Geophysical Research.

Moos, D., Zoback, M. D., and Nur, A., 1982, Pressure dependence of P- and S-wave velocities in crystalline rock (abs.), in press.

Zoback, M. D. and Hickman S., 1982, In situ study of the physical mechanisms controlling induced seismicity at Monticello Reservoir, South Carolina, submitted to Journal of Geophysical Research.

01184 Field Projects Calendar

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Oct     Nov     Dec     Jan     Feb    Mar    Apr    May    Jun    Jul    Aug    Sep    Oct
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 SJB                                                  SJB
-----I                                            I-------I

       HV
      I____I

          PA
        I----I

            NTS                                                                          NTS
         I------I                                                                        I---

                             Oroville                      Oroville
                         I-------------I                I--------I

                                    New York
                                 I-----------I

                                          PF
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HV Hi Vista
PA Panama
PF Pinon Flat
Hfd Hanford

Geological Investigations in an Area of Induced Seismicity at Monticello Reservoir, S. C.

18-08-0001-19833

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Investigations

Monticello Reservoir, S. C., is an area of well documented induced seismic activity in the Charlotte belt of the Piedmont province. This area is the focus of a geological and geophysical research program aimed at evaluating the potential hazard and understanding the causes for the activity. At the onset of the seismic activity, the geology of the region surrounding the reservoir was poorly understood, and this study was undertaken to provide the geological information necessary for evaluating the activity. This study involves the preparation of detailed geological maps in four 7½' quadrangles in the vicinity of the reservoir, the measurement of 120 km of surface magnetic profile in order to detect and map Triassic - Jurassic dikes, and fracture orientation studies at 50 stations in the vicinity of the reservoir.

Results

The Monticello Reservoir area contains a thick stratified sequence of Proterozoic Z and Cambrian metasedimentary and metavolcanic rocks. In the early to middle Paleozoic, this sequence was recrystallized and deformed under metamorphic conditions that ranged from greenschist to amphibolite facies and experienced at least two episodes of folding. The region has been intruded by late- to post- kinematic granitoid plutons of Silurian and Carboniferous ages, and by numerous northwest-trending diabase dikes of Late Triassic and Early Jurassic age. The region south of Monticello Reservoir in the Carolina slate belt experienced two episodes of faulting in the late Paleozoic and/or early to middle Mesozoic. The older group of faults trends approximately east, has only small displacements, and is characterized extensive silicification of the fault zones. The younger group of faults trends approximately north, has experienced dip-slip displacements up to 1700 m, and is characterized by carbonate mineralization in the fault zones. Both sets of faults are cut by an undeformed diabase dike of Late Triassic or Early Jurassic age. The induced seismic activity around Monticello Reservoir is occurring in a heterogeneous quartz monzonite pluton of Carboniferous age. Although laterally extensive faults have not been found in the vicinity of the reservoir, the pluton contains large enclaves of country rock and is cut by numerous, diversely oriented small faults and joints. The local inhomogeneities in the pluton, together with an irregular stress field, are interpreted to control the diffuse seismic activity around the reservoir. In view of the apparent absence of lengthy faults, it is unlikely that a large magnitude earthquake will occur in response to the stress and pore pressure changes related to the impoundment of Monticello Reservoir.

Reports

Secor, D. T., Jr., L. S. Peck, D. M. Pitcher, D. C. Prowell, D. H. Simpson, W. A. Smith and A. W. Snoke, 1982, Geology of the Area of Induced Seismic Activity at Monticello Reservoir, South Carolina: J. Geophys. Res., in press.

Induced Seismicity and Earthquake Prediction Studies in South Carolina

Contract No. 14-08-0001-19252

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1. Induced Seismicity at Monticello Reservoir, South Carolina.

