UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

SUMMARIES OF TECHNICAL REPORTS, VOLUME XVI

Prepared by Participants in

NATIONAL EARTHQUAKE HAZARDS REDUCTION PROGRAM

June 1983

OPEN-FILE REPORT 83-525

Menlo Park, California

1983

INSTRUCTIONS FOR PREPARATION OF SUMMARY REPORTS

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

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

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

    a. Project title

    b. Contract, grant or project number

    c. Name of Principal Investigator(s)

    d. Name and address of institution

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

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

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

6. Only type on one side of the paper.

7. Type all text single spaced.

8. Do not use staples.

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

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Prepared by Participants in

NATIONAL EARTHQUAKE HAZARDS REDUCTION PROGRAM

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 10, 1983 and cover the 6-month period from October 1, 1983 through March 31, 1983. 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. 83- **525**

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

CONTENTS

Earthquake Hazards Reduction Program

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

1. Jim Dewey has recomputed epicenters for over 500 regionally and teleseismically recorded earthquakes that occurred in Montana, northwestern Wyoming, and Idaho in the period 1925 through 1980. These locations are based on arrival time data reported in bulletins and will be refined with the addition of original data read from selected regional stations. The following conclusions are based on the revised hypocenters: (1) As has been noted previously both in the northern Rockies and in other regions of Cenozoic extensional tectonics, many of the major Cenozoic faults have been quiescent and much of the seismicity is occurring away from the major mapped faults. However, in some areas (Flathead Lake, Montana, southwestern Montana, Central Idaho) epicenters define linear zones that are more than 50 km long and approximately parallel to the major mapped faults, although offset from the faults by tens of kilometers. This suggests that the epicenters are occurring along major tectonic features that are caused by the same processes that cause the major Cenozoic faults.

2. It was possible to relocate the four largest 1935 Helena, Montana, earthquakes by using recently recorded earthquakes (Qamar and Hawley, Bulletin Seismological Society America 69, p. 1917-1929, 1979) as calibration events and by exploiting the fact that some seismographic stations that recorded the recent shocks also recorded the 1935 shocks. The minimum variance epicenter of the magnitude 6 1/4 shock of October 19, 1935, was 12 km NNW of Helena, in a region that is today characterized by a high rate of microearthquake activity (Freidline and others, Bulletin Seismological Soceity America, v. 66, p. 81-95, 1976; Qamar and Stickney, Montana Bureau of Mines and Geology Memoir 51, 1983). The minimum variance hypocenter of the magnitude 6 shock of October 31, 1935, was 6 km SW of Helena in a region that is today characterized by a modest rate of microearthquake activity. The 90 percent confidence ellipses associated with the shocks do not preclude their occurring on the Prickley Pear Fault, which passes directly beneath Helena.

3. The Hebgen Lake earthqake of August 18, 1959, and its aftershocks have been relocated by using the Yellowstone Park earthquake of June 30, 1975 (Pitt and others, Bulletin Seismological Society America, v. 69, p. 187-205, 1979) as a calibration event. The epicenters are moved as a group approximately 15 km SW of the positions of the epicenters of the same shocks determined by Dewey and others (NOAA Technical Report ERL 267-ESL 30, 1973), who did not have a locally recorded calibration event available to them. However, the positions of the new epicenters relative to each other are similar to those of the 1973 study by Dewey and others.

Reports

Choy, G. L, Boatwright, John, Dewey, J. W., and Sipkin, S. A., 1983, A teleseismic analysis of the New Brunswick earthquake of January 9, 1982: Journal of Geophysical Research, v. 88, p. 2199-2212.

Dewey, J. W., 1983, Instrumental seismicity of the Northern Rocky Mountains of the United States: Earthquake Notes, v. 54, no. 1, p. 48.

Dewey, J. W., and Gordon, D. W., Seismicity of the Eastern United States and adjacent Canada, 1925-1976 (submitted to Central Technical Reports for publication as a USGS Professional Paper, not yet approved by Director), 106 typescript pages, 17 figures, 4 tables.

National Earthquake Catalog

9920-02648

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Investigations

1. Verified listings and collected intensity data for Southern California local shocks for 1932-1963.

2. Completed correcting, merging, and assigning priorities to the three principal earthquake data base files for Alaska.

3. Developed computer codes for manipulating the data base files.

Results

1. W. H. K. Lee provided event lists (1932-1969), Cal Tech preliminary bulletins (1940-1963) and copies of C. F. Richter's notes (1932-1939) on southern California local shocks. Carol Thomasson and James Taggart verified about 12,000 event listings against the source data for 1932-1963. Values of maximum intensity were estimated or transcribed for about 2,000 of the earthquakes from descriptions in United States Earthquakes for those years. Less than 100 obvious errors were identified, but several thousand listings differ from the source reference listings, indicating that many of the hypocenters have been revised.

2. The three principal Alaskan earthquake data base files, developed from corrected magnetic tape files and from about 1,500 hand-entered event listings, were merged and the preferred listing for each event was flagged. Excluding duplicate and local network listings, the Alaska data base now contains about 14,000 earthquake listings for 1786-1980. Much new magnitude and intensity data were compiled and included in the hand-entered data.

3. Two computer codes for data base manipulation were written by Taggart during this reporting period: 1) a short routine for incorporating HYPO71 and HYPOELLIPSE event lists into the data base, 2) a routine to exchange magnitude and intensity data, as well as adjust uncertainty estimates, among multiple listings of an event.

Reports

Taggart, James, 1982, The United States national earthquake catalog project: IASPEI/UNESCO Regional Workshop on Historical Seismograms, Tokyo, Dec. 20-22, 1982.

Taggart, James and Baldwin, Frank, 1982, Earthquake sequence of 1938-1939 in Mogollon Mountains, New Mexico: New Mexico Geology, v. 4, p. 49-52.

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. Re-evaluated the tectonic setting of the 1978 Santa Barbara earthquake in light of new fault map of Santa Barbara-Goleta metropolitan area (see U.S.G.S Open-file Report 83-90, p. 6-9).

2. Continued subsurface mapping of San Miguelito-Rincon oil field area south of Red Mountain fault.

Results

1. The 1978 Santa Barbara earthquake is generally believed to have occurred on a thrust fault with low to moderate north dip. However, the Santa Barbara region is dominated by reverse faults which dip steeply to the south. This fault orientation is close to the other nodal-plane on the focal-mechanism solution presented by Corbett and Johnson (1982) (Figure 1). The linear map pattern of the aftershock series is better explained by a steeply dipping fault than a low-dipping fault. A relatively small portion of the western Transverse Ranges is characterized by young reverse faults dipping steeply south which may penetrate downward into high-strength rocks; this includes the Goleta, Santa Barbara, and Carpinteria areas and possibly the Ojai Valley and upper Ojai Valley areas. This limited distribution may account for the high historical seismicity of the Santa Barbara-Goleta area in comparison with other parts of the Ventura basin. A manuscript on this subject by Yeats and Olson is now being prepared for the Bulletin, Seismological Society of America.

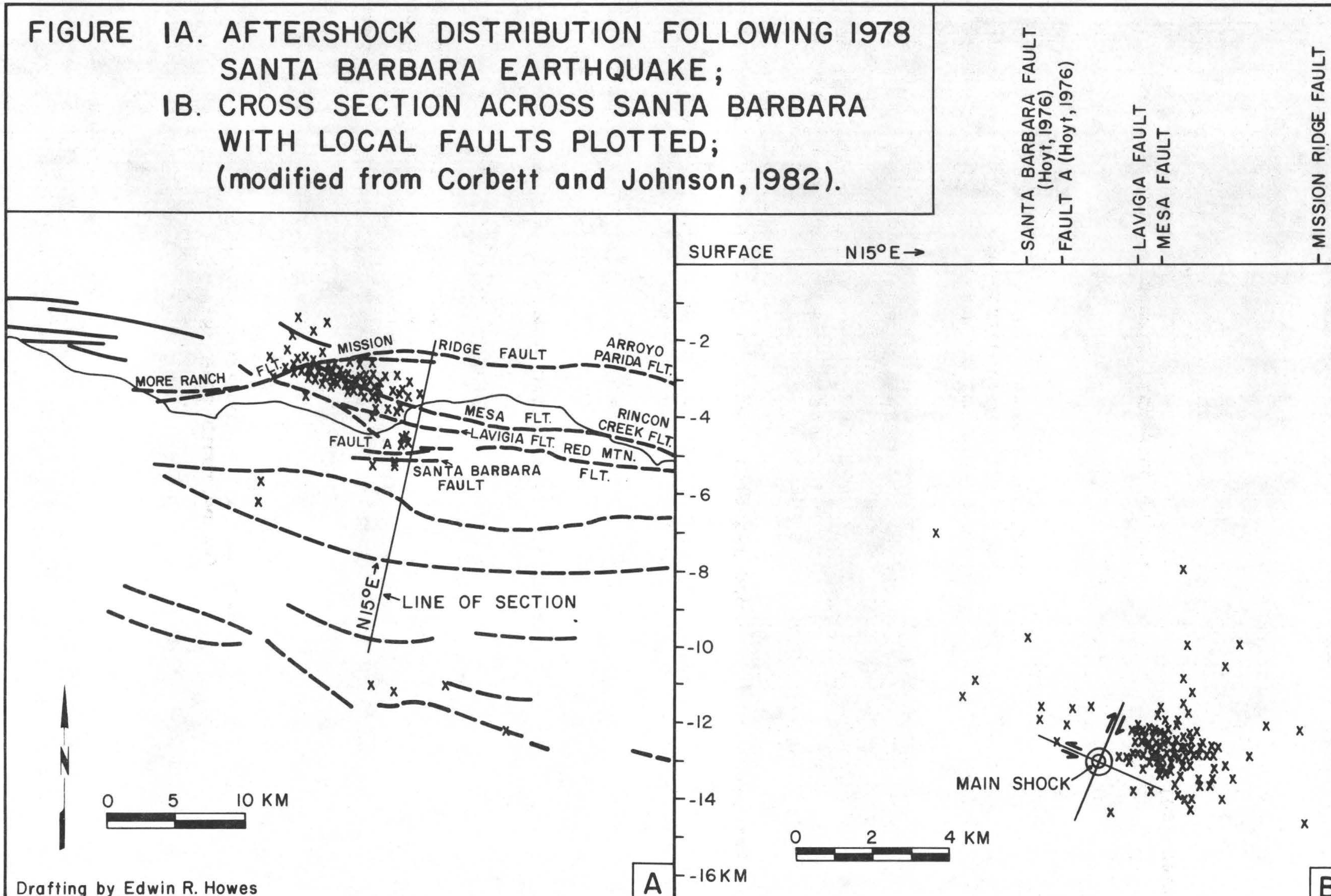
2. Continued mapping in the San Miguelito oil field suggests that the Javon Canyon fault does not extend downward into the Padre Juan fault, as believed previously by our group. It appears that the fault zone mapped by industry as the "zone of steep dips" consists of two faults of different ages, a lower fault which is folded across the crest of the anticline (the Padre Juan fault) and an upper fault which may post-date the main period of folding. The upper fault may be a member of the same set that includes the Javon Canyon fault.

Reports

Olson, D. J., 1983, Surface and subsurface geology of the Santa Barbara-Goleta metropolitan area, Santa Barbara County, California: Geol. Soc. America Abs. with Programs, v. 15, p. 418.

Yeats, R. S., 1983, Large-scale Quaternary detachments in Ventura basin, southern California: Jour. Geophysical Res., v. 88, p. 569-583.

FIGURE 1A. AFTERSHOCK DISTRIBUTION FOLLOWING 1978 SANTA BARBARA EARTHQUAKE;
1B. CROSS SECTION ACROSS SANTA BARBARA WITH LOCAL FAULTS PLOTTED;
(modified from Corbett and Johnson, 1982).



Regional and National Seismic Hazard and Risk Assessment

9950-01207

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Investigations

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

A. Finite fault rupture models.

B. Various published ground motion attenuation models.

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

2. Refinement of computer modeling of seismic source zones using gaussian smoothing techniques at source zone boundaries.

3. Development of a series of efficient computer programs for digitizing and plotting seismicity data.

4. Investigation of efficient data processing techniques for collecting and analyzing earthquake damage.

5. Analysis of long return-period earthquake ground motion hazard in the Eastern United States.

6. Continuing review of intensity data for damaging earthquakes in the Mississippi Vallley in connection with a FEMA supported disaster preparedness study in the Midwest. Areas of potential earthquake-induced ground effects are being investigated.

Results

1. Preliminary results of sensitivity studies related to probabilistic ground motion values are summarized in three reports currently under technical review for journal publication. The manuscripts are concerned with (1) attenuation variability in seismic hazard analysis, (2) maximum likelihood estimation of b-values for magnitude-grouped data, and (3) seismic hazard estimation using a finite-fault rupture model.

2. A two-state model for cyclic earthquake activity has been developed and allows the modeling of "active" and "quiet" periods of earthquake activity. A

manuscript summarizing the technique is currently in technical review for journal publication.

3. A report that estimates economic loss in the Los Angeles, California, area due to a recurrence of historical earthquakes and postulated future earthquakes is in preparation. Economic loss estimates are based on 1980 census data.

4. Five seismic source zone maps for the Eastern United States have been completed. Each map represents a particular seismotectonic model of Eastern U.S. seismicity. Probabilistic evaluation of resultant ground motions is in progress.

5. A maximum Modified Mercalli intensity map has been completed for the Mississippi Valley.

Reports

Algermissen, S. T., Askew, B. L., Thenhaus, P. C., Perkins, D. M., Hanson, S., and Bender, B. L., 1983, Seismic energy release and hazard estimation in the Basin and Range province: U.S. Geological Survey Open-File Report 83-358, 13 p.

Askew, B. L., and Algermissen, S. T., 1983, An earthquake catalog for the Basin and Range province: U.S. Geological Survey Open-File Report 83-86, 41 p.

Bender, B. K., 1983 [abs.], Seismic hazard estimation using a finite fault rupture model: Earthquake Notes, v. 54, no. 1, p. 26.

Bender, B. K., [in press], Maximum likelihood estimation of b-values for magnitude grouped data: Seismological Society of America Bulletin.

Hopper, M. G., and Algermissen, S. T., 1983 [abs.], The earthquakes of January 5, 1843 and October 31, 1895, in the central Mississippi Valley: Earthquake Notes, v. 54, no. 1, p. 7.

Hopper, M. G., Algermissen, S. T., and Dobrovolny, E. E., 1983, Estimation of earthquake effects associated with a great earthquake in the New Madrid seismic zone: U.S. Geological Survey Open-File Report 83-179, 94 p.

Thenhaus, P. C., ed, [in press], Summary of regional seismic source zone meetings concerning parts of the conterminous United States, convened by the U.S. Geological Survey, 1979-1980, Golden, Colorado: U.S. Geological Survey Circular 898, 116 ms. pages.

Seismic Hazard Studies: Anchorage, AK

9950-01205

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Investigations

1. Data analysis of 128 NTS events recorded on strong-motion instruments in the near-field is in progress.

2. Data analysis of 72 events recorded by the New England short-period network for Pg- and Lg-waves in the process of being written.

3. A report entitled "Earthquake Catalog for Peru" by L. A. Casaverde, A. F. Espinosa, J. Michael and J. Vargas Neumann, is in the process of being written.

4. An intensive bibliography search has been performed for retrieving information appertaining with geological, seismological, geotechnical and tectonic studies in the southern part of Alaska.

5. A suite of seismicity maps and depth cross-sections for the Anchorage and vicinity region in Alaska, have been plotted using the epicenter data tape collected by the Alaska Seismic Studies Project for the period from October 1977 through September 1980. A similar set of seismicity maps and depth cross-sections have been plotted for the same region using all the available teleseismic epicenter data tape collected by the National Earthquake Information Service from 1965 through 1982.

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

Reports

Espinosa, A. F., 1982, Seismic hazards and their effects on structures: lecture series for the 1st International Course in Geophysics, University Pierre et Marie Curie, Institut de Physique du Globe, Paris, France, The Center of Theoretical Physics, University of Trieste, Trieste, Italy, and the International Center of Physics, Bogota, Colombia, June 1982.

Espinosa, A. F., 1982, M_L and M_O determination from strong-motion accelerograms, and expected intensity distribution: in the Imperial Valley California earthquake of October 15, 1979, U.S. Geological Survey Professional Paper No. 1254, p. 433-438.

Espinosa, A. F., 1983, Cover picture and caption of a 3-D complex dislocation model representing the vertical displacement field due to the Algerian earthquake of October 10, 1980: EOS, Transaction American Geophysical Union, v. 64, no. 4.

Espinosa, A. F., 1983, Seismology and Earthquake Engineering in Mexico and Central and South America: Earthquake Information Bulletin, v. 15, no. 1, p. 4-6.

Espinosa, A. F., 1983, Editor of 8 papers by our Latin American colleagues: appearing in the Earthquake Information Bulletin, v. 15, no. 1, p. 7-40.

Espinosa, A. F., 1983, Book Review, TERREMOTOS (spanish translation of Earthquakes a Primer) by Bruce A. Bolt: Editorial Reverte, Spain, 266 p.

Espinosa, A. F., 1983, Book Review, Fisica de la Tierra by Agustin Udias, Editorial Alhambra, Spain, 73 p.

Espinosa, A. F., and Michael, J., 1983, Lg-wave data-base tabulation recorded on the: I.LRSM stations in the conterminous United States, II New England Stations: U.S. Geological Survey Open-File Report 83-381, 135 p.

Espinosa, A. F., McKay, S. M., Tongtaow, C., and Yeatts, F. R., 1983, An algorithm to compute a multiple volterra rectangular dislocation; strike-slip, dip-slip, normal-and reverse-faulting cases: U.S. Geological Survey Open-File Report 83- , 89 p.

Investigation of Seismic Wave Propagation for Determination of Crustal Structure

·9950-01896

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Investigations

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

2. Processed the Mini-Sosie high-resolution seismic reflection data from Utah.

Results

1. About 3/4 of the Mississippi River survey is processed and 1/3 of the data interpreted.

2. Processing has been completed on the Mini-Sosie data.

   a. Drum Mountain Scarp System near Delta, Utah.
   b. The fault scarp near Clear Lake Figure 1 south of Delta, Utah.
   c. Fault scarp near Scipio, Utah.
   d. The two lines near Kaysville, Utah.

All the data shows that the fault scarps can be traced to movement on deeper structures. Figure 1 is a very good example of the possible resolution from the Mini-Sosie. The fault can be traced from the surface to around 3500 feet and with commercial Vibrosesis to the Sevier Desert detachment surface.

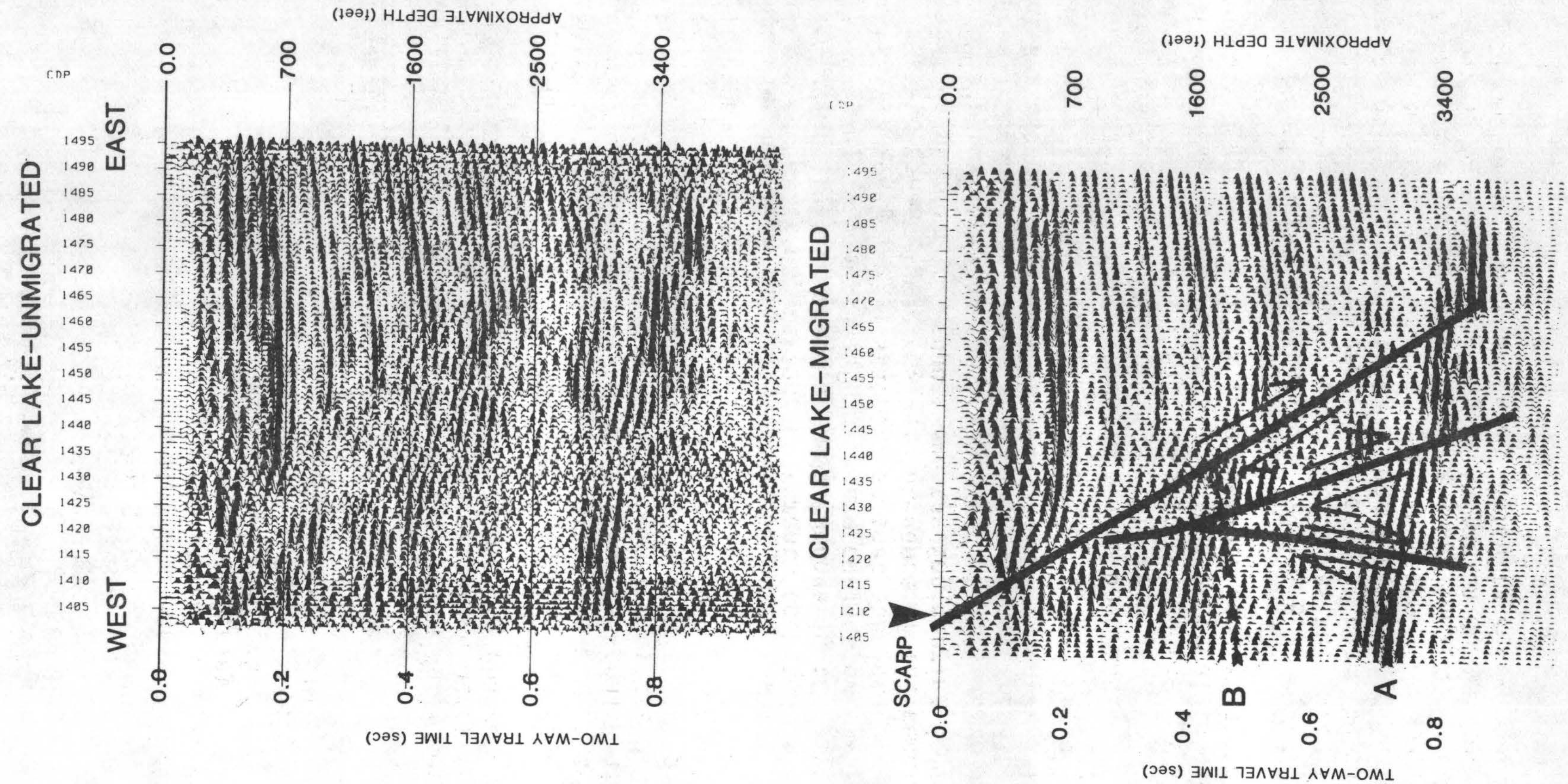

Figure 1.--Mini-Sosie high resolution seismic reflection profile from Clear Lake, Utah. A fault can be traced from the surface to its strong reflector A. A rotated block B within the fault can be seen.

Alaska Seismic Studies

9930-01162

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Investigations

1) Continued collection and analysis of data from a network of 42 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 around the proposed Bradley Lake hydroelectric project on the Kenai Peninsula. In November, 1982 funding for this work was terminated by the U.S. Army Corps of Engineers as responsibility for the hydroelectric project was transferred to the State. The Alaska Power Authority has agreed to continue funding through June 1983.

3) There are 42 strong-motion instruments operated in Alaska by the USGS, including 13 between Icy Bay and Cordova in the area of the Yakataga seismic gap. Fourteen of these are co-located with and connected to telemetered high-gain stations so that absolute time can be obtained for the strong-motion records. Maintenance of the remaining instruments is shared between this project and the Engineering Seismology and Geology Branch.

Results

1) During the past 6 months data processing has remained on schedule, and preliminary earthquake locations have been obtained for September, 1982 through February, 1983. The monthly average of located events was 351. Preliminary epicenters for the past six months are shown in Figure 1. All but two of the events larger than or equal to coda magnitude 3.5 occurred within the Cook Inlet Benioff Zone at depths below 60 km.

One exception was the magnitude 4.0 (m_b 5.3, NEIS) earthquake 35 km westnorthwest of Valdez. This event was felt with intensity IV at Valdez and III at Anchorage and occurred near the southern end of a northeast-southwest oriented concentration of seismicity that has been prominent for at least the past ten years. The other event of note had a magnitude 3.8 (m_b 4.7, NEIS) and was located at a shallow depth about 65 km southwest of Kayak Island on October 19, 1982. This event occurred in an area that is periodically active and was last active between June and October 1980.

East of Prince William Sound the seismicity pattern is similar to previous time intervals with prominent spatial clusters occurring in the following areas: below the Copper River delta; in the Waxell ridge area 75 km northeast of Kayak Island; within the aftershock zone of the 1979 St. Elias earthquake north of Icy Bay; along the Fairweather fault northeast of Yakutat Bay; and in a zone that parallels the Duke River fault north of the network.

2) The andesitic Wrangell volcanoes are distributed along a 200 km long, northwest-southeast oriented zone north of the eastern Gulf of Alaska (figure 1, lower). Although their distribution and composition is typical of volcanoes located above a subducted oceanic slab, no seismic Benioff zone has been previously identified. Recent review of hypocenters of earthquakes recorded by the USGS regional network has now revealed a northeast dipping seismic zone striking subparallel to the trend of the Wrangell volcanoes and reaching a depth of about 85 km (Stephens and others, 1983). If extrapolated to greater depths, the dipping zone would be about 100 to 125 km deep below the Wrangell volcanoes. The newly discovered Wrangell Benioff zone was slow to be identified because of its very low rate of activity, at least 10 times lower than the Benioff zone below Cook Inlet. Although the geometry of the zone is compatable with the interpretation that the activity occurs within the subducted Pacific plate, its lateral extent is not yet well defined.

3) During 1974 through 1981 seismic monitoring along the eastern Gulf of Alaska between Prince William Sound and Yakutat Bay was supported by funding from the NOAA Outer Continental Shelf Environmental Assessment Program. The principal results of this work were recently summarized in a final report to NOAA (Lahr and Stephens, 1983). While the historic data is greatly limited in terms of both completeness and accuracy, the data set for the nearly 10,000 hypocenters determined for 1974-1981 contain a wealth of detailed information. One of the most important results was development of a regional tectonic model (Lahr and Plafker, 1980). Study of the 1979 St. Elias earthquake (M_S 7.1) and its aftershocks (Stephens and others, 1980) provided important constraints on the model. Although there are gaps in processing data from the local network, all events with coda magnitude 3.5 or larger have been located and are shown in Figure 2. Rupture zones of the largest events since 1900 are also shown. Current emphasis is being placed on the operation of high-gain seismic stations and strong-motion stations in and around the Yakataga seismic gap.

References

King, P. B., 1969, Tectonic map of North America: U.S. Geological Survey Map, scale 1:5,000,000, 2 sheets.

Lahr J. C., and Plafker, George, 1980, Holocene Pacific-North American plate interaction in southern Alaska: Implications for the Yakataga seismic gap: Geology, v. 8, p. 483-486.

Lahr, J. C., and Stephens, C. D., 1983, Eastern Gulf of Alaska Seismicity: Final report to the National Oceanic and Atmospheric Administration for July 1, 1975 through September 30, 1981: U.S. Geological Survey Open-File Report (in review).

McCann, W. R., Nishenko, S. P., Sykes, L. R., and Krause, Janet, 1979, Seismic gaps and plate tectonics: seismic potential for major boudaries: Pure and Applied Geophysics, v. 117, p. 1082-1147.

McCann, W. R., Perez, O. J., and Sykes, L. R., 1980, Yakataga seismic gap, southern Alaska: seismic history and earthquake potential: Science, v. 207, p. 1309-1314.

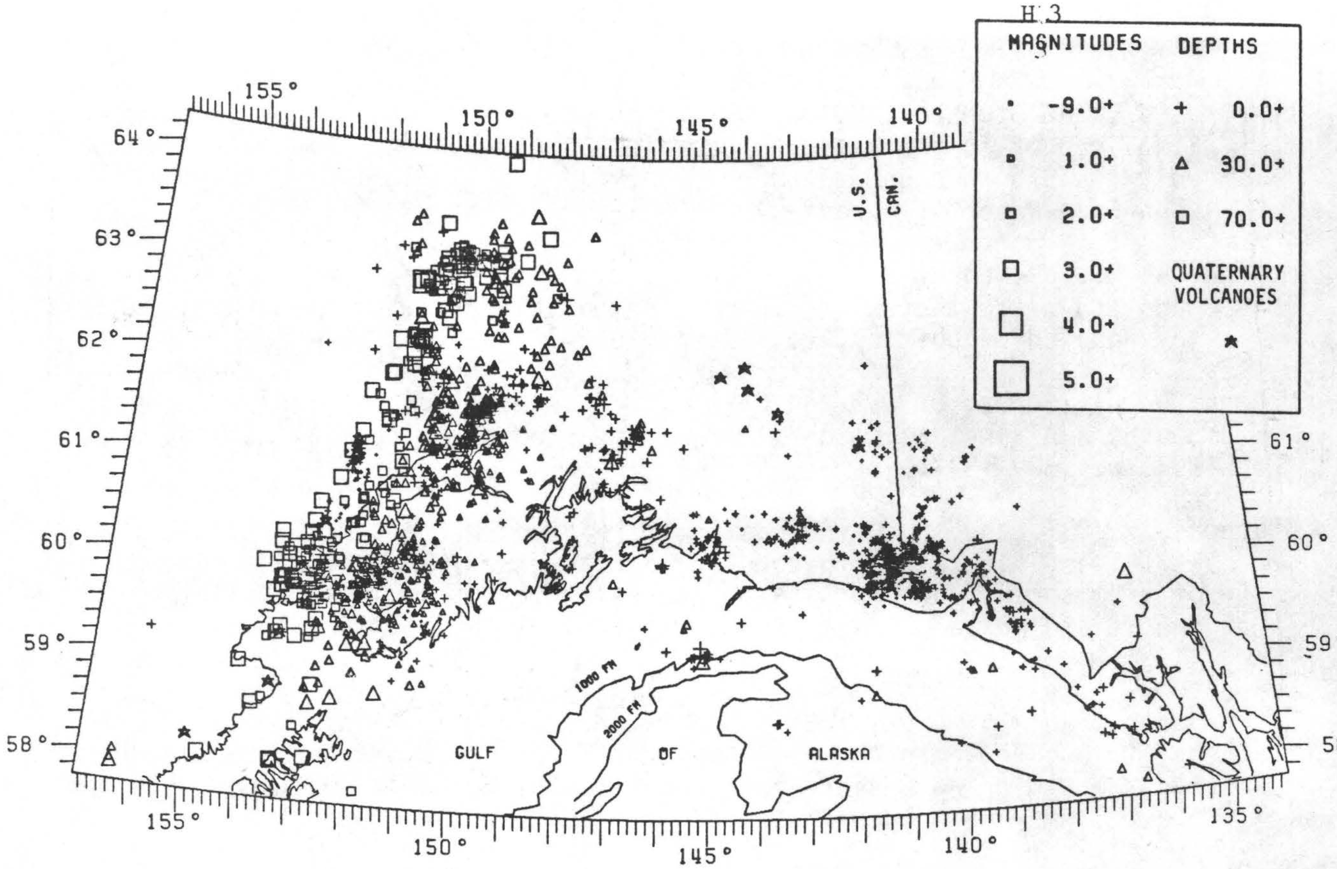
Stephens, C. D., Lahr, J. C., Fogleman, K. A., and Horner, R. B., 1980, The St. Elias, Alaska, earthquake of February 28, 1979: Regional recording of aftershocks and short-term, pre-earthquake seismicity, Bulletin of the Seismological Society of America, v. 70, no. 5, 1607-1633.

Reports

Stephens, C. D., Fogleman, K. A., Lahr, J. C., and Page, R. A., 1983, Evidence for a NNE-dipping Benioff zone south of the Wrangell volcanoes, southern Alaska: America Geophysical Union, Spring Meeting, 1983.

Stephens, C. D., Lahr, J. C., and Page, R. A., 1983, Seismicity in coastal and southeastern Alaska: October 1981 - September 1982, in Bartsch-Winkler, Susan and Reed, Kitty, eds., The United States Geological Survey in Alaska, Accomplishments during 1982, U.S. Geological Survey Circular (in prep).

Stephens, C. D., and Page, R. A., 1982, Seismic activity in the northern Gulf of Alaska since 1974, in Bruns, T. R., ed., Hydrocarbon resource Alaska, northern Gulf of Alaska, Cook Inlet, and Shelikof Strait, Alaska, U.S. Geological Survey Open-File Report 82-928, p. 115-121.



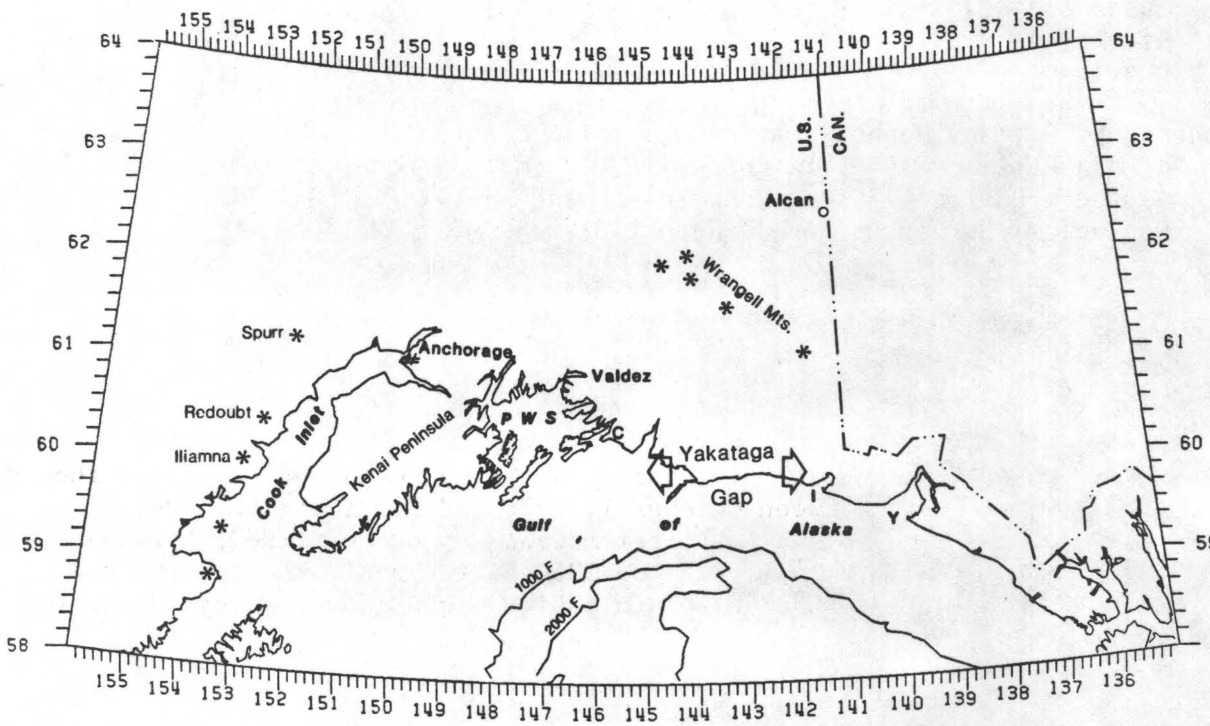


Figure 1 (upper) Seismicity in southern Alaska from September 1982 through February 1983, and (lower) location map for the same region. Abbreviations in lower map are: PWS - Prince William Sound; C - Cordova; I - Icy Bay; Y - Yakutat.

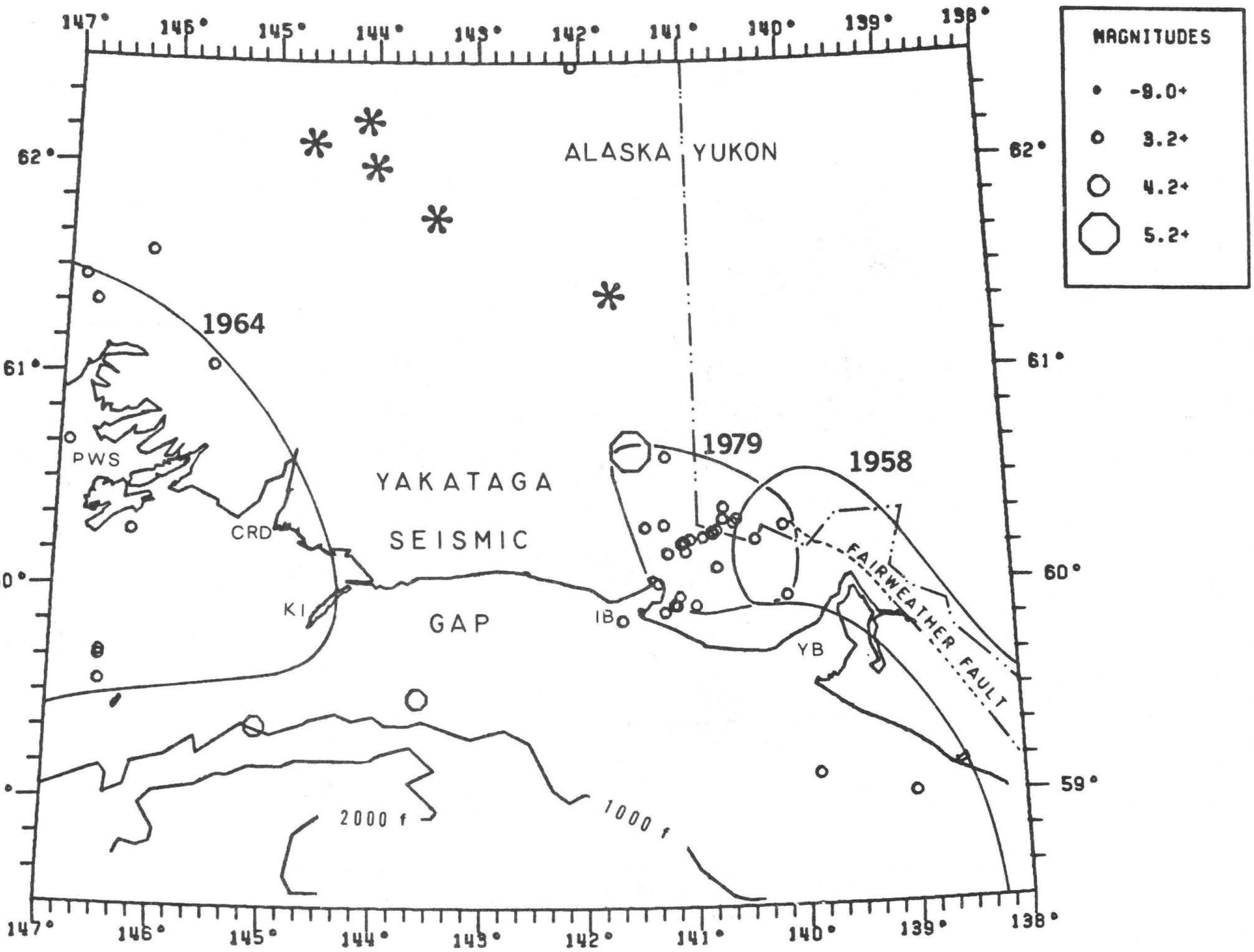


Figure 2. Epicenter map of 42 earthquakes with coda magnitudes greater than or equal 3.5 that occurred between October 1, 1974 and September 31, 1981. Earthquake rupture zone boundaries after McCann and others (1980) for 1958 earthquake, McCann and others (1979) for 1964 earthquake, and Stephens and others (1980) for 1979 earthquake. Stars indicate quaternary volcanoes (after King, 1969).

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

Contract No. 14-08-0001-20513

D. L. Lamar and J. L. Smith
Lamar-Merifield Geologists, Inc.
1318 Second Street, Suite 25
Santa Monica, California 90401
(213) 395-4528

Investigations

Annotated bibliographies have been prepared of reports evaluating seismic conditions at the San Onofre and Diablo Canyon nuclear power (NP) plants and proposed Bolsa Island, San Joaquin, Sundesert and Vidal sites, and engineering geology reports prepared to satisfy the Alquist-Priolo Special Studies Zones Act (AP) along the San Andreas, San Jacinto, San Fernando, Newport-Inglewood, Whittier-Elsinore, Garlock and White Wolf faults.

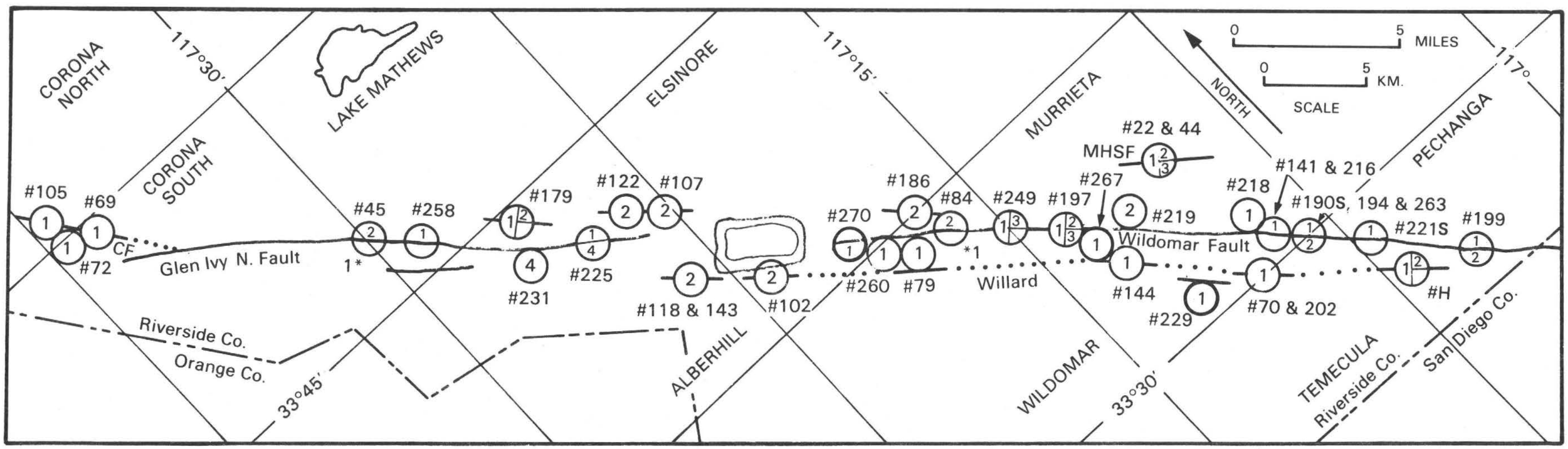
Results

The AP bibliography has 24 strip maps showing locations of reports along individual faults (Fig. 1 is an example). For each report, one or more circles show the ages of rock units exposed and whether the units are faulted. Lines through circles as extensions of faults indicate that the fault was exposed in the trench(es). Lines between numbers in the circle at right angles to the adjacent fault represent depositional contacts. Numbers inside the circle represent ages of earth materials exposed in the trenches:

1 - Holocene, <10,000 years old (recent alluvium)
2 - upper Pleistocene, 10,000 to 500,000 years old (older alluvium and alluvial terrace deposits)
3 - lower Pleistocene, 500,000 to 3,000,000 years old
4 - pre-Pleistocene, >3,000,000 years old

A sample page from the AP bibliography follows for the Elsinore fault.

The number of reports in the bibliography for each NP site varies from 20 to 54; the reports describe the regional and site stratigraphy and structure, seismic history, foundation conditions and ground-motion characteristics. Outlines of areas covered by geologic studies for the San Joaquin Nuclear Power Plant site are shown in Fig. 2, which is an example of 6 similar maps for the nuclear power plant sites. An example page from the annotated bibliography for the San Joaquin Nuclear Power Plant site follows. The NP bibliography also includes a summary of the salient tectonic aspects of each site. The NP reports vary greatly in length, scope of subject, degree of detail and direct relevance to the major faults of interest. Some reports are comparable to those of the AP bibliography in that they document in great detail the results of subsurface exploration by trenches and borings, and they indicate the location, characteristics and minimum age of last movement on faults. Others report, for example, investigations of large areas (tens to hundreds of square miles) to develop an understanding of Pleistocene stratigraphy and geomorphology applicable to evaluating local and regional tectonic activity.



CF: Chino Fault: MHSF: Murrieta Hot Springs Fault

Fig. 1 - Locations of engineering geology reports along strands of Elsinore fault zone by Riverside County number.

County (City) of Jurisdiction	County (City) File Number	CDMG AP File Number	7-1/2 Minute Quadrangle(s)	Date of Report(s) (Mo/da/yr)	Investigating Firm or Geologist	Identification Number and Site Description Where no City or County Number
Elsinore Fault Zone, Riverside County (Fig. 26)						
Riverside	H	-	Temecula, Pechanga	7/10/73	F. Beach Leighton and Associates	Job #73222
			Trenches, 8-13 feet deep, across strands of Wolf Valley fault zone (Kennedy, 1977; CDMG, 1980f,a) and Willard fault zone (Envicom, 1976). Near vertical joints with no offset in alluvium (Qal, Kennedy, 1977) across strand of Wolf Valley fault in southernmost trenches. Fault cuts old terrace deposits (Pauba Formation, Qps, Kennedy, 1977) and does not displace alluvium along possible northern extension of Wolf Valley fault or strand of Willard fault (Envicom, 1976).			
Riverside	22	-	Murrieta	11/29/74 rev. 7/12/75	Murphy, M.A. and Associates	Revised specific plan 103-C/W
			Trenches, average depth 5-7 feet, across Murrieta Hot Springs fault (Kennedy, "Fractures" in "Temecula Arkose" (Qus and Qps, Kennedy, 1977); no faulting in floodplain sediments (Qal, Kennedy, 1977).			
Riverside	44	-	Murrieta	2/13/76	Earth Research Associates, Inc.	
			Trenches, depth 7-14 feet, across Murrieta Hot Springs fault (Kennedy, 1977). Gouge zones, in unnamed pre-Pauba Formation (Qus, Kennedy, 1977); no faulting in alluvium (Qal, Kennedy, 1977).			
Riverside	45	-	Corona South, Lake Mathews	2/13/76	Pioneer Consultants	Job #2316-001
			Trenches to a depth of 12 feet across strands of Glen Ivy North fault (Weber, 1977; CDMG, 1980c,g.) Fault gouge and slickensides reported in older fan deposits (Qof, Weber, 1977). "Rift valley" (30 ft. deep, 100 ft. wide); water line in vicinity of Hunt Road requires annual repair; may be caused by continuous creep; parallel cracks in asphalt of Lawson Road.			
Riverside	69	-	Corona South	3/22/77	Pioneer Consultants	Job #2466-001
			Trenches up to 10 feet deep across Chino fault (Weber, 1977; CDMG, 1980c). Consultant reported that Chino fault cuts alluvium (Qsc or Qof, Weber, 1977) in three trenches. The structures observed were dismissed as sedimentary features by Tony Brown (Riverside County geologist) upon examination of trenches in neighboring sites GR-72 and 105.			
Riverside	70	-	Temecula	3/21/75	Pioneer Consultants	Job #1208-095
			Trenches, depth 12-14 feet, across strand of Willard fault (Kennedy, 1977). No faulting in alluvium (Qal, Kennedy, 1977).			

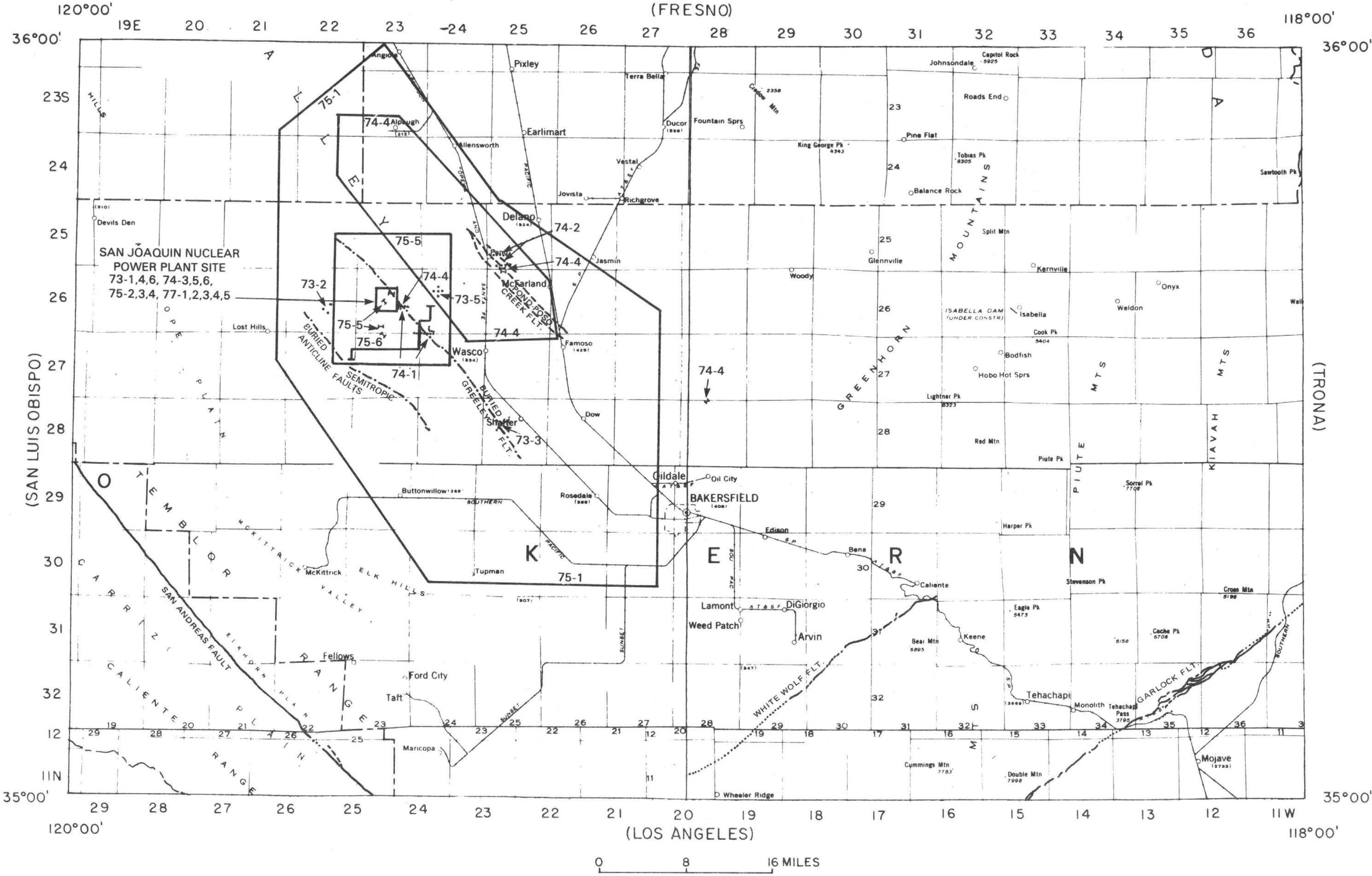


Fig. 2 - Areas covered by geologic studies for San Joaquin Nuclear Power Plant Site on Bakersfield sheet.

H3

SAN JOAQUIN NUCLEAR POWER PLANT SITE

74-4 Fugro, Inc., 1974b, Offsite exploratory programs - Greeley fault, Northwest Semitropic fault, near-site subsurface investigation, and Pond-Poso Creek fault investigation: in SJNP ESRR, Volume III, Appendix 2.5F, p. 2.5F-1 to 2.5F-85W.(74-3)

Results of an extensive drilling and trenching program designed to detect displacement along fault traces projected toward or underlying the SJNP site. Interpretations of downhole geophysical data are included as five subappendices of Appendix 2.5F.

The results of these investigations are: (1) no evidence of faulting or folding of strata 700,000 years or younger can be found along traces of the Greeley fault in the Shafter Gas Field, 15 miles southeast of the SJNP site; (2) the mid-Pleistocene E-clay layer has no demonstrable evidence of vertical or horizontal offset across the Greeley fault in the southeastern part of the SJNP site; (3) re-examination of offset on the E-clay layer, previously reported by the U.S. Bureau of Reclamation, 4 miles southeast of the SJNP site, indicates that the structure is an unfaulted gentle northeasterly-sloping homocline; (4) no evidence for offset on the Northwest Semitropic fault younger than 600,000 to 700,000 years was found in the Northwest Semitropic Gas Field 5-1/2 miles west of the SJNP site; (5) downhole geophysical studies 4 miles east of the SJNP site show good correlation among six geophysical horizons identified at the SJNP site (see Crosby, 73-1); (6) the results of airphoto, seismic profile, hydrologic, exploratory trenching, and downhole geophysical investigations of the Pond-Poso Creek fault, 11 miles northeast of the SJNP site, indicate predominantly near-vertical oblique-slip movement on the fault system and no evidence for strike-slip movement. The total cumulative apparent-vertical offset across three faults of the Pond-Poso Creek system is 32 feet, down displacement.

75-1 Farr, J.B., Mateker, E.J., Jr., Wu, C., 1975, Interpretation of seismic reflection data for the San Joaquin Nuclear Project: in SJNP ESRR, Volume IIA, Appendix 2.5E, 83 p. (74-3)

Interpretations by Western Geophysical Company of 77 seismic-reflection profiles (530 line miles) within a 20-mile radius of the SJNP site. Four geophysical horizons were contoured to illustrate structure. Three northwest-trending major fault systems, the Pond-Poso Creek, the Greeley, and the Semitropic Anticline faults, were analyzed for amount and age of movement. The study concludes that: (1) the Pond-Poso Creek System, 11 miles northeast of the site, is a zone of normal faults, down on the southwest. At a depth of 875 to 1,500 feet, a Plio-Pleistocene horizon is displaced, but the displacement dies out 9 miles from the SJNP site. (2) The Greeley fault system consists of three different faults; the shallowest displacement occurs 20 miles southeast of SJNP within Pliocene strata at depths of no less than 8,000 feet. (3) The Semitropic Anticline fault system is southwest of the SJNP site and displaces Miocene strata at depths no shallower than 10,000 feet.

The report contains four tables listing fault displacements, 33 plates which are mostly structural sections, correlation sections, contour maps and isopach maps.

Paleomagnetic Stratigraphy of the Saugus Formation Los Angeles County, California

14-08-0001-21219

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The Saugus Formation is widely exposed in the East Ventura Basin in areas undergoing rapid urbanization north and west of Los Angeles (Figure 1). In the area of our study near Castaic Junction the Plio-Pleistocene Saugus Formation consists of nonmarine conglomerates, sandstones, silty sandstones, and sandy-siltstones.

The primary objective of our paleomagnetic investigation has been to identify dated magnetozones and geomagnetic reversal boundaries to more accurately date the Saugus sediments in this area. This would enable one: to make correlations with other age calibrated sections of Saugus nearer to the Pacific coast; to determine average sedimentation rates and possibly detect changes of deposition with time; to identify rates of displacement, uplift and rotation associated with the major faults cutting the Saugus.

Sampling sites were chosen along the transmission line and Santa Clara River for establishing a reference magnetostratigraphic section in the Castaic Junction oil field just north of Pico Canyon (Figure 2). Fresh outcrops are exposed along the transmission line (TL) section which is an unfaulted homocline with beds dipping approximately 40-50° to the north-northeast (Winterer and Durham, 1962). The Saugus beds in the Santa Clara River (SCR) section are dipping more gently at 20-30° to the northeast. Paleomagnetic sites were selected in the finer-grained interbeds, and from each site three independently oriented handsamples were usually obtained. Of the 56 sites measured thus far, 51 yielded polarity information and 30 sites provided complete paleomagnetic direction.

The sampled sections are predominantly of reversed polarity containing dispersed normal beds, and capped by a sequence of normal polarity. An ash layer in the upper normal zone of the TL section is chemically very similar to the ∿0.7 MY Bishop and Friant ashes (analysis by Sarna-Wojcicki, 1983). The chemistry of the ash bed together with the biostratigraphically determined Plio-Pleistocene age suggest that the Saugus in our sampling area was deposited during the Matuyama (reversed) and lower Brunhes (normal) epochs, and its bottom age is <2.5 MY (Figure 3).

Sedimentation rates would vary from about 0.7 to 3.1 km/MY, depending on whether the normal polarity site in the Matuyama reversed interval represents the Olduvai or Jaramillo event. It is inferred from subsurface well data that the upper 350 m of Saugus are covered by younger deposits in the study area and are unavailable for sampling. Hence, depending on the invoked sedimentation rate, the youngest Saugus was deposited at about 0.2 or 0.5 MYBP.

The mean paleomagnetic direction of the Matuyama sites of both TL and SCR is $\overline{D} = 32°$, $\overline{I} = 57°$, $k = 48$, $\alpha_{95} = 4°$, $N = 23$. The mean direction of the Brunhes sites of both TL and SCR sites is $\overline{D} = 14°$, $\overline{I} = 51°$, $k = 120$, $\alpha_{95} = 6°$, $N = 7$ (Figure 4). The observed average inclination is not significantly different from the expected geocentric axial dipole value (54°). Hence, there is no evidence for north-south translation of the sampling site. The measured declination, however, indicates progressive clockwise rotation of the study area by as much as 32° since the Matuyama epoch, $t < 2.5$ MY.

References

Winterer, E. L. and D. L. Durham, 1962. Geology of southeastern Ventura Basin, Los Angeles County, California, U. S. Geological Survey Prof. Paper 334-H, p. 275-366.

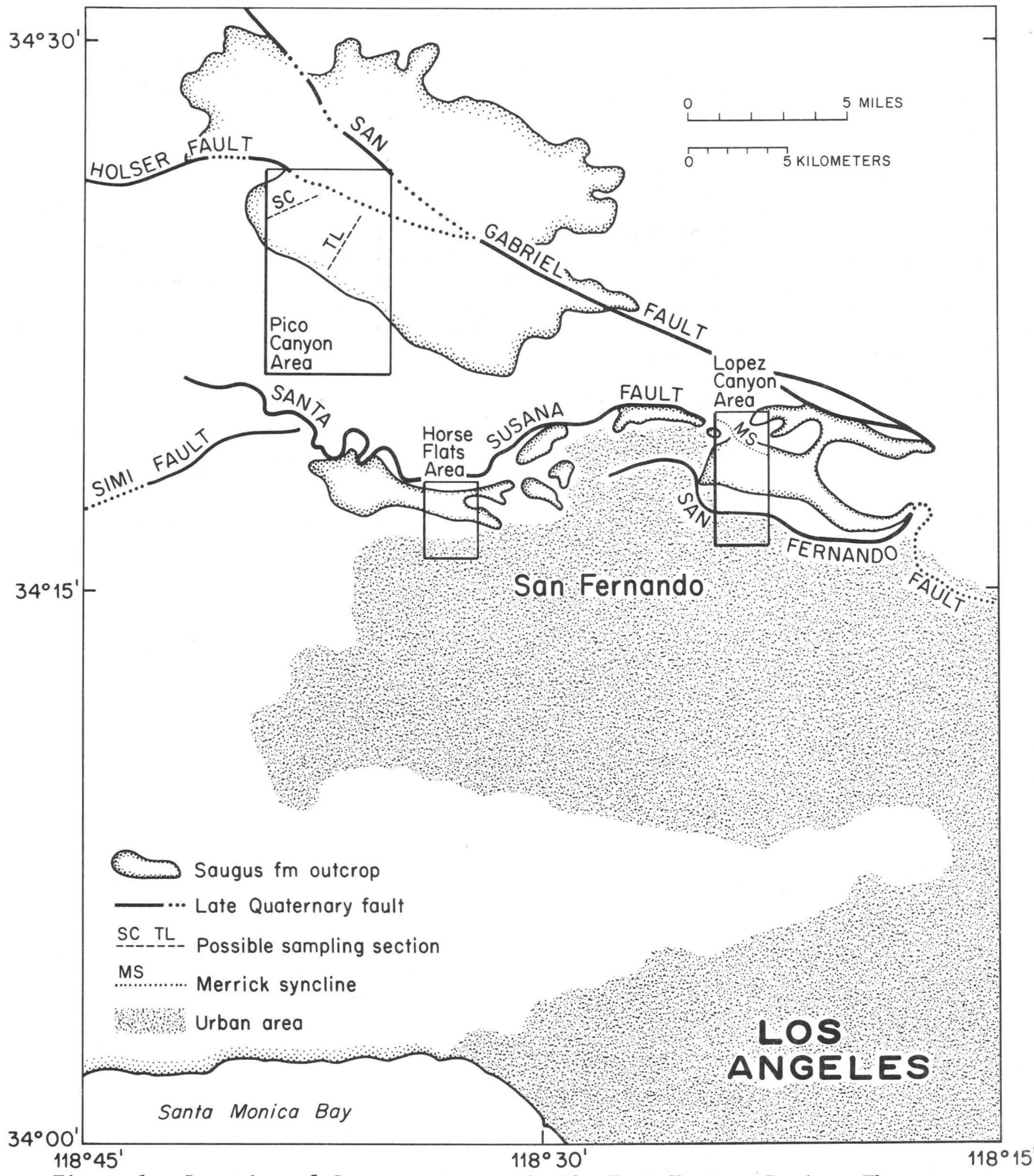

Figure 1. Location of Saugus outcrops in the East Ventura Basin. The rectangles enclose regions where detailed magnetostratigraphic studies are planned. (SC = Santa Clara River section; TL = transmission line section; MS = Merrick syncline). Adapted from "Geologic Map of the San Gabriel Mountains, California:, 1:250,000, by W. G. Bruer, California Division of Mines and Geology Bull. 196, 1975.

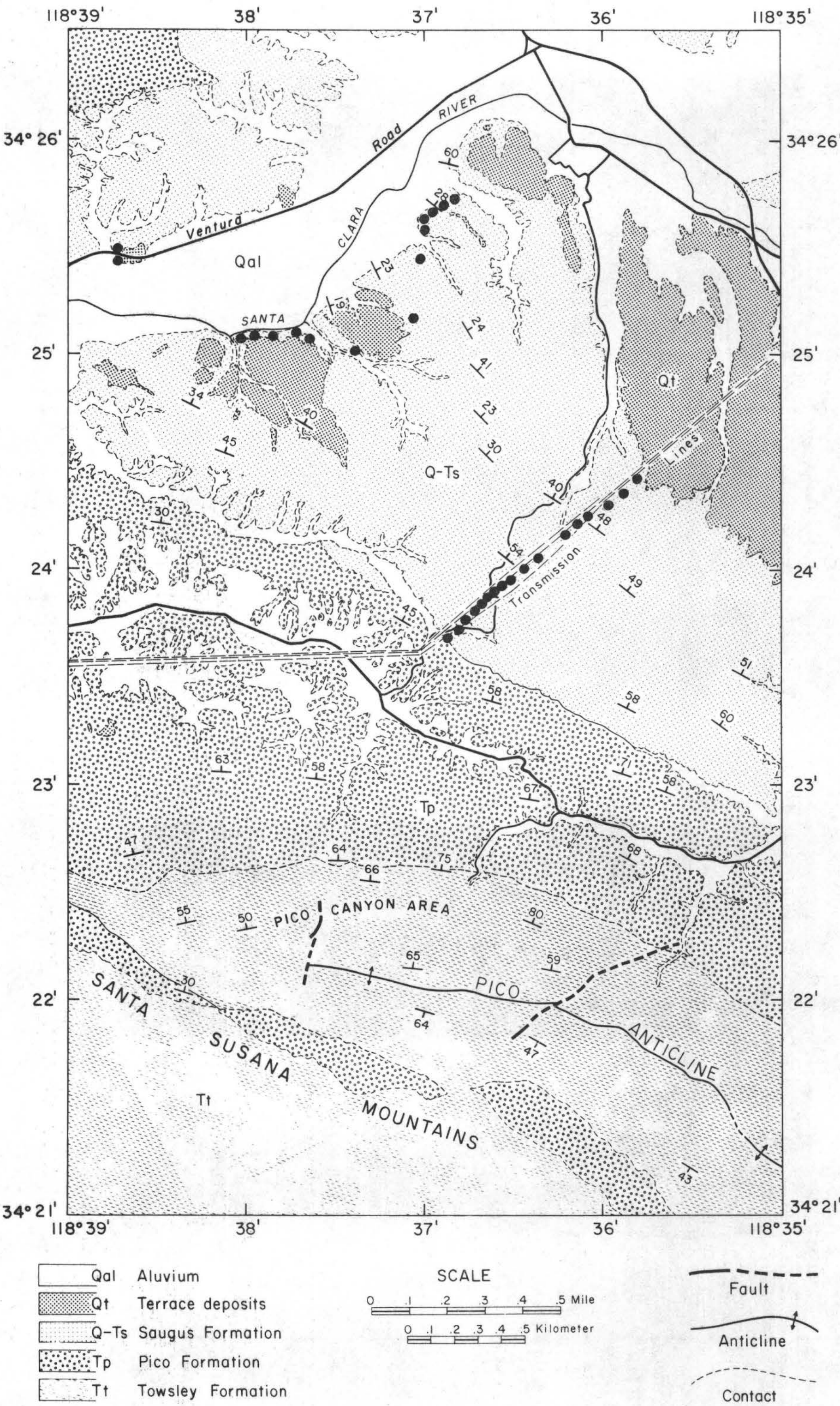

Figure 2. Geologic map of Castaic Junction/Pico Canyon area, site of transmission line and Santa Clara River sections. Redrawn from "Geologic Map of part of the Ventura Basin, Los Angeles County, California:, 1:24,000, Winterer and Durham, 1962. Closed circles represent paleomagnetic sites (in transmission line section not all sites could be drawn).

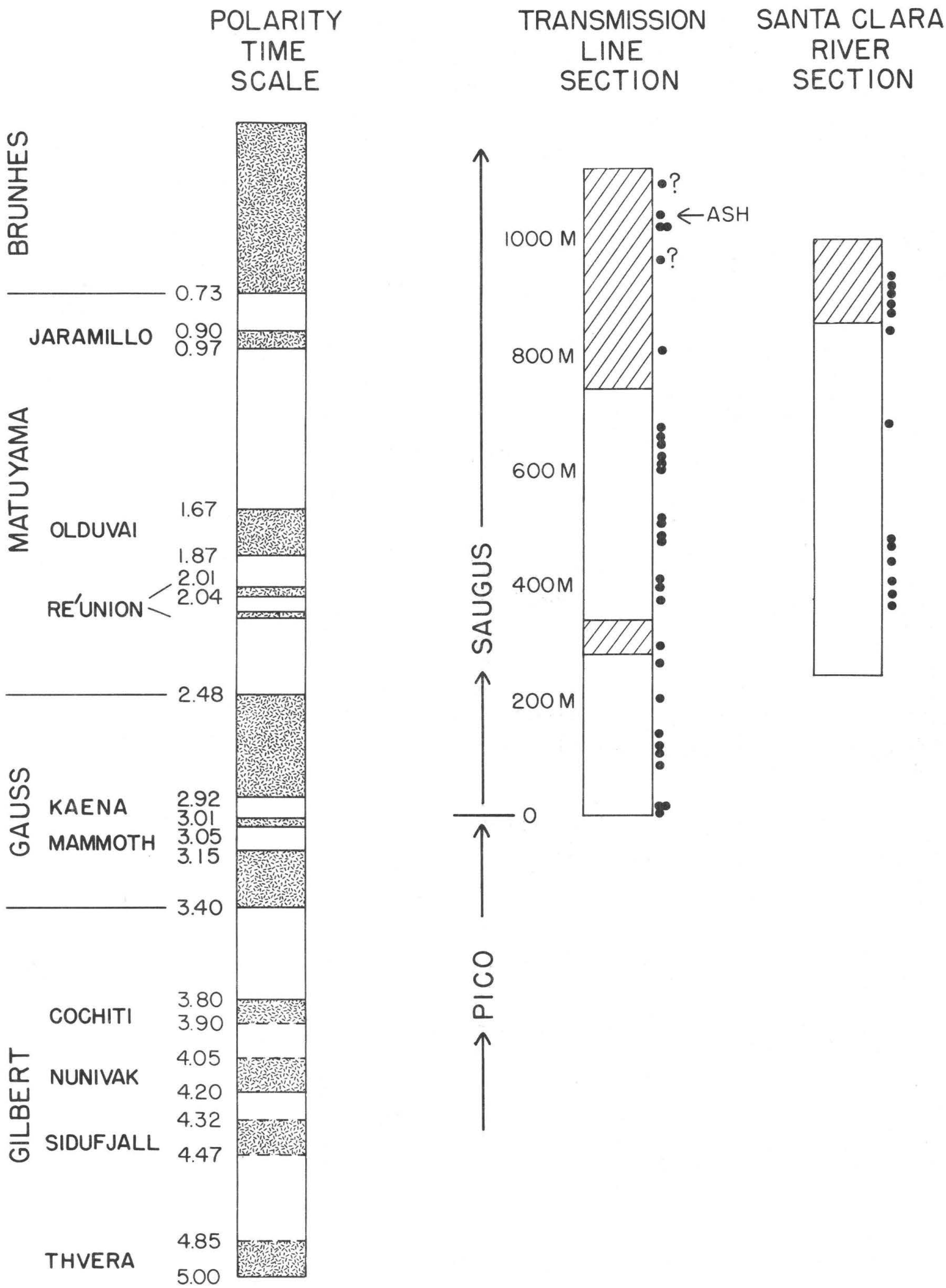

Figure 3. Magnetostratigraphy of the transmission line (TL) and Santa Clara River (SCR) sections and magnetic polarity time scale of Mankinen and Dalrymple (1979). Closed circles alongside the two stratigraphic columns indicate sampling sites.

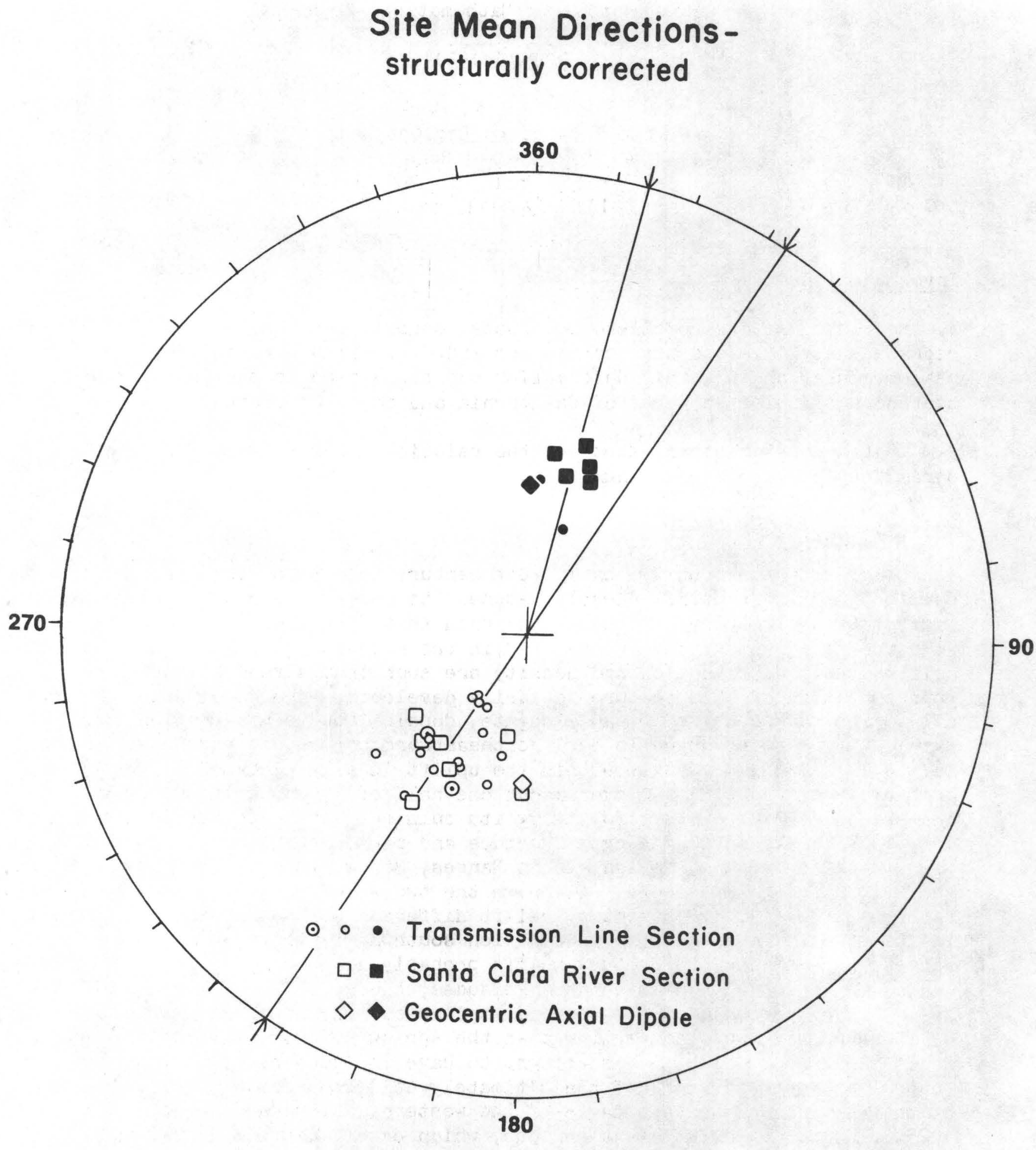

Figure 4. Paleomagnetic directions of Saugus sites. Closed/open symbols designate lower/upper hemisphere vectors. The two open circles with central dots indicate normal Matuyama sites which were inverted through the origin to distinguish between Brunhes and Matuyama data. Arrows along the circumference indicate the mean declination for Matuyama (32°) and Brunhes (14°) sites.

Applications of Mathematical Modeling

9540-03301

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Investigations

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

2. Continued statistical study of the relation among surface faulting parameters and earthquake magnitude.

Results

1. Completed report on "An early 20th century uplift in southern California." This uplift closely matched its modern analogue in areal extent, magnitude, and history. Although the data that permitted its detection are much more fragmentary than those used in the reconstruction of the modern uplift, their distribution and density are such that a generalized representation of this feature is easily developed. The early 20th century uplift was characterized by an elongate, double-lobed configuration that extended from Point Arguello east-southeastward to the northern edge of the Salton Sea. Height changes within the uplift locally exceeded 0.5 m, but probably averaged 0.3-.4 m over about one-half of its roughly 50,000-km^2 extent. At or immediately following its culmination the uplift included most or all of the Transverse Ranges province and parts of the Coast Ranges, San Joaquin Valley, Sierra Nevada, Basin Ranges, Mojave Desert, Peninsular Ranges, and Salton Trough provinces. Although the two were remarkably similar in many respects, the early 20th century uplift differed from its modern counterpart in its significantly greater penetration southward into the Peninsular Ranges. The early 20th century uplift probably achieved most of its growth during two relatively well defined episodes, the second of which was followed by or closely associated with partial collapse. The first major spasm of uplift probably began no earlier than the spring of 1906, was largely over by the beginning of 1907, and is thought to have included nearly all of the central and western parts of the ultimately uplifted area. Partial collapse of the central and western parts of the western lobe began no later than 1925. The uplift of the eastern lobe, which exceeded 0.5 m, could have occurred in association with or following the identified collapse. The growth of the early 20th century uplift, unlike its modern analogue, is at least vaguely correlated with the contemporary seismicity. Comparison with the seismicity both within or around and north of the early 20th century uplift suggests that the growth of this feature may have been triggered by one or more relatively large shocks.

2. Manuscript in review (Bonilla, Mark, and Gilmore) includes regression models relating surface faulting parameters and earthquake magnitude.

Reports

Gilmore, T. D., and Castle, R. O., 1983, A proposed tectonic contribution to the preservation of the divide between the Salton basin and the Gulf of California (abs.): Rocky Mountain and Cordilleran Sections Annual Mtg., May 2-4, 1983, Salt Lake City, Geological Society of America, Abstracts with Programs, v. 15, no. 5, p. 439.

Gilmore, T. D., and Castle, R. O., 1983, A contemporary tectonic boundary coincident with the Arizona-California border (abs.): Rocky Mountain and Cordilleran Section Annual Mtg., May 2-4, 1983, Salt Lake City, Geological Society of America, Abstracts with Programs, v. 15, no. 5, p. 315.

Castle, R. O., Church, J. P., Elliott, M. R., Gilmore, T. D., Mark, R. K., Newman, E. B., and Tinsley, J. C., III, 1983, Comment on "The impact of refraction correction on leveling interpretations in southern California" by William E. Strange: Journal of Geophysical Research, v. 88, no. B3, p. 2508-2512.

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

2. Neotectonic studies of the Cucamonga, Banning, and San Andreas fault zones. The study has focused on: (a) mapping fault strands that deform crystalline basement rocks, Tertiary sedimentary rocks, and Quaternary surficial units; (b) identification of Quaternary units to establish Quaternary depositional patterns and the relative ages of displacements along various fault strands; and (c) interpreting inter-relationships between the Banning fault system and the south branch of the San Andreas fault.

Results

1. Our regional study of seismically-induced liquefaction in the upper Santa Ana River valley area still is in the data-interpretation phase, and is focussing on the correlation of shallow-subsurface geotechnical data with surficial geologic units mapped on aerial photographs and identified in the field. The geotechnical data base described in the previous summary of technical reports (v. 15) has been plotted on 1:24,000-scale topographic maps, and has been overlaid on our geologic base for the upper Santa Ana River valley region. Our preliminary evaluation suggests that we can make generalized correlations between specific geologic units and geotechnical parameters obtained in test borings, especially standard penetrometer resistance.

From our initial studies, we are discovering that loosely to moderately consolidated Holocene sedimentary materials throughout the valley region apparently constitute only a thin veneer (< 50 ft typically) that is developed on top of well-consolidated older alluvial deposits (Pleistocene). Previous interpretations by other workers have characterized the Holocene sedimentary fill as a wedge of sediment that is considerably thicker. Our preliminary interpretation is based on Scott E. Carson's examination of standard-penetrometer data derived from test borings conducted by California Department of Transportation and the U.S. Army of Corps of Engineers. Penetrometer resistance rises significantly at depths ranging from about 30 to 50 ft subsurface. In some test borings, the increase in penetrometer resistance coincides with empirical features identified by the driller or logger: (1)

the transition from stiff, dense sedimentary materials to very dense sedimentary materials, and (2) the transition from grayish-colored sediment to brownish-colored sediment. We suspect that the rise in penetrometer resistance 30 to 50 ft subsurface, coupled with the empirical changes in sediment firmness and sediment color observed in some boring logs, signals the transition from slightly consolidated Holocene sediment to more consolidated Pleistocene sediment. We presently are evaluating these relationships in the context of what is known about the surface and subsurface distribution of Holocene and Pleistocene units within the upper Santa Ana River valley.

If confirmed, the meager Holocene thicknesses within the valley region will have significance for interpretations of liquefaction susceptibility and ground response. The Holocene-thickness estimates have been utilized for ground-response studies by W. B. Joyner and T. E. Fumal, and will be incorporated by these authors in a predictive model of ground motion in the upper Santa Ana River valley to be included in the U.S. Geological Survey professional paper on earthquake hazards in southern California.

2. J. C. Matti and J. C. Tinsley have calculated a net-slip rate of 3.9 mm/year for late Quaternary fault strands at Day Canyon in the Cucamonga fault zone. Here, earlier studies (Morton and others, 1982; Matti and others, 1982) proposed that Cucamonga strands A, B, and C have generated about 36 m of vertical slip during about 13,000 years of latest Pleistocene and Holocene time. These figures yield a 2.77 mm/year rate for the vertical component of slip. By trigonometric calculations, this figure can be converted into a 3.9 mm/year long-term net-slip rate during the last 13,000 years. These calculations assume that faults observed in trenches to have 35° northward dips steepen in the subsurface to average dips of 45°; if the faults retain a 35° north dip in the subsurface, the slip rate increases to 4.8 mm/year. The net-slip data will be incorporated on a U.S. Geological Survey MF map compiled by M. M. Clark that will summarize state-of-the-art information for slip rates on faults in California.

Similar slip-rate values may apply to fault strands occurring about one mile east on the fanhead of East Etiwanda Canyon. There, Tinsley and Matti have estimated cumulative vertical displacements on strands A, B, and C using photogrammetric methods. The results suggest that the three strands have produced 35-43 m of vertical displacement of the same 13,000-year-old alluvial surface displaced on Day Canyon fanhead. These separations are compatible with a cumulative vertical separation of 34-42 m also determined by photogrammetric methods for strands A, B, and C at Day Canyon fanhead (where actual field measurements indicate 36 m of cumulative displacement). These scarp-height data suggest that vertical-slip rates are similar at the two different localities; the net-slip rates at Day Canyon and East Etiwanda canyon probably also will be similar.

The preliminary interpretation that cummulative net-slip rates for strands A, B, and C are similar at Day Canyon and East Etiwanda Canyon will allow us to evaluate the timing and amount of displacements on individual fault strands within the Cucamonga fault zone. For example on Day Canyon fanhead, 16 m of the measured 36 m of cumulative separation occurred on strand C; thus, a significant fraction of the calculated 3.9 mm long-term slip rate can be apportioned to strand C. When traced eastward to the East Etiwanda fanhead, the strand-C scarp decreases in height. Previously (Matti and others, 1982), we attributed this scarp-height decrease to the interpretation that strand C had disrupted progressively younger alluvial sediment eastward along its strike. Follow-up studies now suggest that the alluvial sediment disrupted by strand C does not vary much in age between Day Canyon and East Etiwanda fanheads; thus, decrease in strand-C scarp height eastward must reflect either a decrease in activity (i.e., number of ground-rupture events) or a decrease in the amount of displacement per event. In either case, on East Etiwanda fanhead a smaller fraction of the calculated 3.9 mm slip rate must be apportioned to strand C; accordingly, because the 3.9 mm slip rate apparently applies to strands A, B, and C on both Day Canyon and East Etiwanda Canyon fanheads, strands A and B on East Etiwanda fanhead must be apportioned a greater fraction of the overall 3.9 mm slip rate in comparison to their rate on Day Canyon fanhead. These preliminary observations and interpretations underscore two points: (1) fault strands that break alluvial materials can yield important information on slip rates and displacement history, provided that the age of the alluvial units can be documented carefully by soil-profile characteristics or by radiometric determinations; and (2) thrust-fault zones developed in alluvial materials are far more complex in terms of their geometry, distribution, and displacement history than indicated by the simplistic assumptions of Matti and others (1982, p. 43).

References Cited

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.

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, p. 218.

Geologic Earthquake Hazards in Alaska
9310-01026

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Investigations

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

1. Continued work on neotectonic map of Alaska, active fault data file, and report on 1899 Yakutat Bay earthquakes.

2. In North Yemen from December 28, 1982 to January 10, 1983, studying effects of the earthquake of December 13, 1982.

Results

The destructive Yemen earthquake of December 13, 1982 (M_S=6.0) resulted in at least 1700 deaths and left tens of thousands homeless in a region centered 70 km south of the capital city, Sana (Fig. 1). The extensive destruction and heavy loss of life resulted primarily from widespread collapse of unreinforced masonry and adobe structures. Except for numerous rockfalls, geologic effects attributable to shaking were minimal. Maximum estimated MMI was probably only VII-VIII. The main surface geologic effect that is ascribed to tectonic activity is the occurrence of north- to northwest-trending earthquake-related extensional ground cracks in the epicentral region. The known cracks occur in four relatively continuous linear zones with average north-northwest trends that are from a few hundred meters to 15 km in length. Data from strain quadrilaterals across the cracks indicate that dilation was continuing at a high rate almost 1 month after the main shock.

Available data suggest that the earthquake sequence is caused primarily by dilatant cracking. It is inferred that extension in the source region reflects local uplift at the surface over an area up to 15 km long and 10 km wide, most probably related to upward movement of magma at depth. This preliminary interpretation is based on: 1) the occurrence of purely extensional surface cracking in the epicentral region, 2) a high level of aftershock activity as is common for many earthquake sequences related to volcanism, and 3) a geologic setting in a region of young bimodal volcanic activity where there has been at least one historic eruption.

Reports

Plafker, George, and Jones, D. L., 1982, Geologic and tectonic evolution of Alaska, *in* Palmer, A. G., ed., Regional Geological Synthesis: Geological Society of America D-NAG Special Publication 1, p. 77-80.

Plafker, George, 1983, Tectonic evolution of the Yakutat block: an actively accreting tectonostratigraphic terrane in southern Alaska [Abs.]: Proc. of XV Pacific Science Congress, Dunedin, N.Z., Feb. 1-11, 1983, p. 188.

Decker, John, and Plafker, George, 1983, The Chugach terrane--a Cretaceous subduction complex in southern Alaska [Abs.]: Geological Society of America Abstracts with Programs, v. 15, no. 5, p. 386.

Plafker, George, 1983, The Yakutat block--an actively accreting tectonostratigraphic terrane in southern Alaska [Abs.]: Geological Society of America Abstracts with Programs, v. 15, no. 5, p. 406.

Plafker, George, Agar, Robert, Ali Hussein Al-Thahiri, Asker, and Hanif, Mohammed, 1983, Surface effects and tectonic setting of the 13 December 1982 Yemen earthquake [Abs.]: Earthquake Notes, v. 54, no. 1, p. 20.

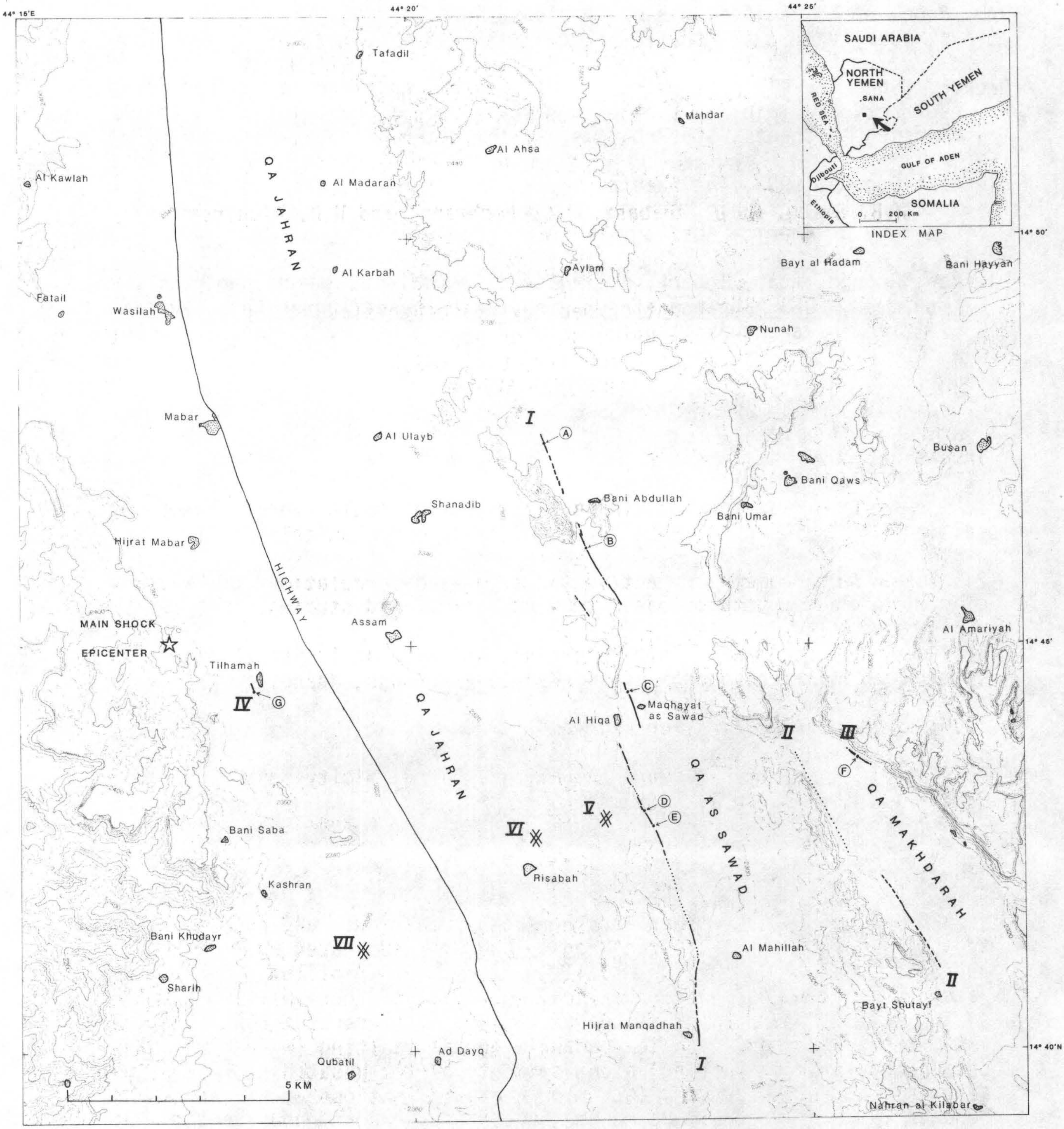

Figure 1. Map showing the main shock epicenter of the Yemen earthquake of december 13, 1982 and zones of linear extension cracks associated with the earthquake and its aftershocks (Roman numerals I to IV). Local zones of irregular ground cracks are indicated by diagonal pattern (Roman numerals V to VII). Letters A to G indicate locations of strain quadrilaterals installed across the crack zones.

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

14-08-0001-21184

October 1, 1982 to March 31, 1983

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Investigations

1. Subsurface geometry and kinematics of normal fault zones based on seismic reflection,earthquake data, and thermal-mechanical modeling.

2. Subsurface geometry of active faulting--and correlation of seismicity with fine structure--based on earthquake field studies.

3. Emergency response, field recording, and data analysis relating to earthquake swarm episode ($M_L \leq 4.7$) near Soda Springs, Idaho.

4. Instrumental calibration program.

5. University of Utah network operations and seismicity for the period: October 1, 1982-March 31, 1983.

Results

1. The relationship between earthquakes, faulting, and contemporary tectonics of the Wasatch Front region has been evaluated using geologic and seismic moment rates, detailed reflection profiles across the Wasatch fault zone, and numerical modeling of quasi-plastic flow to evaluate maximum depths of seismogenic zones. Interpretations of these data reveal: (1) moderate to low angle normal faulting (with some indications of listric faulting) along segments of the Wasatch fault and the East Cache fault zones; (2) low-angle reflections at 6-7 km depths beneath the eastern Great Basin that appear to be continuous beneath the

*The following individuals also contributed significantly to this project during the report period: D.R. Julander, E. McPherson, and G.E. Randall.

Wasatch Front and are interpreted as westward-dipping, thrust-related detachment surfaces; (3) a general observation that many normal faults rotate into a low-angle geometry producing asymmetric grabens; and (4) a recognition that earthquake hypocenters and fault plane solutions do not correlate directly with the low-angle detachments. Accurate foci and epicenter distributions suggest that earthquakes east of the Wasatch fault are distributed throughout the thick (5-7 km thick) sedimentary column and in the footwall portions of the normal fault systems. Nucleation depths of larger ISB earthquakes may be near the bottom of the brittle layer.