One spurt of activity was observed in March-April, 1981, with the largest event of M_L 2.4 occurring on April 1, 1981. This event occurred to the west of earlier activity, but was confined to the region between the Broad River and Monticello Reservoir. This was the most important activity in 1981 (Fig. 1). The seismicity in 1981 was mainly concentrated in the central region. The seismicity in this central cluster was more to the south than in previous years, suggesting that the observed gap between the central and southern clusters may be filling up.

A magnitude 2.8 event on April 13, 1982, the largest since the October 1979 swarm, was located near the edge of the northernmost dam, at a depth of $\sim$ 1 km.

2. Ground Motion, Depths and In Situ Stresses.

At Monticello Reservoir there appears to be an inverse correlation between the depth and recorded ground accelerations for earthquakes recorded within 1 km epicentral distance from the SMA on the dam. At shallow depths (to 500 m) there is a significant difference in the percentage of the larger events, which appears to be in agreement with the observed deviatoric stress (Fig. 2). We are studying various factors that control ground acceleration associated with RIS.

3. Azimuthal Dependence of Radiation Pattern.

Spectral analyses of S waves of the earthquake records at different stations at Monticello were performed to study azimuthal dependence of radiation pattern. Our results for the October 1979 swarm show significant changes in the high frequency (> 10 Hz) contents of S waves, recorded along different azimuths with respect to the source. Results for two stations (A and B) are shown in Figure 3. In this plot each amplitude spectra was first normalized with its maximum amplitude and then band-pass filtered between 10-30 Hz to enhance high frequency contents. Spectra from three main epicentral zones (1, 2, 3; shown in the inset) are grouped together along x - axis; the diagonal axis showing frequencies and the vertical axis the amplitude.

We note that at station A events from source area 2 are lacking in high frequency content and those from source area 3 are rich in it. The reverse seems to be the case at station B. Events from source 1 appear to have similar high frequency content at both sites. It appears that there is a rapid fall off in the high frequency content when the waves travel in a N-S or S-N direction, but not in a E-W or NW-SE direction.

4. Induced Seismicity at Lake Jocassee, South Carolina.

Seismicity at Lake Jocassee has been monitored since October 1975, using portable seismographs and recently three permanent stations. One of these stations, SMT, was connected to the state seismographic network on February 25, 1980. In 1980 there were 8 events, in 1981 3 events with magnitudes greater than 2.0. This compares with 7 and 1 events with magnitudes greater than 2.0 at Monticello Reservoir in 1980 and 1981, respectively.

The low level seismicity at Lake Jocassee has been fairly widespread in 1981 (Fig. 4). However, its spatial extent has been confined to within an epicentral area defined within the first year of activity.

5. 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. Anomalous changes in radon concentration were noted before the April 1, 1981 earthquake.