An important constraint on the maximum depths of earthquakes and hence on the seismogenic behavior has been investigated by modeling quasi-plastic strain rate and temperature dependent flow of crustal rocks. Seven different rock types have been modeled using appropriate strain rates of 10^{-13} to 10^{-15} (derived from moment rates calculated from contemporary seismicity and quaternary geology) and show that the transition from brittle to ductile behavior may begin at relatively shallow depths, as little as 6 km in the Wasatch Front area.

2. The best observational data yet available for correlating seismicity with complex subsurface structure in the Utah region come from portable-network studies augmenting our regional telemetry network. Detailed observations from central Utah--and recently from SE Idaho (see item 3, below)--suggest that pre-Neogene, low-angle structural discontinuities in the crust may play an important role in separating locally intense upper-crustal (h 6<km) brittle deformation from subjacent (h=6-10 km) seismic deformation on blind structures. Understanding how and where large earthquakes nucleate in the Intermountain seismic belt becomes increasingly problematical. Background earthquakes of small to moderate size may be causing a blurred picture by their occurrence within the interior of blocks--or perhaps as a pattern of shallow seismicity superimposed upon a different pattern of more episodic mid-crustal seismicity. Evidence for seismic slip on low-angle or downward-flattening normal faults remains elusive.

3. An earthquake swarm episode occurred close to Soda Springs, Idaho, between mid-September and mid-November 1982. The sequence included more than 50 felt earthquakes and peaked with a shock of M_L 4.7 on October 14. Following the latter shock, a dense network of 19 stations was jointly operated in the epicentral area by the Univ. of Utah and the USGS/Golden for 11 days (Oct. 15-26; >2,000 earthquakes recorded). Important findings include: (1) epicentral alignment along the SW flank of the Aspen Range, SE of Soda Springs, along a 13-km long zone trending N30°W and located a few km NE of and parallel to the NE boundary of the Bear River Valley; (2) evidence for SE migration of seismicity; (3) foci from near surface to 10 km depth, chiefly clustering above 6 km within a thrust

plate defined by pre-Cenozoic structure; and (4) the predominance of strike-slip focal mechanisms--with one dextral-slip nodal plane trending NW in agreement with planar-clustered foci.

4. As a means of calibrating our array for digital analysis we have modeled our seismic telemetry stations with a simple frequency-domain response, from which we can calculate both magnitude and phase responses. We use a simple weighted least-square procedure to fit our theoretical system response to our measured calibration data. The response consists of seismometer response and constant-amplitude acceleration followed by a filter (in the VCO). Our model has been verified by both engineering analyses and bench-test measurements.

5. During the six month period October 1, 1982-March 31,1983, 658 earthquakes were located within the Utah region. The largest event was a magnitude (M_L) 4.7 earthquake 10 km SE of Soda Springs, Idaho on October 14, 1982. This earthquake was part of a swarm sequence from December 1981 through March 1983 including at least 30 earthquakes with magnitude greater than 3.0. Other felt earthquakes during this report period included: 1) a magnitude 3.5 shock on December 24, 1982 in western Pocatello Valley, 20 km SW of Malad City, Idaho; 2) a magnitude 3.2 earthquake on March 6, 1983 near Mountain Green, Utah, 10 km SE of Ogden, Utah; and 3) a magnitude 3.1 event near Sunnyside, Utah on March 22, 1983 in the vicinity of extensive underground coal mining.

Reports and Publications

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Owens, T.J., 1983, Normal faulting and flexure in an elastic-perfectly plastic plate, Tectonophysics, v. 93, p. 129-150.

Randall, G.E. and McPherson, E., 1983, Beyond the "digital develocorder"--the quest for quality waveforms using the University of Utah's seismic network (abs.), Earthquake Notes, v. 54, no. 1, p. 13.

Richins, W.D., Arabasz, W. J. and Langer, C.J., 1983, Episodic earthquake swarm ($M_L \leq 4.7$) near Soda Springs, Idaho, 1981-82: Correlation with local structure and regional tectonics (abs.), Earthquake Notes, v. 54, no. 1, p. 99.

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Smith, K.A. and R. B. Smith, 1982, Low-angle faulting in an extensional domain: identification and mechanism of deformation, Eos, Trans. Am. Geophys. Union v. 63, p. 1033.

Smith, R. B. and Bauer, M.S., 1983, Elastic strain release in the Basin-Range and southern California: Inferences from seismicity and geologically derived moment rates (abs.), Earthquake Notes, v. 54, no. 1, p. 45.

Earthquake Hazards of the Reno NE Quadrangle: Part I, Geology

14-09-0001-20563

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Goals

The goal of this study was to map the surficial geology of the Reno NE 7 1/2-minute quadrangle, with emphasis on the Quaternary stratigraphy, in order to determine the recency and magnitude of movement on major faults in the area.

In addition, data from this study are currently being used to develop the earthquake hazards map for the Reno NE quadrangle. This map provides 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 on faults in the quadrangle. Final results of this part of the study will be reported following completion of the map.

Investigation

In order to complete the geologic map, the following tasks were completed:

1) collection and compilation of all published and unpublished geologic studies for the area, and acquisition of 1:12,000-scale, low sun-angle photography for mapping;
2) mapping of the quadrangle at 1:12,000 and transfer to 1:24,000 topographic base;
3) detailed alluvial- and soil-stratigraphic studies to differentiate and date key deposits for fault hazard purposes;
4) description of geologic units with emphasis on physical (engineering) properties, and description of young faulting as it relates to major tectonic features of the region.

Results

The Reno NE quadrangle is composed of several bedrock mountain ranges separated by the intermontane basins of Lemmon Valley, Hungry Valley, and Antelope Valley. Field mapping indicates that the bedrock areas are predominantly light gray Mesozoic granodiorite intruded by lesser amounts of pink to white Mesozoic quartz monzonite. Isolated pendants of Mesozoic Peavine Sequence metavolcanics crop out locally, surrounded and intruded by granodiorite. These metavolcanics were regionally metamorphosed to the greenshist facies (Bonham, 1969) prior to the Jurassic-Early Tertiary intrusion of the granitic rocks.

A prominent outcrop of mid-Tertiary (late Oligocene-early Miocene) volcanics, commonly referred to as the Hartford Hill Rhyolite, unconformably overlies the Mesozoic granodiorite in the southwest quarter of the quadrangle. These volcanics are comprised largely of pale pink, cream, reddish brown, or gray ash-flow tuffs of rhyolitic to rhyodacitic composition which trend approximately N-NE and dip 10-30° NW. They exhibit all stages of welding and are generally crystal-rich. The Hartford Hill volcanics once formed a continuous volcanic pile covering a large part of west-central Nevada; however, subsequent faulting, tilting, and extensive erosion prior to the extrusion of late Miocene volcanic rocks have left only remnants of the original section exposed.

Isolated outcrops of post-Hartford Hill, Miocene volcanic rocks unconformably overlie granodiorite (Alta Fm and Pyramid Sequence) in the northwest or Hartford Hill volcanics (Kate Peak Fm) in the southwest.

The Basin and Range episode of extensional tectonics in late Cenozoic (~17 m.y.a) resulted in the major ranges and valleys that characterize the current topography in Reno NE quadrangle. With the uplift of the ranges came extensive erosion of the highlands and deposition into the basins. This period is represented in Reno NE by thick sequences of late Tertiary to early Quaternary alluvial, fluvial, and lacustrine sedimentary deposits which underlie the intermontane basins. These deposits have been faulted, warped, and eroded, and in most places are covered by younger alluvium.

Eroded, faulted remnants of early Pleistocene pediments cut in the basin-fill sediments, crop out at the margins of the basins suggesting that extensive pediments may have surrounded the mountain blocks in early Quaternary.

In general, the late Tertiary-early Quaternary deposits are overlain by younger mid- to late Quaternary alluvial and pluvial sediments. In particular, late Quaternary beach, forebeach, and lake sediments indicate the existence of pluvial lakes in Lemmon Valley and Antelope Valley. These lakes were contemporaneous with, but hydrologically isolated from, the last high stand of Lake Lahontan (Mifflin and Wheat, 1979).

Holocene deposits in the quadrangle include alluvium derived, in part, from existing early to late Pleistocene alluvial deposits; clay dunes and windblown sands derived from pluvial lake sediments; alluvial plain, sheetwash, and stream sediments, and recent alluvial fans and colluvium.

The Reno NE quadrangle is in a tectonic area dominated by three major features: 1) the north-south-trending Sierra Nevada Frontal Fault Zone (normal faulting) to the west, 2) the Walker Lane, a northwest-trending zone of right-slip transcurrent faulting to the north-northeast, and 3) the northeast-trending, left-lateral Olinghouse Fault Zone to the south. Structures in the quadrangle include northerly-trending, range-bounding faults, northeasterly- and northwesterly-trending alluvial faults, miscellaneously-oriented bedrock faults, and a series of northeasterly-trending lineaments.

The bedrock faults are predominately pre-Pleistocene in age; whereas the range-bounding faults appear to have moved as recently as mid-Pleistocene. Of note, is the "Airport Fault" which trends northeast and extends from the southwest quarter of the quadrangle along the west side of Lemmon Valley. This fault scarp is over 27 m high and has had multiple movements, the most recent of which occurred in mid-Pleistocene as indicated by trenching data. No evidence of Holocene movement on faults in Reno NE quadrangle was found. The lineaments in the northeast quarter of the quadrangle appear to be surficial expressions of the upturned, warped bedding of Tertiary-Quaternary basin-fill sediments.

Publications

Szecsody, G. C. (in press) Geologic map of the Reno NE quadrangle, Nevada: Nev. Bur. of Mines and Geology, Reno Area Map 4Cg, 1:24,000.

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Quaternary Framework for Earthquake Studies
Los Angeles, California

9540-01611

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Investigations

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

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

3. Completed appraisal of regional liquefaction potential in the Los Angeles area. (J. C. Tinsley, T. L. Youd, D. M. Perkins and D. Merritts).

4. Continued preparing and revising drafts of 5 chapters for inclusion in the U.S.G.S. Professional Paper describing earthquake hazards in the greater Los Angeles region.

Results

1. Data base compilation is 80% complete in the Van Nuys and Burbank quadrangles.

2. Surficial geologic mapping is 95% complete and 40% of that is field-checked in the Los Angeles basin area.

3. Sediment most likely to contain clay-free, granular materials susceptible to liquefaction is that deposited during the past few hundred years (latest Holocene) and, to a lesser degree, that deposited during the past 10,000 years (earlier Holocene). Latest Holocene deposits occur in the active, or youngest, parts of depositional basins. Areas of latest Holocene deposits are distinguished from the areas of earlier Holocene deposits because the former areas typically have a recent (documented) history of flooding and are characterized by cumulic inceptisols and entisols having minimally developed A and C horizons. Earlier Holocene deposits have mollic A horizons. oxidized C (Cox) horizons up to 2 m thick, and a minimally developed textural B horizon or cambic B horizon may be present. Pleistocene deposits typically have pedogenic soils that have a moderate or well-developed textural B horizon and a Cox horizon more than 2 m thick. Rubification (reddening) is a compelling argument for a Pleistocene age designation. Designations of high, moderate, and low susceptibility reflect the age of, depth to, and penetrometer resistance of the water-saturated sediment.

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

Reports

Tinsley, J. C., Youd, T. L., and Perkins, D. M., 1983, Evaluation of liquefaction potential in the Los Angeles area, California: Geological Society of America, Cordilleran Section, Abstracts with Programs, v. 15, no. 5, p. 373.

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

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Potentially Active Reverse Faults of Eastern Ventura Basin, Los Angeles County, California

14-08-0001-21279

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Investigations

1. Prepared surface geologic maps of Valverde and south half of Whitaker Peak 7½ minute quadrangles. These will be field-checked during the summer. Cross sections are being made through critical wells intersecting the faults under investigation.

Report

Levi, S., Schultz, D. L., Yeats, R. S., Stitt, L. T., and Sarna-Wojcicki, A. M., 1983, Paleomagnetism of the Saugus Formation, Los Angeles County, Ca.: Geol. Soc. America Abs. with Programs, v. 15, p. 391.

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). Work continues on the wealth of unpublished data on aftershocks of the March 11, 1933 Long Beach earthquake (see previous report). Phase data from all available sources (CIT southern CA Listing, CIT Phase Card Library, unpublished notes of C. F. Richter, and publications by H. O. Wood and H. Benioff) for about 250 aftershocks have been collected, cross-checked, and compiled for the interval March 10 to April 6, 1933. The data include: a) essentially complete and accurate phase data from the permanent stations Pasadena, Mt. Wilson, and Riverside; b) a small body of incomplete phase data (5-10 stronger shocks) from permanent stations Santa Barbara, La Jolla, Tinemaha, and Haiwee; and c) all phase data from several temporary stations operated near Long Beach from March 13 to April 6. Valuable data on the 1933 sequence are now being recovered from seismograms recorded at Santa Barbara for about 30 shocks and at La Jolla for about 40.

2. Quaternary fault map and earthquake hazards (R. F. Yerkes). Completed classification and compilation of Quaternary faults at 1:250,000 for the 23,000-km^2 region, including all results from cooperative investigations through 1982. Constructed map and structure sections (at 1:24,000) of all available surface (soils, trenching, aerial photo studies) and subsurface (exploratory well, geophysical) data bearing on the Santa Monica zone of faults in the northwest Los Angeles basin. Results indicate that the zone is cut and offset by at least two northwest-trending faults, including the Inglewood fault; that west of the intersection the Santa Monica fault is buried by chiefly Holocene deposits, whereas to the east it is buried by Pliocene and younger units. However, the subprallel Hollywood fault at the base of the Santa Monica Mountains shows late Quaternary activity along most of its length, and its apparent extension east of the Los Angeles River overlies a subsurface fault recognized independently from water-well data and appears to cut the 6,000 year-old floodplain.

Comparison with a map of 1970-1981 seismicity (at 1:250,000) indicates a prominent correlation of seismicity and Holocene ruptures. Several prominent concentrations cannot be associated with recognized structure, one example of which extends S 25° W beneath the Santa Monica Mountains from the 1971 San Fernando "downstep" to the offshore Santa Monica zone.

Completed through branch approval two chapters for comprehensive (Professional Paper) summary study of earthquake hazards of the Los Angeles region: a) Geologic-Seismologic Setting--in very general terms why, how, and where earthquakes occur and detailed review of damaging historic earthquakes; b) Fault Hazards (with J. I. Ziony)--details on location, geometry, style, and offset of 96 mapped late Quaternary faults. In review: chapter on a Postulated Earthquake--detailed description of a postulated earthquake on the Newport-Inglewood zone immediately north of the 1933 rupture, with analysis of geologic effects, to be accompanied by other reports on analysis of engineering effects.

3. Late Cenozoic ashes (A.M. Sarna-Wojcicki):

a) Initiated study of oxygen-isotope variations in benthic foraminifera in the Ventura Avenue anticline-Santa Paula Creek-Balcom Canyon sections of the Ventura area to develop a detailed climatic record for the period 0.2 to 2.0 m.y. B.P., and to provide a high-resolution curve that will enable us to correlate in detail among on-land marine sections and deep-ocean sites of the northeastern Pacific. The oxygen-isotope curve will be age-calibrated by tephrochronology and magnetostratigraphy (fig. 1). Slow deposition rates at deep ocean sites, combined with ocean-bottom bioturbation and drilling disturbance, result in poor age resolution of oxygen-isotope curves derived from cores drilled at deep ocean sites. Because deposition rates along continental margins are more rapid, we may be able to derive oxygen-isotope curves with much greater age resolution (in coop. with Kristin McDougall and Jim Gardner, U.S.G.S.).

b) A comparison of planktonic foraminiferal zonation in Balcom Canyon (Ingle, 1967; 1981) with the stratigraphic positions of tephra layers and their correlated ages (fig. 2) suggests that the two are generally in agreement. The Venturian-Wheelerian boundary, inferred by Van Eysinga (1975) to be about 1.9 m.y. B.P., lies close to the Huckleberry Ridge ash bed, dated about 2 m.y. (Naeser, 1971; Izett, 1981). The apparent age reversals of the two horizons (fig. 1) may be due to the time-transgressive nature of the biostratigraphic datum or to the lack of precision in the isotopic age of the ash bed. The normal interval below the Bailey ash bed and above the Huckleberry ridge ash bed (Liddicoat, 1982), however, is probably too high in the section to be the Olduvai event.

c) A new ash bed has been found stratigraphically below the Huckleberry Ridge ash bed, near the base of the Pico Formation in Balcom Canyon (Unnamed ash, figs. 1, 2). This ash bed lies within the Repettian stage, as determined by planktonic foraminiferal biostratigraphy (Ingle, 1967; 1981). This ash bed does not correlate with any other ashes we have analysed to date, but is most similar to tephra erupted from the Sonoma Volcanic field of west-central California, active during a period from about 6 to 2.5 m.y. ago.

d) Preliminary results of electron-microprobe and energy-dispersive X-ray fluorescence analyses suggest that a tuff bed in the Monterey Formation at Balcom Canyon (M-5, figs. 1, 2), correlates well with a tuff in the Monterey Formation near Lompoc, Calif. (table 1). This tuff has been dated by the fission-track method on zircons as 7.6 m.y. (Obradovich and Naeser, 1981). The tuff at Balcom Canyon is the uppermost of a sequence of eight tuffs.

e) Figure 1 represents the current status of the available age control in the Ventura-Balcom Canyon area from tephrochronology (this project) and magnetostratigraphy (J. C. Liddicoat, Lamont-Doherty, and J. W. Hillhouse, U.S.G.S.).

Reports

Yerkes, R. F., Ellsworth, W. L., and Tinsley, J. C., Triggered reverse fault and earthquake due to crustal unloading, northwest Transverse Ranges, California: accepted for publication by Geology.

Sarna-Wojcicki, A. M., Meyer, C. E., and Slate, J. L., 1983, The Lava Creek, Bishop, and Huckleberry Ridge ash beds in Pacific Coast Quaternary marine deposits--on land and in deep-ocean cores: Geological Society of America, Cordilleran Section, Abstracts with Programs, v. 15, no. 5, p. 389.

Lajoie, K. R., Sarna-Wojcicki, A. M., Robinson, S. W., Liddicoat, J. C., and Davis, J. O., 1983, Late Pleistocene stratigraphic correlations and lacustrine histories in the western Great Basin: Geological Society of America, Cordilleran Section, Abstracts with Programs, v. 85, no. 5, p. 300.

Levi, Shaul, Schultz, D. L., Yeats, R. S., and Sarna-Wojcicki, A.M., 1983, Paleomagnetism of the Saugus Formation, Los Angeles County, California: Geological Society of America, Cordilleran Section, Abstracts with Programs, v. 15, no. 5, p. 391.

Table 1. Analyses of glass of tuffs from the Monterey Formation. Tuff M-5 is from Balcom Canyon; tuff Y448A is from the Johns-Manville quarry near Lompoc Calif. a- electron microprobe analysis, oxides in percent. C. E. Meyer, analyst. b- energy-dispersive XRF analyses, in spectral peak ratios. M. J. Woodward, analyst. Note that K_2O and TiO_2 concentrations for the two tuffs are different in the probe analyses, and that K values are different in the XRF analyses. Potassium may be selectively leached from the volcanic glass under different storage conditions. The differences in TiO_2 are difficult to explain, and may represent analytical error, because the Ti peak intensities in XRF analyses are very similar.

a.	SiO_2	Al_2O_3	Fe_2O_3	MgO	MnO	CaO	BaO	TiO_2	Na_2O	K_2O	Cl
M-5	76.45	12.59	2.00	0.11	0.03	0.71	0.10	0.34	3.12	4.50	0.05
Y448A	76.95	12.11	2.09	0.12	0.01	0.71	0.11	0.17	3.26	5.41	0.04

b.	K	Ca	Ti	Mn	Fe	Cu	Zn	Rb	Sr	Y	Zr	Nb
M-5	706	30	196	121	912	35	104	1155	433	828	3884	730
Y448A	495	31	206	123	955	37	111	1125	416	869	3802	756

GENERALIZED STATIGRAPHY & AGE CONTROL, VENTURA AVE ANTICLINE AND BALCOM CYN SECTIONS

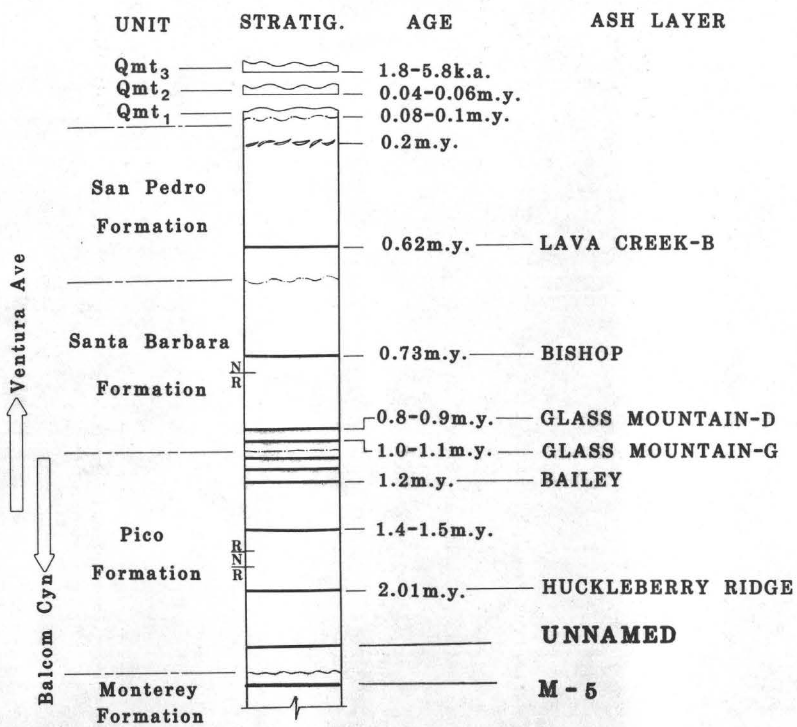

Figure 1. Age control on late Cenozoic strata of the Ventura area. Age control for the older part of the section is from Balcom Canyon, and from the Ventura Avenue anticline, for the younger part of the section. Age control for the lower through middle part of the section is from volcanic ashes. Ash layers are shown as solid lines. Ages of the Glass Mountain-D and -G ash layers and the ash at about 1.4-1.5 m.y. are estimated from sedimentation rates and magnetostratigraphy. Age control in the upper part of the section is from amino-acid racemization, U-series, and radiocarbon dating (with K. R. Lajoie, USGS). Magnetostratigraphy by J. C. Liddicoat (Lamont-Doherty), and by J. W. Hillhouse (USGS).

BALCOM CANYON

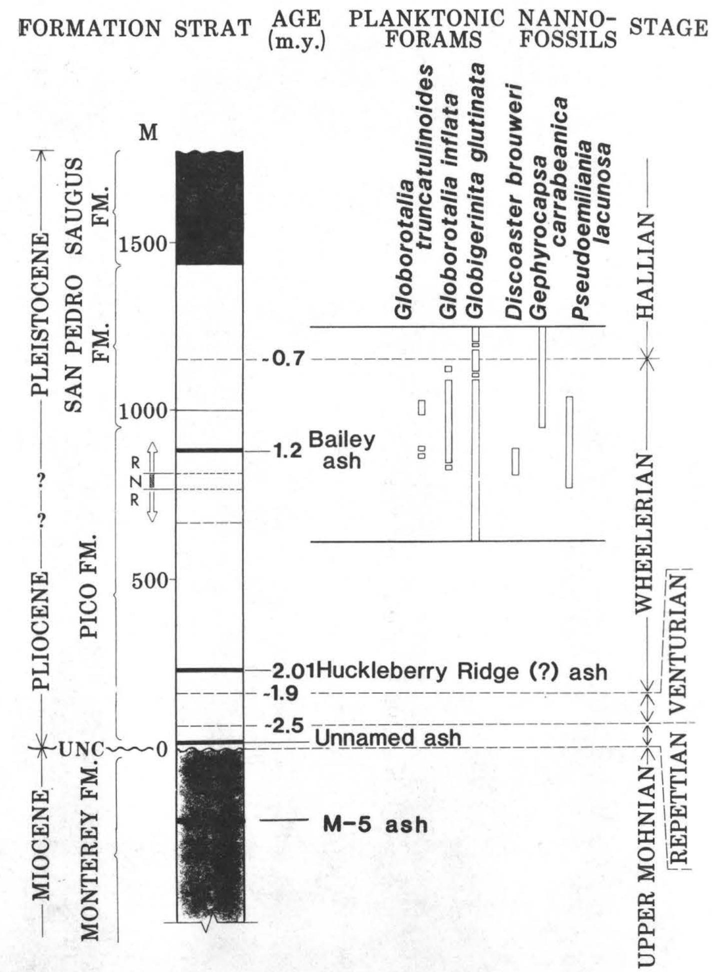

Figure 2. Age control in the Balcom Canyon section from ash layers, and comparison with biostratigraphic zonation of Ingle (1967; 1981). Ages of planktonic foraminiferal stages from Van Eysinga (1975).

Earthquake Hazards
Puget Sound, Washington

9540-02197

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Investigations

Puget Sound has suffered the effects of damaging earthquakes in the past (1949, M=7.1; 1965, M=6.5) and will undoubtably feel the effects of future earthquakes of comparable size. Rates of motion for the Juan de Fuca Plate calculated from seismic moments compare well with rates calculated from plate tectonic models, and clearly indicate that either subduction is continuing today beneath Puget Sound, or that the Juan de Fuca Plate is deforming (Weichert and Hyndman, 1983; Hyndman and Weichert, 1983). Recent analysis of seismicity beneath the Olympic Peninsula further supports the conclusion that subduction is continuing today beneath Puget Sound (Taber, 1983).

The major damaging effects of past earthquakes have been related to ground shaking and liquifaction phenomena. Ground rupture along faults breaking to the surface within Puget Sound has never been reliably reported for historic earthquakes. Therefore, investigations for earthquake hazard evaluation have centered on characterizing the nature and distribution of near surface geologic materials that control ground shaking and liquifaction, and on delineation of the major bedrock configurations that likely focus seismic energy at the ground surface. Specifically, the major investigations carried out during the first half of this fiscal year are:

1. Completion of 1:24,000 scale mapping of surficial deposits in the Seattle 1:100,000 Quadrangle. Compilation of this mapping onto the Seattle 1:100,000 surficial geologic map is 75% complete.

2. Analysis of the relationship of standard penetration versus depth for 12 geologic units underlying the Seattle South 7 1/2' Quadrangle for purposes of delineating liquifaction susceptibility.

3. Compilation of depth-to-bedrock information from drill holes and marine seismic reflection profiles, in the Seattle and Port Townsend 1:100,000 Quadrangles.

Results

1. Plots of standard penetration (blow count for 140 lb weight dropped 30 inches) versus depth for various geologic units in the Seattle area reveal trends which are useful for catagorizing the susceptibility of materials to

liquifaction (fig. 1). Muddy fill, young alluvium, and fine-grained advance outwash deposits appear particularly sensative. Most of the glaciogenic sediments from the last and older glaciations and all of the pre-12,000 year-old nonglacial sediments occupy an intermediate category of resistance. Glacial till of the last or previous glaciations is as or more resistant than most bedrock units, and comprises the category least susceptible to liquifaction.

2. Depth- to bedrock information in the Seattle 1:100,000 Quadrangle shows the coincidence between thickness of young unconsolidated sediment and the pattern of Bouguer gravity (Stuart, 1965; Rogers 1970). Also, it is clear that major geophysical and geologic lineaments interpreted as faults and large folds (Gower and Yount, in press) influence the distribution of young sediments. Selective erosion and deposition during successive glaciations, coupled with differential compaction of unconsolidated sediments may explain these distributions. But the possibility of differential Quaternary uplift along these structures must also be considered as a causative mechanism.

Reference

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Report

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Figure 1. Plots of standard penetration versus depth for fill, alluvium, recessional and advance outwash deposits, nonglacial fluvial deposits, till and associated gravels, and bedrock from the Seattle area.

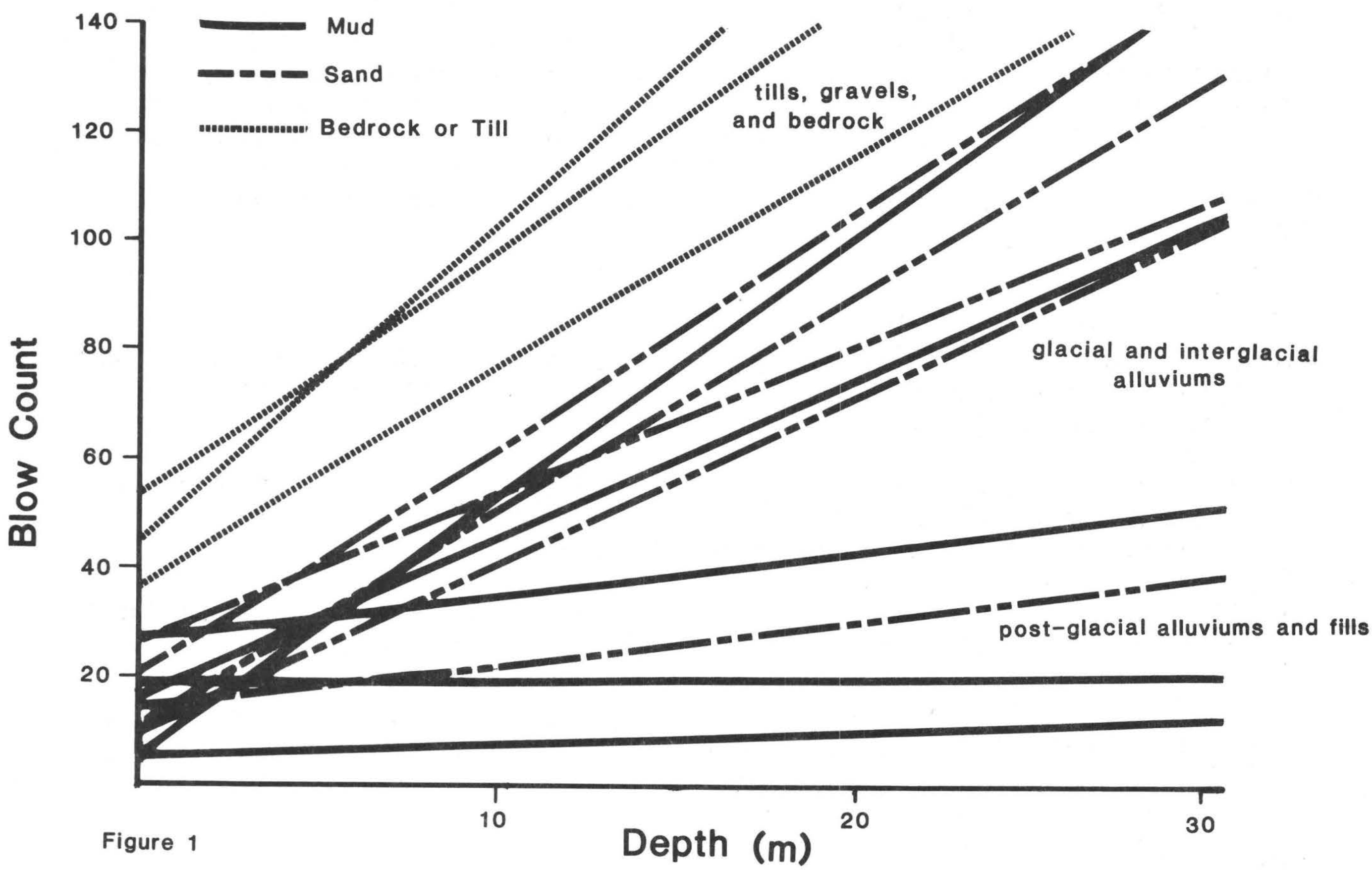

Figure 1

Regional Syntheses of Earthquake Hazards in Southern California

9910-03012

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Investigations

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

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

Results

1. We have compiled slip rate estimates for late Quaternary time for faults of the Los Angeles region. The resulting data base is sparse (rates of the late Quaternary displacement can be estimated for less than 25 percent of the more than 90 active faults); we believe, however, that these rates are more representative of the current tectonic stress field, and thus a more reliable basis for assessing relative fault activity, than published estimates (e.g., Lamar and others, 1973; Anderson, 1979; and Bird, in press) based on widely different spans of late Cenozoic time.

The best constrained are rates of right-slip along the San Andreas (about 20-30 mm/yr) and San Jacinto (about 8-12 mm/yr) fault zones, and of left-slip along the Cleghorn fault (about 2 mm/yr). For the other late Quaternary faults of the region, only the vertical component of the slip rate has been determined. However, this parameter can be used to assess relative activity if the ratio of vertical to horizontal offset can be estimated. Even where this ratio is highly uncertain, comparison of rates of vertical separation for individual subparallel faults provides a gross measure of their relative activity.

For the dominantly reverse-slip faults of the western Transverse Ranges, rates of vertical separation probably approach actual slip rates and thus can be used to identify systematic areal differences in relative activity of the late Quaternary faults. The southern boundary faults of the Transverse Ranges west of Pasadena, for example, have late Quaternary vertical separation rates of 0.1-0.5 mm/yr. In contrast, the frontal faults between Pasadena and San Bernardino have vertical separation rates of 1 to 3 mm/yr, about an order of magnitude higher. Within the Transverse Ranges, an interior belt of late Quaternary faults that extend from near Santa Barbara to Pasadena also shows vertical separation rates of about 1 to 3 mm/yr along individual faults.

Closely-constrained late Quaternary slip rates have not yet been determined for the Palos Verdes Hills and Newport-Inglewood fault zones, which probably pose the major earthquake threat to the Los Angeles basin, although rates of vertical separation can be calculated locally (0.3 mm/yr and > 0.1 mm/yr, respectively). Woodward-Clyde Consultants (1979) estimated a slip rate of 0.5 mm/yr for the Newport-Inglewood Zone on the basis of displaced 3- to 5-million-year-old markers, but this value may not represent the slip rate during the past several hundred thousand years. Because the geometry of the faults suggests dominantly right-lateral displacement, the vertical components of the offset rate probably are a fraction of the actual slip rate. Until additional geologic constraints on late Quaternary offset can be obtained, we suggest that it is reasonable to assume slip rates of about 1 mm/yr for these faults.

2. A first draft of the professional paper, "Earthquake Hazards of the Los Angeles Region", has been completed. The 15 chapter contributions are in technical review, and final drafts are anticipated by October, 1983. Preliminary results of several of these studies that concern hazard assessment methods were summarized at an international conference on earthquake hazard mitigation/response sponsored by the City of Los Angeles in February, 1983.

Reports

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Seismotectonics of Northeastern United States

9950-02093

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Investigations

1. Compilation and interpretation of regional earth science information relevant to the seismicity and seismic zoning of the eastern United States continued. Particular attention is being given to thickness of the seismogenic layer and its relation to seismicity.

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

3. A DOE report on the seismological, geophysical, and geological aspects of storage of radioactive wastes in granitic plutons of northeastern United States was reviewed.

4. A brief trip to Saudi Arabia was made to examine certain aspects of earthquake hazards. A proposal was written.

Results

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

2. An average elevation map of the conterminous United States was produced at a scale of 1:2,500,000; 20 m contours in the east, 100 m in the west. This map has now been printed and distributed, as GP-933. Additional maps using different averaging schemes are under construction.

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

Reports

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PROJECT TITLE: Earthquake Hazard Studies in Northeastern United States

CONTRACT NUMBER: USGS-14-08-0001-19750

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

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

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The Lamont-Doherty seismic network, operating in the states of New York, New Jersey and Vermont currently consists of thirty-eight stations. The signals are telemetered to a central recording site at Palisades, NY. The network has recently been converted to digital recording. The network data are routinely analyzed to identify and preliminarily locate earthquakes, and particular events are analyzed in more detail to determine accurate locations, depths, fault plane solutions, and other source parameters whenever possible.

Since the inception of the network in 1970, more than 800 earthquakes ($1.0 \leq m_b \leq 5.0$) have been located in the northeastern United States and adjacent Canada. This record of instrumentally located earthquakes reveals the same general features as the longer term (several hundred years) historical record, suggesting that the spatial distribution of earthquakes has been relatively stationary over the last few hundred years. The most important difference between the historical data and the network data is the accuracy of earthquake locations and the ability to estimate focal depth. The details of hypocentral distribution and the possible association of earthquakes with mapped faults or other structural features can only be meaningfully attempted with the instrumental data.

Earthquakes located by the Lamont-Doherty network are, most likely, confined to the upper crust (depths <20 km), and most appear to be located within the upper 10 km. In general, however, focal depths of these events cannot be determined to better than about ±5 to 10 km. Short period surface waves recorded by the network (e.g., 1 sec Rg waves) are being investigated as possible depth diagnostics.

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

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

(2) New Brunswick, Canada - 9 January 1982;
12:53L52.0 UT; 47.0°N, 66.5°W; $m_b \approx 5.9$

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

Determination of the crustal and upper mantle velocity structure is a prerequisite for accurate earthquake locations and meaningful interpretation of the seismic data. Thus far, tentative crustal and upper mantle velocities have been deduced from P and S wave travel time studies in parts of New York State. The resulting preliminary velocity models are used in our earthquake location procedures. Our more recent investigatins of relative residuals of P waves from distant earthquakes and nuclear explosions indicate that residuals vary from -0.3 to +0.6 sec. The pattern of residuals is found to be constant to within 0.15 sec in broad subregions, but to vary markedly between subregions. Since the transition zones between subregions are no more than 50 to 100 km wide, most differences in velocity appear to be situated in the upper 100 km.

The magnitudes and distribution of earthquakes recorded by microearthquake networks in the New York City metropolitan area have been analyzed to obtaine a map of the recent seismicity of this region that is not biased by station distribution. A magnitude scale based on signal duration is found to be the most appropriate scale for comparing the size of these earthquakes. Seismic waves recorded on instruments with peak response near 1 Hz are used to compare duration measured from the higher frequency ($\approx$10 Hz) data recorded by the local networks with m_b and M_L. A map of the distribution of the larger events in this study suggests that earthquakes in the New York City metropolitan area are primarily concentrated in geologic structures that surround the Newark (Triassic-Jurassic) basin.

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

USGS-14-08-0001-20552

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Investigations

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

Results

The current configuration of stations for the portable network consists of three 3-component sites plus one single-component (vertical) site. This configuration increases coverage in the Manhattan prong and Atlantic Coastal Plain provinces. Two of the stations are in the vicinity of the epicenter of a magnitude 3.0 earthquake (maximum intensity VI) that occurred on January 30, 1979 beneath the coastal plain sediments near Cheesequake, NJ. One of these two stations is located on Staten Island, NY (SINY), and the other is located near Freehold, NJ (FREH). A third station (POCO, 3-components) is located near the epicenters of two felt earthquakes that occurred in the Manhattan prong near Mt. Kisco, NY (December 30, 1979) and Thornwood, NY (September 4, 1980). In addition to these 3-component stations, a single-component (vertical) station is operating at Palisades, NY next to the permanent short-period station operated by Lamont-Doherty as part of the permanent network in the states of New York, New Jersey, and Vermont. This station is used as a convenient site for testing the portable network and for comparing signals recorded by the portable network with those recorded by the permanent network.

The software we received for the PDP 11/03 was not adequate for our purposes for a number of reasons. For example, the pre-event memory was only about 2 seconds long, and the tape format, did not have end-of-file markers at the end of each event recorded. Two seconds of pre-event memory would severely limit the diameter of the array. Without end-of-file markers between events it becomes difficult and very time consuming to search for seismograms recorded on the tape. We have hired Phill Gross, who began development of the software for this system at Pennsylvania State University, to correct these problems and to finish developing the software to make the portable network more useful. He is currently working on increasing the pre-event memory to 12 seconds and changing the tape format.

Reports

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MISSISSIPPI VALLEY SEISMOTECTONICS

9950-01504

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Investigations

A variety of concurrent studies at reduced effort compared to previous report periods were conducted to understand better the tectonic framework and geologically young deformation relevant to seismicity in the New Madrid region. The studies are as follows:

1. Continued processing and interpretation of seismic reflection data recorded on the R/V Neecho on the Mississippi River between Osceola, Arkansas, and Wickliffe, Kentucky. Approximately 90 percent of the traverse has been processed.

2. Digitizing of seismic reflection profiles as a first step in computer modeling Cretaceous and Tertiary reflectors in the New Madrid region was started.

3. Evaluation of data obtained from trenching in the Blytheville, Arkansas area was continued.

4. Continued acquisition, organization, and compilation of level line data to search for zones of recent vertical deformation.

5. Mini-Sosie seismic reflection data collected on a traverse over a suspected fault scarp near Union City, Tennessee, was processed.

6. A quantitative geomorphic study of about 10,000 km^2 on the southeast flank of the Ozark uplift was started.

Results

1. A number of near-surface faults have been inferred in the Mississippi River seismic reflection data. Preliminary interpretation of the most recently processed data indicate that a few faults may extend to the bed of the Mississippi River, where water falls were reported in 1811. Considerable additional interpretation and compilation are still required to confirm or negate this observation.

   Detailed interpretation of the segment of the river data in the vicinity of Caruthersville, Missouri shows that the Cottonwood Grove fault can be traced to the river, a total distance of 20-25 km. The river data shows the fault as a zone of warping and complex faulting that deforms Eocene sedimentary rocks.

A second are of extensive faulting in the Caruthersville area coincides with the northeasterly extension of the 120-km-long trend of seismicity between Marked Tree, Arkansas and Caruthersville, Missouri. Faults in this zone have both normal and reverse apparent movements and are interpreted to have post-middle Eocene movement.

2. Digitizing the large amount of reflection profile data allows various subsets of the data to be independently analyzed and studied to clarify the Cretaceous and Tertiary depositional and tectonic evolution of the region.

3. Holocene sediments in the Blytheville area trench were not faulted. The trench did reveal excellent cross-sections of unusual liquefaction features probably formed during the 1811-12 earthquakes.

4. Data from about 130 level lines surveyed at various times during the past 99 years have been evaluated for constructing profiles showing differences in elevation. Four areas have been selected to search for differential vertical displacement between the seismically active Mississippi flood plain and adjacent highlands.

5. Interpretation of the Mini-Sosie seismic reflection data indicates two reverse faults that extend nearly to the surface. Neither of the faults are coincident with a scarp crossed by the reflection traverse. Recent field examination of the area and discussion with local residents who farm the land strongly indicate that the features, which first suggested that the scarp was related to a fault, are erosional in origin. Shallow subsurface faults near the east and west ends of the traverse are, however, prime targets for exploratory trenches.

6. The quantitative geomorphic study was initiated because (a) no geologic study of the important Arkansas earthquake swarm was being done and (b) qualitative information that suggests uplift of at least the eastern part of the Ozark Mountains has existed for many years, but no serious attempts to confirm or negate the suggestion have been made. Detection of geologically young deformation of the eastern Ozarks is important because of a coincident diffuse zone of seismicity, and because the deformation almost surely must effect the stresses related to earthquakes in the New Madrid zone less than 50 km to the southeast.

   Accomplishments of the geomorphic study to date are as follows:

   a. Sixty-four streams greater than 10-km long in 138 7-1/2 minute quadrangles have been digitized and elevations of contour crossings recorded in data files.

   b. The digitized information has been plotted as stream courses, stream profiles in cartesian coordinates, stream profiles in semi-log coordinates, and elevations to construct a sub-envelope map. In the near future, the data will be used to calculate steam gradient indices, normalized stream gradient indices, and psuedo-hypsometric values, all of which will be contoured.

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Active Seismology in Fault Zones

9930-02102

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Investigations

1. Analysis of seismic refraction data in several locations in the Great Valley of California and adjacent Coast Ranges and Sierran foothills (A. Walter, J. Murphy, and W. Mooney).

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

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

4. Interpretation of the deep-crustal structure of the Mississippi Embayment of the central United States.

5. Collaboration with the State Seismological Bureau (Beijing) in a program of crustal studies in Yunnan Province.

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

Results

1. Analysis continues on five research profiles collected in the Great Valley between Stockton and Fresno, California. Three of the profiles are subparallel to the Valley axis and are located on the west side, at the center, and on the east side of the Valley. Two transverse profiles extend from the Diablo Range to the Sierra Nevada and are located near the latitudes of Tracy and Los Banos, California. Along each profile, 100 seismic cassette recorders were deployed at spacings of 1.0 to 1.5 km and shots were fired at shotpoints located near the endpoints and centers of the profiles. The collected traveltime data are being used to construct a crustal velocity model for the Great Valley between the Coast Ranges and the Sierra Nevada. This model better belineates the feature producing the aeromagntic and gravity highs in the Great Valley.

   Refraction data was also collected along two end-to-end 120-km long profiles extending from Morro Bay, on the California coast, across the southern Great Valley to the Sierra Nevada east of Delano, California. For each of these profiles, the 100 cassette recorders were deployed at 1 to 1.2 km intervals and shots were fired at four shotpoints spaced 20 to 50 km apart.

2. Earthquakes occur in many locations on either side of the San Andreas fault in central California. In order to investigate the deep structure of the crust in this region, and relate it to earthquake occurrence. Vibroseis reflection data was purchased from Western Geophysical along the route of our seismic refraction profiles from Marro Bay to the Sierra Nevada. The refraction data are being analyzed to provide velocity-depth functions that can be used to reprocess the reflection data. Geophysical Systems Corporation has been contracted to collect vibroseis reflection data along our refraction profile through Los Banos, California. The line is east-west and 120 km long. The reflection records have a two-way time of 12 seconds in order to study the deeper parts of the crust.

3. The deep crustal structure of the Imperial Valley, southern California, has been investigated thoroughly and these results reported (e.g., Fuis and others, 1982). In order to extend the coverage possible in our previous interpretations, the time-term method has been applied to the 1979 seismic refraction data. All of the traveltime data were next integrated to produce a time-term map, which in principle eliminates distortions of features seen on traveltime maps and can be converted to a sediment isopach map. Striking features seen on this map include the following: 1) A complex buried scarp along the west side of the Imperial Valley. This feature, seen on the earlier traveltime maps, trends roughly north-south; it appears to be terraced and also segmented. The Superstition Hills fault and Superstition Mountian fault bound one segment and northwest-striking buried faults (?) farther south appear to bound other segments. 2) A prominent scape is also seen northeast of the Salton Sea and appears to be a continuation of the modern mountain front beneath the sediments. (We had surmised earlier than such a scarp existed about 10 km farther southwest, along the San Andreas fault). 3) Geothermal areas are reflected on the maps as areas of relatively low time-terms. These areas have varied shape and relief on the map. The Salton geothermal area has the strongest relief and is the largest areally. In conjuction with this investigation a computer program was written for machine contouring of data points.

4. An extensive seismic refraction investigation was conducted in the Mississippi Embayment in September 1980 in order to provide detailed information regarding the deep crustal structure. During the investigation 34 shots from nine shot points were recorded along aseries of profiles. The profiles were parallel to and across an inferred Precambrian rift zone which is outlined by a series of magnetic anomalies and covers an area at least 200 km long and 70 km wide.

Along the northeast-southwest trending axis of the rift a 0.7- to 1.1-km-thick 1.8-km/s layer representing the unconsolidated Tertiary and Cretaceous sediments overlies a 2-km-thick 5.95-km/s layer representing a Paleozoic carbonate sequence. Beneath the carbonates is a 3-km-thick low-velocity layer which probably consists of late Precambrian clastics. An 11-km-thick 6.2-km/s basement overlies a lower crust comprised on a 6.6-km/s layer whose thickness decreased to the northeat due to its replacement by an anomalous high-velocity 7.3-km/s basal layer. The base of the crust varies from 39-km depth at the southern end of the profiles to 46-km depth at the northern end where the 7.3-km/s layer is 20-km thick. Below the base of the crust (Moho) the upper mantle has a velocity of 8.0-km/s.

The velocity structure beneath the west flank of the Embayment is simpler than that of the axis: 5.95-, 6.2-, 6.6-, 7.3-, and 8.0-km/s. The low-velocity layer is absent and the anomalous 7.3-km/s layer is thinner than along the axial profile. The profiles perpendicular to the rift show that the low-velocity layer is restricted to the axial zone and that the anomalous 7.3-km/s basal crustal layer reaches maximum thickness there.

The tectonic model proposed to explain the origin of this embayment velocity structure is that a late Precambrian mantle plume intruded into the lower crust of the northern embayment, causing uplift (and/or crustal stretching) and the sebsequent rifting of the axial area. This was followed by erosion, subsidence, and subsequent deposition of sediments in the resulting trough.

5. Working through the US-PRC protocol for Earthquake Prediction Research, we have been cooperating with the State Seismological Bureau in a program studying the deep-crustal structure in Yunnan Province, southwestern China. In addition, we are providing technical assistance in the area of digital processing of seismic data. In order to strengthen this effort, we hosted a meeting in December, 1982, to discuss research goals which was attended by twenty-five scientists. A research proposal to the NSF from UC-Berkeley was an outgrowth of this meeting. This proposal will provide the university with support, thus, making the cooperation a USGS-PRC-UC Berkeley effort. An electrical engineer will work in Menlo Park for two months on instrument design needed to facilitate data processing. The project will result in new information regarding the crustal structure in the seismically active region in southwestern China.

6. Geologic transect provide a useful summary of the present knowledge of the geology and deep structure in key areas. Ocean-continent transect C-D, constructed for the U.S. Geodynamics Committee's Transect Program, extends from offshore southern California to central New Mexico. The transect consists of: 1) a one-degree-(110-km) wide, 1:500,00 geologic strip map, 2) two 1:5000,000, 1:1 geologic cross sections, one colored by age, the other by lithotectonic "kindered", 3) gravity, magnetic, heat flow, and seismic-velocity profiles, and 4) ancillary diagrams explaining the progressive tectonic development of the region. The major tectonic provinces crossed by the transect include, from west to east, the southern California borderland, the Transverse Ranges, the Peninsular Ranges, and Salton Trough, the southern Basin and Range, the northern Sierra Madre Occidental, and the Rio Grande Rift provinces. This work is in its final stages.

Reports

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Northeastern U.S. Seismicity and Tectonics

9510-02388

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Investigations

1. Develop strategy for integrated study of Ramapo zone seismicity utilizing Vibroseis reflection profiling.

Results

1. Planning for a multi-year geophysical study of the Ramapo seismic zone has been completed with institution of a cooperative agreement between USGS and the Virginia Polytechnic Institute and State University (VPI) to conduct Virbroseis reflection profiling of the Ramapo seismic zone with funding provided by the Nuclear Regulatory Commission for fiscal years 1983, 1984, and 1985.

2. The data collection for fiscal year 1983 will consist of two short line profiles across the Newark Basin northeast of Princton, N.J., and at the northern end of the Newark Basin in Rockland County, N.Y.

3. Ancillary wide-angle reflection studies utilizing VPI Vibroseis energy will be conducted by Robert Phinney of Princeton University.

4. Preliminary results are expected by October 1, 1983.

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

14-08-001-18200

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Investigations

A plane-table map (Fig. 1) was made at a stream crossing on the fault in order to document the evidence for three offset stream channels.

Results

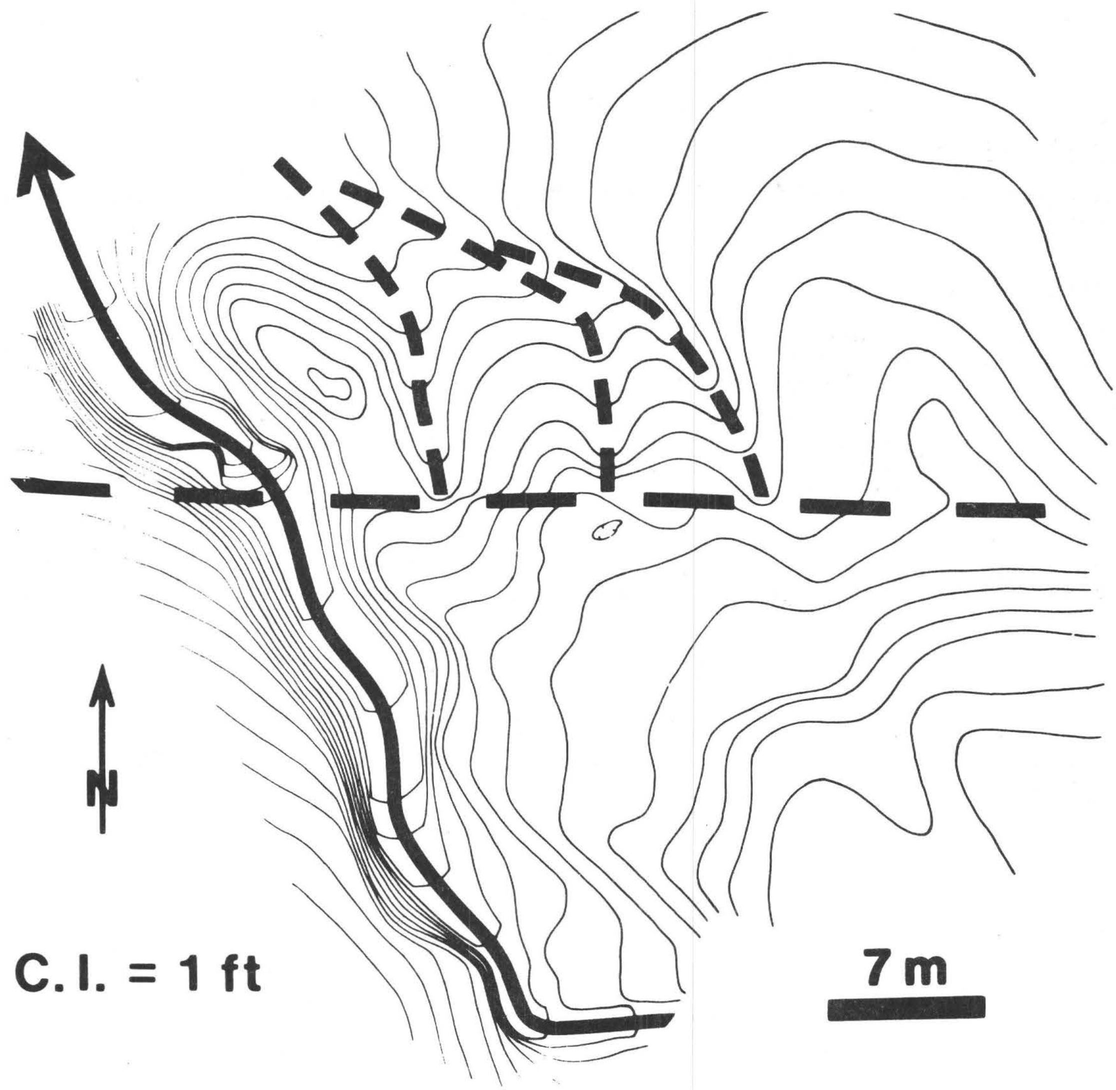
The mapping provided confirmation that the three channels were offset successively from a single source by lateral movement on the San Andreas fault. Most significant was the remarkable uniformity in amount of offset between each channel. Each offset was about 7-7.5m, substantiating similar values measured on offset and deflected stream channels over a 25km long reach of the fault spanning the plane-table mapping site.

These results indicate that the past three large earthquakes have been very similar in this part of the "Big Bend", and strengthens the suggestion that the 1857 earthquake is a likely model for the next large earthquake here.

Reports

Rust, D. J., 1982, Evidence for uniformity of large earthquakes in the "Big Bend" of the San Andreas fault: EOS, Trans. Amer. Geophysical Union, v.63, no.45, p.1030.

Fig. 1. Plane-table map of Cow Spring Canyon at San Andreas fault crossing. Showing three offset channels, each offset about 7-7.5m. Site located about 23km. SE of Tejon Pass.



Earthquake Hazard Studies in Southeast Missouri

14-08-0001-19751

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Goals

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

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

Investigations

1. The project consists of monitoring data from a network of 26 USGS and 8 NRC seismograph stations located in the central Mississippi Valley. These will be augmented by 8 additional USGS and 8 additional NRC stations in the near future. In addition telemetered data from eight Tennessee Earthquake Information Center stations in the southern part of the New Madrid Seismic Zone will be recorded digitally. The seismic data are also recorded on 16mm film and on a PDP 11/34 digital computer. Since the initial deployment of seismograph stations in July, 1974 1767 earthquakes have been located through the end of September, 1982. Operation, analysis and publication of quarterly bulletins are an ongoing task. Cooperative arrangements with other organizations, such as the Tennessee Earthquake Information Center and the University of Kentucky, have been made in order to make the quarterly published Central Mississippi Valley Seismic Bulletin as complete as possible.

2. The implementation of advanced analysis tools on the PDP 11/70 and improved detection codes on the PDP 11/34 is progressing. We have been working on methods to guarantee long triggers for larger events so that Chouet - Aki - Tsujiura coda analysis techniques can be used to study coda Q and source spectral scaling. Work has begun on implementing routine determination of spectral parameters, corner frequency and seismic moment, for inclusion into the quarterly bulletin.

Results

1. During the third quarter of 1982, 81 earthquakes have been located, including 3 events with $m_{bLg} > 3.0$.

2. Major research results are listed in the paper below.

Publications

Herrmann, R. B. and A. Kijko (1983). Short period Lg magnitudes: Instrument, attenuation and source effects, Bull. Seism. Soc. Am. (in review).

Herrmann, R. B. (1982). Digital processing of regional network data, Bull. Seism. Soc. Am. 72, S377-S392.

Herrmann, R. B. and A. Kijko (1983). Modeling some empirical Lg relations, Bull. Seism. Soc. Am. 73, 157-171.

Singh, S. and R. B. Herrmann (1983). Regionalization of crustal Q in the continental United States, J. Geophys. Res. 527-538.

3. The following is the abstract of the paper on Lg, which presents recent results on Lg:

The application of the Nuttli (1973) definition of the m_{bLg} magnitude to instruments and wave periods other than the short-period WWSSN seismograph is examined. The basic conclusion is that the Nuttli (1973) definition is applicable to a wider range of seismic instruments if the $\log_{10}(A/T)$ term is replaced by $\log_{10}A$. For consistency and precision, the notation m_{bLg} should be applied only to magnitudes based upon 1.0 Hz observations. In general, for measurements made at a frequency f, the notation $m_{Lg}(f)$ should be used, where

$$m_{Lg}(f) = 2.94 + 0.833\log_{10}(r/10) + .4342\gamma r + \log_{10}A,$$

and r is the epicentral distance in km, γ is the coefficient of anelastic attenuation and A is the reduced ground amplitude in microns. Given its stability when estimated from different instruments, the $m_{Lg}(f)$ magnitude is an optimum choice for an easily applied, standard magnitude scale.

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

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15 December 1981-14 December 1982
United States Geological Survey
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The purpose of this research is to estimate the source characteristics of selected earthquakes in eastern and central United States and adjacent areas in Canada, primarily, from analyses of signals recorded by the Catskill Seismic Array (CSA). CSA is a tripartite array of digital, three-component broad-band instruments, unique in eastern United States, that was located near the Catskill Mountains about midway between New York City and Albany and operated by Rondout Associates, Incorporated under contract from the Air Force Office of Scientific Research from 6 September 1980 to 18 November 1981.

This report presents the results of the first year's research of a project originally for a two year duration. We are currently in the beginning of the second year of research; at a reduced level and under a new contract. During the first year, the major effort was divided between establishing and implementing procedures required for processing the CSA data, choosing appropriate events for analysis, and beginning the analyses of significant events required for the determination of the source characteristics. During the current year, additional array data (for eight or more earthquakes, total) are being analyzed and in some cases synthetics of the "whole" seismogram will be generated for comparison with the array data in order to improve the reliability of the source characterizations and to obtain some measure of their uniqueness. Complimentary digital data will be obtained from DWWSSN and SRO stations in central Pennsylvania and from an RSTN station in the Adirondacks, New York and incorporated in the analyses.

A number of appropriate earthquakes have been selected for detailed study and analytical procedures have been applied to a few events. Some representative results from four earthquakes provide an indication of the quality of the data available and the effectiveness of the procedures: New Madrid, Missouri, $\Delta = 13.1^o$, $m_b = 3.8$-3.9; Rhode Island, $\Delta = 2.2^o$, $m_b = 2.7$; New Brunswick, $\Delta = 7.3^o$, $m_b = 3.6$; Keewatin, N.W.T., $\Delta = 25.6^o$, $m_b = 4.5$.

Computer programs for three-component polarization filtering, beam forming, and horizontal slowness stacking were developed and applied to CSA data along with frequency filtering and spectral analyses. These procedures aid the evaluation of the importance of scattering and lateral refraction in the vicinity of the array; improve signal-to-noise ratio; aid the identification of wave types and isolation of surface wave modes; and provide spectral estimates used in the determination of certain source parameters.

Structural Framework of Eastern United States Seismic Zones

9950-02653

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Investigations

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

1. Compilation and interpretation of a map of known continental rifts, graben, and other extended terranes in the central and southeastern U.S., to test the suggested association between damaging seismicity and rifts. See Result 1, and Reports 2 and 3.

2. Descriptions of seismicity in and near Giles County, southwestern Virginia, and geological evaluations of the most probable types of causative faults. See Result 2, and Report 1.

3. Planning for a multi-sheet seismotectonic map of the East. The intent is to examine and test spatial associations of geologic, geophysical, and other factors that are thought to contribute to damaging eastern seismicity, and to identify complexes of factors that are necessary and sufficient for seismicity. Each map sheet will show one or more factors. All sheets will be at a scale and projection that allow them to be overlain on geologic, tectonic, and other maps to be produced for the Decade of North American Geology (1:5,000,000 scale, Transverse Mercator projection). A 9-page description is available on request.

4. Analysis of stratigraphic data to seek evidence of Devonian tectonism at the Allegheny Front in Maryland, West Virginia, and Virginia. A manuscript of 57 pages is in review for a Festschrift honoring W. Lowry, and a supporting Open-File Report of 23 pages is also in review.

Results

1. (See Investigation 1.) The findings, hypotheses, and speculations that were described in the last Semi-Annual Technical Report have been presented to several audiences and discussed with colleagues, with the following additional results:

a. In the eastern Piedmont province of the southern and central Appalachians and in the Coastal Plain, east of the large eastward rise in the Bouguer gravity field, seismicity appears to be at least as closely associated with a few suspect terranes as it is with the structure of the rifted Atlantic continental margin. A manuscript with G. A. Bollinger as senior author describes that spatial association. In particular, 3 seismically active areas lie on or east of the gravity rise in the area considered. In central Virginia, microseismicity occurs within and at the base of a detached suspect terrane rather than on Mesozoic extensional faults (L. Glover III, J. Costain, and G. A. Bollinger, oral and written communs.). The same may be true for microseismicity in and near the Ramapo area (N. Ratcliffe, oral and written communs.). Only near Charleston, South Carolina do reactivated Mesozoic extensional faults seem as likely sources as do reactivated detachment faults of Paleozoic age. Thus the gravity rise may separate a cratonic region in which seismicity prefers rifts and related extensional systems, from a series of discrete and distinct orogenic regions in which the habit of seismicity is more varied, because more varied Phanerozoic histories present more varied structural fabrics to the ambient stress field.

b. Seismicity of southwestern Virginia, eastern Tennessee, and central Alabama all occurs within the eastern portion of the cratonic region, where Iapetan normal faults are known to exist and are inferred to provide reactivatable sources.

c. Seismicity near Anna, Ohio, in the Mississippi embayment, and near Sharpsburg, Kentucky all occurs in known or inferred rifts of Paleozoic and Keewenawan age. All 3 areas appears to lie in rifts sensu stricto, because gravity and magnetic maps imply the presence of abundant mafic igneous rocks, mantle pillows, or both: the entire crust appears to have cracked and extended in those areas.

d. Most of the rest of the Paleozoic and Mesozoic extensional systems lack the gravity and magnetic expressions of a true rift, and appear only to be graben or structural depressions. They also appear to be relatively aseismic.

2. (See Investigation 2.) Four independently-produced and independently-published maps of Landsat lineaments overlap to cover about 40,000 square km surrounding the Giles County seismogenic zone. Two maps each cover the entire study area, and the other 2 cover the Virginia portion and the West Virginia portion separately. Two of the 4 maps were each produced by 2 operators working independently, who then compared their lineaments and classified them according to certainty. A third map was produced by a single operator who also classified his lineaments. For these three maps, only the more certain classes of lineaments were examined. Because each portion of the study area is covered by 3 maps, the area provides an unusual opportunity to test reproducibility, and perhaps to overcome the notorious unreliability of Landsat lineaments. The hope is that features can be found that are common to all overlapping maps. If so, some of those features may record an imprint on the exposed thrust sheets of repeated motion on the seismogenic fault or fault zone that underlies the thrust sheets. Such an investigation is justified because a large area can be examined fast and cheaply. Preliminary results include the following:

a. Reproducibility of single lineaments has not yet been examined, because single lineaments are known to be poorly reproducible where compared in other study areas.

b. Preferred orientations are widely regarded as among the most reproducible aspects of lineament maps. In the study area, no preferred orientation is statistically significant on all maps, nor is any avoided orientation.

c. Contour maps of the areal density of lineament length are also widely regarded as reproducible. In the study area, contour maps using 15 minute quadrangles as cells show patterns that appear reproducible to the eye, but which differ significantly when compared statistically. Similarities between maps increase slightly when cell values are smoothed with a 4-cell moving average.

d. The contour maps are more readily compared by normalizing cell values. When that is done, ten small areas are either reproducible or statistically significant. Only one of the 10 is both: five 15 minute quadrangles form a contiguous area of low lineament density that is centered over, but several times the area of, the Giles County seismogenic zone.

e. Judging from this example, it is feasible to evaluate reproducibility in an objective way, and thereby to identify reliable aspects of lineament maps. Unfortunately such evaluation appears to require the unusual circumstance of 3 overlapping lineament maps that were produced independently. The common technique of using 2 operators to produce a single map may not be sufficient.

Reports

Bollinger, G. A., and Wheeler, R. L., 1983, The Giles County, Virginia, seismic zone: Science, v. 219, p. 1063-1065.

Wheeler, R. L., 1983a, Rifts and passive margins in and near the southern Appalachians: indirect inheritance? [abs.]: Geological Society of America Abstracts with Programs, v. 15, no. 3, p. 183.

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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 Cushenbury Canyon.. Our goal is to (a) establish a better constrained uplift history for the San Bernardino Mountains, (b) elucidate the nature and modes of deformation acting on the northern range front, (c) estimate Holocene rates of deformation along the northern range front and (d) estimate, if possible, recurrence intervals and vertical/lateral offsets for the frontal fault system. In this summary, we will present the results of our paleomagnetic dating and trenching programs. The area between Silverwood Lake and Dry Canyon has been discussed in detail in previous Summaries.

Results

1. Trenching: We excavated two trenches along the north frontal fault system of the San Bernardino Mountains in Lovelace Canyon and on Ocotillo Ridge.

The Ocotillo Ridge trench was excavated on County of San Bernardino right-of-way at the corner of Ocotillo Way and Pioneer Road (sec 15, R3W T4N) in the Marianas Rancho area of Apple Valley. The site lies on the steepest part of the northwest slope of Ocotillo Ridge, just west of a scarplike lineament on the 1939 airphotos. The structure underlying Ocotillo Ridge appears to be continuous with the structure responsible for the impressive scarps on the west flank of the Ord Mountains. Bedding attitudes of the Ocotillo Ridge deposits define an asymmetric anticline, with steep northern and shallow southern limb A fault was mapped on the north side of the anticline by F. Miller (pers. comm.). The trench was 65 feet long, and a maximum of 13 feet deep.

The Ocotillo Ridge trench exposed a 55° north-dipping section of coarse fluvial sand and gravel underlain by several massive debris-flow units. These sediments, part of the "Ocotillo Ridge" deposits, are correlated with the Older Alluvium underlying the Victorville Fan to the west and estimated to be about 500,000 years in age. A soil developed on the debris-flow unit and the presence of rotten diorite clasts support this age; no C^{14}-datable material was found in this unit.

Multiple $CaCO_3$-filled fractures were evident in the debris-flow deposit at the south end of the trench. These fractures were confined to the better-indurated, $CaCO_3$-cemented soil-zone in the debris-flow unit, dying out in the softer underlying material. The majority of the fractures dipped steeply to the south, a lesser set dipped shallowly north. There was no evidence of offset across any of the fractures. Several of the fractures could be traced into the fluvial sand unit that overlies the debris-flow, where they were abruptly truncated by liquefaction structures. We interpret the steep, south-dipping fractures as tension cracks developed in the brittle $CaCO_3$-cemented soil zone of the debris-flow deposit in response to the bending moment applied to the beds during folding. Shallow north-dipping fractures possibly represent similar features, now rotated out of alignment by folding. Alternately, these shallow fractures may be basal shears for small slumps developed on the oversteepened hillslope.

Liquefaction structures were abundant throughout the coarse sand body immediately overlying the debris-flow unit. A large, amorphous sand, silt and clay intrusion appears to have invaded the fluvial unit along bedding planes. We also noted evidence of in-situ liquefaction included pods of well-sorted, structureless, medium-grained sand, and coherent blocks of laminated sand surrounded by chaotic laminations. Liquefaction can occur in response to depositional loading or seismic shaking of saturated sand. In this case, sediment loading can be ruled out, since liquefaction structures cut tension cracks in the soil developed on the Ocotillo Ridge deposits.

Collectively, these findings seem best explained by co-seismic folding of the Ocotillo Ridge deposits in response to movement on a buried, high-angle reverse fault. This structure seems to be a straightforward extension of the reverse fault on the west flank of the Ord Mountains. The scarps on the 1939 airphotos appear, upon careful re-examination, to be the expression of a resistant gravel bed within the Ocotillo Ridge deposits. We can find no compelling evidence of faulting on the north side of Ocotillo Ridge.

The Lovelace Canyon trench was excavated on the property of L. E. and Marcia Alter (sec 27, R2W T4N). The site lies in the modern stream bed on the projection of a wide gouge zone cutting bedrock in the canyon walls. Although the trench was 120 feet long, and reached a depth of 14 feet, it was only possible to safely shore 50 feet of the excavation to a depth of 10 feet due to extremely unstable soil conditions.

The ground surface at the trench site had clearly been disturbed by the property owners prior to our activities. A sprinkler system had to be disassembled before, and reconstructed after, our operations. A dirt road crossing the channel immediately downstream of the site is constructed entirely of fill with no culvert; it is, in effect, a dam across the stream channel.

Nevertheless, several geomorphic features at the trench site suggest the presence of a fault in the alluvium. A vegetation anomaly that defines a linear zone of moisture in the alluvium on line with gouge exposed in the west canyon wall leads to a shallow linear depression across the canyon. High on the east wall of the canyon, Pleistocene(?) alluvial fan deposits terminate abruptly against bedrock along the projection of the gouge zone; although the contact is not exposed, they appear to be faulted. We had hoped to find older, C^{14}-datable deposits buried beneath the modern channel fill and see if they were deformed or faulted.

The excavation at Lovelace Canyon revealed several massive debris-flow deposits overlain by more than a meter of moderate- to well-bedded, moderately sorted coarse sand interpreted as modern channel fill. A disarticulated clay layer within the debris-flow unit and a gentle rise in its upper surface coincided with a moist zone at the base of the excavation. The modern channel sands grade laterally to massive silts which abut and overlie old road-fill at north end of the trench. Thus the upper meter of channel fill in the trench is historic.

About a meter of massive fluvial(?) sand underlies the debris-flow unit in the north end of the trench. This deposit was moist and highly unstable, undermining the overlying units and making it impossible to shore this segment of the trench. Hence, it was not possible to map the sand in detail or search for datable material.

No conclusive evidence of faulting or deformation was found in the Lovelace Canyon trench. Detailed mapping did not reveal any evidence of internal shearing or deformation. Based on inspection from outside the excavation, the contact between the massive fluvial sand and overlying debris-flow deposit did not appear to be offset. We conclude that faulting has not occurred since deposition of the debris-flow unit and that, quite possibly, all of the above features are the result of a groundwater barrier created by the bedrock gouge zone depth.

2. Paleomagnetism: The Brunhes/Matuyama polarity reversal (730,000 years B.P.) occurred during deposition of the Victorville Fan complex. Based on the results from progressive demagnetization of 50 paleomagnetic samples, the upper 50 meters of the Harold Formation and at least 88 meters of the Shoemaker Gravel are of reversed polarity, and therefore older than 730,000 years old. The entire 70-meter-thick section of sediments exposed in the bluffs along the Mojave River in Summit Valley is also reversed. The basal Older Alluvium capping the Victorville Fan complex in Cajon Pass is reversed, while higher levels within the Older Alluvium are normal.

Paleomagnetic samples from the Victorville Fan and related units permit preliminary age assignments, providing a much needed framework on which to base an interpretation of drainage development and depositional history. A border of dissected Older Alluvium that rims the Victorville Fan northeast of Cajon Pass and in Summit Valley is partly reversed. A central fan-shaped body of undissected Older Alluvium occupying the region underlying Hesperia is, in part, normal.

The Ord River Gravel east of the Mojave River on the west flank of the Ord Mountains is correlated with the Victorville Fan complex on the basis of similarity of geomorphic, lithologic and paleomagnetic characteristics. Reversed samples from exposures of the Ord River Gravel near Deep Creek are correlated with the dissected Older Alluvium that predates the development of Summit Valley. Well-graded deposits in the Apple Valley Highlands/Marianas area are normal and postdate the development of Summit Valley.

The sediments underlying the Arrastre Canyon Fan and terrace remnants of its ancestral trunk stream are normal, hence younger than 730,000 years B.P. A small patch of reversed sediment which unconformably underlies the Arrastre Canyon Terrace deposits is of unknown age and affinity.

Regional and Local Hazards Mapping in the Eastern Great Basin

9950-01738

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Investigations

1. Study the late Quaternary stratigraphy of the eastern Great Basin (W. E. Scott).

2. Collect, process, and interpret high-resolution seismic reflection profiles across selected faults in the eastern Great Basin (S. T. Harding, A. J. Crone, R. C. Bucknam, and R. E. Anderson).

3. Study the subsurface geometry and behavior of faults in the eastern Great Basin (M. L. Zoback).

4. Determine paleostress orientations in southwestern Utah and adjacent Nevada (R. E. Anderson).

5. Collaborate with Jacques Angelier and his colleagues from the Acadamie of Paris on determination of the late Cenozoic paleostress history at Hoover Dam, Nevada-Arizona (R.E. Anderson).

Results

1. Stratigraphic studies in the eastern Bonneville Basin have refined our understanding of the duration of the last lake cycle (named the Jordan Valley cycle). On the basis of ^{14}C dates, the last cycle started rising by 26,000 yr. B.P., reached its highest level at the Bonneville shoreline by 16,000 yr. B.P., and ended by 11,000 yr. B.P.

2. High-resolution seismic reflection profiles have been obtained across selected young fault scarps in Utah as part of an effort to better understand the size and subsurface geometry of the faults with which the scarps are associated. An 8 km-long east-west profile across a system of Holocene scarps on the east flank of the Drum Mountains northwest of Delta shows a strong doublet reflector at the west end of the line that is believed to be consolidated rock beneath the alluvium at an approximate depth of 61 m. This reflector is vertically displaced approximately 133 m across a 640-m-wide zone that is coincident with the westernmost major fault scarp. At the east end of the line, an approximately 1-m-high, west-facing fault scarp overlies a zone where the reflector is vertically displaced approximately 66 m. A 450-m-long reflection profile across a 1-m-high fault scarp near Clear Lake, south of Delta, contains numerous prominent reflectors that are displaced vertically

about 300 m at a depth of about 2000 m across the fault. Published vibroseis data shows that this fault may be a major graben-bounding fault that extends downward to a major regional detachment fault. A 450-m-long reflection line across an east-facing, 3-m-high scarp at Scipio, Utah, shows strong reflectors at an approximate depth of 185 m in the downthrown block that cannot be traced across the fault. Two parallel profiles approximately 0.7 km long, which cross the Wasatch fault zone at Kaysville, Utah, show a complex system of faults with a well-developed, 280-m wide graben at the base of the fault scarp.

3. Recently acquired seismic reflection profiles together with well, gravity, and previously published reflection data help to define the shallow structure of the Sevier Desert Basin, Utah. An updip eastward projection of the regionally identified Sevier Desert detachment fault intersects the ground surface near the east edge of the Sevier Desert along the west margins of the Pavant and Canyon Ranges. The detachment fault dips 3^{o}-7^{o} west beneath the Sevier Desert and reaches a maximum depth of about 12 km near the Cricket and Drum Mountains. The upper plate is complexly deformed and includes cross-strike and along-strike reversals in fault-related stratal tilts. A tentative correlation of upper-plate pre-Tertiary rocks with those exposed in ranges to the east of the Sevier Desert indicates a minimum displacement of 45 km on the detachment fault. Preliminary analysis of available well data suggests that the detachment does not coincide with any of the major thrust faults of the region.

4. The orientation of striae on about 550 fault surfaces in the Nevada-Utah border area between 37^{o} and $37^{o}30'$ together with a newly compiled 1:100,000 geologic map of that area provide a basis for identifying 10 structural domains within which paleostress orientations have been determined. Three orientations predominate: σ_3 orientated NE-SW with σ_1 oriented vertical, σ_3 oriented E-W with σ_1 oriented vertical, σ_3 E-W with σ_1 oriented N-S. The first is interpreted to have survived from an episode of widespread late Miocene NE-SW extensional deformation. The latter two are interpreted to have resulted from contrasting aspects of a subsequent episode of E-W extension. The orientations that indicate horizontal compression (σ_1 N-S) are consistent with mapped geologic relationships. They may reflect brittle failure above ductile cells of south-directed rock flowage. Such flowage may result from second-order tectonic transport into zones that would otherwise form voids created at or near the margin of an extending terrain.

5. At Hoover Dam 40 km southeast of Las Vegas, Nevada, deep downcutting by the Colorado River and numerous excavations related to dam construction provide excellent bedrock exposures more than 0.5 km deep within less than 1 km^2. Miocene rocks in this small area are highly faulted and fractured, and most surfaces contain one or more sets of striae produced during fault movement. Study of these fault surfaces has shown that the sense of slip can be determined for most of them. Thus, this intensely excavated and faulted area offers an excellent opportunity to study brittle failure in three dimensions and to attempt to solve the state or states of stress associated with the faulting. The sense of slip on 497 faults at the Hoover Dam locality provides an exceptionally comprehensive data set from which paleostress axes are confidently determined. These data indicate a very complex stress

history that includes changes in stress orientation with time. If some of these complexities are ignored, two paleostress orientations of approximately equal representation predominate: (1) σ_3 NE-SW with σ_1 vertical, and (2) σ_3 NE-SW with σ_1 oriented NW-SE and approximately horizontal. The mixture of horizontal and vertical pressure axes seen in the paleostress data is similar to the results of focal mechanism solutions from the study of microseismicity of the area reported by Rogers and Lee (1976). However, the azimuthal orientations resulting from the two studies are very different and suggest a clockwise rotation of σ_3 with time. A mixture of horizontal and vertical pressure axes is also seen in paleostress determinations from the Nevada-Utah border area west of St. George, Utah (see investigation 4 above).

Reports

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Surface Faulting Studies

9910-02677

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Investigations

The investigations were focused on the study of: (a) statistical data related to surface faulting, in collaboration with J. J. Lienkaemper and R. K. Mark, and (b) the appearance of active faults in exploratory trenches.

Results

Compilation and analysis of data on some of the factors that affect the correlations among earthquake magnitude, surface rupture length, and fault displacement at the surface were completed. These factors include measurement error, variations in shear modulus, variation in stress drop, relation to plate boundaries, variations within plates, and type of faulting.

Thatcher and Hanks (1973, Journal Geophysical Research, v. 78, p. 8573) developed a theoretical equation relating rupture length, earthquake magnitude, and stress drop. Anderson (1979, Earthquake Notes, v. 50, no. 2, p. 6-7) suggested that a high value of stress drop could be chosen if an upper bound estimate of earthquake magnitude is needed for a given rupture length. However, published stress drops for the historic faulting events do not show the systematic relation to earthquake magnitude and rupture length implied by the theoretical analysis. Thus, based on the compiled data, assumption of a stress drop commensurate with a desired level of conservatism does not seem justified.

R. K. Mark completed his statistical analysis of the relations among earthquake magnitude, surface rupture length, and surface fault displacement. He has confirmed the earlier tentative conclusion that stochastic variation dominates errors in measurements of the magnitude, length, and displacement and that ordinary least squares regression models which yield two regression lines are more appropriate than the one-line (functional) regression models. Use of weighting factors based on the measurement errors generally have little effect on the results, but for some correlations they do improve the correlation coefficients. J. J. Lienkaemper prepared a report describing the methods he used in uniformly determining surface wave magnitudes for earthquakes associated with the surface faulting. The summary report on this work, coauthored by Bonilla, Mark, and Lienkaemper, is nearing completion.

The study of trenching as an investigative tool was resumed after many postponements. Data are being compiled on what influence such things as the amount of displacement, fault type, and material penetrated have on the expression of faults in trench exposures.

Reports:

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ACTIVITY AND EARTHQUAKE POTENTIAL OF THE PALOS VERDES FAULT

14-08-0001-19786

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Overview

The regional and local fault geometry, recency of activity, and displacement history of the Palos Verdes fault were investigated using geological and geophysical techniques. Approximate locations of onshore surface traces and amounts and rates of late Quaternary deformation were evaluated using available surface and subsurface data, and the geologic and tectonic setting of the fault was studied. Offshore fault segments were mapped; recency of activity was evaluated; and Holocene displacement rates were estimated. These investigations formed the basis for evaluations of earthquake capability of the fault. Based on comparison of fault behavior on major segments of the fault through time and fault displacement parameters inferred from interpretation of seismic profiles, the size of late Holocene earthquakes and frequency of occurrence of potentially damaging earthquakes along the fault were estimated.

Investigations

1. Late 19th and early 20th century topographic maps and 1928 vintage pre-development aerial photographs were evaluated for evidence regarding fault locations and information that may allow inferences regarding nature and amounts of late Quaternary displacements.

2. Subsurface lithologic data from drillers and geologists logs and synoptic water level measurements from approximately 250 water wells were analyzed for evidence regarding fault locations, stratigraphic discontinuities in late Quaternary age strata, and potential water table variations across the fault.

3. Results of horizontal and vertical geodetic surveys transecting the onshore fault trace were analyzed for evidence of distortion that may be attributed to fault movement.

4. A late Quaternary seismic stratigraphic sequence analysis, including correlation with borehole logs, was completed for the outer Los Angeles Harbor area and the outer San Pedro margin.

5. Regional bathymetric, geologic, late Quaternary isopach, and topographic anomaly maps and cross-sections were prepared for the San Pedro shelf from Los Angeles Harbor to water depths of about 325m, and detailed geologic, sediment isopach, and structure contour maps and sections were prepared for the outer Los Angeles Harbor and outer San Pedro margin areas.

6. Magnitudes and frequency of occurrence of potential earthquakes were estimated using fault displacement data.

Results

1. Analysis and interpretation of topographic maps and aerial photographs suggest the main trace of the Palos Verdes fault follows the base of the Palos Verdes escarpment at an approximate elevation of 200 feet. Near the northwest and southeast ends of the escarpment, the base of the escarpment decreases to about 50 to 100 feet in elevation. Interpretation of aerial photographs revealed several topographic features which could be related to faulting; however, no compelling geomorphic evidence of youthful faulting was noted along the onshore fault trace.

2. Synoptic water level measurements for wells developing the merged 400-foot Gravel and Silverado aquifers in the vicinity of the fault were contoured. Due to well locations, no useful water level measurements are available southwest of the fault. The water table surface northwest of the fault slopes southwestward, with contours generally normal to the fault. The contour pattern is consistent with a no-flow boundary across the fault.

   Drillers logs of water wells were correlated near Torrance where wells are present on both sides of the fault. Wells north of the fault penetrate the Bellflower aquiclude and merged 400-foot gravel and Silverado aquifers, while those south of the fault penetrate dune sand, the San Pedro Sand and the Upper Monterey Formation. In addition, the data suggest the plane of the fault is intersected by one of the wells. These relationships indicate post-mid Pleistocene vertical separation of at least 210m (710 feet) and suggest a long-term average vertical separation rate of 0.2 to 0.5 mm/yr.

3. Analysis of available geodetic survey data across the fault did not reveal evidence of distortion of vertical or horizontal survey nets that may confidently be attributed to fault movement. Although some interpretations suggestive of active faulting are permissible,

nontectonic influences in the area may be causing the observed elevation changes. Therefore, analysis of geodetic data does not necessarily provide a basis for valid assessment of the magnitude or rate of deformation along the onshore portion of the fault.

4. The late Quaternary stratigraphy of the San Pedro shelf was subdivided into four seismic stratigraphic sequences designated Holocene-Pl-I through Pl-IV and mapped over the inner and mid-shelf and outer margin areas. These seismic units were correlated with the oxygen isotope paleotemperature record and assigned tentative ages ranging from the present to approximately 365,000 ybp. In the Los Angeles Harbor area channel-fill sequences of the Holocene-Pl-I interval were further subdivided and correlated with the Holocene Gaspur aquifer.

5. A major zone of seafloor bowing was mapped along the offshore extension of the Palos Verdes uplift. In addition, four eliptical topographic anomalies up to 1.5 km wide and 4 km long and with amplitudes of up to 4m above a regional datum plane were mapped in the inner to mid-shelf area. Two of these anomalies overlie the Palos Verdes fault and two overlie the Cabrillo fault.

6. Regional and detailed mapping of the Palos Verdes fault revealed a zone of deformation approximately 1.5 km in width consisting of a complex pattern of en echelon and anastomosing fault splays. Surface traces of individual fault segments range from about 1.5 to 11 km in length. Prominent segments of the fault extend from the Los Angeles Harbor to the outer shelf margin. Separation along the zone inferred from seismic profiles is southwest-side-up high angle reverse, but en echelon fault patterns and the oblique trend of associated fold axes suggest a dextral slip component.

   High resolution (3.5 kHz) and Uniboom profiles reveal evidence for Holocene to modern (?) activity along major segments of the fault on the San Pedro shelf. Evidence exists for approximately 3m of offset of the basal Holocene reflector in both the Los Angeles Harbor/inner shelf and outer margin detailed study areas, and major segments of the fault displace the seafloor forming a 1 to 1.5m high scarp in Holocene age sediments. Based on these interpretations, we believe the Palos Verdes fault displays evidence of repeated activity during the Holocene. Evidence of seafloor disruptions and offsets occurs along major fault segments extending from the inner shelf to the outer margin.

   Holocene vertical separation rates were estimated based on heights of seafloor scarps and topographic anomalies along the fault and offsets of the basal Holocene reflector. Estimated rates range from 0.1 to 0.4 mm/yr, with a best estimate of 0.3 mm/yr.

7. Magnitudes of earthquakes that may have occurred along the Palos Verdes fault during the late Holocene were estimated from inferred and observed late Holocene deformations using both empirical

regression relationships and seismic moment and moment magnitude techniques. From these considerations it could be inferred that the fault has experienced one or more earthquakes in the range of M 6.5 to 7.0 with a corresponding M_L of about 6.4 to 6.6 and M_S of 6.6 to 7.1. Because the area over which late Holocene activity has occurred probably extends beyond the limits of our regional study area, we recognize the possibility that events somewhat larger than these could have occurred. Using a variety of techniques, estimates of recurrence intervals of earthquakes of this size range from 2,000 to 8,000 years.

Tectonics of Central and Northern California

9910-01290

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Investigations

1. Relations between seismicity and crustal out-gassing of carbon dioxide: collaboration with Ivan Barnes.

2. Paleomagnetic study of Permian and younger strata of the Eastern Klamath terrane: collaboration with E. A. Mankinen and C. S. Gromme.

3. Tectonic accretion of terranes of northern California: collaboration with C. D. Blome, M. C. Blake, and J. P. Albers.

Results

1. Revision of a map and report on the global relationships of carbon dioxide discharges and major zones of seismicity was completed and received Director's approval for publication in the Miscellaneous Investigations Map series. The report discusses the tectonic environments of the carbon dioxide discharges and also the isotopic basis for identifying the source of the carbon dioxide as organic material, metamorphosed marine carbonate rock, or the mantle. Owing to its buoyancy, carbon dioxide is speculated to be the causal agent for the upward movement of magma in addition to being a product of degassing. Discharges of carbon dioxide along crustal spreading centers may indicate that mantle convection and seafloor spreading are facilitated by buoyant gas-charged melts.

2. Laboratory work on our latest core drilling for paleomagnetic study of northern California is not yet complete. However, preliminary results on cores taken from the Eastern Klamath terrane and superjacent strata of the Great Valley sequence indicate that the Eastern Klamath terrane: (1) rotated about 50^{o} relative to stable North America during Late Triassic or Early Jurassic; (2) rotated an additional 50^{o} during Early, Middle, or Late Jurassic; and (3) had virtually ceased rotating by Early Cretaceous time. No latitudinal displacement is indicated. These results are compatible with newly published data obtained by other researchers on Devonian strata and Jurassic plutons of the Klamath Mountains.

3. Lower and Upper Cretaceous strata of the Great Valley sequence unconformably overlie the basement rocks at the south end of the Klamath Mountains. They provide an upper limit to the time of accretion of the

various basement terranes, but the lowermost of these strata are not well dated. The youngest basement rocks overlain by them are Upper Jurassic (Kimmeridgian) beds of the Galice Formation and Shasta Bally batholith. The batholith yields isotopic ages of 134 m.y. (K-Ar) and 136 m.y. (U/Pb) and, depending on the time scale used, is either latest Jurassic (Tithonian) or Early Cretaceous (Valanginian) in age. To obtain a precise age for the overlying strata, we sampled several thin nodular calcareous beds that are separated from the basement rocks by less than 10 m of coarse basal conglomerate. Analysis of the samples showed them to contain pyritized foraminifers and radiolarians. These fossils were not preserved well enough to be dated precisely but indicate that additional sampling is warranted.

Study of the complex tectonic junction of the Coast Ranges, Klamath Mountains, and Great Valley provinces will be facilitated by a new geologic map of the Red Bluff metric sheet (scale 1:100,000). Compilation of the Red Bluff sheet, done in collaboration with M. C. Blake and others, was completed during this report period. The geology of the Redding 2-degree sheet (scale 1:250,000) is being compiled in collaboration with J. P. Albers.

Reports

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Irwin, W. P., and Thurber, H. K., 1983, Agua Tibia Primitive Area, in The Wilderness Book, Marsh, S. P., ed.: U. S. Geological Survey Professional Paper 1300, in press.

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Barnes, I., Irwin, W. P., and White, D. E., 1983, Global distribution of carbon dioxide discharges and major zones of seismicity: U. S. Geological Survey Miscellaneous Investigations Map I-1528, with text, in press.

Blome, C. D., and Irwin, W. P., 1983, Tectonic significance of Late Paleozoic to Jurassic radiolarians from the North Fork terrane, Klamath Mountains, California: Society of Economic Paleontologists and Mineralogists, Symposium on Paleozoic and Mesozoic rocks in microplates of western North America, in press.

Coastal Tectonics, Western U.S.

9940-01623

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Investigations

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

Project personnel are Scott Mathieson, Dan Ponti, Patricia McCrory and Marylynn Vivrette.

Results

1. We use the relative sea level curve of Bloom and others (1973) as a datum for determining total uplift of emergent marine terraces (fig. 1). To do this, we must assume, 1) that the sea level curve is correct, 2) that the geoid does not change shape with time, and 3) that long term (10^5 yrs) uplift rates are constant. All three of these assumptions have been challenged and some workers in the field believe this approach is invalid. However, we have six terrace sequences in central and southern California that fit the uplift model. Independent paleontological and amino-acid dating control support the terrace age assignments derived from this technique. Workers in other parts of the world report similar success. Therefore, we conclude that our assumptions, especially the first two, are correct. We also conclude that if a terrace sequence does not fit the sea level curve, the uplift rate has not been constant.

The Santa Cruz terraces in central California (Bradley and Griggs, 1976) fit the uplift/sea level model nicely (fig. 1). However, the terrace ages derived from this model differ from those tentatively assigned by Bradley and Griggs. The temperature aspect of a fossil molluscan fauna from the Highway 1 platform in Santa Cruz recently collected by G. Weber will be a test of the age assignments derived from the model. If the fauna has a cool-water aspect, the age assignments will be confirmed.

2. Early aerial photographs and detailed topographic maps (1" = 50'; 2' contour interval) reveal 7 to 9 minor topographic scarps (shorelines) on the emergent Holocene marine terrace (5.8-0 ka B.P.) at Pitas Point, Ventura

County, CA. Similar scarps in Japan and New Zealand were created by coseismic tectonic uplift associated with historic earthquakes. However, similar scarps could be formed by slight sea level fluctuations or storm events on a coastline emerging at a constant rate. We have no means of determining the origin of these scarps, but if they are of tectonic origin, they represent 7-9 uplift events totaling 20 m in about 6,000 years (670-860 yr repeat interval and 2.2-2.9 m per event). We are cooperating with archeologists working on a site on the 8 m (1,700 yr B.P.) terrace at Pitas Point to try to determine the exact origin of these minor scarps. The highest terrace in the Ventura area (dated at 5.8 ka) yields a maximum uplift rate of 5.8 m/ka.

3. With Sam Morrison, completed detailed mapping of the emergent marine Holocene terrace at Ocean House near Cape Mendocino in northern California. There are 5 to 7 minor scarps and beach ridges on this terrace; each represents an uplift or climatic event. The highest terrace (14.1 m) in this area yields an average uplift rate of 3.1 m/ka.

4. With Scott Mathieson, completed detailed mapping of the emergent Holocene marine terrace at Big Flat in northern California. There are 13 minor scarps and beach ridges on this terrace. The highest terrace (20 m) yields an average uplift rate of 4.0 m/ka. The high uplift rates derived from the Ocean House and Big Flat terraces (normal uplift for coastal California is 0.3 m/ka) reflect underthrusting of the Gorda Plate and overthrusting of the Pacific and North American plates at the Mendocino triple junction.

5. With Scott Mathieson and Dan Ponti, visited Edward Hare, Carnegie Institute, to set up portable amino-acid laboratory for Menlo Park.

6. With Scott Mathieson, flew coastline of Santa Cruz and San Mateo Counties to photograph sea cliff erosion associated with two large storms in January and February, 1983. Extensive property damage was associated with structures built on upstable cliffs or on active beaches.

7. Dan Ponti altered computer programs to compile and analyze geotechnical data from bore holes in Los Angeles basin.

8. K. Lajoie assisted T. Hanks, R. Wallace and R. Bucknam in completing and submitting manuscript on mathematical modelling of erosional and fault scarps. The diffusion equation accurately models four progressively older sea cliffs in the sequence of emergent marine terraces in Santa Cruz, California (figure 2).

9. With A. Sarna-Wojcicki, J. Davis and G. Spencer, correlated tephra layer #15 from the Wilson Creek beds in Mono Basin, California, with the Carson Sink ash in the Sehoo Formation in Carson Sink Nevada, and tephra layer #6 in Lake Bonneville. This tephra layer, which is dated independently at 28-29 ka B.P. in the three basins, provides a precise datum for stratigraphic correlation throughout the Great Basin.

Stratigraphic and geomorphic data in Mono Basin indicate that Lake Russell (Pleistocene Mono Lake) stood at intermediate levels from 25 to 15 ka B.P., which indicates that the climate was cool and dry during full glacial times (figure 2). A sharp rise to high levels between 15 and 11 ka B.P. indicates that cool wet (pluvial) conditions prevailed as glaciers melted away at the end of the Pleistocene. During the past 10 ka Mono Lake stood at or near its present lowstand, which reflects the warm, dry conditions of Holocene time. This pattern is found in the Lake Lahontan and Lake Bonneville Basins to the north and east of Mono Basin, respectively. This pattern implies that the large, intermediate level Provo shoreline in the Bonneville Basin is older than the small, high level Bonneville shoreline. These relative ages are reversed from those proposed by G. K. Gilbert and most modern workers in the Bonneville Basin. However, assigning the major construction of the Provo shoreline to an intermediate level during full glacial times violates none of the geologic or age data in the Bonneville Basin. If this Bonneville chronology is correct, the overflow of Lake Bonneville and drastic downcutting of its sill at Redrock Pass are easily explained. The lake rose to its overflow level (Bonneville shoreline) during the late Pleistocene pluvial event (15-11 ka B.P.) that followed the glacial maximum. The fact that it downcut its overflow channel so drastically (~40 m), easily indicates that the lake had not been at this high level for a considerable period of time (10^5 yrs?) prior to 15,000 years ago.

The new and precise chronologies being worked out for these large Great Basin lakes provide valuable age control for tectonic studies throughout the Great Basin.

Reports

Hanks, T. C., Bucknam, R. C., Lajoie, K. R., and Wallace, R. E., submitted to JGR 1983, Modification of wave-cut and faulting-controlled landforms.

Lajoie, K. R., Sarna-Wojcicki, A. M., Robinson, S. W., Liddicoat, J. C., and Davis, J. O., 1983, Late Pleistocene stratigraphic correlations and lacustrine histories in the western Great Basin [abs.]: Geological Society of America Abstracts with Programs, v. 15, no. 5, p. 300.

Figure Captions

Figure 1.

A. Topographic and geologic profile of emergent marine terraces in Santa Cruz County, California. Faunal and amino-acid data from fossil mollusks on the Davenport (D) terrace indicate an age of 82,000 years BP. Assuming a constant rate of uplift (0.35 m/ka), the Highway 1 (H-1) terrace is 105,000 years old and the cement (C) terrace is 124,000 years old (see figure 1-B). Extrapolation of this rate yields an age of 490,000 years BP for the Black Rock (BR) terrace.

B. Sea level curve from Bloom and others, 1973. Uplift rate of 0.35 m/ka is derived from the age (82,000 yrs. BP) and uplift (29 m) of the Davenport (D) terrace.

Figure 2.

Lake level fluctuation curves for Lake Russell (solid line) in Mono Basin, CA, Lake Lahontan (dashed line; from Benson, 1979) in Nevada, and Lake Bonneville (dotted line; modified from W. Scott) in Utah. All three lakes stood at intermediate levels during full glacial times (shaded area) and rose to maxima between 14,000 and 12,000 years ago. If this general pattern is correct the Provo shore line (P) in Bonneville is correlative with the Lee Vining shoreline (LV) in Mono Basin and is older than the higher Bonneville shoreline (B) which is correlative with the Mono shoreline (M) in Mono Basin. These dated shorelines provide convenient data for tectonic studies throughout the Great Basin.

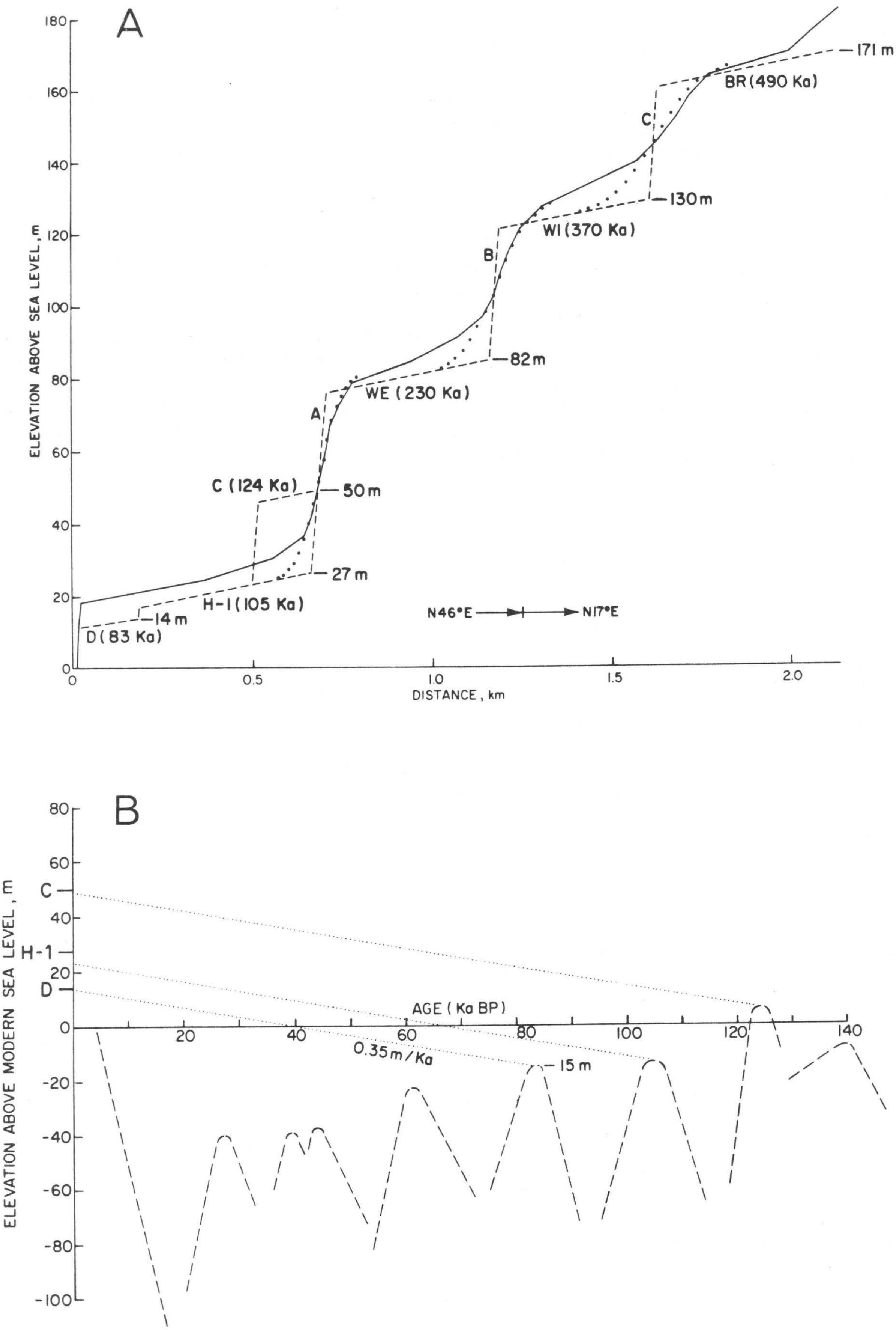
A
ELEVATION ABOVE SEA LEVEL, m
DISTANCE, km
D (83 Ka)
14 m
H-1 (105 Ka)
27 m
C (124 Ka)
50 m
A
WE (230 Ka)
82 m
B
WI (370 Ka)
130 m
C
BR (490 Ka)
171 m
N46°E
N17°E
B
ELEVATION ABOVE MODERN SEA LEVEL, m
C
H-1
D
AGE (Ka BP)
0.35 m/Ka
15 m

Figure 1

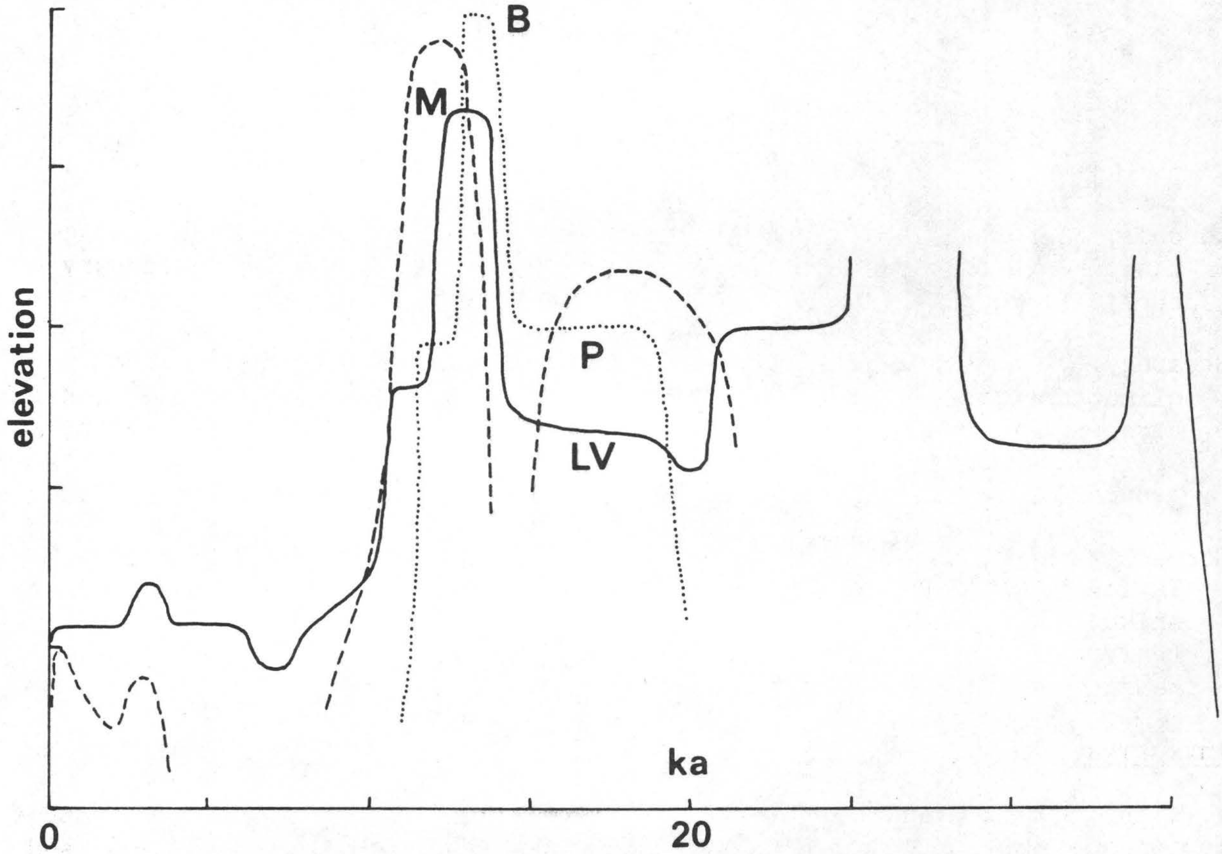

Figure 2

Soil Dating Techniques, Western Region

9540-02192

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

Strategy: Fourteen numerically dated soil chronosequences from varied climatic and geologic environments have been sampled (see table 1) and are being analysed to see which soil properies are the most useful indicators of soil age for geologic studies and how rates of soil development vary in response to different climates and types of parent materials.

Current personnel: M. N. Machette, J. W. Harden, M. C. Reheis (WAE), E. M. Taylor (WAE), and Glenn Dembroff (WAE). On contract: M. J. Singer, J. R. Aniku, and Peter Janitzky (University of California at Davis); M. L. Gillam (University of Colorado at Boulder); D. P. Dethier (Williams College, Massachusetts).

Investigations

1. Three project members attended the Geological Society of America Penrose Conference (April 24-29) on Tectonic Geomorphology, Winnemucca, Nevada, and presented the following informal papers or poster sessions during the conference. Harden: The soil-development-index as a method of assessing the usefulness, reliability, and versatility of soils in correlating and dating geologic deposits in various climatic regions. Machette: Dating Quaternary faults using the development of calcic soils; Quaternary tectonic history of the La Jencia fault, central New Mexico; Quaternary faulting in the Rio Grande rift of Colorado, New Mexico, and west Texas (with S. M. Colman). Reheis: Climatic implications drawn from the Rock Creek and Kane Fan soil chronosequences of the northern Bighorn Basin (Wyoming-Montana).

2. Reheis and Machette presented papers at the GSA Rocky Mountain-Cordilleran section meeting held May 1-4, at Salt Lake City, Utah.

3. Authors prepared outlines and preliminary discussions of the field data from 14 chronosequences with descriptions of regional geology, Quaternary stratigraphy, soil sites, and soil-forming factors. Each chronosequence will be treated separately as sequential chapters in a U.S. Geological Survey Bulletin. As of May 1, received drafts for the following soil chronosequences: Reheis: Rock Creek, Montana, and Kane Fan, Wyoming; Harden: Merced River, California. Expect remaining drafts during the summer, but before the end of the fiscal year (see table 1).

4. Revised draft of laboratory manual describing the chemical, mineralogical, and physical analyses of samples collected from the 14 soil chronosequences of this study. Manuscript currently in U.S.G.S. technical review. (Singer, Janitzky, Busacca, Harden, Ko, LaMothe, Machette, Meixner, Reheis, Taylor, and Walker).

5. Completed laboratory analysis of samples from the Kane Fan chronosequence; continuing analysis of samples from the Rock Creek, Animas River, Santa Cruz, and Ano Nuevo chronosequences. (Aniku, Gillam, Janitzky, Reheis and Singer).

Results

1. Preliminary analysis of ^{10}Be in soils of the Merced chronosequence has been completed by Milan Pavich (USGS-Reston). These analyses confirm that the volume of cosmogenically produced ^{10}Be can be determined for soils and that the total soil-^{10}Be content is largely a function of soil age. The ^{10}Be-dating method has now been tested, at least in a preliminary fashion, on one of the best dated chronosequences in the U.S. (Harden).

2. Completed the tabulation of soil description data and site characteristics for the 14 chronosequences. Transferred these data onto the NBI system, which will be used to prepare camera-ready copy for each of the Bulletin appendices.

3. Submitted methods manual for review: "Field and laboratory procedures used in a soil-chronogsequence study. Manual documents research on effectiveness and appropriateness of 24 field, laboratory, and data analysis techniques that were tested, designed, and (or) used by this project. It includes a detailed description of procedures, emphasizing aspects that are most difficult or critical to the analysis. Most of the research was overseen or directed by Harden over the past seven years and was conducted by U.C. Davis and U.S.G.S. staff. The manual is edited by Singer and Janitzky (major contributor) and includes contributions by these and other project participants. (Singer Janitzky, Busacca, Harden, Ko, LaMothe, Machette, Meixner, Reheis, Taylor and Walker.

4. Properties of soils formed in the cool arid climate of the Kane alluvial fans, north-central Wyoming, are controlled by time-dependent accumulation of aerosolically derived gypsum. Despite the availability of $CaCO_3$ in eolian dust and in the parent material, secondary $CaCO_3$ does not accumulate continuously, probably because gypsum suppresses the solubility of $CaCO_3$. Soil pH and a measure of its textural development (total texture) increase in soils less than 400,000 years old, but decrease or show irregular trends in older soils because of pervasive accumulation of gypsum. Rubification (a measure of reddening and brightening of color-Harden 1982) increases at depth in the soil profiles rather than near the surface as in most weathering environments. The depth to the top of the gypsic horizon is apparently controlled both by climate and by the hygroscopic properties of gypsum. The continual increase in gypsum suggests that the local precipitation level has not increased substantially in the past 600,000 years.

In the northwestern part of the Big Horn Basin, the soils formed on glaciofluvial terraces of Rock Creek, south-central Montana, provide information on soil development as modified by local climate. Logarithmic rates of development in mountain-front soils are probably controlled by near-surface weathering processes, whereas downstream, linear rates of development in drier soils seem to be controlled by the influx of eolian dust. Evidence of permafrost conditions, periodic dissolution of $CaCO_3$, and depths of pedogenic clay, support a substantial increase in available moisture during glaciations in response to decreasing evapotranspiration when temperatures were lowered. The soils farthest downstream have $CaCO_3$ morphology that suggests a concomitant decrease in precipitation. (Reheis)

Table 1. SUMMARY OF SOIL CHRONOSEQUENCES BEING INVESTIGATED BY THE SOIL-DATING TECHNIQUES PROJECT (9540-02192) OF THE U.S. GEOLOGICAL SURVEY

	Chronosequence	Age range	Climate	Mean temp. Mean precip.	Provenance[1] Texture[2]	Number of units	Number of soils	Present status	Primary authors of soil chronosequence report
1.	Sierra Nevada Foothills, CA.	9 ky to 600 ky	Mediterranean	60°F 32"	mv psgr	5	12	6	Marchand, Harden
2.	Merced River, CA.	0-3 my	Mediterranean	62°F 12"	gr sa	9	22	4	Harden
3.	Dry Creek, CA.	0-1 my	Mediterranean	62°F 12"	m, a si,sa	8	9	2	Machette and Singer
4.	Front Range, CO.	0-10 ky	Highland	25°F 30-35"	gr psbo,sa	4	8	2	Burke and Birkeland
5.	Palisades, CA.	0-10 ky	Highland Tundra	25°F 35"	gr psbo, sa	3	7	2	Birkeland and Burke
6.	Cowlitz River, WA.	0 to 1.5 my	Marine West Coast	52°F 47"	a si/cogr	9	12	2	Dethier
7.	Ventura, CA.	0 ky to 85 ky	Coastal Mediter.	56°F 15"	gr si/psgr	4	7	2	Harden, Lajoie, and Sarna-Wojcicki
8.	Ano Nuevo, CA.	60 to 320 ky	Mediter. to West Coast Marine	56°F 37"	s2 psgr	4	6	2	Burke and Harden
9.	Santa Cruz, CA.	60 ky to 1 my	Mediter. to West Coast Marine	56°F 37"	gr sa	9	9	2	Burke and Harden
10.	Honcut Creek, CA.	10 ky to 3 my	Mediterranean	62°F 21"	a, mv, gr si, cogr	9	19	2	Busacca
11.	Beaver Basin, UT.	10 ky to 750 ky	Contin. Subarctic	48°F 12-16"	r, a, b cogr, sa	5	22	2	Machette
12.	Rock Creek, MT.	10 ky to 2.1 my	Contin. Subarctic	42°F 14-23"	gr cogr	7	33	4	Reheis
13.	Kane Fans, WYO.	10 ky to 600 ky	Contin. Subarctic	45°F 7"	s3, s4 psgr	7	9	4	Reheis
14.	Animas River: Durango, CO. to Farmington, NM.	10 ky to 1.5 my	Contin., Subarctic to Semiarid	46°-51°F 18-8"	mixed si/cogr	11	nd	3	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-final stage of laboratory analysis, 2-data interpretation, 3-preliminary draft of report, 4-technical review of report, 5-directors approval, 6-report published.

Publications

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Busacca, A. J., Aniku, J. R., and Singer, M. J., Dispersion of soils by a cup-type ultrasonic method that eliminates probe contact and titanium contamination (abs.): submitted to Soil Science Society of America Journal, 20 ms. p.

Harden, J. W., 1983, Order and rates of element loss form central-California soils (abs.): American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America Abstracts, Annual Meeting, August 14-19, 1983, Washingtion, D.C.

Harden, J. W., and Taylor, E. M., A quantitative comparison of soil development in four climatic regimes: Submitted to Quaternary Research (11/82).

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Machette, M. N., Harper-Tervet, Jan, and Timbel, N. R, Calcic soils and calcretes of the southwestern United States, in Weide, D. L., and Farber, M. L., eds., Surficial Deposits of the Southwestern United States: Geological Society of America Special Paper, 58 ms. p (Directors approval 4/83)

Reheis, M. C., 1983, Glaciofluvial origin and drainage history revealed by terraces in the northern Bighorn basin, Montana (abs.): Geological Society of America Abstracts with Program, v. 15, no. 5, p. 431.

Basement Tectonic Framework Studies
Southern Sierra Nevada, California

9910-02191

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Investigations

1. Re-examination of specimens, thin sections, and notes of mafic magmatic and metamorphic rocks of the southernmost Sierra Nevada.

2. Preparation of report on mafic rocks of the southernmost Sierra Nevada and their implication for crustal depth and batholithic roots.

3. Preparation of report on petrographic descriptions of selected mafic rocks of the southernmost Sierra Nevada.

4. Petrographic study of magmatic and metamorphic samples from the area near the Kern Canyon fault zone.

Results

1. Recent studies have focused on and re-evaluated widely exposed hornblende-rich gneissic to granoblastic, amphibolite- to granulite-grade, metamorphic rocks and associated magmatic rocks, all of mid-Cretaceous age, in the southernmost Sierra Nevada. These hornblende-rich rocks appear to reflect a deeper crustal level than the dominantly granitic terrane to the northeast based on: 1) widespread occurrence of hypersthene, coarse red garnet, and brown hornblende, 2) ambivalence in the meaning of textures (whether metamorphic or magmatic), 3) the presence of granulite-grade rocks, and 4) the presence of migmatite and evidence of local melting and mobilization of the metamorphic rocks. These hornblende-rich rocks may be exposures of the upper part of the root zone and metamorphic substrata of the Sierra Nevada batholith. Xenoliths of gneiss, amphibolite, and granulite, that represent sub-batholithic crustal levels, have been transported upward and preserved in exposures of Tertiary volcanic rocks in the central Sierra Nevada. Some of this xenolithic material is similar to the relatively deep crustal rocks exposed in the southernmost Sierra Nevada.

2. Hypersthene-bearing granulite and tonalite of mid-Cretaceous age are exposed in the Santa Lucia Rnage, some 300 km northwest of the southernmost Sierra Nevada. The Santa Lucia outcrops also contain distinctive quartz-bearing granofels with abundant red brown biotite, coarse graphite, and brown hornblende. In addition, coarse red garnet is conspicuous in both metamorphic and magmatic rocks in a region of coarse gneiss and abundant migmatite. The overall geologic setting with respect to metamorphic grade, rock types, and crustal depth, is strikingly similar to that of the southernmost Sierra Nevada. A body of Pelona-type schist

in the Santa Lucia Range further adds to the geologic similarity of the two areas. These similarities naturally invite speculation about correlation and former juxtaposition. Erasing of currently accepted amounts of San Andreas fault movement would juxtapose the two areas but would leave problems in the matching of certain rock types and in the distribution of areas of various metamorphic grade. Nevertheless, the presence of similar and unusual geologic features in both the Santa Lucia Range and the southernmost Sierra Nevada such as: 1) mid-Cretaceous hypersthene granulite, 2) coarse garnet and hypersthene-bearing tonalite, 3) Pelona-type schist, and 4) migmatite and coarse gneiss in a "Sierran" environment, seems to be almost too much of a coincidence, if these two terranes are as unrelated as recent paleomagnetic studies appear to suggest. If the Santa Lucia Range along with the rest of the Salinian block is as far travelled as these paelomagmetic studies suggest, its parent terrane (perhaps ironically) should look much like the southernmost Sierra Nevada!

Reports

Ross, D. C., 1983, Generalized geologic map of the southern Sierra Nevada, California, showing the location of samples for which K-Ar radiometric age data and Rb/Sr data have been determined: U. S. Geological Survey Open-File Report 83-231.

Moore, J. G., Ross, D. C., and Sisson, T. W., 1983, Tourmalinization in the Kern Canyon fault zone, California: Geological Society of America Abstracts with programs, v. 15, no. 5, p. 322 (May 1983 Salt Lake City, Utah meeting.

Sams, D. B., Saleeby, J. B., Ross, D. C., and Kistler, R. W., 1983, Cretaceous igneous metamorphic and deformational events of the southernmost Sierra Nevada, California: Geological Society of America Abstract with programs, v. 15, no. 5, p. 294 (May 1983 Salt Lake City, Utah meeting).

Tephrochronology

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 in combination with petrographic characteristcs, to identify widespread tephra units of known radiometric age. New tephra units identified by chemical and petrographic analyses are dated by appropriate radiometric age dating methods (with C. E. Meyer, J. L. Slate, J. R. Rivera, and Gail McCoy, BWRG).

Investigations

1) Continued work on specific teprochronologic problems in Nevada, the western coastal states of the conterminous U.S., and the northeastern Pacific Ocean adjacent to the continent (see item 1, Summary of Technical reports, v. XV, Jan., 1983, p. 154-156, U.S.G.S. OFR 83-90).

2) Completed, through Branch Chief approval, report on correlation of the Rockland ash bed, a widespread mid-Pleistocene time and stratigraphic marker in northern and central California and western Nevada.

3) Collaborated on four reports for the GSA Cordilleran Sectional Meetings at Salt Lake City, summarizing several different lines of project research (see Reports), and gave one invited talk titled "How can we determine whether there is a relationship between the prehistoric tephra record and the climatic record?" at the conference on Climatic Effects of Volcanic Dust and Aerosols in the Upper Atmosphere, sponsored by the A.G.U., the American Meteorological Society, and the U.S.G.S., Boulder, Co., March 18, 1983. Our research on the last subject suggests that the best sites to study parallel records of past volcanism and climate are in thick, continuous, on-land sections of Quaternary marine deposits exposed along active continental margins. In such sections, deposition rates will probably have been sufficiently high to provide good age resolution for both the climatic signal and the volcanic record. We have initiated such a study in the Ventura, Ca., area (see report by Yerkes, this volume).

4) A volcanic ash bed produced by an eruption a short time after about 820 ^{14}C years ago from Panum Crater, the northernmost of the Mono Craters chain of volcanoes east of the central Sierra Nevada, has been identified in

young deposits on the floor of Yosemite Valley near Bridalveil Falls, on the basis of electron-microprobe and energy-dispersive X-ray fluorescence analyses (table 1). This ash layer, previously believed to be the "tephra layer 2" of Wood (1978), erupted about 1200 ^{14}C yrs. ago, matches the Panum Crater ash layer extremely well in all respects, and most probably represents the younger of the two eruptions. Similarity coefficients for the young ash erupted from the Panum Crater and the ash in Yosemite Valley range from about 0.97 to 0.99, where 1.00 represents an ideal match (work in coop. with Scott Stine, Dept. of Geography, Univ. of Calif., Berkeley; K. R. Lajoie, U.S.G.S.; and James Milestone, National Park Service).

5) We identify a volcanic ash bed exposed near Summer Lake, Ore., as ash layer Mp (table 2), erupted from Mount St. Helens between about 18,000 and 20,000 yrs. ago, according to Crandell and Mullineaux (1981) (work in coop. with J. O. Davis, Desert Research Institute, Univ. of Nev.). This ash has also been identified in deposits of pluvial lake Lahontan by Davis, who cites an age of about 18,200 ^{14}C yrs. b.p. on ostracodes obtained from close above this ash layer--an age in excellent agreement with ^{14}C data obtained near the volcano.

6) The Loleta ash bed of the Hookton Formation has been correlated among several exposures in the tectonically-active Humboldt basin of northwestern California (work in coop. with S. D. Morrison and K. R. Lajoie, U.S.G.S.; Ross Wagner, Woodward-Clyde Consultants; and Mike Perkins, Berkeley, Ca.). We have now identified this ash in DSDP core 36, drilled in the northern Pacific Ocean, about 500 km west of Cape Mendocino, Ca. (table 3). In the core, the Loleta ash overlies another ash layer, the Huckleberry Ridge (?) ash bed, by about 30 m (fig. 1). The latter ash lies stratigraphically close to the Plio-Pleistocene boundary, as defined by stratigraphic criteria. Assuming a constant sedimentation rate at the deep-ocean site and a 1.9 m.y. age (Naeser and others, 1971) for the putative Huckleberry Ridge ash bed, the Loleta ash bed is calculated to be about 0.39 m.y. old. In the Humboldt basin, the Loleta ash bed closely overlies the Rockland ash bed, dated previously by us as 0.45 m.y. using the fission-track age method on zircons (Meyer and others, 1980). Thus the age of the Loleta ash bed calculated from sedimentation rates in core 36 agrees well with age data and stratigraphic sequence observed in the Humboldt basin, and in a reiterative manner, lends additional credence to the identification of the Huckleberry Ridge (?) ash bed in core 36. Samples of ash cores obtained courtesy of the Scripps Institute of Oceanography, La Jolla, Calif.

Reports

Sarna-Wojcicki, A. M., Meyer, C. E., and Slate, J. L., 1983, The Lava Creek, Bishop, and Huckleberry Ridge ash beds in Pacific Coast Quaternary marine deposits--on land and in deep-ocean cores: Geological Society of America, Cordilleran Section, Abstracts with Programs, v. 15, no. 5, p. 389.

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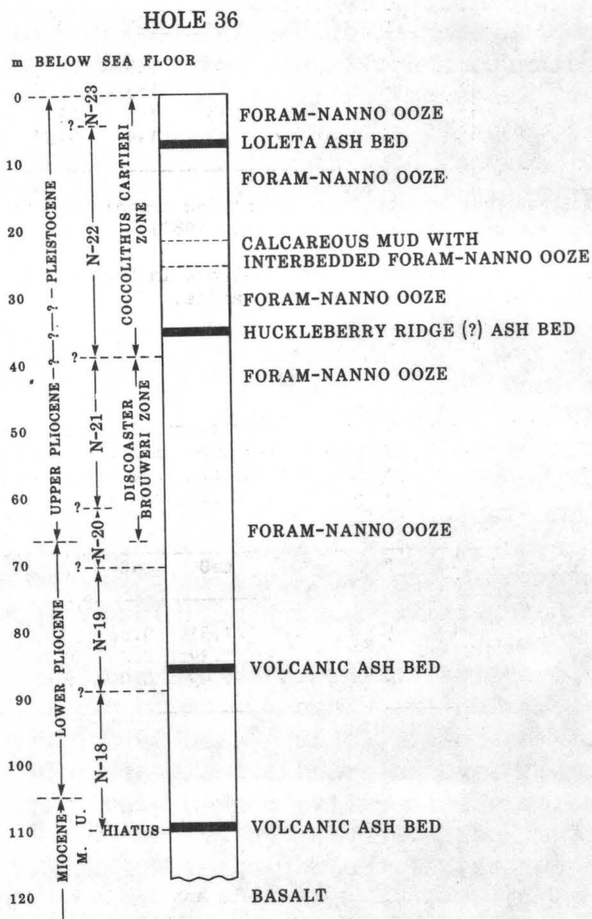

Figure 1. Generalized stratigraphy and biostratigraphy in the upper part of DSDP core 36 (from D. A. McManus and others, Initial Reports of D.S.D.P. for site 36, 1970), and positions of the Loleta and Huckleberry Ridge (?) ash layers.

(continued)

Table 1. a- Electron microprobe analyses of glass of young tephra layer erupted from Panum Crater, and correlative layer, Yosemite Valley, California; C. E. Meyer, analyst. b- energy- dispersive X-ray fluorescence analysis of same ash layer. J. L. Slate, analyst.

a	Sample	SiO_2	Al_2O_3	Fe_2O_3	MgO	MnO	CaO	BaO	TiO_2	Na_2O	K_2O	Cl
	1	76.52	12.91	1.10	0.02	0.05	0.54	0.01	0.07	4.12	4.58	0.08
	2	76.51	12.91	1.16	0.03	0.05	0.54	0.01	0.07	4.03	4.63	0.07
	3	76.53	13.09	1.17	0.03	0.03	0.53	0.00	0.06	3.96	4.60	ND

b	Sample	K	Ca	Ti	Mn	Fe	Cu	Zn	Rb	Sr	Y	Zr	Nb
	1	1028	280	64	180	886	50	148	2243	320	980	1957	780
	2a	1016	271	69	185	896	53	155	2265	329	964	1906	795
	2b	1018	269	62	185	880	48	146	2169	338	974	1944	772
	3	1019	276	61	181	885	49	144	2197	310	967	1991	775

1. Tephra layer from Panum Crater, overlying organic sediments ^{14}C dated about 820 yrs. b.p. (S. Stine, oral commun., 1982).

2, 3 Tephra layer from two different locations in Yosemite Valley; Samples 2a and 2b are replicate analyses of the same sample.

Table 2. Electron microprobe analysis of glass of tephra layer Mp, erupted from Mount St. Helens (1), and correlative ash layer at Summer Lake, Ore. (2), and the Lahontan basin, western Nevada (3). Samples (2) and (3) are from Jonathan Davis, Desert Research Institute, University of Nevada, Reno. C. E. Meyer, analyst.

Sample	SiO_2	Al_2O_3	Fe_2O_3	MgO	MnO	CaO	BaO	TiO_2	Na_2O	K_2O	Cl
1	76.48	13.60	1.24	0.30	0.05	1.51	0.06	0.17	4.12	2.39	0.10
2	76.30	13.90	1.23	0.26	0.03	1.39	0.06	0.21	4.20	2.30	0.10
3	76.20	13.90	1.21	0.29	0.01	1.49	0.04	0.18	4.20	2.40	0.13

Table 3. Electron-microprobe analysis of the Loleta ash bed in the Hookton Fm. of the Humboldt basin, northwestern California (1-3), and in DSDP core 36 (4, 5), about 500 km west of Cape Mendocino in the northeastern Pacific Ocean. C. E. Meyer, analyst.

Sample	SiO_2	Al_2O_3	Fe_2O_3	MgO	MnO	CaO	BaO	TiO_2	Na_2O	K_2O	Cl
1	74.45	13.88	2.00	0.11	0.06	0.73	0.09	0.17	5.16	3.20	0.15
2	74.49	13.81	1.99	0.10	0.06	0.74	0.08	0.17	5.26	3.13	0.17
3	74.32	13.81	2.02	0.12	0.03	0.78	0.09	0.14	5.33	3.17	0.18
4	73.97	14.02	2.06	0.12	0.06	0.73	0.07	0.14	5.40	3.26	0.17
5	74.11	14.01	1.98	0.12	0.05	0.74	0.10	0.14	5.42	3.14	0.19

Detailed Geologic Studies, Central San Andreas Fault Zone

9910-01294

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Investigations

Detailed geologic field investigations of structure, and surficial and bedrock deposits were conducted in and adjacent to the central section of the San Andreas fault zone (San Juan Bautista to Wallace Creek, Carrizo Plain) to determine horizontal and vertical slip rates and the detailed tectonic environment of the zone.

Results

1. Alluvial fill (?) terraces were mapped along Cholame Creek and Little Cholame Creek in the Parkfield area. At least four and possibly five terraces were mapped in and adjacent to the San Andreas fault zone (SAFZ). No dateable material has yet been retrieved from any of the terrace deposits. None of the terraces are demonstrably offset by the San Andreas primarily because deformation in the SAFZ yields large pressure ridges and shutter ridges. The two youngest terraces are cut by the SAF where it crosses Little Cholame Creek at Parkfield. However, erosion of the banks of Little Cholame Creek has destroyed any record of offset of the terraces. Fluvial deposits in the upstream reaches of Little Cholame Creek may yield information on recurrence intervals, and the elevated terraces of both Cholame and Little Cholame creeks may yield vertical uplift rates for the Parkfield area.

2. Studies of the terraces along the San Benito River continue to be of primary interest in the northern area of study. The San Benito River is situated between the Calaveras-Paicines fault and the San Andreas fault; thus, tectonic movement generated by these crustal discontinuities may be manifested in the terraces flanking the river. Unraveling the complex history of these terraces may result in a fuller understanding of the lateral and vertical tectonics of the region. Photogeologic mapping of all seven terraces flanking the San Benito River between Swanson Bluff and the town of San Benito is complete. Preparation for trenching the terraces at Melendy Ranch are underway. The results of which may yield multiple late Holocene slip rates for this section of the San Andreas fault.

3. Geologic mapping by M. J. Rymer of the San Andreas fault zone in the Mustang Ridge area (reported in earlier Semi-Annual Technical Reports) pointed out local variation in orientation of active fault traces in the Monarch Peak quadrangle relative to the fault both to the southeast and northwest. In a follow-up investigation Rymer constructed rose diagrams

of active fault-strand orientations at 5^{0} intervals to check and quantify the earlier observations. Plots of fault orientation for about a 60 km length of the fault zone were subdivided at major steps on the main trace. Plots of both main trace plus subsidiary faults and only main trace confirm that the fault within Monarch Peak quadrangle has anomalous orientations, interpreted as a response to a local change in trend of the fault and to a large right stepover of the main trace. Of the six major fault segments that were studied, the mean variation in orientation for 90% of the active fault traces is about 20^{0}; for the segment in the Monarch Peak quadrangle the variation is about 40^{0} for 90% of the active fault traces. When subsidiary faults are included in the plots the Monarch Peak segment has a variability of about 60^{0}, further suggesting that this part of the fault is a transitional area between segments to the southeast and northwest.

Reports

Rymer, M. J., Lisowski, Michael, and Burford, R. O., in press, Structural explanation for low creep rates on the San Andreas fault near Monarch Peak, central California: Bulletin Seismological Society of America.

Sims, J. D., Rymer, M. J., and Perkins, J. A., 1983, Late Quaternary stratigraphy and paleolimnology of Clear Lake, California: Geological Society of America Abstracts with Programs, v. 15, p. 27.

Heusser, L. E., and Sims, J. D., 1983, Pollen counts for core CL-80-1 Clear Lake, Lake County, California; U.S. Geological Survey Open-File Report 83-384, 20 p.

Robinson, S. W., Adam, D. P., and Sims, J. D., 1983, Radiocarbon content, sedimentation rates, and a time scale for Clear Lake, California core CL-734: Geological Society of America Abstracts with Programs, v. 15, p. 279.

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Perkins, A. J., 1983, Provenance of the Etchegoin Formation: Implications for paleogeography of the southern Diablo Range: Society of Economic Paleontologists and Mineralogists, Pacific Section, Program and Abstracts, 58th Annual Meeting, May 18-21, 1983, p. 122-123.

Seismic Studies in Eastern US

9950-03545

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Investigations undertaken

This project is concerned with investigation of crustal wave velocity and physical properties of crustal rocks in seismogenic zones. Work in the first half of FY 1983 was devoted to completing analysis of acoustic wave velocities measured in the laboratory in a suite of graywackes from the Franciscan assemblage of Northern and Central California The purpose of the measurements was to determine the effect of water saturation on wave velocity in Franciscan rocks, with the goal of assessing the fluid pressure in the Franciscan assemblage near the San Andreas fault.

Results

Measurements of shear and compressional wave velocity in nine samples were analyzed. (Dry and saturated samples were used, with independently variable fluid and confining pressure.) The ratio of compressional to shear wave velocity in dry rock at 2 kb confining pressure ranged from 1.62 to 1.81. The average ratio for seven samples of higher-grade rocks present near creeping portions of the San Andreas fault was 1.72. The remaining two samples, relatively immature zeolite facies sandstones from the coastal belt of the Franciscan, had velocity ratios of 1.77 and 1.79. Observed values of the ratio of compressional to shear wave velocity in the Franciscan terrane in Central California are typically near 1.8. In order to achieve a ratio of this order in the laboratory samples from Central California, fluid pressures approaching confining pressure are required.

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

14-08-0001-20618

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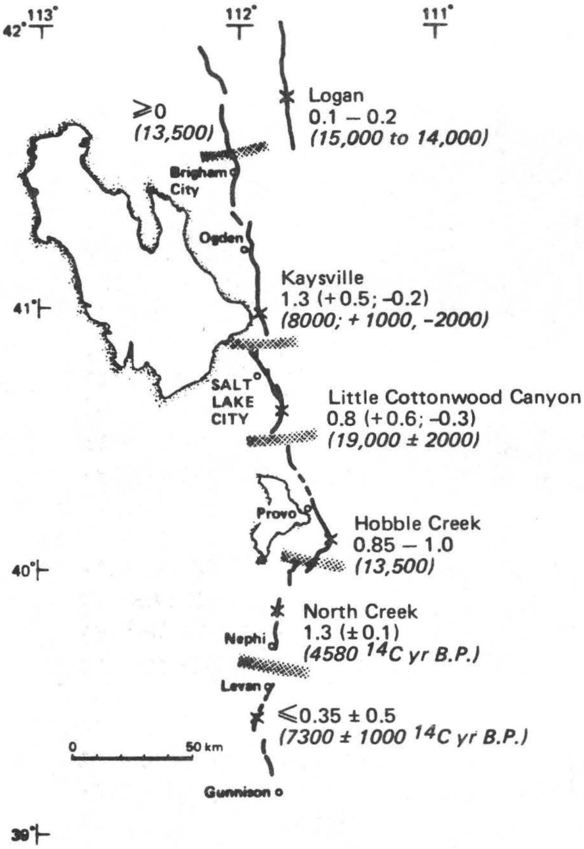
Detailed geologic investigations including trenching, at the Kaysville, Little Cottonwood, Hobble Creek and North Creek sites along the Wasatch fault zone and at Logan Canyon along the East Cache fault (Figure 1) have yielded information on slip rate, recurrence intervals for past surface faulting earthquakes, displacement per event for past earthquakes, and fault segmentation. These data provide a basis for evaluating the late Pleistocene - Holocene behavior of the Wasatch fault zone and for assessing the recurrence of moderate to large magnitude earthquakes on the 370-kilometer long fault zone.

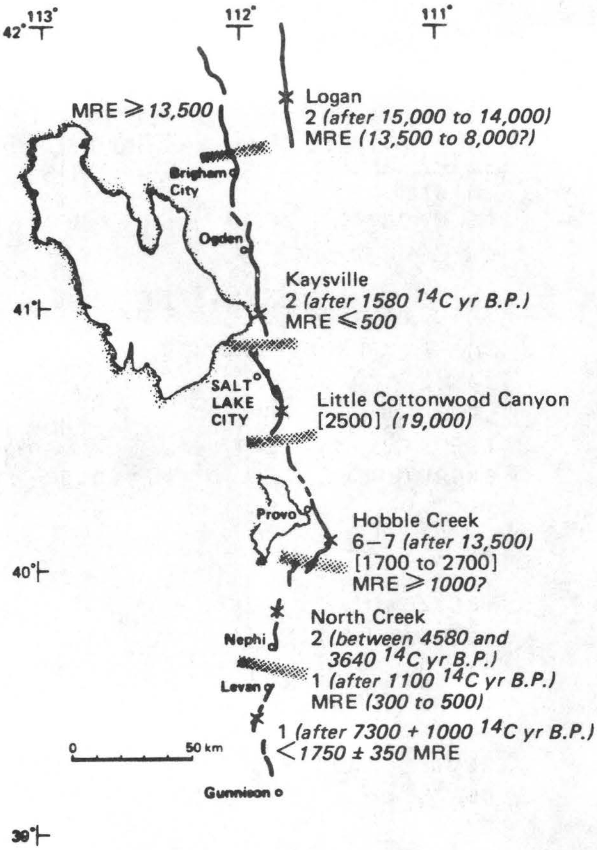
Slip Rate

Slip rate data for the Wasatch fault zone are summarized on Figure 1a. The rates, which range from near 0 to 1.3 mm/yr, were developed from topographic profiling of displaced surfaces that grade to the Provo shoreline, glacial moraines, alluvial fans, and stream terraces. They represent cumulative vertical tectonic displacement that has been corrected for the distortion (backtilting and graben formation) that increases scarp height at most places along the fault. The rates at the Kaysville and Hobble Creek sites differ slightly from previously published values (Swan and others, 1980) because of recent revisions in the ages of the displaced datums (Scott and others, 1982).

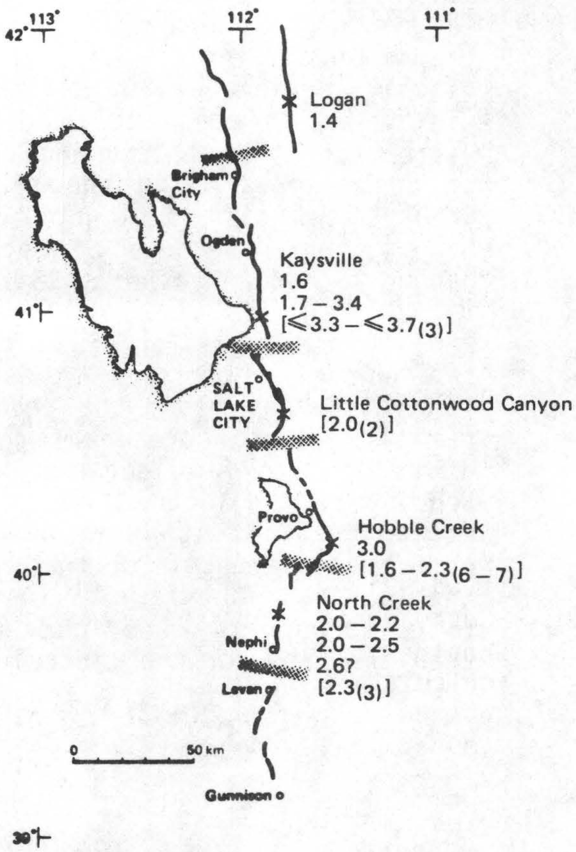
Rates based on different-aged datums may not be exactly comparable. Also, care must be exercised in extrapolating rates calculated at a point for long distances along the trace of the fault. Considering these factors, the slip rates represent a generally constant rate of strain accumulation of about 1 mm/yr along the Wasatch fault zone between Brigham City and Nephi during Holocene time. However, the incremental strain rate at specific locations is variable and the observed variations in slip rate may reflect differences in the timing of surface faulting earthquakes along the length of the fault. The rates of strain accummulation on the Wasatch fault zone north of Brigham City and south of Nephi are markedly slower than the rate for the central part of the zone.



A) Slip Rate



B) Recurrence



C) Displacement per Event

Figure 1. Summary of Fault Behavior Data for the Wasatch and East Cache Fault Zones (all data based on Hanson and others, 1981; Hanson and Schwartz, 1982; Schwartz and others, 1982; Swan and others, 1980, 1981, 1982).

A) Slip rate in mm/yr age of the displaced datum (yr B.P.) on which rate is based is shown in italics.

B) Large numerals represent the number of surface faulting earthquakes after the dates shown in italics; brackets contain average recurrence (yr) for the interval shown in italics; MRE is the elapsed time (yr) since the most recent surface faulting earthquake.

C) Measured displacement per event in meters; average displacement per event and number of events are shown in italics. Dashed lines represent proposed major segment boundaries

Displacement Per Event

Information on the amount of displacement per event for past surface faulting earthquakes is important for assessing the magnitude of past earthquakes and for developing models of earthquake recurrence. The use of colluvial wedges provides a basis for evaluating paleodisplacements. The thickness of the wedge adjacent to the fault provides a minimum value for the height of the fault scarp free face that was exposed during a surface faulting event. In some cases, such as the most recent event at the North Creek site, the thickness of the wedge approximates the total height of the free face produced during that event. Profiling of scarps that have experienced multiple events is also useful in obtaining data on displacement per event.

Displacement per event data (net vertical tectonic displacement) are summarized on Figure 1c. Investigations of historical surface ruptures on normal faults in the Basin and Range, such as the 1915 Pleasant Valley earthquake (Wallace, 1980), show systematic variation in displacement along the surface trace of the fault. For the Wasatch fault zone, we do not know where individual trench sites were located along past rupture segments; therefore, it is uncertain whether an individual measurement represents a minimum, an average, or a maximum displacement for that surface faulting event. Despite these uncertainties, the data clearly show that displacement per event has been consistently large. The measured values range from 1.4 to 3.4 m, and the average displacement per event generally exceeds 2 m. The data from the North Creek site indicate that displacements at the same location along the fault can be essentially the same during successive events.

The occurrence of successive large- and similar-displacement events along the Wasatch fault zone, coupled with the variability in timing between these events and the lack of evidence of small-displacement events, has led to the development of the characteristic earthquake recurrence model (Schwartz and others, 1981). This recurrence model suggests that: a) linear frequency-magnitude distributions over a full range of earthquake magnitudes may not be appropriate for individual faults or fault segments and moderate magnitude events smaller than the characteristic earthquake may be relatively less likely to occur than the larger event, b) the magnitude of the characteristic earthquake may approximate the maximum earthquake and, c) stress application appears to be non-uniform and faults may fail in response to localized, rapid increase in stress. Similar behavior appears to characterize other Basin and Range normal faults.

Recurrence Intervals on the Individual Fault Segments

Data on the recurrence of surface faulting earthquakes at specific locations along the Wasatch fault zone are shown on Figure 1b. At the Little Cottonwood Canyon and Hobble Creek sites the ages of individual events could not be determined and only average recurrence intervals could be calculated. At the North Creek site the interval between successive events was not uniform and varied from somewhat less than 1,000 years to longer than 3,000 years indicating that the actual interval between events can vary from the average recurrence by at least a factor of two.

Swan and others (1980), on the basis of rupture lengths of historical Basin and Range surface faulting earthquakes having M > 6-1/2 < 7-1/2, suggested that the Wasatch fault zone consists of 6 to 10 segments. Based on additional investigations, we presently believe there are at least six major segments (Figure 1). Selection of each segment is based to varying degrees on fault geometry, scarp morphology, slip rate, recurrence, and timing of the most recent event. From north to south, the proposed segments are as follows: 1) Collinston - Brigham City; 2) Brigham City - Bountiful; 3) North Salt Lake City - Corner Canyon; 4) Alpine - Spanish Fork; 5) Payson - Nephi; and 6) Levan - Fayette. The Collinston - Brigham City segment is about 30 km long. No post-Provo (13,500 yrs B.P.) surface faulting events have been identified along this segment. Along the subparallel East Cache fault to the east there has only been one post-Provo event. There have been two events post 1580 ^{14}C yr. B.P. along the 70 km-long Brigham City - Bountiful segment; the most recent event is estimated to have been less than about 500 years ago. The 35 km-long North Salt Lake - Corner Canyon segment has had an average recurrence of 2500 years. The 55 km-long Alpine - Spanish Fork segment has an average recurrence interval of 1700 to 2700 years and the most recent event is estimated to have been about 1000 years ago. The 35 km-long Payson - Nephi segment had two events between 4580 and 3640 ^{14}C yr. B.P. and the most recent event is estimated to have occurred within the past 300 to 500 years. The 40 km-long Levan - Fayette segment has had only 1 event post 7300 ^{14}C yr. B.P.; this event occurred less than 1750 ^{14}C years ago.

The proposed segment boundaries are not sharply defined and may represent structurally complex transition zones several kilometers wide. It is uncertain to what degree changes in fault geometry, by themselves, can be used as a basis for segmenting the fault zone. While it appears that some geometric changes and older structural trends observed at the surface have expression at seismogenic depths and may act as real boundaries or barriers to rupture, rupture propagation may bypass or take near-surface en echelon jumps across others.

Estimated Recurrence on the Zone

Swan and others (1980) estimated that the recurrence interval for the entire zone was 50 to 430 yr for moderate to large magnitude (M_S 6-1/2 to 7-1/2) surface faulting earthquakes. Based on these new data, the average recurrence interval on the zone appears to be closer to 350 to 400 years per event. The geologic data suggest that the most recent event occurred about 300 years ago.

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Pnysical Constraints on Source of Ground Motion

9910-01915

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Investigations

Digital recordings of small earthquakes are being analyzed to find the probability distribution function of stress drop, which then might be applied to strong ground motion prediction.

Results

Dynamic stress drops of 300 events recorded by USGS on a local network of digital event recorders during the May-June 1980 earthquake sequence at Mammoth Lakes, California are independent of corner frequency (and hence source radius) and are log-normally distributed.

Acceleration spectra from clear S-wave arrivals, while showing large individual variations in shape, are generally flat from the source corner frequency to a maximun frequency, fmax, dependent on the station but not on the event, above which the spectra decline steeply. For each event source parameters were found from a weighted mean spectrum formed from spectra from individual stations. Weighting factors depend on signal-to-noise ratio, distance, and acceleration bandwidth. Corner frequency is found from the ratio of the integral of the velocity spectrum to the integral of the displacement spectrum and is normalized to be the conventional value for a Brune spectrum. Dynamic stress drop, determined from the product of the corner frequency and the acceleration spectral level, equivalent to the stress drop determined from rms acceleration, is found to be uncorrelated with corner frequency. Dynamic stress drops of the 40 best-recorded events have a log-normal distribution centered at 56 bars with the standard deviation being a factor of 2.1. Smaller values of stress drop are more frequent for the entire data set, but the tail of the distribution at large stress is about the same. Corner frequencies range up to 10 Hz, but none are higher. This cutoff is probably a sampling effect rather than a source effect.

Reports

Andrews, D. J., 1983, Distribution of dynamic stress drop [abs.]: AGU Spring Meeting, May 30, 1983, Baltimore, Maryland.

National Strong Motion Data Center

9940-02085

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Investigations

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

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

2) Support research projects in the Branch of Engineering Seismology and Geology by providing programming and cumputer support for computation of numerical models;

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

Results

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

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

Hardware

A 254 MByte disk drive was transferred from the office VAX, bringing the total on-line public disk storage to 750 MBytes. Future acquisitions include improved field-based microcomputer systems, appropriate desk-top work stations (particularly for graphical presentation and manipulation of data), and possibly some special purpose processors, such as array processors.

Software

The operating systems were upgraded to RSX-11M-Plus V2.1 and RSX-11M V4.1. Future acquisitions may include data query languages and report writers, data base management systems for time series data, spread sheet calculators for administrative support, and software to support mixed vendor local area networks, such as Ethernet.

Data

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

Numerous events were recorded from the earthquake sequence of January 6, 1983 in the Mammoth Lakes area of California.

Reports

Fletcher, J. B., and Hanks, T. C., Baker, L. M., Berger, J., Vernon, F., and Brune, J., 1982, Source parameters and strong ground motion estimates from the Anza digital array [abs.]: Eighth World Conference on Earthquake Engineering, July 21-28, 1984, San Francisco, California.

Fletcher, J. B., Haar, L., Hanks, T. C., Baker, L. M., Vernon, F., Berger, J., and Brune, J., 1983, Earthquake source parameters from the Anza digital array [abs.]: AGU Spring Meeting, May 30, 1983, Baltimore, Maryland.

Office of Earthquakes, Volcanoes, and Engineering Analysis Center

9910-03430

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Investigations

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

Results

The OEVE VAX Analysis Center consists of a Digital Equipment Corporation VAX-11/780 minicomputer and associated peripherals running under the vendor supplied operating system, VMS. The facility serves a diverse user community from all the branches in the Office of Earthquakes, Volcanoes, and Engineering in Menlo Park. The disk and CPU resources are partitioned and distributed equitably among the various user groups such that any policy decisions that become necessary can usually be taken care of within the confines of a single group.

The configuration at the end of this report period includes:

VAX-11/780 CPU with 8 MBytes MOS memory
FP780 Floating Point Accelerator
130 MBytes of system disk storage
1000 MBytes of public disk storage
One 10 MByte removable cartridge disk drive
Two 512 KByte floppy disk drives
Two 800/1600/6250 bpi tape drives
One 600 lpm printer
One 11 inch electrostatic plotter
32 terminal ports
1 Mbit links to each of two colocated minicomputers

The software in use includes:

VAX/VMS operating system
NASA Share scheduler

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

Future acquisitions include software and hardware for improving communication between the various computer facilities located in Menlo Park.

Reports

None.

Global Accelerograph Program (GAP)

9910-02689

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Investigations

The objective of this program is to obtain critically needed records of damaging levels of ground motion close to the source of earthquakes of magnitude M 6.5 and greater.

During the first half of FY 83, the following activities were carried out:

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

(2) Field deployments of a General Earthquake Observation System (GEOS) were carried out near Mammoth Lakes, CA and Coalinga, CA.

Results

The prototype GAP agreement developed for the program identifies the following primary activity elements: (1) continued long-term strong-motion data and information exchange between the U. S. Geological Survey and the agency(ies) identified in the host country; 2) the rapid exchange (preferably as soon as possible--within 1-4 days following damaging events) of scientific teams to investigate engineering and scientific effects of large earthquakes in the U. S. and the host country; and 3) the rapid deployment of U. S. personnel and instruments to the host country after a large earthquake (M 7.5 and greater) has occurred to record large (M 6.5 and greater) aftershocks. In some cases, the installation and long-term operation of a permanent network of strong-motion instruments in the host country shall also be considered under the agreement.

(1) Follow-up responses were transmitted to the countries initially asked to participate in the program.

(2) Finalized GAP agreements have been signed by the U.S.G.S. for consideration by the appropriate agency(ies) in Italy and Turkey.

(3) Wide dynamic range, broad frequency band-width data sets were collected near Mammoth Lakes, CA and Coalinga, CA using the General Earthquake Observation System (GEOS). Extensive data sets ranging in event magnitude from those with signals above the seismic background noise to 3+ for Mammoth Lakes and to 5+ for Coalinga were obtained. Interpretation of the data sets is proceeding.

Reports

Borcherdt, R. D., 1982, Recent advances in the acquisition of strong-motion data [abs.]: Eighth World Conference on Earthquake Engineering, July 21-28, 1984, San Francisco, California.

Maxwell, G. L., Jensen, E. G., Borcherdt, R. D., Fletcher, J. P., McClearn, R., Van Schaack, J. R., and Warrick, R. E., 1983, Preliminary GEOS and field deployment results from Mammoth Lakes, CA [abs.]: Seismological Society of America Meeting, May 2-4, 1983, Salt Lake City, Utah.

Nonlinear Soil Response at Imperial Valley Recording Sites

9910-03390

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Investigations

(1). Continued to assess the shear strength profiles for stations 6 & 7 of the El Centro Strong Motion Array from additional laboratory data and new field data.

(2). Conducted response computations for stations 6 and 7 and analysed the results.

Results

(1). Computational results on the basis of shear strength profiles estimated from cone penetration records could not reach the peak acceleration values recorded in the field and therefore suggested that these strength estimates may be too conservative.

(2). Experimental results from laboratory triaxial tests on samples from station 6 and 7 showed that strength values from rapid consolidated-undrained tests could be 80% higher than those from standard consolidated-undrained tests for medium-stiff clayey silts and silty clays.

Reports

There were no reports this period.

"Hybrid Ray-Mode Method for Synthetic Seismology"

H6

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This report summarizes progress and accomplishments during the period March 11, 1982 to March 10, 1983.

As reported previously, the hybrid ray-mode method has been extended to study two-dimensional SH motion in a two-layer half space consisting of a homogeneous sediment above a homogeneous semi-infinite bedrock, with the source located in the sediment. This has required inclusion of a rich variety of ordinary ray arrivals (trapped and leaky), as well as refraction arrivals (lateral rays) excited by the critically incident ordinary ray. The collective treatment of multiply reflected arrivals leads to stronger excitation of trapped modes and leaky modes than when the source is located in the bedrock, as investigated previously. The results of the analysis were summarized in the last Summary Report. During the present period, a manuscript has been prepared, submitted and published.[1]

Also, as noted in the previous report, the hybrid analysis has been generalized to accommodate SH motion in a vertically inhomogeneous sediment. Emphasis has been placed on correcting asymptotic ray theory (ART) in transition regions near the critically reflected ray, the glancing ray, and caustics of the surface reflected rays (Fig. 1). Major effort has been expended on numerical studies for two model profiles (Fig. 2) to assess the feasibility of replacing non-legitimate transitional ray fields by a group of modes plus remainders. The first profile models data for the sediment in the Imperial Valley[2] but it involves wave functions for which numerical implementation poses difficulties. The second profile does not model the data equally well but it has more easily computable wave functions. To obtain quantitative information about the ray-mode equivalence, we have therefore concentrated the numerical effort on the second profile.

Preliminary mumerical results, as well as the detailed analysis, have been presented in a paper published in the Proceedings of the 16th Workshop on the Dynamic Characteristics of Faulting Inferred from Recordings of Strong Ground Motion.[3]

These preliminary numerical results have been extended and are now being examined critically to provide options that can be built into a computer program based on ART. Our goal is to complete these studies during the remainder of the contract period so as to furnish workable recommendations for dealing with the failures of ART numerical codes in this model environment.

References

1. Kamel, A. and L. B. Felsen, "Hybrid Green's Function for SH Motion in a Low Velocity Layer," Wave Motion 5, p. 83-97 (1983).

2. McMechan, G. A. and W. D. Mooney, "Asymptotic Ray Theory and Synthetic Seismograms for Laterally Varying Structures: Theory and Application to the Imperial Valley, California," Bull. Seismol. Soc. Am. 70, 2021-2035 (1980).

3. Niver, E., A. H. Kamel and L. B. Felsen, "SH Rays and Modes in a Two-Layer Earth Model with Application to the Imperial Valley," Proceedings of the 16th Workshop on the Dynamic Characteristics of Faulting Inferred from Recordings of Strong Ground Motion," USGS Report 82-591.

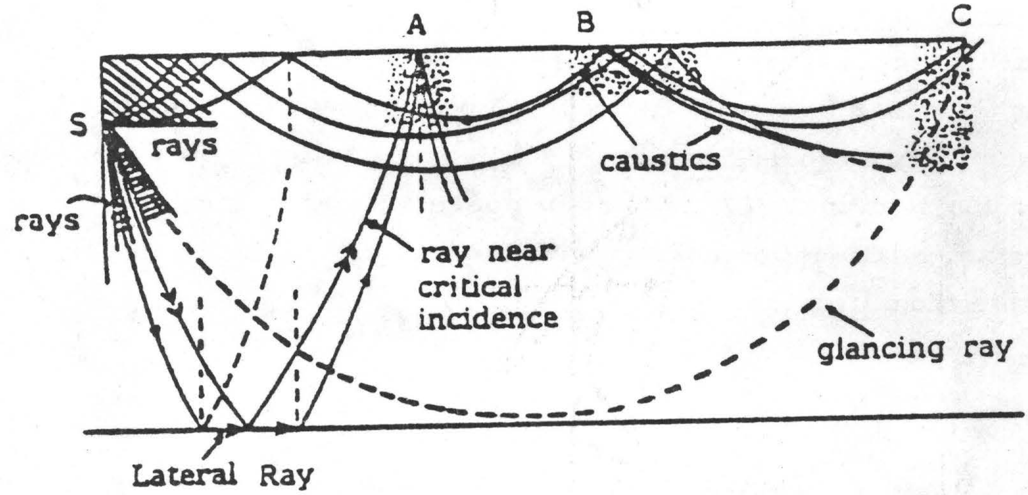

Fig. 1. Hybrid combinations that avoid corrections of the simple asymptotic ray field in transition regions A, B, and C on the surface. The corresponding angular intervals (shown shaded) are filled with modes.

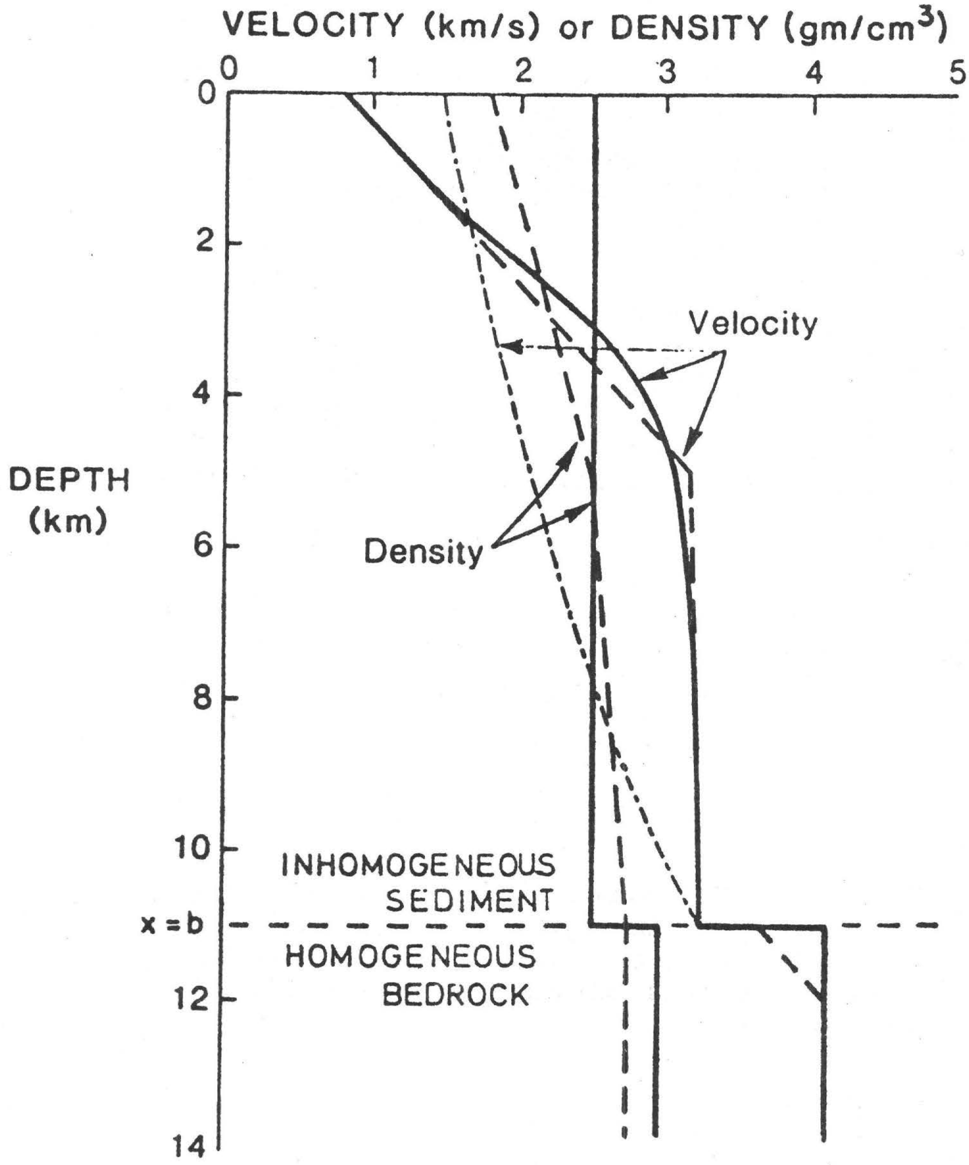

Fig. 2. SH velocity and density profiles for imperial Valley terrain. Dashed curves: data from reference 2. Solid curves: proposed model with $n(x) = [p+q\exp(-2x/a)]^{1/2}$ (profile 1). Dot-dashed curve: simplified model with $n(x) = \exp(-x/a)$ (profile 2).

Strong Ground Motion Data Analysis

9910-02676

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Investigations

The following were topics of investigation during the first half of 1983:

1) Analysis of the ground motion parameter $R\underline{v}$ when R is hypocentral distance and $\underline{v}$ is peak velocity.
2) Determine the role of the state-of-stress in the scaling of strong ground motion.
3) Calculate source parameters for the San Jacinto fault near Anza.
4) Correlation of peak to rms of acceleration.

Results

1. (McGarr) The analysis of how the ground motion parameter $R\underline{v}$, where R is hypocentral distance from the earthquake to the recording site and $\underline{v}$ is peak velocity, scales with seismic moment M_o revealed, unexpectedly, that this parameter is also a strong function of the state of stress and hypocentral depth. The term "state of stress" as used here simply refers to the value of the vertically oriented principal stress Sv relative to those of the two horizontal principal stresses S_{Hmin} and S_{Hmax}. For normal faulting or extensional tectonics, for example, $Sv > S_{Hmax} > S_{Hmin}$. The essential conclusions of this analysis are as follows:

1) For events at similar depths and in similar states of stress, $R\underline{v} \propto M_o^{1/3}$. This, of course, is the expected scaling.
2) For a given state of stress, $R\underline{v} \propto$ focal depth.
3) At fixed depth, $R\underline{v}$ (normal) < $R\underline{v}$ (strike-slip) < $R\underline{v}$ (thrust). Provisionally, it appears that

$$\frac{R\underline{v}\text{ (strike-slip)}}{R\underline{v}\text{ (normal)}} \approx 2.$$

The contrast between $R\underline{v}$ (normal and $R\underline{v}$ (thrust) is even greater.

2. (McGarr) In an article published last December (McGarr, 1982) I presented an argument to the effect that there exist absolute upper bounds for peak acceleration $\underline{a}$, as recorded at the surface directly above the earthquake hypocenter. These bounds depend on the state of stress, as defined above. For normal faulting, $\underline{a}$ < 0.4 g and for thrust, $\underline{a}$ < 2.1 g.

An implication of this conjecture, which is consistent with observations, is that the highest localized stress drop $\Delta\tau_i$ within an earthquake source region depends both on focal depth and state of stress, but is independent of seismic moment. For normal faulting, $\Delta\tau_i$ 67 (bars/km) Z, where Z is depth, and for thrust faults, $\Delta\tau_i$ < 334 (bars/km) Z. The corresponding bound for strike slip faulting can fall anywhere between these other two limits. A considerable body of data for $\Delta\tau_i$ (normal) which can be determined either from the peak acceleration or the peak velocity, is very consistent with the above bounds. We observe that $\Delta\tau_i$ (thrust) >> $\Delta\tau_i$ (normal) at a given focal depth. Because $\Delta\tau_i$ is directly proportional to peak acceleration, this finding implies that peak acceleration is highly dependent on the state of stress.

In general, these findings demonstrate the hitherto unappreciated importance of the state of stress on peak ground motion. Tentatively, it appears that ground motion in a compressional tectonic regime may be as much as a factor of 5 greater than for an extensional regime. Certainly, these are first order affects that should be taken into account in attempting to predict ground motion at a given site.

3. Anza (Fletcher)

We have installed an array of three component seismographs along a 30 km section of the San Jacinto fault near the town of Anza. Thatcher and Hanks (1973) interpreted this section of the San Jacinto fault to be a gap in the occurrence of $M \sim 6$ to 7 earthquakes from the distribution of large shocks since the late 1800's. The southern half of this slip gap is presently active at the $M \sim 4.5$ to 5.5 level. Our array extends from north of the slip gap, south through the presently active portion to just north of the rupture zone of the Borrego Mountain earthquake. The array was established to provide a catalog of earthquake source parameters that could be used to study the scaling of ground motion and earthquake interaction.

Each station in the array consists of a three component set of 2 hz geophones matched to a 16 bit analog-to-digital converter by a pre-amplifier. The analog data are digitized at a rate of 250 samples/sec/component. Digital words are sent by VHF telemetry to a low peak where the data from all stations are collected and retransmitted to IGPP in San Diego through a PDP 11/34 computer which stores files of earthquakes.

Since October of 1982 the array has been operational with 7 stations and we have now located over 100 events and calculated source parameters for about 1/3 of those. The seismicity is clustered in three zones. The southern zone is at the intersection of three fault segments (the Buck Ridge, San Jacinto, and Coyote Lake faults) and is the location of several M 4 to 5.5 earthquakes in the past 10 years. A middle zone is defined by an east-west trend in seismicity that intersects the San Jacinto fault near the middle of the seismic gap from the west. It does not extend to the east much beyond the San Jacinto fault. A northern cluster of activity near the southern terminus of the Hot Springs fault probably marks the northern extend of the Anza gap. The activity extends down to 18 km along the San Jacinto fault, but shallower along the east-west trend away from the fault to the west. Moments range from 10^{18} to 10^{21} dyne-cm and stress drops (Brune) from a few bars to nearly 200 bars. The largest stress drop occurred in the southern zone, but all three zones have had at least one high stress drop event. Stress drops computed from rms of accelerations (Hanks and McGuire 1981) are more constant at around 100 bars, but larger stress drops of around 60 bars have also been recorded in the zone.

4. Envelopes for Acceleration Waveforms (Boatwright):

The correlation between measurements of peak and rms acceleration has been recently examined using the statistical distribution of the maxima of a finite duration, band-limted, random function. Analysis of accelerograms written by specific earthquakes, however, indicates that the distributions of the ratio of the peak to the rms acceleration are 35% narrower than predicted by the statistical theory. This result suggests that the envelopes of the accelerations radiated by a specific earthquake are correlated from station to station. To test this hypothesis, we analyzed the envelopes of the acceleration waveforms written by three aftershocks of the 1975 Oroville, California, earthquake using the envelope function:

$$a^*(t) = (a^2(t) + H^2[a(t)])^{1/2},$$

where H[a(t)] is the Hilbert transform of a(t). Our analysis indicates that the envelopes of the total horizontal acceleration (obtained by combining the envelopes of the two horizontal components) are strongly correlated for those stations not contaminated by site effects.

Simple models for these envelopes are determined from Boatwright (1982) and the assumption that the rupture is perfectly incoherent. Under these assumptions, the height of the envelope is determined by the integral of the square of the dynamic stress drop along the rupture front, modified by the usual directivity function. The accuracy of this prediction, however, appears to degrade as the complexity of the rupture increases.

Reports

Hanks, T. C., and McGuire, R., 1981, The character of high-frequency strong ground motion: Bulletin, Seismological Society of America, v. 71, p. 2071-2095.

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McGarr, A., 1983, Estimating ground motions for small nearby earthquakes: Proceedings of Symposium on "Seismicity and Seismic Design for Earth and Rock Structures", American Society of Civil Engineering, Philadelphia, 17 May 1983, in press.

Theoretical and Empirical Studies of Strong Ground Motion

Contract No. 14-08-0001-20559

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INVESTIGATIONS

The principal objective of this work is to use a hybrid strong ground motion technique with Eastern U.S. (EUS) earth structures in order to extend the observational database to conditions present in the EUS. Response spectral scaling curves are developed to quantify the effects of rupture depth, fault type, local soil conditions and epicentral distance on the response spectra for simulated EUS earthquakes with magnitudes ranging between 4.5 and 6.5. The simulations are carried out for four velocity/attenuation models representing a range of EUS sites from hard rock to very soft soil.

RESULTS

The paucity of strong ground motion data in the EUS, combined with well recognized differences between Eastern and Western U.S. attenuation, suggest that simulation studies will play a key role in assessing earthquake hazard in the EUS. Using a hybrid methodology (wave propagation is modeled with an efficient frequency-wavenumber integration algorithm; the source time function for each grid element is empirical, simply scaled from near-field accelerograms), we have simulated over 5000 components of motion representing a parameter study for magnitude, distance, source orientation and source depth. These simulations were performed using a generic EUS crustal model with four different near-surface site conditions ranging from very hard rock (V_β = 3.3 km/s) to soft soil (V_β = 0.2 km/s).

Pseudo-velocity response spectra have been calculated at periods between 0.03 - 10 sec for two percent critical damping for all of the acceleration time histories simulated in this study. For a given depth, fault type, earth structure and site distance, the response spectral values from ten horizontal components and five vertical components of motion, resulting from five distinct rupture configuation simulations, are individually averaged at each period to produce horizontal and vertical response spectra unbiased by rupture direction or receiver azimuth, parameters that will seldom be known in advance.

To facilitate using the results of this study for scaling response spectra for distance, all response spectra are presented in a normalized format. The normalized shapes are calculated by adjusting all response to a common zero period acceleration (ZPA) and then by dividing each adjusted spectra by the corresponding spectra calculated for the distance of 5 km. The presentation format emphasizes how the shape of the spectra changes with distance. Accompanying the spectral shape figures are plots of the behavior of ZPA. For each plot, the response spectral ratios are shown using individual broken line types for the six different site distances considered.

Figures 1 and 2 show the computed changes in spectral shape with distance for a shallow magnitude 5.5 earthquake for strike-slip faulting for the soft and average soil models, respectively. Rupture depth is from 0 to 5 km. The left plot is for the horizontal component, the right plot is the corresponding vertical component. Figure 1 shows a pronounced increase with distance, relative to the zero period, in the long period portion of the response spectra. This reflects the observation that shallow sources rupturing in a soft surface layer efficiently excite surface waves. Because of the high attenuation in the soft soil model, the high frequency surface waves are quickly attenuated and the response is not greatly altered by distance for periods less than about 1 sec. This example represents a case where impedance amplification and the development of surface waves is nearly counterbalanced by attenuation. Figure 2 shows the comparable results for the average soil model. For this case the effects of attenuation do not balance other wave propagation effects; the response for period larger than 0.2 - 0.3 sec grows dramatically with distance. The averaged ZPA values resulting from the simulated shallow magnitude 5.5 earthquake for strike-slip and dip-slip faulting, for all four soil profiles and for the six distances studied are presented in Figure 3. This study shows that ZPA, for soft soils and shallow rupture, is expected to exceed the response for stiff soils to rock sites at distances of less than about 15 km. This trend reverses at larger distances.

For the case of a deeper rupture (10 - 15 km), the ZPA for the soft soil site exceeds the stiff and hard rock sites at all distances studied. In the shallow rupture case for the soft-soil model a large percentage of the seismic energy propagates horizontally through a high attenuation media. Hence, at some distance the effects of impedance amplification are suppressed through attenuation. For the deep source, most energy traverses a deep, very high Q path and impedance amplification dominates the results for all distances simulated. Nonetheless, the ZPA ratio of rock decreases with distance.

In summary, the shape of the response spectrum is dependent upon all parameters studied; the combined effect of all parameters predicts a dispersion of response spectral values that is consistent with observations. Characterizations that focus on only one parameter, eg. soil versus rock, may be overly simplistic and should be used with caution.

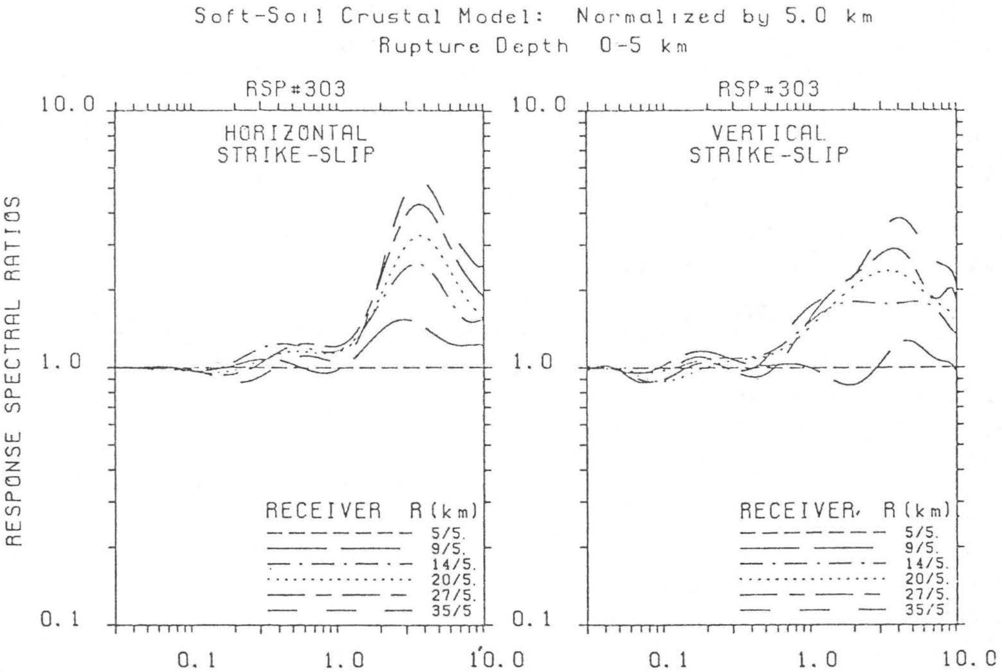

Figure 1. Variation of response spectra shape with distance for strike-slip faulting, soft-soil model. The normalized shapes are calculated by adjusting all response to a common zero period acceleration and then by dividing each adjusted spectra by the spectra calculated for the distance of 5 km. Each broken line type corresponds to the response at a particular distance (range 5-35 km).

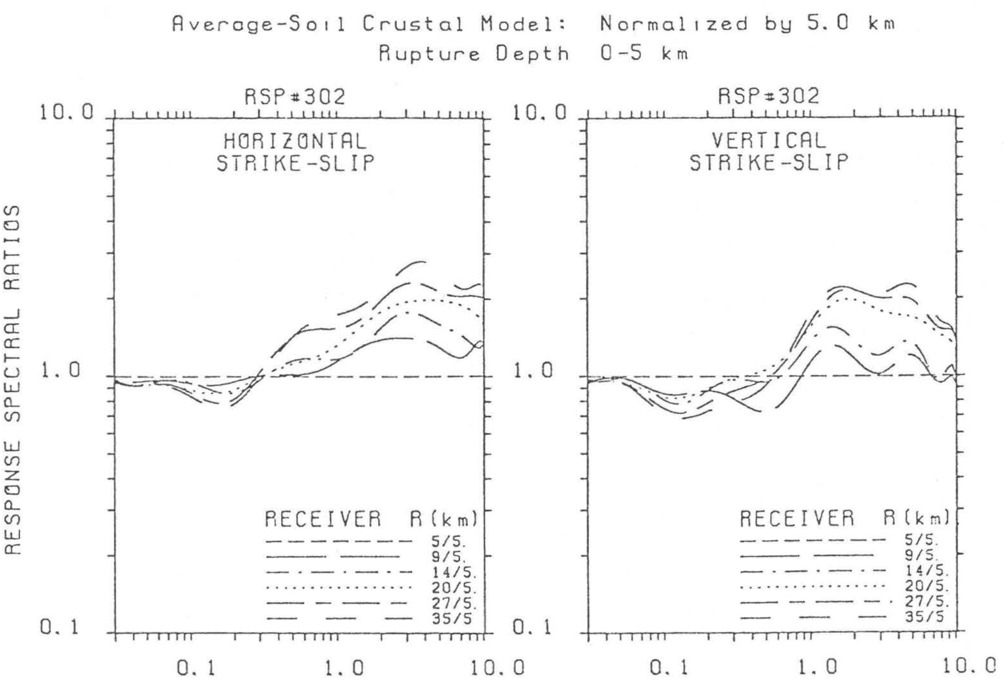

Figure 2. Variation of response spectra shape with distance for strike-slip faulting, average soil model.

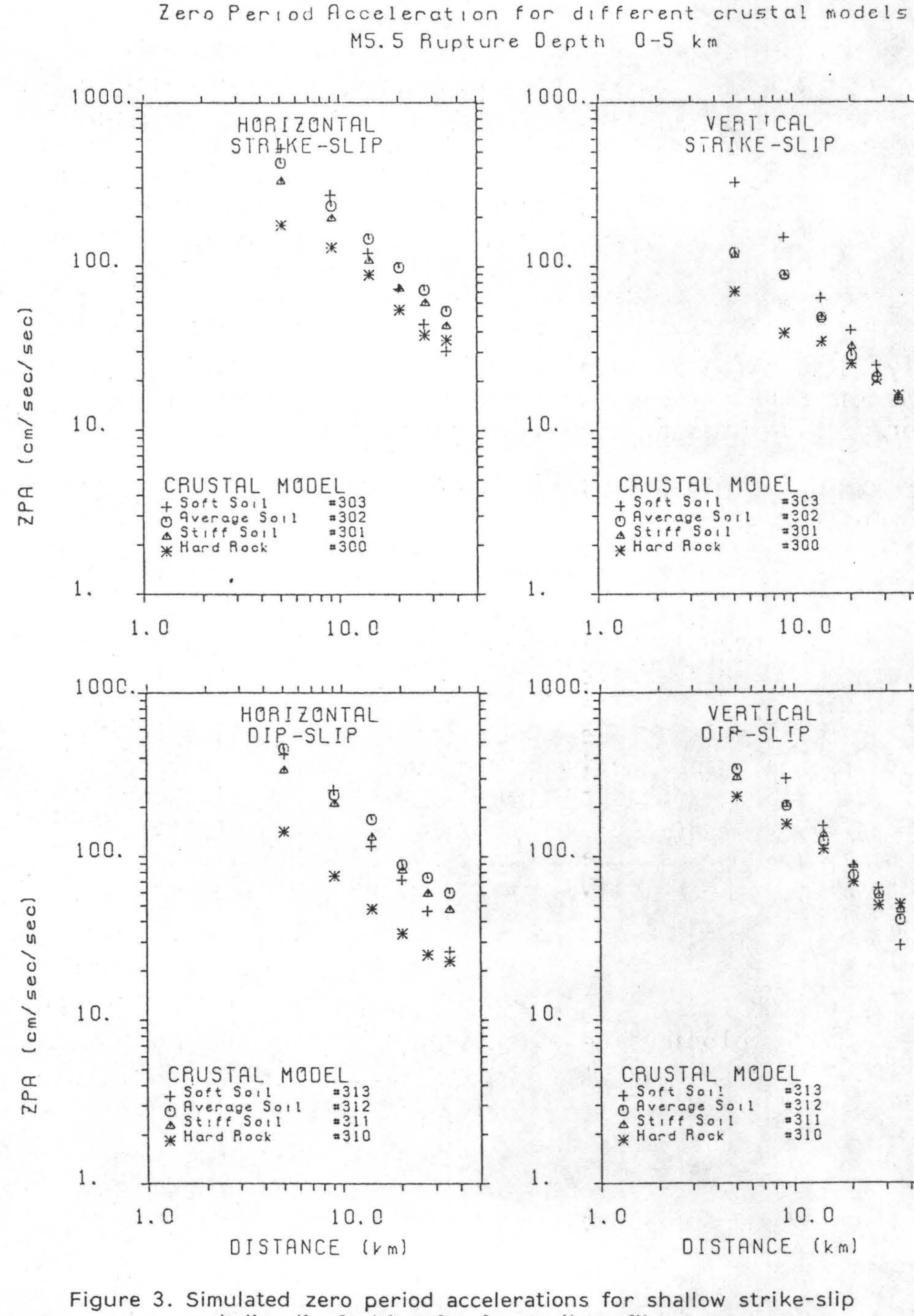

Figure 3. Simulated zero period accelerations for shallow strike-slip and dip-slip faulting for four soil profiles.