Papers

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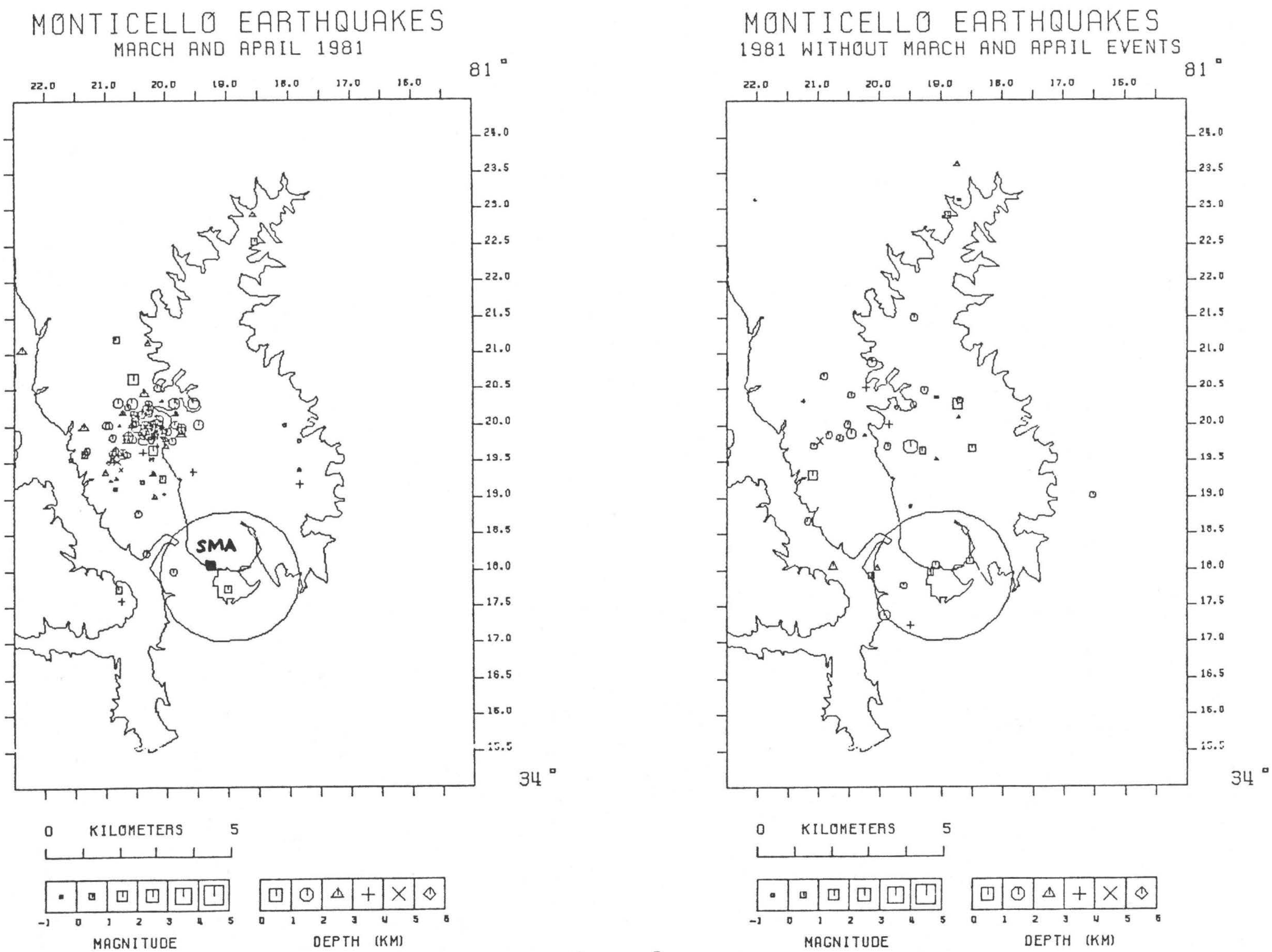
MONTICELLO EARTHQUAKES
MARCH AND APRIL 1981
81°
22.0 21.0 20.0 19.0 18.0 17.0 16.0
24.0 23.5 23.0 22.5 22.0 21.5 21.0 20.5 20.0 19.5 19.0 18.5 18.0 17.5 17.0 16.5 16.0 15.5
34°
SMA
0 KILOMETERS 5
-1 0 1 2 3 4 5
MAGNITUDE
0 1 2 3 4 5 6
DEPTH (KM)
MONTICELLO EARTHQUAKES
1981 WITHOUT MARCH AND APRIL EVENTS
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