Estimating Strong Ground Motion for Engineering Design and Seismic Zonation

9910-01168

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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

1. We have developed a simple method for making predictive maps of earthquake ground motion and have applied it to a test area in the Los Angeles region. The predicted quantity may be peak horizontal acceleration, velocity, or a response spectral value. The method incorporates (1) predictive equations for earthquake ground motion derived from analyses of strong motion data, (2) an improved method for expressing the effect of local site conditions in terms of estimated average shear wave velocity to the depth of one-quarter wave length for the period of interest, and (3) a method for characterizing the earthquake potential of faults primarily in terms of geologically determined slip rates.

Reports

Joyner, W. B., and Fumal, T. E., 1982, Use of measured shear-wave velocity for predicting geologic site effects on strong ground motion [abs.]: Eighth World Conference on Earthquake Engineering, July 21-28, 1984, San Francisco, California.

Joyner, W. B., and Boore, D. M., 1983, Comments on "New attenuation relations for peak and expected accelerations of strong ground motion" by B. A. Bolt and N. A. Abrahamson: Bulletin, Seismological Society of America.

Joyner, W. B., and Boore, D. M., 1983, Sensitivity of probabilistic estimates of near-fault ground motion to parameters of the frequency-magnitude relationship [abs.]: Seismological Society of America Meeting, May 2-4, 1983, Salt Lake City, Utah.

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

14-08-0001-20524

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Investigations

Geologic data consisting of isopach maps of sedimentary structure in the Seattle area were used to construct models for the Duwamish River Valley of central Seattle. A three-dimensional ray tracing scheme was used to examine strong motion amplification above the river valley structure. This was done in an effort to explain the relatively severe shaking effects observed there during the 1965 Puget Sound earthquake.

Results

The following is the abstract of a paper in preparation entitled "Effect of structure geometry on strong ground motions: The Duwamish River Valley, Seattle, Washington" by C. A. Langston and J. J. Lee.

A three-dimensional ray tracing algorithm is used to compute the high frequency response of an SH plane wave incident under several models of the sediment filled Duwamish River Valley of central Seattle. Models are based on valley geometry previously determined using borehole logs. The SH wave response is considered in an effort to stimulate the S wave radiation from the 1965 magnitude 6.5 Puget Sound earthquake. Although the structure models considered are two dimensional, three dimensional ray tracing is needed to treat incident SH waves of various incidence angles and azimuths of approach appropriate for the USCGS and ISC hypocenters of the 1965 event. Generally, amplification of the direct SH wave due to the curved basin geometry is comparable to an equivalent elastic layer over a halfspace model. However, for points near the center of the valley multiple S rays become focused after undergoing several reflections from the curved lower boundary of the valley fill. This produces an order of magnitude increase in effective amplification. A detailed study of these rays shows that significant amplitudes occur over narrow distance ranges (~ 200m) at the surface and that they are

sensitive to moderate changes in incident wave direction. Focusing effects of this type were probably an important factor in damage caused by the 1965 earthquake, especially over the thicker portions of the Duwamish River Valley. Effects of "randomly" focused rays also give an explanation for the apparently capricious nature of strong ground shaking in the Puget Sound area.

Reports

Lee, J. J. and C. A. Langston (1983). Wave propagation in a three-dimensional circular basin, submitted to Bull. Seis. Soc. Am.

Post-Earthquake Shaking Effects and Fault Creep

9910-03027

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Investigations

1. Although the areas of liquefaction-type ground failure in downtown San Francisco were destroyed by the post-earthquake fire in 1906 before any regular investigations were made, the amount of earthquake-only damage can be investigated from pre-fire descriptions that occur in letters, diaries, local and distant newspapers, and other sources.

Results

1. Damage descriptions have been found for 21 brick buildings in the mapped 1906 ground failure areas in downtown San Francisco. Of the 21 described brick buildings, only one suffered internal collapse, 15 buildings had outward fall of bricks from walls, and 8 brick buildings had only cracks or no damage. This is significantly less damage than occurred to brick buildings in the nearby areas of ordinary ground, which suggests that the occurrence of liquefaction ground failure may reduce the strength of the shaking in strong earthquakes, opposite to the interpretations of current seismic intensity scales and risk maps.

Reports

Nason, R., 1982, Store disturbance as a reliable indicator of seismic intensity: Bulletin, Seismological Society of America.

Nason, R., 1982, Brick building damage in ground-failure areas in the 1906 San Francisco earthquake [abs.]: Eighth World Conference on Earthquake Engineering, July 21-28, 1984, San Francisco, California.

Strong Ground Motion Prediction in Realistic Earth Structures

9910-03010

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Investigations

1. Array analysis of the ground velocities and accelerations from the April 1971 San Fernando earthquake to determine the effects of propagation path irregularities on waveforms and amplitudes.

2. A comparison of strong ground motions recorded in Japan and the western United States.

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

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

5. Use of the Gaussian beam method to calculate theoretical body wave seismograms for aftershocks of the 1979 Coyote Lake earthquake.

Results

1. Array analysis of ground motions from the 1971 San Fernando earthquake: Profiles of ground velocity and acceleration, displayed as a function of epicentral distance, are investigated. Three long profiles (> 50 km) along different azimuths, and three short profiles (< 2 km) are studied. Ground velocities observed along the long profiles show a striking correlation with geologic structure which is principally characterized by the geometry of large-scale sedimentary basins. High peak amplitudes and long signal durations appear to be caused by surface waves trapped within the San Fernando and Los Angeles basins. Ground velocities from stations located on basement rock have relatively smaller amplitudes and durations and appear to be composed primarily of direct S-body-waves. Ground acceleration, however, is relatively unaffected by the existence of sedimentary basins and the duration of large accelerations is similar to the estimated source duration.

The three short profiles, which are all located within the Los Angeles basin, demonstrate that ground velocities are nearly identical over distance scales of less than several kilometers. Although a greater variation is observed in the waveforms and amplitudes of ground acceleration seen along these short profiles, strong phase coherence is still observed.

2. Catalogs of accelerograms from the western U. S. and from Japan are studied to compare the relationship between peak values of displacement, velocity, and acceleration with fault distance and earthquake magnitude. The distribution of available Japanese records with respect to magnitude and site distance is markedly different from the distribution of U. S. records. In Japan, few records are available at small distances from any earthquakes larger than M 5.5. There are, however, many records available at large distances (> 100 km) from large earthquakes (M > 7). In Japan, the largest motions have been recorded at site distances beyond 50 km from large subduction zone events. This contrasts with data from the western U. S. where the largest ground motions have been recorded at small source distances from moderate-sized shallow crustal earthquakes. Despite these differences, when peak ground motions observed at comparable site distances and magnitudes are compared, we find that Japanese and U. S. motions are remarkably similar.

3. Los Angeles ground motions: In collaboration with S. H. Hartzell, we have completed a project initiated in FY 1982. In this project, ground motions in the period range from 30 s to 0.5 s were calculated for a magnitude 6.5 earthquake rupturing unilaterally from Long Beach to Westwood along the Newport-Inglewood fault. Strike-slip motion and a faulting width from 3 km to 13 km depth were assumed. Different seismic velocity models were used on either side of the fault to accomodate for the known large offset in basement depth across the fault. For this event ground motions were strongly enhanced in the direction of rupture propagation (NW), with peak velocities on the component perpendicular to the fault reaching 120 cm/s in the Inglewood region, midway along the fault, and 80 cm/s at the NW end of the fault in Westwood. By contrast, at Long Beach Airport, near the epicenter at the SE end of the fault, peak velocities were only about 5 cm/s. We calculated theoretical ground motions for two different rupture velocities and have found that peak ground velocities are considerably higher in the forward direction for the faster rupture velocity. This work has been contributed to the U. S. Geological Survey Professional Paper on earthquake hazards in the Los Angeles basin.

4. Differential array analysis: The 1979 Imperial Valley earthquake was recorded by a 210-m-long linear array of five digital, three-component accelerometers with preevent memory and 100-Hz sampling rate per component. Using a moving window cross-correlation-analysis technique, we, in cooperation with E. Cranswick, have measured the correlation and apparent velocity of seismic arrivals along the array as a function of time during the first 20 s after the initial P-wave motion. For the vertical component of motion, apparent velocities initially are about 10 km/s, rise to infinity about 5 s after the initial P-wave motion, and drop back to about 7 km/s 9 s after P. After 9 s, the vertical accelerograms rapidly become very poorly correlated, and the apparent velocity fluctuates randomly. For the horizontal components of motion, correlation is very poor and velocities random until the large S arrival at 6.4 s, when apparent velocity is about 9 km/s. This velocity becomes infinite at 7.4 s after P and drops to about 6 km/s 11 s after P. After 11 s, apparent velocity becomes erratic.

Both the P and S observations are consistent with the hypothesis that the strong motions are caused by direct P and S waves radiated from a rupture travelling at 0.78 of the local shear velocity, although this estimate is based on some assumptions.

5. Gaussian beam synthetics: We are collaborating with V. Cormier, who has adapted the Gaussian beam method to use a point double couple source. We have successfully used the method to model multiple P arrivals observed in the Calaveras fault zone from aftershocks of the Coyote Lake earthquake, thereby verifying the presence of low velocities in this fault zone. In addition, we are using the method to study S to P conversion at the base of the Santa Clara Valley, which may have been responsible for the largest accelerations recorded during the Coyote Lake mainshock.

Reports

Cormier, V. F., and Spudich, P., 1983, The effects of lateral heterogeneity on strong ground motion modeled by the Gaussian Beam Method [abs.]: Spring AGU Meeting, May 30-June 3, 1983, Baltimore, Maryland.

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Fast Computation of Near Field Strong Motion for Complex Source Earthquakes and Inversion of Source Slip for Some Recent Events in Italy and California

14-08-0001-19883

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Investigation

Efficient computational tools are being developed for modelling of strong-motion earthquake data. A source model is being developed based on the dynamic solution for the slip on the fault, where realistic dynamic and static friction as well as pre-stress are acting on the fault surface. This source model will be incorporated into an algorithm[1,2] for calculating the complete seismogram at distances 50 km. or more from the fault zone in a laterally homogeneous crust and an algorithm[3] for computing body waves at both local and regional distances in a laterally heterogeneous crust.

Results

The source models currently available for earthquake studies are mostly kinematic. In the kinematic approach one specifies the source as a function of space and time. Only in a very simple situation does this agree with the basic relations of stress and displacement on the surface of the fault. In the dynamic approach the slipping on the fault surface is determined analytically.

We developed a mathematical solution for the time history of the slip on the fault surface similar to the results obtained by Achenbach and Abo-Zena[4] Burridge and Halliday[5], and Abo-Zena[6] Unlike these results, which were strictly for a linear friction with depth, the new results are for a general variation with depth of the static and the dynamic friction as well as the pre-stress on the surface of the fault. This variation allows modelling-buried slippage on the fault surface, such as the 1979 Coyote Lake earthquake, where no clear surface faulting was found. Now we are in the process of coding the mathematical results to produce the time history of the slip on the surface of the fault.

The known lateral variation of the crustal structure in the vicinity of the 1979 Coyote Lake, California earthquake[7] has been shown to be consistent with the arrival times of direct P and S to P converted phases of aftershocks recorded by a local array surrounding the fault zone[8]. The Gaussian beam method[3] was used to synthesize body waves propagating through the laterally varying structure of the fault zone to further refine the structure and to estimate the source parameters of the aftershocks. The method remains valid directly over the axial caustic of the fault zone and in the vicinity of travel time cusps formed by a wedge-shaped low velocity zone surrounding the fault. The wedge-shaped zone explains a complex P arrival observed at station CAN in the fault zone. The CAN waveform can be used to refine estimates of the size and shape of the low velcity zone surrounding the fault. At stations in the Santa Clara Valley west of the fault, the arrival time and amplitude of a phase following P, but arriving before S, was shown to be consistent with an S wave propagating from the source and being converted to a P wave at the basement-sediment interface of the Santa Clara Valley.

Reports

Abo-Zena, A.M., Dynamic analysis of strike-slip faulting for general friction and pre-stress variation (abs.): *EOS, Trans. Am. Geophys. Un.*, submitted to Spring 1983 Annual Meeting AGU.

Cormier, V.F. and P.K. Spudich, The effects of lateral variation on strong ground motion modeled by the Gaussian beam method (abs.): *EOS, Trans. Am. Geophys. Un.*, submitted to Spring 1983 Annual Meeting AGU.

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6. Abo-Zena, A.M., *Bull. Seism. Soc. Am.*, 71, 405-422, 1982.

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Developent of General Earthquake Observation System

9910-03009

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Investigations

The objectives of this program are to complete the assembly, testing, and documentation of the General Earthquake Observation System (GEOS). An expanded memory is being developed for an enhanced detection program. A digital to analog board is being developed to replace the analog to digital board. With a change in the program a recording system can be made into a playback system.

Results

Sixteen systems have been tested and are now operational. Another nine systems are approximately 90% complete. Seven GEOS systems were deployed near Mammoth Lakes in January 1983. These systems were operated with both force balance accelerometers and velocity sensors. Record quality was very good and indicated that the instruments were operating near their maximum dynamic range of 96Db.

Aftershock Investigations and Geotechnical Studies

9910-02089

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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. Gene Sembera continued to maintain and operate the DR-100 systems. Field deployment included the January 1983 Mammoth Lakes experiment (Borcherdt) and a building response (ambient noise) study (Brady).

Five DR-100's were modified to achieve synchronous sampling for precision measurement applications (Liu).

1b. Gene Sembera continued work on the GEOS systems including field tests at Mammoth Lakes and a "Hot Soak" test in attempts to discover system weaknesses.

1c. The open-file report on our Force Balance accelerometers was completed and sent to Reston for review. Of the 105 accelerometer elements in the 35 three-component systems, 8 elements were found not to meet specifications. The defective units were successfully restored by the manufacturer.

1d. A prototype sensor leveling system which allows the initial set up of accelerometers without requiring the use of a recording system on other instruments was designed and constructed. A coil position determining circuit was added to permit accurate leveling of low-frequency (1 Hz) velocity sensors.

2a. The progress in developing a convenient data processing process for the Nimbus-Geometrics data reached an impasse but is now scheduled to resume in a new direction, that of utilizing the programs developed by Ed Cranswick.

Reports

None.

Semi-Annual Technical Report
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

In our earlier reports, we described a method to determine the mechanism and seismic moment from long-period seismic surface waves. Since the inversion used in this method is ill-conditioned for shallow events, some source parameters are indeterminate. In order to remove this indeterminacy, we developed a method which combines both P-wave first-motion data and surface-wave data.

Results

Combined use of body-wave first-motion data and surface-wave spectra for earthquake mechanism determination.

Kanamori and Given (1981, 1982) describe a method to determine the focal mechanism from long-period surface-wave spectra. In this method, surface-wave spectra are inverted to obtain moment tensor elements, M_{xy}, $M_{yy} - M_{xx}$, $M_{yy} + M_{xx}$, M_{zy} and M_{zx}. However, for shallow earthquakes, the inversion is ill-conditioned and M_{zx} and M_{zy} are almost indeterminate. Assuming that the source geometry is the same for both body and surface waves, we can eliminate this indeterminacy by combining P-wave first-motion data.

Referring to the coordinate system defined by Figure 1 of Kanamori and Given (1981) we write the far-field P-wave displacement (longitudinal component) due to a moment tensor (M_{xx}, M_{yy} etc.) as :

$$u(\theta,\phi) = M_{xx}\sin^2\theta\cos^2\phi + M_{yy}\sin^2\theta\sin^2\phi + M_{zz}\cos^2\theta + M_{xy}\sin^2\theta\sin 2\phi + M_{xz}\sin 2\theta\cos\phi + M_{yz}\sin 2\theta\sin\phi$$

(see e.g. Strelitz, 1978; Fitch et al., 1980). Assuming $M_{xx} + M_{yy} + M_{zz} = 0$, and using the take-off angle i_h instead of θ (i.e. $\theta = \pi - i_h$), we have

$$u(i_h,\phi) = M_{xy}\sin^2 i_h\sin 2\phi - (M_{yy}-M_{xx})(1/2\sin^2 i_h\cos 2\phi) + (M_{xx} = M_{yy})(1/2(1-3\cos^2 i_h)) - M_{yz}\sin 2 i_h\sin\phi - M_{xz}\sin 2 i_h\cos\phi \qquad (1)$$

If we use a fault model, we have

$$
\begin{aligned}
u(i_h,\phi) = & (\sin\lambda \ \sin\delta \ \sin\delta)\ (3\cos^2 i_h - 1) \\
& -(\sin\lambda \ \cos 2\delta \ \sin\phi + \cos\lambda \ \cos\delta \ \cos\phi)\ \sin 2 i_h \\
& -(\cos\lambda \ \sin\delta \ \sin 2\phi - \sin\lambda \ \sin\delta \ \cos\delta \ \cos 2\phi)\ \sin^2 i_h
\end{aligned}
\qquad (2)
$$

where ϕ_s is the station azimuth, ϕ_f is the fault strike, δ is the dip angle and λ is the slip angle. (For the definition of these parameters, see Figure 10 of Kanamori and Cipar, 1974).

If we can determine u from the observed amplitude data at many stations we can invert them to determine the moment tensor by using either (1) or (2) in a straightforward fashion. However, in practice, it is very difficult to estimate u from the observed data. We therefore use a very crude measure: u = +1, 0 and -1 for a clear "up", ambiguous or nodal, and clear "down" first motions respectively. We first invert these amplitude data (first-motion data) using (1) to obtain a moment tensor and determine the major double couple. Then using it as the first approximation we invert the amplitude data using (2) to obtain a fault model. Although the measure of the amplitude used here is very crude, the fault-plane solution thus obtained is generally consistent with the observed first-motion data.

We then convert the fault parameters to the corresponding moment tensor elements using (Mendiguren, 1977),

$$
\begin{aligned}
M_{xy} &= -\frac{1}{2}\sin 2\phi \ \sin 2\delta \ \sin\lambda - \cos 2\phi \ \cos\lambda \ \sin\delta \\
M_{yz} &= -\sin\phi \ \cos\delta \ \cos\lambda + \cos\phi \ \sin\lambda \ \cos 2\delta \\
M_{zx} &= \cos\phi \ \cos\delta \ \cos\lambda + \sin\phi \ \sin\lambda \ \cos 2\delta \\
M_{xx} &= -\sin^2\phi \ \sin 2\delta \ \sin\lambda - \sin 2\phi \ \cos\lambda \ \sin\delta \\
M_{yy} &= -\cos^2\phi \ \sin 2\delta \ \sin\lambda + \sin 2\phi \ \cos\lambda \ \sin\delta \\
M_{zz} &= \sin 2\delta \ \sin\lambda
\end{aligned}
$$

We use these moment tensor elements in the surface-wave inversion in the following manner.

Since M_{zx} and M_{zy} are poorly constrained by the surface-wave data, we first invert them with the constraints $M_{zx} = M_{zy} = 0$ as is done in Kanamori and Given (1981, 1982). As a result of this inversion, we obtain $A_1 = M_{xy}$, $A_2 = M_{yy} - M_{xx}$ and $A_3 = M_{yy} + M_{xx}$. We then choose A_i (i = 1, 2 or 3) whose absolute value is largest as a reference element, and define α and β by

$$
\alpha = M_{zy}/A_i \ \text{and} \ \beta = M_{zx}/A_i \ (i = 1, 2, \text{or } 3).
$$

We constrain α and β to be equal to those determined from the body-wave data, and reinvert the surface-wave data to obtain the final solution. The solution thus obtained is usually consistent with both surface-wave and body-wave data. Since M_{zx} and M_{zy} have very little effect on surface-wave radiation (for this very reason, they are unresolvable), inclusion of non-zero M_{zx} and M_{zy} does not significantly affect the fit of the surface-wave data. At the same time, since the values of M_{zx} and M_{zy} are constrained with respect to the largest element of the moment tensor (either M_{xy}, $M_{yy}-M_{xx}$ or $M_{yy} + M_{xx}$), the final solution is not very different from the body-wave solution.

A drawback of this method is that error estimates of the body-wave solution are rather difficult to make since very crude amplitude data are used. Also, the consraints $\alpha = M_{zy}/A_i$ and $\beta = M_{zy}/A_i$ do not have a rigorous theoretical basis. These constraints are used because they are linear and represent the gross geometry of the body-wave solution.

If one or both of the nodal planes can be unambiguously determined by the body-wave data, it is probably better to constrain their geometry, and invert the surface-wave data to determine the remaining parameters, as is done in Kanamori and Given (1981) or Michael and Geller (1982). The method described here is useful when neither one of the nodal planes can be determined unambiguously by the body-wave data; the ratios α and β obtained from the body-wave data provide constraints necessary for stabilizing the surface-wave solution.

So far we have been concerned with only shallow events. Similar indeterminacy sometimes occurs for intermediate-depth events (Kanamori and Given, 1981). The method described here can be used for intermediate events with minor modifications.

Reports

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Seismic Slope Stability

9550-03391

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Investigations

1. Developed methods and demonstration maps for predicting landslide occurrence in earthquakes.

   a. Developed correlations between earthquake magnitude and maximum epicentral and fault-rupture distance to landslides of various types and correlations between shaking intensity and landslide occurrence. (D. K. Keefer)

   b. Developed numerical slope-stability model and correlated slope displacements predicted by the model with Arias intensity, peak ground acceleration, and duration of shaking. (R.C. Wilson)

   c. Integrated results from (a) and (b) to prepare demonstration maps showing probabilities of slope failure at various distances from fault rupture. (R. C. Wilson and D. K. Keefer)

   d. Prepared description of types of landslides and geographic areas most likely to experience slope failure in a M 6.5 earthquake on the Newport-Inglewood fault zone in southern California (E. L. Harp and R. C. Wilson).

2. Analyzed landslide data from recent and historical earthquakes to determine factors significant in landslide susceptibility.

   a. Added landslide data from 1933 Long Beach, Calif. and 1957 Kern County, Calif. earthquakes to data base. (D. K. Keefer)

   b. Began statistical analysis of distribution of rock falls and rock slides in the May 1980 Mammoth Lakes, Calif. earthquakes to determine influence of slope, bedrock type, and variations in shaking on landslide occurrence. (D. K. Keefer)

   c. Refined criteria for predicting catastrophic earthquake-induced rock avalanches. (D. K. Keefer)

   d. Developed criteria for mapping susceptibility of various geologic materials to earthquake-induced landslides. (D. K. Keefer)

3. Measured and analyzed earthquake-induced changes in pore-water pressures in saturated granular sediments.

a. Analyzed ground-motion and pore-water pressure records obtained from Convict Lake site during aftershocks of May 25-27, 1980 Mammoth Lakes, Calif. earthquakes. (E. L. Harp in cooperation with G. M. Mavko).

b. Measured ground motions and pore-water pressures at an alluvial site near Mammoth Creek during the January 7-9, 1982 Mammoth Lakes, Calif. earthquake sequence. Records were obtained in eight events with M $\leq$ 3.5. (E. L. Harp)

c. Installed permanent instrument site for recording ground-motions and pore-water pressures in the Imperial Valley, Calif. (E. L. Harp in cooperation with T. L. Youd)

4. Began study of mechanics of failure of loess bluffs along the Mississippi River caused by the 1811-1812 New Madrid, Missouri earthquake sequence. (R. W. Jibson)

Results

1. Minimum levels of shaking that cause landslides of various types were determined using threshold magnitudes, maximum distances of landslides from epicenters and fault ruptures, and threshold Modified Mercalli intensities. Rock falls, rock slides, soil falls, and disrupted soil slides have the lowest threshold magnitude (M $\simeq$4.0) and occur at the greatest distances in larger events; they are, thus, triggered by the weakest shaking. Stronger shaking is needed for coherent slides (primarily slumps and block slides) (min M $\simeq$ 4.5), and even stronger shaking for lateral spreads and flows (min M $\simeq$ 5.0). The highest levels of shaking are needed for highly disrupted rock avalanches and soil avalanches; their threshold magnitudes are 6.0 and 6.5, respectively. In most earthquakes studied, the minimum modified Mercalli intensity (MMI) for rock falls, rock slides, soil falls, and disrupted soil slides was MMI=VI, and the lowest intensity in any event was MMI=IV. For landslides in other categories, the most common minimum intensity was MMI=VII, and the lowest intensity in any event was MMI=V.

2. As a demonstration of the method for predicting probability of slope-failure as a function of magnitude and fault-rupture distance, a refined map for a M 6.5 event in southern California is being prepared. This map is based on (1) empirical magnitude-distance relations for various types of landslides and (2) correlations between slope displacement calculated by the Newmark seismic slope-stability analysis, Arias intensity, peak acceleration, and duration.

3. Several materials have been identified as being especially susceptible to earthquake-induced landslides. These materials and the predominant types of landslides in each are: (1) weakly cemented, weathered, sheared, intensely fractured, or closely jointed rocks (rock falls, slides, avalanches, slumps, and block slides), (2) more indurated rocks with prominent discontinuities (rock falls, slides, block slides and, possibly, slumps), (3) unsaturated residual or colluvial sand (disrupted soil slides and soil avalanches), (4) saturated residual or colluvial sand (rapid soil flows), (5) saturated volcanic soils containing sensitive clay (disrupted soil slides, soil

avalanches, and rapid soil flows), (6) loess (rapid soil flows) (7) cemented soils (soil falls), (8) deltaic sediments containing little or no clay (soil lateral spreads and subaqueous landslides), (9) floodplain alluvium containing little or no clay (soil slumps, block slides, and lateral spreads), and (10) uncompacted or poorly compacted man-made fill containing little or no clay (soil slumps, block slides, lateral spreads, and rapid soil flows).

4. Data from historical events indicate that all earthquake-induced rock avalanches occur on slopes made unstable by existing topographic and geologic conditions. These conditions provide criteria for recognizing potential sources of these large and destructive landslides. Slopes most likely to produce rock avalanches (i) are steeper than 25° and higher than 150 m, (ii) are undercut by active fluvial erosion or active or geologically recent glacial erosion, (iii) are composed of intensely fractured rocks, and (iv) exhibit at least one other geologic indicator of instability such as weathering, weak cementation, adverse dip of planes of weakness, or evidence of previous slope failure. Slopes that meet criteria (i) and (ii) and either criterion (iii) or (iv), but not both, have a lesser but still significant likelihood of producing rock avalanches; slopes not meeting these criteria are unlikely to produce rock avalanches during earthquakes.

5. Preliminary airphoto mapping of landslides along 200 miles of the Mississippi River bluffs north of Memphis has been completed. The mapping identified numerous landslides, only a few of which were active or recent. Morphology of the vast majority of the landslides suggests that they are of the same age and that they are probably attributable to the 1811-1812 earthquake sequence.

6. Accelerometers and piezometers have been emplaced in a permanent site near Calipatria, in the Imperial Valley, California, to measure ground motions and pore-water pressures during earthquakes. A surface accelerometer and a downhole accelerometer at 8 m depth have been installed. Piezometers were installed in a 4.6 m diameter circle around the accelerometers. The piezometers are at equal arc spacing around the circle at depths ranging from less than 3 m to 12 m in silt and silty sand that are highly susceptible to liquefaction.

Reports

Keefer, D. K., in press, Landslides caused by earthquakes: Geological Society of America Bulletin, 78 ms. p. (Accepted for publication)

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Wilson, R. C., and Keefer, D. K., 1983, Dynamic analysis of a slope failure from the August 6, 1979, Coyote Lake, California, earthquake: Seismological Society of America Bulletin, v. 73, no. 3, 16 p. (In press).

CPT Pore-Pressure Measurements and SPT Hammer - Energy Calibration, Contract No. 14-08-0001-19105 No. 3, Geoffrey R. Martin, Bruce J. Douglas, Andrew I. Strutynsky, Ertec, Inc., 3777 Long Beach Blvd., Long Beach, Calif. 90807, (213) 595-6111

As an extension to our study for the U.S.G.S., titled "Evaluation of the Cone Penetrometer for Liquefaction Hazard Assessment", Ertec is currently completing the measurements of the input energy of the various SPT hammers previously used, and the performance of piezometric CPT to define static and dynamic pore pressure response to cone penetration. Both of these measurements are intended to supplement the previous data base allowing increased refinement of the CPT-liquefaction potential method.

To date, energy measurements have been taken of the trip and donut SPT hammers used for the previous study. Additional SPT energy data on 3 types of safety hammers, using two different drilling rig types (rope around the cat head, and spool-off winch) have also been obtained.

Piezometric CPT soundings measuring dynamic and static pore pressure response have been performed at the San Diego, Heber Road, and Salinas, California sites. Two different designs of piezometric elements were used. These designs were: 1) a tip sensing piezometric element which incorporates transducer inlet ports on the face of the conical tip of the cone instrument; and 2) a side sensing piezometric element which incorporates transducer inlet ports just behind the conical tip, but before the friction sleeve, of the cone instrument.

The results of these SPT calibration tests will be used to calibrate the: CPT-liquefaction potential predictive method and to enhance the data base describing United States Average Energy used in the SPT. The piezometric CPT results will be used to assess the value and effectiveness of pore-pressure measurement with regard to liquefaction potential evaluations.

Liquefaction Investigations

9910-01629

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Investigations

1. Completed liquefaction susceptibility map for San Mateo County, California

2. Continued compilation of liquefaction potential maps for the Los Angeles Basin area, California

3. Continued subsurface investigation of sites in the Imperial Valley, California, where liquefaction occurred during earthquakes in 1957, 1979, and 1981, by making cone and standard penetration soundings, taking Osterberg piston samples, measuring seismic wave velocities in the sediments, and conducting flat-plate dilitometer tests. Parts of these investigations are in cooperation with Purdue and Stanford Universities and the University of Texas.

4. Began an investigation of liquefaction potential of the debris in the blockages impounding pirit and Castle Creek Lakes north of Mount St. Helens, Washington. These lakes are impounded by debris produced during the May 18, 1981 eruption of Mount St. Helen~.

Results

A liquefaction susceptibility map of San Mateo County, California, was completed and sent to TRU for further processing and publication. This map divides the county into four different susceptibility zones. The base for mapping these zones is geologic maps that have been digitized and assigned to 1-hectare cells. Susceptibilities in the four zones are labeled very low, low, moderate, and high with distinction between zones being the likelihood of underlying liquefiable sediment. These likelihoods, in percent, are less than 0.01, 0.01 to 0.1, 0.1 to 1, and 1 to 10, respectively. These likelihoods are calcualted from three component likelihoods, (1) the likelihood of encountering clay-free sediment (based on the percent of drill-holes in a particular geologic unit that encounterd layers of clay-free sediment), (2) the likelihood that those layers are saturated (based on water table maps of the county), and (3) the likelihood that the clay-free layers are prone to liquefaction (based on the percent of standard-penetration-test data indicating high susceptibility to liquefaciton). Areas of high susceptibility include units covering the lowlands along San Francisco Bay, channel and floodplain deposits along present streams, and beach deposits adjacent to the Pacific Ocean. Areas of moderate susceptibility include units marginal to lowlands along San Francisco bay, most of the Colma Valley and adjacent hillsides, and upland dunes and former beache . Areas of low susceptibility include most of the gently sloping plain between the Santa Cruz Mountains and the lowlands along the bay and upland terraces along the Pacific Coast. Areas of very low susceptibility are confined to upland hills where unconsolidated layers are generally thin and ground water levels generally deep. Many bore-holes have been drilled in the high susceptibility zone adjacent to San Francisco Bay. Locations of many of those bore-holes are noted on the map by markings on the 1-hectare cells that indicate the highest susceptibility of materials encountered in holes within that cell. The principal use of the map is as a guide to planners, engineers, building officials, and others responsible for minimizing seismic risk by marking areas where a potential hazard may exist. Further study, zoning, or emergency preparations may be required in the more susceptible areas to assure public safety and minimize damage to present facilities and future developments. Conversely, the map also delineates areas where there is little potential for liquefaction and where special precautionary measures may not be necessary.

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Youd, T.L., and Wieczorek, G.F., 1982, Liquefaction and secondary ground failure in The Imperial Valley, California, Earthquake of October 15, 1979: U.S. Geological Survey Professional Paper 1254, p. 223-246.

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Tinsley, J.C., Youd, T.L., and Perkins, D.M., 1983, Evaluation of liquefaction potential in the Los Angeles Area, California (abs.): Geological Society of Anmerica, Abstracts with Programs, v. 15, no. 5, p. 373.

Southern California Seismic Arrays

Contract No. 14-08-0001-21209

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Investigations

This semi-annual report summary covers the six-month period from 1 October 1982 to 31 March 1983. The contract's purpose is the partial support of the joint USGS-Caltech Southern California Seismographic Network, which is also supported by other groups as well as by direct USGS funding through its employees at Caltech. Other supporting groups during the report period include the California Division of Mines and Geology and the Caltech Earthquake Research Affiliates. According to the contract, the primary visible product will be a joint USGS-Caltech catalog of earthquakes in the southern California region; quarterly epicenter maps and preliminary catalogs are also required and have been submitted as due during the reporting period. About 250 preliminary catalogs are routinely distributed to interested parties.

Results

Figure 1 shows the epicenters of all cataloged shocks during the 6-month period that have been located, although we have fallen behind in locations due to the high activity in the Coso area; coverage of Magnitude 3 and larger events is thought to be complete through 24 January 1983. Some of the seismic highlights during the period are as follows:

Number of earthquakes currently entered in catalog: 2,685
Number of earthquakes of M = 3.0 and greater: 204
Number of earthquakes of M = 4.0 and greater: 19
Number of earthquakes for which systematic telephone notification to agencies was made: 8
Largest earthquake (1 October 1982, Coso area): 5.2
Smallest felt earthquake (14 October 1982, Canoga Park): 2.2
Number of earthquakes reported felt: 13

The most obvious continuing seismic activity during the reporting period has been that near China Lake (Fig. 2). Although referred to as the "Coso area," recent activity has been centered in the Indian Wells Valley, somewhat south of the principal Coso volcanic field. Seismic activity in this general area has been notable for several years, and is discussed in earlier Technical Report Summaries, but it seems to have reached a high point--at least to date--in the final quarter of 1982. Activity was most intense in the southern "hot spot," only about 10 km from the China Lake Naval Weapons Center, and Dr. Carl Johnson suggests that events may have been occurring along sequentially developing northwest-trending fractures beneath the alluviated floor the valley. Activity remains high in this area, although not at the level of October and November 1982.

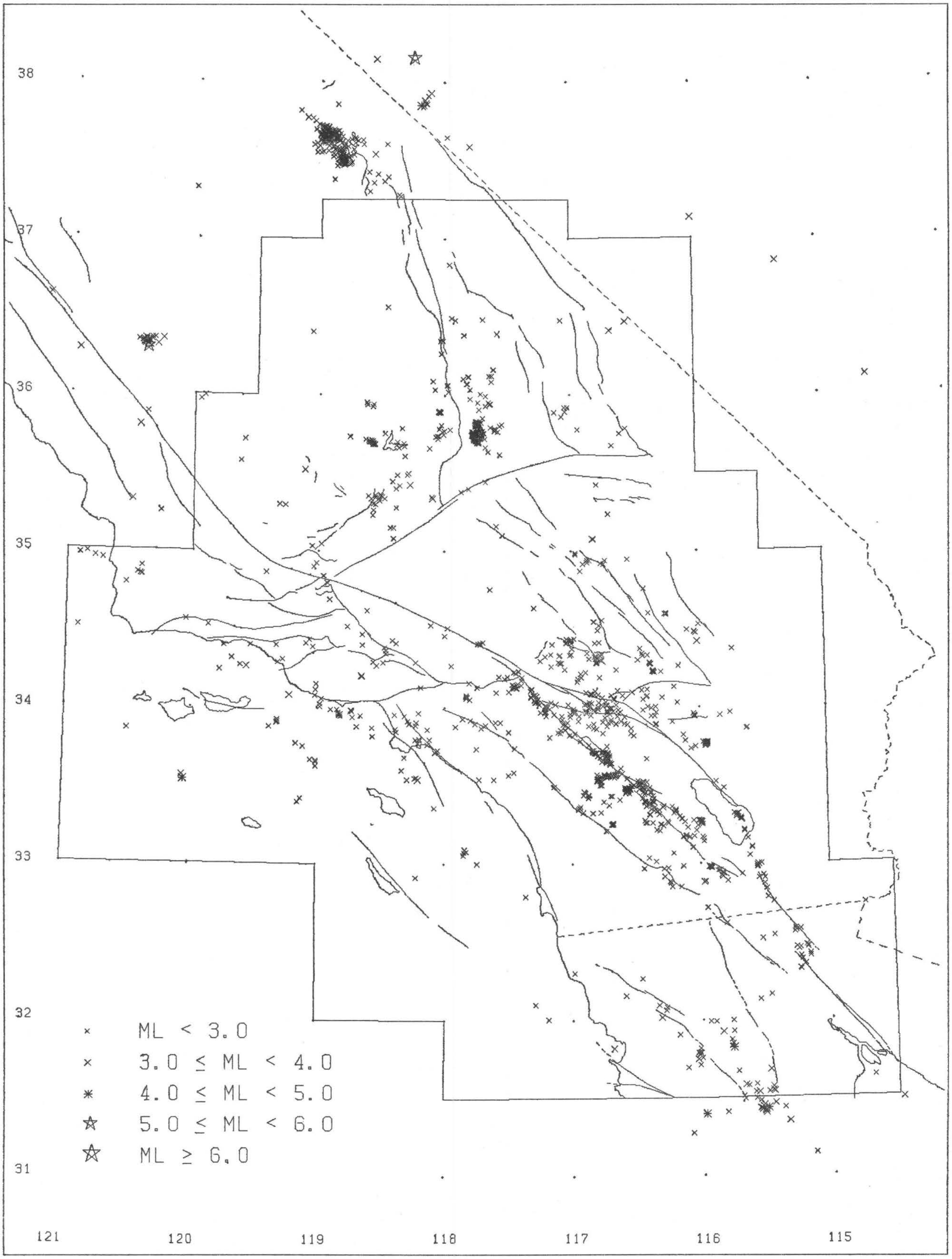

Fig. 1.--Epicenters of larger earthquakes in the southern California region, 1 October 1982 to 24 January 1983.

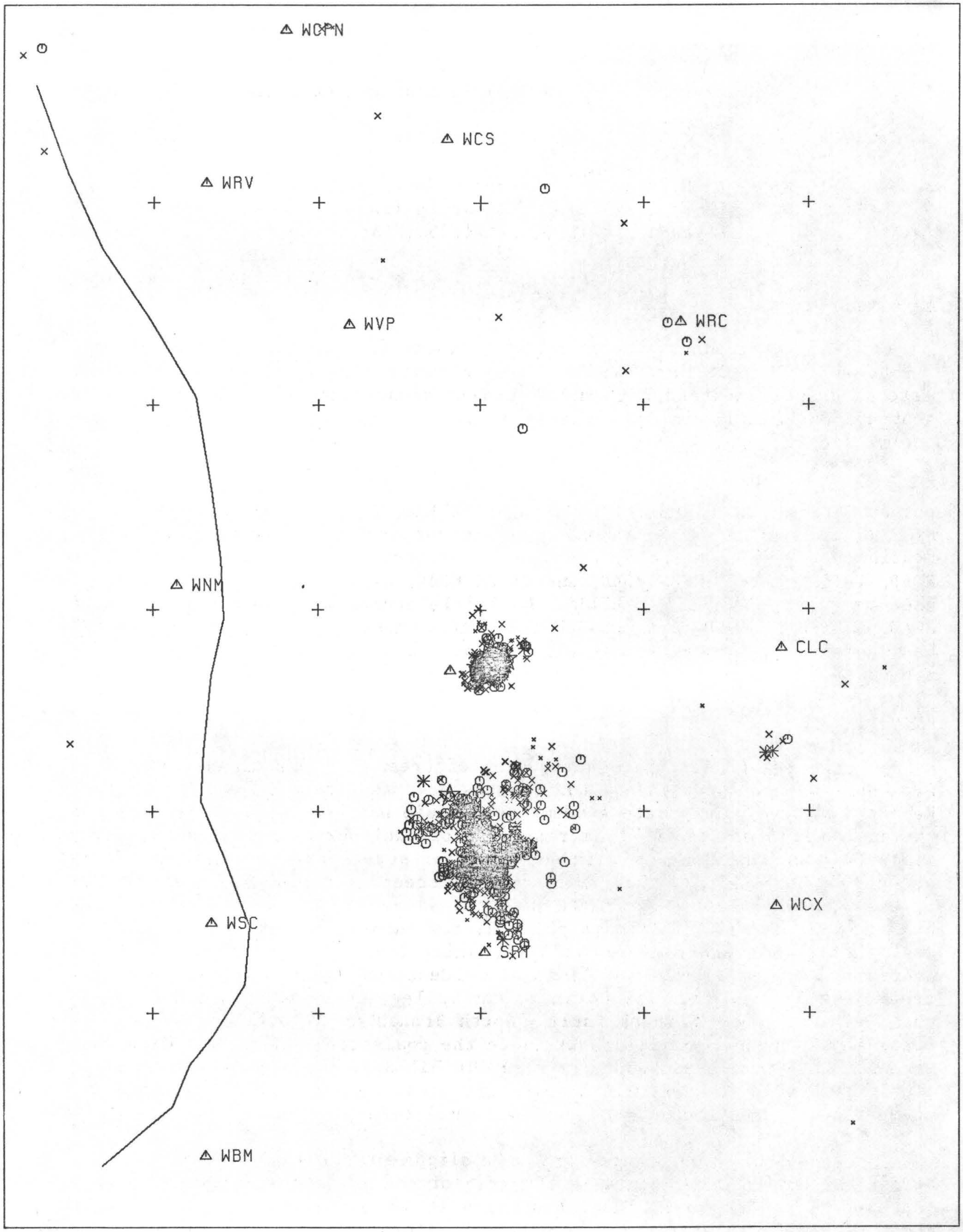

Fig. 2.--Seismic activity in the Coso area, 1 October 1982 to 25 January 1983.

Creep and Strain Studies in Southern California

Contract No. 14-08-0001-21212

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Investigations

This semi-annual report summary covers the six-month period from 1 October 1982 to 31 March 1983. The contract's purpose is to monitor creepmeters, displacement meters, and alignment arrays across active faults in the southern California region. Primary emphasis focuses on faults in the Coachella and Imperial Valleys.

During the reporting period resurveys of alignment arrays were carried out at CAJON, DILLON ROAD, INDIO HILLS, DEVERS HILL, ANZA, ALL AMERICAN CANAL, HIGHWAY 80, and RAND. Locations of alignment arrays are shown in Figure 1. Continuously recording creepmeters were serviced at at MECCA BEACH, HARRIS ROAD, TUTTLE RANCH, ROSS ROAD, and HEBER ROAD, as well as the dial-gauge creepmeter at SUPERSTITION HILLS. Nail-file arrays were resurveyed at ROSS ROAD, ANDERHOLT ROAD, and WORTHINGTON ROAD. Unusually heavy winter rainfall had caused damage to some installations and also slowed the resurveying schedule.

Results

The rather surprising discovery of creep (or episodic slip) along the San Andreas fault near the Salton Sea has been discussed in earlier Technical Report Summaries. Graduate student John Louie has been vigorously examining the entire file of records from resurveys of fault-crossing alignment arrays since 1967 and has come up with some further surprising conclusions. It is now clear, for example, that right-lateral creep is taking place as far north in the Coachella Valley as DEVERS HILL, at an average rate of 2.0 mm/yr between 1972 and 1982. This is particularly surprising in view of the fact that the alignment array crosses the Banning fault ("South Branch" of the San Andreas), whereas a number of lines of evidence would have suggested that if creep were present this far north in the valley, it should instead occur on the diverging Mission Creek fault ("North Branch"). Farther southeast, creep rates along the San Andreas fault (here the coalesced Banning and Mission Creek faults) have been 1.8 mm/yr at INDIO HILLS, 0.7 mm/yr at DILLON ROAD, and 3.8 mm/yr at RED CANYON. Despite the presence of creep, this fault segment continues to be marked by low-to-nil seismicity.

Re-examination of data from the alignment array at BAILEYS WELL, across the Coyote Creek fault in the area of the 1968 Borrego Mountain earthquake, reveals that creep has taken place at 5.8 mm/yr since 1971--the highest creep rate we have observed in southern California (Fig. 2). Somewhat surprisingly, there is no suggestion of decreasing creep rate with time, at least since 1971.

Another surprising result is that 4.5 mm/yr of right-lateral creep has been taking place across an un-named fault at DIXIELAND, where the array had been established in 1970 because of a series of conspicuous fissures that had developed in the desert floor (Fig. 3). Until now, it was thought the the cracks probably represented subsidence along the edge of the Imperial Valley. It is perhaps significant that this locality is nearly on a line projected between the southeastern end of the Coyote Creek fault and the northwestern end of the Cerro Prieto fault in Mexico--an interval in which no active fault has heretofore been mapped.

Along the San Jacinto fault, re-evaluation of the stability of monuments at the ANZA alignment array indicates that the most stable monuments confirm the absence of significant creep here since establishment of the array in 1970. This is significant because the array is situated squarely within the current "Anza seismic gap." On the other hand, 80 km northwest along the fault, at COLTON, right-lateral slip is clearly taking place, but it appears to be distributed in a wide zone that includes many of our survey markers and precludes assignment of a meaningful slip rate without further study.

Along the "locked" segment of the San Andreas fault northwest of San Gorgonio Pass, re-evaluation of the alignment-array data from SANTA ANA WASH and UNA LAKE confirms that no significant slip has occurred at either site since establishment in 1970 and 1971. In view of reports from the San Bernardino County Surveyor's Office that some 2 cm of slip occurred on the San Andreas fault at Interstate 10 in Cajon Pass between September and October 1982, data from our nearby alignment array at CAJON have been re-evaluated. Although the array is not a good one, no slip greater than a few mm along the fault is indicated by 6 resurveys of the array since 1979. We conclude that the fresh breaks in the highway are instead caused by subsidence in artificial fill.

Re-analysis of the alignment array data from CAMERON, on the Garlock fault, indicates that 4 mm/yr of left-lateral slip has taken place across a 150-meter-wide zone since 1971, and perhaps as much as 6 mm/yr across a wider zone. New surveys at RAND, 70 km northeast along the fault, substantiate that no creep is occurring along this eastern segment of the Garlock fault.

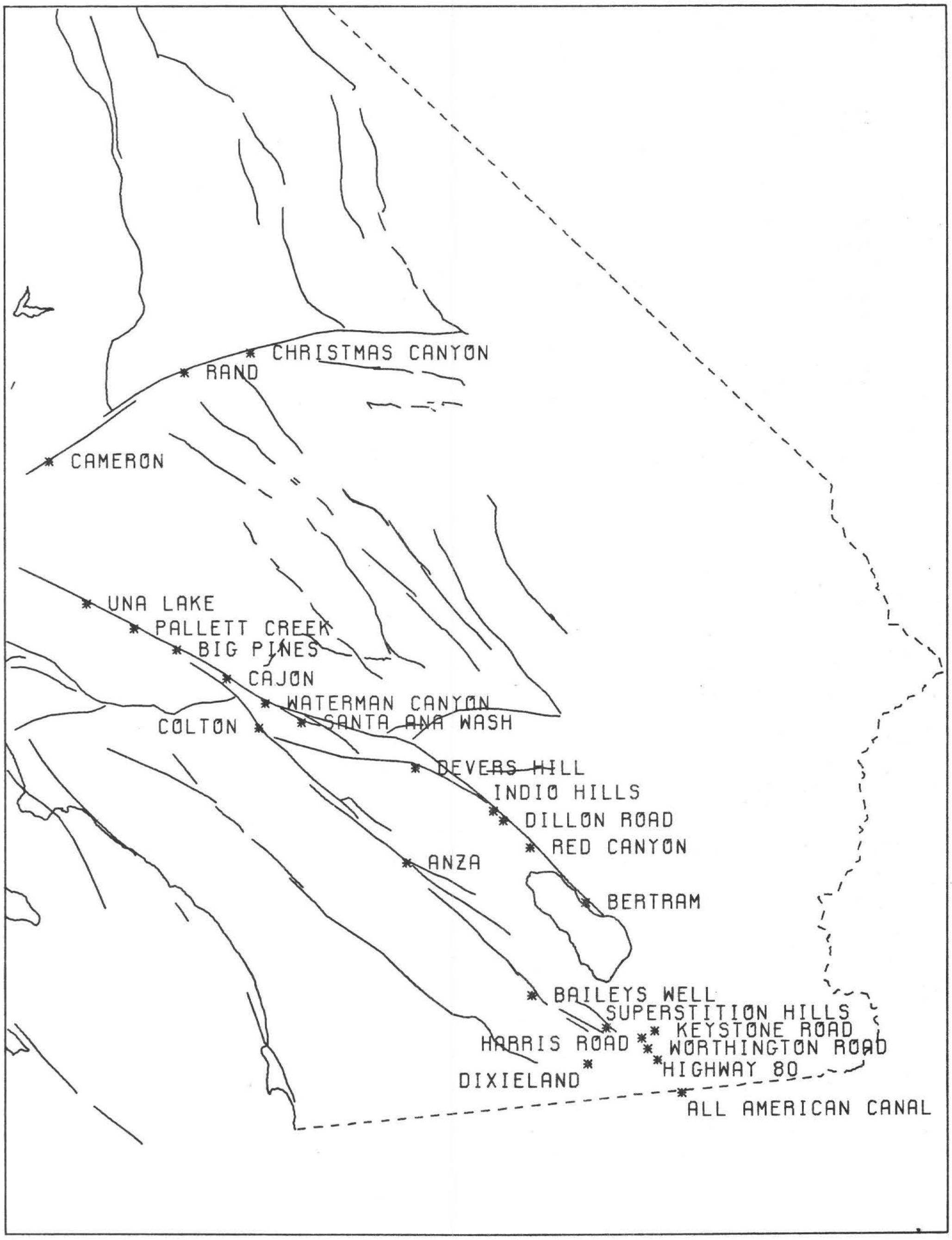

Figure 1.--Map of Caltech theodolite alignment arrays across major faults in southern California.

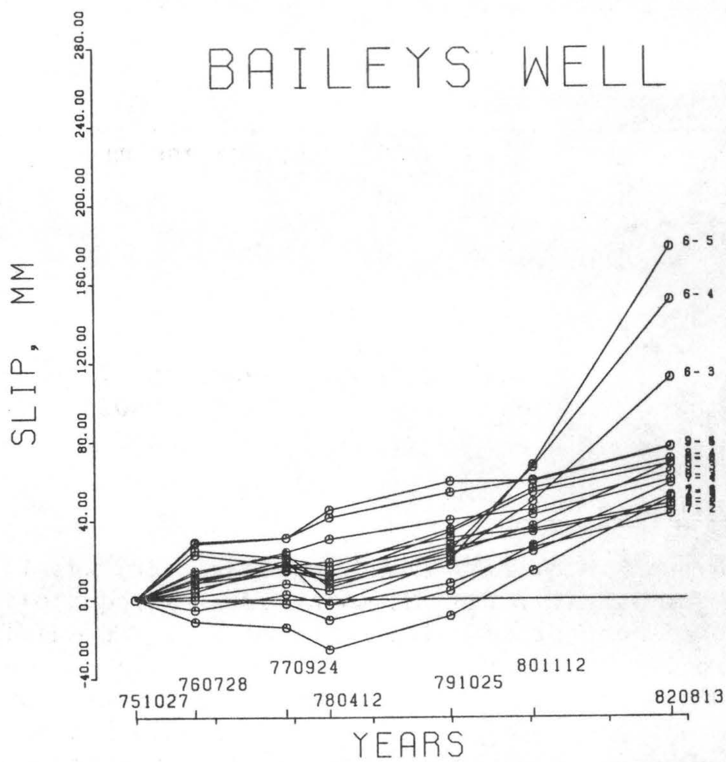

Figure 2.--Results of resurveys since 1975 of alignment array across Coyote Creek fault at BAILEYS·WELL, along segment that broke in 1968 Borrego Mountain earthquake. Average slip rate since 1971 is 5.8 mm/yr, with no evidence of decreasing rate with time.

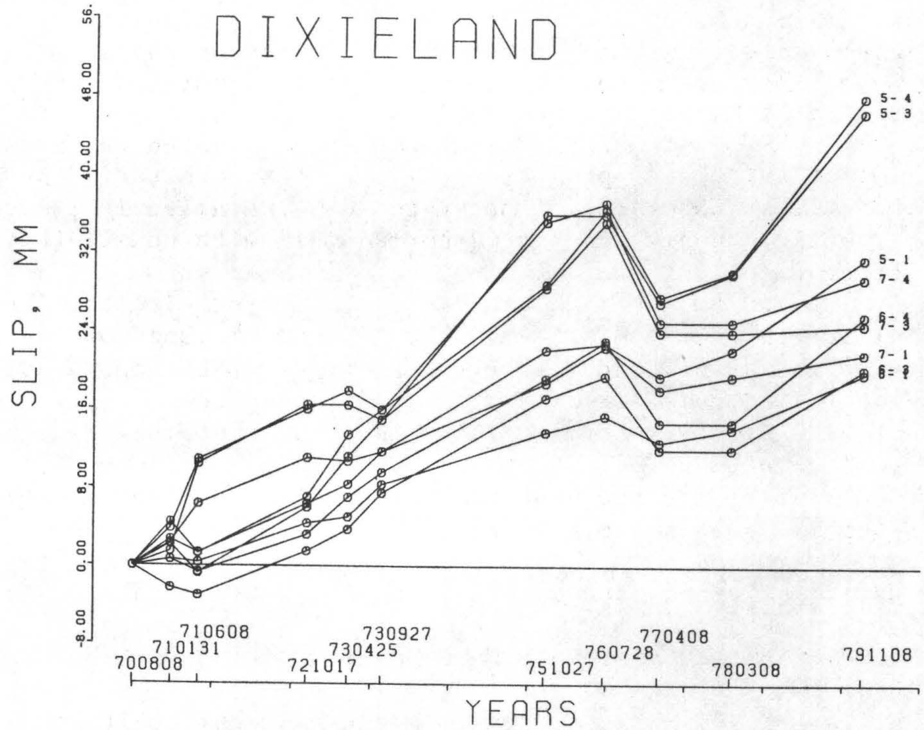

Figure 3.--Results of resurveys since 1970 across series of northwest-trending fissures in floor of Imperial Valley at DIXIELAND. Right-lateral slip rate is about 4.5 mm/yr, although no throughgoing fault has heretofore been mapped here. Note that vertical scale is different from that of Fig. 2.

On-Line Seismic Processing

9930-02940

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Investigations and Results

The Menlo Park real time processor (RTP) was in operation during the January, 1983 Mammoth Lakes earthquake swarm, and in general, performed quite satisfactory. It enabled seismologists observing the seismic activity to monitor continuously in real time the level and location of most intense activity. This was especially valuable during those periods when earthquake occurrence rates were so high as to make it difficult to separate events on visual recordings. The RTP was not able to deal with all the events by any means. It was completely unable to deal with many of the most confused records, but those it was able to process effectively were sufficient to define areas and levels of activity. Several deficiencies in the RTP algorithms appeared during the concentrated activity of the swarm, and have engendered changes subsequently incorporated in the RTP system at Menlo Park and at the other sites.

An RTP system for 32 stations was delivered to Caltech and is being used primarily for real-time monitoring of the Ridgecrest-Coso area. The system was installed in Pasadena in early January and has performed well with no significant troubles.

During this period Jim Ellis has worked with the RTP prototyping system at Menlo Park in identifying some of the problems associated with the RTP data transfer bus. He has identified and corrected problems in the line drivers/receivers and the termination resistors, which we believe will enable us to construct future systems with more confidence. In the past each system has required different treatment for these bus lines.

We should have a test fairly soon of this, as we are now buying parts for and beginning construction on RTP systems for use at the University of Utah on Yellowstone data, and for an on-site system at Mammoth Lakes.

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 and monitor earthquakes in northern California.

Results

The PDP11-70 UNIX system has continued to operate smoothly, and performs a large amount of computing for program projects. Some current statistics:

223	registered users
637976	1024-byte disk storage blocks used
40	different users per weekday
177	average hours login time per day

Recent events of particular importance include:

The real-time Ppicker data is now checked continuously for activity at Mammoth. If more than 20 events in the previous 1 hour period have occured, or any one event has a coda length longer than 95 seconds, a phone number connected to a "beeper" is called. This system is also running on the Tectonophysics PDP 11/44 under the UNIX operating system as a backup alarm.

The Operating system has been updated to Berkeley version 2.9. Enhancements include out of kernel buffer caching allowing for a larger in-memory cache of disk buffers; user program overlays which allow programs of 300 Kbytes text and 64 Kbytes data to be run on the machine; and job control. The job control feature lets a user stop the current program to run another program. A stopped process can be restarted either as a foreground process or a background process which frees the terminal for other interactive work.

PROJECT TITLE: Crustal Deformation Measurements Near Yakataga, Gulf of Alaska and the Shumagin Islands, Alaska Peninsula

CONTRACT NUMBER: USGS-14-08-0001-19745

PRINCIPAL INVESTIGATORS: R. Bilham and J. Beavan

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

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Investigations

We have measured crustal deformation, specifically short level lines and relative sea level, in the Shumagin Islands, Alaska in an attempt to (i) better understand the subduction process in this seismic gap and (ii) possibly measure signals premonitory to a great earthquake. We have interpreted our observations in conjunction with seismicity measurements in the area.

1982 Measurements

During the summer 1982 field season we remeasured 7 of our 9 level lines. We made major improvements to the three existing sea level sites by installing more massive instrument housings, using larger rock bolts and by using double armoured steel cable to carry power and signals between the gauge (which is bolted to bedrock near low tide) and the electronics (which is located a safe distance above high tide). We also installed one new sea level site at Saddler's Mistake (SAD) on Nagai Island.

Tilt and Seismicity

Some of the level line data are shown in Figure 1. Most of our lines are oriented roughly NW-SE, in the direction of plate convergence. They are measured to first-order standards and systematic errors due to ocean loading and refraction are much less than ± 0.5 μrad on each tilt determination.

The tilt on the SQH line, some 200 km from the trench, was -0.9 ± 0.3 μrad yr^{-1} between 1972 and 1978. The sense of tilt was downwards towards the trench, and this is in the correct direction and of roughly the expected magnitude (see for example, Rundle, 1982) for the tilt on the free surface while the downgoing slab subducts at 7.5 cm yr^{-1} (Minster and Jordan, 1978) with the plate boundary remaining locked to depths of 70 km or so. Between 1978 and 1980 a significant reversal occurred with the tilt rate being down away from the trench at a rate of $+2.2 \pm 1.0$ μrad yr^{-1} or a total of 4.4 μrad over the two years. This change correlates very well with the measurements on line SPA some 10 km distant. After 1980 the signal on both lines returned to a slow tilting down towards the trench. The signal on line SMP, some 80 km closer to the trench, also showed a signal in the same sense, rising between 1978 and 1980 and falling since. The five more recently installed lines also show relatively good coherence between 1980 and 1982, with slow tilting down toward the trench. We believe that the good coherence of tilt direction observed on the lines implies that the source of the signals is at some depth in the Earth, rather than resulting from local effects in the immediate vicinity of the lines.

Figure 1a shows a superposition of the SQH and SPA levelling data. Figure 1b (Hauksson et al., personal communication) shows three plots of cumulative number of earthquakes between 1972 and the present. There is a pronounced increase in PDE-reported earthquakes in the Shumagin area in late 1978 and 1979 compared to the Aleutian arc as a whole, and this corresponds with a rate of seismicity recorded by the local network almost double that which has been observed since 1980. Another enigmatic observation depicted in Figure 1c (S. McNutt, personal communication) shows that Pavlof volcano was unusually quiet between 1977 and 1980.

We have modelled the tilt changes as resulting from aseismic slip at depth; we infer that the increase in the microseismicity in the overlying brittle, near surface, rocks was caused by stress concentrations resulting from the slip . Such a slip event, or series of slip events, occurred fairly rapidly (certainly in less than two years) so that they may be modelled as a single elastic dislocation. The most likely location of the slip event is on a shear zone located above the subducting slab between a depth of approximately 25 km and approximately 70 km. This coincides with the upper edge of the Benioff zone defined by the seismicity. The shallower part of the plate boundary, between ≈25 km depth and the surface at the Aleutian trench, is the main thrust zone which we assume remains locked. In order to fit the magnitude of the observed tilt signal at SQH and SPA a total slip of some 80 cm is required. The sense and the small size of the tilt signature at SMP suggest that the inferred slip event also propagated beneath SMP to a depth of perhaps 20 km.

The slip event will have caused an increase in the stress acting on the locked main thrust zone, thus bringing it into a more advanced stage of preparation for a great earthquake. With the increased stress on the main thrust, a similar slip event in the future may have sufficient slip intensity factor to propagate into the main thrust zone and cause a great earthquake. Since the aseismic slip occurred over a relatively short period of time and caused a measurable geodetic signal, it is probable that any resumption of aseismic slip in the future could be detected by suitable geodetic monitors, and would provide a warning of the increased probability of a great earthquake.

Sea Level Measurements

Sea level measurements are important as they are the only continuous geodetic recordings being made in the Shumagin gap. We have been measuring sea level at three sites since July 1981 (Beavan et al., 1981). In our installations a pressure gauge is bolted to bedrock near low tide and measures the sum of atmospheric pressure and sea water pressure. Power to the gauge and the returned pressure and temperature signals are fed along a cable bolted to or buried in the beach. The pressure gauge is occasionally exposed above low water when it reads atmospheric pressure and permits a check of any relative drift between the two pressure gauges. The short gaps in the sea level series which result are filled with data predicted from a synthetic sea level series. An absolute datum is provided by annual levelling between the sea level gauge and nearby bedrock benchmarks.

This year, the SMH gauge and the new gauge at SAD are still operating at this writing (April 1983). The PRC gauge ceased transmission at the end of November due, we believe, to battery failure. We are confident we have solved all the mechanical problems of operating the gauges remotely for a full year with our present installations and the problems we have had with batteries are unlikely to recur. Low pass filtered data from the sea level gauges show a 30 cm annual term and other long period oscillations with amplitudes of ≈20 cm due to oceanographic and atmospheric effects. These can be reduced by subsequent processing using multivariate correlation and prediction procedures (e.g., Chelton, 1980). By taking level differences between adjacent stations the long period oscillations are reduced to about ±3 cm because such signals are fairly coherent across the array (this corresponds to an effective tilt noise of ±1 μrad). Long-term trends amounting to as much as 1 cm/month are visible in some of the difference records. These are due in part to drift in some of the pressure transducers which substantially reduces the fidelity of our sea level measurements, particularly affecting our search for long term variations. While we believe that we can resolve relative height between stations to better than ±3 cm in the absence of drift, the uncertainties introduced by the drift degrade our present measurements to a ±8 cm level. Although some of the instrumental drift can be identified by checking the consistency between gauges when the sea gauge is above water, and by using the fact that long period air pressure variations are the same at all sites, we feel that a better solution will be to use more stable (and more expensive) gauges in the future.

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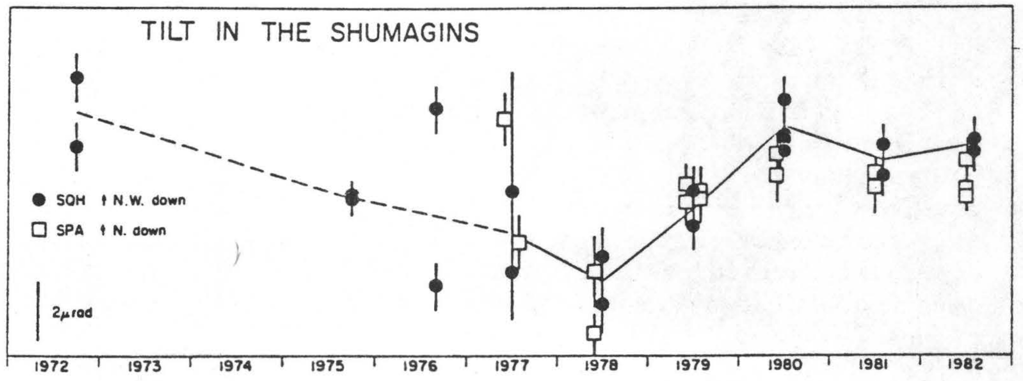
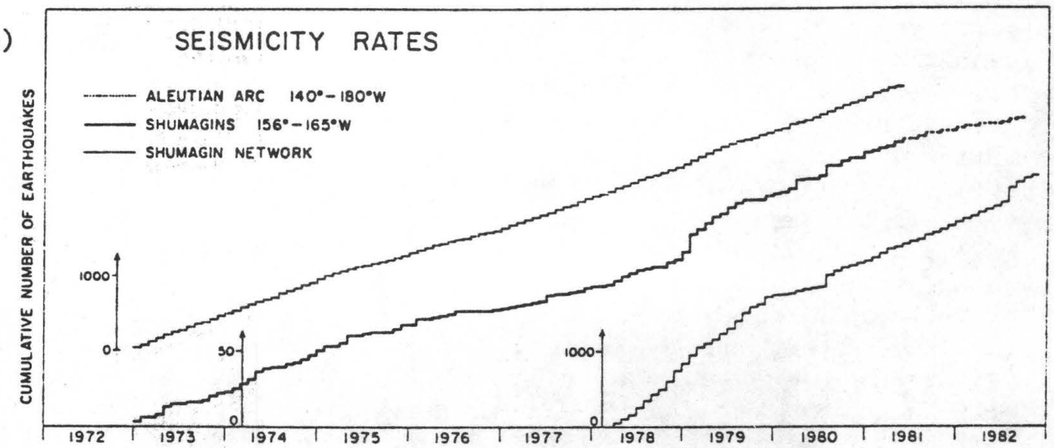
(a)



(b)



(c)

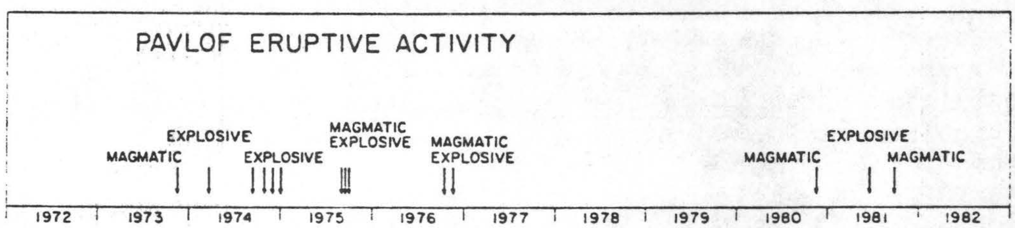


Figure 1: (a) Tilt data superimposed from lines SQH and SPA.
(b) Seismicity rate for (i) teleseismic earthquakes along whole Aleutian arc, (ii) teleseismic earthquakes in the Shumagin area, and (iii) microearthquakes ($m_b > 1.5$) recorded by the Shumagin seismic network.
(c) Eruptive activity at Pavlof Volcano.

Historical Slip Rates on the Hayward, Calaveras, and Concord Faults

9910-03553

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Investigations

Compilation of information on offsets of cultural features along the Hayward fault is nearing completion. Each reported offset, including results from repeated local surveys, has been re-evaluated and assigned to one of three general reliability categories--A, B, or C. This work represents the first stage of a long-term project effort to update and upgrade the catalog of information concerning distribution of historical slip rates and any evidence for past changes in slip rate along the several active faults northeast of San Francisco Bay.

Results

The highest quality (Category A) offset values along the Hayward fault indicate a range in slip rates between about 4 and 10 mm/yr. The highest rates and the greatest scatter in values occur along the southeastern section of the fault in the cities of Hayward and Fremont. The most reliably documented offsets in south Fremont indicate a local slip rate of about 10 mm/yr. The average slip rate decreases northwestward to about 5.5 mm/yr at the northernmost sites near San Pablo Bay.

A 24-km gap in reliable data coverage remains for the section of the fault passing through parts of Kensington, Berkeley, Oakland, and San Leandro. This gap is attributable in large part to complications caused by downslope movements of soil and shallow bedrock on the steep, southwest-facing slopes along that section of the fault trace. A few scattered slip-rate determinations of low quality indicate a range of 2.5 to 6.8 mm/yr for the poorly covered section in reasonable agreement with the more reliable data at each end of the gap. However, there are other indications that the slip rate within the 24-km gap may be near zero or otherwise very low in comparison with values for the adjacent sections. The strongest indication of a very low slip rate is the lack of noticeable lateral offset in the San Pablo Water Tunnel.

The San Pablo Tunnel, completed in 1920, penetrates the Hayward fault about 90 meters beneath the surface in the Kensington, Tilden Park area at point about 12 km southeast of the shoreline of San Pablo Bay. Although the tunnel liner has been repaired occasionally within several zones of disturbance, including one coincident with the Hayward fault zone, the damage has been such that distress in the liner can be attributed to "squeezing ground" rather than to lateral offset caused by fault slip. A possible exception to this general conclusion is the indication of a few inches of lateral offset within a zone of disturbance about 2 km notheast of the Hayward fault.

A high priority for continued work on the Hayward fault will be to add information from any offset structures in the data gap not previously documented, especially any near the San Pablo Tunnel, in order to confirm or clarify the preliminary findings reported here. If data can be found that confirm the indications of a local low in long-term slip, the clear implication will be that the low slip-rate section should be more carefully monitored, as it would appear to be a likely source region for significant earthquakes sometime in the future.

Reports

There were no reports for this period.

Fault Slip Measurements

9960-02943

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Investigations

The relation between shallow aseismic slip as determined from alinement array surveys along the central segment of the San Andreas fault and moderate earthquakes that occurred during the period of measurements (1966-82) was examined.

Results

Moderate earthquakes occurred along the southern (Parkfield) transition section of the central segment during 1966 and 1975. Moderate activity also occurred along the northern (San Benito) transition section during 1972. The increase in slip rate following the 1966 and 1972 events has been previously described. A similar increase in slip rate occurred following the August 1975 event near Parkfield. A low rate of slip prior to the Bear Valley events has also been previously described. Prior to the 1975 event, slip rates at two sites northwest of the epicenter were also low. Measurements reported here began after the 1966 event, thus no comparable information concerning rates prior to the 1966 earthquakes is available.

Reports

Harsh, P.W., Distribution of afterslip along the Imperial fault, in the Imperial Valley earthquake of 15 October 1979, R.V. Sharp, ed., U.S. Geol. Surv. Prof. Paper, 1254, pp. 193-203.

Langbein, J., A. McGarr, M.J.S. Johnston, and P.W. Harsh, 1983, Geodetic Measurements of Postseismic Crustal Deformation Following the Imperial Valley Earthquake, 1979, Journal of Geophysical Research, in press.

VERY LONG BASELINE INTERFEROMETRIC GEODESY WITH GPS SATELLITES

Contract No. 14-08-0001-19864

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Introduction

The purpose of this work is "simply to determine the accuracy with which the lengths and the relative directions of very long baselines can be determined with a GPS-based interferometry system. We expect to be able to show that the geodetic accuracy obtainable with GPS is similar to that hitherto obtained only with extragalactic sources."(1)

GPS stands for Global Positioning System.(2) This military navigation system includes several earth-orbiting satellites which emit microwave radio signals strong enough to be received with compact, portable antennas and electronics packages. In contrast, equipment capable of receiving the weak radio signals that come from extragalactic sources is very large and expensive. The latter equipment can, however, yield geodetic position determinations of 1- to 10-centimeter accuracy over very long distances, up to several thousand kilometers.

For geophysical research, and especially for earthquake-predictive reserch, a compact instrument that determined positions in three dimensions with centimeter-level accuracy would be extremely useful. Such an instrument might be used, for example, to monitor a network of geodetic monuments that extended along both sides of an active fault, or that surrounded a volcano. Such an instrument can be obtained by appropriately combining the technologies of GPS (with its compact electronics) and radio-astronomical interferometry (with its centimeter-level accuracy).

Accomplishments

With compact GPS equipment and interferometric techniques, we have shown that we can determine the relative position coordinates of fixed points with one-centimeter accuracy when the distance between the points is 10 kilometers. All three coordinates are determined with this accuracy. For intersite distances less than 1 kilometer, the uncertainty is 3 millimeters or less. For distances of several tens of kilometers the uncertainty in each coordinate is about 1-2 parts per million of the distance.(3) The time span of satellite observations required to achieve this level of uncertainty has been 2-3 hours. For a distance of 3600 kilometers we have obtained precision of 1 part in 2 million with about 6 hours of observation time. All of these results have been obtained with the use of standard ephemerides (i.e., orbital position data) for the satellites, derived from conventional Doppler tracking.

Tasks Remaining

The geodetic accuracies that we have been able to obtain so far have been limited by the accuracy of the standard ephemerides. In order to be able to make any substantial improvement in geodetic accuracy, we must have more accurate knowledge of the orbits of the satellites. At present, orbital position uncertainties are 10-20 meters. For geodetic accuracy of 1 part in 10 million (e.g. 1 cm in 100 km), which is needed for geophysical research, the orbits must be known within about 2 meters. We expect to be able to reduce orbital uncertainty to this level, and perhaps to an order of magnitude below this level, by using very-long-baseline interferometry to determine the orbits. (The fixed observing sites that serve to determine the satellite orbits must also be equipped with hydrogen-maser frequency standards and dual-frequency-band GPS receivers in order for the projected level of accuracy to be reached. The portable interferometric terminals that are used for field measurements do not need any kind of atomic frequency standard, although dual-band receivers are desirable in the field units.)

On two days in April, 1983, we performed interferometric observations of the GPS satellites at three hydrogen-maser-equipped sites: at the Haystack Observatory in Massachusetts, at the National Radio Astronomy Observatory (NRAO) in West Virginia, and at the Maryland Point Observatory in Maryland. Unfortunately, at the last minute the maser at Maryland Point failed and we were forced to use a much less stable rubidium-vapor frequency standard there. Consequently, we do not expect to attain the hoped-for level of accuracy from these observations. Another attempt will be made soon.

In order to assess the accuracy of an orbit determination, geodetic position measurements must be made simultaneously at other sites for which accurate information on position is available independently. For our April experiment we made simultaneous geodetic measurements at five suitable other sites: in Phoenix, Arizona; in Woburn, Massachusetts; and three other sites in Maryland.

For our April experiment, only single frequency band receivers were available. Two dual-band receivers have been built but were not available in time to be used; four more dual-band units are under construction. Future experiments will use dual-band equipment as it becomes available.

Acknowledgements

The work described here has been supported mainly by sources other than the cited U.S.G.S. contract. All of the GPS interferometer terminals that we have used to date have been lent, at no cost to the contract, by Macrometrics, Inc., a subsidiary of the Steinbrecher Corporation of Woburn, Massachusetts, except for the terminals used during April at NRAO and Maryland Point, which were supplied and operated by the National Geodetic Survey, and the terminals used at Greenbelt and Rockville, Maryland, which were owned and operated by Geo/Hydro, Inc., of Rockville, Maryland. Construction of most of the dual-band equipment has been supported by the U.S. Air Force Geophysics Laboratory under contract F19628-82-K-0002 with M.I.T. This contract has also been the main source of salary and related support for the M.I.T. staff members who have contributed to this work. The single-band interferometer terminals were developed by Macrometrics, Inc., without government support.

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Theodolite Meausrements of Creep Rates on San Francisco Bay Region Faults

Contract No. 14-08-0001-19767
(1 December 1980 - 30 November 1982)

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We began to measure creep rates on various faults in the San Francisco Bay region in September 1979. The total amount of slip is determined by noting changes in angles between sets of measurements taken across a fault at different times. This triangulation method uses a theodolite set up over a fixed point used as an instrument station on one side of a fault, a traverse target set up over another fixed point used as an orientation station on the same side of the fault as the theodolite, and a second traverse target set up over a fixed point on the opposite side of the fault. The theodolite is used to measure the angle formed by the three fixed points to the nearest tenth of a second. Each day that a measurement set is done, the angle is measured 12 times and the average determined. The amount of slip between measurements can be calculated trigonometrically using the change in average angle.

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 remeasure most of our sites about once every two months.

The following is a brief summary of our results thus far:

Seal Cove-San Gregorio fault - We began our measurements on the Seal Cove fault in Princeton in November 1979. 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 past 17 months, however, our measurements indicate virtually no additional net movement.

Following the difficulty of finding a logistically acceptable spot on the San Gregorio fault, we established a site on Pescadero Road in San Mateo County in May 1982 that requires a particularly long theodolite shot (about 450 meters). After two remeasurements, there has been a net right lateral slip of about six millimeters in the past seven months. However, any conclusions regarding slip characteristics of the San Gregorio fault are premature. Additional data need to be gathered over a longer period of time before meaningful interpretations can be made.

San Andreas fault - Since March 1980, our site in South San Francisco has shown a net right lateral slip of about one millimeter. This indicates that the San Andreas fault is virtually locked in the San Francisco area. Our site in the Point Arena area showed a slightly more than one millimeter of right lateral slip between January 1981 and January 1982.

Calaveras fault - We began monitoring the Calaveras fault at two sites in the Hollister area in September and October 1979. Slip in this area is quite episodic with times of relatively rapid right lateral movement alternating with times of little net movement. For the past three years, there has been an overall average of about a centimeter per year of right lateral slip at our site within the City of Hollister and about a centimeter and a half per year for our site 2.3 kilometers to the northwest. These results indicate that the Calaveras fault in the Hollister area is the most rapidly creeping fault in the San Francisco Bay region. In contrast, our site in San Ramon near the northwesterly extent of the Calaveras fault has shown little movement. During the past two years, there has been a net right lateral slip of about two millimeters.

Rodgers Creek fault - Since we began our measurements on the Rodgers Creek fault in Santa Rosa in August 1980, there has been an overall net left lateral movement of a few millimeters. However, our results show large variations in the amounts and directions of movement from one measurement day to another which are probably due to seasonal and/or gravity-controlled mass movement effects, not tectonic slip.

West Napa fault - Since we began our measurements on the West Napa fault in Napa in July 1980, the overall net movement has been about a millimeter in a left lateral sense. Similarly to our results for the Rodgers Creek fault, however, large variations between measurement days have occurred. We hope that continued monitoring of the West Napa fault will help sort our tectonic creep from other possible effects.

Hayward fault - We began our measurements at sites in Fremont and Union City in late September 1979. In the 40 months since then, the average rate of right lateral slip has been 3.1 millimeters per year in Fremont and 4.8 millimeters per year in Union City. Periodic aberrations involving apparent left lateral slip have also occurred at both these sites. U.S.G.S. creepmeter data from Fremont also suggest an overall average rate of right lateral slip between three and four millimeters per year and also show aberrations in direction of movement.

We began our measurements at two sites within the City of Hayward in June 1980. Over the past two and one-half years, the average rate of right lateral slip has been between 3.8 to 3.9 millimeters per year at both sites. U.S.G.S. creepmeters in Hayward also show a rate of about four millimeters per year over the same time interval.

We began measurements in San Pablo near the northwestern terminus of the Hayward fault in August 1980. Although there have been changes of several millimeters between successive measurement days, there has been virtually no net slip in the past two and one-half years.

In summary, both our theodolite data and U.S.G.S. creepmeter data indicate that the Hayward fault in the Hayward to Fremont area has been moving at a rate of about four millimeters per year for the past several years.

Concord fault - We began our measurements at two sites on the Concord fault in the City of Concord in September 1979. Both sites showed about a centimeter of right lateral slip during October and November 1979, perhaps the greatest amount of movement in a short period of time on this fault in the past two decades. In the three years since the rapid slip, both sites have shown additional right lateral movement of only about one to two millimeters per year.

Antioch fault - We began our measurements at the more southeasterly of our two sites on the Antioch fault in the City of Antioch in January 1980. After measuring a few millimeters of apparent left lateral slip, we measured about a centimeter and one-half of right lateral slip in the six-month period from May through October 1980. During the next year and one-half we measured a net of about half a centimeter of additional right lateral movement. A tendency toward left lateral displacement seems to occur toward the end of one calendar year and/or beginning of the next. This seasonal effect has occurred three times at our southeasterly site. Where the fault zone appears to be less specifically delineated at our northwesterly site, we have measured virtually no net slip since we began measurements in May 1980. Much subsidence and mass movement creep are occurring inside and outside the Antioch fault zone and it is probable that these nontectonic movements are influencing our theodolite results for this fault.

Central California Network Operations

9930-01891

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Investigations

1. Maintenance and recording of 375 seismograph stations, located in northern California and Oregon. The area covered is approximately 83,000 square miles. Recording 20 tiltmeter, 4 strainmeter, and 18 creepmeter sites.

Results

1. Wired in 420 seismic analog discriminator outputs to tustin AD converter.

2. New Seismic Stations Installed:
   11 new stations in Shasta-Lassen area
   4 new stations in Mammoth area
   1 station in southern Oregon.

3. Completed work on new RFP for outside maintenance contract with Procurement and Contracts office.

4. Completed updated version of "Seismic System Procedures Manual".

5. Completed fabrication of 100 ea. DC-DC converters.

6. Converted approximately 15 seismic stations from air cell powered to solar power.

7. Field testing 12 solar powered VCO's.

Instrument Development and Quality Control

9930-01726

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Investigations

This project supports other projects in the Office of Earthquakes, Volcanoes, and Engineering 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-basis.

Results

A new Tustin A/D converter was received and installed on the Calnet on-line PDP11/34 system. Shortly thereafter additional Calnet stations were added to the digitizer inputs to increase the total number of active channels from 144 to 420. The old Tustin A/D has been returned to the manufacturer to be modified to match the new one. A system similar to the Calnet on-line digitizer but using a PDP11/44 to be installed in China was set-up and tested here. This involved simulating Chinese power conditions and seismic inputs. A prototype of a seismic computer/digitizer system to be deployed in Jordan has been set-up here. Seismic and timing inputs have been installed and software development is proceeding.

Telemetry to Menlo Park has reestablished from the radon station at San Juan Bautista after being lost due to several configuration changes. A 12 channel low-noise preamplifier system was constructed and is currently in use with two GEOS recorders to monitor down-hole seismometers in Oroville. Design of a hardware implementation of a teleseismic trigger to be used with any recorder has been initiated.

Numerous terminal lines and related computer communications equipment have been installed. During this period the Seismic Cassette Recorder (SCR) system was operated and maintained at Shasta and Mammoth Lakes. Twenty new SCR's have been made operational and were added to the system for the Mammoth project. Construction of 200 new J110 discriminators was completed. Turning and installation is in progress. Repair or alignment of 100 radio transmitters or receivers and calibration of approximately 120 seismometes were preformed during this period.

Southern California Cooperative Seismic Network

9930-01174

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Investigations

1. Routine processing using stations of the southern California cooperative seismic network was continued for the period October 1982 through March 1983. Routine analysis includes the timing of phases, event location and preliminary catalog production using the newly developed CUSP analysis system.

2. We are proceeding with the development of a southern California earthquake prediction data base. Geophysical data (e.g., seismicity, strain, tilts, radon, water levels) are collected from a variety of researchers in southern California.

3. We are continuing operation of a system for the timely recognition of anomalous activity of southern California water wells. Yearly requests are mailed to private and municipal water companies requesting that anomalous activity be immediately reported to our staff. These data are logged and, if necessary, further investigation is conducted.

Results

1. In Indian Wells Valley, the decrease in activity following a magnitude 5.2 event on 01 October 1982 was interrupted by a swarm of earthquakes arising from two spatially distinct areas in central Indian Wells Valley. Activity peaked on 01 January 1983. The largest events in the January sequence were two M_L 4.0 events on 31 December 1982 and 04 Janaury 1983. There were 44 M_L 2.5 and larger earthquakes during the period 31 December 1982 through 08 January 1983. Of these, 17 events were M_L 3.0 or greater. While the activity has been spatially stationary, there has been a gradual decline in the number of events; Mid January averaged 14 events exceeding M_L 2.0 per week while late March averaged 10 events per week.

2. The development of the CUSP routine data analysis system was continued. The data capture function was completed during March. Preliminary testing at Menlo Park has demonstrated a system capacity of 510 seismic channels at a sampling rate of 100 hz. This provides a throughput of 51000 samples per second requiring roughly 50% of available CPU time for detection and spooling of detected events to digital magnetic tape. Completion of the analysis portion of the CUSP system is anticipated during the third quarter.

3. A 32-station RTP (real time picker) was installed in early January to closely monitor evolving seismicity patterns in Indian Wells Valley. The output of the RTP is integrated with the CUSP routine analysis system providing a daily assessment of changes in seismicity. During the second quarter the RTP has provided locations for more than 1000 earthquakes per month.

References

Given, D.D., R.S. Dollar, and C.E. Johnson, 1983, An unusual sequence of swarms in Indian Wells Valley, southern California, Earthquake Notes, vol. 53, No. 2, p. 38.

Heaton, T.H., and H.L. Liu, 1983, Array analysis of ground velocities and accelerations from the 1971 San Fernando earthquake, Earthquake Notes, vol. 53, No. 2, p. 57.

Heaton, T.H., and A.W. Mori, and H. Kanamori, 1983, A comparison of strong ground motions recorded in Japan and the western U.S., Earthquake Notes, vol. 53, No. 2, p. 57.

Hill, D.P., R.S. Cockerham, J.P. Eaton, W.L. Ellsworth, A.G. Lindh, C.R. Allen, L.K. Hutton, C.E. Johnson, A.M. Rogers, W.J. Carr, and A.S. Ryall, 1983, Seismicity along the Pacific - North American plate boundary in California and western Nevada, 1980-1981, Earthquake Notes, vol. 53, No. 2, p. 46.

Johnson, C.E., 1983, CUSP - automated processing and management for large regional seismic networks, Earthquake Notes, vol. 43, No. 2, p. 13.

Earthquake and Seismicity Research Using SCARLET and CEDAR

Contract No. 14-008-0001-21210

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Investigations

Research supported wholly or in part by this contract during the six-month reporting period from October 1, 1982 to March 31, 1983 concentrated on:

1. Determination of rupture duration and stress drop for earthquakes in Southern California.
2. The three-dimensional seismic structure beneath Southern California.

Results

1. Determination of rupture duration and stress drop for earthquakes in Southern California.

We have completed this study and a paper has been written (Frankel, A., and H. Kanamori, Determination of rupture duration and stress drop for earthquakes in Southern California). The manuscript has been submitted to the Bulletin of the Seismological Society of America.

A simple technique is developed for determining the rupture duration and stress drop of earthquakes between magnitudes 3.5 and 4.0 using the time between the P-wave onset and the first zero crossing ($\tau 1/2$) on seismograms from local seismic networks. This method is applied to ten mainshocks in Southern California to investigate regional variations in stress drop. The initial pulse width of 65 foreshocks or aftershocks of these events was measured. Values of $\tau 1/2$ for small earthquakes below about magnitude 2.2 are generally observed to remain constant with decreasing magnitude in four sequences studied. The relative pulse width of a particular mainshock ($M \geqslant 3.5$) at a given station is found to be correlated with the relative pulse width of its aftershocks recorded at that station. These observations are interpreted to signify that the waveforms of these small events ($M \geqslant 2.2$) are essentially the impulse response of the path between the source and receiver. Values of $\tau 1/2$ determined from small foreshocks and aftershocks are, therefore, subtracted (in effect deconvolved) from those of each mainshock to obtain an estimate of the rupture duration of the mainshock which is corrected for path effects.

Significant variations in rupture duration and stress drop are observed for the mainshocks studied (Figure 1). Aftershock locations and $\tau 1/2$ both indicate that the rupture zone of one earthquake expanded unilaterally. A factor of ten variation in stress drop is calculated for two adjacent events of similar seismic moments occurring one hour apart on the San Jacinto fault system. The first event in this pair had the highest stress drop of the events studied (860 bars) and was followed within eight months by a magnitude 5.5 earthquake two km away.

2. A Tomographic Inversion of Teleseismic P Delays Below the Transverse Ranges

An investigation of teleseismic P arrivals to the Southern Califonia Seismic Array has resulted in a determination of the variations in seismic P velocity below Southern California to a depth of 500 km. A tomographic method of inversion was used on relative P delays for about 8000 rays well distributed in azimuth and ranging in slowness from 0 to 10 sec/deg. The tomographic method allows for a fairly detailed inverse; in this case the inversion was done with nearly 2500 bins, each approximately cubic and about 50 km on a side. Teleseismic rays cannot resolve absolute velocity or changes which may occur at a given depth across the entire study region, but given a reference "background" velocity model can resolve local perturbations to the reference model. The deviations in bin velocity range from plus or minus 2.5% of the average reference model velocity to account for a net delay of plus or minus 1 second of travel time. The most pronounced feature is a high velocity region roughly below the Transverse Ranges apparently extending in depth to at least 500 km, with the maximum of the anomaly at about 150 km depth. The shallow features of this anomaly appear to align with the strike of the Transverse Ranges while the deeper parts follow a more north-south strike.

This work has been presented by E. D. Humphreys at the 76th annual meeting of the Seismological Society of America, held in Salt Lake City, Utah.

Reports and Publications

Pechmann, J. C. and H. Kanamori, Waveforms and spectra of preshocks and aftershocks of the 1979 Imperial Valley, California earthquake: A test of the asperity model, J. Geophys. Res, 87, No B13, 10,579-10,597, 1982.

Sauber, J., K. C. McNally, J. C. Pechmann, and H. Kanamori, Seismicity near Palmdale, Caliornia, and its relation to strain changes. J. Geophys. Res., 88, No. B3, 2213-2219, 1983.

Abstracts

Humphreys, E. D., A tomographic inversion of teleseismic P delays below the Tranverse Ranges, Earthquake Notes, 54, No. 1, 66, 1983.

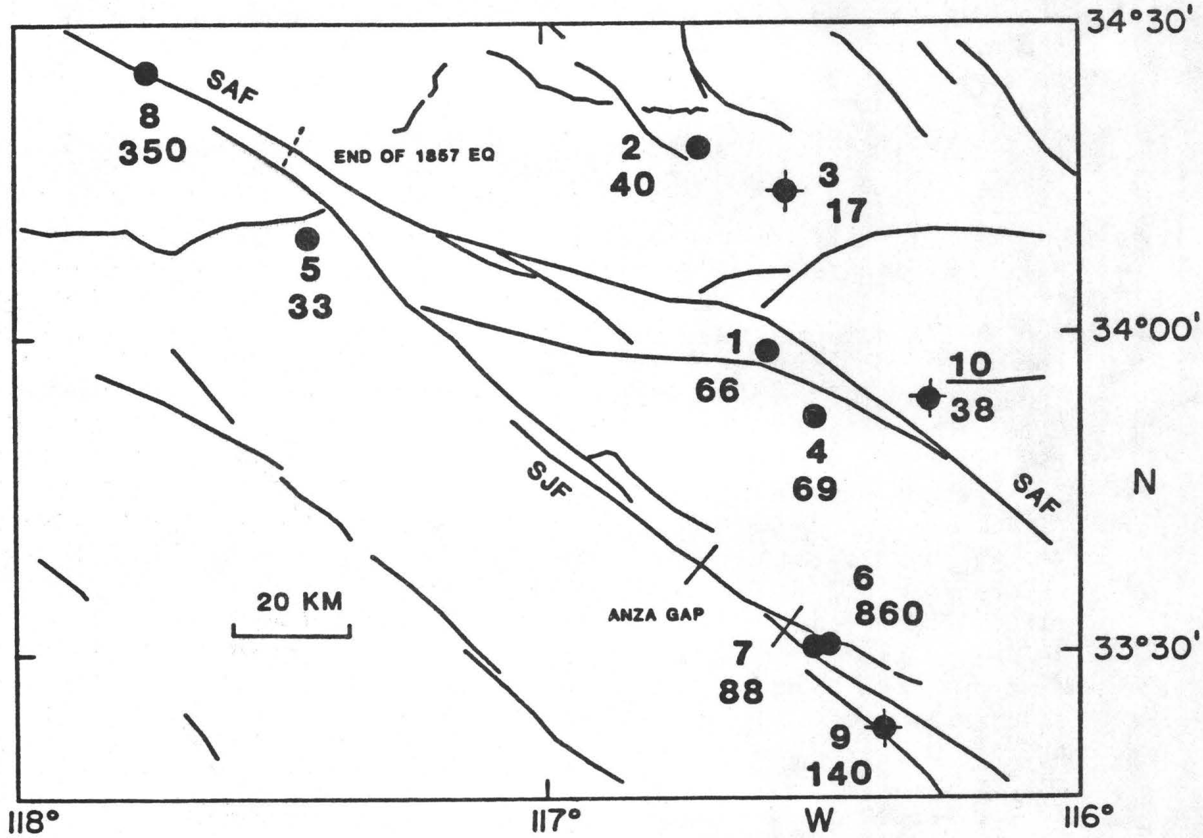

Figure 1. Locations of the events studied. The event number (upper) and the stress drop (lower) are shown. Note the proximity of event 6 with the 860 bar stress deop (#6) to event 7 with a 88 bar stress drop.

Seismological Study on Rupture Mode of Seismic Gaps

Contract No. 14-08-0001-21223

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Investigations

Research supported wholly or in part by this contract during the six-month reporting period (October 1, 1982, to March 31, 1983) includes:

1. Analysis of body waves from the Loyalty Islands sequence in October, 1980.
2. Analysis of long-period surface waves from the events of the 1980 Santa Cruz Islands sequence.

Results

1. Analysis of body waves from the Loyalty Islands sequence in October, 1980.

As we have reported earlier, four large earthquakes occurred in 1980 in a seismic gap of category 2 (McCann, 1980) near the Loyalty Islands in the New Hebrides. At 3:25 on October 24 an event with M_s = 6.7 initiated the sequence. Three events, M_s = 6.7, 7.2, and 6.5, followed on the next day. We investigated the expansion pattern of the aftershock area, and suggested that the initial rupture zone represents a zone of increased strength (i.e. an asperity), and the stress change due to failure of this asperity subsequently migrated outward. In order to understand the details of the rupture mode of this sequence, we analyzed the body waves from the largest event of this sequence.

The source time function and the body wave moment are estimated by comparison of the observed and synthetic seismograms. The observed waveforms are digitized from film chips of long-period WWSSN records for COL, KIP, LON, and MSO. All four stations are well away from nodes in the focal mechanism radiation pattern. We found that a source process time of 11 sec fits the observed records best. The amplitudes of the records for COL, KIP, LON, and MSO yield body wave moments of 0.28, 0.48, 0.36, and 0.22 x 10^{27} dyne-cm, respectively. The body wave moment is between 11 and 24% of the 256 second period surface wave moment of 2 x 10^{27} dyne-cm. These results substantiate our earlier conclusions.

2. Analysis of long-period surface waves from the events of the 1980 Santa Cruz Islands sequence.

A sequence of three large earthquakes (M_s = 7.5, 6.7, and 7.9) occurred in the Santa Cruz Islands region, from July 8 to 17, 1980. Regionally, the epicentral area of this sequence had been assigned a relatively low seismic potential. We have investigated the rupture mode of this sequence. As a part of this study we made detailed analyses of surface waves from these events. The results are summarized in the following table.

Event	ϕ_1	δ_1	λ_1	ϕ_2	δ_2	λ_2	Mo (10^{27} x dyne-cm)
July 8, 1980	168^o	60^o	90.5^o	-13.0^o	30.0^o	89.1^o	1.9
July 9, 1980	172^o	68^o	98.8^o	-30.5^o	23.6^o	69.3^o	0.13
July 14, 1980	165^o	54^o	89.0^o	-13.3^o	36.0^o	91.4^o	5.6

ϕ = strike δ = dip λ = rake

Carbon Fiber Strainmeter Studies in Southern California

14-08-0001-19760

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Investigations

A network of nine carbon fiber strainmeters at six sites in the San Gabriel Mountains continuously records crustal events in the Palmdale, California area of the San Andreas fault.

Results

The current six-site, nine-instrument carbon fiber strainmeter net (Figure 1) was begun in 1978 at Bouquet Reservoir (BQ) as an independent USC/Lamont observational program. During the spring and summer of 1981, USC located half a dozen additional suitable tunnel sites in the San Gabriel Mountains (AW, 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 Jackson 155° instrument (JK) sites for 1982 is shown in Figure 2.

Occasionally a large scale quantifiable strain source is recorded on a strainmeter. This is the case for the Bouquet (BQ) instruments. Records for one quasi-static cycle and one rapid cycle of reservoir loading and unloading are shown in Figure 3. The reservoir and strain curves are normalized for the first (quasi-static) cycle and show a dramatic instance of rate-dependency and possibly amplitude dependency of crustal response to the draining of the reservoir in the spring of 1981 and the refilling of the reservoir in winter of 1982.

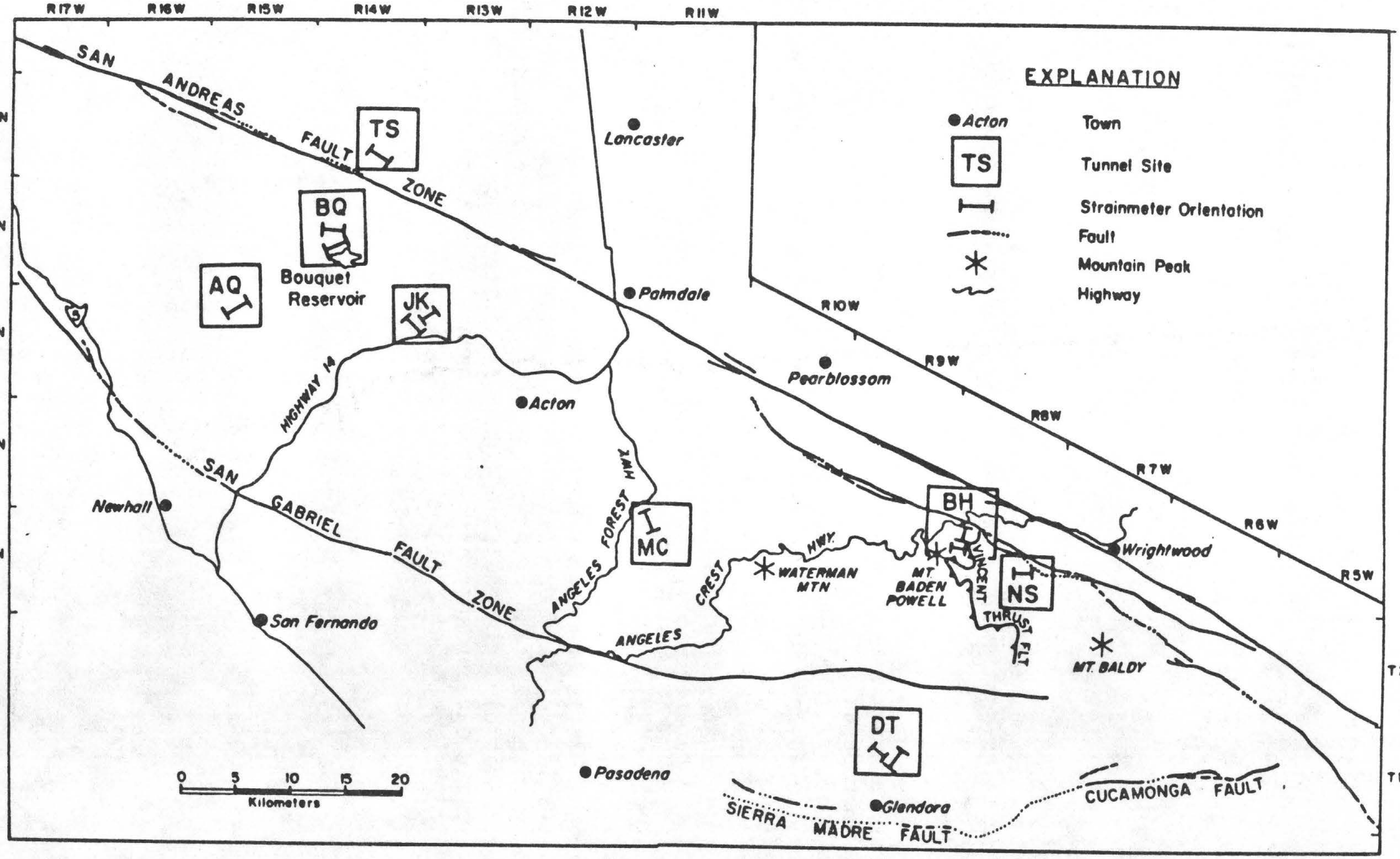

Figure 1. Location map for carbon fiber strainmeter array in San Gabriel Mountains of southern California.

P1

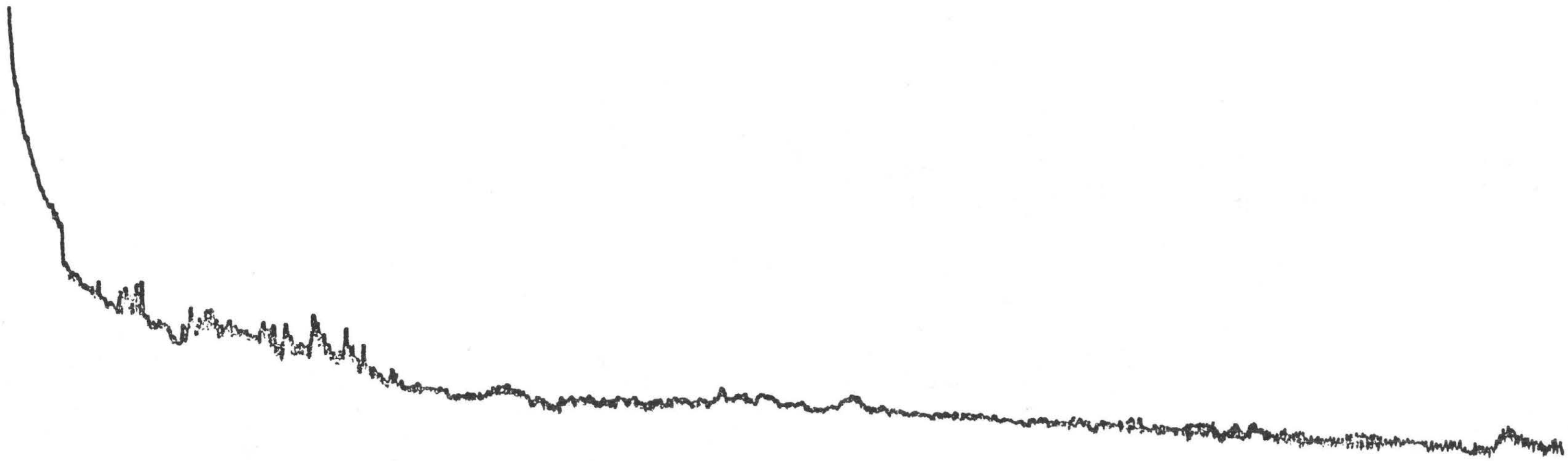

Figure 2. Jackson (155°); data interval February 9 - December 10, 1982; early structure is instrument curing; large thermal signal in early record reduced by blocking tunnel and insulating instrument; tunnel is dry, so no effect from rainfall. Time scale is 1 page = 10" = 1 year. Amplitude scale is given by tidal signal.

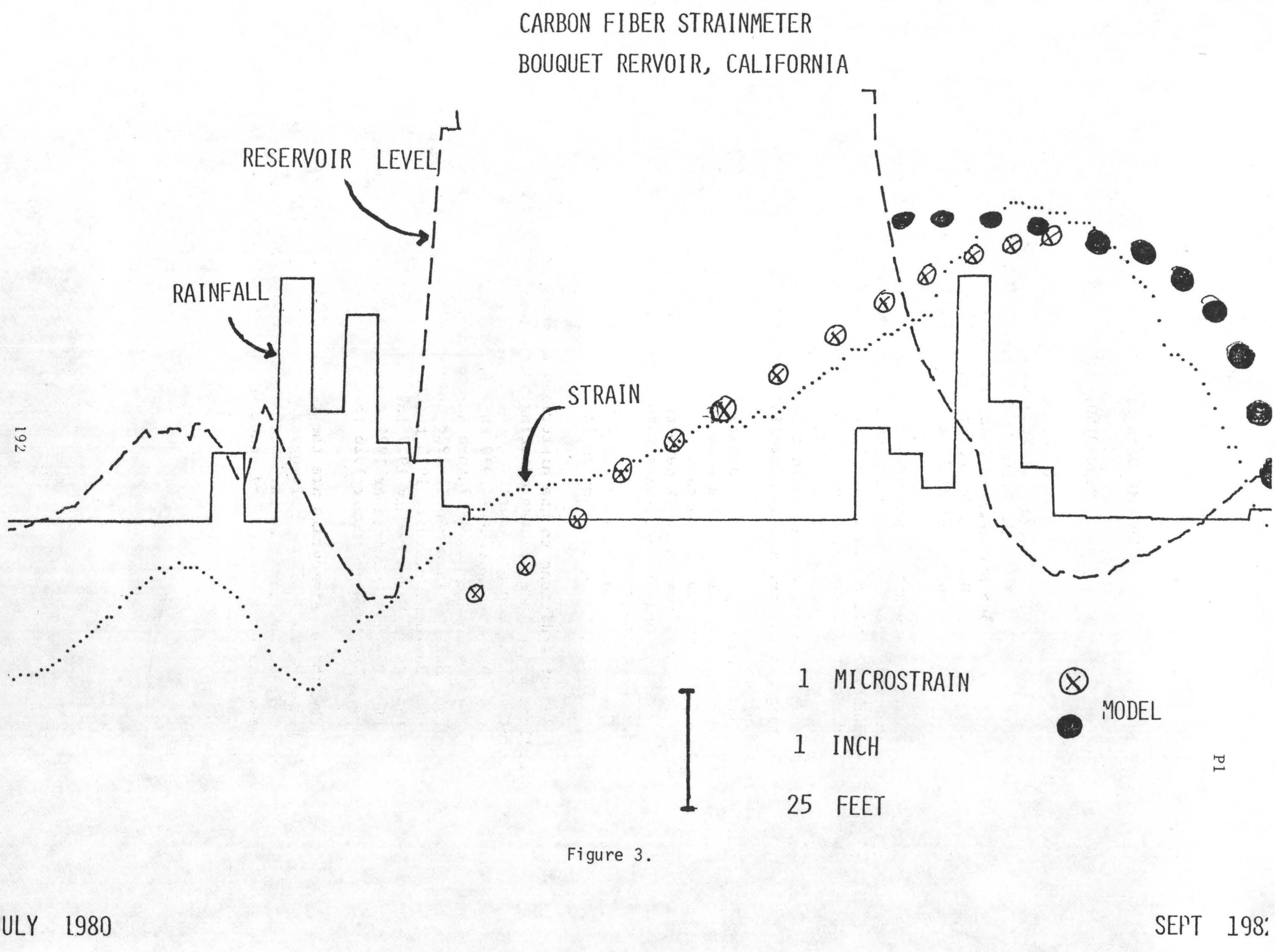
CARBON FIBER STRAINMETER
BOUQUET RERVOIR, CALIFORNIA
RESERVOIR LEVEL
RAINFALL
STRAIN
1 MICROSTRAIN
1 INCH
25 FEET
MODEL
JULY 1980
SEPT 198

Figure 3.

Seismic Data Library

9930-01501

W. H. K. Lee
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345 Middlefield Road, Mail Stop 77
Menlo Park, California 94025
(415) 323-8111, extension 2630

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

Major holding of the seismograms are:

(1) WWNSS film chips and fiches (1963-present)--about 4,000,000 seismograms.
(2) USGS local network develocorder films (1966-1979)--equivalent to about 1,500,000 seismograms.
(3) Historical seismograms (1903-present)--about 350,000 seismograms so far.

Recent additions to the historical seismograms collection include all the existing seismograms of the following Caltech stations:

(1) Haiwee--September 1929 thru April 1939.
(2) La Jolla--May 1927 thru August 1939
(3) Mount Wilson--April 1928 thru October 1939.
(4) Pasadena--January 1923 thru April 1934.
(5) Santa Barbara--May 1927 thru August 1939.
(6) Tinemaha--September 1929 thru August 1939.
(7) Riverside--October 1926 thru September 1939.

The above seismograms are the results of a major effort to film all the Caltech seismograms since the beginning of the Caltech Seismic Network. So far, about 100,000 seismograms have been filmed under the supervision of Dr. J. Goodstein of Caltech.

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. From September to December of 1982, I investigated the present technology in storing and processing seismic data, and had also continued the development of an archiving and retrieval system for earthquake data. From January to March of 1983, I was very ill and was mostly absent from work.

Results

Results of my investigations for this period have been presented in the following two papers:

(1) I was invited to Centenial International Symposium of the Geological Survey of Japan, and presented a paper on the importance of an international earthquake data bank on December 15, 1982.

(2) I chaired the IASPEI/UNESCO Regional Workshop on Historical Seismograms held at the University of Tokyo, and presented a paper on the Historical Seismogram Filming Project and progress towards an international earthquake data bank on December 20, 1982.

Reports

Lee, W. H. K., 1982. Historical Seismogram Filming Project and progress towards an international earthquake data bank, in Program and Abstracts, Regional Workshop of IASPEI/UNESCO Working Group on Historical Seismograms, Earthquake Research Institute, University of Tokyo, Tokyo, Japan, p. 1-20.

Lee, W. H. K., 1982. The importance of an international earthquake data bank (abs.): International Symposium celebrating the 100th Anniversary of the Geological Survey of Japan, Japan.

LaForge, R., and Lee, W. H. K., 1982. Seismicity and tectonics of the Ortigalita fault and southeast Diablo Ranges, California: Special Publication 62, California Division of Mines and Geology, p. 93-101.

Northern California Network Processing

9930-01160

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Investigations

Signals from 425 stations of the multipurpose Northern California Seismic Network (Calnet) are telemetered continuously to the central laboratory facility in Menlo Park where they are recorded, reduced, and analyzed to determine the origin times, magnitudes, and hypocenters of the earthquakes that occur in or near the network. Data on these events are presented in the 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 further research in seismicity, earthquake hazards, and earthquake mechanics and prediction. A magnetic tape library of "dubbed" unprocessed records of the network for significant local earthquakes and teleseisms is maintained to facilitate further detailed studies of crust and upper mantle structure and physical properties, and of the mechanics of earthquake sources.

Results

1. Figure 1 shows the seismic activity of Northern California for the period October 1, 1982 through March 31, 1983. The 4112 earthquakes plotted are all locations using 4 or more phase readings in the solution, exclusive of the area in and around the Long Valley Caldera. The phase readings were obtained either by hand timing or by the Real Time Picker (RTP) or they are a combination of both sources. The Coast Ranges have been screened for quarrys and those data have been eliminated. Identification of quarrys in the Sierra Nevada Foothills is a constant problem so that all quarry data have not yet been eliminated from the catalog. We feel that the catalog of location data maintained by Calnet is relatively complete for earthquakes M 1.5 and larger.

2. Data for the second half of calendar year 1982 are completely processed and have been prepared for open-file publication in May 1983. Processing of data for the first half of calendar year 1978 is nearly complete and the data should be open-filed in the summer of 1983.

3. As a result of Volcano Hazards Notice released on May 27, 1982, for the Long Valley Caldera (LVC) area of eastern California special attention has been placed on the monitoring of seismic activity by R. Cockerham and A. M. Pitt. Figure 2 shows 4765 earthquakes located in the region since October 1, 1982. On January 7, 1983 a swarm of earthquakes began 4 km ESE of the town of Mammoth Lakes. This swarm included 2 earthquakes larger than magnitude 5 (5.3 and 5.6) and produced a sixfold increase in the number of earthquakes located in the LVC in an average month. Initial activity and the 2 magnitude 5+ events occurred in the SW moat of the caldera. A second area of activity, 6 km SE of the first area, became active after the occurrence of the first magnitude 5+ event (M 5.3). These two clusters presisted during the swarm with few events locating between the clusters. Focal depths of these earthquakes ranged from 2 km down to 10 km. This is the usual range of depth for events located in the LVC since May 1982. Location errors are believed to be 1 km in both a vertical and horizontal sense. Investigations are currently underway to determine the mechanism that produced these earthquakes, particularly the swarm activity.

4. Beginning December 1, 1982 10 new seismic stations were installed in the area around Lake Shasta, California. These were installed in an effort to monitor the seismicity in the vicinity of Shasta Dam for the Bureau of Reclamation. Little is known about the historical seismicity of this area except for some poor locations that were determined using readings from distant stations near Mount Shasta and in Lassen Park. Data from these 10 new stations are currently being telemetered to Menlo Park and a scheme is being developed for routinely processing these data. Once developed this procedure will be incorporated into the general processing and analysis scheme used for the rest of the network data.

5. <u>November 8, 1980, Eureka earthquake aftershocks</u>
Phase data for aftershocks larger than M 2.5 were obtained from the PG&E Humbolt Bay Network and additional Calnet and 5-day-recorder tapes were played back and read in an attempt to complete the data set for aftershocks larger than M 2.5 for the period November 8 through December 3. Most of the 137 events added in this process occurred before the 3-component 5-day-recorder stations were installed, beginning on November 10. The augmented data set provides a more comparable and balanced picture of the temporal evolution of the aftershock sequence, but it does not alter the pattern of aftershock distribution.

A plot of log N vs MA, figure 3, fits the line log N = 4.3 - 0.73 MA between M2.5 and M4.8, where N is the cummulative number of events larger than MA and MA is the USGS local earthquake magnitude based on maximum recorded amplitude and associated period. The processing cutoff at M2.5 is reflected in the sharp drop in the frequency of located events smaller than M2.5.

Magnitudes determined by the Humbolt Bay Network are calculated from record durations at one or more stations according to the equation M_D = 2.46 + 2.82 log D, where D is the duration at one or more stations according to the equation M_D = -2.46 + 2.82 log D, where D is the duration, in seconds, of motion above background level. A plot of M_D vs MA for 408 events, figure 4, yields the relationship M_D = -0.04 + 1 MA, with a standard deviation of 0.37. There appears to be no systematic difference bewteen the magnitudes determined by the two methods.

The pattern of aftershocks of the 1980 earthquake, figure 5, contrasts sharply with patterns of ongoing seismic activity in the same region during 1981 and 1982, figure 6. These two maps may illustrate complementary processes in the disruption and subduction of the southeastern corner of the Gorda Plate.

Reports

Allen, R. V., and Pitt, A. M., 1983, Realtime monitoring of the Mammoth Lakes, California earthquake with automatic processing equipment, Earthquake Notes, vol. 54, no. 1, p. 14.

Hill, D. P., Cockerham, R. S., Eaton, J. P., Ellsworth, W. L., and Lindh, A. G., 1982, Seismicity along the Pacific-North American plate boundary in California and Western Nevada, 1980-81: Earthquake Notes, vol. 54, no. 1, p. 46.

Julian, B. R., and Cockerham, R. S., 1983, Mechanisms of the May 1980 earthquakes near Long Valley Caldera, California: Evidence for dike injection: Earthquake Notes, vol. 54, no. 1, p. 88.

Pitt, A. M., and Cockerham, R. S., 1983, Long Valley Caldera earthquake swarm: January 7, 1983, Earthquake Notes, vol. 54, no. 1, p. 73.

Wallace, R. E., Hill, D. P., Ryall, A. S., and Cockerham, R. S., 1983, Potential for large earthquakes in the central Nevada-eastern California seismic belt: Earthquake Notes, vol. 54, no. 1, p. 46.

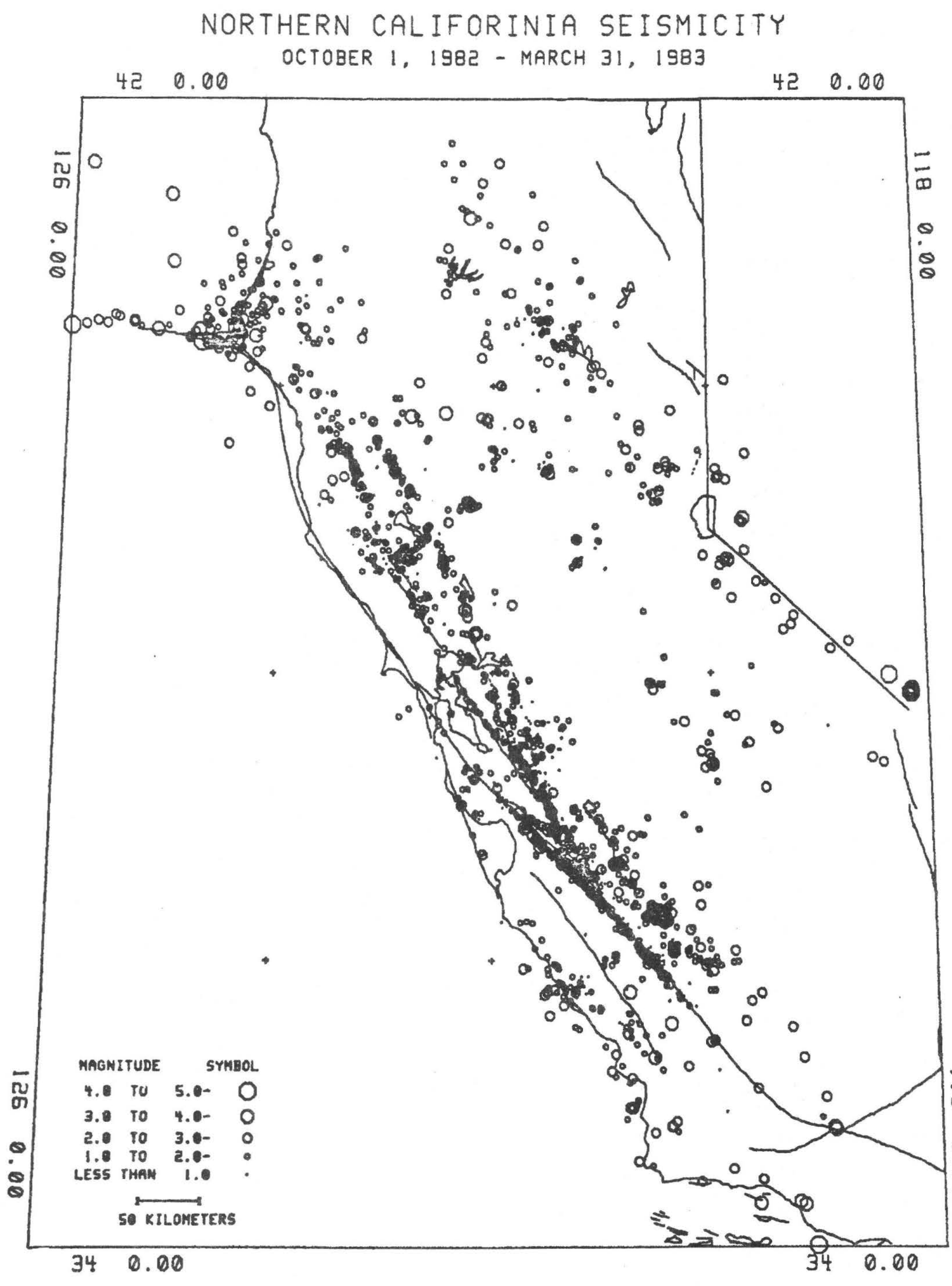
NORTHERN CALIFORINIA SEISMICITY
OCTOBER 1, 1982 - MARCH 31, 1983
42 0.00
42 0.00
126 0.00
118 0.00
126 0.00
118 0.00
34 0.00
34 0.00
MAGNITUDE SYMBOL
4.0 TO 5.0-
3.0 TO 4.0-
2.0 TO 3.0-
1.0 TO 2.0-
LESS THAN 1.0
50 KILOMETERS

FIGURE 1

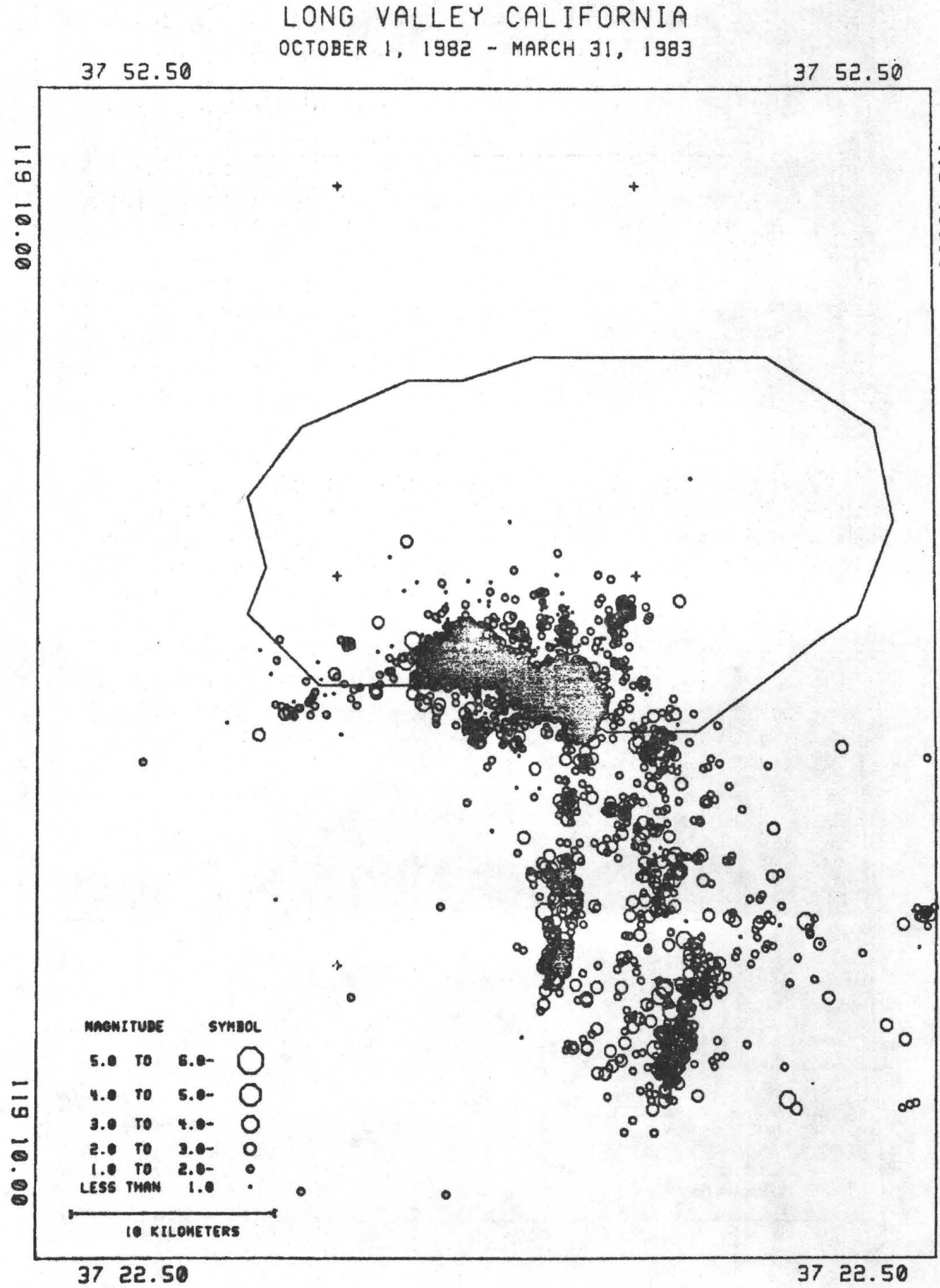
LONG VALLEY CALIFORNIA
OCTOBER 1, 1982 - MARCH 31, 1983
37 52.50
37 52.50
119 10.00
118 40.00
119 10.00
118 40.00
MAGNITUDE SYMBOL
5.0 TO 6.0-
4.0 TO 5.0-
3.0 TO 4.0-
2.0 TO 3.0-
1.0 TO 2.0-
LESS THAN 1.0
10 KILOMETERS
37 22.50
37 22.50

FIGURE 2

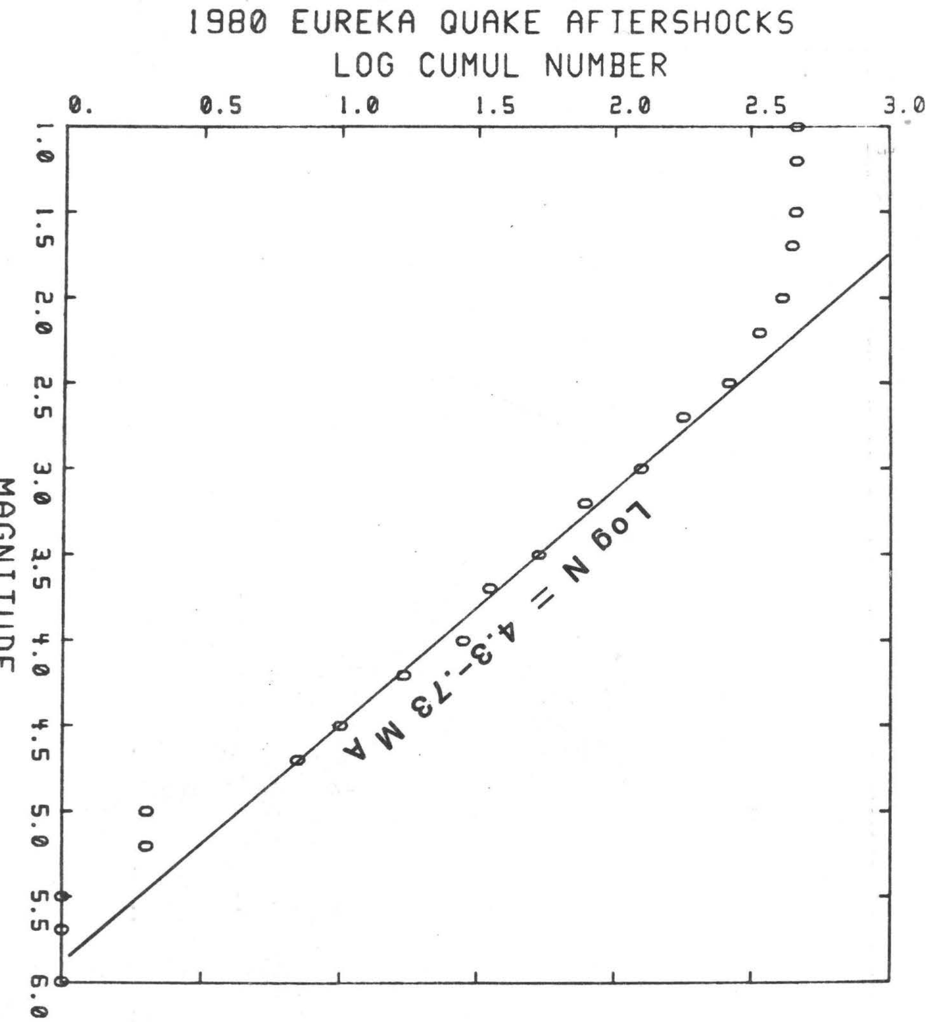
1980 EUREKA QUAKE AFTERSHOCKS
LOG CUMUL NUMBER
0.
0.5
1.0
1.5
2.0
2.5
3.0
MAGNITUDE
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
Log N = 4.3-.73 M A

FIGURE 3

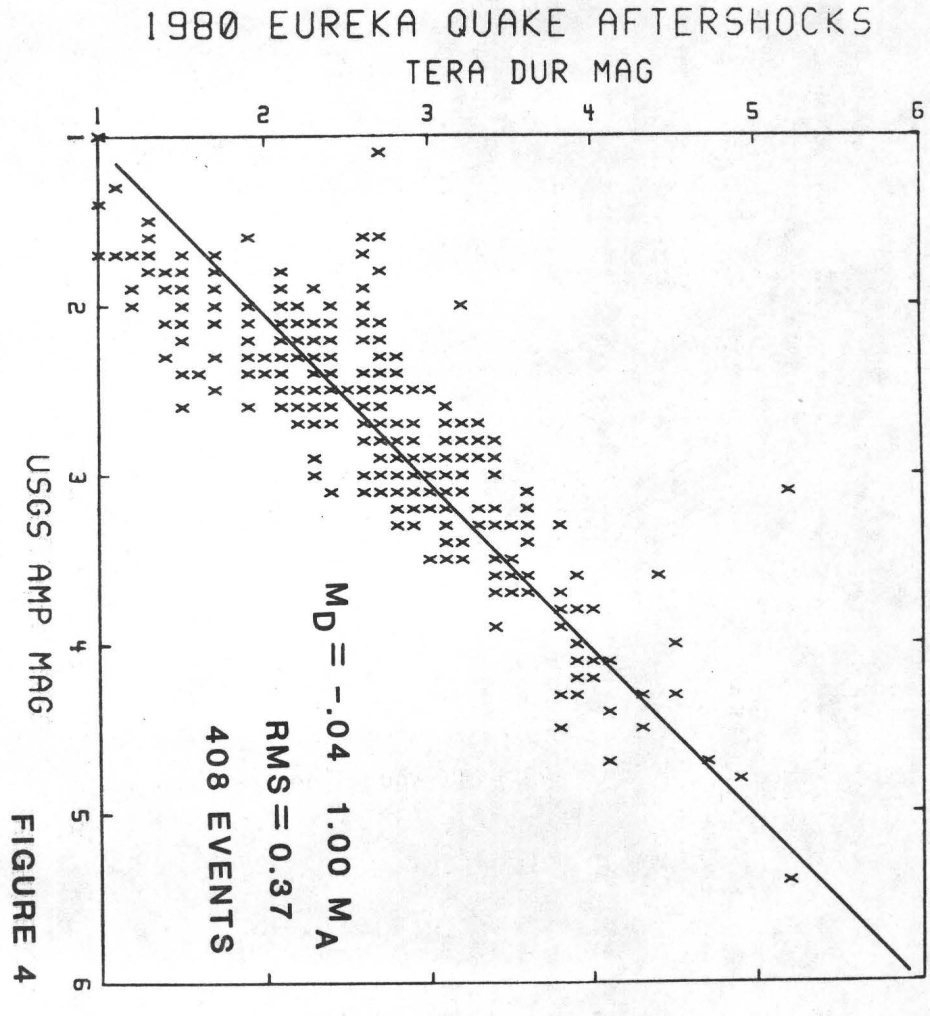
1980 EUREKA QUAKE AFTERSHOCKS
TERA DUR MAG
USGS AMP MAG
$M_D = -.04 \quad 1.00 \ M_A$
RMS = 0.37
408 EVENTS

FIGURE 4

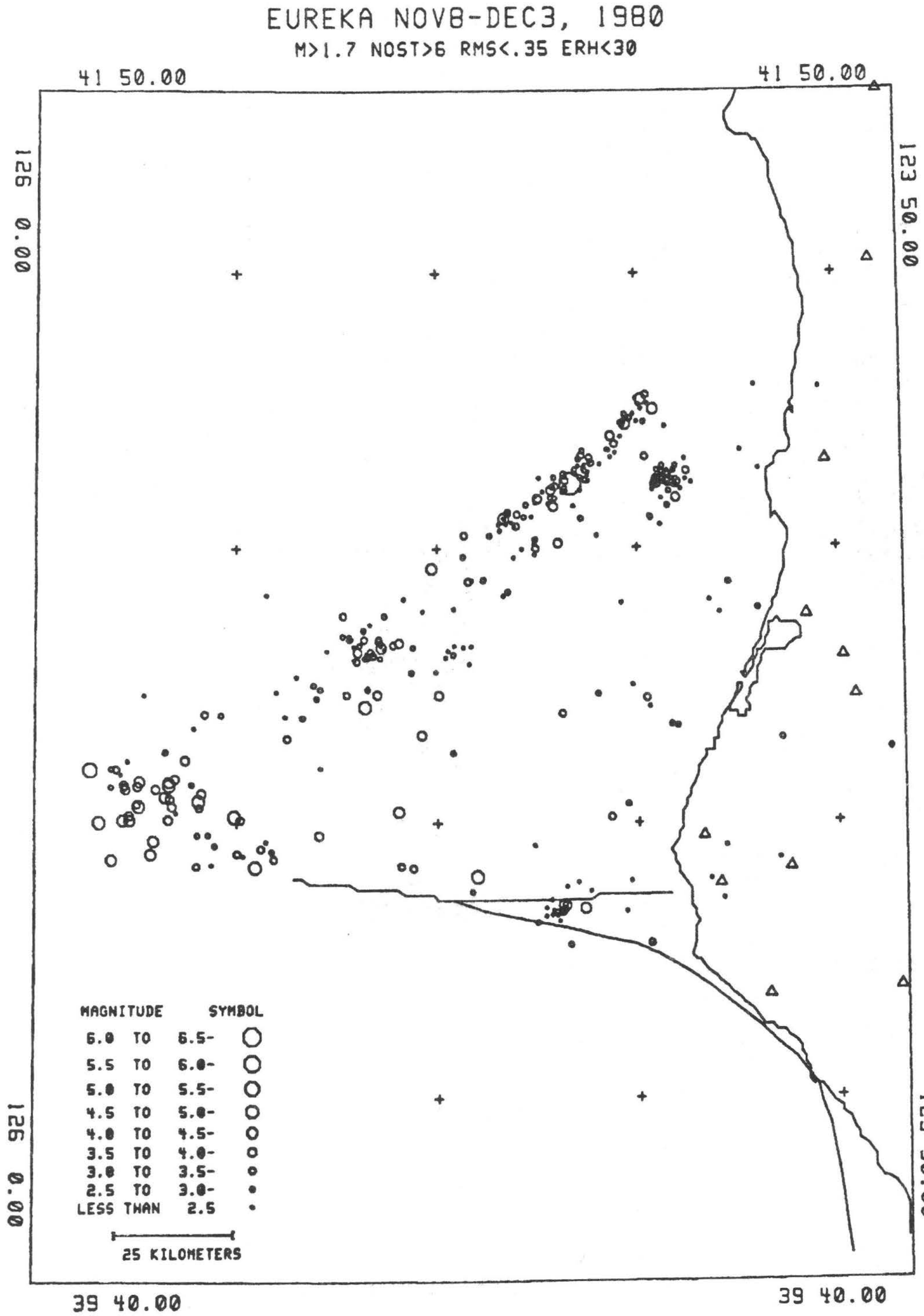
EUREKA NOV8-DEC3, 1980
M>1.7 NOST>6 RMS<.35 ERH<30
41 50.00
41 50.00
126 0.00
123 50.00
126 0.00
123 50.00
39 40.00
39 40.00
MAGNITUDE SYMBOL
6.0 TO 6.5-
5.5 TO 6.0-
5.0 TO 5.5-
4.5 TO 5.0-
4.0 TO 4.5-
3.5 TO 4.0-
3.0 TO 3.5-
2.5 TO 3.0-
LESS THAN 2.5
25 KILOMETERS

FIGURE 5

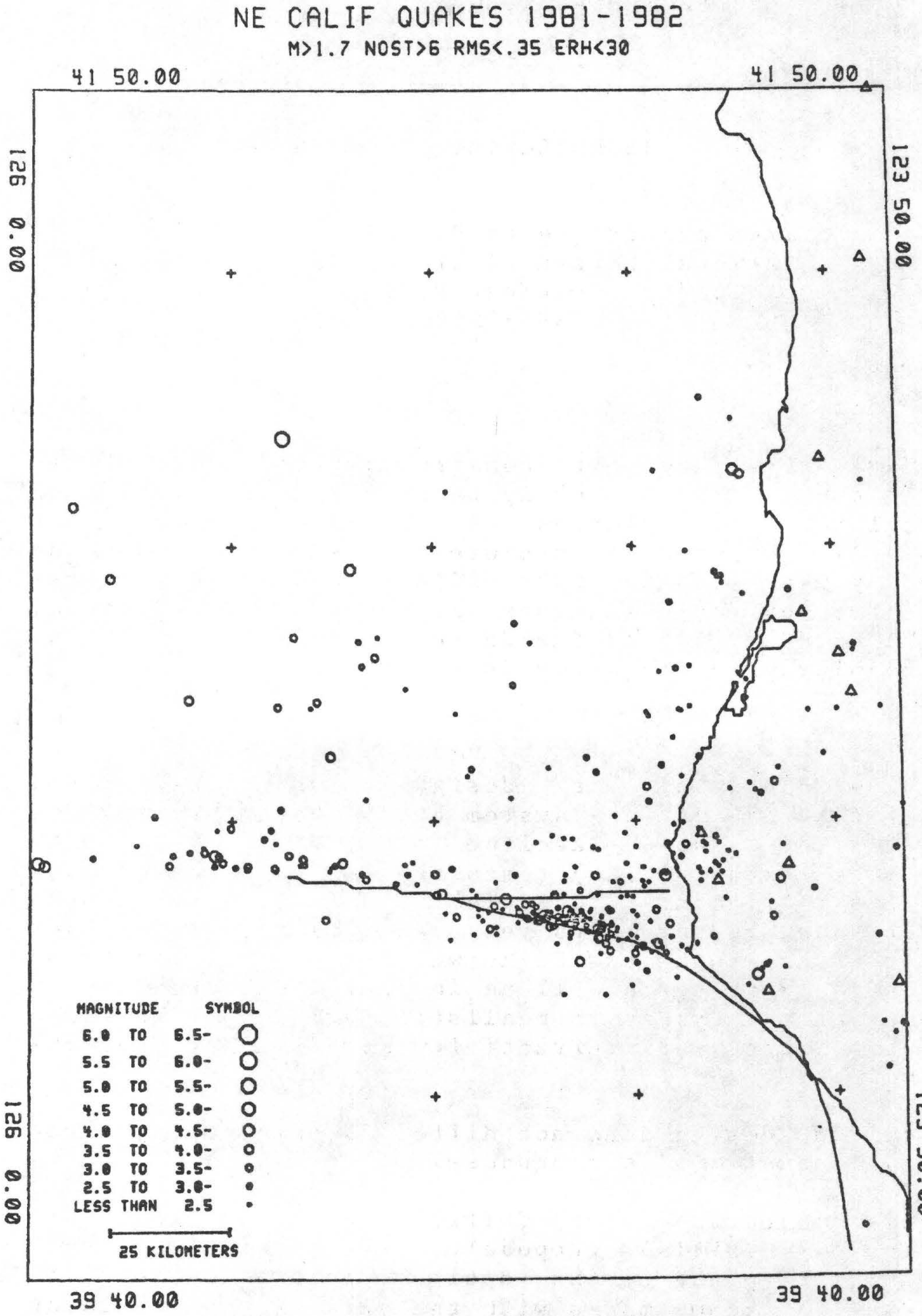
NE CALIF QUAKES 1981-1982
M>1.7 NOST>6 RMS<.35 ERH<30
41 50.00
41 50.00
126 0.00
123 50.00
126 0.00
123 50.00
39 40.00
39 40.00
MAGNITUDE SYMBOL
6.0 TO 6.5-
5.5 TO 6.0-
5.0 TO 5.5-
4.5 TO 5.0-
4.0 TO 4.5-
3.5 TO 4.0-
3.0 TO 3.5-
2.5 TO 3.0-
LESS THAN 2.5
25 KILOMETERS

FIGURE 6

CONSTRUCTION OF AN ELECTROMAGNETIC DISTANCE-MEASURING SYSTEM

110121

Judah Levine

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National Bureau of Standards
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(303) 497-3903

Investigations

We have continued our construction of a three-wavelength system for measuring baselines up to 50 km long with fractional uncertainties of about 0.02 ppm. The instrument is designed to measure the refractivity of the atmosphere by measuring the path differences between three signals: two optical and one microwave. The optical wavelengths used are 632 nm (He-Ne red) and 441.6 nm (He-Cd blue); the microwave frequency is 8.1 GHz.

Results

We have completed the design, construction and laboratory testing of the system and we began testing the system over a very short baseline on 2 May 1983. The short-baseline (about 1 km) tests are designed to test our steering and alignment procedures; we will not make distance or index measurements yet. We expect to extend our baselines to 2 km, 10 km and 20 km within the next month or two. Although these tests will be initially used to measure the response of our system to realistic turbulence, we plan to initiate range and refractivity measurements over the longer baselines.

Our current design does not differ substantially from the dual i.f. system of our proposal.

We have encountered two difficulties that were not forseen in our initial proposal. The first is a strong dependence of the phase of the optical modulation on the angle that the beam makes with the axis of the modulator crystal. In order to pass through the modulator, the beam must be aligned only to within approximately 1 mrad. Since the phase of the modulation was found to depend on this angle, we found it necessary to actively steer the two telescopes to keep it constant.

We found that a system in which each telescope was steered to keep its received image centered on a four quadrant photocell (rather than the more intuitive system of steering the telescope at the opposite end to keep the beam centered) was perfectly adequate and much simpler since it saved two telemetry links. The adequacy of this system is being evaluated in our initial tests.

The dependence of the phase of the modulation on the angle of the beam may be present in other existing systems, but we have not evaluated its significance in other optical configurations.

The second difficulty we encountered was the short lifetime of medium-power solid-state microwave power amplifiers. We have had four units fail in two years. The amplifiers were purchased from two different suppliers. The manufacturers typically quote repair times of a few months, and this has resulted in some delays in our work. We are currently purchasing new amplifiers from a third company. The typical delivery time for these components is 20 to 30 weeks after receipt of order, and this is one reason we will not be able to make distance measurements over our short baselines.

Parkfield Seismology Experiment

9930-02098

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Investigations

Recent work on the recurrence of M 5 3/4 earthquakes on the San Andreas fault near Parkfield, California, suggests that the next event can be expected in 1987-1988, although estimates of the credible time window range from 2 to 10 years. We have undertaken a detailed examination of the seismicity near the 1966 epicenter in hopes of (1) understanding the physical process leading up to a larger event, and (2) predicting the next M 5 3/4 or larger event. Master-event relocation of the 1966 event shows that it occurred at Lat. 35° 57' N; Long. 120° 30' W at a depth of 9 ($\pm$1) km. The M 5 foreshock that preceded it by 17 minutes was located 1 km to the northwest at about the same depth. Relocation of 15 years of subsequent seismicity within a 10 km radius reveals several spatial and temporal patterns. Although M 3 events were rare to the northwest of the 1966 hypocenter before 1975, M 3-4 events have been frequent in the same area in recent years. These event occur in distinct clusters below and to the northwest of the 1966 hypocenter, in sequences that migrate upward from depths of 13 to 8 km over 3-4 year periods. The immediate hypocentral area of the 1966 foreshock and main event, including a zone 1-2 km in diameter, remains seismically quiet. We anticipate that the next M 5 3/4 Parkfield event will nucleate within this zone. Stress drops of $2 < M < 4$ events, estimated from P-wave zero-crossing times, are uniform over the fault plane except for three events with stress drops about 3 times greater located 2-3 km below the 1966 hypocenter. On-scale seismograms from an array of digital event recorders deployed in this area will be used to relate stress drops derived from corner-frequency measurements to these estimates, and also to establish any spatial and temporal patterns in other source parameters.

Results

A short-term (minutes to days) prediction of the next characteristic Parkfield earthquake must be based on anamolous seismicity, fault creep, and crustal strain. M_L 5.1 foreshocks located 1 km northwest of the characteristic epicenter occurred 17 minutes before the 1934 and 1966 events. Thus, the occurrence of an M_L 4-5 earthquake, or many smaller earthquakes, near the 1966 epicenter would be unusual and would indicate heightened earthquake risk. A pipe crossing the fault 6 km south of Parkfield broke 10 hours before the 1966 event. Very fresh-appearing en echelon cracks, probably less than 1 month old and located on the fault trace, were photographed 11 days before the 1966 event, implying 2 cm or more of accelerated fault slip following the spring rains, a period of about 3 months. This rate is about 8 times the average creep rate measured near Parkfield over the past 10 years. A comparable increase in creep at any of the seven Parkfield area creepmeters would thus constitute heightened risk. Observation of increased rate of strain in nearby crustal blocks would corroborate any creep evidence for increased stress near the expected source area of the earthquake.

Except for an $M_L = 5.0$ shock at the 1966 epicenter, the satisfaction of any individual condition listed in the preceding will not be sufficient to issue an earthquake waring. An isolated anomalous condition would, however, merit intensified monitoring over a 3-week period, including resurvey of the trilateration and leveling nets. The satisfaction of more than one condition will, in some cases, be sufficient to issue a warning and intensify the monitoring effort.

Geodetic Strain Monitoring

9960-02156

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Investigations

1. A portable two-color laser geodimeter (terrameter) is being used in high-resolution trilateration surveys in selected areas of the San Andreas fault system.

Results

1. During the preceding six months there have been four significant developments in this progam. First, Dr. Larry Slater's two-color geodimeter has continued to be operated at the Pearblossom Observatory to continue the high-resolution monitoring program begun in November, 1980. The updated observations of strain accumulation are shown in Figure 1 complete through the end of April, 1983. The most remarkable feature is the high rate of shear strain from mid-November, 1982, until the end of January, 1983. During this period the rate of shear strain accumulation was about five times its long-term secular rate. Since the end of January the average rate of shear strain has been rather low. Interestingly, the episode of high shear-strain rate was not accompanied by any very unusual behavior of the other strain components. Over the long term (2 1/2 years) the shear strain shows a substantial secular rate of 0.22 ppm/a whereas the other strain components have long-term rates close to zero.

Second, after an extensive program of testing in the laboratory, the problem with the terrameter, which, as outlined in the previous semi-annual report, showed substantial instability last summer, appears to have been isolated to a single component and a proper solution seems likely in the near future. Thus, this instrument should be available for use later this spring in a field-portable mode and we will be able to recommence survey operations that were abruptly terminated last summer when the instrumental instability was first recognized.

Third, acceptance tests have been completed on a second terrameter, ordered in September, 1982, and delivered in March, 1983. The new instrument is currently considered acceptable and will be put into field operation soon, but minor problems will have to be corrected during the course of the next year.

Fourth, a geodetic network suitable for two-color ranging has almost been completed in the Long Valley, California region. High-resolution strain monitoring using one of the terrameters should commence there before the end of June, 1983.

Reports

Langbein, J.O., McGarr, A., Johnston, M.J.S., and Harsh, P.W., Geodetic measurements of postseismic crustal deformation following the Imperial Valley earthquake, 1979, Bull. Seismol. Soc. Am., in press, 1983.

Langbein, J.O., Linker, M.F., McGarr, A., and Slater, L.E., Increase in shear strain rate across the San Andreas fault near Pearblossom, California: Results from two-color ranging, EOS, Trans. Am. Geophys. Un., 64, p. 208, (abstract), 1983.

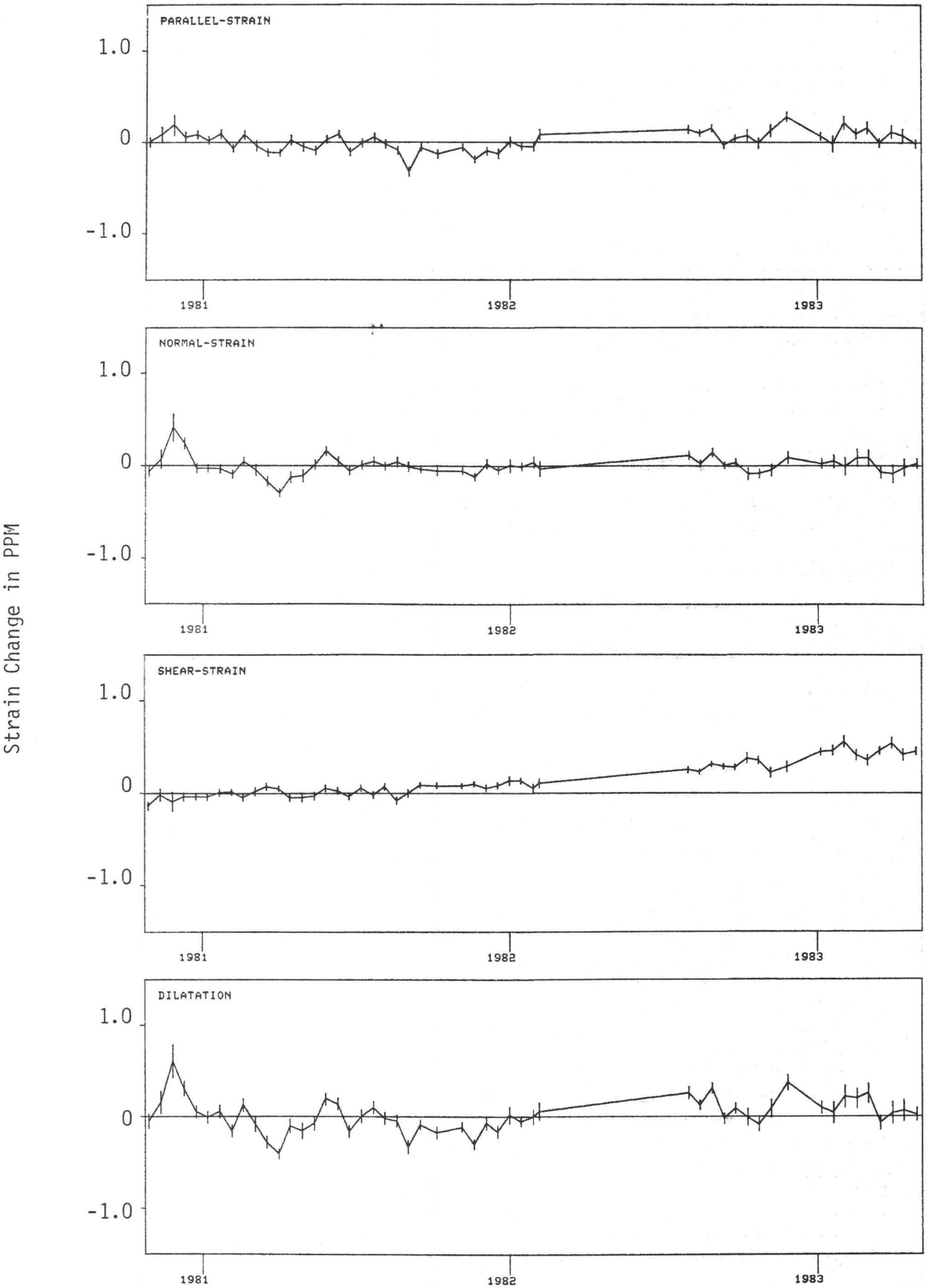

Figure 1. Strain accumulation within the Pearblossom network.

Determination of 'Whole Earthquake Cycle' Systematics: Continued Studies of Large Earthquakes (M_s 7-7.5) Along the Middle America Trench to Refine Methodologies and Models for Earthquake Prediction

14-08-0001-20511

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INVESTIGATIONS

Seismicity patterns (in time, space, energy release and mechanisms) which precede and follow each of six large earthquakes ($M_s \geq 7$) along the Middle America Trench offshore from Mexico are being analyzed with respect to mainshock source rupture parameters and source regions. The objectives are: (1) to determine whether seismicity patterns can be reliably used for earthquake prediction, i.e. that patterns can be found which are consistent and only occur prior to major earthquakes and which are recognizable relative to background activity, (2) to determine whether particular aspects of seismicity patterns (such as duration of seismic quiescence, etc.) correlate with mainshock source parameters (magnitude, stress drop, etc.), and (3) to determine whether the seismicity patterns are consistent with a model of strain accumulation and failure along a fault zone which is heterogeneous.

We are relocating all earthquakes ($m_b \geq 4.0$) along the Middle America Trench from 1964 to present, as well as selected earthquakes from 1928 to 1964, in order to make dependable interpretations of the spatio-temporal patterns in reference to mainshock rupture zones. ISC and USGS/NOAA catalogs have been synthesized for listings which are as complete as possible. Data from field array studies in Mexico are used as calibration events with the JHD method for relocations. (Standard catalog locations vary by as much as $\pm$ 30 km from the redetermined locations, an uncertainty which is unacceptable for associating seismicity patterns with mainshock rupture processes.) Waveform modeling is being used to study source rupture mechanisms for mainshocks ($M_s \geq 7.0$) and fault mechanisms are being constructed from P-wave first motions for earthquakes $m_b \geq 5.5$. A model of inhomogeneous faulting for seismic gaps, asperities, and fault barriers is being developed with J. Rundle and is being tested with the refined seismicity data. The combined case histories of seismic activity preceding and following the six mainshocks spans $\pm$ 15 years, a time period comparable to the average repeat time of 33 $\pm$ 8 years for this region, i.e. one "earthquake cycle."

A seismic quiescence ($m_b \geq 4$) SE of Acapulco is being monitored on an ongoing basis. Data from a field array study in the same region have been analyzed and indicate a relative seismic quiescence (at magnitudes $M \geq 2.5$) which is nearly coincident in location with that found from WWSSN data.

RESULTS

Ten separate projects have been conducted under this contract and are nearing completion, with several manuscripts to be submitted in July for publication. Due to space limitations for this summary, interested persons are referred to the following abstracts for results which have been presented to date.

REPORTS

Beroza, G., J. A. Rial and K. C. McNally, 1982, Source mechanism of the June 7, 1982, Mexico earthquakes, EOS Trans., AGU, in press.

Brown, E. and K. C. McNally, 1982, Spatial and temporal seismicity patterns associated with the 1973 Colima, Mexico earthquake M_s=7.5, EOS Trans., AGU, in press.

Gonzalez, J. and K. C. McNally, 182, Recent seismic patterns in the Acapulco-Pinotepa area of the Middle America Trench, southern Mexico, EOS Trans., AGU, in press.

Harlow, D., J. A. Rial and K. C. McNally, 1982, The June 19, 1982, earthquake near El Salvador: A double event double mechanism earthquake, EOS Trans., AGU, in press.

Lefevre, L. V. and K. C. McNally, 1982, Stress distribution in the Mexican subduction zone, EOS Trans., AGU, in press.

McNally, K. C. and J. B. Rundle, 1982, Interpretations of seismicity systematics for the earthquake cycle in relation to an inhomogeneous fault model, Terra coq., v. 2, n. 2, p. 172-173.

Nava, F. A., G. Beroza and K. C. McNally, 1982, Microseismicity of the Acapulco quiescent zone, EOS Trans., AGU, in press.

Rial, J. A., J. Gonzalez and K. C. McNally, 1982, Two recent large normal fault earthquakes in south central Mexico, EOS Trans., AGU, in press.

Rundle, J. B., K. C. McNally and H. Kanamori, 1982, Seismic triggering of earthquakes, EOS Trans., AGU, in press.

Seismicity Studies for Earthquake Prediction in Southern California Using a Mobile Seismograpic Array

14-08-0001-20546

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INVESTIGATIONS

During the time period of this report, we have studied the seismicity in California from two perspectives related to earthquake prediction:

(1) Field studies of seismicity using the mobile seismographic trailer and portable MEQ-800 arrays.

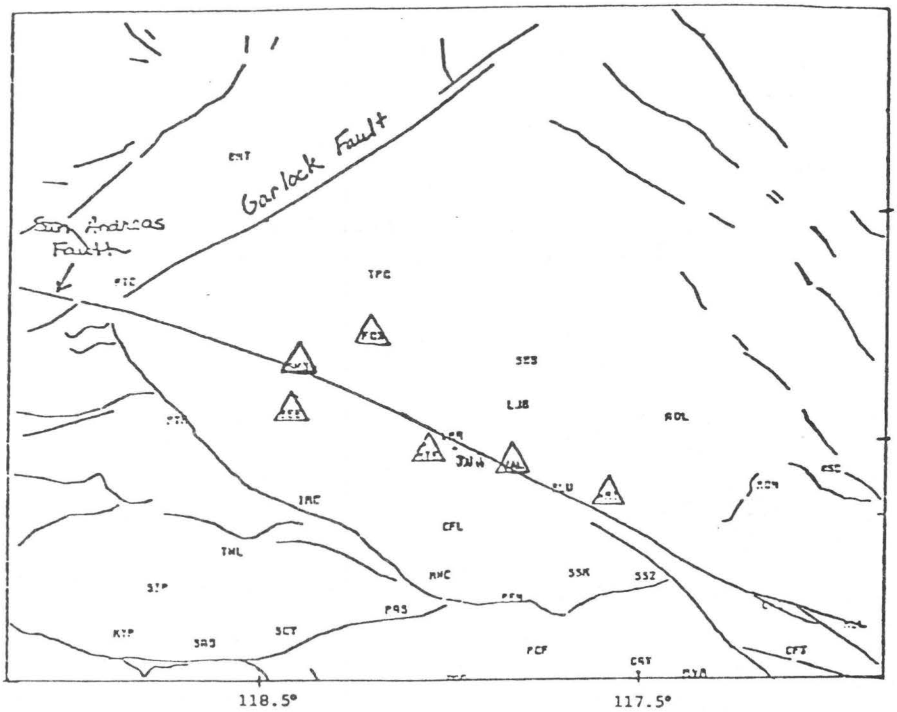
The first aspect of our work involves detailed studies of fault zone seismicity in southern California using the 7-station mobile seismographic trailer array and the portable MEQ-800 seismograph array to supplement the more sparse USGS/Caltech permanent seismograph network. These studies allow us to monitor the detailed unique data so that (a) well-constrained fault mechanisms can be obtained, (b) locations and depths are more accurately determined, and (c) smaller events can be detected. The last aspect is particularly important in regions of low-level activity, or 'seismic gaps.' The seismographic trailer array of 7 stations provides the only dense continuous recording array capability in southern California at the present time, as the permanent array is an event trigger system and nearly all continuous film recording (develocorder) of seismograph stations has now been terminated. As a result of equipment improvements, the trailers only need to be serviced every three weeks. In regions of sparse station coverage and low levels of activity, subtle changes in seismicity patterns in and around seismic gaps which might be missed by the permanent array can be fully documented by the trailer array.

Three field studies have been conducted during this year. From January through June 1982, the mobile array operated in the Palmdale or 'big bend' stretch of the San Andreas fault from Ft. Tejon to Cajon Pass (Figure 1). The trailers were then moved to the Carrizo Plains segment and operated from June through December 1982 (Figure 1). Data analysis is in progress at this time.

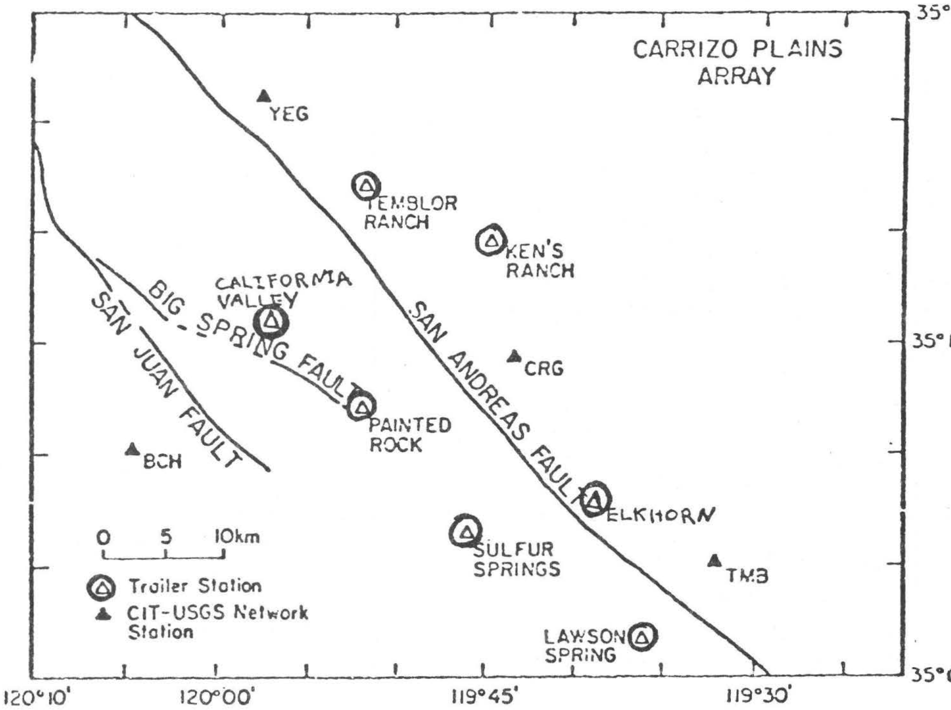
The third field study was at the Anza 'seismic gap' along the San Jacinto Fault for one month in the summer of 1982, using the MEQ-800

FIGURE 1 MICRO-EARTHQUAKE SURVEY

Palmdale, California (2/1980 - 6/1982)



Carrizo Plains, California (6/1982 - 11/1982)



array. The purpose of this work is to document spatial and temporal changes in seismicity and faulting mechanism with time, presumably leading up to a future large ($M_S \geq 6.5$) earthquake in this region. This work repeats an earlier study in 1981, similar studies will be conducted each year at the same location to monitor changes. Excellent data have been obtained during each study and the data from summer 1982 are now being reduced for interpretation.

(2) Seismicity studies for earthquake prediction.

The second aspect of our work has been to develop new methodologies for monitoring seismicity patterns in California, based on results of our previous studies. The current emphasis should be, we believe, to develop more quantitative and objective approaches using the long-term history of seismicity for intermediate-term predictions (years). Within this context, the short-term precursory patterns might be more reliably interpreted. Both statistical and graphical methods have been used to characterize trends in seismicity patterns in time, space, and energy release/seismic slip/seismic moment on both the local and regional scales.

The first aspect of our seismicity studies has emphasized seismic behavior near possible fault zone 'asperities.' We have selected three possible 'asperities' for initial study: Borrego Mountain (San Jacinto Fault, southern California), Imperial Valley (southern California) and San Juan Bautista (central California). The zones which are surrounded by areas of increased activity. They seem to separate fault segments which have differing modes of seismic slip, such as (1) seismicity distributed in a spatially diffuse pattern across the fault vs. a concentrated pattern near the fault, and (2) energy release is regular in time vs. sporadic. We are planning to include fault mechanism information in the characterization. With these criteria, we hope to identify and monitor possible asperities associated with future earthquakes.

PUBLICATIONS

McNally, K. C., 1982, Variations in seismicity as a fundamental tool in earthquake prediction, Seismol. Soc. Am. Bull., v. 72, n. 6B, p. S351-S366.

McNally, K. C., 1983, Seismic gaps in space and time, Ann. Rev. Earth Planet, Scr., in press.

Sauber, J., K. C. McNally, J. Pechmann and H. Kanamori, 1983, Seismicity near Palmdale, California, and its relation to strain changes, J. Geophys. Res., v. 88, n. B3, p. 2213-2219.

ABSTRACTS

Deardorff, D. G. and K. C. McNally, 1982, Seismic slip patterns of three possible asperities in California, EOS Trans., AGU, 63, 1030.

Delsemme, Jacques, 1983, Migration of moderate earthquakes in Central California, Earthquake Notes, Seismological Society of America, 54, 38.

McNally, K. C., 1982, Variations in seismicity as a fundamental tool in earthquake prediction, Earthquake Notes, Seismological Society of America, 53, 55.

McNally, K. C. and J. B. Rundle, 1982, Interpretations of seismicity systematics for the earthquake cycle in relation to an inhomogeneous fault model, Terra cog., v. 2, n. 2, p. 172-173.

Rundle, J. B., K. C. McNally and H. Kanamori, 1982, Seismic triggering of earthquakes, EOS Trans., AGU, 63, 1028.

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

9940-03005

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Investigations

During this reporting period, little new work was done on this project.

Results

1. An operator's manual for the four-film digitizing system was published as an open-file report.

2. A short contribution on the fault zone geometry of the 1979 St. Elias earthquake was prepared.

3. Three oral papers were presented on results summarized in the previous technical report for this project.

Reports

Astrue, M. C., Pelton, J. R., Lee, W. H. K., and Page, R. A., 1983, An operator's manual for a four-film, computer-based, sonic digitizing table to locate earthquakes, U.S. Geological Survey Open-File Report 83-319, 40 p.

Page, R. A., Hassler, M. H., Stephens, C. D., and Criley, E. E., 1983, Fault zone geometry of the 1979 St. Elias, Alaska, earthquake, _in_ Bartsch-Winkler, S., and Reed, K. (eds.), The United States Geological Survey in Alaska, Accomplishments during 1982; U.S. Geological Survey Circular (in prep.)

Crustal Strain

9960-01187

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Investigations

The principal subject of investigation was the analysis of deformation in a number of tectonically active areas in the western United States.

1. Deformation across the Long Valley, California, caldera associated with the January earthquake swarm. Following the January 7, 1983, earthquake swarm in the south moat of the Long Valley caldera, seven Geodolite lines across the caldera that had been measured the previous summer were remeasured. Changes in length as great as 34 mm in 20 km were observed. These changes in length can be explained as a result of magma intrusion and right-lateral slip on a vertical rectangular surface that coincides with the hypocenters of the January, 1983, earthquake swarm. About 0.2m strike slip and about 0.02 km^3 of magma injection are required. The dike injection extends to within about 3 km of the surface.

2. Deformation across the Coso, California, volcanic field 1982-83. An unusual series of earthquake swarms have occurred in Indian Wells Valley north of Ridgecrest, California. The sequence began in April 1981 and culminated in a M_L = 5.2 earthquake in October 1982 that caused damage at the Naval Weapons Test Center. A geodetic network spanning the Coso volcanic field about 20 km north of the swarm epicenters was surveyed in 1977, May 1981, November 1982 (partial survey), and April 1983, the last three surveys being very precise Geodolite surveys. The volcanic field was selected for study because it was thought that the swarms in Indian Wells Valley might be analogous to the 1978-79 swarm activity that occurred outside the Long Valley caldera. However, no significant deformation was detected between successive surveys of the network.

3. Deformation across the San Andreas fault in the 1906 epicenter area. Preliminary results were obtained for the first broadscale trilateration network in the epicentral area of the great 1906 earthquake. It is difficult to measure deformation to the west of the San Andreas fault in this region, because

the fault is a coastal or offshore feature. However, the Farallon Islands, 36 km west of the San Andreas fault, provide a base for geodetic measurements. There are 3 lines from the Farallons to the coast, all quite long with correspondingly large standard deviations. Analysis of a 16-line network shows that deformation is confined to a narrow zone of less than 10 km on either side of the fault. The maximum right-lateral shear strain rate is 0.68 $\pm$ 0.07 microrad/yr near the fault, and 0.09 $\pm$ 0.07 microrad/yr off the fault. The near-fault value is consistent with shear strain rates observed immediately north and south of this network, and with a model of 12 mm/yr of slip at depths below 6 km. The velocity field is quite noisy, and is consistent with either no slip errors the entire network, or with the model described above. Station Farallon, 36 km from the fault, is displaced no more than near-fault stations, indicating that deformation dies off rapidly west of the San Andreas fault.

4. Deformation in the northern San Francisco Bay Region, California. Analysis of measurements spanning the past 10 years indicates that relative motion north of San Francisco Bay is distributed over a band at least 70 km wide, parallel to the San Andreas fault. The measured lines cover an area from just southwest of the San Andreas fault at Pt. Reyes to just short of the Green Valley fault 65 km northeast. Shear strain rates are highest on the San Andreas fault, 0.63 $\pm$ 0.07 microrad/yr. Near the Rodgers Creek fault the shear strain rate is 0.31 $\pm$ 0.02 microrad/yr, and near the West Napa fault 0.18 $\mp$ 0.06 microrad/yr. The right-lateral displacement rate parallel to the plate boundary is 25 $\pm$ 1 mm/yr. It is probable that additional displacement is occurring southwest, and possibly northeast, of the region spanned by the observations. Deformation appears to have occurred at a uniform rate during the 1972-1982 time period.

5. Monitor network on San Andreas fault in South San Francisco Bay Area. Frequently repeated measurements of 3 lines near the San Andreas fault show no short-term variations (Figure 1). These lines have been measured about 30 times since September 1981 and September 1982. The measurement conditions spanned a temperature range of 20^{o}C. Despite the large atmospheric variations, the line lengths show no excursions. Scatter in the observations is consistent with previously published estimates of the errors, about 7 mm for these 30 and 40 km long lines. Strain field components calculated from the observed line length changes also show no significant perturbations above 0.2 microstrain. Regression of the distances on the refraction index, temperature, pressure, and vapor pressure indicates that there is a small (-0.01 ppm/^{o}C) and weak (-0.3) correlation with temperature. Several conclusions are

suggested by this data set: 1) No annual cycle is apparent in the measurements; 2) No significant systematic errors result from meteorlogical measurements; 3) High frequency variations in strain that might alias in annual measurements are less than the 0.2 microstrain noise level; and 4) A 1-year data set is inadequate to define the long-term rate of strain accumulation, even with 30 observations.

6. Deformation across the San Andreas fault south of Parkfield, California. There are 2 trilateration networks south of Parkfield, in the transition zone between the creeping and locked sections of the San Andreas faults. The northern network, San Luis, spans the San Andreas fault in the zone where surface slip decreases from 30 mm/yr to zero. This network has been measured, at irregular intervals, by the California Division of Mines and Geology, and once by USGS. Depending on the method used to separate the effects of slip at depth and fault creep, estimates of the maximum right-laterial shear strain rate range from 0.38 ± 0.05 microrad/yr to 0.64 ± 0.02 microrad/yr. The Carrizo network has been surveyed 4 times since 1977. This network lies about 60 km south of Parkfield, well into the locked region. The maximum right-lateral shear strain rate on the San Andreas fault is 0.62 ± 0.13 microrad/yr. For both networks, the right-lateral shear strain rates decrease with distance from the fault, and the best-fitting dislocation model requires slip of approximately 40 mm/yr below 20 km.

7. Deformation measured near Gold River, Vancouver Island. A trilateration network spanning a 40 km by 80 km area east of Nootka Sound, Vancouver Island, was established. The network includes 5 stations from a 1947 second-order triangulation survey. Assuming uniform strain, 1947-1982 angle changes from adjusted directions yield an estimated engineering shear of 0.07 ± 0.2 microrad/yr, with the axis of maximum compression N22 E $\pm 8^{\circ}$. Compression in this direction is intermediate between that expected for the Pacific-North American plate motion and that expected for the Juan de Fuca-American plate motions.

Reports

King, N.E., and J.C. Savage, Strain-rate profile across the Elsimore, San Jacinto, and San Andreas faults near Palm Springs, California, 1973-81, Geophysical Research Letters, 10, 55-57, 1983.

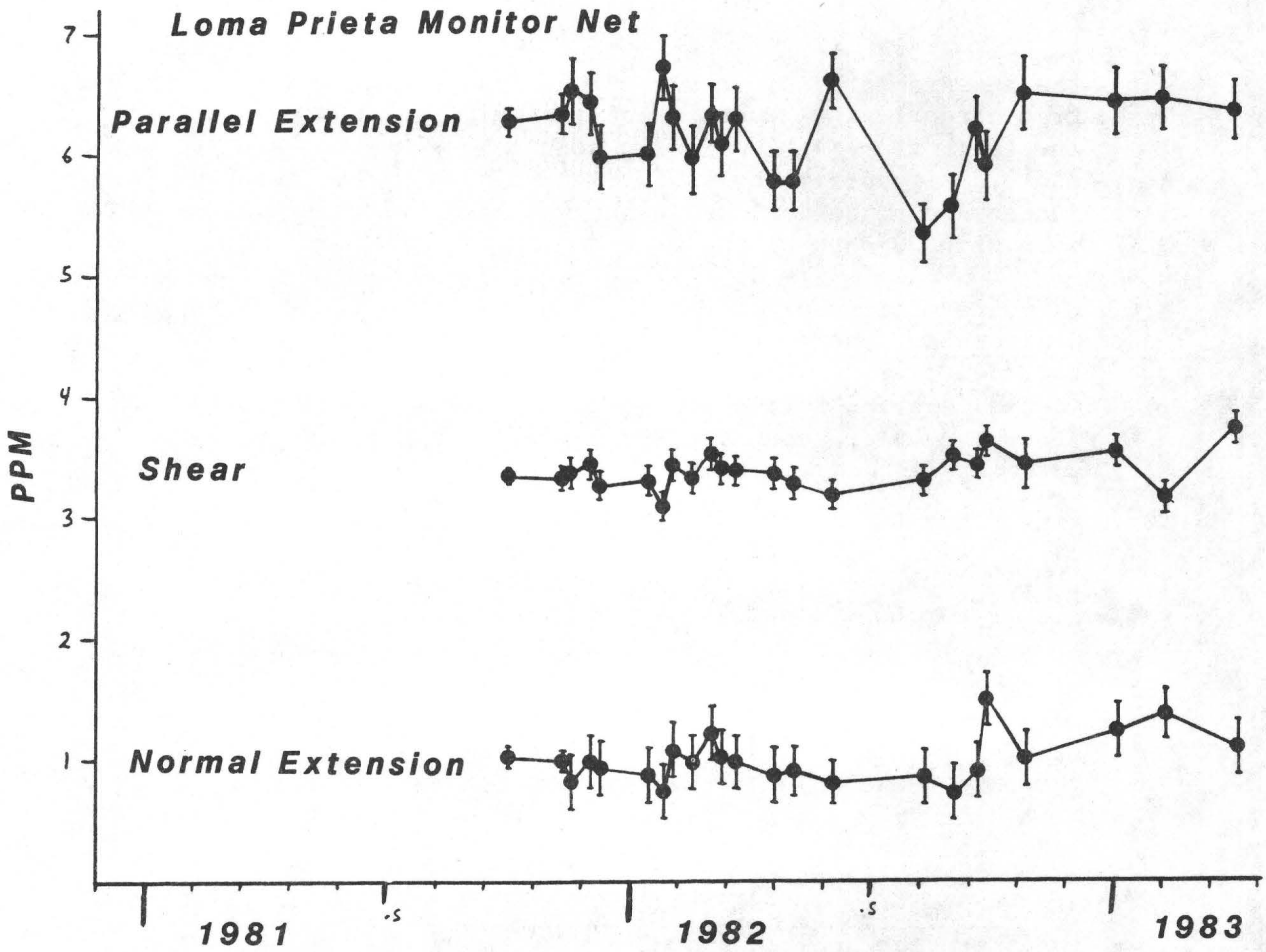

Figure 1. Strain components calculated from observations of the three lines of the monitor network. Top trace is extension parallel to San Andreas Fault. Bottom trace is extension normal to San Andreas fault. Middle trace is right lateral shear across fault strike.

Seismic Studies of Fault Mechanics

9930-02103

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Investigations

During the first half of FY-83 a new study was begun to investigate seismicity patterns in central California. We are searching for occurrences of patterns in the earthquake catalog (1969-1982) that can be understood in terms of either systematic interactions among fault components, or as pre-earthquake preparation processes.

Daily monitoring of seismicity in the San Juan Bautista area continues. High precision hypocentral determinations obtained with a tailored local velocity model are scrutinized daily for notable changes.

Results

1. We approach the problem of seismicity patterns by studying the second-order moment of central California seismicity 1969-1982, following Kagan and Knopoff. An earthquake is considered as a point process in five-dimensional position-time-magnitude space. Thus, the second-order moment, which statistically describes the set of all possible pairs of earthquakes, is a ten-dimensional matrix. This is a natural statistical approach to earthquake interaction because the fundamental unit of interaction is the earthquake pair. Features such as gaps, donuts, migrations and quiescence are directly related to patterns in the second-order moment.

2. A San Francisco Bay Region offshore seismicity map for the period January 1, 1969 through December 31, 1982 was completed. Epicenters were determined from (USGS) Central California Seismograph Network data. Also, preliminary San Francisco Bay Region seismicity maps for the period January 1, 1969 through December 31, 1980 have been completed. Epicenters were determined from the USGS Central California Seismograph network data.

Seismicity and Structure of the San Pablo Bay-Suisin Bay Seismic Gap from Calnet and Explosion Data

9930-02938

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Investigations

In the San Francisco Bay Region micro-earthquakes tend to occur in clusters or swarms, in contrast to their occurrence to the southeast along the Calaveras and San Andreas Faults where micro-earthquakes are distributed more uniformly along the major faults. An investigation of the location of these swarms, their depths, and their temporal relationships reveals interesting patterns.

Results

Using data from Calnet, years 1969 thru 1980, I have plotted the locations of swarms in the Bay Region, together with the average depth of each swarm (Figure 1). The four swarms of greatest depth form a northeast trend approximately perpendicular to the major faulting direction. The average depths of these swarms are 9, 10, 13, and 20 km; all other swarms in the region have depths of 7 km or less and a preliminary average of their depth is 5 ± 1 km.

There is also a striking temporal relationship in that three of the swarms were exceptionally active in 1977 (Figure 2). The San Andreas Fault was also unusually active in 1977 along the trend. An exception is the Concord Fault which was nearly dormant along the trend.

J. P. Eaton (personal communication) has repicked and relocated the 1977 earthquakes in the swarm just northeast of Suisin Bay. His careful work improved the spatial characteristics of the swarm. It would be well to re-examine the data for the other swarms.

The cross section (Figure 2) suggests that deeper activity is terminated in the shallow crust at the normal. swarm depth. It is possible that the patterns of seismicity observed is due to a transfer in the lower crust of right lateral strike-slip motion from the Hayward fault to the Concord and Antioch faults further northeast.

Considerable time was spent on completing the Willits aftershock study by refining the fault mechanism solutions. The new results need to be incorporated into the text.

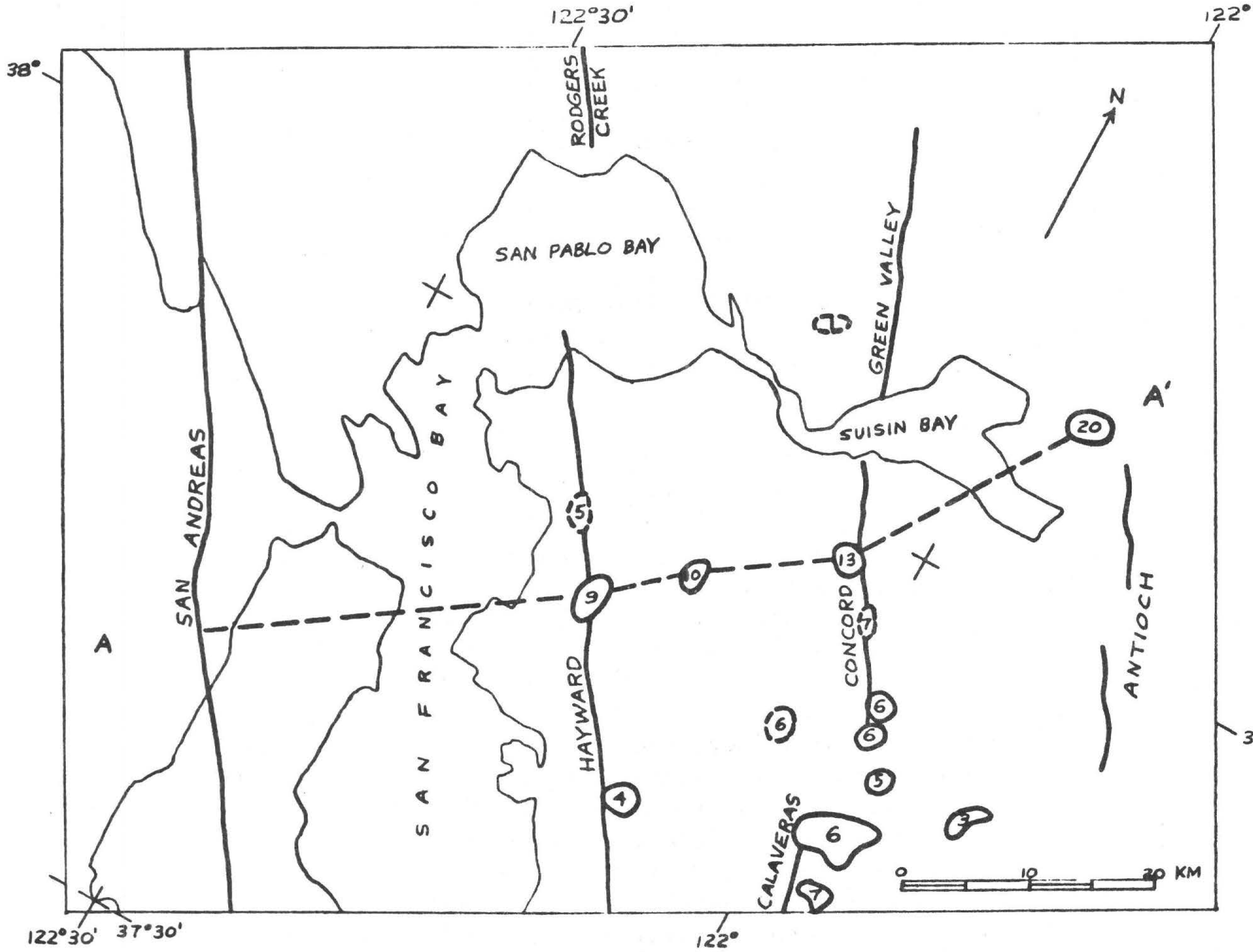

Figure 1. Location map showing micro-earthquake swarms from 1969 thru 1980 and the four major fault trends: San Andreas, Hayward-Rodgers Creek, Calaveras-Concord-Green Valley, and Antioch. Earthquake swarms are shown as irregular oval shapes, and the number shown within each one represents the depth to the center of the swarm to the nearest km. The dashed line represents a trend that was unusually active in 1977.