IS

460

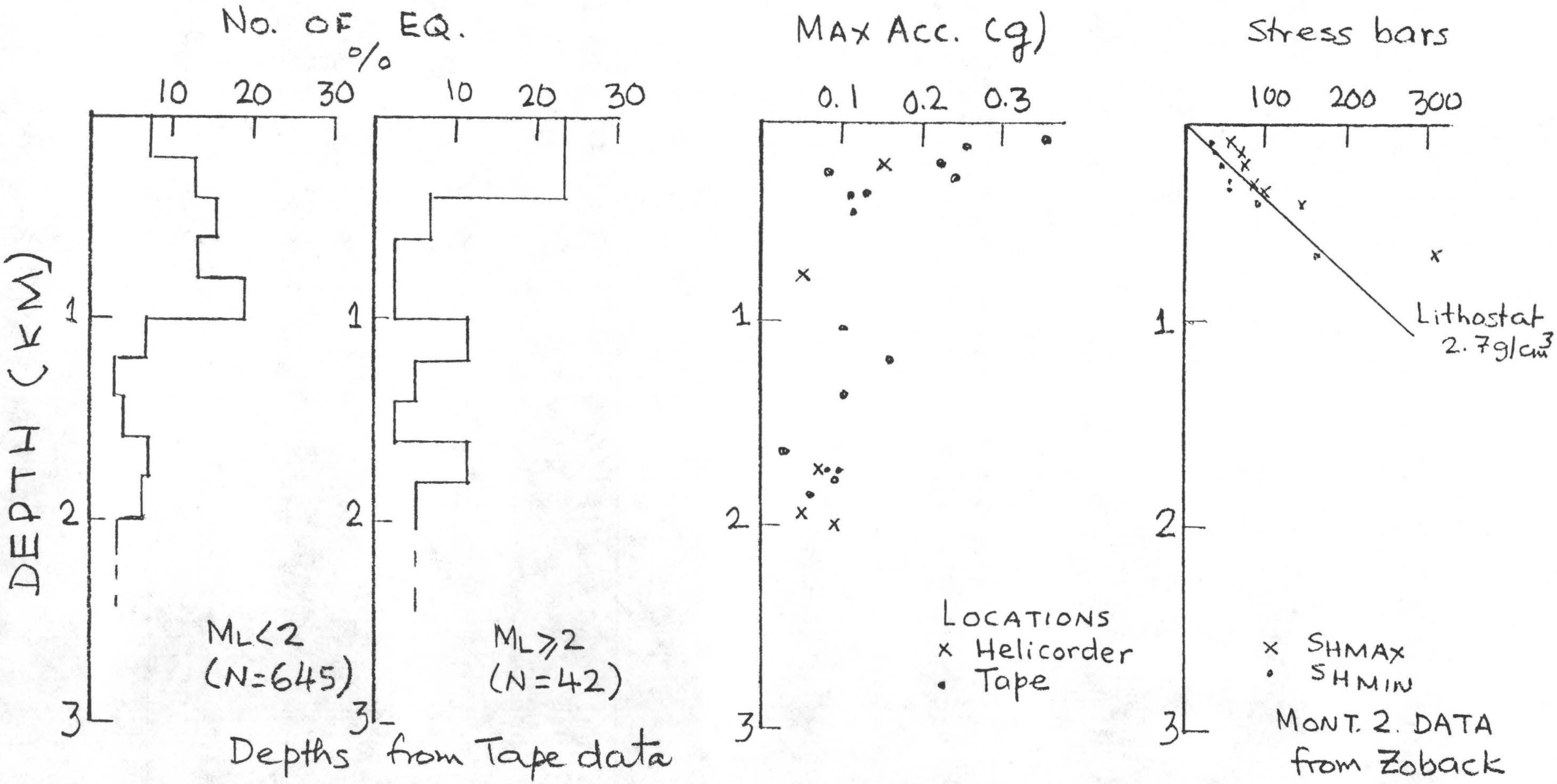

Figure 2

SI

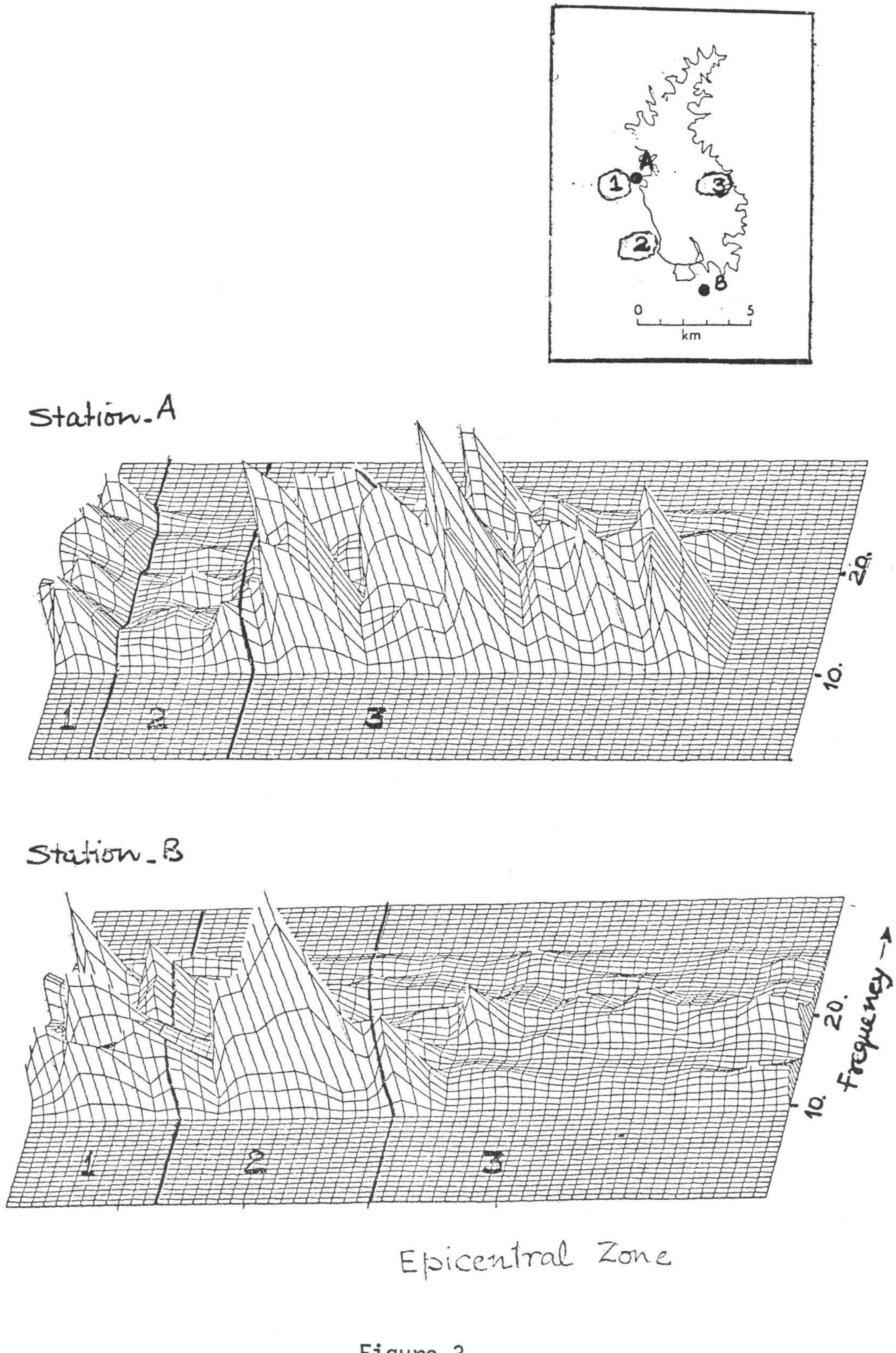
1
2
3
A
B
0
5
km
Station_A
1
2
3
10.
20.
Station_B
1
2
3
10.
20.
Frequency →
Epicentral Zone