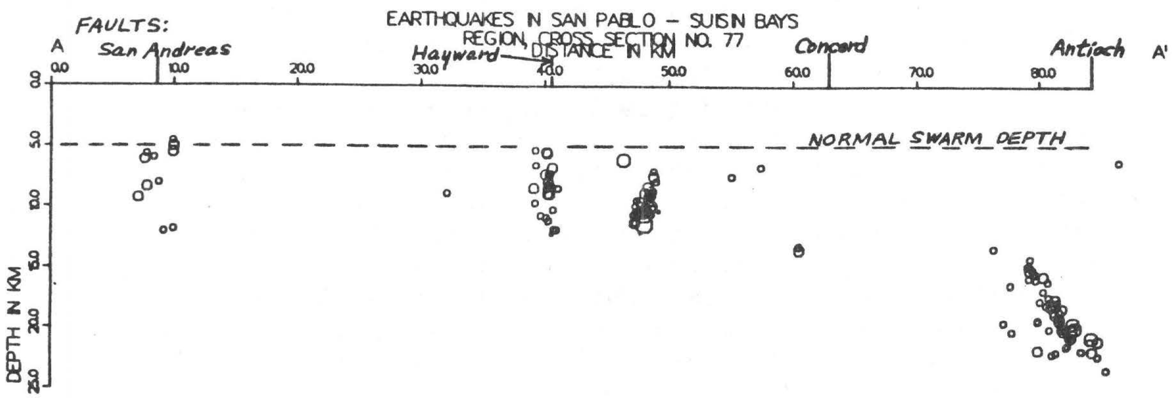

Figure 2. Cross section AA' showing earthquake activity in 1977 only. The San Andreas, Hayward, and Antioch fault zones were active and a swarm also occurred just northeast of the Hayward fault. Symbol size is proportional to magnitude, ranging from zero to 3+.

Consolidated Digital Recording and Analysis

9930-03412

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Investigations

1. The goal is to develop and operate a computer-automated system that will detect and process earthquakes occurring within the USGS Central California Micro-earthquake network (aka CALNET). Presently the network telemetered the output from more than 400 short-period seismometers to a central recording point in Menlo Park, California. A DEC PDP 11/34 computer is used for online, realtime detection of events, and a DEC PDP 11/44 computer is used for processing and archiving. Both computers use the DEC RSX11M operating system.

   Software has been developed largely by Carl Johnson, but with some assistance from Bob Dollar, Peter Johnson and myself.

Results

1. A new online detection system was written and is now being tested. In Menlo Park we are digitizing 510 channels each at a rate of 100 Hertz. More than 300 channels are actively processed by the detection algorithm in its search for the onset of an earthquake. This thruput rate (51 KHz) is seven times greater than that of the previously used online system. The improvement was achieved primarily by writing events to a high-speed, 456 mByte disk with a 'smart' controller, and by using efficient data handling techniques suggested by earlier online systems.

   We are comparing the detection log of this system with the combined detection log of the Allen/Ellis RTP online P-picker system and the CALNET daily scan of the Develocorder films. Shirley Marks reports that, from a sample of about 300 earthquakes, the online detection system has missed 15-20 earthquakes greater than magnitude 1. We think we know the reason for this, and have taken steps to minimize these misses. One or two telemetry lines into Menlo Park are particularly noisy. This causes many false triggers to occur, and decreases the overall efficiency of the system. This problem is still unresolved.

2. The offline processing and archiving system is undergoing initial testing in Pasadena, and is expected to begin testing in Menlo Park by mid-May, 1983.

3. Utility programs necessary to monitor system performance, to track down problems, and to make the system easier to work with are being developed. These include programs to plot (online) the seismic traces from the earliest triggering subnetwork, to monitor (online) the data coming in from any particular seismic station, and to write out to magnetic tape the data on the high-capacity online disk.

Reports

None.

"Crustal Deformation Observatory, Part B: Precision Geodesy"

Contract No. 14-08-0001-19292

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Investigations

To establish and monitor geodetic networks at Pinyon Flat and Dalton Canyon as a complement and control for investigations of tilt and strain that other investigators are doing by means of electro-optical and fluid systems.

The network at Pinyon Flat is a quadrilateral-shaped array of 70 permanent benchmarks 2583 m long. The benchmarks are no more than 40 m apart and all consist of coupled steel rods driven to refusal, each capped by a stainless steel nipple. Three of the benchmarks are coupled steel rods lowered into drilled holes 6, 11, and 21 m deep. Five complete and six partial surveys have been done of the array since 1978.

The network in Dalton Canyon is an irregular-shaped leveling array consisting of 35 permanent benchmarks in a line 309 m long. All monuments are similar to those at Pinyon Flat. The array was surveyed initially in spring 1981 to First Order, First Class precision. Five complete resurveys have been performed in 1981-82.

Results

Mean standard deviation of heights of individual benchmarks at Pinyon Flat equals 400 microns (0.4 mm) ± 300 microns, whereas the mean of the standard deviation of the height differences between pairs of adjacent benchmarks is equal to 300 microns ± 200 microns. Sighting errors and random benchmark motions contribute the most significant errors in the 11 surveys at Pinyon Flat. Sighting errors have standard errors of about 120 microns. Random errors accumulate with a deviation of 0.6 mm x(km)1/2, yielding a tilt uncertainty of 0.8 microradians over the 500 meter baseline between long-base fluid tiltmeter piers. Five direct measurements of average slope between tiltmeter piers agree to within a standard deviation of 0.4 μrad. Forward/backward differences in several surveys correlate with topography, suggesting that refraction contributes up to 120 microns error between monuments. Elevation differences between surveys do not correlate with topography, possibly because benchmark motions overwhelm refraction effects. Benchmark motions appear random with standard deviations ranging from 100 microns for the most stable benchmarks to 1300 microns for the least. The deephole benchmarks are stable to within 400 microns, comparable to the end piers of the tiltmeters. In agreement with the tiltmeter results, no evidence is present for tectonic tilt at Pinyon Flat or Dalton Canyon.

Nearfield Geodetic Investigations of Crustal Movements, Southern California

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Investigations

Precision leveling arrays across the San Jacinto fault near Anza and in the Long Valley near Mammoth Lakes were resurveyed once and thrice, respectively, during the first half of the contract period.

Results

Anza - The 12th complete resurvey in 2 years of the Anza leveling array was completed in December, 1982, with no height changes among benchmarks greater than the mean standard error of 0.2 mm. This result accords with all previous levelings, showing that neither differential displacement nor tilt has taken place at the Anza site in the two year period of geodetic monitoring.

Long Valley - A tenth "dry tilt" leveling array was established in December, 1982 and all 10 were surveyed December 15-17, January 8-9, following the intense earthquake swarm which commenced on 6 January, and 27-29 March. The March resurvey constitutes the sixth resurvey of 5 arrays established in May 1982 by Dan Dzurisin and Kathy Cashman of the Cascades Volcano Observatory, the fifth resurvey of 4 arrays established by Sylvester in July, 1982, and the third of one array established by Sylvester in December 1982.

The tilt changes from January to March are plotted in Figure 1 together with the tilt changes observed in the previous resurvey interval, December 1982-January 1983. The latest changes range from zero (VOORHIS) to as much as 14 µrad (TUFF LUCK, CLAY PIT, LAUREL). Three of the tilts fall within the measurement limit (5 µrad) of the dry tilt method (REST AREA, SEWAGE PLANT, HOT CREEK). HARDING and LAUREL point at one another whereas in the December-January resurvey, they pointed away from a point in the middle of the resurgent dome area.

The stations evincing the smallest changes continue to be those established in glacial moraine (SECTION CORNER, SEWAGE PLANT, VOORHIS); those showing the greatest changes continue to be stations in bedrock near known fault scarps (CASA DIABLO, CLAY PIT).

Discussion

Dzurisin and Sylvester concluded that the December-January tilts evinced a small and irregular pattern of radial-outward tilt with the apex near CASA DIABLO. The January-March data show an irregular pattern of opposed tilt directed outward from a NW-trending line near and approximately parallel to Hwy 395 (Fig. 1). Thus, TUFF LUCK and HOT CREEK tilted NE; REST AREA, CASA DIABLO and LAUREL tilted WSW; SEWAGE PLANT, SECTION CORN[illegible] VOORHIS and HARDING did not move or did so very slightly; and CLAY PIT broke the pattern by tilting W.

This pattern is similar to the long-term pattern (Fig. 2, 3). Thus:

VOORHIS hardly moves;
DIABLO, on the edge of a fault scarp, is erratic;
CLAY PIT fluctuates from 10 to 15 μrad back and forth, chiefly in the ENE-WSW direction;
HARDING tilts SE by fits and starts to a cumulative tilt of 25 μrad in 9 months;
HOT CREEK slowly tilts to the NE to a cumulative tilt of about 15 μrad in 11 months;
TUFF LUCK fluctuates E-W from 10 to 15 μrad;
REST AREA tilts W in only two resurveys to nearly 15 μrad in 3 months;
SEWAGE PLANT hardly moves;
LAUREL, by fits and starts, has tilted SW almost 30 μrad in 11 months;
SECTION CORNER hardly moves. The January-March change was almost exactly equal to, but 180 degrees opposite to the December-January change, but the change is small, right at the measurement sensitivity of 5 μrad.

The explanation for the difference in signal character with respect to station fundament may be real or due to benchmark motions. The fact that the resurveys are so reproducible for the glacial moraine stations shows that there is little error in the measurements themselves. We have difficulty believing the benchmarks on bedrock sites are unstable, therefore we tend to believe the tilts are real.

The cumulative changes plotted in Figures 2 and 3 reveal a NW-trending zone of "uplift," parallel and approximately coincident with Hwy 395, between 2 stations (TUFF LUCK, HOT CREEK) which tilted NE and 3 stations (REST AREA, CASA DIABLO, LAUREL) which tilted W and SW. Three stations are stable (SECTION CORNER, SEWAGE PLANT, VOORHIS); HARDING and CLAY PIT do not fit the pattern, but CLAY PIT is on the edge of a NW-trending fault scarp and may be decoupled from a coherent regional pattern of tilt, if indeed one really exists.

The pattern of opposed tilts along the length of a fairly narrow, NW-trending zone is more consistent with Savage's hypothesis of emplacement of a ring dike along the south wall of the caldera than with radial uplift of the resurgent dome. To obtain more definitive data will require larger tilts or more tilt stations more evenly distributed. A few optimally situated short level lines would be preferable to elucidate the nature and magnitude of tilt because of their greater precision (1 μrad) and redundancy of measurements.

P1

LONG VALLEY TILT CHANGES

December 1982 to January 1983
January 1983 to March 1983

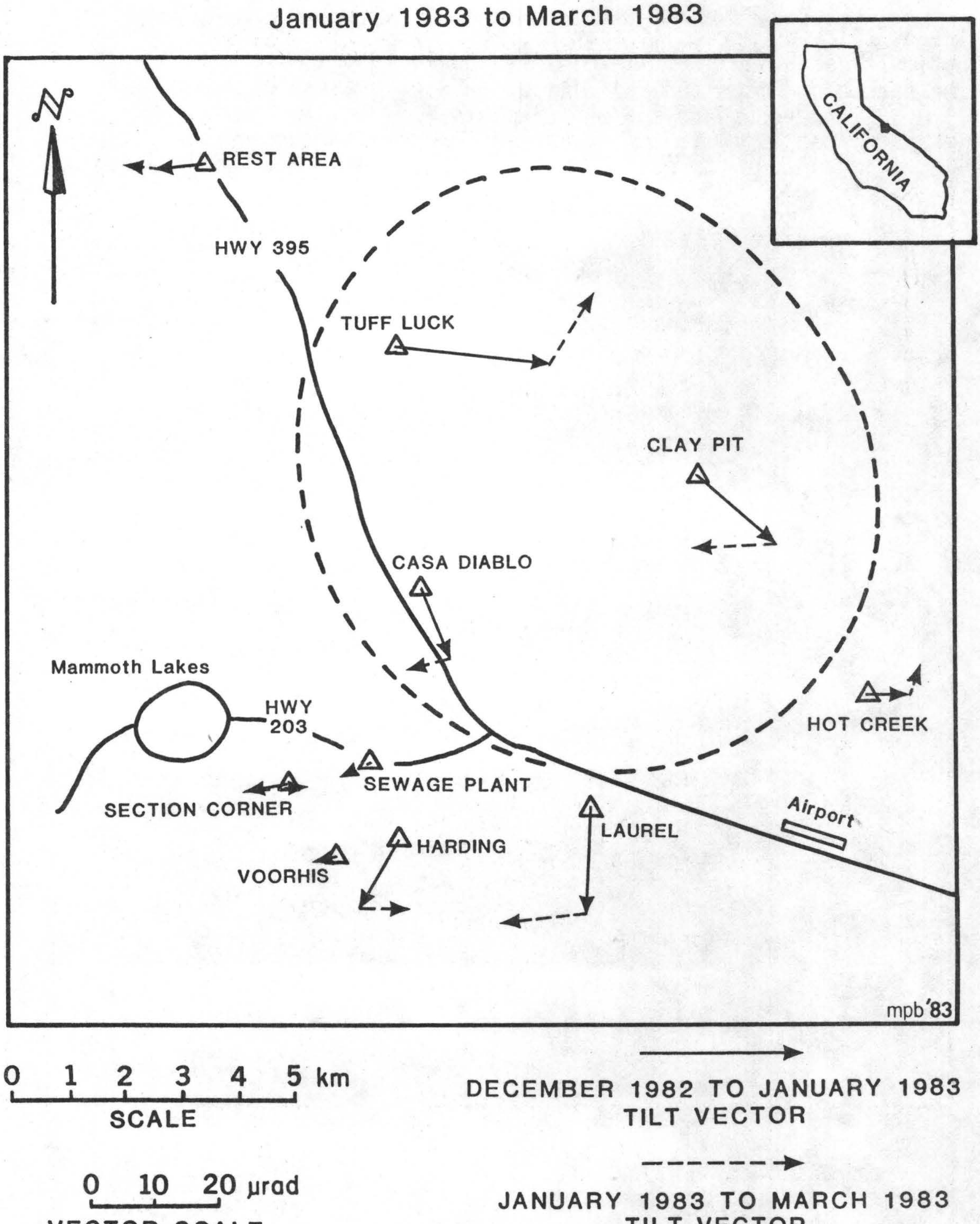


FIGURE 1. Dry tilt changes in the survey periods December 1982-January 1983 (solid line vectors) and January 1983-March 1983 (dashed line vectors). The December 1982-January 1983 resurveys indicated a center of uplift north of the January epicentral zone, perhaps one kilometer SW of Casa Diablo Hot Springs. The January-March 1983 data indicate an irregular pattern of tilt directed outward from a NW-trending line near and approximately parallel to Hwy 395. Arrows point in the direction of downward tilt; dashed ring represents the margin of the resurgent dome.

LONG VALLEY TILT CHANGES

May - July 1982 to March 1983

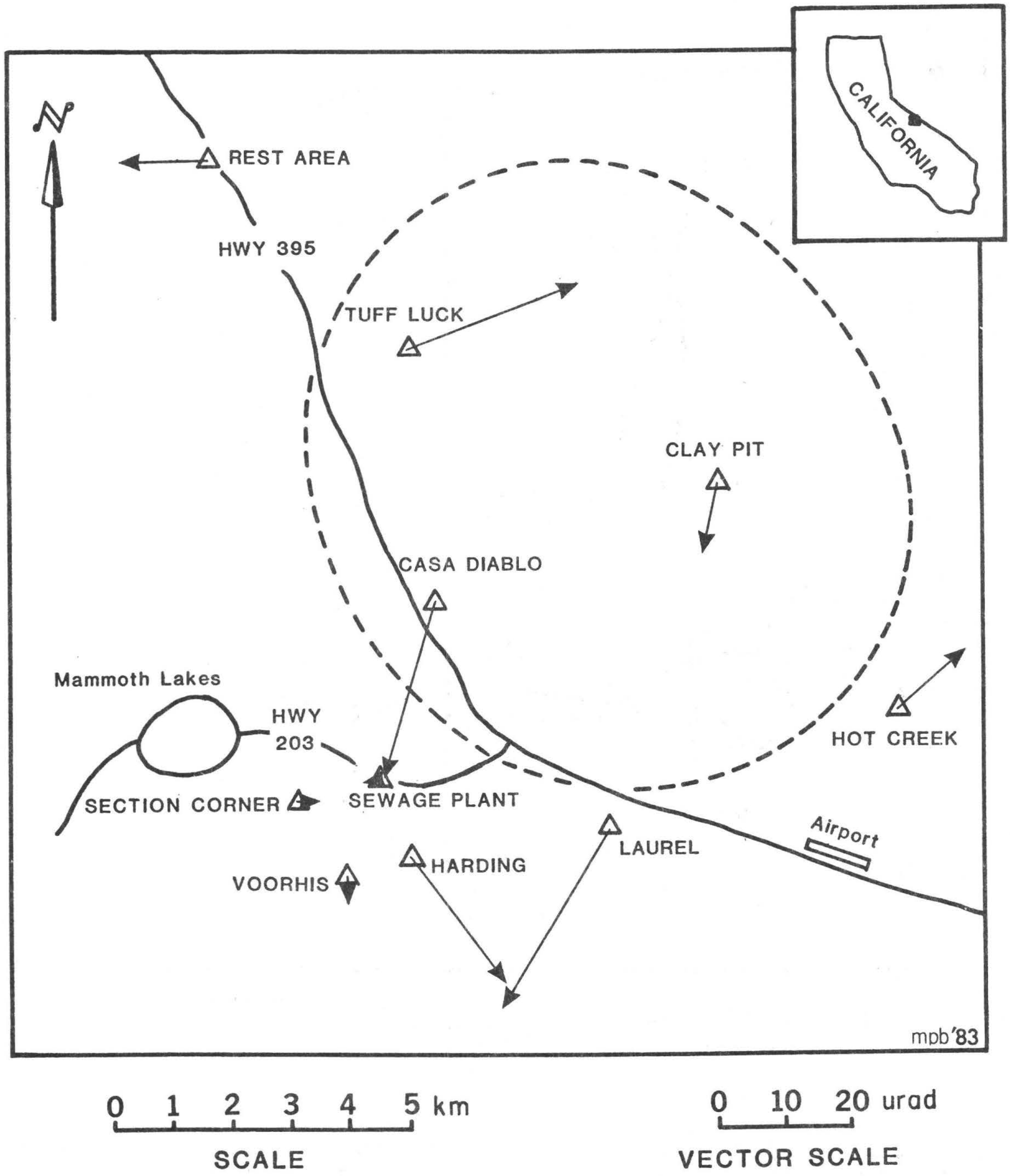
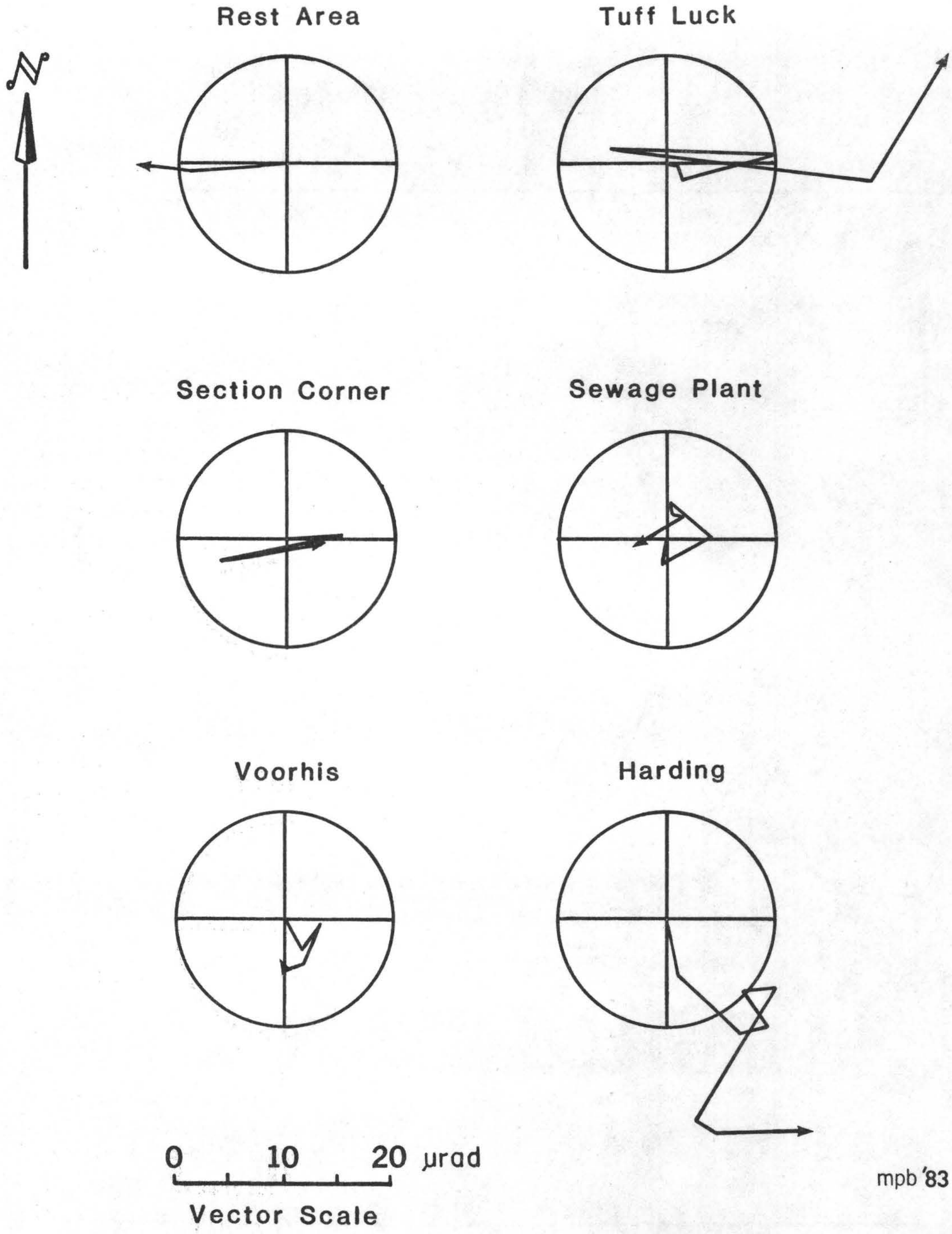


FIGURE 2. Cumulative dry tilt changes for May/July 1982 to March 1983. REST AREA is shown for the period December 1982 to March 1983. Except for CLAY PIT and HARDING, the overall pattern of tilt is outward from a NW-trending zone approximately parallel to Hwy 395. CLAY PIT and CASA DIABLO are on the edges of fault scarps which may tilt independently of any kind of an otherwise coherent pattern. The width of the tilt zone is abruptly limited on the SW by the cluster of stations which do not tilt.



FIGURES 3a, 3b. Synoptic diagrams of tilt changes at 10 Long Valley dry tilt stations, from the time the stations were established (center of each diagram) to March 1983 (arrowheads). North is at the top of the page, circles correspond to a conservative error envelope of 10 µrad. SECTION CORNER, SEWAGE PLANT, and VOORHIS are located on glacial moraine and are very stable. HARDING, HOT CREEK, CASA DIABLO, LAUREL, and perhaps TUFF LUCK show episodic tilt in preferred directions. REST AREA has only two surveys since it was established in December 1982.

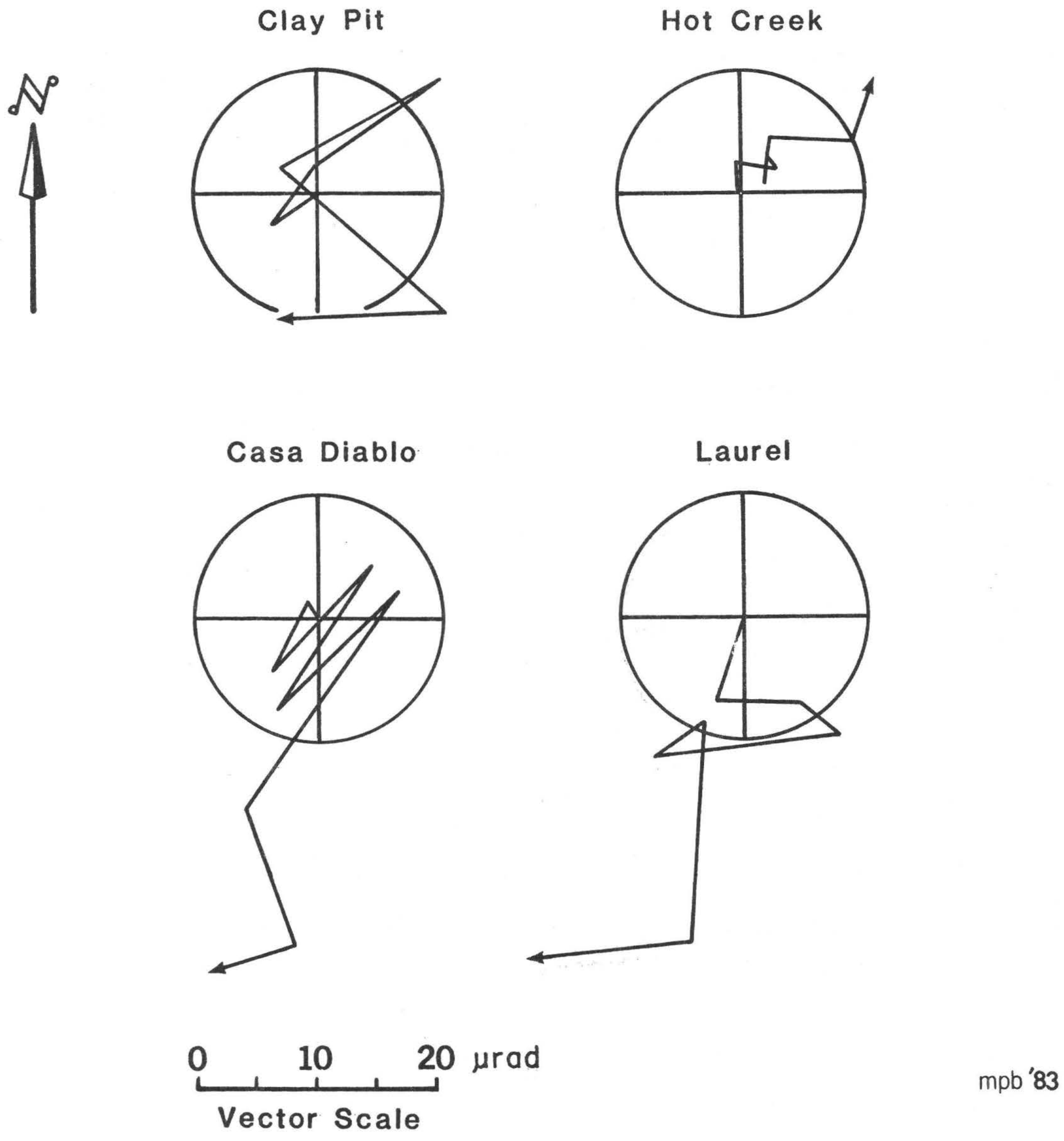

Clay Pit
Hot Creek
Casa Diablo
Laurel
0
10
20 µrad
Vector Scale
mpb '83

Fig. 3b

Crustal Deformation Observatory, Part B: Precise Leveling

Contract No. USDI-USGS 14-08-0001-21234
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Investigations

Two complete resurveys each of leveling arrays at Pinyon Flat and at Dalton Canyon are planned for this contract period. This will include levelings among and between the UCSD and LDGO long-base fluid tiltmeters and the NASA benchmarks at Pinyon Flat.

Results

One partial resurvey of benchmarks 1-17 out of 70 total at Pinyon Flat, together with levelings across the UCSD and LDGO tiltmeters, was completed in December, 1982. Changes in heights among tiltmeter benchmarks did not exceed the mean standard survey error of 0.2 mm, and within the array itself, the observed tilt was less than the mean observed sensitivity of the method: 1 microradian.

FIELD STUDIES OF ROCK MICROFRACTURING - ACOUSTIC EMISSIONS FOR EARTHQUAKE PREDICTION

14-08-0001-20553

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Investigations

Field deployment of acoustic emission recording packages have resulted in the detection of minute seismic emissions in downhole environments. Field investigations continue to study the following questions:

1) What is the origin of these seismic emissions?
2) What are their source characteristics?
3) How far are they from the sensors and what are the effects of the medium on their propagation?
4) Are these events related to regional earthquakes?

Results

High-frequency, wideband (20 Hz to 16 Khz) recording instruments for the detection of minute seismic emissions in borehole environments have been designed, developed, and deployed in three deep wells within seismically active regions. Two of these well sites are within a few km of the San Andreas fault near Palmdale, California; the third site is at the Monticello Reservoir, South Carolina. Seismicity near the Monticello Reservoir is induced by the recent impounding of water. The sensor is a highly-sensitive hydrophone emplaced at the bottom of the fluid-filled well. The surface recording package is an analog event recorder complete with event-detecting logic and digital delay circuit. At all three sites, numerous minute seismic emissions were detected with dominant spectral energy in the band 0.5 to 5 kHz and a peak at about 2 kHz. These events have durations of the order of 10 to 100 milliseconds and waveforms similar to a near-field earthquake greatly scaled down in size.

Recordings from the Skelton and Monticello Wells were subjected to waveform analysis. At this stage of our experimental work, we seek to answer two questions: 1. Is high-frequency seismic radiation generated in stressed rocks in the field? And if so, 2. What is the character of its waveforms? The existence of numerous events indicates the answer to the first question to be affirmative. To study the waveforms, the analog recording tapes were played back through a fast sample-and-hold device and in turn the digitized data were fed through a minicomputer which stored the digitized events on disk. At a sampling rate of 40 kHz, the playback system was consistent with the bandwidth of the recording system. Signals on the disks were dumped one file at a time back through the minicomputer and displayed on an oscilloscope. Signals were carefully examined, and windowed for spectral analysis. Durations of the events are primarily in the range of 5 to 100 ms. The unclipped amplitude is of the order of 10 μbar. Risking the downward extrapolation of the total duration vs. magnitude scale (Real and Teng, 1973), the corresponding magnitudes for these events are -1.5 to -4 (using an equation by McGarr and Green, 1978, the magnitude range is -2 to -5). From the spectra, one finds the dominant energy peak to be about 2 kHz. This peak drops off sharply at the low-frequency end. The data from the Skelton well show little or no energy below 1.5 kHz, whereas the Monticello data have energy down to 1 kHz and below. The high-frequency end does not drop off as sharply; occasional secondary peaks are present. Little energy exists beyond 6 kHz. It is interesting to note that the events have very similar waveforms and spectrums whether from the Skelton well in California or from the Monticello well in South Carolina. Since the sensor is a hydrophone emersed in the borehole fluid, no shear waves were recorded; the converted compressional waves from incident shear waves at the rock-fluid interface were probably small, and no such phase was identifiable. Assuming the S-P interval velocity to be ~ 10 km/sec (or 10 m/ms) and that shear-converted compressional waves are not negligible in amplitude, the maximum epicentral distance of these acoustic emission sources should not exceed 1 km. For a signal duration of 10 ms, the source distance probably is less than 100 m.

During the recording period, at least 30 events per day were recorded at the Skelton well and about 500 at the Monticello well. For these two periods of recording, instruments were set at comparable gain. If all other ambient conditions are the same, a high event rate would suggest a high stress state (Mogi, 1968; Lockner and Byerlee, 1977). Recent results from hydro-fracturing stress measurements at sites near Palmdale and at the Monticello well site also suggest that the Monticello well is subject to a higher ambient stress (Zoback, 1980). For a given monitoring site, if the number of events detectable is large enough to make the time series statistically meaningful, then the rate of occurrence may be used as a reference for the ambient stress state, and thus as an earthquake precursory parameter. The short detection distance (<< 1 km) is not a severe drawback, so long as during stress buildup (e.g. Mogi's stage B), the occurrence of acoustic emissions is more-or-less homogeneous over the entire source region. This region may have dimensions on the order of 10-100 km, depending on the magnitude of the impending earthquake. Thus, for a given monitoring site away from the eventual rupture surface, first a gradual increase of the rate of events may be observed, followed by a short quiescent period before the final rupture.

At the Del Sur well, recorded signals had much higher frequency content. The waveforms also show a characteristic pulse shape that is not expected from a typical disturbance of seismic origin. We suspect that these signals may be related to the casing-wall rock interaction since the Del Sur well is cased over its entire length.

Our findings are quite preliminary. Further confirmation on the seismic origin of these detected signals must be carefully established. This work suggests that future acoustic emission detection or monitoring should be performed in uncased wells. Better identification of the source distance would be desirable.

Earthquake Hazard Research in the Greater Los Angeles Basin and its Offshore Area

14-08-0001-19261

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Investigations

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

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

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

Results

The University of Southern California has monitored seismicity in the Los Angeles Basin since 1971 with particular attention to the activities associated with oil exploration. However, because of unknowns in the velocity structure and noise problems in the urban environment it is often difficult to determine locations with the precision needed to identify the causal faults.

We are currently finishing a study of the three-dimensional velocity structure of the Los Angeles Basin and to make use of that revised structure in the relocation of all earthquakes during the past decade. By doing so, it is hoped that an improvement in the hypocentral determination of these earthquakes will aid in the identification of the involved faults and thus help in the formulation of public policy.

At present, the method used to locate earthquakes in the Los Angeles Basin and for most other local networks assumes a flat layered structure with seismic velocity varying only in the vertical direction. Because the velocity most often varies laterally, the assumption of lateral homogeneity leads to systematic errors in earthquake hypocenter location. For example, a seismometer located on rocks with relatively high seismic velocity, or receiving a signal which has passed through such rocks, will have an arrival time which is earlier than would be expected by assuming lateral homogeneity. In order to minimize station residuals, the location program will place the hypocenter closer to such a station, resulting in a systematic error. Similarly, hypocenters will be "pushed" away from stations which receive signals through rocks with relatively slow seismic velocity.

The use of station delays is the current technique to correct for this error by simply adding to or subtracting from the observed arrival times at each station. If all of the anomalous velocity is in the immediate vicinity of the station, this is a good solution to the problem. However, velocity anomalies elsewhere along the ray path are not so easily accounted for.

Several attempts have been made to resolve these problems. For example, a simple scheme used by McElrath and Teng (1980) applies a station delay which is a function of azimuth and distance from a given event. This was used in a relocation of events in the Los Angeles Basin. An inherent weakness with this approach is that it assumes lateral velocity anomalies are constant as a function of depth. Another problem is that because of uneven distribution of earthquakes and stations, large areas are poorly constrained.

This new study is divided into two parts. In the first part, explosion data is used to invert for an improved velocity structure of southern California and the borderland. Then, in the second part, the velocity structure obtained in the southern California inversion is used as a starting point for a simultaneous inversion for velocity structure and improved earthquake locations within the Los Angeles Basin.

The problem in part 1 is to take a set of P-wave travel times from explosion sites to seismometer stations and use this information to find out the three-dimensional seismic velocity structure of southern California. In this case the steps are:

1. Assume a P-wave velocity model for the region.

2. Calculate the theoretical travel times from the source to receivers and determine the station residuals by comparison with observed travel times.

3. Calculate partial derivatives of travel times with respect to variation in velocity structure.

4. Set up a system of linearized equations and invert for adjustments to the velocity parameters which will minimize station residuals.

5. Go back to step 2 and repeat iteratively until some cutoff criteria are achieved.

Steps 2 and 3 require ray tracing of some form in order to calculate the minimum travel path between source and receiver. Varying the velocity model can cause large differences in the travel time and path and in the partial derivatives computed in step 3.

In order to make use of available explosion data in improving the seismic velocity structure of the Los Angeles Basin and surrounding areas, the program SIMUL 3B (Thurber, 1981) is being modified to allow its use in a larger area. The approximate ray tracing routine used by Thurber in the original program is not applicable for ray paths longer than a few tens of kilometers (Thurber, personal communication, 1983). Instead, a routine designed by R. Comer is being substituted and other necessary modifications are being made.

In order to study the three-dimensional seismic velocity structure of southern California, P-wave arrival times from known explosion sources within the area have been compiled. The compilation includes data from several sources:

1. Quarry blasts monitored by H. Kanamori during the period 1973 to 1980 and received at C.I.T./U.S.G.S. seismometer stations.

2. Similar quarry blast data accumulated by G. Fuis.

3. Refraction study explosions received at C.I.T./U.S.G.S. stations and obtained from G. Fuis.

4. A large quarry blast on Santa Catalina Island monitored by D. Given and received at C.I.T./U.S.G.S. stations.

For the second part of the study, simultaneous inversion is used. Simultaneous inversion as used in this work is a method for determining both the hypocentral parameters of a set of local earthquakes and the seismic velocity structure of the earth in the vicinity of the seismic array. This differs from a standard earthquake location program which uses an assumed velocity structure and inverts simply for the hypocentral parameters (location and origin time). It also differs from three-dimensional velocity inversions which use teleseismic data (e.g. Aki et al., 1977), or explosion data as described above. The steps involved in simultaneous inversion are similar to those in an iterative earthquake location program:

1. Assume a P-wave velocity model for the study region.

2. Make trial estimates of the earthquake location and origin time.

3. Calculate theoretical travel times from the trial hypocenter to observing stations, and determine station residuals.

4. Calculate partial derivatives of travel times with respect to variations in hypocentral parameters and velocity structure.

5. For a set of earthquakes, set up a system of linearized equations, and invert for adjustments to hypocentral and velocity parameters which will minimize station residuals.

6. Go back to step 3 and repeat iteratively until some cutoff criteria are attained.

Steps 3 and 4 require some form of ray tracing. As in part 1 this involves the calculation of the minimum time travel path between the assumed hypocenter and each station. Varying the velocity model can cause large differences in the travel path and travel time and in the partial derivatives computed in step 4.

In order to determine a more precise velocity model for the Los Angeles Basin, the program SIMUL 3B (Thurber, 1981) is being applied to Los Angeles area earthquake data for the period 1973 to 1982.

To study the three-dimensional seismic velocity structure of the Los Angeles Basin, P-wave arrival times from local earthquakes and one explosion have been compiled. The earthquakes were chosen from the earthquake list of the University of Southern California for the period 1973 to 1982. Only events with eight or more P-wave arrivals were chosen. The earthquakes were carefully relocated using the standard location program HYPO 71R (Lee and Lahr, 1975). In order to assure high quality of chosen events, the list was further culled to eliminate questionable locations.

Geodetic Modeling and Monitoring

9960-01488

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Investigations

Analysis and interpretation of repeated geodetic survey measurements relevant to earthquake-related deformation processes operative at or near major plate boundaries. Principal recent activities have been:

1. A study of the advantages and limitations of using geodetic measurements to estimate recurrence intervals for large earthquakes.

2. An analysis and interpretation of the deformation of a small chained survey net near Tokyo during 1916-1980 and the relation of these movements to the great 1923 Kanto earthquake, M=8.1.

Results

1. Geodetic and geologic observations from a handful of well-studied great plate boundary earthquakes provide a basis for exploring those features of the deformation cycle having the strongest influence on recurrence estimation. In ideal circumstances, the time-predictable model requires knowledge of only the seismic slip (and time) of the last earthquake and the rate of relative plate motion or fault slip. Practically, indirect measurements must usually suffice, local coseismic strain changes rather than seismic slip, and local deformation rate rather than slip rate. Permanent, non-recoverable deformation, often roughly half the coseismic strain offset near great thrust earthquakes, complicates the inference of interplate seismic slip. Due to short-and long-term postseismic transients, commonly 20 to 40% of the coseismic strain drop, deformation rates are variable and not simply related to the plate motion rate. In rare instances these complications can be avoided and seismic slip and slip rate can be obtained more or less directly. When these favourable circumstances are absent and when knowledge of the deformation cycle is incomplete, recurrence accuracy can be improved by empirically correcting for unknown elements of the cycle. Systematic features in the spatial distribution of the transients and permanent deformation

near subduction zones help identify the regions where these corrections are largest and where the shortcomings of the empirical approach are most severe. (W. Thatcher)

2. Frequently repeated surveys of a local network near Tokyo provide considerable detail on the horizontal strain changes immediately adjacent to the rupture zone of the M=8.1 Kanto earthquake. Changes in the three independent tensor strain components are determined for 35 epochs during 1916-80 to a precision of about ± 1.5 μstrain. No significant shear or elongational strain changes preceded the earthquake; a change in dilational strain is marginally significant. Postseismic movements are large, accumulating to 40% or more of the coseismic strain drop. They have at least two timescales. A distinct short-term transient lasting less than a year is explained well by slip or localized deformation downdip of the coseismic rupture plane. More complex, longer period post-seismic movements continue for at least another 10 years. Their precise duration, as well as the transition to presumably steadier interseismic deformation, is obscured by notable irregularities in the strain buildup at Mitaka. As a result neither the interseismic strain rate nor the occurrence time of the next Kanto earthquake can be reliably estimated from these observations. (W. Thatcher and N. Fujita)

Reports

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Data Processing Center Operations

9930-01499

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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 scientific user projects. 5-day recorder tapes can now be digitized under control of the Eclipse computer.

Central American Seismic Studies

9930-01163

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Invesigations

1. A network of 6 seismograph stations and one tiltmeter were installed around the active strato-volcano Fuego in Guatemala in February of 1975 in order to study the seismicity and tilt associated with eruptions at aluminum-rich basaltic volcanoes. The seismograph network has been continuously operated since 1975. The tiltmeter located 6 km southeast of the crater was operated until 1978.

2. Primary source records of damaging historical earthquakes have been collected for the Carribean-North American plate boundary area of Guatemala. The plate boundary fault zone contains at least four active sub-parallel strike-slip faults, the de Chama, Chixoy-Polochic, Motagua, and Jocotan-Chamelecon faults (from north to south). This diffuse plate boundary is similar to the San Andreas fault zone near San Francisco, California, where the plate motion is taken up on the Hosgri, San Andreas, Hayward, and Calaveras faults. The Motagua fault ruptured in a M_W 7.5 earthquake in 1976, but no damaging earthquakes have previously been known for the other faults.

Results

1. From February 1975 to December 1976, five weak ash eruptions occurred at Fugeo, accompanied by small earthquake swarms. During this interval between 0 and 140 (average = 10) A-type (high frequency) seismic events per day with M_L 0.5 were recorded. Estimated thermal energies for each eruption are greater by a factor of 10^6 than cumulative seismic energies, a ratio larger than reported for other volcanoes.

From January 3 thru January 7, 1977 over 4000 A-type events were recorded (cumulative seismic energy = 10^9 joules), however no eruption occurred.
During this interval the seismicity occurred mostly as five 2-hour-long swarms of intense seismicity separated by 6-hour quiescent intervals. B-values range from 0.7 to 2.1 with the lower values corresponding to the periods of most intense seismicity. During this period the tiltmeter recorded a 14 $\pm$ 3 microradian tilt event (up towards crater). This is much larger than any tilt event associated with the earlier eruptions and is too large to be caused by a simple change in the elastic strain field due to the earthquake swarm. The earthquake swarm and tilt are probably indicative of subsurface magma movement.

2. A new historical catalog of shallow damaging earthquakes has been compiled for the back-arc of strike-slip plate boundary region of Guatemala. The catalog contains 23 damaging earthquakes since 1538, 17 of these earthquakes were not previously known until this study. The earthquakes are clustered into two active periods, from 1702 to 1821 (17 damaging earthquakes) and from 1945 to the present (5 damaging earthquakes), and one earthquake in 1538. The activity during the 18th century culminated with the rupture of the Chixoy-Plochic fault in 1785 (eastern portion) and 1816 (western portion). Magnitudes, estimated from the area of reported damage, are 7.4 $\pm$ 0.3 and 7.6 $\pm$ 0.3, respectively. The recent active period may have terminated with the rupture of the Motagua fault in 1976 and aftershocks thru 1979.

This cyclic pattern of seismicity looks remarkably similar to the pattern of historical seismicity in the San Andreas fault region of northern Californa in several respects: (1) the cycle-controlling rupture of the plate boundary is followed by a few years of damaging aftershocks and then by a prolonged period of seismic quiescence; (2) this is followed by an active stage of rather frequent (one per decade) damaging earthquakes that lead up to the next cycle-controlling rupture; (3) during the active stage most of the damaging eathquakes occur up to 80 km away from, rather than on, the falt that ruptures catastrophically; (4) during the active stage there is no increase in the seismic moment release rate, reflected as either an increase in the rate of occurrence or in magnitudes, with the approach of the cycle-controlling rupture.

Reports

Yuan, Annette T. E., McNutt, Stephen R., and David H. Harlow, 1983. Seismicity and eruptive activity at Fuego Volcano, Guatemala: February 1975-January 1977: (submitted to Journal of Volcanology and Geochemical Research, 4-25-83).

White, Randall H., 1983. The Guatemala earthquake of 1816 on the Chixoy-Polochic fault: (submitted to the Seismological Society of America Bulletin).

Studies of the Seismic and Crustal Deformation Patterns of an Active Fault: Piñon Flat Observatory

14-08-0001-18398

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Investigations

This contract supports the ongoing research program at Piñon Flat Observatory. The objectives of this program are: 1) To provide a location, facilities, and support for research and development of precision geophysical instrumentation; 2) To establish the true accuracy with which these instruments measure the different geophysical variables; 3) To monitor reliably the state of tectonic strain in the lithosphere in the region of the observatory, an area of imminent seismic activity.

Results

1. In addition to serving our own needs during this period, the facilities at Piñon Flat Observatory were utilized for the following investigations:

Strong Motion recording
Seismometer testing
IDA Global Seismic Network
Anza Seismic array
Absolute Gravity measurement
Survey Gravity measurements
NASA / VLBI
Satellite Doppler survey
Borehole Stressmeter measurements
Ground Water level recording
Heat Flow measurements
Hydraulic Deformation measurements
Borehole Gas measurement
Crustal Deformation Observatory Program

2. Several environmental enclosures and electrical power lines were added to the physical plant in 1982 to increase the reliability of existing instrumentation.

3. Because of the growing likelihood of a moderate eqrthquake along the nearby San Jacinto fault zone, we currently view our most important work at PFO to be the precise and frequent measurement of the crustal deformation in the area. Refinements in both the long-base laser strainmeters and fluid tiltmeter have led to records which show good stability: long-period variation of less than .1 $\mu\varepsilon$ (or .1 μrad) from a purely linear trend. Figure 1 presents a year of data from the 535 m fluid-filled tiltmeter at PFO.

This particular section of data is uncorrected for possible random motions of the end-point benchmarks. (Our optical anchor vertical displacement meters did not become fully operational until October 1982, and so were not available for this data set.) Nevertheless, the tilt rate shown here, .27 μrad/yr down to the ESE, is the lowest we have measured at PFO. Moreover, it is in good agreement with the rates observed geodetically. Wilson and Wood, (Science 207, 1980) find rates of .1 to .4 μrad/yr measured by leveling and lake-level measurements in the adjacent Imperial Valley. Most of the tilts they found, like that measured by the long fluid tiltmeter, were down to the SE.

Removal of the tidal signals from the tilt record yields the trace labeled Residual. An examination of this record provides us with some clues about the sources of noise for this instrument. At the two times marked by asterisks the water table under the westerly end of the tiltmeter was perturbed by drilling operations. Of the events, the response around time 81.8 is easiest to understand; it was caused by water being removed from a borehole about 30 m distant from the tiltmeter monument, on four successive days. This resulted in the ground subsiding nearly 25 μm, for an apparent tilt of .05 μrad. If we assume 64 m as the water level change causing this effect (the distance between the initial water depth, 36 m, and the fracture depth, 100 m), the tilt-water level sensitivity is .7 nrad/m, a very small but significant value. The actual coefficient may be much larger than this because our estimate is based towards the short period (a few hours) response of the hydrological system: a permanent water level decrease should cause a greater subsidence. Fortunately the natural water level fluctuations over the past year have been less than 1 m, which is too small to cause an appreciable error signal.

However, obvious changes have been caused by the temperature sensitivity of the instrument. In particular, temperature variations at the west end of the tiltmeter around date 1982.6 produced a very large tilt signal. The thermal coefficient is .02 μrad/°C (10 μm/°C). We believe this response to be the result of the thermal contraction of the 1 m high cement platform which supports the tiltmeter transducer (1 m * 10 $\mu\varepsilon$/°C = 10 μm/°C). One approach to reducing this problem would be to allow the temperature of the two ends of the tiltmeter to track one another, following the mean air temperature, as was done throughout most of the record presented here. A better approach, which we are now pursuing, is to keep both vaults at a constant temperature. It is possible that all of the noticeable variations in this residual tilt record were caused by thermal changes. However, now that the vertical optical anchors are operating, motions of the cement monuments, whether thermally induced or otherwise, should not affect the corrected tilt record.

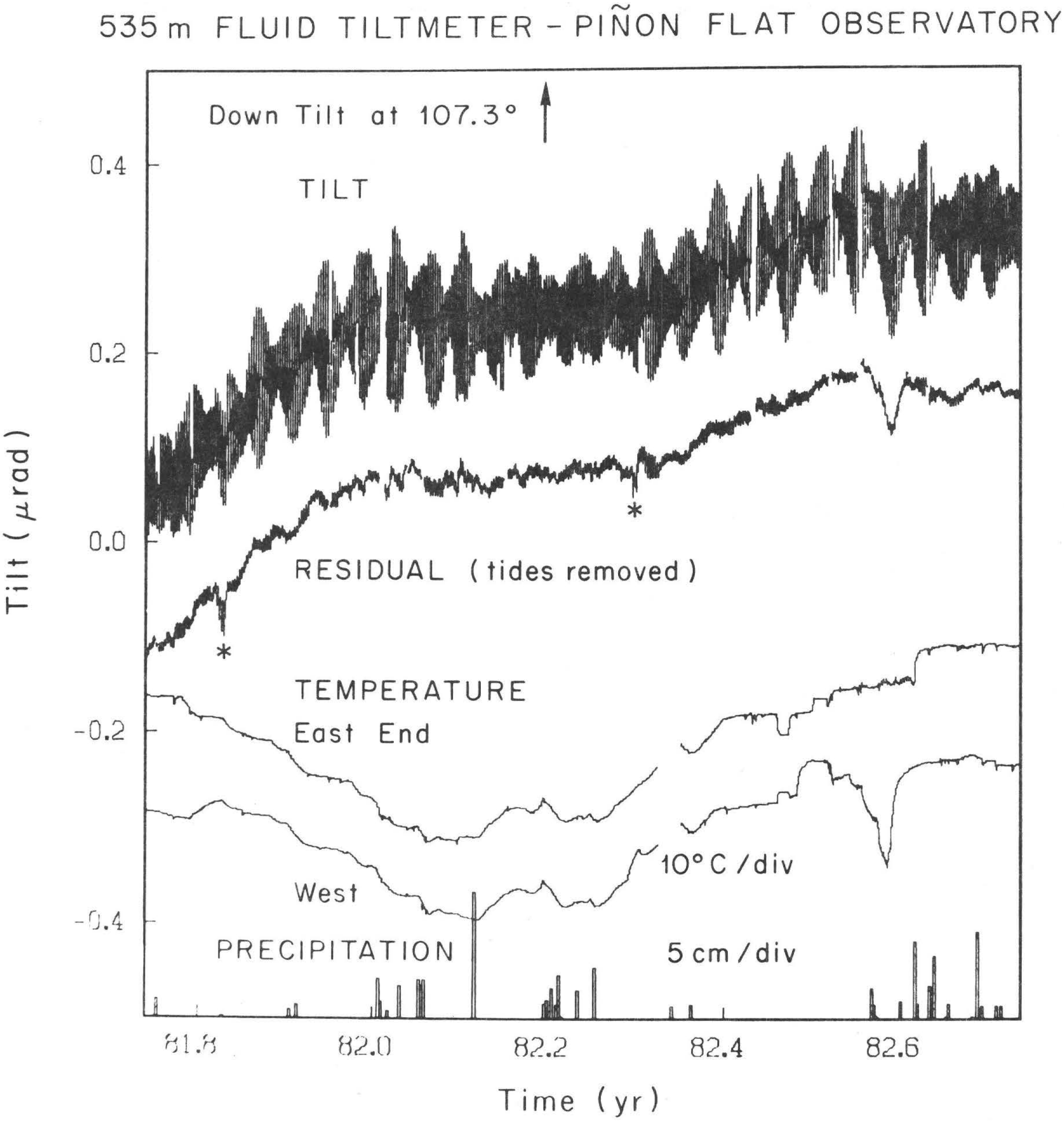
535 m FLUID TILTMETER - PIÑON FLAT OBSERVATORY
Down Tilt at 107.3°
TILT
RESIDUAL (tides removed)
TEMPERATURE
East End
West
10° C /div
PRECIPITATION
5 cm /div
Tilt (μrad)
0.4
0.2
0.0
-0.2
-0.4
81.8
82.0
82.2
82.4
82.6
Time (yr)

Figure 1.

Crustal Deformation Observatory
Part D - Data Logging Facilities

14-08-0001-19762

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Investigations

This report covers the six-month period from May 1982 through October 1982. The purpose of this contract is to provide research coordination, operational support, data recording, and preliminary data analysis for investigators participating in the Crustal Deformation Observatory (CDO) program at Piñon Flat Observatory. The CDO program is a cooperative effort, designed to evaluate existing and proposed instrumentation for measuring long-period (hours to years) ground deformation in an area of ongoing tectonic activity.

Results

1. In May, a well-calibrated (gain uncertainty < 1%) A.D. Little borehole tiltmeter was installed in a 25 m hole at Piñon Flat Observatory (PFO) by Dr. Gerald Cabaniss of the Air Force Geophysics Laboratory. This transducer was mounted on a stainless steel down-hole platform and aligned with the nearby long-fluid tiltmeters to within $\pm .5°$. While we were hoping for high quality tidal records from this instrument, to date we have been plagued by a number of component failures in the badly weathered electronics circuitry. Efforts are underway to improve this situation.

2. The differential-pressure tiltmeter designed by investigators from Cambridge University has worked reliably throughout this period, suffering only from the effects of nearby lightening strikes. Tim Owen plans to modify this instrument in early 1983 to reduce the apparent temperature sensitivity ($\sim .35$ μrad/°C).

3. During April 1982, three Sacks-Evertson volumetric strainmeters were installed by a team from the Carnegie Institution of Washington, led by Alan Linde. The depths of the sensors are: CIA, 200 m; CIB, 214 m; and CIC, 142 m. The initial records from these instruments have shown pure compression at a rate of (roughly) -1 με/mo, consistent with our understanding of how the bonding cement hardens. We are currently investigation a variety of unexpected high frequency signals produced by the transducers.

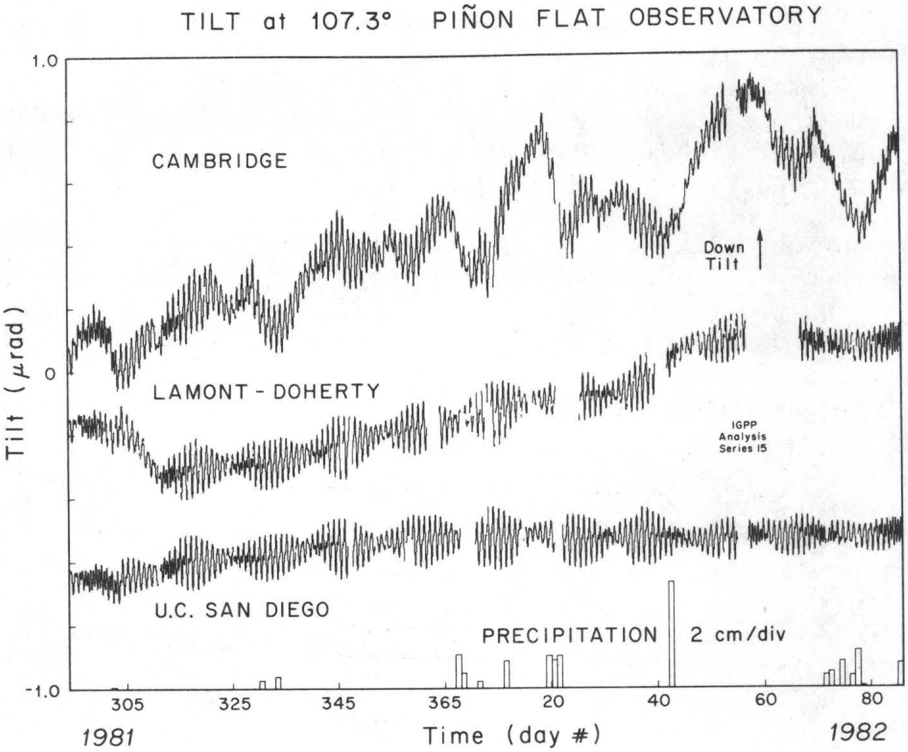
4. Larry Slater, of CIRES, has made frequent trips to PFO in order to complete his two-fluid tiltmeter. The end monuments, buildings, and the connecting tubing (filled with the appropriate liquids) are now all in place.

5. The Lamont-Doherty long-fluid tiltmeter was serviced frequently in this six-month interval. A combination of electronic breakdowns and optical alignment problems resulted in a significant loss of data. Since this period, a number of alterations have been made by John Beavan, Larry Shengold, and Roger Bilham. The latest records produced by this instrument appear to be quite good.

6. As part of our effort to monitor and improve the performance of the instruments in the CDO program, we have performed a preliminary analysis of the data from the three operational long-fluid tiltmeters. Dave Jackson, of UCLA, presented an analysis of this same data segment in an earlier edition of the Summaries of Technical Reports (Volume XV). The top half of Figure 1 shows the edited records from these instruments, after correcting for erroneous data (indicated by gaps in the records). Except for the U.C. San Diego tiltmeter, the choice of offset across such gaps is arbitrary and often not well constrained by the data. While most edits are so short ($<$ 1 hr) that the offsets can be determined easily, editing the longer gaps is inevitably somewhat subjective. The daily precipitation record is displayed as a bar graph along the bottom of the plot. For this period, there is no obvious correlation between the rainfall and episodes of high tilt rates.

The lower half of Figure 1 displays the same data set with the tides removed, to show the underlying trends better. It is unfortunate that the Lamont-Doherty instrument was not functioning well in this period (owing to a faulty laser), so the results are biased by the choice of editing procedures. However, during the longer stretches of error-free data, the comparison of this signal with that produced by the UCSD instrument is quite favorable. The unusual bump evident near the start of the UCSD record (marked by an asterisk), shows the response of the tiltmeters to forced changes in the underlying water table when, on four consecutive days, water was removed from a nearby borehole during drilling operations.

The power spectra and relative coherence of these tilt signals are presented in Figure 2. This plot extends out only to periods of 20 days, which is all that is justified with such a short data set (157 days). For this particular segment, the noise levels of the three instruments are markedly different. We hope continued improvement by the individual researchers will bring these results into agreement. Not surprisingly, in light of the differences in the observed power levels, the coherence plots do not suggest any significant coherent energy outside of the tidal bands. Other measures of the data set are presented in Table 1.


TILT at 107.3° PIÑON FLAT OBSERVATORY
1.0
0
-1.0
Tilt (μrad)
CAMBRIDGE
LAMONT - DOHERTY
U.C. SAN DIEGO
Down
Tilt
IGPP
Analysis
Series 15
PRECIPITATION
2 cm/div
305
325
345
365
20
40
60
80
1981
Time (day #)
1982

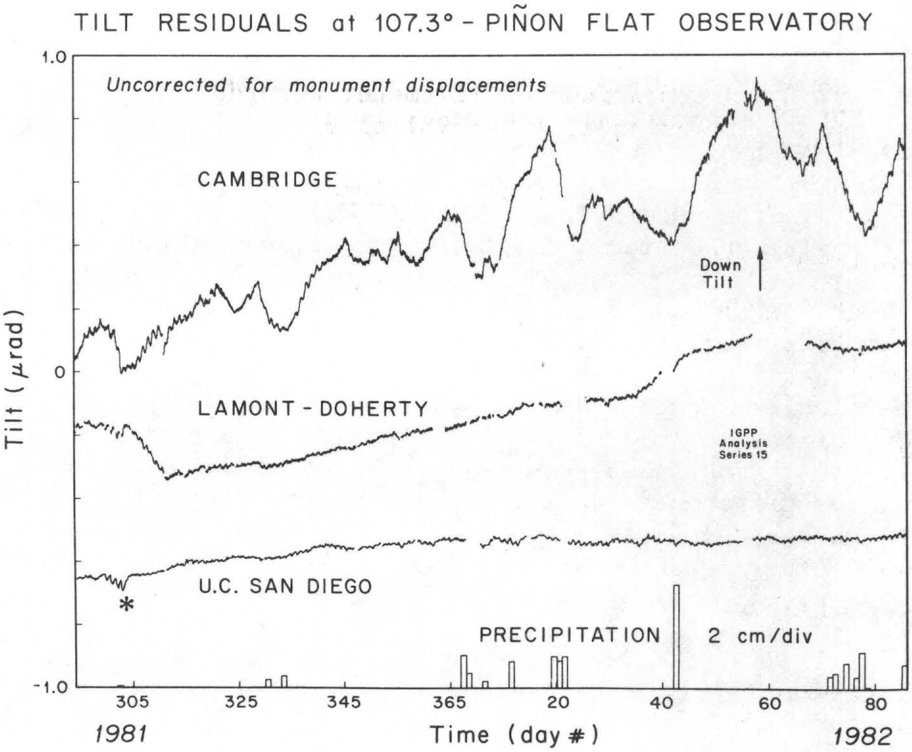

TILT RESIDUALS at 107.3° - PIÑON FLAT OBSERVATORY
1.0
0
-1.0
Tilt (μrad)
Uncorrected for monument displacements
CAMBRIDGE
LAMONT - DOHERTY
U.C. SAN DIEGO
*
Down
Tilt
IGPP
Analysis
Series 15
PRECIPITATION
2 cm/div
305
325
345
365
20
40
60
80
1981
Time (day #)
1982

Figure 1.

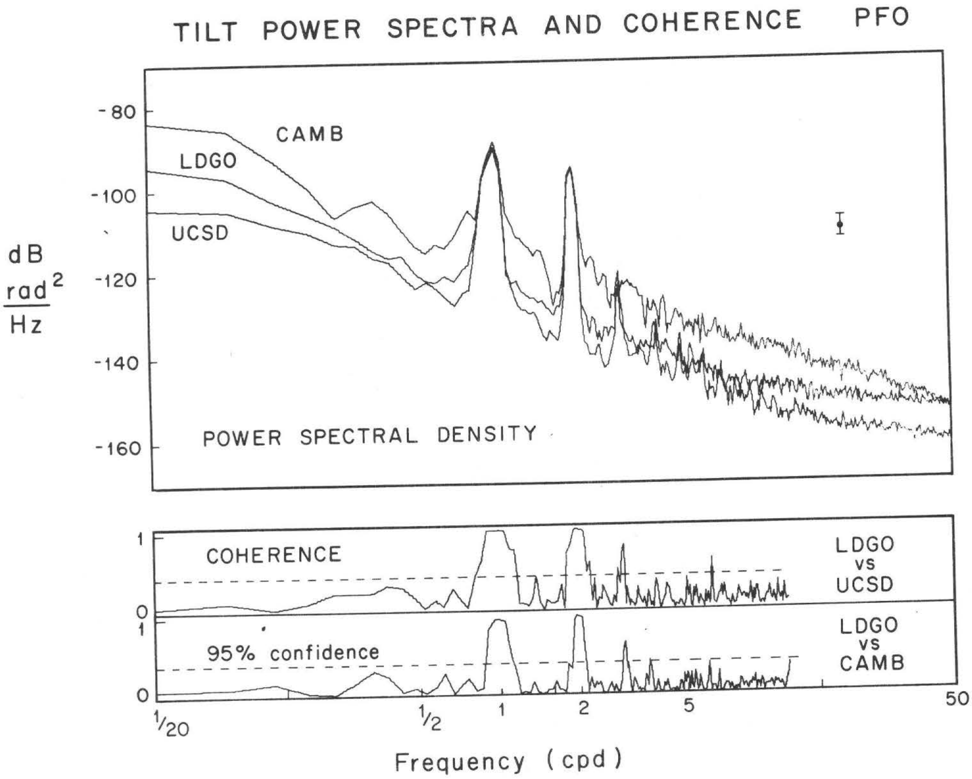


Figure 2.

Comparison of Tiltmeter Records
Series 15 (294:1981 to 86:1982)

	Cambridge	Lamont-Doherty	UC San Diego
Sensitivity (nrad/1c)	.652	.867	.389
Relative Tidal Response			
M_2 (21.421 hr)			
Amplitude	1.02±.03	1.03±.01	1. ±.01
Phase	-0.2	1.0	0.
O_1 (25.819 hr)			
Amplitude	1.07±.08	1.04±.03	1. ±.01
Phase	-4.0	-0.2	0.
Trend (μrad/yr)	1.7	1.0	.27
Maximum Deviation* (μrad)	.64	.25	.13
Standard Deviation* (μrad)	.11	.06	.02

*Maximum and standard deviation were calculated after removing both the linear trend and the tidal signals.

MONITORING GEOTHERMAL WELL AND SPRING CONDITIONS IN SELECTED AREAS OF CALIFORNIA FOR EARTHQUAKE PRECURSORS

Contract No. 14-08-0001-20560

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Investigations

Water temperature and electrical conductivity of seven geothermal springs and wells were monitored in the Long Valley caldera near Mammoth Lakes, California to document changes that may be precursory to earthquakes; these sites are shown in the attached table. Temperature was measured using calibrated thermistors. Markson Model 10 portable conductivity meters were used to monitor electrical conductivity. Temperature and electrical conductivity were recorded continuously on Rustrak recorders. The sites were visited bi-weekly to change records and calibrate the instruments. Additional information such as flow rate or water level were recorded at selected sites during site visits. The temperature and electrical conductivity records were compared with seismicity and precipitation data for possible correlations.

Results

Monitoring began in July 1982 when the instruments were installed and operated through March 1983. During the monitoring period, the most significant seismic activity was an earthquake swarm on January 6, 1983 which contained two earthquakes of $M > 5$.

Results of the monitoring are summarized as follows:

1. Two springs, Big Alkali Lake and North of Whitmore Hot Springs, remained at constant temperatures of 58°C and 62°C, respectively, throughout the monitoring period.

2. Two springs, Whitmore Hot Springs and Casa Diablo mudpot, cooled during December 1982 probably as a result of increased precipitation and cooler air temperatures.

3. The Chance Well data set was of limited use because of the lack of continuity of the data. Difficulties were encountered in maintaining an operating thermistor at a depth of 70 meters and a temperature of 137°C.

4. The well temperature at the Sheriff's Substation warmed slightly during December following a gradual cooling of 2°C from July through November. Because this warming is contrary to what would be expected from the increase in precipitation during December, this warming may be a precursory change before the January 1983 earthquake swarm. However, the normal seasonal temperature fluctuations of this well have not yet been established.

5. Hot Bubbling Pool was found to exhibit geyser-like behavior, filling and draining cyclically. From October through December, there was a decrease in the average period length of the cycles from nearly 5 hours to 4 hours. This was accompanied by a decline in the average water levels. This change may be precursory to January earthquake swarms, or it may reflect the seasonal change of some other factor such as barometric pressure. Following the January 6 earthquakes, the cyclic filling and draining ceased for three days. On resumption, the average period length increased from 3.5 hours to 7.5 hours, and the average water level rose above that which had been previously observed by about 30cm.

6. The results of the electrical conductivity monitoring were inconclusive because of problems with fouling of the conductivity cells and electronic drift in the meter between visits to service the instruments which resulted in an unacceptable data uncertainty of ±20%.

It is suggested by the data that water temperature and level are influenced at least by the occurrence of M > 5 earthquakes. However, the eight-month monitoring program that was conducted is not sufficient to establish a base line of normal seasonal variations in the springs and wells from which to identify anomalous conditions which may be of tectonic origin. Further monitoring is needed to establish a longer base line or to observe similar changes preceding future M > 5 earthquakes.

GEOTHERMAL SITES MONITORED
BY
CALIFORNIA DIVISION OF MINES AND GEOLOGY
July 1982 - March 19, 1983

GEOTHERMAL SITES	LATITUDE	LONGITUDE	TEMPERATURE(°C)	CONDUCTIVITY(μmhos)
Casa Diablo Mudpot	37° 38.9'	118° 54.6	92	*
Sheriff's Substation Well	37° 38.3'	118° 53.5	19	*
Chance Well	37° 38.8'	118° 51.6	137	2,600
Hot Bubbling Pool	37° 38.8'	118° 51.6	68 -75	2,600
Whitmore Hot Springs	37° 37.9'	118° 48.6	38	1,200
Hot Springs North of Whitmore	37° 39.0'	118° 48.5	62	1,800
Big Alkali Lake Hot Springs	37° 40.2'	118° 46.9	58	2,200

* Not Monitored

Investigation of Radon and Helium as Possible Fluid-Phase Precursors to Earthquakes

14-08-0001-21186

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Investigations

1. Monitoring radon, helium, and other relevant geochemical parameters in a southern California network of hot springs and wells along the San Andreas, San Jacinto, and Elsinore faults for their temporal variations which may display anomalies in response to pre-seismic events.

2. A general study of the relationships between these components, their origin, and variations due to flow rate changes, seasonal effects, atmospheric contributions, and variable crustal and mantle sources.

3. Monitoring radon continuously (on an hourly interval) with field-installed Continuous Radon Monitors (CRM's) for possible short-term anomalies which may be precursory to earthquakes.

4. Comparison of the CRM data with the discrete data which are collected less frequently at the same site for their compatibility in long-term variations.

Results

1. During the past six months (October 1, 1982 to March 31, 1983) we have observed no significant variations in radon, helium and other parameters in our network beyond baseline fluctuations although southern California had experienced unusually wet and stormy winter and spring seasons associated with rapid changes in weather conditions. Also, no major earthquakes have been reported in the southland during this period. Thus, it appears that meteorological and seasonal effects on our network data are negligible.

2. At Arrowhead Hot Springs along the San Andreas fault, we observed a significant increase in radon, helium, and other dissolved gases prior to the 1979 Big Bear earthquakes. These components show linear correlations for the entire data array, including the new data. This supports a two-endmember mixing model in which the deep-seated reservoir water and the surface spring water in equilibrium with the atmospheric gases mix at variable proportions.

3. Two CRM's have been in operation during this report period. The first unit was installed at Arrowhead Hot Springs to monitor gas-phase radon in September, 1982. Since the unit was located inside an underground cell, severe condensation problems were encountered during the winter months. Circulating the hot spring water through the underground cell has effectively solved the condensation problems. Since January, 1983, we have been accumulating good quality data from this site. The baseline fluctuation is generally less than 6%. A 15% increase was observed within a few days between February and March (Figure 1). No environmental effects were noticed during this increase. A similar increase was also observed at a nearby site by the USC group (personal communication). Since then the radon level has been quite "flat" or constant at higher level. There have been no reports of significant earthquakes in the vicinity since March except for an event of M = 3.7 at Victorville near San Bernardino on March 29, 1983. The discrete radon and helium data show larger-than-normal fluctuations beginning in mid-1982 with a couple of events greater than 3 in July and August.

The second CRM was installed at Murrieta Hot Springs in March after the owners of Hot Mineral Well had further postponed their decision to let us install the unit. Similar to Arrowhead, gas bubbles are collected and fed into the CRM for counting and recording. Since the bubbles rise intermittently, the flow rate is not uniform and so the data fluctuate with large amplitudes ($\sim \pm 10\%$). If this fluctuation persists, we will instead monitor the dissolved-phase radon by using a gas stripping probe. A third CRM on loan from USC will be used at Pinon Flat for intercomparison with the Caltech radon-thoron monitor.

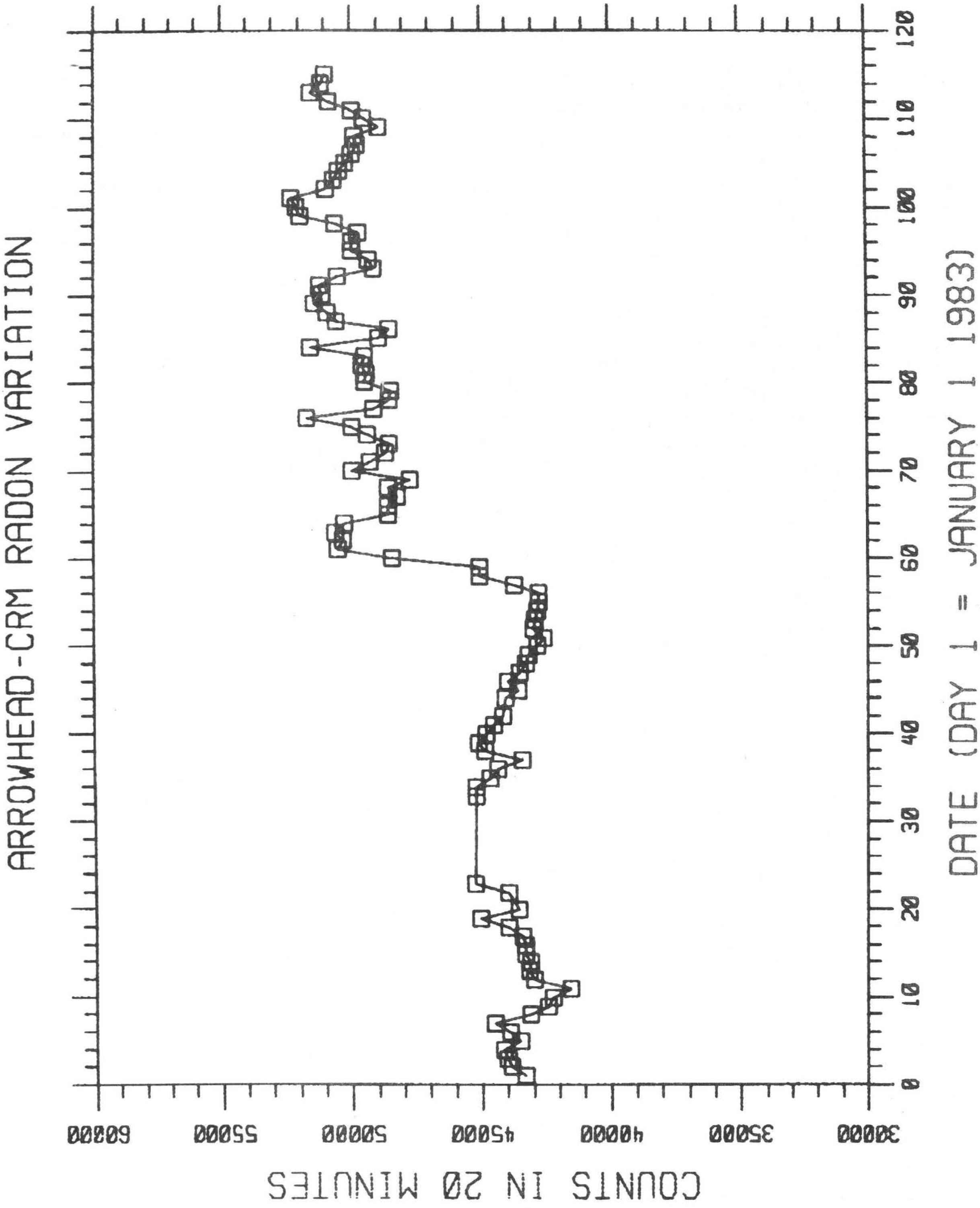

Figure 1. CRM data from Arrowhead Hot Springs. Each data point is an average of 24 hourly values. The increase between late February and early March is real.

Deepwell Monitoring Along the Southern San Andreas Fault

14-08-0001-19759

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Investigations

A group of deep, abandoned, wildcat wells in the locked portion of the San Andreas Fault between Gorman and San Bernardino have been instrumented with continuously recording high-precision water-level transducers and thermal sensors to monitor changes in groundwater parameters which may be sensitive to regional strain or precursory to seismic slip.

Results

Figure 1 shows the 1982 daily averaged water-level data for five representative wells. Hatched lines indicate loss of base lines.

Figure 2 is a representative data set (hourly averages; expanded scale) for January, 1982 during a period of relatively intense storm activity (i.e. large barometric pressure changes). Figure 3 gives the hourly averaged data for the previous six months from August, 1982 to January, 1983 from the Crystallaire well (2600' deep).

Variability in the raw data, due primarily to rainfall, barometric pressure changes and solid earth tides would tend to mask any short term anomalies due to tectonically induced strain, unless they were abnormally large or short in duration (~ 1 hr. or less). Furthermore, secular strain changes having time constants up to one year would also be masked by the rainfall effect which may have decay times on the order of 6 months or more. Thus, in general, data sets of several years in duration will be needed to assess long term strain changes; these data sets are just now becoming available in the southern California area.

Figure 1 illustrates the large changes in water level due to rainfall, which would have masked any strain events related to a small earthquake swarm in the Spring near the Pearblossom area. The effect is particularly impressive in March, followed by a slow recovery over the next several months. For the Anaverde well (Figure 1), an anomaly is also produced by rainfall in September. The precise mechanism by which rainfall is communicated to the water table (or air/water interface in the borehole) is not well understood. Following are some possibilities: (1) early periods of rainfall may wet the soils allowing later rains to permeate directly down to the water table (this is suggested by the data in Figure 1); (2) runoff may enter an aquifer directly along a natural highly conductive path; and/or (3) the borehole, itself, may provide a "short-circuit" pathway for surface water to move down to the water table, locally.

It is interesting to note that the Anaverde, Chief Paduke, and Crystallaire holes all show a strong response to the March rainfall while the Skelton and Fairmont wells showed less response. Furthermore, there was a progressive lag in response from Anaverde at the NW to Crystallaire at the SE.

Reference

McRaney, J. K., T. L. Henyey, and S. P. Lund (1982), Deepwell Monitoring Along the San Andreas Fault Near Palmdale, California, EOS, vol. 63, no. 45, p. 1106.

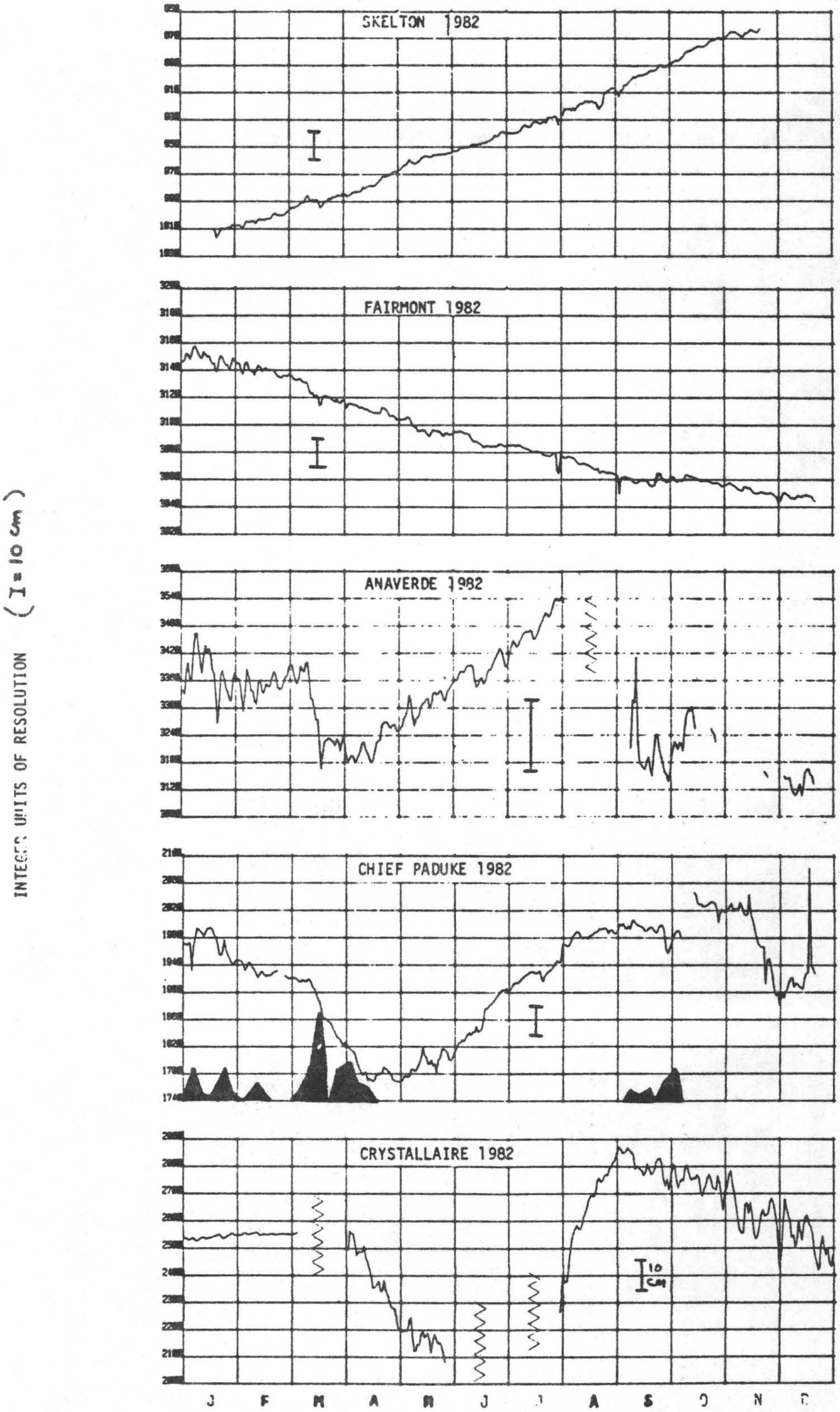

FIGURE 1: 1982 daily average water level from selected wells of the Palmdale region. Water level increases downward. 5-day running mean rainfall is supperposed on the Chief Paduke water level variation (filled curve with one inch per square vertical scale). Note the distinct water level responce to the March rains.

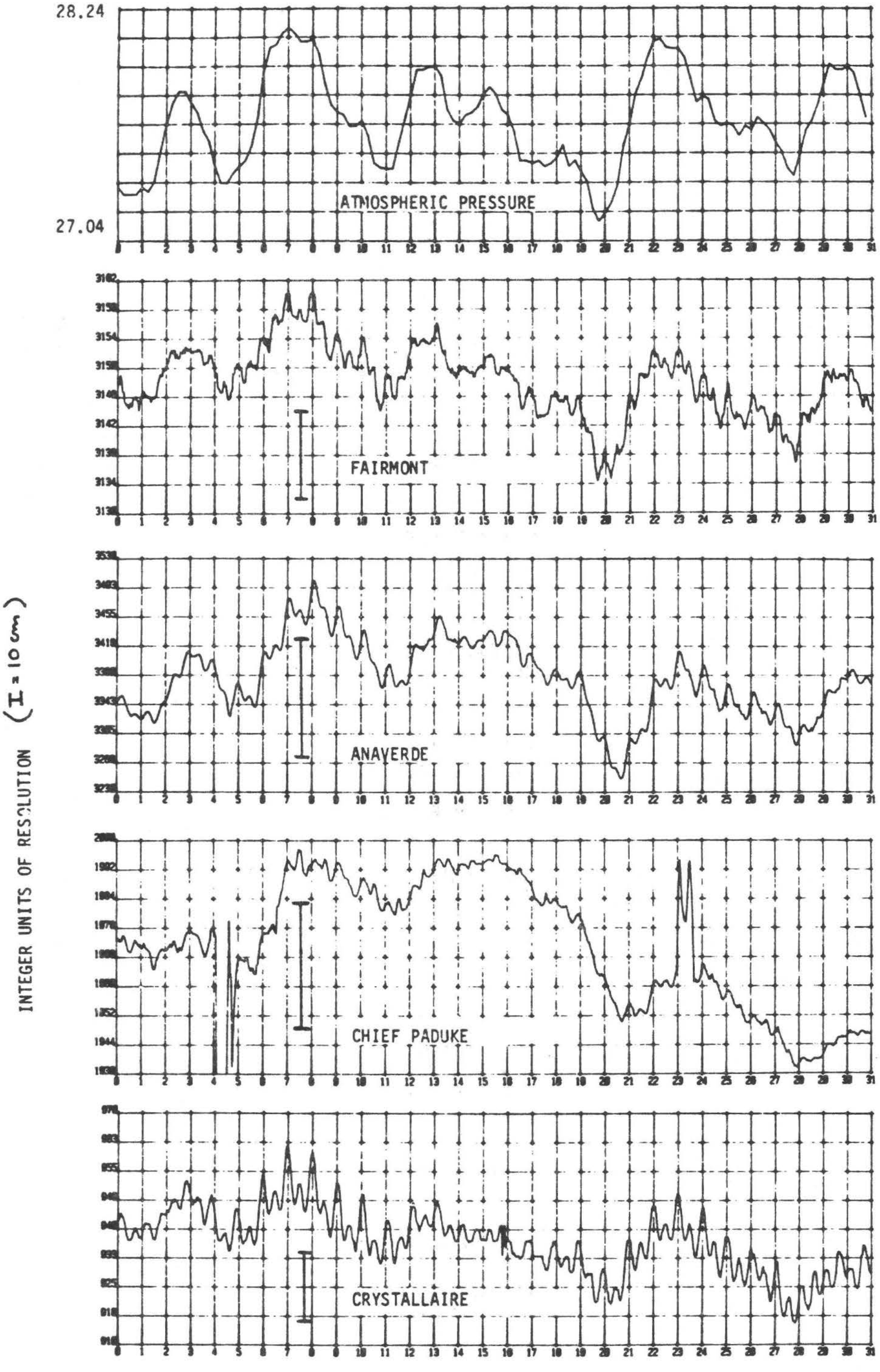

FIGURE 2: January, 1982 comparison of water level and atmospheric pressure variability. (increasing water level downward)

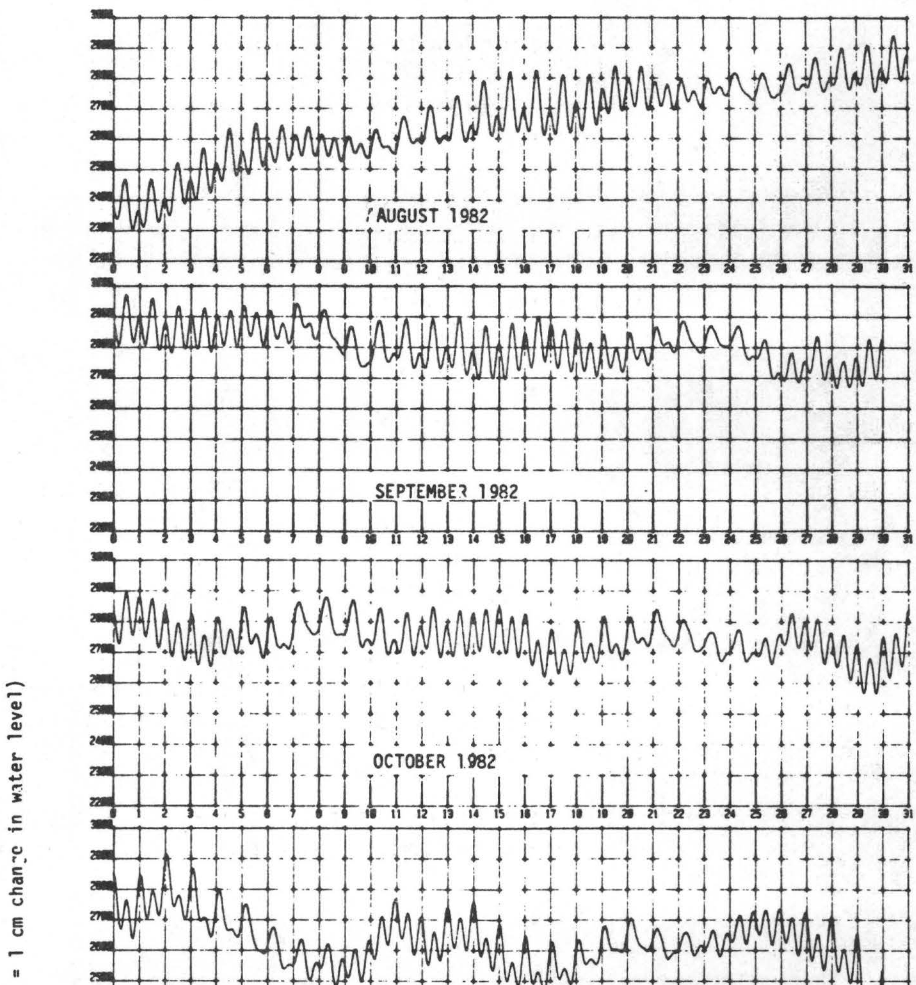

FIGURE 3 : Last 6 months water level variability at Crystallaire.
(increasing water level downward)

Low Frequency Data Network

9960-01189

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Investigations

1. Real-time monitoring, analysis, and interpretation of tilt, strain, magnetic, telluric, and other data within the San Andreas fault system and other areas for the purpose of understanding and anticipating crustal deformation and failure.

2. Compilation and maintenance of long-term data sets free of telemetry induced errors for each of the low frequency instruments in the network.

3. Development and implementation of real-time algorithms for the purpose of detecting earthquake precursors in the low frequency data.

Results

1. Data from low frequency instruments in both Southern and Central California have been collected and archived using the Low Frequency Data System. In the six months three million measurements from 125 channels have been received and subsequently transmitted on the Low Frequency 11/44 UNIX computer for archival and analysis.

2. The project continues to operate a configuration of one PDP 11/44 computer running the UNIX operating system and two PDP 11/03 running real-time data collection software. This 11/44 has been operational as our analysis machine with less than 1% down time. The two 11/03 machines operate redundantly for robustness. Accordingly, our real-time collection has had 0% down time.

3. The data from the Network have been made available to investigators in real time. Data only minutes old can be plotted. Events such as creep events can be monitored while they are still in progress.

4. The working prediction group of the Branch has made extensive use of the timely plots which are produced routinely by the System.

5. A network connection has been completed between the Low Frequency PDP 11/44 and the UNIX PDP 11/70 of the Branch of Seismology. Files can be transferred quickly between the two machines.

6. Historical data is being processed using a new algorithm in order to produce near-error-free records of each of the tilt and strain instruments for the past several years.

7. Graphics on the UNIX system have been improved with the addition of a fast and easy to use program. This new software allows plotting of data in various forms including the System's special data base form as well as universal ascii data. This new graphics software is machine-independent as well as (graphics) device independent. Therefore, in an effort to standardize some software we hope to install this package on the Office's VAX 11/780 machine as well as both UNIX computers.