Figure 3

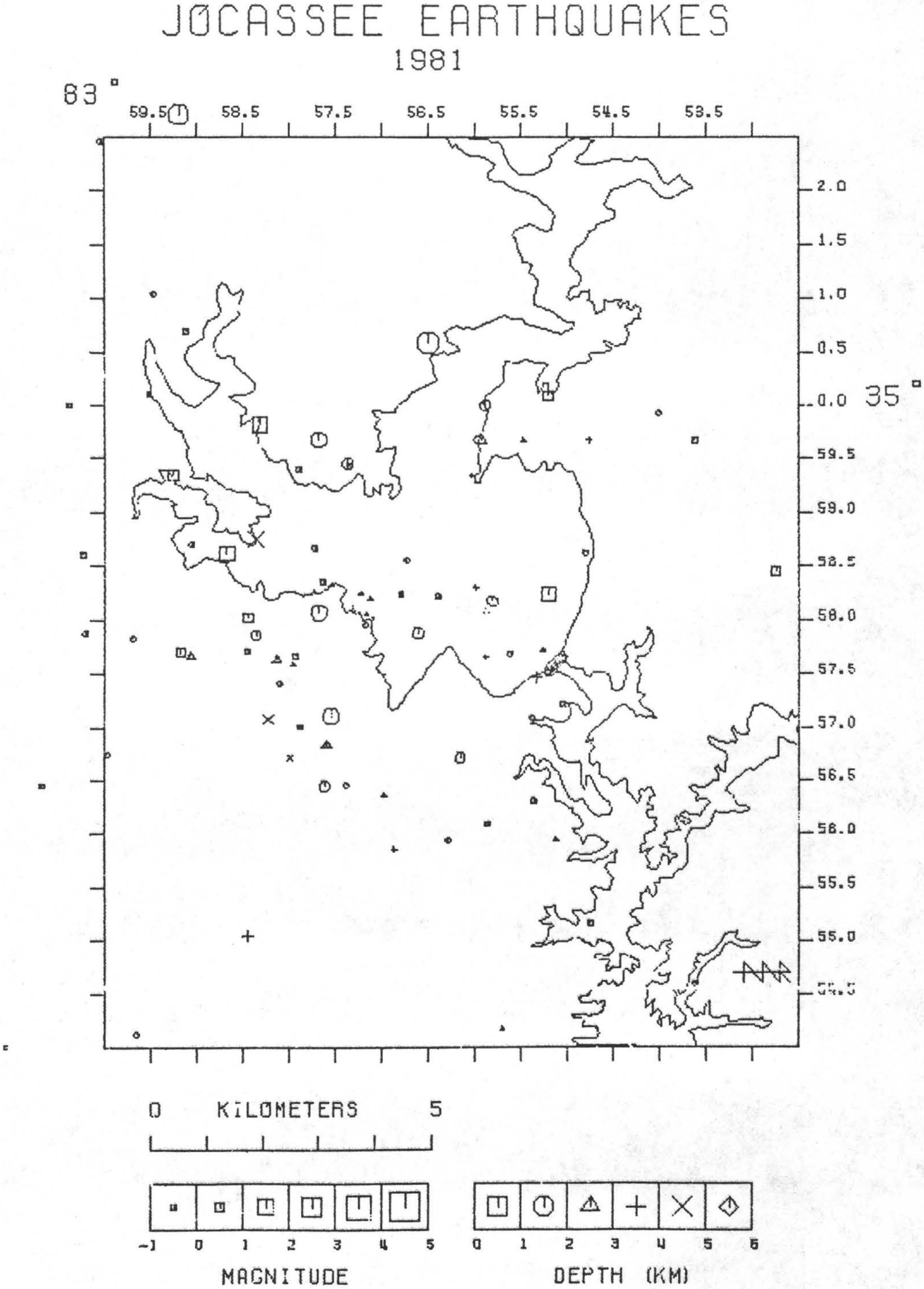
JØCASSEE EARTHQUAKES
1981
83°
59.5
58.5
57.5
56.5
55.5
54.5
53.5
2.0
1.5
1.0
0.5
0.0
35°
59.5
59.0
58.5
58.0
57.5
57.0
56.5
56.0
55.5
55.0
54.5
0 KILOMETERS 5
-1
0
1
2
3
4
5
MAGNITUDE
0
1
2
3
4
5
6
DEPTH (KM)

Figure 4

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