8. Real-time monitoring of designed suites of instruments in particular geographical areas is now operational. Terminals may be dedicated to real-time graphics displays of low frequency data plotted as a time series or seismic data plotted in map or cross-sectional view. For additional clarity these plots can be optionally displayed in color.

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. Measurements of regional magnetic field during gravity, strain and level surveys near the San Andreas fault at Cajon, Palmdale and Tejon are strongly correlated with changes in gravity, areal strain, and uplift in these regions during a five-year period. Because the inferred relationships between these parameters is in approximate agreement with those obtained from simple deformation models, the preferred explanation appeals to short-term strain episodes independently detected in each data set. Transfer functions from magnetic to strain, gravity, and uplift perturbations, obtained by least-square linear fits to the data, are 0.80 nT/ppm, -0.03nT/ugal, and 9.1 nT/m respectively. A common source of meteorologically generated crustal noise could provide an adequate alternative explanation. See Figure 1.

2. Explanations of how earthquake lights might arise have failed to show how large charge densities can be concentrated and sustained in a conductive Earth. A physical model is proposed, based on frictional heating of the fault, that solves this and related problems.

3. Five portable recording magnetometers, an intermediate baseline laser distance meter with two sets of meteorological monitoring equipment and reflectors were installed in Yunnan Province, China during fall 1982. Measurements made on two previously installed arrays near Eryuan indicate shortening of

about 2 cm on most lines. Magnetic measurements show a field change of 5 nT between the east and west sides of the fault.

4. Two telemetered and six portable magnetometers were installed in the Mammoth Lakes/Long Valley area during the swarm in January, 1983 to supplement and upgrade the monitoring there.

5. Measurements of magnetic fields along the San Andreas fault indicate that inhomogeneous tidally generated current systems flow in and around the fault system. These currents limit measurements of short-term local fields of tectonomagnetic origin to about 0.3 nT but can be easily removed. Ocean-tidal induction into a complex fault zone with higher than average electrical conductivity appears to be a more likely explanation than either piezomagnetic effects due to solid-earth tides or ionospheric-tidal induction. The amplitudes of the induced diurnal harmonics decrease fairly linearly to the southeast along the fault. This result is consistent with expectations from a hotter and more conductive crust and upper mantle in southern California, as indicated by heat-flow data for this region.

6. Many new data suggest that near-surface stress and strain redistribution around active faults occurs primarily as a result of interaction between fault blocks separated by weaker fault zones. These data include: 1) observations of increased strain rates near the San Andreas fault compared with geodetic type rates observed at a 10-km distance from the fault, 2) indications of fault interaction in detailed measurements of deformation following the Izu, Japan and the El Centro, California earthquakes, 3) observations of localized strain changes and other deformation related anomalies in fault zones at distances of up to 100 km from subsequent major earthquakes in China, and 4) the clear indication of block tectonics in long-term deformational studies. The surface fields for an instability model applied to the San Juan Bautista section of the San Andreas fault have been obtained. This model includes zones of decreased rigidity associated with four known subsidiary faults. The results indicate major changes in predicted records from near-surface strain monitoring instruments and, if correct; suggest a new strategy for prediction monitoring based on continuous cross fault strain measurements.

7. Measurements of charge-drop size distributions in active thunderclouds indicate that electrostatic forces become important in controlling drop size distributions. In highly charged regions of thunderclouds, electrostatic forces on individual drops will exceed surface tension forces, making large drops unstable and inhibiting particle growth. With the

neutralization of charge accompanying a lightning stroke, droplets will grow rapidly and a rain gush will ensue.

8. Magnetic fields were recorded at five sites on Mt. St. Helens over a 20 day period, which included a dome extrusion-eruption of the volcano. Two of the magnetometers located in the crater measured reversible magnetic changes, which correspond to fluctuations in tilt measured nearby. However, the correlation is highly nonlinear. Electric field were measured on the east flank of the volcano near its summit to search for electrokinetic effects. They show no correlation with the magnetic changes and in the long term are uncorrelated with eruptive activity. Our favoured interpretation of the magnetic changes is that they result from piezomagnetic changes in the magnetization of the volcano induced by eruption stresses. Their reversibility rules out pressure induced magnetization as the dominant mechanism and places an upper limit of σ ~300 bars on the stresses. The limited spatial extent of the magnetic anomaly field places the source of stress at shallow depth beneath the crater floor consistent with models based on strain data.

9. The measurement precision of the U.S. Geological Survey proton magnetometer (PM) array in central California is determined using self-calibrating Rubidium instruments having 10 times greater accuracy. It is found that sensitivity to transient magnetic events with periods less than 4 minutes is increased by up 20dB for the SCRs, compared to the PMs. This presents an opportunity to improve the sensitivity to short period events by an order of magnitude. In addition, instrument precision and local noise are determined from short baseline tests in Colorado. It is found that the high frequency local noise is 30 dB below the PM noise for periods less than one hour. In both locations, for periods greater than two hours and site separations of 10km, local variations in magnetic field limit the measurement precision of both SCRs and PMs.

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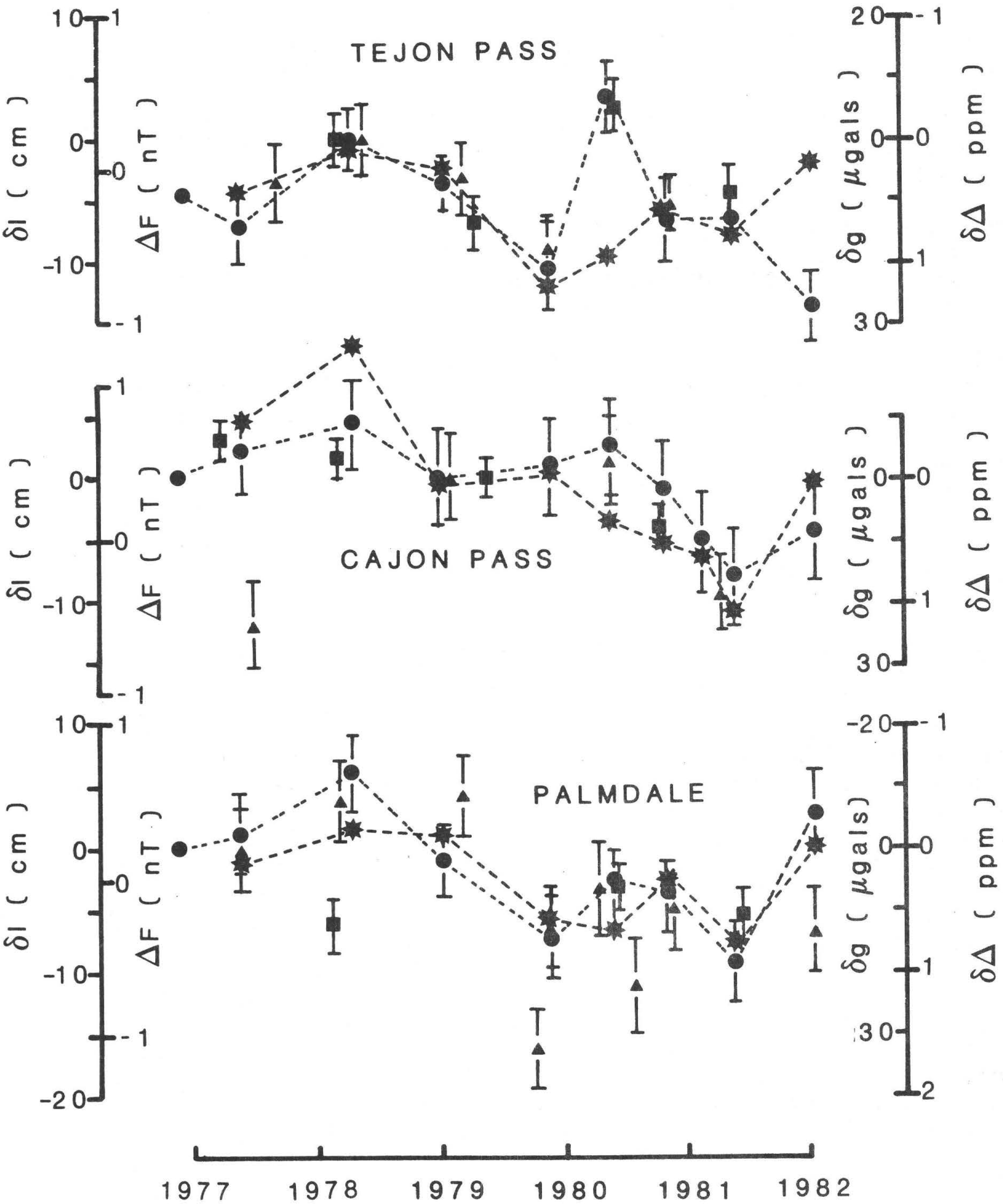

Figure 1. Superimposed time-histories of magnetic field (stars), gravity (dots), areal strain (triangles), and elevation (squares) data, together with their error bars, from the three study regions in southern California. Single dashed lines connect the gravity data points and double dashed lines connect the magnetic data points. Error bars for the magnetic data lie within the star symbol.

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 samples were periodically taken from the wells for chemical analyses.

Results

Figure 1 shows radon data recorded at an artesian well at Mission Farm Campground near San Juan Bautista from February 1978 to April 1981, together with rainfall in Hollister (bar graphs) and earthquakes of magnitude 4.0 or larger (arrows, labelled with magnitude and epicentral distance in km). During 1978, a year of relatively low seismicity in San Juan Bautista, the radon value appeared to show a seasonal variation between 550 p C/L in the summer and 650 p C/L in the winter. (The horizontal dashed lines indicate the mean 1978 value $\pm$ one standard deviation.) The radon data were apparently unaffected by rainfall but showed a gradual long-term increase due to build-up of the radon daughter ^{210}Po in the instrument.

Two possible anomalies were noticeable in the radon data: During a one-week period in mid-April 1979, the radon value dropped from 670 to 500 p C/L, then fluctuated more than before and did not recover until November. A second change of comparable amplitude but much shorter duration (about ten days) occurred in mid-February 1980. These changes preceded, respectively, the magnitude 5.9 Coyote Lake earthquake on August 6, 1979, 30 km to the north of the well and a sequence of earthquakes of magnitude up to 4.8 along the San Andreas fault.

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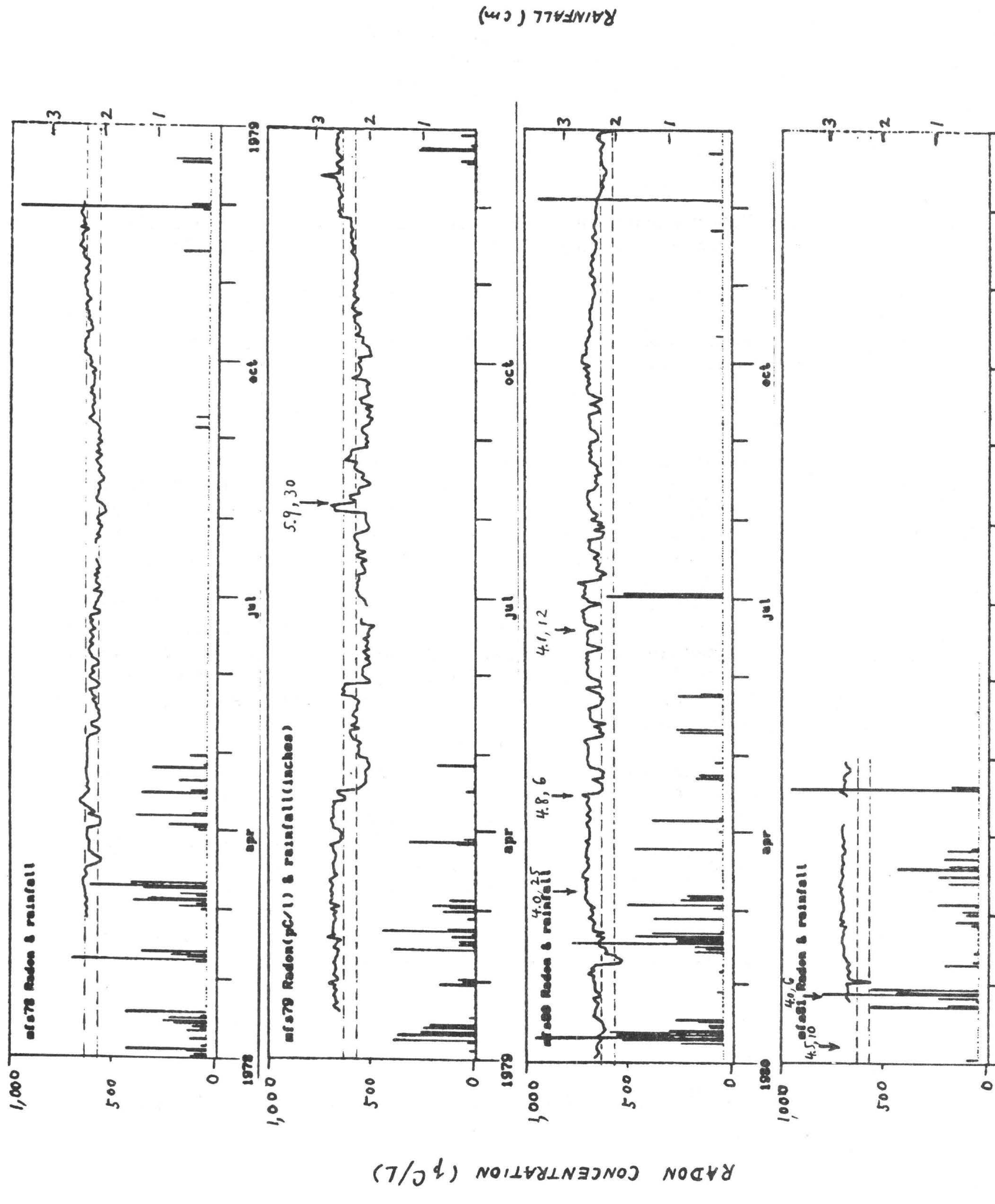
P2



RAINFALL (cm)
RADON CONCENTRATION (pC/L)
mfs78 Radon & rainfall
mfs79 Radon(pC/l) & rainfall(inches)
mfs80 Radon & rainfall
mfs81 Radon & rainfall
5.9, 30
4.1, 12
4.8, 6
4.0, 25
4.0, 6
4.5, 10
apr
jul
oct
1978
1979
1980
1981
1982

Fig. 1

Hydrological/Geochemical Monitoring Along San Andreas and San Jacinto Faults, Southern California, During First Half of Fiscal Year 1983

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Investigations

Water levels in over thirty wells along the San Andreas and San Jacinto fault zones were monitored during the current reporting period. Water levels in seven wells and barometric pressure at two wells were monitored by the Caltech Remote Observatory Support System (CROSS). Another ten wells were monitored continuously with Stevens Type F recorders, two of which are maintained by W.R. Moyle, Jr., of the Geological Survey. The remaining wells were probed monthly, weekly, semiweekly, or daily with the aid of volunteers. In addition, water samples were analyzed monthly for fluorine, chlorine and sulfate ion concentrations.

Temperature, salinity and conductivity were measured in ten selected wells at the time the water-level charts were changed. Equipment to monitor water temperature and conductivity is installed in one well in Anza on CROSS.

Results

Figures 1 and 2 illustrate typical computer-generated hydrographs of well 5N/12W-3N1 in the Palmdale area for the past 6-1/2 years. Daily and seasonal rainfall are plotted for comparison with water levels. Figure 3 is a typical Stevens Type F recorder chart of monthly water levels for well 11S/6E-1C1 in Borrego Valley, and Figure 4 is a record for well 5N/12W-3N1 in the Palmdale area from the Caltech CROSS system. These short-term records show variations in water level due to atmospheric pressure and possibly earth-tides.

Insufficient data are available on the timing of water-level changes prior to earthquakes; thus both short- and long-term hydrographs are now essential for earthquake prediction. Our records now extend over a long enough time period that we should be able to identify anomalous water-level changes which may be premonitory to a major earthquake.

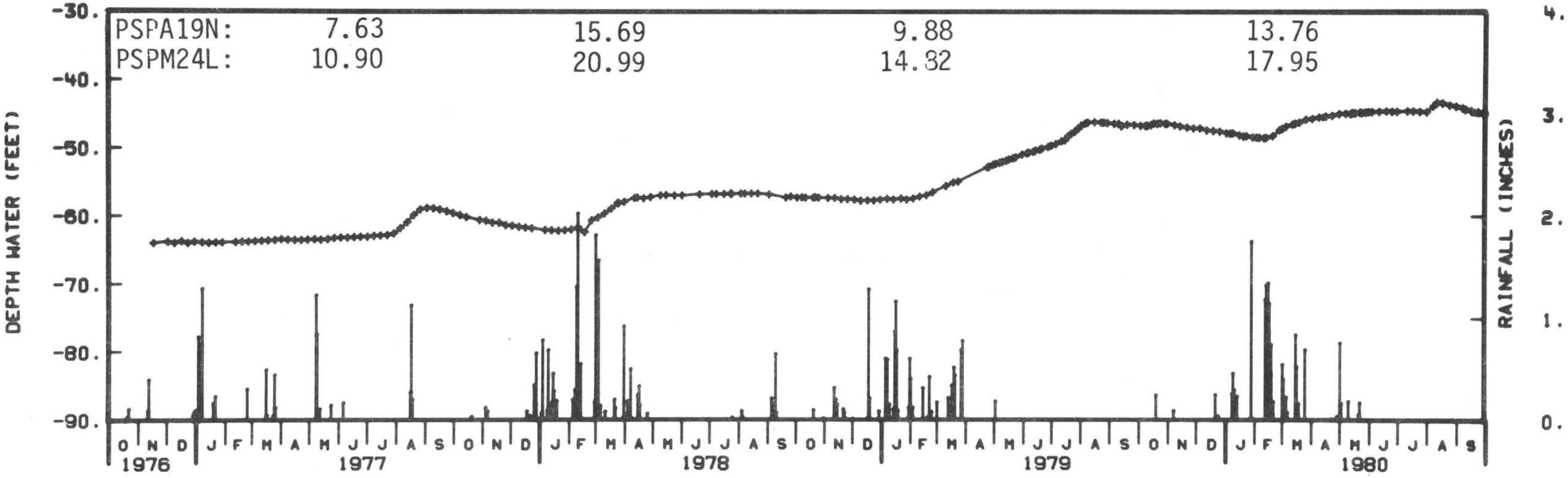


FIGURE 1 -- WEEKLY OBSERVATIONS OF WATER LEVEL (+) AND RAINFALL (.) IN WELL NUMBER 05N/12W-03N01 DURING 1976-1980 PALMDALE AREA
SEASONAL RAINFALL AT ADJACENT STATIONS IN INCHES ACROSS TOP

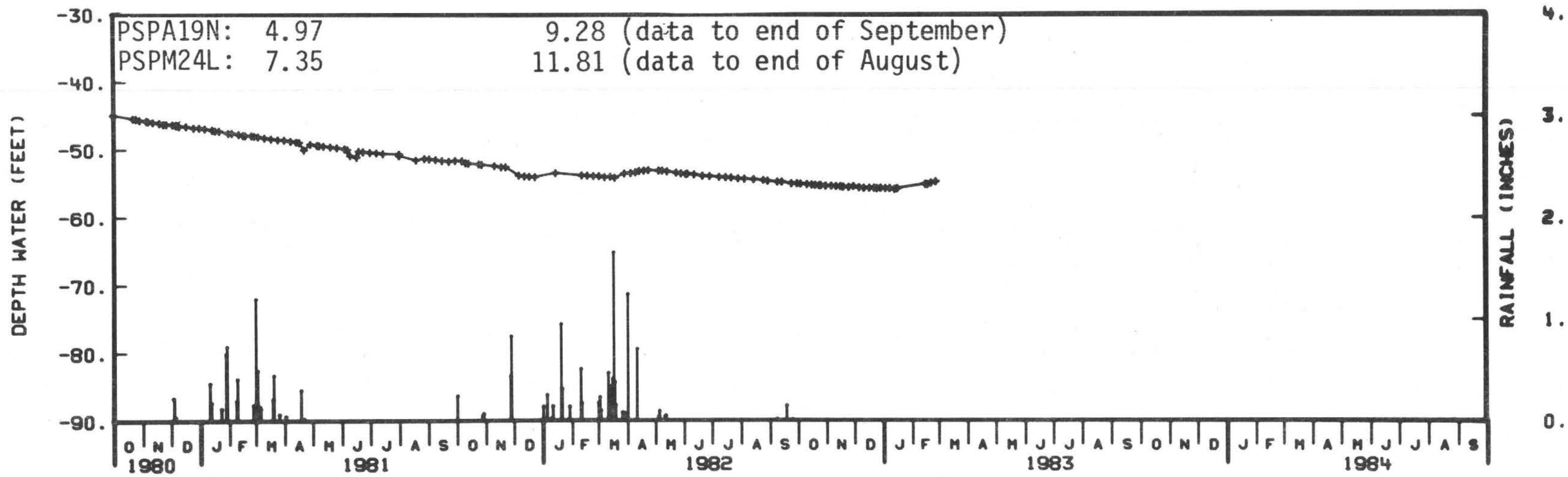
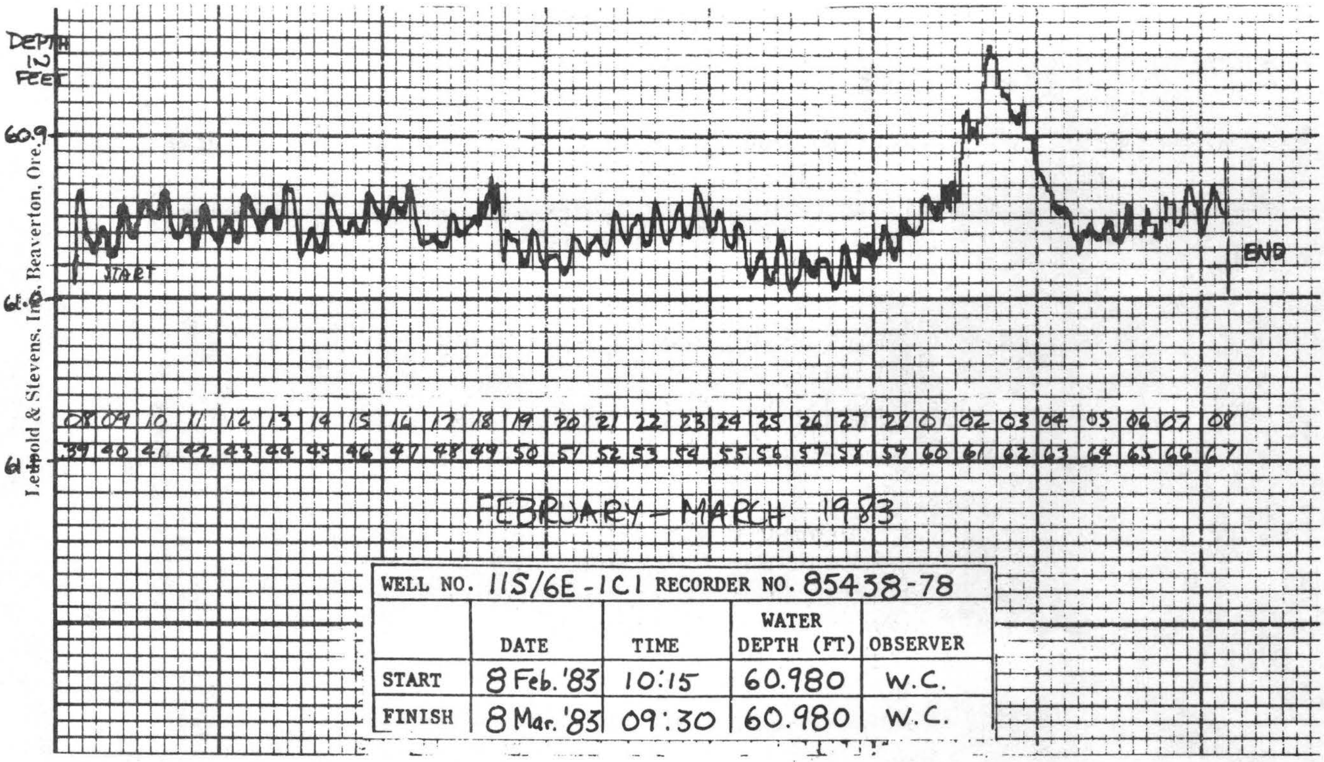


FIGURE 2 -- WEEKLY OBSERVATIONS OF WATER LEVEL (+) AND RAINFALL (.) IN WELL NUMBER 05N/12W-03N01 DURING 1980-1984 PALMDALE AREA
SEASONAL RAINFALL AT ADJACENT STATIONS IN INCHES ACROSS TOP



WELL NO. 11S/6E-1C1	RECORDER NO. 85438-78			
	DATE	TIME	WATER DEPTH (FT)	OBSERVER
START	8 Feb.'83	10:15	60.980	W.C.
FINISH	8 Mar.'83	09:30	60.980	W.C.

Fig. 3 - Stevens Type F recorder chart for well 11S/6E-1C1, Borrego Valley, 8 February - 8 March, 1983.

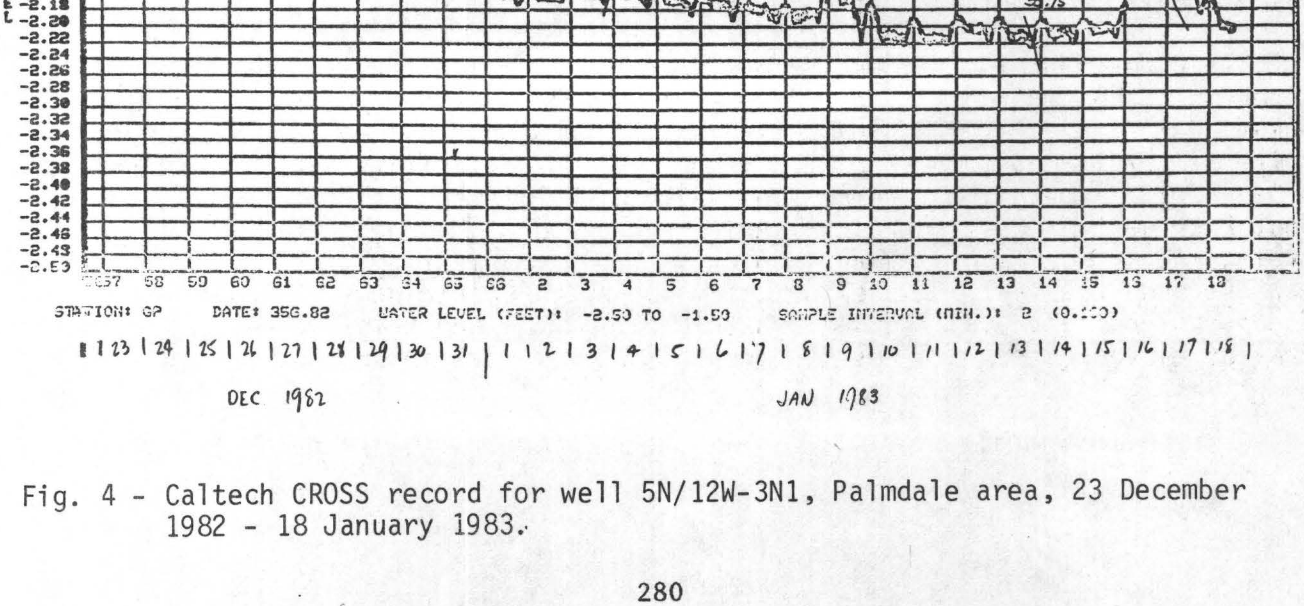


Fig. 4 - Caltech CROSS record for well 5N/12W-3N1, Palmdale area, 23 December 1982 - 18 January 1983.

Can Animals Anticipate Earthquakes?
A Search For Correlations Between Changes in the Activity Patterns of Captive Fossorial Rodents and Subsequent Seismic Events

Contract 14-008-001-17686

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This is the final summary report for an experimental investigation of unusual animal behavior prior to earthquakes which began acquiring data in 1977. The experimental animals were field-captured burrowing rodents native to the arid regions of the southwestern United States which were housed individually in running wheel cages designed to electronically record running wheel revolutions and in artificial burrow systems equipped to record gross motor activity. The purpose of the investigation was to place animals in a seismically active region and to continuously record their activities for extended periods in order to determine whether and to what extent deviations from the 'normal' pattern and intensity of animal activity might be correlated with nearby seismic events. Small rodents were the experimental animals of choice because they are easily maintained and monitored in captivity and exhibit activity patterns which bear regular and predictable relationships to environmental variables such as photoperiod and thermoperiod, and because there are many ancedotal reports that such animals often behave anomalously prior to earthquakes.

Two experimental sites were used. From 1977-1981 a facility was maintained in the Big Morongo Wildlife Reserve, Morongo Valley, San Bernardino County, California, a few kilometers from the Banning-Mission Creek branch of the southern San Andreas Fault. From 1979-1982 a facility was maintained in San Benito County in Stone Canyon, south of Hollister, California and about 2 km west of the central San Andreas Fault. At Morongo Valley 20 running wheel cages housing kangaroo rats (Dipodomys merriami) and pocket mice (Perognathus fallax) were located indoors and maintained in conditions of controlled light (LD 12:12 or constant dim light) and temperature. An array of eleven burrow systems was located out-of-doors in an open field.

Six housed little pocket mice (Perognathus longimembris) and five housed larger rodents (D. merriami and P. fallax). The Stone Canyon facility consisted of an outdoor array of 10 burrow systems — six for P. longimembris and four for the larger P. californicus.

Each burrow system consisted of three activity boxes (10in. x 15in. x 4in. high for the little pocket mice; 13in. x 18in. x 5in. high for the kangaroo rats and larger pocket mice). One box was exposed at ground level; one was buried just beneath the ground surface; and the third was buried at a depth of about 0.8m. The boxes were connected by PVC pipe so that each animal was free to move from box to box within its own burrow system. Each box was divided into three sections. To enter or leave a box or to pass from one section of a box to another, an animal had to pass through a LED-phototransistor gate. One channel of an event recorder was dedicated to each box, so that a record of where and how active each animal was throughout each 24 day was obtained.

During the first year of the study data were recorded via a pen and ink strip chart recorder. From 1978 onward, quantitative data consisting of accumulated running wheel revolutions or burrow system gate counts were recorded on magnetic tape cassettes once every 10 or 20 minutes. At approximately monthly intervals, cassettes were retrieved from the study sites and computer processed. Figure 1 shows a typical printout for one of the burrow system boxes.

As with many prediction studies, the present investigation suffered from the complete absence of large and moderate earthquakes near either study site. The most significant occurred during the Landers, California swarm of March 1979 which was located about 30 km NNE of the Morongo Valley site and comprised one magnitude 5.2 event, six events of magnitudes from 4.0 to 4.9 and 36 events of magnitude 3.0 to 3.9. Many of the larger events produced significant ground motion at the study site. During the balance of the study seismic activity was infrequent, with only a few $3.0 \leq M \leq 4.0$ events occurring within 20 km of the study site. On the other hand, small earthquakes were numerous near the Stone Canyon site — often so numerous as to preclude establishment of a reliable baseline of normal animal activity. The most significant earthquakes to occur near Stone Canyon while reliable animal activity data were being acquired comprised one magnitude 4.8 event at about 30 km from the site, 2 M=4.2 events at 15 km, one M=4.0 event at 11.5 km, and for $3.0 \leq M \leq 3.9$ there were 7 events within 10 km of the site and 5 events within 20 km.

For the earthquakes noted above, and for even smaller ($M<3.0$) events occurring within 20 km of the Stone Canyon site, animal activity data were scanned for evidence of unusual behavior within a few days prior to each earthquake. Anomalies might consist of increased or decreased activity relative to the mean activity for several days preceding and following the earthquake, or changes in the daily pattern of activity such as the time of most intense activity, periods of quiet, or distribution of activity among the three levels of a burrow system.

Prior to most of the earthquakes with epicenters located near the study sites few or no animals exhibited behavior that could reasonably be termed anomalous. Moreover, in no case did all, or even most, animals exhibit unusual behavior prior to an earthquake. Such anomalous behavior as did occur prior to a nearby earthquake was either indistinguishable from similarly anomalous behavior which occurred frequently in the absence of seismic activity or was coincident with changes in nonearthquake-related environmental factors such as air temperature or precipitation. For example, about 10 days prior to the commencement of the Landers earthquake swarm, several animals at the Morongo Valley site began to be active in their surface boxes during daylight hours. Because the animals are considered nocturnal and hence should not have been active above ground during daylight, and because the animals had not been active above ground for several weeks owing to winter weather, their behavior appeared likely to have been precipitated by the impending earthquake swarm. However, subsequent investigation revealed a dramatic increase in local daytime air temperatures coincident with the above ground animal activity. In addition, data obtained in the following years at Morongo Valley and Stone Canyon revealed that sudden commencement of daytime activity above ground in the spring was in fact normal for our experimental animals.

The most reasonable conclusion to be drawn from these data is that the animals species involved in our investigation generally do not exhibit unusual behavior prior to nearby small earthquakes. Such anomalous behavior as does occur is most probably fortuitous since it is either coincident with nonearthquake-related environmental events or is unspectacular and indistinguishable from similar behavior which occurs frequently in the absence of earthquakes.

Our data cannot rule out the possibility that some of the behavioral anomalies recorded prior to some earthquakes were indeed caused by physical earthquake precursors. But the data do indicate that such precursory behavior is rare and not useful for prediction of small earthquakes. However, it must be clearly understood that these conclusions should not be extrapolated to apply to large or moderate earthquakes or to species other than those examined. In particular, our findings provide no basis for summarily rejecting the numerous retrospective, anecdotal reports of anomalous animal behavior prior to large earthquakes which exist in the modern and historical literature.

Whether animals can anticipate seismic events is not a trivial question. But the scientific evidence is clear that organisms are not only incredibly sensitive to certain changes in the physical parameters of their environment but can also discriminate very small signals from noise. The reported characteristics of physical seismic precursors indicate that such precursors are within the range of detection of some form of life and are thus capable of producing biological earthquake precursors. Therefore, it should not be surprising to find that some animals behave anomalously prior to earthquakes. Unfortunately, convincing scientific evidence to that effect does not yet exist. (However, some encouraging results have been obtained; e.g., Hatai and Abe 1932, Lott, et. al. 1979, Otis and Kautz 1983.) If for even a single species such behavior could be demonstrated, or if the mechanism by which that species 'anticipates' an earthquake could be understood, that knowledge could result in significant human benefits. We believe that these considerations provide ample justification for continued scientific investigation of unusual animal behavior prior to earthquakes.

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USCS EQ PREDICT OUTDOOR

STONE CANYON
ANIMAL P-4

DAYS/YEAR 106/82 - 127/82
ACTIVITY BOX TOP

TIME PST	127	126	125	124	123	122	121	120	119	118	117	116	115	114	113	112	111	110	109	108	107	106	TIME PST	
1200												3											1200	1
1220																							1220	2
1240																							1240	3
1300									1														1300	4
1320											1												1320	5
1340								1				1			1								1340	6
1400													1										1400	7
1420												1											1420	8
1440																							1440	9
1500										1													1500	10
1520										1													1520	11
1540																							1540	12
1600																							1600	13
1620						1	1					3											1620	14
1640		2								2			6	1									1640	15
1700		3				1							2										1700	16
1720																							1720	17
1740																							1740	18
1800		1																					1800	19
1820		3												2									1820	20
1840	2								1					6				2					1840	21
1900	3	6	1	7	4	3		5		1	3		4	5	2	L		4	5	3	5		1900	22
1920	20	10	15	9	8	7	1	2	5	8	3			18	4	6		10	7	5	1		1920	23
1940	29	41	44	16	6	1	5	2	2	9			6	4		13	2	6	5	4	3	5	1940	24
2000	37	32	36	14	6	1		1	2	5	4		5			16	9	6		2	8	7	2000	25
2020	29	31	30	24	4				3	4	4			1	2	5	5	10	5	13	7		2020	26
2040	30	43	47	7	7									1			2	10	6	8	5		2040	27
2100	38	48	28	1	5	2			1	4	3					2	2	5	1	3	5	2	2100	28
2120		37	5		1	4			1		11	1						4	3	1		2	2120	29
2140		45	1						1		12	3		1	7				1	9			2140	30
2200		16					1	5	1	3				3				4					2200	31
2220				2			1		2	6			18		7	2	2	1	3		5		2220	32
2240						1				7			32	7		2		1	1	11	7	5	2240	33
2300					4	11			8	1			22	5	7	14	3			1		7	2300	34
2320	12		11			2		1	7		4	3	20		15	6			3		1	5	2320	35
2340	26		16	4		1		3	3		4	1	5		3			4	6		3	9	2340	36
0	26	4	31	8		7	5				5	8				6	3		4	4		8	0	37
20	5		18	17	2		1	3		9	9	5				11	8	2	1			11	20	38
40		2	32	30	7			8		3					2		1					9	40	39
100		3	19	20	9	14	8	4					2	3	4	1		4		2		7	100	40
120		11	6	25	6	8			4				10	5		ı						2	120	41
140	7				10	5	12		4	1	6	6			9	10			5	5			140	42
200		24		2	8	7	2	3	5	6	9	2	5		8	1	3		7	2			200	43
220	17	1		10	5	8		4	4	6			8	9	4		1	2	12	4			220	44
240	27	18	1	5	10	7	10	6	5	5		3	7	12		1			8				240	45
300	37	25	24	7	10	11	6	6	8		2	2		2		5	4		10		4		300	46
320	15	11	19	6	5	13		6	6	6	15				6	2	4	2		4	15		320	47
340	7	2	17	7	1	10	6	10	5	6	4	3	8	3		2	2	3		5	8		340	48
400	5	9	6	4	7		2	14	2		5	7	4	3	1			3		7	9		400	49
420	5	10	5	5	8	4	2	10	4	8	6	1	2		4	1	4				12		420	50
440		5		1		2	2		2			6	6	5		3			4		2		440	51
500																	2		4	2			500	52
520																			8				520	53
540																							540	54
600																							600	55
620																							620	56
640																							640	57
700																							700	58
720																							720	59
740																							740	60
800																							800	61
820																							820	62
840																2							840	63
900												2											900	64
920																							920	65
940									1														940	66
1000																							1000	67
1020																							1020	68
1040											2												1040	69
1100										1													1100	70
1120																							1120	71
1140										1													1140	72

	128	127	126	125	124	123	122	121	120	119	118	117	116	115	114	113	112	111	110	109	108	107	MEAN	SD
ACTOT	5.2	6.2	5.7	3.2	1.8	1.8	.9	1.3	1.2	1.4	1.6	.8	2.4	1.3	1.2	1.6	.8	1.2	1.5	1.3	1.4	1.1	2.0	1.5
N20	20.0	27.0	22.0	23.0	22.0	24.0	16.0	19.0	26.0	24.0	20.0	19.0	20.0	20.0	17.0	23.0	17.0	19.0	22.0	20.0	17.0	13.0	20.5	[illegible]
SUM/N	18.8	16.4	18.7	10.0	6.0	5.5	4.1	4.9	3.4	4.3	5.6	3.2	8.6	4.8	5.1	4.9	3.4	4.4	5.0	4.8	5.9	6.1	7.0	[illegible]
HRACT	10.0	12.3	9.7	10.0	9.7	12.7	12.7	15.0	21.0	21.0	21.7	21.3	15.0	12.3	15.0	14.0	9.7	9.7	10.7	10.3	10.0	6.0	13.2	4.1
ACRO	34.0	32.0	33.4	35.8	37.9	39.8	41.0	41.7	38.9	35.8	37.8	38.4	35.3	34.1	36.8	34.1	36.5	29.9	38.2	34.1	38.1	34.7	36.3	2.8

Figure 1. Computer printout of above ground activity record of *Perognathus longimembris* P-4 from Stone Canyon for days 106-127, 1982. Data are the number of times P-4 tripped switch gates in the top activity box of its burrow system during a 20 minute period.

Air-gun Seismic Velocity Measurements in the San Andreas Fault Zone

9960-02413
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Investigations

1. Tidal stress variation of seismic traveltimes in shallow crust.

2. Elastic properties of rocks: development of a quasi-static, small strain (10^{-8} - 10^{-7}) apparatus for measuring Young's modulus of rocks. This apparatus is to be used for determining the effect of cracks and rock fabric on elastic anisotropy and, by comparison with ultrasonic velocity measurements, determining the Young's modulus dispersion (in collaboration with Lou Peselnick, 9960-01490).

3. Preparation of chapter on Internal Friction in Rocks and Minerals for the volume Geophysics of the series Methods of Experimental Physics published by the Academic Press (in collaboration with Lou Peselnick, 9960-01490).

Results

1. Because our results (Liu et al., 1983) of eight precise seismic surveys near the San Andreas fault in central California corroborate only partially the previously reported tidal stress variation of traveltimes in the shallow crust (DeFazio et al., 1973; Reasenberg and Aki, 1974), a decision has been made to conduct a series of precise seismic surveys with digital recorders and our new data reduction techniques at the North Chelmsford, Massachusetts site chosen by Reasenberg and Aki (1974) in order to investigate the site-dependence (rock type, degree of weathering, crack orientation and distribution, water saturation etc.,) of the reported tidal variation of traveltimes. Work carried out during this report period include: negotiation with landowners at the North Chelmsford site, seismic noise surveys of the site, and modification of 3 additional Sprengnether DR 100 recorders for precise time synchronization, making a total of 5 DR 100 recorders capable of being synchronized to within 10 s of each other.

2. Work is continuing on the apparatus which measures quasistatically the Young's modulus of rocks at small strains (10^{-8} - 10^{-7}). A single crystal quartz rectangular plate has been oriented to generate piezoelectrically a pure longitudinal displacement along its maximum plate dimension to serve as a displacement calibrator. Methods for applying a uniformly distributed load to the rock end surface by mercury loading has been devised and the parts are currently under construction by the machine shop.

3. A review paper on laboratory measurement of rock and mineral internal friction at seismic frequencies has been completed for publication in the volume Geophysics, of the series Methods of Experimental Physics, published by the Academic Press.

Reference Cited

DeFazio, T.L., K. Aki, and J. Alba, Solid earth tide and observed change in the in situ seismic velocity, J. Geophys. Res., 78, 1319-1322, 1973.

Liu, H.-P., R.E., Westerlund, and J.B. Fletcher, Precise measurement of seismic traveltimes - investigation of variation from tidal stress in shallow crust, Geophys. Res. Lett., 1983 (in press).

Reasenberg, P., and K. Aki, A precise, continuous measurement of seismic velocity for monitoring in situ stress, J. Geophys. Res., 79, 399-406, 1974.

Report

Liu, H.-P. and L. Peselnick, Investigation of internal friction in fused quartz, steel, plexiglass, and westerly granite from 0.01 to 1.00 hertz at 10^{-8} to 10^{-7} strain amplitude, J. Geophys. Res., 88, 2367-2379, 1983.

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 11/44 computer.

3. Made alinement array surveys on actively creeping faults.

4. Developed experimental procedures aimed at an operational prediction program.

Results

1. Currently 38 extension creepmeters operate; 26 of the 38 have on-site strip chart recorders; and 18 of the 26 are telemetered to Menlo Park.

2. Fault creep data from all 38 USGS creepmeter sites on the San Andreas, Hayward, and Calaveras faults have been updated (through March 1983) and stored in digital form (1 sample/day). A report of all data from recently operating creepmeters was published in August 1982.

3. Alinement arrays have been established and surveyed across active faults in central California as a continuation of work started by P. Harsh and R. Burford (Project 9960-02943). The arrays will be used for siting and checking creepmeters as well as for monitoring fault creep where creepmeters are impractical.

4. More frequent examination of daily creepmeter data has begun in order to document and analyze the relation between fault creep and earthquakes. This was prompted by (1) the accumulation of nearly 15 years of creepmeter data, (2) the increased occurrence of moderate central California earthquakes, and (3) our desire to develop inputs to an operational prediction program. Experimental algorithms are being tested against past creep data to identify possible anomalies preceding earthquakes.

Theoretical Mechanics of Earthquake Precursors

9960-02115

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Investigations

1. Continued analysis of strain-induced pore pressure changes in a seismically active region.

2. Studied the mechanics of interaction of the Hayward and Calaveras faults southeast of San Francisco Bay (with B. Mavko).

3. Modeled large-scale strike-slip earthquakes with a laboratory-inferred friction law.

Results

1. Simultaneous in-situ recordings of acceleration and wave-induced pore pressure changes (recorded by E.L. Harp, Engineering Geology Branch, USGS, project 9550-01452) were analyzed to determine the fluid effects on wave propagation and to test existing models of pore deformation. The recordings were made in saturated lake gravels near the epicenters of the 1980 Mammoth Lakes, California, earthquakes.

   Near-surface strains, determined from the acceleration records, were less than 10^{-4}, and the relation between pore pressure and acceleration indicates primarily linear deformation. Measured pore pressure, P, is proportional to, and in phase with, surface vertical acceleration during the P-wave train, and it lags by 1/4 cycle the surface acceleration during the S-wave train. In both cases, P is approximately proportional to the solid dilatational strain and the phase difference between P-waves and S-waves is due to interference and mode conversion at the free surface.

2. A theoretical model of the zone of intersecton of the Hayward and Calaveras faults was constructed on the basis of seismic and geodetic data and dislocation calculations. The strike-slip faults were modeled as two-dimensional cuts in an otherwise homogeneous elastic plate. Geodetically determined slip rates were specified on faults outside of the modeled region, and remote displacements were imposed parallel to the plate boundary. Slip on the modeled faults was computed, subject to frictional boundary conditions on the fault surfaces. Geodetic constraints (lack of strain accumulation) require smooth, barrier-free faults near the zone of intersection. Patterns of recent uplift and subsidence further constrain the models and seem to favor slip along the trend of the Mission Peak fault.

3. Theoretical models of two-dimensional faults using a Dieterich friction law were modified to allow chaotic solutions. Instabilities of apparently random size and recurrence time were found but only over a very narrow range of model parameters. Chaotic solutions resulting from simple material constitutive laws is an attractive explanation of varying event sizes. However, the model requirements for chaotic solutions appear to be too restrictive to account for the universally observed random features of earthquakes.

Reports

Mavko, B., and G. Mavko, 1982, A seismic, geodetic, and mechanical model of fault interaction, (abstract) AGU Chapman Conference on Fault Behavior and the Earthquake Generation Process, 1982.

Mavko, B., and G. Mavko, 1982, A seismomechanical model of interacting faults, (abstract) EOS, v. 63, 45, 1030.

Mavko, G., 1982, Analysis of wave-induced pore pressure changes, (abstract) EOS, v. 63, 45, 1123.

Experimental Tilt and Strain Instrumentation

9960-01801

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Investigations

1. An evaluation of the low frequency telemetry system was undertaken by Vince Keller. The purpose of the evaluation was to determine where the weaknesses exist in the design, application, operation and maintenance of the system and to make specific recommendations for upgrading the system and modifying operating and maintenance procedures. The evaluation concentrated predominantly on the field transmitter since most of the observed problems seemed to occur in that unit, probably because of its exposure to environmental influences.

2. The intense swarm of earthquakes at Mammoth Lakes in January 1983 prompted a decision to install four tiltmeters at two sites near the region of uplift and seismicity in order to continuously monitor deformation. Working long hours, Doug Myren, Rich Liechti and Bob Mueller readied instruments and equipment and assembled and tested satellite telemetry units. Possible site locations were identified in consultation with Dan Dzurisin of CVO and the U.S. Forest Service. The feasibility of getting the necessary equipment to the sites with the unusually heavy snow cover was examined. With some plowing by the USFS snowcat, and chains on all six wheels of the drill rig, it was possible to install two instruments at a site overlooking Hot Creek, shown in Figure 1. Magnetometers were located near the Hot Creek tiltmeters and at Smokey Bear Flat, labelled SB on Figure 1. Due to the shortness of preparation time, the tiltmeter data are transmitted by 8-bit telemetry and the magnetometer data by 16-bit telemetry through the GOES satellite. Resolution of the 8-bit telemetry is only about 2 microradians. Some data from the HC2 (Hot Creek) instrument are shown in Figure 2. Because of the infeasibility of installing instruments at a second site, the extra instruments and equipment were stored locally until snow melting permits additional work.

If summer ever arrives at Mammoth Lakes, plans call for installing six tiltmeters at various sites in coordination with the CVO instrumental monitoring program.

3. Routine maintenance was conducted as weather permitted on the shallow borehole instruments in the San Juan Bautista and Parkfield regions. Damage from the heavy winter rainfall will necessitate refurbishing some sites.

4. Doug Myren and Rich Liechti participated in the dilatometer project under Malcolm Johnston. They conducted maintenance, installed pressure transducers, plugged the boreholes above the dilatometers with grout, installed satellite telemetry to relay dilatometer data from Pinon Flat Observatory, and performed other tasks.

Results

1. Evaluation of the low frequency telemetry system revealed some systematic failures of particular components of the field transmitter unit. Modifications and more reliable parts not available at the time the unit was designed were recommended. The major category of failure was environmental. In this regard, it should be noted that the field units tested displayed no significant response to temperature cycling when dry, but when moisture was allowed to condense on the circuit boards substantial fluctuations in output with temperature were noted. Combinations of factors such as temperature, humidity, power supply voltage and others can explain a significant number of the observed failures. The changes recommended at the conclusion of the evaluation are being implemented as time permits.

2. After a settling-in period during January and February the tiltmeter at the Hot Creek site recorded a gradual tilt down to the east-southeast. For the month of March this amounted to 8.75 ± 1.24 microradians S53E. Since March the tilt recorded at Hot Creek has shifted to a due-east direction and has slightly diminished in amplitude. Minor fluctuations cannot be resolved in the 8-bit data. The Hot Creek record for the period 20 February through 20 April is shown in Figure 2. The second instrument at this site cannot be used to verify the recorded tilt change due to a malfunction. Two attempts to fix the second instrument have failed and replacement will have to await improved weather. The recorded tilt change is consistent with the results of a nearby tilt array, but the noise level of the dry tilt measurement is undesirably high. The instruments to be installed during the hoped for summer will be emplaced at greater depth for better noise immunity, and data will be returned using 12-bit telemetry for better resolution.

Reports

1. Mortensen, C.E., 1982, Short-term tilt events preceding some local earthquakes on the central Calaveras fault: additional evidence, in: Proceedings, Conference on Earthquake Hazards in the Eastern San Francisco Bay Area, CDMG Special Publication 62, p. 289-298.

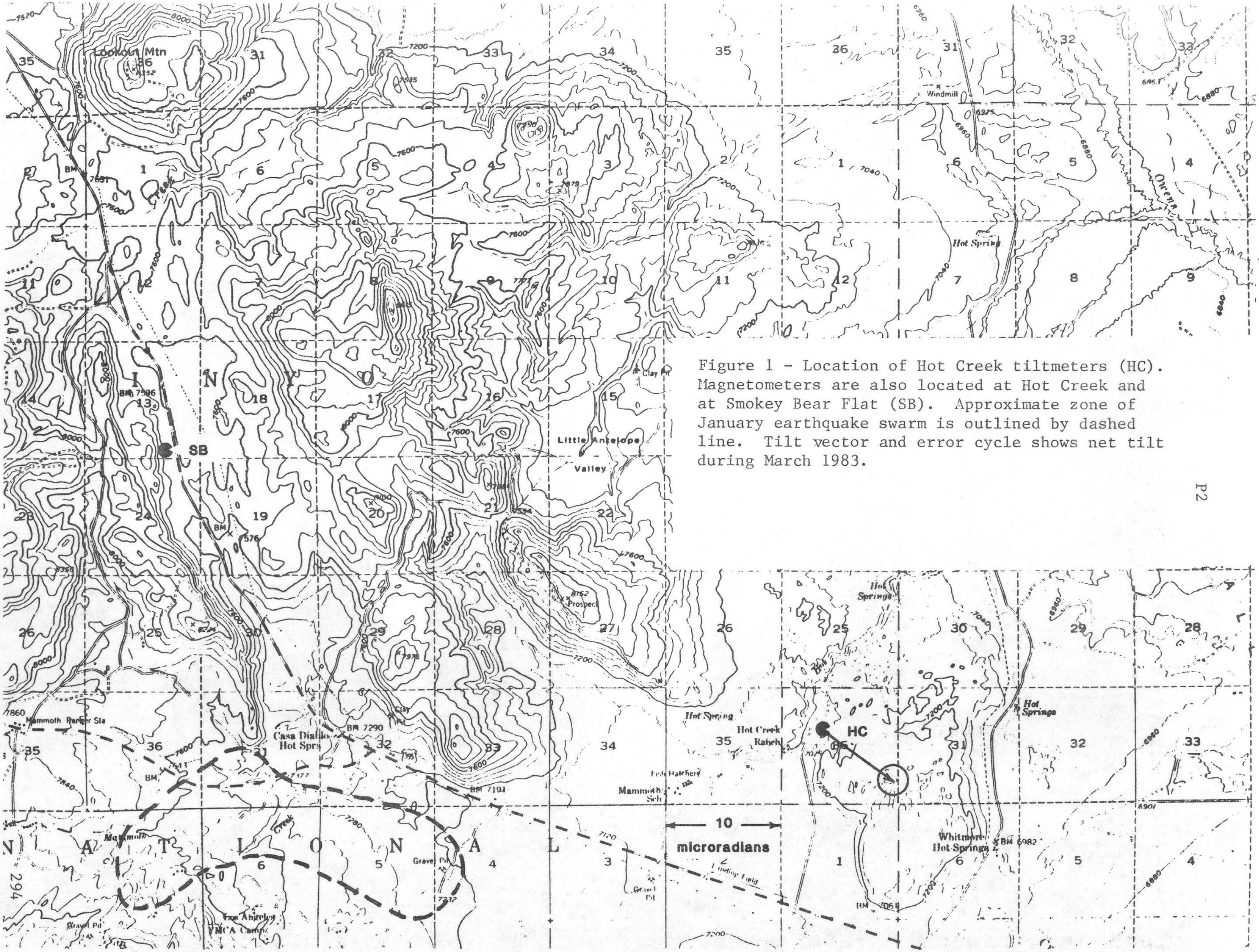

Figure 1 - Location of Hot Creek tiltmeters (HC). Magnetometers are also located at Hot Creek and at Smokey Bear Flat (SB). Approximate zone of January earthquake swarm is outlined by dashed line. Tilt vector and error cycle shows net tilt during March 1983.

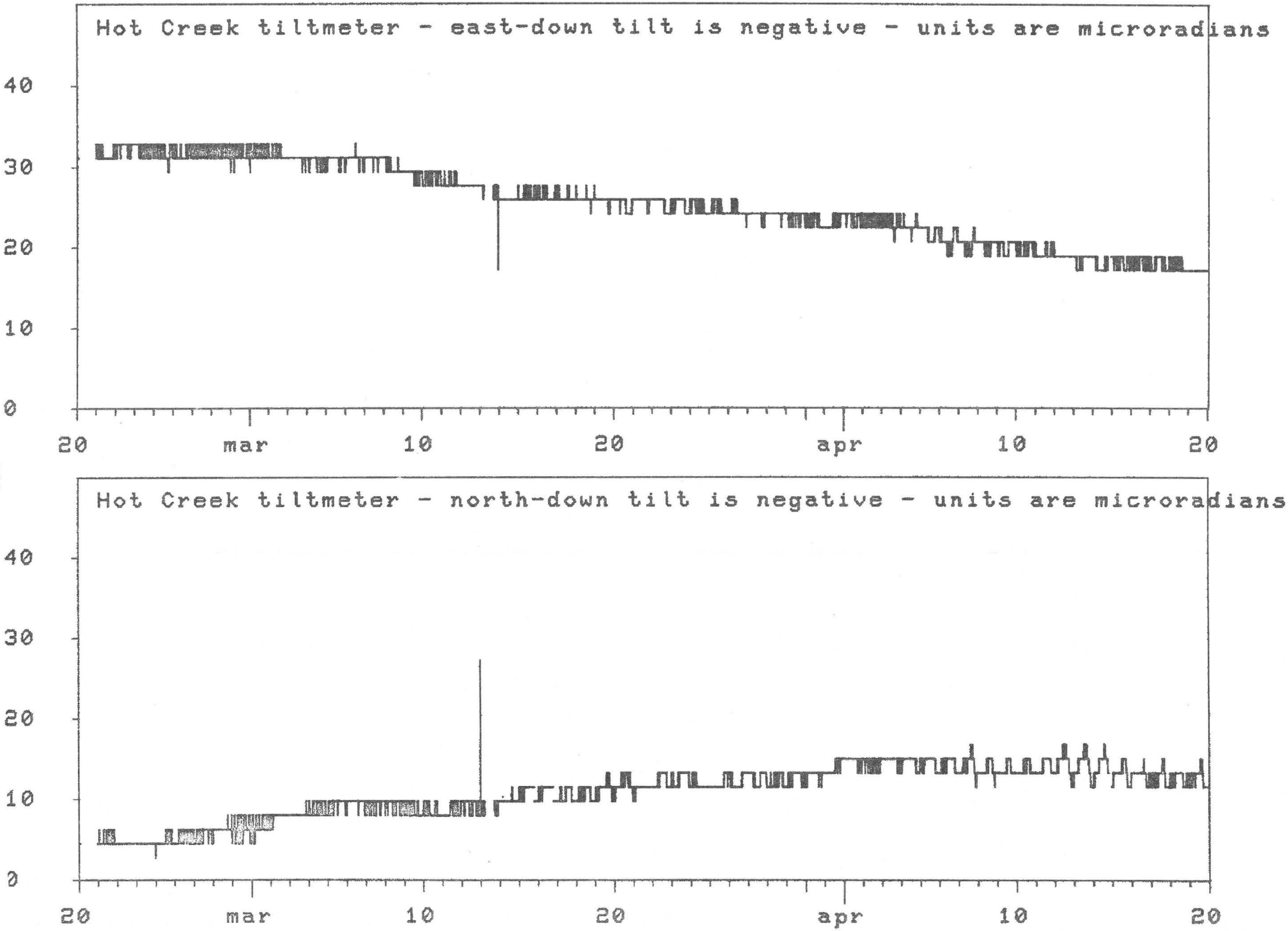

Figure 2 - Hot Creek tiltmeter data for the period 20 February to 20 April 1983.
Least significant bit is 1.75 microradians.

Internal Friction and Modulus Dispersion

9960-01490
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Investigations

1. Elastic properties of rocks: Development of quasistatic, small strain (10^{-8} - 10^{-7}) apparatus for measuring Young's modulus of rocks and solids. This apparatus is to be used for determining the effect of cracks and rock fabric on elastic anistropy and internal friction, and for determining the frequency dependence of Young's modulus' for rocks at seismic frequencies and small strain amplitudes.

2. Preparation of chapter on "Internal Friction in Rocks and Minerals" for Methods of Experimental Physics Series, Academic Press.

Results

1. We previously observed a difference of 30 percent between the quasistatic and high frequency measurements of Young's modulus of aluminum. Two sources of instrumental error which could result in this observed difference were investigated: (1) low sensitivity and non-pure mode deformation of the piezoelectric quartz element used for the strain calibration, and (2) non-homogeneous strain in the sample resulting from non-uniform application of load. A "rotated" X-cut quartz plate was designed to have a greater sensitivity and to execute a purely longitudinal displacement in the direction of the load. The resulting difference between the measured static and high frequency moduli was reduced from 30 percent to ~15 percent. A method for applying a uniformly distributed (fluid) load to the rock was devised and most of the parts were constructed.

Reports

H.-P. Liu and L. Peselnick, Investigation of Internal Friction in Fused Quartz, Steel, Plexiglass, and Westerly Granite from 0.1 to 1.00 Hertz at 10^{-8} to 10^{-7} Strain Amplitude, J. Geophys. Res., 88, 2367-2379, 1983.

THE EXTENSION AND OPERATION OF A COMPUTER-CONTROLLED RADON MONITORING NETWORK FOR EARTHQUAKE PREDICTION, INVESTIGATION OF ENVIRONMENTAL EFFECTS ON SUBSURFACE RADON, AND COMPARISON OF RADON MONITORING TECHNIQUES

14-08-0001-19752

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INVESTIGATIONS AND RESULTS

During FY82, we upgraded several of our radon monitoring sites to permit the monitoring of additional geochemical and environmental parameters. This included the installation (in collaboration with Gulf Science and Technology Corp.) of several continuous CO_2 monitors; the installation of a dual gas chromatograph to measure hydrogen, helium, and hydrocarbon gases at Kresge; the installation of several fuel cell type hydrogen monitors (in collaboration with Dr. Sato -- USGS-Reston); the replacement of flexible bubbler tubes with rigid tubes and pressure sensors for water level measurements at several sites; and the installation of water temperature sensors at several sites. New monitoring sites were established along the San Jacinto fault at Alandale and at Anza.

During this period, the development of the final version of the software for automatic network interrogation, data storage and archiving, and daily printing of the network data was completed and placed in operation. The radon/geochemical network now is interrogated daily, and the information is stored in continuous, contiguous archive files. Hard copies of data are produced automatically six days a week, and full graphic plots are produced automatically on Monday, Wednesday, and Friday.

Towards the last half of 1981 large increases in radon levels accompanied by similar large increases in CO_2 concentration were observed at our Lake Hughes and Lytle Creek stations. At the same time a substantial decrease in radon level at our Sky Forest site occurred. During the first part of 1982 the radon and CO_2 levels at Lake Hughes and Lytle Creek returned to "normal" as did the radon level at Sky Forest. Data obtained during the remainder of 1982 suggests that the "anomalous" data from these sites were the result of environmental rather than tectonic influences.

During the latter two-thirds of 1982 the radon data from most of our older sites returned to pre-1979 levels. This return to generally less noisy and in some cases lower radon levels occurred at the same time that the level of seismicity (particularly the frequency of $M > 5$ events) declined from the 1979-81 values. Radon data from the network are shown in figures 1 and 2.

REPORTS

M.H. Shapiro, Radon monitoring and earthquake prediction. 1982-3 McGRAW-HILL YEARBOOK OF SCIENCE AND TECHNOLOGY

M.H. Shapiro, J.D. Melvin, T.A. Tombrello, Jiang Fong-liang, Li Gui-ru, M.H. Mendenhall, A. Rice, S. Epstein, V.T. Jones, D. Masdea, and M. Kurtz, Correlated radon and CO_2 variations near the San Andreas fault, Geophys. Res. Lett., 9, (1982) 503-506.

Jiang Fong-liang, Li Gui-ru, J.D. Melvin, M.H. Shapiro, and T.A. Tombrello, Seismo-geochemical characteristics of the Caltech radon-thoron monitoring network, LiAP-47 Technical Report, W.K. Kellogg Radiation Laboratory, Caltech.

T.A. Tombrello, M.H. Shapiro, J.D. Melvin, M.H. Mendenhall, and A. Rice, Remote monitoring of seismo-geochemical variables in southern California, LiAP-48 Preprint, W.K. Kellogg Radiation Laboratory, Caltech (paper presented at the Int. Conf. on Continental Tectonics and Earthquake Prediction, Beijing China.)

M.H. Shapiro, J.D. Melvin, M.H. Mendenhall, A. Rice and T.A. Tombrello, Recent changes in southern California radon and geochemical data, (paper presented at the fall annual meeting, American Geophysical Union.)

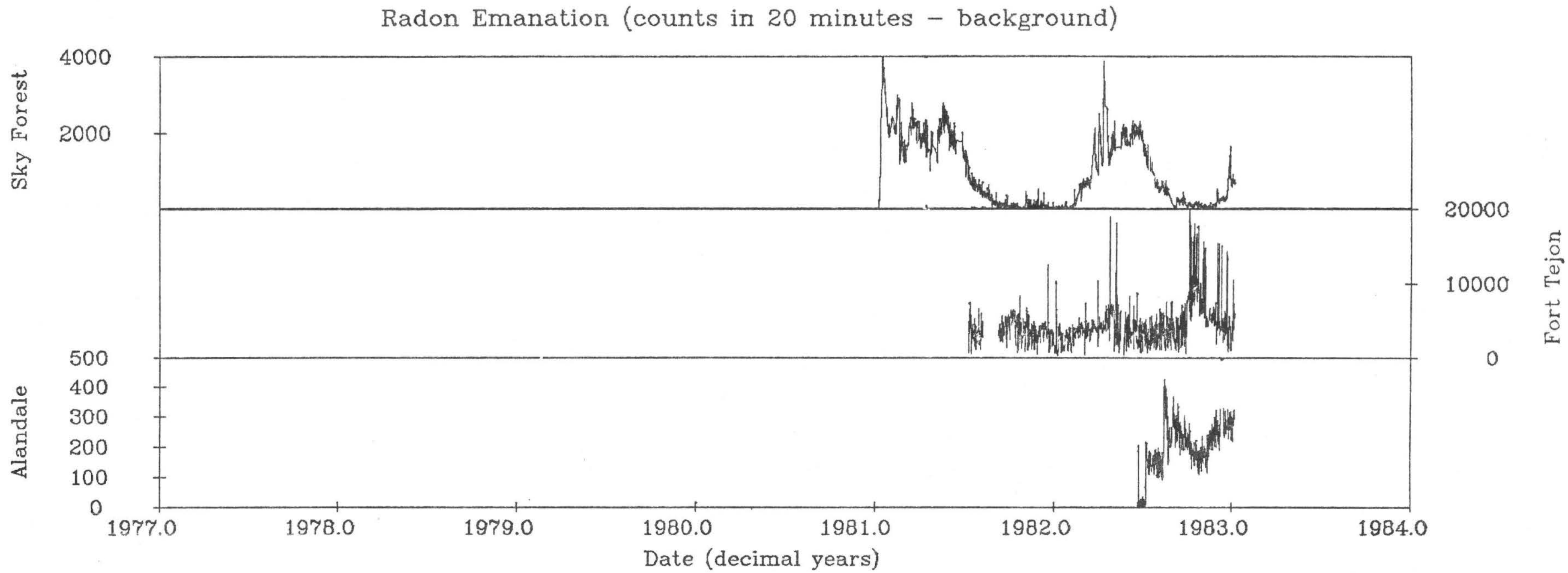
Radon Emanation (counts in 20 minutes - background)
Sky Forest
4000
2000
Fort Tejon
20000
10000
0
Alandale
500
400
300
200
100
0
1977.0
1978.0
1979.0
1980.0
1981.0
1982.0
1983.0
1984.0
Date (decimal years)

Fig. 2

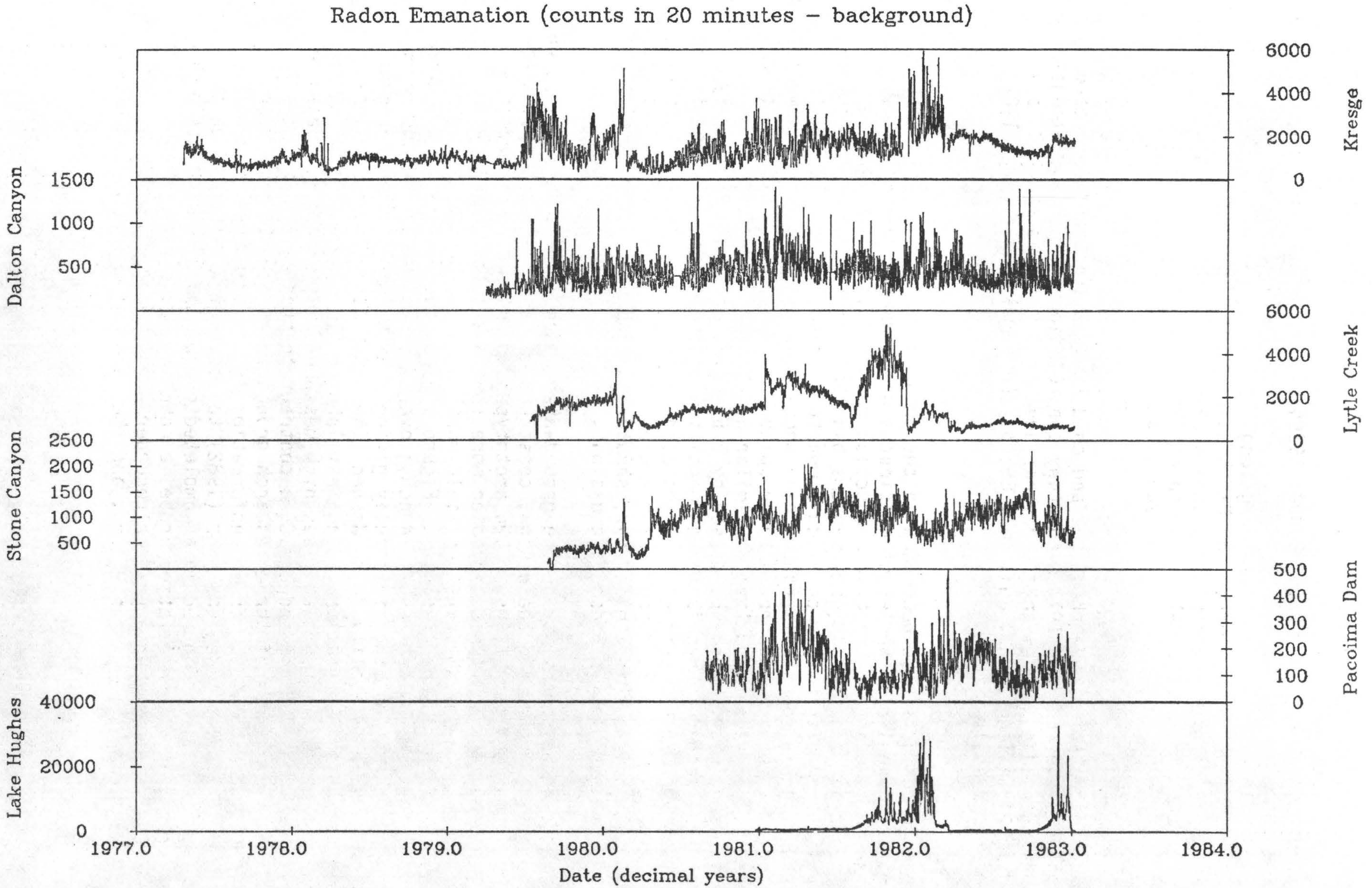
Radon Emanation (counts in 20 minutes – background)
Kresge
6000
4000
2000
0
Dalton Canyon
1500
1000
500
Lytle Creek
6000
4000
2000
0
Stone Canyon
2500
2000
1500
1000
500
Pacoima Dam
500
400
300
200
100
0
Lake Hughes
40000
20000
0
1977.0
1978.0
1979.0
1980.0
1981.0
1982.0
1983.0
1984.0
Date (decimal years)

Fig. 1

P2

Groundwater Radon Studies for Earthquake Precursors

14-08-0001-19264

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Investigations

A fourteen station network of hot and cold springs and deep wells have been sampled since the late 1970's to study the relationship between changes in groundwater radon content and nearby earthquakes. Previous results have been published in Teng (1980, JGR, vol. 85; p. 3089) and Teng et al. (1981, GRL, vol. 8, p. 441).

Results

Two major efforts have been made in the program during the past year. One is to bring on line a series of continuous groundwater radon monitors. Through an independent contract, a production run of a dozen continuous groundwater radon monitoring (CRM) systems has been carried out. This change of emphasis, from discrete to continuous monitors, results from the P.I.'s findings during his recent visits to China where many reported radon anomalies before large earthquakes are found to be spike-like with short duration (about a day or so). If radon anomalies of similar nature were to occur in California, they might easily be missed by a practice of weekly or monthly sampling. The second change is the augmentation of the monitoring activity to include studies of other parameters associated with the groundwater hydrology; these include temperature, conductivity and pH value. This additional effort, to be brought on line this coming year, should increase our insight into the mechanisms responsible for radon fluctuations.

To augment our capability on the groundwater radon content monitoring, we have been actively pursuing the design, construction, and field deployment of continuous radon monitors (CRMs). Two prototype CRM units have undergone a series of laboratory and field tests for more than one year. The tests demonstrate that these CRM units are field-worthy and give reliable radon measurements of sufficient precision. Figure 1 gives the records of two CRMs installed at the same site (Haskell Ranch); over a six-month period the radon measurements track each other faithfully giving a high degree of measurement reliability and repeatability. The dashed lines give ±10% data variations. The field data have been calibrated against laboratory measurements using the cold-trap α-counting method that gives high measurement resolution. Based on these results, the USGS granted U.S.C. a contract to produce 12 CRM units to meet the immediate needs of three research groups (King of USGS, Craig and Chung of UCSD, and U.S.C.). The transformation of the prototype into well packaged CRM units has taken one year (1982) to accomplish. The CRM unit (Figure 2), as it is configured in a completed production run, consists of a flushing probe, an α-scintillation probe, a counting, calculating, and printing (CCP) circuit, and a printer/recorder with absolute time base. The entire package weighs less than 20 lbs, and the recorder can accommodate two more analog inputs in addition to the radon counting. These two inputs can be temperature, barometric pressure, pH value, conductivity or any parameters deemed useful alongside with radon monitoring. The CRM is packaged neatly in a 15" x 12" x 10" fiberglass carrying case and can run on either AC or DC. Currently, six groundwater sampling sites in the southern California Uplift area are deployed with the CRM units, they are: Arrowhead Hot Spring (two units monitoring two different springs), Haskell Ranch, Wrightwood, Seminole Hot Spring, and Warm Springs. Radon values are taken and recorded automatically (programmable) on an hourly basis, with daily average also printed on the record.

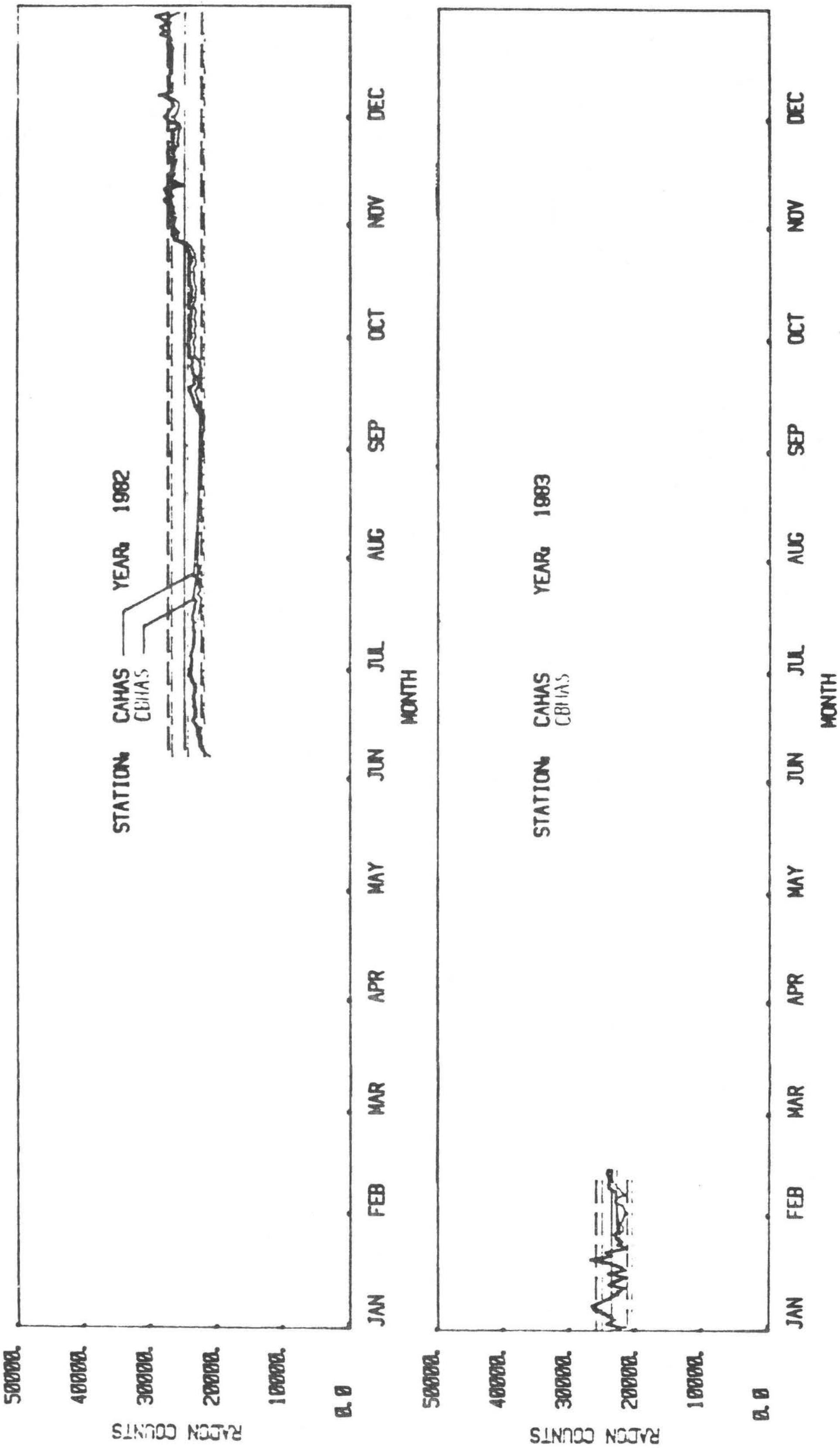
STATION: CAHAS
CBHAS
YEAR: 1982
RADON COUNTS
50000.
40000.
30000.
20000.
10000.
0.0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
MONTH
STATION: CAHAS
CBHAS
YEAR: 1983
RADON COUNTS
50000.
40000.
30000.
20000.
10000.
0.0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
MONTH

Figure 1.

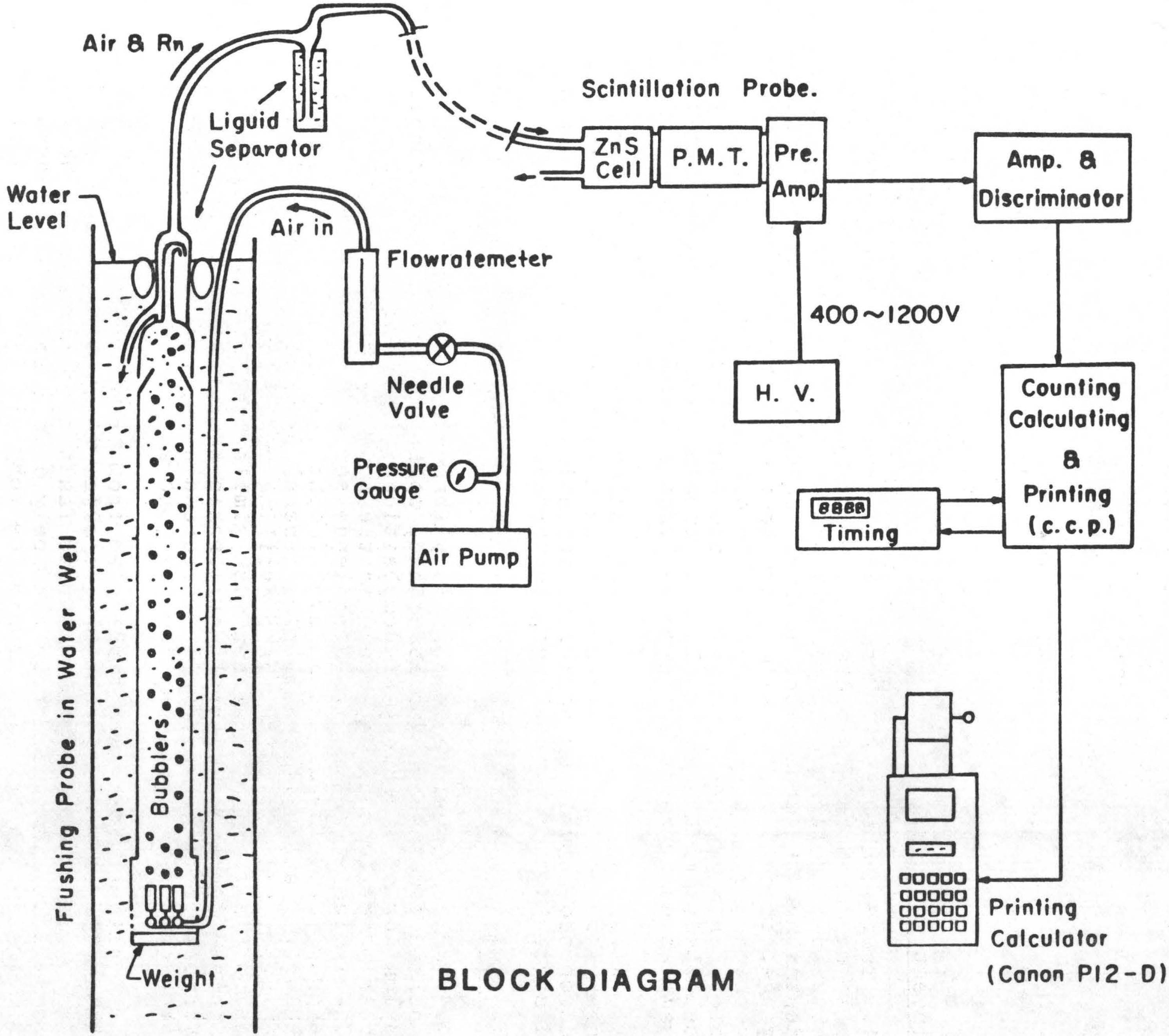
Air & Rn
Liquid Separator
Water Level
Air in
Flowratemeter
Scintillation Probe.
ZnS Cell
P.M.T.
Pre. Amp.
Amp. & Discriminator
400～1200V
H. V.
Needle Valve
Pressure Gauge
Air Pump
Counting Calculating & Printing (c.c.p.)
8888
Timing
Flushing Probe in Water Well
Bubblers
Weight
BLOCK DIAGRAM
Printing Calculator (Canon P12-D)

Figure 2.

Petrologic Constraints on Physical and Chemical Conditions of Faulting, San Andreas Fault System

14-08-001-19845

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Investigations

1. The Punchbowl fault zone and other exposed zones in the eastern San Gabriel Mountains of southern California were studied to determine the conditions of faulting prevalent at depth when the zones were active. Collected fault rocks include gouge, breccia, cataclasite, and true mylonite. Laboratory methods included petrographic examination of thin sections, electron microprobe analysis of the composition of minerals in selected samples, and whole-rock chemical analysis of selected samples using rapid silicate analysis methods.

2. A portion of the eastern Peninsular Ranges mylonite zone near Borrego Springs was studied in a manner similar to that described above. In addition, attention was paid to the spatial distribution of microstructures across the zone.

Results

1. The Punchbowl fault zone is a former trace of the San Andreas fault which was abandoned, uplifted, and deeply eroded. Mylonites of a variety of compositions, including amphibole-bearing mafic schists, occur in the zone. Compositions of Ca-amphibole (actinolite-hornblende series) in mylonites with appropriate mineral assemblages (amphibole, plagioclase, quartz, chlorite, and a Ti-phase, plus others) provide evidence of the relative P/T ratio for the prevailing conditions of mylonitization. Comparison with similar amphiboles in mafic schists from the regional metamorphic terrain of northern Vermont, a relatively well-understood area, indicate that the average thermal gradient for the zone was about 25^{o}/km.

Also studied were amphiboles from mylonitized mafic schist in small shear zones that are parallel to the San Andreas fault and occur between the San Andreas fault zone and the Punchbowl fault zone. A small shear zone only 1 km from the San Andreas zone has mylonites with amphiboles very similar to those that appear to have formed during mylonitization in the Punchbowl zone. Similar results also come from a small zone 2 km from the San Andreas zone. Overall, the data indicate that the current thermal regime for the San Andreas zone in the area is also applicable to the past history of the zone. No evidence of the effects of any frictional heating has been found. High fluid pressure in the zones when active appears probable.

Results from mylonitized mafic schists of the Vincent thrust, older than the Punchbowl zone, are generally similar to the results from the zones described above. One difference between the Vincent thrust and the Punchbowl zone is that prehnite is common in many of the mylonites from the latter, but has not been found in any mylonites from the Vincent thrust. The conclusion that the Vincent thrust produced enough frictional heating during shearing to have metamorphosed surrounding rocks (Graham and England, 1976; Scholz, 1980) appears to be incorrect.

2. Peraluminous and metaluminous plutonic rocks of the Peninsular Ranges batholith in southern California were mylonitized in the southern portion of a large shear zone known as the eastern Peninsular Ranges mylonite zone and underwent mylonitic metamorphism at low-pressure amphibolite facies conditions. Activity in the mylonite zone overlapped with Cretaceous intrusive activity of the batholith. In the San Ysidro Mountain - Pinyon Ridge area west of Borrego Springs, four north-south trending zones of differing intensity of deformation have been defined; the degree and nature of deformation gradually change from unmylonitized rocks on the western side to mylonites on the eastern side.

Electron microprobe analyses of recrystallized hornblende and plagioclase indicate a range of conditions of mylonitization appropriate to the andalusite-staurolite through sillimanite-muscovite grades as defined for pelitic rocks. The stability of muscovite+quartz in the mylonite assemblages and the lack of remelting of granitic rocks throughout the study area place upper limits on the maximum conditions attained. The maximum temperature did not exceed about 660° during mylonitization and the maximum lithostatic pressure did not exceed about 4.5 kbar. Over time any given rock volume experienced a range of temperature, lithostatic pressure, and perhaps fluid pressure and differential stress.

Possible migration of K and Fe on a large scale in the zone is indicated by whole-rock chemical data. The mineral reactions which occurred involved hydration, requiring introduction of water into the zone. Brittle and ductile deformation features are closely associated in one part of the mylonite zone. The combined evidence suggests that a pore fluid was present and that the fluid pressure was high relative to the lithostatic pressure for most of the active period of the EPRMZ. Short periods of low fluid pressure and possible high differential stress cannot be ruled out.

Reports

1. Anderson, J. R., ms submitted for publ., Petrology of a portion of the eastern Peninsular Ranges mylonite zone, southern California: submitted to Contributions to Mineralogy and Petrology.

2. Davis, M. E. and J. R. Anderson, 1983, Metamorphism accompanying mylonitization of hornblende-quartz syenite, Carthage-Colton mylonite zone, NW Adirondacks: (abstract, in press) Geol. Soc. Amer. NE regional meeting.

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Stress Corrosion and Microseismic Activity During Tensile, Shear and Compressive Failure of Rocks

14-08-0001-20558

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Report Prepared By: P.G. Meredith, B.K. Atkinson and N.J. Price

Investigations

This project has the aim of understanding more about the chemical effects of pore water on the long-term strength of rocks in the upper levels of the Earth's crust. To this end fracture mechanics studies of subcritical cracking in rocks under conditions of geophysical interest are being run so as to aid the interpretation of triaxial deformation experiments on hot, wet rocks at low strain rates. Various studies relating to the microstructural aspects of chemically-enhanced weakening are involved. These include acoustic emission studies, ion-microprobe analyses and electron microscopy. Crack-healing and strength recovery, memory effects and non-linear behaviour during failure are also being studied.

Results

1. An extensive series of experiments have been made to measure the fracture toughness of a representative range of crustal rocks in tensile loading.
   It was considered desirable to utilise two independent testing techniques on each material because of the discrepancies between published results for similar materials and to the many simplifying assumptions made in the analysis of experimental data. The short-rod and double torsion testing methods were selected for this.
   Fracture toughness values for rocks determined by these two methods correlate well throughout the entire range of toughness tested ($0.4 - 3.74$ MPa . $m^{1/2}$), provided that short rod data were corrected for non-linear processes at the crack tip. Non-linear processes include plastic deformation, diffuse microcracking and the existence of residual strains. In some rocks residual strains influnce fracture toughness results but in most cases the non linear effects are due to a large zone of microcracking (process zone) around crack tips.

Fracture toughness values for silicate rocks increase apparently with increase in grain size. Granitic rocks may show a reduction in toughness at very large grain sizes. The toughness of silicate rocks increases with decreasing quartz content. Dunite has the highest value of fracture toughness (3.74 MPa $m^{1/2}$) measured on a rock in our laboratory.

Extensive tabulations of our data and comparisons with other workers are given in the full report.

2. High temperature tensile fracture toughness data for quartz, Black gabbro and Westerly granite have been determined in vacuum at temperatures up to 400°C.

Quartz showed a reduction in toughness as temperature was raised. The toughness of granite and gabbro first increased as temperature was raised to around 100°C, and then decreased as temperature was raised further. The behaviour of the rocks and the difference betwen them and the behaviour of quartz is attributed to the development of thermal microcracks. The initial rise in toughness is due to the formation of short, isolated thermal microcracks that act to blunt the macrocrack tip. With further temperature rise these macrocracks extend and become denser and can assist microcrack growth once they start to interact.

The fracture toughness depends not only on the test temperature, but on the thermal history of the rock (heating and cooling rates, maximum temperature attained, number of thermal cycles). Granite shows a greater reduction in toughness than gabbro for a given temperature increment.

3 Subcritical crack growth experiments using double torsion specimens of Whin Sill dolerite and Ralston basalt have been monitored using acoustic emission techniques. These studies confirm earlier findings with granite and gabbro that the detailed mechanism of crack growth is strongly dependent on the crack tip environment and that acoustic response can be used to monitor the humidity of this environment and the approach of a crack to catastrophic propogation.

Trends in the reduction of b-value with increase in stress intensity factor depends strongly on the crack tip environment but appear to be virtually independent of rock type.

4. An extensive analysis is presented of experimental data on subcritical tensile crack growth in quartz, Black gabbro and Westerly granite in wet environments and at temperatures up to 300°C. These data had previously only been presented in outline form.

For quartz,the dependence of crack velocity on water vapour pressure is fairly insensitive to changes in temperature. These data suggest that the order of the chemical reaction involved in stress corrosion is one. The slope of stress intensity factor/crack velocity curves (n value) is very sensitive to changes in humidity. Under a vacuum of 0.1-0.5 Pa n = 40-46, whereas under a water vapour pressure of 300 Pa, n = 12-18.

For rocks, raising the temperature increases the microcrack density (physical effect) and raises the activity of water species (molecular or ionized)(chemical effect). At low temperatures (less than 100°C) these effects oppose one another, i.e. the isolated microcracks strengthen the rock whereas the increased activity of water species weakens the rock. At higher temperatures, the two influences reinforce one another. It is not easy to separate the effects of these two influences.

The influence of water vapour pressure on crack velocity appears to be independent of temperature. The n value decreases on raising water vapour pressure. At low water vapour pressure (0.6 kPa) the n value decreased from around 55 at 20°C to 28-38 at 300°C. Classical trimodal behaviour is observed in both granite and gabbro in tests at 200°C and water vapour pressure of 0.6 kPa.

n-values determined using load relaxation and constant displacement rate tests compare favourably

Reports

Atkinson B K 1983	Subcritical crack growth in geological materials USGS Open File Report and J. Geophysical Research (to appear).
Atkinson & S M Dennis 1982	Experimental constraints on the mechanisms of water-induced weakening of fault zones in crustal rocks. Earthquake Prediction Research (in press).
Meredith P G & B K Atkinson 1982	High-temperature tensile crack propagation in quartz: Experimental results and application to time-dependent earthquake rupture. Earthquake Prediction Research (in press).
Meredith P G, Atkinson B K & Hillman N 1983	Comparison of fracture toughness data for rocks obtained using short rod and double torsion testing methods (to be submitted to Int. Rock Mech. Min. Sci. Geomech. Abstr.

Digital Signal Processing of Seismic Data

9930-02101

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Investigations

1. Seismograms from the 1922, 1934, and 1966 Parkfield, California earthquakes recorded at DeBilt, the Netherlands (1922, 1934, 1966), Edinburgh, Scotland (1922, 1934), Strasbourg, France (1934, 1966), St. Louis, Missouri (1922, 1934). Tacubaya, Mexico (1934, 1966), La Paz, Bolivia (1934, 1966), and Berkeley, California (1922, 1934, 1966) were used to compare the source parameters of the events.

2. Seismograms for earthquakes $1 \leq M_L \leq 4$ from San Juan Bautista and the Parkfield sections of the San Andreas, Coyote Lake section of the Calaveras fault, the Sargent fault and near Livermore were used to estimate seismic moment M_0, and local magnitude, M_L. These data were compared to M_0 and M_L estimates for $4 \leq M_L \leq 6$ earthquakes in the same five areas to determine whether a linear log M_0 versus M_L relation exists.

Results

1. The recurring Parkfield, California earthquakes are characteristic, having the same epicenter, magnitude, seismic moment, rupture area, and southeast direction of unilateral rupture expansion. The comparable seismic moments and disparate interevent times, 12 versus 32 years, are incompatible with a simple application of either the time- or slip-predictable earthquake recurrence models.

2. Seismic moments and local magnitudes cannot be fit to a single linear log M_0 versus M_L relation. For $3 \leq M_L \leq 6$, the data are consistent with Thatcher and Hanks' (1973) equation for southern California. For earthquakes of magnitude $1.5 \leq M_L \leq 3.5$, Bakun and Lindh's (1977) Oroville relation is appropriate.

Reports

Bakun, W. H., Seismic moments, local magnitudes, and coda duration magnitude for earthquakes in central California (abs.): submitted to IUGG.

Bakun, W. H., Lindh, A. G., Stein, R. S., A strategy for predicting the next Parkfield, California earthquake (abs.): submitted to IUGG.

THERMODYNAMIC DETERMINATION OF HYDRATION BOUNDS FOR WEAK CLAYS AND RECONSIDERATION OF THEIR FRICTION

14-08-0001-19795

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Investigations

1. Measurement of X-ray diffraction d-spacings and weight gains of mono-ionic montmorillonites derived from CMS standards SWy-1 (Na-MM) and SAz-1 (Ca-MM), as a function of humidity at 20C, without confining pressure.

2. Identification of hydration phases, and extrapolation of phase boundaries to geologic pressures and temperatures. Hydration enthalpies needed were determined from vapor pressure data in the range 20-60 C.

3. Measurement of shear strength of each phase (without excess water) at effective normal stresses appropriate for the stability of that phase in a vertical strike-slip fault in continental crust.

Results

1. Results are shown in Fig. 1 and compared to published results on non-standard clays. Na-MM shows apparent mixed phases in limited humidity ranges, and weight hysterisis. Ca-MM has a polymorph pair at 5-20 % RH, and final dehydration of this clay requires humidity below 00.04 % RH.

2. Suggested phase identifications and model curves are shown in Fig. 1. Here, D indicates dehydration, I indicates a single water layer, II indicates two, and III three (following symbols are explained in full text of report). Assuming a compliant open system, these phase boundary humidities are extrapolated to higher confining pressures in Fig. 2 by using the generalised Clapeyron law. At low water pressure, 250-450 MPa of confining pressure cause complete dehydration with release of water. If water pressure is allowed to rise, hydration at 20C is governed by effective pressure $P_s - P_w$. The effect of high temperature is to assist dehydration (Fig. 3); along a typical geotherm, Na-MM dehydrates by 8 km depth, but Ca-MM retains one water layer to at least 11 km depth.

3. Slow-sliding friction tests on stable mono-phase clays between granite wedges show stable-sliding with some strain-strengthening but negligable viscoelastic relaxation. Addition of each layer of water per unit cell decreases strength (Fig. 4). Na-MM phases are all weaker than their Ca-MM equivalents. Strengths of dehydrated montmorillonite resemble those of other non-swelling clays. However, average friction coefficients in the top 10 km of a strike-slip fault filled with Ca-MM gouge could be only about 0.35, due to the low strengths of the stable hydrated phases.

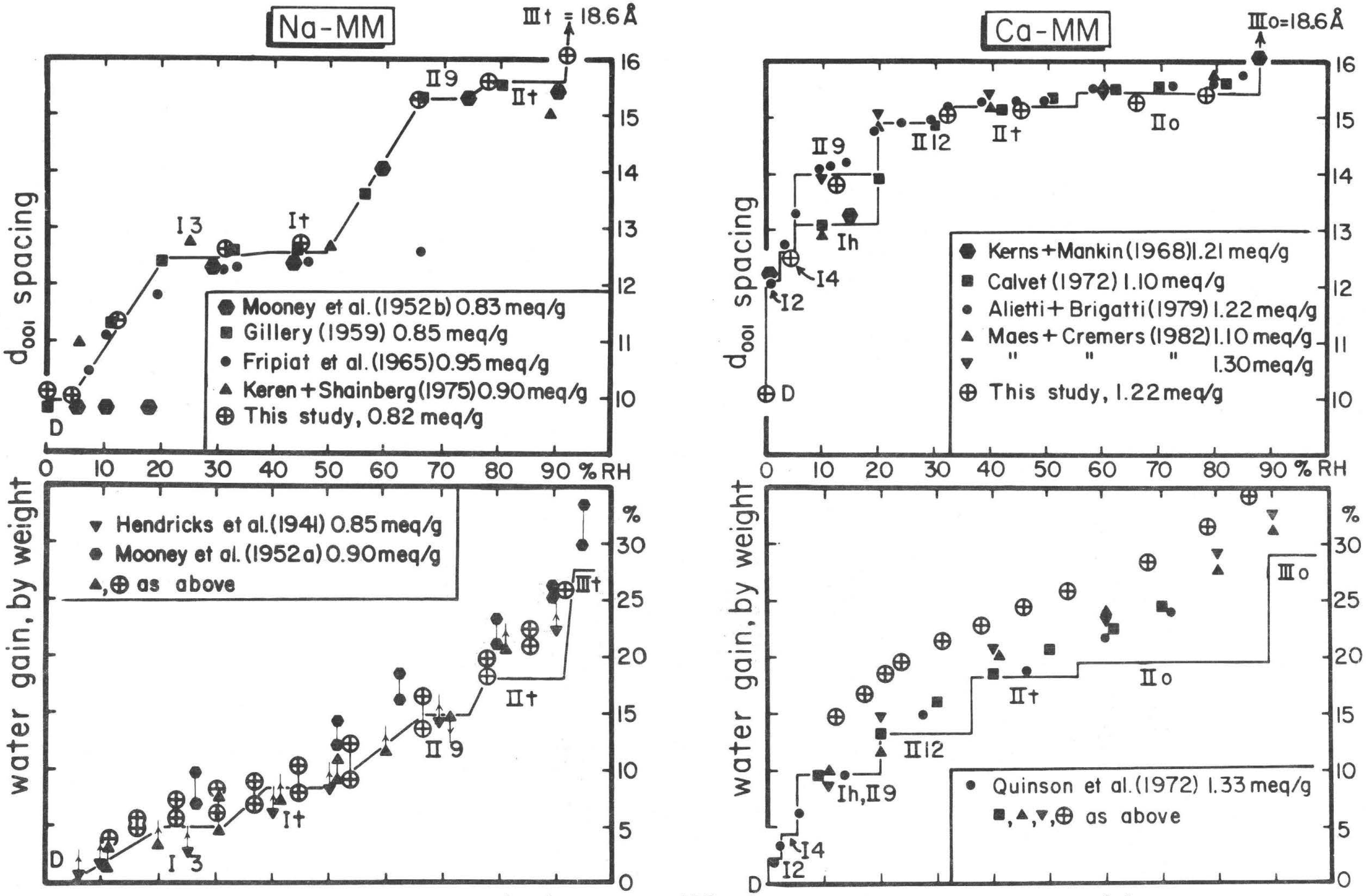

Figure 1. Studies of monoionic montmorillonites at room temperature without confining pressure. X-ray d-spacings (top) and weight gains (below) of Na-MM (left) and Ca-MM (right), combining new results with those in the literature. Stair-step lines indicate model of succesive hydration phases fit to these data; Na-MM appears to have transitional mixed phases at some humidities. Models do not include surface adsorption, and are fit to lower limit of the weight data.

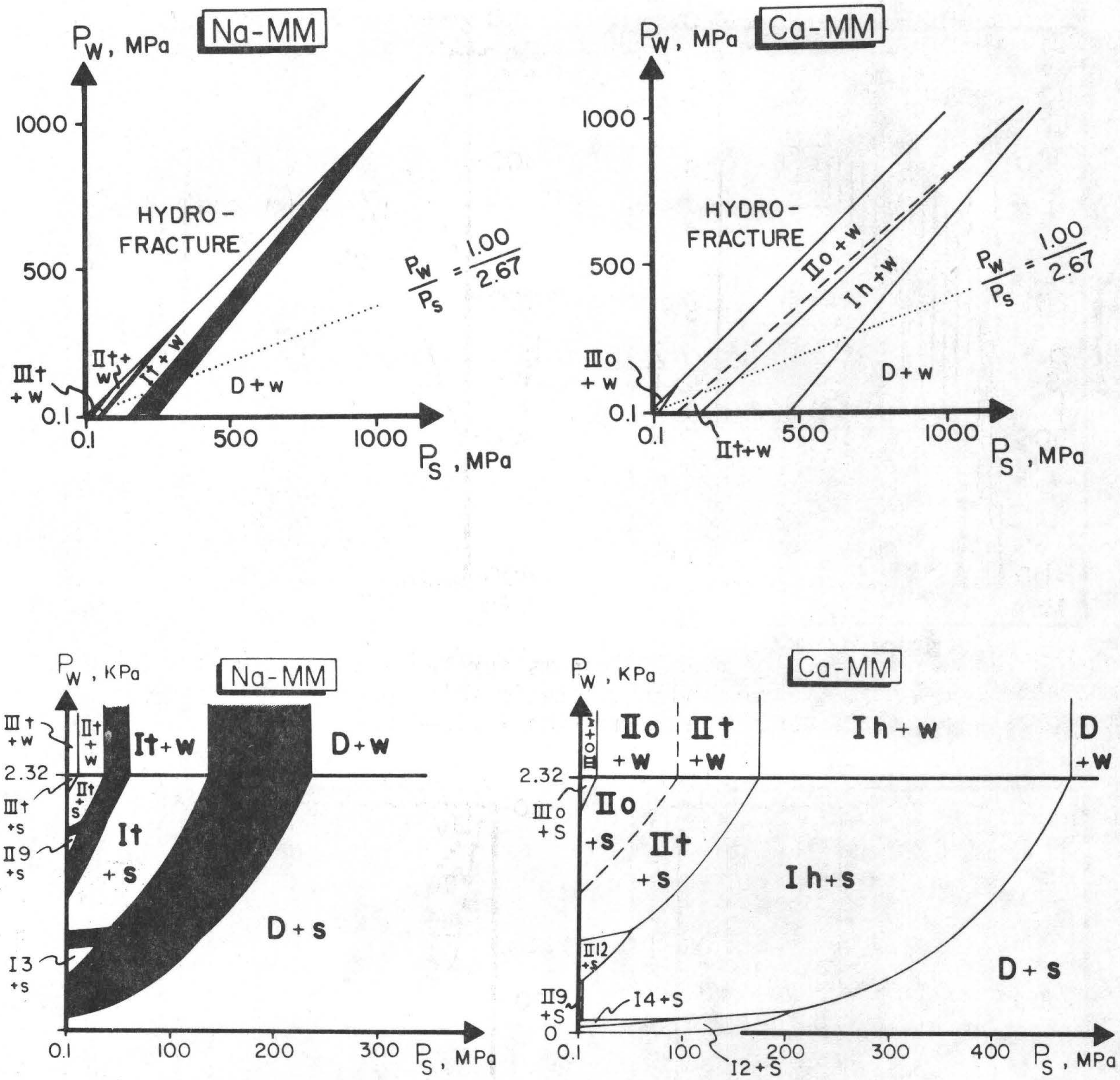

Figure 2. Hydration-phase diagrams for Na-MM (left) and Ca-MM (right) at room temperature, as a function of confining pressure P_S and water pressure P_W. Lower figures are for the unsaturated state, with P_W equal to partial pressure of steam at 20C. Upper figures are for the saturated state, with P_W equal to water pressure. Black bands indicate transitional mixed-phase regions for Na-MM. Dotted lines indicate conditions of lithostatic solid pressure and hydrostatic water pressure found in the crust.

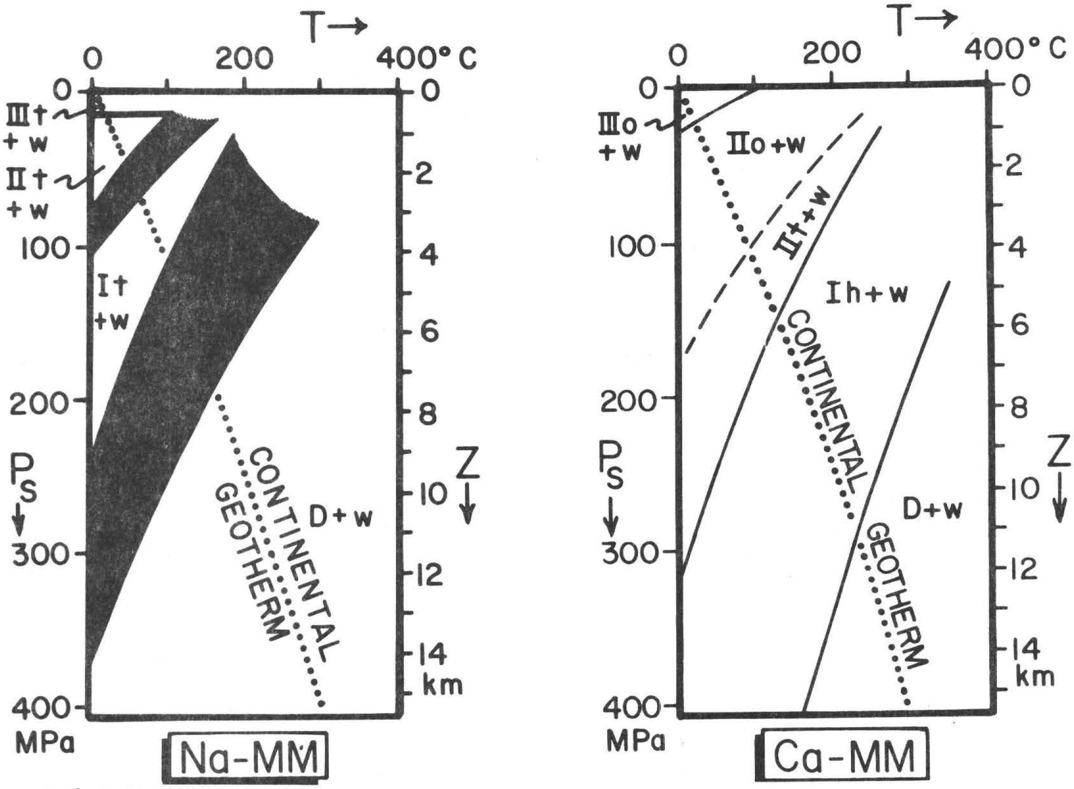

Figure 3 (above). Hydration-phase diagrams for Na-MM and Ca-MM at various temperatures and depths, assuming lithostatic solid pressure and hydrostatic water pressure. Black bands are transitional mixed-phase regions for Na-MM.

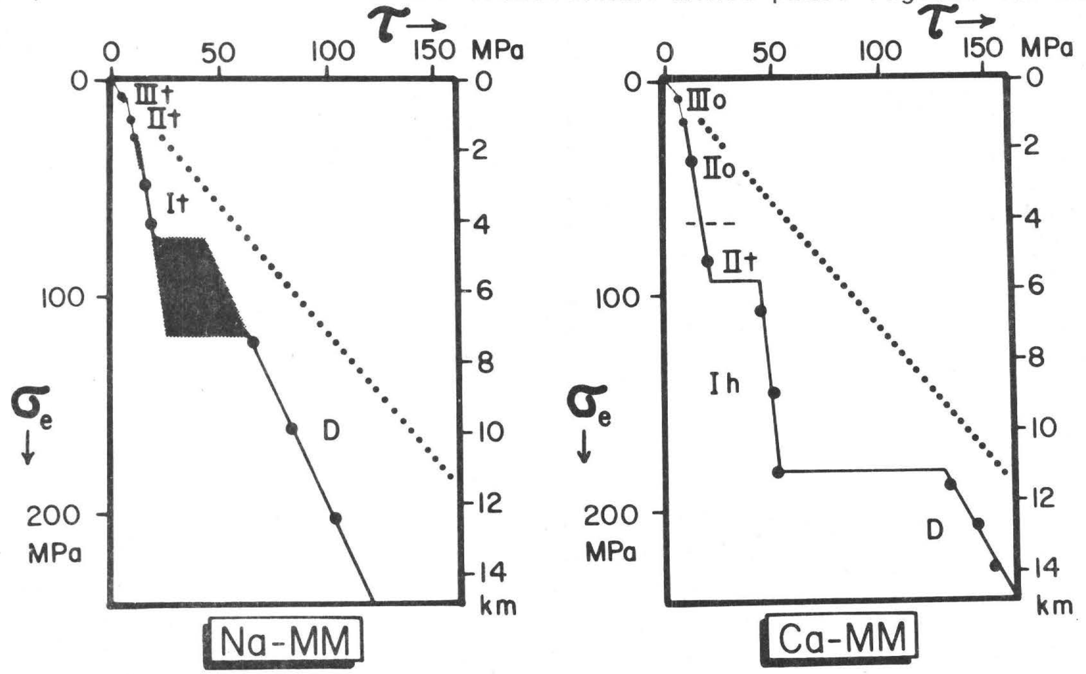

Figure 4 (below). Friction tests on various phases of Na-MM and Ca-MM, measured without excess water at normal stresses (σ_e) appropriate to the depths indicated (from Fig. 3 above). All shear stresses (τ) reported at a strain of seven. Dotted lines indicate shear stresses in other rocks of normal friction coefficient= 0.85.

Rock Mechanics

9960-01179

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Investigations

Laboratory experiments are being carried out to study the physical properties of rocks at elevated confining pressure, pore pressure and temperature. The goal is to obtain data that will help us to determine what causes earthquakes and whether we can predict or control them.

Results

In order to characterize and compare the behavior of different fault gouge materials at depth, the strength of four gouges were measured at elevated temperatures and confining pressures. The strengths of a serpentinite gouge and two clay gouges were nearly identical, despite differences both in their initial mineralogy and in their mineralogical responses to the imposed temperatures and pressures. These three gouges showed increases in strength with both temperature and confining pressure, accompanied by progressively greater degrees of induration of the samples. They also showed stick-slip behavior, that was most pronounced at the lowest confining pressures and highest temperatures examined. This contrasts with many previous studies in which stick-slip was more common at high pressures and low temperatures. The fourth gouge, derived from crushed Westerly granite, slid stably in all runs, and its strength increased with confining pressure but was unaffected by temperature. The mineralogy of the crushed granite gouge was little modified at high temperatures, and this gouge showed no significant induration during the experiments.

Reports

D.E. Moore, R. Summers and J.D. Byerlee, 1982, Strength of fault gouges at elevated temperatures and pressures, EOS, Vol. 63, No. 45, p. 1109.

D.A. Lockner, M.J.S. Johnston and J.D. Byerlee, 1983, A mechanism to explain the generation of earthquake lights, Nature, 302, pp. 28-33.

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

The permeability of both clay-rich and non-clay gouges, as well as several pure clays, was studied as a function of confining pressures from 5 to 200 MPa and shear strain to 10. Permeability ranged over four orders of magnitude, from around 0.1 nanodarcy to 1 microdarcy. The lowest values were characteristic of the montmorillonite-rich and finer grained non-clay gouges. Illite, kaolinite and chlorite had intermediate permeabilities, while the highest values were typical of the serpentine and coarser grained non-clay gouges. Grain size was an important factor in determining permeability, particularly for the clay-rich samples. The coarse grained gouges were the most permeable and decreased in permeability after shearing. Conversely, the fine grained gouges had characteristically lower permeabilities that did not vary significantly after various amounts of shearing. The permeabilities of the non-clay samples were not significantly different than those of the clays. Therefore, comminuted rock flours can be equally as effective in reducing the flow of water as the characteristically low permeability clay gouges.

The strengths of the samples were quite variable. The non-clay gouges were consistently the strongest with yield points (beginning of non-elastic behavior) around 850 MPa, while montmorillonite had an anomalously low strength in relation to all the other gouges at 250 MPa. Strength of the saturated samples under drained (low pore pressure) conditions did not correlate with high or low permeability. However, the low permeabilities of these gouges could be a factor in the measured low shear stresses along fault regions if excess pore pressures were created as a result of shearing or compaction, and this pressure was unable to dissipate through a thick section of the material.

Reports

D.E. Moore, C.A. Morrow and J.D. Byerlee, 1983, Chemical reactions accompanying fluid flow through granite held in a temperature gradient, Geochimica et Cosmochimica Acta, vol. 47, pp. 445-453.

J.D. Byerlee and C.A. Morrow, 1983, Final report on the permeability of geopressured gulf coast shale cores, U.S. Geol. Survey Open-File Report 83-180, pp. 1-10.

Earthquakes and the Statistics of Crustal Heterogeneity

9930-03008

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Investigations

Both the initiation and the stopping of earthquake ruptures are controlled by spatial heterogeneity of the mechanical properties and stress within the earth. Ruptures begin at points where the stress exceeds the strength of the rocks, and propagate until an extended region ("asperity") where the strength exceeds the pre-stress is able to stop rupture growth. The rupture termination process has the greater potential for earthquake prediction, because it controls earthquake size and because it involves a larger, and thus more easily studied, volume within the earth. Knowledge of the distribution of mechanical properties and the stress orientation and magnitude may enable one to anticipate conditions favoring extended rupture propagation. For instance, changes in the slope of the earthquake frequency-magnitude curve ("b-slope"), which have been suggested to be earthquake precursors and which often occur at the time of large earthquakes, are probably caused by an interaction between the stress field and the distribution of heterogeneities within the earth.

The purpose of this project is to develop techniques for determining the small-scale distributions of stress and mechanical properties in the earth. The distributions of elastic moduli and density are the easiest things to determine, using scattered seismic waves. Earthquake mechanisms can be used to infer stress orientation, but with a larger degree of non-uniqueness. Some important questions to be answered are:

** How strong are the heterogeneities as functions of length scale?

** How do the length scales vary with direction?

** What statistical correlations exist between heterogeneities of different parameters?

** How do the heterogeneities vary with depth and from region to region?

Scattered seismic waves provide the best data bearing on these questions. They can be used to determine the three-dimensional spatial power spectra and cross-spectra of heterogeneities in elastic moduli and density in regions from which scattering can be observed. The observations must, however, be made with seismometer arrays to enable propagation direction to be determined. Three-component observations would also be helpful for identifying and separating different wave types and modes of propagation.

The stress within the crust is more difficult to study. Direct observations require deep boreholes and are much too expensive to be practical for mapping small-scale variations. Earthquake mechanisms, on the other hand, are easily studied and reflect the stress orientation and, less directly, its magnitude, but are often not uniquely determined by available data.

This investigation uses earthquake mechanisms and the scattering of seismic waves as tools for studying crustal heterogeneity.

Results

Scattering Theory

Work has continued on two aspects of the theory of elastic-wave scattering.

Previously, the general theory of weak scattering of elastic waves in anisotropically random solids, had been used to calculate the scattering patterns expected in the case of statistically independent heterogeneities in the elastic moduli and density. It was found that all types of scattering exhibited front-to-back symmetry; waves scattered forward and backward were of equal strength. In real earth materials, however, heterogeneities in the different parameters are strongly correlated. The effects of such correlation have now been investigated, and it has been found that front-to-back symmetry no longer holds. For scattering without mode conversion (P-to-P and S-to-S), backward scattering is enhanced, while scattering with mode conversion (P-to-S and S-to-P) is stronger in forward directions. These effects are important because seismic coda waves, which are widely used in determining the magnitudes of earthquakes, are thought to consist mostly of back-scattered energy.

Investigations of strong scattering from heterogeneities such as cavities and cracks has continued. A computer program to analyze such scattering, using a matrix theory derived by Waterman and based on Huygens' principle, is partially completed.

Dike-intrusion earthquake mechanisms

A reanalysis of the magnitude 6 earthquakes that occurred near Long Valley caldera in eastern California on May 25 and 27, 1980, suggests that at least two of them, including the largest, were probably caused by fluid injection along nearly vertical cracks, and not by slip on faults.

The Long Valley earthquakes have been the object of intensive seismological study, which has been unable to reconcile the observed data (body-wave first motions and waveforms, and surface-wave amplitudes and phases) with conventional focal mechanisms, appropriate for shear faulting. Mechanisms with conical P-wave nodal surfaces, rather than the conventional quadrantal configuration, turn out to explain all the data well, over a frequency range of some three decades, from .005 Hz (200 s period) to around 5-10 Hz. Such mechanisms were originally proposed more than 50 years ago by some Japanese seismologists, who attributed earthquakes to magma motion at depth. They have been reconsidered occasionally since then, but have never been unequivocally observed, partly because unusually complete data are required to distinguish between quadrantal and conical-type mechanisms. Conical mechanisms seem most likely to be produced by tensile failure in rocks subjected to high fluid pressure, with the fluid flowing rapidly into the cracks formed. A more complicated possibility, which cannot be ruled out conclusively, involves simultaneous slip on two or more faults, which would probably have to be controlled by dike intrusion.

The earthquake mechanisms thus reinforce several other lines of evidence that recent earthquakes near Long Valley caldera are related to igneous processes, which must now be considered highly probable. A paper describing these results is in press in the journal Nature, and a talk on the same subject was persented on May 4, 1983 at the annual meeting of the Seismological Society of America in Salt Lake City.

Reports

Julian, B. R., and R. S. Cockerham, 1983, Mechanisms of the May, 1980, earthquakes near Long Valley caldera, California: evidence for dike injection (abs.): Earthquake Notes, v. 54, no. 1, p. 88-89.

Julian, Bruce R., 1983, Evidence for dyke intrusion earthquake mechanisms near Long Valley caldera, California: Nature, in press.

Crack Fusion Dynamics

14-08-0001-20529
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Investigations

The physical processes of the fusion of small cracks into larger ones are nonlinear in character. A study of the nonlinear properties of fusion may lead to an understanding of the instabilities that give rise to clustering of large earthquakes. We have investigated the properties of simple versions of fusion processes to see if a catastrophic cascade of crack fusion events can produce the time delays (macroscopically) associated with anelastic creep and stress-corrosion in the laboratory and whether large scale instabilities culminating in repetitive massive earthquakes are possible.

Results

1. We have taken into account such diverse phenomena as the production of aftershocks, the rapid extension of large cracks to overwhelm and absorb smaller cracks, the influence of anelastic creep-induced time delays, healing, the genesis of "juvenile" cracks due to plate motions, and others. A preliminary conclusion is that the time delays introduced by anelastic creep may be responsible for producing catastrophic instabilities characteristic of large earthquakes as well as aftershock sequences.

2. By modifying the model of the preceding paragraph to take into account the stress release associated with the occurrence of large earthquakes, we obtain repetitive periodic cycles of large earthquakes. A preliminary conclusion is that a combination of the stress release or elastic rebound mechanism plus time delays in the fusion process are sufficient to destabilize the crack populations and, ultimately, give rise to repetitive episodes of seismicity.

3. Employing scale-invariance of fracture surfaces of earth materials that range from millimeter to ten kilometer size-scales, we have constructed a skeletal, dynamic model of crack fusion utilizing renormalization group techniques. We have shown that a critical value for micro-crack densities exists above which crack fusion events proceed in a catastrophic way. The time required for the cascade of crack fusion events conforms with the time-to-failure observed in the experiments of Griggs and others. The process explains pre- and post-shock creep as a sub-threshold seismic activity and provides a possibility for deriving equivalent viscosities for plate boundary frictional effects. This has the potential that a convection model for the mantle can be derived which takes earthquake activity into account approximately.

Recommendations for Further Research

1. Space dependent effects must be incorporated into the time-only crack fusion model considered up to now. It is known in other areas of mechanics that non-linear diffusion can exhibit wave-like behavior. Does stress redistribution due to earthquake occurrence have similar wave-like behavior or is it strictly diffusive (as one might expect for linear viscoelasticity)? We believe wavelike behavior is likely to be exhibited with strong implications for epicenter migration.

2. A larger hierarchy of crack sizes (than the two considered hitherto in Results Parts 1 and 2) should be taken into account in the modeling. We have found (in Results 3) that creep induced time delays probably need not be introduced as a parametric model, but can be replaced by a large hierarchy. But this was for a skeletal version of the full fusion model. Thus the model can, and should be simplified conceptually. This broadening of the scope of the model will allow for investigation of variations in seismicity across the full spectrum of magnitudes, i.e. we can look for clustering effects as manifested in changes in b-values, and other premonitory statistical phenomena that may be anticipatory of large earthquakes.

3. The equivalent viscous properties of fault creep due to microearthquake activity should be determined as well as the nature of stress wave diffusion within this regime of motion at a level of seismicity below detection thresholds.

Reports

Newman, William I., and Leon Knopoff, 1982. Crack Fusion Dynamics: A Model for Large Earthquakes, Geophys. Res. Lett., 9, pp. 735-738.

Newman, William I., and Leon Knopoff, 1982. A Model for Repetitive Cycles of Large Earthquakes, submitted to Geophys. Res. Lett.

Mechanics of Geologic Structures Associated with Faulting

9960-02112

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Investigations

1. Field studies of extension fractures and faults in granitic rock of the Sierra Nevada, Mt. Abbot Quadrangle.
   a. The nucleation and development of strike-slip faults with up to 100 m of left-lateral offset.
   b. Growth of single sets of joints filled with hydrothermal fluids.

2. Theoretical studies of the geometry and formation of cracks in rock.
   a. The form and propagation of dilatant echelon cracks.
   b. The evolution of an array of parallel extension cracks.
   c. Rate-dependent deformation in a rock mass as controlled by crack growth.
   d. Stress, strain, and displacement fields around cracks subject to dilation and shear.

3. Analysis of fault-zone mechanics.
   a. The geometry of major fault systems including zig-zag normal faults and orthogonal ridges and transforms (with Atilla Aydin).
   b. Effect of fault zone geometry on the rupture process (with Bill Bakun).
   c. Redistribution of stress accompanying fault slip (with Gary Mavko).

Results

1. a. The field study of fault growth in granite is summarized in J.G.R., 1983, v. 88, p. 555-568.
   b. The estimation of the extension and state of stress during jointing is described in G.S.A. Bull., 1983, in press.

2. a. The study of dilatant echelon cracks is described in G.S.A. Bull., 1982, v. 93, p. 1291-1303.
   b. The work on evolution of extension crack arrays will appear in the G.S.A. Bull. later this year.
   c. Rate dependent extension due to crack growth is considered in a paper in press at J.G.R.
   d. A review paper entitled "A Reference Guide to Displacement and Stress Near Cracks in Rock" is in manuscript form. The following summary indicates the scope of this work.

Faults, joints, veins, sheet intrusions, and solution surfaces form structural discontinuities in a rock mass. Lithologic units and older structures are offset by sliding motions on faults; by opening on joints, veins, dikes, and sills; and by closing on solution surfaces. Many of these discontinuities approximate two planar surfaces that are bounded in extent and across which the relative motion has been small compared to the in-plane dimensions of the discontinuity. They may be idealized as cracks in an elastic material. To set the stage for a mechanical analysis of cracks, the basic equations of elasticity are reviewed. For two-dimensional plane and antiplane strain with uniform loading a single stress function exists from which the displacement, stress, and strain fields around cracks may be calculated. This approach unifies the mechanical interpretation of structural discontinuities in rock.

The general equations for displacement and stress fields around the crack are recorded. Displacement vectors, stress trajectories, and contours of mean normal stress and maximum shear stress are illustrated. Equations for the displacement field along a crack reveal a simple method for estimating the ratio of driving stress to rock stiffness and the static moment due to motion across a discontinuity. Exact equations for the displacement and stress along symmetry lines are recorded, as are approximate equations for three regions around a crack. These regions are distinguished on the basis of different spatial dependence of the stress: (1) near the crack tip stress decreases as the reciprocal of the square root of distance from the tip; (2) near the crack center stress increases in proportion to distance from the center; and (3) greater than one crack half-length from the center stress decreases as the reciprocal of the square of distance from the center.

A number of examples are presented to illustrate the application of these results to problems of structural geology. We analyze the geodetic displacements accompanying the 1906 San Francisco earthquake to determine the depth of faulting and the seismic moment. The location and orientation of veins and solution surfaces adjacent to a small fault in limestone of southern France are interpreted through an examination of the stress field near the fault terminations. The thickness profile of a basaltic dike segment near Shiprock, New Mexico, is analyzed to estimate the magma driving pressure and the dike's static moment. The spacing of systematic joints in layered rocks is interpreted by analyzing the rate at which stress increases with distance from the joint plane.

3. a. We have investigated the propagation of echelon spreading ridges and the angular relation between ridge segments and transform faults using the stress distribution in elastic plates. Ridge-propagation force and a path factor that controls propagation direction were calculated for a process in which two echelon ridges propagate toward each other. For reference, θ is the angle between a ridge and the line connecting adjacent ridge ends. The results are: (1) Ridge-propagation force declines sharply as the ends of two ridges pass each other ($\theta \simeq 90^\circ$), so ridges are not expected to greatly overlap; (2) the sign of the path factor changes as ridge ends approach and pass each other, so ridges may follow a hook-shaped path. The magnitudes of shear stresses and orientations of maximum-shear planes were calculated for two loading conditions, remote tension simulating plate-pull, and pressure within the ridge simulating ridge-push. The results for both cases are: (1) The shear stresses that might cause transform faulting are largest for $\theta = 90^\circ$; (2) the orientations of prospective transform fault planes are 45° for $\theta = 45^\circ$, slightly less than 90° for $\theta = 90^\circ$, and only slightly greater than 90° for $\theta = 135^\circ$. Thus, the favored angle between ridges and transform faults is about 90°. However, these models do not preclude a range of angles less than 90°, in agreement with available geologic and geophysical data in which angles range from 50° to 90° and are predominantly between 80° and 90°. The orientations of prospective fault planes for the two loading conditions do not differ enough to discriminate between plate-pull and ridge-push using these data. However, a conspicuous depression observed between overlapping echelon ridges is consistent with a tensional state of stress there, produced by plate-pull.

3. b. The effects of fault zone geometry on the rupture process were summarized by Pollard for a session of the A.G.U. Chapman Conference. Several key questions were addressed in the session <u>Fault Zone Geometry and Segmentation</u>: (1) What is the nature of fault geometry at the Earth's surface in relation to tectonic regime and length scale ; (2) Does surface geometry extend to seismogenic depths ; (3) What are the tools and techniques available for determining geometry at depth ;

and (4) What are the implications of complex fault geometry for fault behavior and earthquake forecasting A wide range of data gathered by geologists and geophysicists were brought to bear on these questions. The geological and geophysical data from active faults demonstrate that geometric discontinuities such as changes in strike or segmentation play an important role in creep and rupture propagation, secondary faulting, surface deformation, and aftershock distribution and focal mechanisms. Although it has not yet been demonstrated, methods of earthquake forecasting will probably have to encompass the major aspects of fault geometry and their role in fault behavior.

In a more specific paper delivered at the same conference, Segall considered examples from Central California where surface traces of active faults have complex and varied geometries including: bends, echelon steps, and parallel overlapping segments. Seismicity patterns in some localities indicate that such surface fault geometries extend to seismogenic depths. Quasi-static elastic analyses indicate that fault geometries strongly influence stress and slip distributions along fault zones. Depending on the precise configuration, slip on one segment may enhance or inhibit slip on adjacent segments. In fact, prominent geometric features of faults at a number of localities correlate with: 1) points of rupture initiation and termination (Parkfield); 2) clusters of foreshocks and aftershocks (Parkfield, Bear Valley); and 3) locations of secondary faulting oblique to the main fault (Coyote Lake).

The correlation of seismicity with fault geometry is most useful for earthquake prediction if important aspects of fault geometries are stable over many earthquake cycles. Fortunately, there is both geologic and geophysical evidence that this is often the case. Grabens and horsts in echelon steps between strike-slip fault segments persist over long periods of time. It also appears that both the 1934 and 1966 Parkfield earthquakes initiated at the same bend and stopped near the same right-step along the San Andreas Fault. This is an extremely important observation because it suggests that current fault geometries are appropriate for modeling future events.

3. c. Slip on a fault, occurring either seismically or as aseismic creep, causes redistribution of stress on the fault surface. In a homogeneous, elastic earth one can predict the static stress change everywhere, if the exact distribution of slip or stress is known within the slip zone. Yet, in most cases, only the average slip or stress change is known. We examine the effect of the poorly-known, spatially heterogene-

ous stress changes within the slip zone for two-dimensional, planar faults. Following Mavko (1982), the stress change in the slip zone $/x/\leq a$ is expanded in a series of Chebyshev polynomials

$$\sigma = \sum_n C_n T_n(x/a) \qquad /x/\leq a$$

The condition that the stresses are everywhere finite reduces to $C_0=C_1=0$. The stress away from the edge of the slip zone is approximately

$$\sigma \cong \sum_{n=2}^{\infty} \left[\frac{C_n}{2^n} \left(\frac{x}{a}\right)^{-n} + 0\left(\left(\frac{x}{a}\right)^{-n-1}\right)\right] \qquad /x/>a$$

The stresses due to higher order polynomials decrease more rapidly with distance from the end of the slip zone. At the slip zone edge the stress is equal to the sum of the coefficient C_n. However, the stress outside a small region near the edge of the slip zone is accurately determined by the first few terms in the expansion, assuming the C_n do not increase with order n. It is thus possible to calculate the stress change outside the slip zone with some confidence given only partial data on the slip distribution.

This result is used to examine the redistribution of stress during the 1966 Parkfield earthquake sequence on the San Andreas Fault near Parkfield, California. A M=5.1 foreshock preceded the M=5.5 mainshock, which was located approximately 1 km to the southeast, on the opposite side of a 5° clockwise bend in the strike of the fault. Calculations indicate that the foreshock increased the shear stress and decreased the normal (compressive) stress acting at the eventual mainshock epicenter. The ratio of shear stress to normal stress at this location increased by an amount equivalent to a 30 bar increase in shear stress. Following the mainshock two independent effects caused the change in ratio of shear to normal stress to reach a maximum off the southeast end of the mainshock rupture zone. First, the right step in the fault at the southeast end of the zone caused a decrease in the compressive stress, thereby increasing the ratio of shear to normal stress. Second, the foreshock previously relaxed the shear stress at the northwest end of the mainshock rupture zone. The observed distribution of aftershocks correlates well with the calculated ratio of shear stress to normal stress. These results indicate that stress redistributions following slip exert important controls on the location of future earthquakes.

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THEORETICAL STUDIES OF RUPTURE PROCESSES IN GEOLOGICAL MATERIAL WITH APPLICATIONS TO EARTHQUAKE FAULTING

14-08-0001-20577

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Investigations

1. Effects of dilatant hardening on the inception shear of rupture.

2. Effects of slip zone interaction on moment, stress drop, and strain energy release.

Results

1. We have continued study of the shear deformation of a fluid saturated layer containing a weakened sublayer. Based on a more elaborate analysis described in a previous report we have adopted a simplified model in which the deformation in each sublayer is assumed to be homogeneous and the fluid mass flux between the sublayers is assumed to be proportional to the difference in the pore fluid pressures. The stress-strain behavior of both sublayers is nonlinear in a way which is representative of brittle rock and the weaker sublayer has a lower peak stress than the surrounding material. Dilatant hardening delays the onset of localization instability and gives rise to a more pronounced precursory period of rapidly accelerating strain prior to instability. Numerical results indicate that for imposed strain-rates that are very slow, compared to the diffusion time through the weakened sublayer, the duration of the precursory period t_{prec} satisfies

$$t_{prec} \propto (h^2/\lambda c)^{2/3} \dot{\gamma}_\infty^{-1/3}$$

where h is the height of the weakened sublayer, c is an effective diffusivity, λ is the half-width of the peak of the stress vs. strain curve and $\dot{\gamma}_\infty$ is the applied farfield (tectonic) strain-rate. For plausible values of material and geometric parameters, and strain-rates representative of tectonic strain-rates, the length of the precursory period ranges from several hours to a few days.

2. Work in this area has been done in collaboration with J. D. Achenbach and K. Hirashima, who are not supported by this project.

The work of Rudnicki and Kanamori (JGR, 86, 1785-1793, 1981), which used collinear crack solutions to examine quantitatively the effects of fault slip zone interaction on moment, stress drop and strain energy release, is extended to consider the effects of interactions between different size slip zones. The calculations demonstrate that the presence of a large pre-existing slip zone can substantially amplify the signal due to slip on a nearby smaller slip zone. For example, if the length of the larger slip zone is L, that of the smaller slip zone is L/10, and the distance between the nearest ends of the zones is L/100, the seismic moment due to slip on the smaller zone is about 2.5 times the value for an isolated zone of the same size. Furthermore, the moment due to slip induced on the larger solid zone by slip on the smaller zone is about 5 times the moment due to slip on an isolated zone of length L/10. Conversely, estimates of stress drop based on the measured value of the moment and the total length on which slip occurs substantially underestimate the actual stress drop. Because the stress drop on the larger slip zone is zero, the induced slip there appears to make no contribution to W_0, the difference between the strain energy decrease and the frictional work. The formula $W_o = \tau_{eff} M/2\mu$ where τ_{eff} is the effective stress, M is the actual value of the seismic moment and μ is the shear modulus, is, however, shown to remain valid for segmented faulting.

CONSTITUTIVE LAWS FOR SLIP AND THEIR RELATION TO FAULT INSTABILITIES

14-08-0001-20616

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Investigations (June 1, 1982 - May 5, 1983)

We have been conducting experimental, numerical, and analytical work aimed at understanding rock friction and instabilities in elastic systems with frictional boundaries. The projects can be broken up as follows:

1. Experiments with rock surfaces in a servo-controlled rotary shear testing machine aimed at determination of constitutive laws for slip (with Frank Horowitz, Cornell).

2. Analytical modeling of slip instability (with James Rice, Harvard and Chung Yuen Hui, Cornell).

3. Numerical modeling of elastic systems with frictional boundaries (faults) governed by rate and state dependent friction laws (with Frank Horowitz, Cornell).

4. Experiments on heat production in laboratory friction (with Gerald Conrad, U.S.G.S.).

Results

1. Rotary Shear Experiments: We are currently using 1 inch diameter quartzite samples in a rotary shear geometry shown in figure 1 (not all of the equipment shown is fully developed). The sample is mounted in an Instron servo-controlled testing machine which is in the room environment. Our progress in experiments is of two types: a) understanding, controlling and measurement from the testing machine and; b) new data on rock friction.

a) Computer programs controlling the testing machine have been completed and now work satisfactorily (though they require constant upgrading). The computer system allows an arbitrary sequence of normal stress levels to be imposed simultaneously with an arbitrary sequence of either shear stress or slip rate. The computer controls the Instron analogue circuitry.

We purchased a new control amplifier so that we could use our own cantilever displacement transducer (from Ruina [1980]) in the servo-control loop. Temperature and light sensitivity of the transducer have required that experiments be performed in a box. The Instron bridge balancing circuits were modified to reduce drift. Displacement measurement with resolution of .1μm is now reliable and our goal of .02μm has been obtained for short periods of time.

We have modified the control circuitry to compensate for non-linearities in the mechanical testing machine. These were causing servo-control instabilities which were previously avoided only by unacceptable compromise in the accuracy and speed of the servo-control. This modification appears to be a major improvement.

We have altered our sample geometry slightly so that the samples are now interlocked (see figure 1). This prevents the samples from "wandering" due to slight surface irregularities.

We have begun development of a capacitive transducer for measurement of surface dilation during slip. A transducer has been built but the electronic instrumentation is not yet complete.

b) We have reproduced some of the data of Ruina [1980] (see figure 2) and should soon be able to extend these results to lower slip rates than have been previously observed with our displacement resolution. This work is aimed at understanding the transition from "static" to "sliding" friction which plays a key role in slip instabilities.

We have begun experiments in which the normal stress is changed in a controlled manner. Figure 3 shows typical results for step changes in normal stress during constant slip rate experiments. As expected, normal stress changes cause friction stress changes. The experiments show a very small transient thus indicating that the effects of small normal stress changes may be well described with the classical description of the friction stress being proportional to the normal stress. That is, normal stress variations have a strong effect on friction that do not necessarily strongly involve higher order memory effects.

2. Both linear and non-linear <u>analytical models</u> for frictional instabilities in elastic systems with rate and state dependent friction on a slipping boundary have been pursued. The linear models examine the response of an elastic system that has constant normal stress on one slipping boundary and another boundary which moves at constant rate. Only motions very close to constant slip rate are analyzed. Thus the linear analysis can only be used strictly to determine conditions under which steady fault creep is a possible motion. However, the modes of instability in the linear models suggest behavior to be investigated in more realistic non-linear modeling. The linear models of Rice and Ruina [1983] include inertia and make use of a general rate and state dependent friction law. The analysis of steady sliding in a spring and block model show the existence of a critical stiffness at which oscillations occur. For greater (or lesser) stiffness steady slip is stable (or unstable). For a deformable elastic solid, solutions were found for perturbations from steady sliding that are sinusoidal with position. These solutions were shown to be exact analogues of spring -block motions. Oscillations in the spring block model correspond to either standing or propagating sine waves for the deformable elastic solid.

We have begun to investigate the propagation and growth of local disturbances by using the above solutions in a Fourier superposition. The asymptotic results we have obtained so far indicate that a local perturbation from steady state on the boundary of a half space leads to an instability that does not extend spatially until inertia or, possibly, non-linearities become important. This work has been put aside until it can be checked with numerical calculations.

Non-linear analysis with spring and a massless block model has led to the submission of a paper [Gu, Rice, Ruina and Tse 1983] which slightly extends results obtained previous to the initiation of this reporting period. The primary results being a) instabilities are possible in systems that are extremely stable by a linear analysis, if they are sufficiently perturbed and, b) when a two state variable friction law is used, apparently chaotic motion is possible for a limited range of system stiffness.

Work completed previous to this grant relating to basic principles in state variable friction laws has been extended slightly and is pending publication [Ruina 1983]. The recent work in this paper is the numerical simulation of "time dependent static" friction using a rate and state variable friction law with two state variables which do not evolve when the slip rate is zero.

3. We have nearly completed development of a numerical fault model for a linear elastic (plane strain or anti-plane strain) slab that is infinite in length and either finite or infinite in thickness (with inertia neglected). The program will be able to use a variety of non-linear friction laws. Initial results have been consistent with the linear results named above. The particular result we are interested in generating is the propagation of stable creep waves.

4. Laboratory work at the USGS in Menlo Park has been aimed at determining whether the creation of new surface area, during brittle fracture of asperities, requires a measurable amount of energy. The basic method of measurement is to compare the heat generated in a friction experiment to the heat generated by an electrical resistor in exactly the same geometry. The data currently constrains the surface energy to within about 15% of the total energy budget. This implies, as is usually assumed, that frictional dissipation in rocks is almost completely irreversible (in the thermodynamic sense). We hope to further constrain our number 85+% "thermodynamic inefficiency" by further analysis or experiment.

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Fig. 1

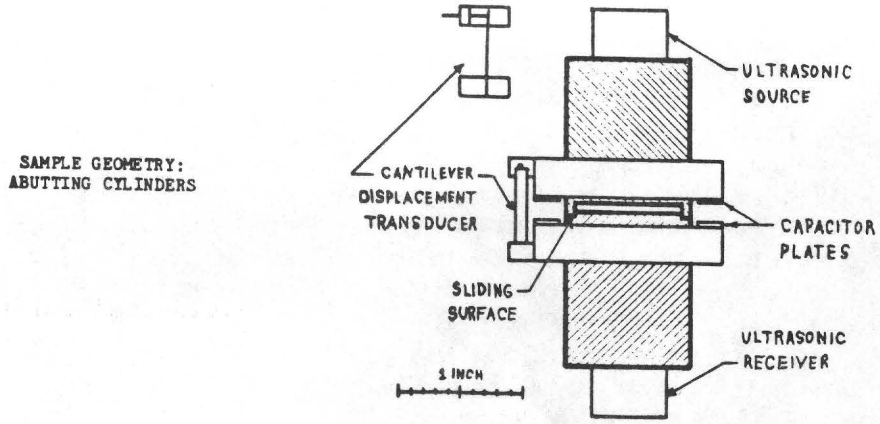
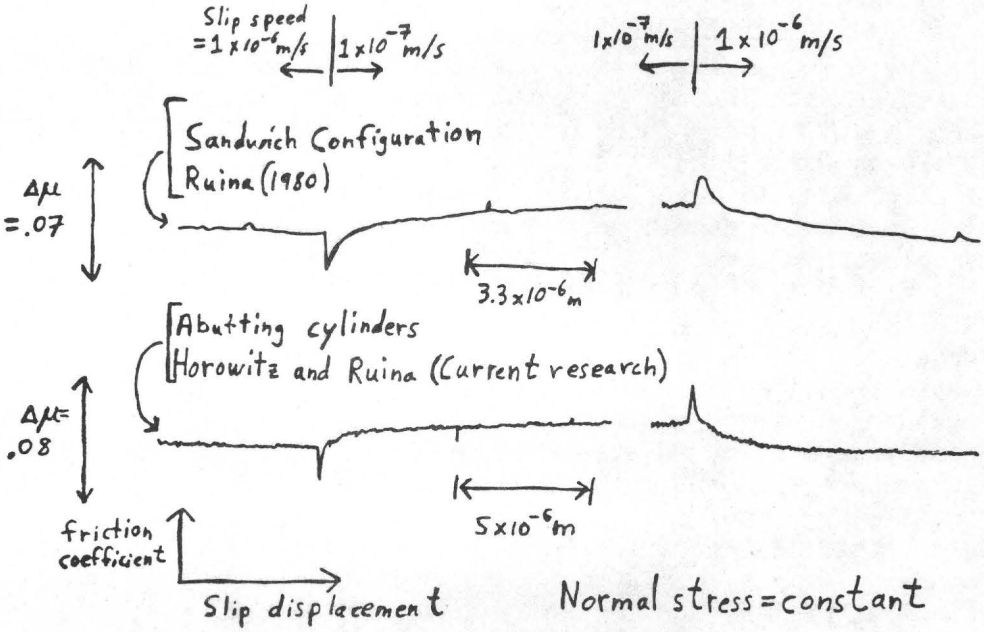
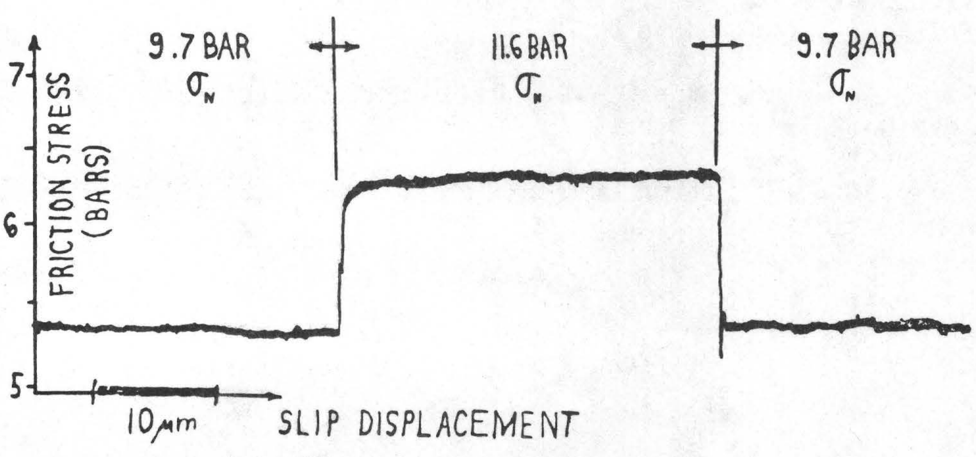


Fig. 2



COMPARISON of RECENT and PAST DATA

Fig. 3



CONSTANT SLIP SPEED = 0.1 μm/sec.

Earthquake Forecast Models

9960-03419

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Investigations

1. Finished study of an earthquake instability model for the next M=5.5 earthquake at Parkfield, California. Modified the model for the currently locked section of the San Andreas fault in southern California.

2. Formulated an interacting fault model for recent crustal deformation in southern California.

Results

1. The Parkfield instability model simulates slow faulting and ground deformation leading up to an earthquake as well as sudden fault slip during an earthquake. In the model, the unstable failure of a relatively strong patch of fault zone near Parkfield represents a moderate earthquake like the 1966 event. Model parameters describing fault geometry and fault zone constitutive properties are chosen so that theoretical and observed fault creep and trilateration line lengths agree. Observed fault creep data, up to 15 years duration, are for eight creepmeters from XSC1 to TWR1 (except JKR1). Trilateration data for four lines have similar duration. Observed creep and trilateration line lengths have been approximately linear since 1970, but the model predicts accelerating rates beginning about two years before the next moderate earthquake. Predicted increases of creep rate are largest at XPK1 and XDR1, which are closest to the assumed fault patch, and should easily exceed the normal noise level. Trilateration lines spanning the fault patch have largest predicted increases, though perhaps too small to detect within observational error.

   A related but more general instability model allows pressure dependence of fault properties; the pressure changes are due to slippage on non-coplanar faults and regional stress. This model will be used to study instabilities analogous to earthquakes on the currently locked section of the San Andreas fault in southern California, and to study conditions when a moderate Parkfield earthquake can expand into a larger earthquake.

2. The interacting fault model for southern California allows oblique slip on vertical and subhorizontal faults of arbitrary dip and strike. Preliminary simulations produce uplift and partial collapse of the ground surface in the western Mojave desert.

Reports

Stuart, W.D., R.J. Archuleta, and A.G. Lindh, Forecast model for moderate earthquakes near Parkfield, California, Science, submitted.

Seismic Source Mechanism Studies In The Anza-Coyote Seismic Gap

14-08-0001-18397

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1.0 Network Status

During the fall and winter months of 1982, the Anza network was recording up to eight stations of three component digital telemetry data. The network operated almost continuously in this period of time with only a few communication failures. The largest events inside the array which have been recorded are in the magnitude 2 to 3 range. Recordings have also been made of earthquakes of magnitude M_L 4.4 and 3.6 located respectively 60 km and 40 km away from the nearest station. Currently the network is recording about 7 to 8 earthquakes per week. The trigger algorithm seems to be working fairly well with about 60 percent of all triggers being real events.

2.0 Seismicity

Figure 1 (from USGS, Menlo Park, Routine Operations) shows our epicentral locations from October 1, 1982, through January 11, 1983; it is complete above a magnitude threshold of about 2 (CIT-USGS) duration magnitudes. These locations are based solely on P- and S-wave arrival times from the eight-station ANZA array. Mislocations with respect to CIT-USGS determinations are typically 1 to 2 km, both in plan and in depth. This is surprisingly good agreement, in view of the considerable differences in station densities of the ANZA array and the CIT-USGS southern California array.

While it is premature to make too much of 3 1/2 months of precise locations in the Anza area from our array, there are nevertheless two significant features of the seismicity results to date. In the first place, not much of this seismicity is associated with the San Jacinto fault itself (or, south of the trifurcation just east of Anza, with any of its three principal branches). Secondly, the located events extend to a depth of 18 km. These compare with some of the deepest earthquakes ever recorded in California south of the Mendicino escarpment.

3.0 Scientific Results

On the larger recorded events, preliminary source parameter estimates have been determined in a conventional way (body-wave spectra interpreted according to Brune (1970)[1], with a corner frequency shift (Hanks, 1981)[2] of $\sqrt{3}$ for the P waves). By conventional standards, we consider these estimates to be quite well-determined, although they are all based on a single pass through each record for each earthquake. P-wave moments are usually within a factor of two of the corresponding S-wave moment. The largest moments for events inside the array are on the order of 1×10^{21} dyne-cm. P-wave stress drops are also comparably close to the S-wave stress drops. These values range from 6 to 60 bars.

One of the reasons for working in this particular area was our guess that typical propagation paths are very low-loss. Figure 2 is an example of this. On the left side of the figure are two components of S-wave spectra from a site "close" to the earthquake (R = 14 km). Each component spectrum is corrected for two different Q's (300 and 2000). At the close sites, the only effect is a differing high-frequency spectral decay rate; for both events, a shear-wave corner frequency of approximately 20 Hz is indicated by both components. On the right side of the figure are the same calculations for a more distant site (21 km). When these more distant spectra are corrected at Q = 2000, the same shear-wave corner frequencies as at the close stations are indicated. Corrections of the distant spectra at Q = 300 (upper left of Figure 2) flatten the spectra to the point where there is no longer a corner frequency. Evidently, whole-path shear-wave Q's in the southern California batholith in the vicinity of Anza are in the neighborhood of 1000 (or greater), far above the conventionally assumed values of 200 to 300.

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[1] Brune, J.N. (1970), J. Geophys. Res., 75, 1-27.
[2] Hanks, T.C. (1981), Bull. Seism. Soc. Am., 71, 597-612.

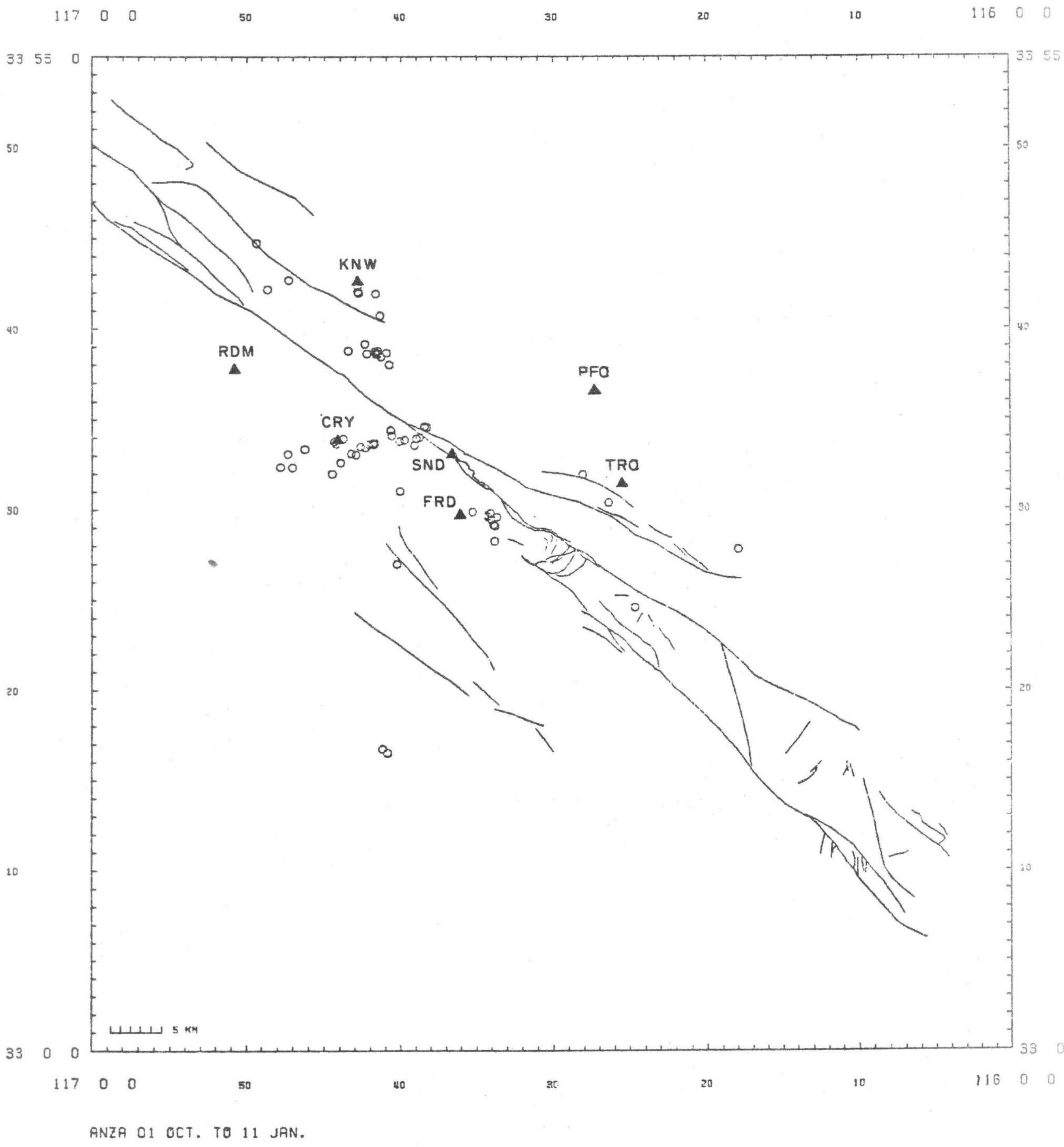
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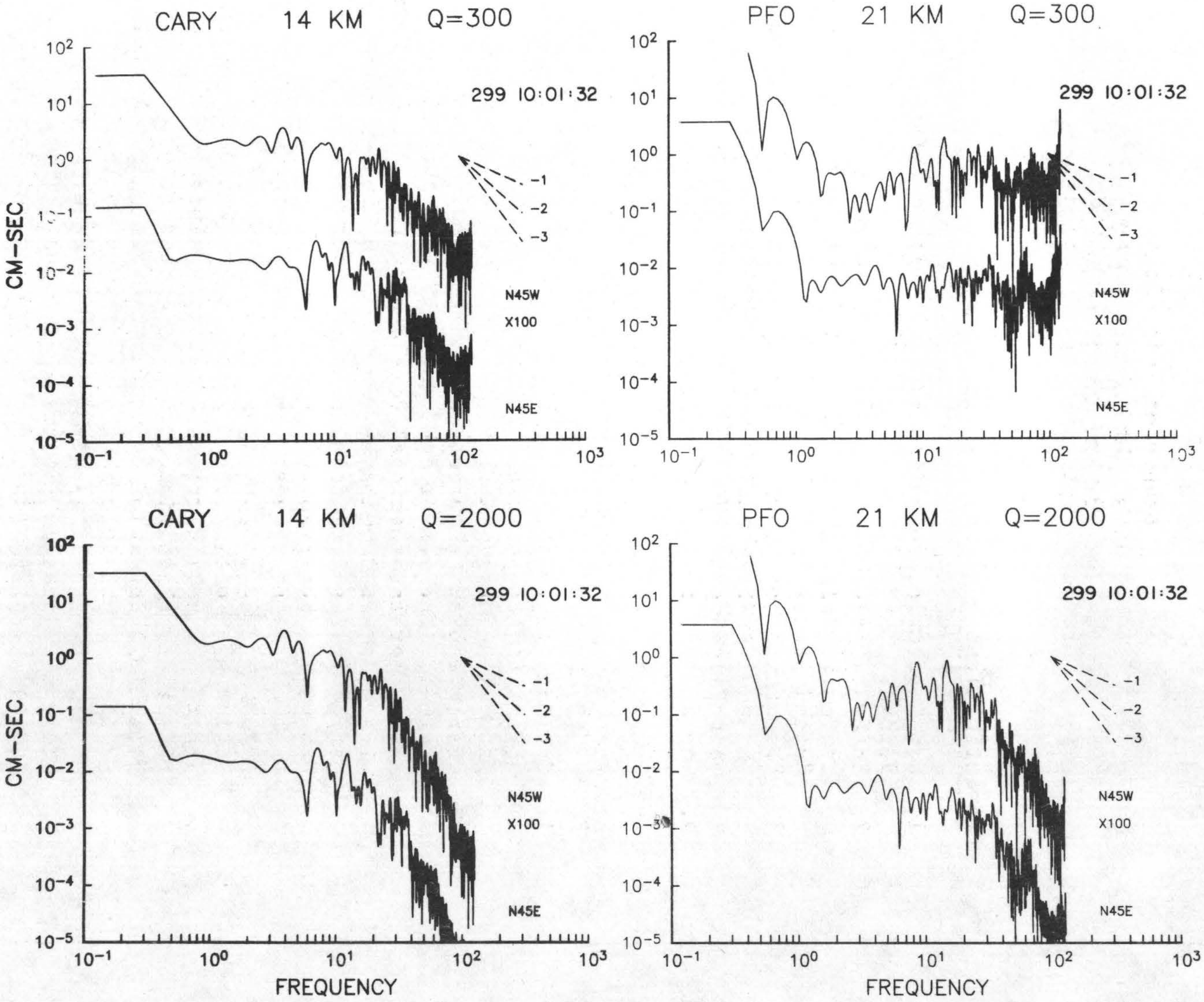
Figure 1.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N45E
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-3

Figure 2.

Fault Zone Structures

9930-01725

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Investigations

1. Development of an automatic microseismic network in Jordan.
2. Interpretation of the deep crustal structure and tectonic evolution of the Mississippi Embayment, central United States.
3. Preparation of journal articles on the crustal structure of Saudi Arabia, based on U.S. Geological Survey Open-File Report OF-02-37. (Healy and others, 1982).
4. See project report 9930-02102: Active seismology in fault zones, Walter D. Mooney.

Results

1. For many years the Geological Survey has maintained scientific cooperation with the Government of Jordan, Natural Resources Authority (NRA), in the exploration of their natural resources and conventional energy sources. The most recent activity was sponsored by the Agency for International Development (AID) in the form of a Minerals Development Grant for a Kingdom-wide geophysical survey, designed and supervised by Geological Survey staff members.

   The present request for Office of Earthquakes, Volcanoes, and Engineering (OEVE) services is part of a follow-up program to the geophysical surveys to measure and record microearthquake activity along the Dead Sea rift zone. Resulting data is expected to provide valuable information on subsurface geologic structure related to possible geothermal energy sources of the numerous hot springs along the rift zone. The data would also provide important earthquake risk and earthquake prediction information for the Government or Jordan, particularly for AID assistance programs for the construction of dams, roads, and other construction projects in the developing country.

   Specifically, OEVE, at the request of AID, through the Office of International Geology (OIG), will assist in the design of an automated microseismic network observatory. The work includes design of state-of-the-art instrumentation for a 20-station network, site construction, telemetry to a central observatory, recording, playback and data display system, and operation and training programs for Jordanian seismologists.

The development and deployment is based on a new system concept that integrates seismic systems, telemetry, specialized computer hardware and software, and technical personnel to produce high quality results with minimal cost of long-term monitoring. This system is named "JSS" (Jordan Seismic System) to identify its unique qualities and combination of components. Data will be gathered by clusters of as many as eight seismic stations, telemetered by radio to a central collection point where routine, automatic analysis will take place by a data processing system. These results will then be transmitted to the Central Observatory for further analysis and display.

2. We have developed a tectonic model for the Mississippi Embayment based on new geophysical and existing geologic data. The model is constrained by two features of the crust: a high velocity, high density lower crust, interpreted to be a fossil rift cushion, and an upper crustal low velocity zone, interpreted to be a rift graben.

   Based on the geophysical model for the crustal structure of the Embayment and on geologic evidence the following model for the evolution of the Embayment is proposed. The intrusion of mantle derived material into the lower crust occurred in the Late Precambrian causing the initiation of crustal rifting in the northern Embayment area. Isostatic subsidence caused by the cooling of the lower crustal intrusion created a broad, elongate basin in Cambro-Ordovician time that accumulated thick sequences of carbonate sediments. In the late Paleozoic, compressive tectonic forces from the south, at a high angle with the rift zone, caused uplift and igneous activity along previously faulted zones in the Embayment. Another phase of uplift was initiated before late Cretaceous time. This uplift and associated igneous activity was in response to isostatic rebound forces caused by renewed injection of mantle material into the lower crust. Major subsidence followed in late Cretaceous and early Tertiary time due to cooling of the altered lower crust. It was during this time that the present configuration of the embayment was established.
3. Three manuscripts have been prepared (see 'Reports').

Reports

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In Situ Stress Measurements

9960-01184

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Investigations

During this reporting period efforts of this project were devoted to the following tasks:

1. Stress measurements in two holes on Yucca Mountain as part of the waste disposal investigations on the Nevada Test Site.

2. The selection of sites, examination of geology, and drilling of holes for instrument emplacement, primarily Sacks meters, but also for a three-component strain meter to be deployed by M. Gladwin, and holes for fluid pressure investigations at our test site near Hi Vista, California.

In project 01184 we are now developing the capability to provide an instrument emplacement service for a variety of instruments being developed to measure temporal changes in stress at very high sensitivity. We envision this task as providing not only the boreholes but also measurements of the physical properties needed to understand the response of the instrument/rock system to deep seated stress anomalies.

3. We are working with the Bureau of Reclamation to develop a plan and an experimental system to measure stress in a 15,000'-deep hole in Colorado. This effort will require changes in many components of our present system, and we are proceeding with the development and testing of new packer systems and associated pump and pressure measuring systems needed to make successful measurements at greater depths.

4. We are engaged in a cooperative program with the People's Republic of China to assist in the development and initial measurement of in situ stresses in China.

5. We are still involved with stress measurements and televiewer logging in the Deep Sea Drilling Project, and some time has been spent on that project during the reporting period.

6. A major portion of the time available during the reporting period was spent on the preparation of papers reporting the results of data collected during previous periods. These include 1) an interpretation of stress measurements at Oroville, California, 2) an interpretation of televiewer measurements at Hanford, Washington, 3) completion of the open-file report for hole USW-G1 at the Nevada Test Site, 4) work on report on stress measurements for USW-G2 at the Nevada Test site, 5) work on the Auburn, NY, report, 6) work on the Hi Vista report. We also spent considerable time working on the preparation of a large number of oral presentations that have been made at various scientific meetings.

Results

We do not wish to discuss detailed results from all of these efforts at this time. We refer the interested reader to the attached bibliography for better discussions of our results than we can give in the limited space here. We do want, however, to make a few general points to show the relationship of this project to the Earthquake Prediction Program. It is becoming increasingly obvious that the borehole physics needed to correctly interpret the results of hydrofrac stress measurements has a very close relationship to the physics and experimental work needed to emplace borehole instrumentation to monitor stress and interpret the results from this instrumentation. It is now demonstrated beyond any reasonable doubt that stress increases with depth in the Earth in a way that is not explained by the effect of gravitational loading. In particular, horizontal shear stress increases with depth and this effect cannot be explained by uniform gravitational loading. It is more likely that this stress increase with depth results from the fact that rocks near the surface in most tectonically active regions are close to the point of failure. This fact has profound implications for an understanding of tectonic processes and also for the practical decisions involved with emplacing instruments to measure deep seated stress changes.

Over the past few years an increase in the quantity of data available, the quality of these data, and the intense effort on the interpretation of these data have all provided a stronger foundation of experimental evidence that will be needed to understand the processes that cause stress to increase with depth and to vary laterally in response to tectonic forces. As this work continues, and in particular, as techniques are developed to measure stress at greater depths, we can anticipate that this research will provide critical data needed to understand the fundamental physics of the earthquake process. If shear stress, for example, continues to increase at the same rate observed at depths to 3,000', then it will weigh heavily on the side of those researchers who are arguing for high stress in fault zones. On the other hand, if faults are failing at stresses on the order of 100 bars, stress cannot continue to increase with depth at the rate we have observed, and we should begin to see a decrease in the rate of change with depth as we make measurements to depths between 2 and 3 km in the Earth.

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Heat Flow and Tectonic Studies

9960-01176

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Investigations:

1. Heat flow and tectonics of the western United States: Additional data on temperature, thermal conductivity, and radiogenic heat production were obtained in the Mojave-Salton Trough area of California, the Yucca Mountain area of Nevada, and the Vekol Valley, a tertiary tectonic basin in Arizona. Detailed thermal data are being obtained from the USBR's Brantley Dam site near Carlsbad, New Mexico. Temperature measurements were also obtained in the Santa Maria and Ventura Basins, California. Interpretive studies of the Salton Trough are nearing completion.

2. Heat flow and tectonics of Alaska: Heat flows were determined to depths of up to 6 km in 25 wells from the National Petroleum Reserve on the North Slope.

3. Thermal studies related to nuclear waste isolation: Equilibrium temperature measurements have been completed on most wells in the Yucca Mountain area. Additional conductivity data are being obtained, and interpretation is continuing.

4. Equipment development: A commercially available transient-source thermal conductivity apparatus was compared with our conventional divided-bar apparatus. A line-source "half space" thermal conductivity apparatus was built, tested, and deployed.

Results:

1. Heat flow and tectonics of the western United States: Recent heat-flow results suggest that the Imperial Valley of California can be viewed as an area of very high regional heat flow ($\sim$130 mW/m^2), modified locally by the effects of upper-crustal intrusion and fault-controlled hydrothermal circulation to depths of a few kilometers. This regional heat flow, which extends into the bordering crystalline rocks, is what would be expected from a conducting crust $\sim$25 km thick resting directly on asthenosphere if there were no extension or sedimentation. However, geologic and geophysical observations suggest that both processes are active there. A seismic refraction study by

Gary Fuis and coworkers revealed that the broad sedimentary basin in the Imperial Valley is underlain (beneath a basement layer) by a sub-basement of presumably mafic rocks (v_p ~7.2 km/s) at a depth of ~12 km; our gravity model extends this sub-basement to a depth of 23.5 km, with asthenosphere below. In a simple one-dimensional kinematic model for the evolution of this configuration, the sediment and mafic rock accumulated simultaneously on opposite sides of the original crust as it thinned and subsided during distributed extension of the basin. Assuming that sedimentation continually maintained the surface near sea level, an isostatic constraint yields the ratio of rates of crustal additions by sedimentation and basal intrusion; for a reasonable choice of densities, this ratio is about 2/3. Simple analytical thermal models for underplating or distributed lower-crustal intrusion show that for this ratio, surface heat flow is consistent with the estimated regional value. Conditions of heat and mass balance between crust and asthenosphere yield estimates of long-term average extension rates on the order of several microstrains per decade. Additional heat-flow measurements to test this model are in progress.

Temperature data from about 20 test wells in the Vekol Valley, a small (~500 km^2) tertiary tectonic basin in south-central Arizona, indicate a rather complex hydrologic regime in the sediments and underlying crystalline rocks superimposed on a regional thermal regime typical of the Basin and Range province. The north valley is characterized by conductive but variable heat flow indicating that convection is occurring in the basement rocks. In the south valley, there is evidence for both vertical and lateral movement of water in the sediments which average about 2000 feet in thickness. A detailed thermal and hydrologic budget is being calculated as data become available.

Temperature gradients in dolomites, sandstones and evaporites in seven cased and grouted wells near Carlsbad, New Mexico, appear to be conductive and yield preliminary estimates of heat flow of only 70% to 80% of the regional value. The holes are ~100 m downstream from a proposed dam site beneath which there are several cavernous zones. The thermal data indicate little potential for pervasive vertical seepage into the caverns; however, vertical and lateral leakage along discrete fractures remains a possibility.

A heat flow of 81 mWm^2 was calculated from thermal gradients and conductivity measurements on core from a well in Pierre Shale near Hayes, South Dakota, confirming that this portion of the mid-continent is characterized by high heat flow. The vertical component of thermal conductivity was determined on a well-preserved core and is considerably lower than some previous estimates from poor quality samples. This, in turn, suggests that a number of heat-flow estimates within the Pierre Shale are systematically high by perhaps 50% or more.

2. Heat flow and tectonics of Alaska: There is considerable variation in heat flow calculated from corrected bottom-hole temperatures at 25 sites in the National Petroleum Reserve - Alaska (NPRA) on the North Slope. The general tendency is for heat flow to increase systematically northward from the Brooks Range.

3. Thermal studies related to nuclear waste isolation: From the thermal information obtained from wells in the Yucca Mountain area, Nevada (Figure 1), we may make the following observations:

a. Temperature profiles in the unsaturated zone show a great deal of variation from well to well. The general tendency is for gradients to increase with depth, consistent with a regional hydrologic recharge with vertical (Darcian) flow velocity of a few mm y^{-1}.

b. Between the static water level and depths of about 1 km, temperature profiles are quite erratic and vary laterally, showing evidence of upward flow in some wells and downward or lateral flow in others. This thermally chaotic zone was the original focus of attention as potentially the most suitable repository depths.

c. Below depths of ~1 km, most temperature profiles indicate that heat flow is primarily by conduction. The gradients vary laterally, however, and the conductive heat flow is likely to vary between about 30 and 70 mWm^{-2} (.75 and 1.7 HFU) within the very small area defined by Figure 1. This, in turn, suggests very shallow (in the range 2.5 to 5 km) heat sources and sinks, most likely associated with hydrologic processes.

From the accumulated thermal data, it seems clear that various fluids are moving about in the unsaturated zone, that water is moving in a very complicated manner within the saturated zone to depths on the order of 1 km, and that in the Paleozoic rocks beneath the tuffs, there probably is also a complex hydrothermal circulation system.

4. Equipment development: A commercially available transient-source "half space" device yields values of thermal conductivity on large samples in good agreement with those obtained using the USGS divided-bar apparatus. This prompted us to modify two needle probes for use in the half-space configuration (as opposed to the conventional "infinite medium" approach which requires that long holes be drilled in solid rock samples). Exhaustive tests established that the method is very reliable, and the half-space apparatus is now in routine use.

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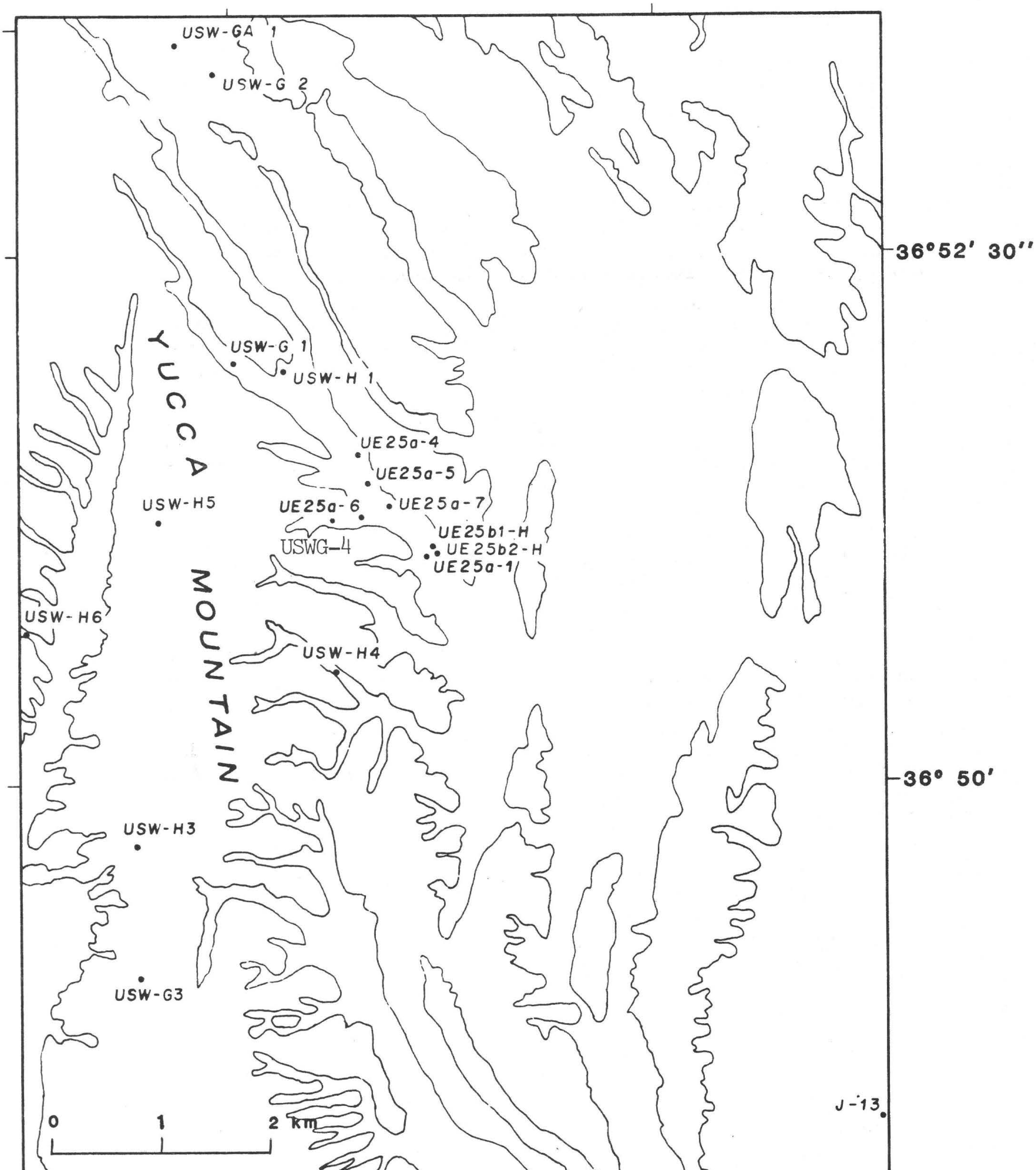

Figure 1. Sketch map showing the relative positions of test wells at Yucca Mountain.

Active Seismology in Fault Zones

9930-02102

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Investigations

1. Analysis of seismic refraction data in several locations in the Great Valley of California and adjacent Coast Ranges and Sierran foothills (A. Walter, J. Murphy, and W. Mooney).

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

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

4. Interpretation of the deep-crustal structure of the Mississippi Embayment of the central United States.

5. Collaboration with the State Seismological Bureau (Beijing) in a program of crustal studies in Yunnan Province.

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

Results

1. Analysis continues on five research profiles collected in the Great Valley between Stockton and Fresno, California. Three of the profiles are subparallel to the Valley axis and are located on the west side, at the center, and on the east side of the Valley. Two transverse profiles extend from the Diablo Range to the Sierra Nevada and are located near the latitudes of Tracy and Los Banos, California. Along each profile, 100 seismic cassette recorders were deployed at spacings of 1.0 to 1.5 km and shots were fired at shotpoints located near the endpoints and centers of the profiles. The collected traveltime data are being used to construct a crustal velocity model for

the Great Valley between the Coast Ranges and the Sierra Nevada. This model better belineates the feature producing the aeromagntic and gravity highs in the Great Valley.

Refraction data was also collected along two end-to-end 120-km long profiles extending from Morro Bay, on the California coast, across the southern Great Valley to the Sierra Nevada east of Delano, California. For each of these profiles, the 100 cassette recorders were deployed at 1 to 1.2 km intervals and shots were fired at four shotpoints spaced 20 to 50 km apart.

2. Earthquakes occur in many locations on either side of the San Andreas fault in central California. In order to investigate the deep structure of the crust in this region, and relate it to earthquake occurrence. Vibroseis reflection data was purchased from Western Geophysical along the route of our seismic refraction profiles from Marro Bay to the Sierra Nevada. The refraction data are being analyzed to provide velocity-depth functions that can be used to reprocess the reflection data. Geophysical Systems Corporation has been contracted to collect vibroseis reflection data along our refraction profile through Los Banos, California. The line is east-west and 120 km long. The reflection records have a two-way time of 12 seconds in order to study the deeper parts of the crust.

3. The deep crustal structure of the Imperial Valley, southern California, has been investigated thoroughly and these results reported (e.g., Fuis and others, 1982). In order to extend the coverage possible in our previous interpretations, the time-term method has been applied to the 1979 seismic refraction data. All of the traveltime data were next integrated to produce a time-term map, which in principle eliminates distortions of features seen on traveltime maps and can be converted to a sediment isopach map. Striking features seen on this map include the following: 1) A complex buried scarp along the west side of the Imperial Valley. This feature, seen on the earlier traveltime maps, trends roughly north-south; it appears to be terraced and also segmented. The Superstition Hills fault and Superstition Mountian fault bound one segment and northwest-striking buried faults (?) farther south appear to bound other segments. 2) A prominent scape is also seen northeast of the Salton Sea and appears to be a continuation of the modern mountain front beneath the sediments. (We had surmised earlier than such a scarp existed about 10 km farther southwest, along the San Andreas fault). 3) Geothermal areas are reflected on the maps as areas of relatively low time-terms. These areas have varied shape and relief on the map. The

The Salton geothermal area has the strongest relief and is the largest areally. In conjuction with this investigation a computer program was written for machine contouring of data points.

4. An extensive seismic refraction investigation was conducted in the Mississippi Embayment in September 1980 in order to provide detailed information regarding the deep crustal structure. During the investigation 34 shots from nine shot points were recorded along aseries of profiles. The profiles were parallel to and across an inferred Precambrian rift zone which is outlined by a series of magnetic anomalies and covers an area at least 200 km long and 70 km wide.

Along the northeast-southwest trending axis of the rift a 0.7- to 1.1-km-thick 1.8-km/s layer representing the unconsolidated Tertiary and Cretaceous sediments overlies a 2-km-thick 5.95-km/s layer representing a Paleozoic carbonate sequence. Beneath the carbonates is a 3-km-thick low-velocity layer which probably consists of late Precambrian clastics. An 11-km-thick 6.2-km/s basement overlies a lower crust comprised on a 6.6-km/s layer whose thickness decreased to the northeat due to its replacement by an anomalous high-velocity 7.3-km/s basal layer. The base of the crust varies from 39-km depth at the southern end of the profiles to 46-km depth at the northern end where the 7.3-km/s layer is 20-km thick. Below the base of the crust (Moho) the upper mantle has a velocity of 8.0-km/s.

The velocity structure beneath the west flank of the Embayment is simpler than that of the axis: 5.95-, 6.2-, 6.6-, 7.3-, and 8.0-km/s. The low-velocity layer is absent and the anomalous 7.3-km/s layer is thinner than along the axial profile. The profiles perpendicular to the rift show that the low-velocity layer is restricted to the axial zone and that the anomalous 7.3-km/s basal crustal layer reaches maximum thickness there.

The tectonic model proposed to explain the origin of this embayment velocity structure is that a late Precambrian mantle plume intruded into the lower crust of the northern embayment, causing uplift (and/or crustal stretching) and the sebsequent rifting of the axial area. This was followed by erosion, subsidence, and subsequent deposition of sediments in the resulting trough.

5. Working through the US-PRC protocol for Earthquake Prediction Research, we have been cooperating with the State Seismological Bureau in a program studying the

deep-crustal structure in Yunnan Province, southwestern China. In addition, we are providing technical assistance in the area of digital processing of seismic data. In order to strengthen this effort, we hosted a meeting in December, 1982, to discuss research goals which was attended by twenty-five scientists. A research proposal to the NSF from UC-Berkeley was an outgrowth of this meeting. This proposal will provide the university with support, thus, making the cooperation a USGS-PRC-UC Berkeley effort. An electrical engineer will work in Menlo Park for two months on instrument design needed to facilitate data processing. The project will result in new information regarding the crustal structure in the seismically active region in southwestern China.

6. Geologic transect provide a useful summary of the present knowledge of the geology and deep structure in key areas. Ocean-continent transect C-D, constructed for the U.S. Geodynamics Committee's Transect Program, extends from offshore southern California to central New Mexico. The transect consists of: 1) a one-degree-(110-km) wide, 1:500,00 geologic strip map, 2) two 1:5000,000, 1:1 geologic cross sections, one colored by age, the other by lithotectonic "kindered", 3) gravity, magnetic, heat flow, and seismic-velocity profiles, and 4) ancillary diagrams explaining the progressive tectonic development of the region. The major tectonic provinces crossed by the transect include, from west to east, the southern California borderland, the Transverse Ranges, the Peninsular Ranges, and Salton Trough, the southern Basin and Range, the northern Sierra Madre Occidental, and the Rio Grande Rift provinces. This work is in its final stages.

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Crustal Deformation Observatory Part H:

Installation of Volume Strainmeter Array at Pinon Flat Observatory

Contract No. 14-08-0001-19769

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During April of 1983, a group from Carnegie's Department of Terrestrial Magnetism installed three Sacks-Evertson borehole strainmeters at Pinon Flat Observatory.

Installation Techniques

The depth at which the instrument is to be installed is selected on the basis of hole log information provided by the Geological Survey; in particular this includes televiewer logs and caliper logs.

The next stage involves lowering a grout mix in a container (bailer) so that the mix of cement and silica flour is delivered with a minimum of disturbances which could result in separation.

The instrument is then lowered into the hole and sinks through the grout mix so that the space between the instrument and the hole wall is completely filled with grout. The volume of grout delivered to the bottom of the hole is sufficient to provide several feet of coverage over the instrument, the top two feet of which are not active. Signal wires in the cable attached to the instrument are connected to an electronics package to provide input and output signals.

The cement used is an expansive cement so that the instrument is placed under significant compression. Thus it is well coupled to the rock and is able faithfully to follow future dilatational as well as compressional changes in strain.

Problems in the Installation

The rock at Pinon Flat has many fractures (this seems to be common to all holes in granite in California) and this presents many difficulties for the installation. We attempt to install the instrument in a section of hole which is fracture free; in practice we are forced to select a section which has a minimum number of fractures.

Wherever the hole is fractured and not cased, there exists the possibility of small pieces of rock being dislodged and falling into the hole. If this happens during the installation, these small rocks may jam the bailer or instrument during its motion up or down the hole. This is a common problem with installations in California and in the case of one Pinon Flat hole (CIC), we experienced major problems. These resulted in the loss of one instrument.

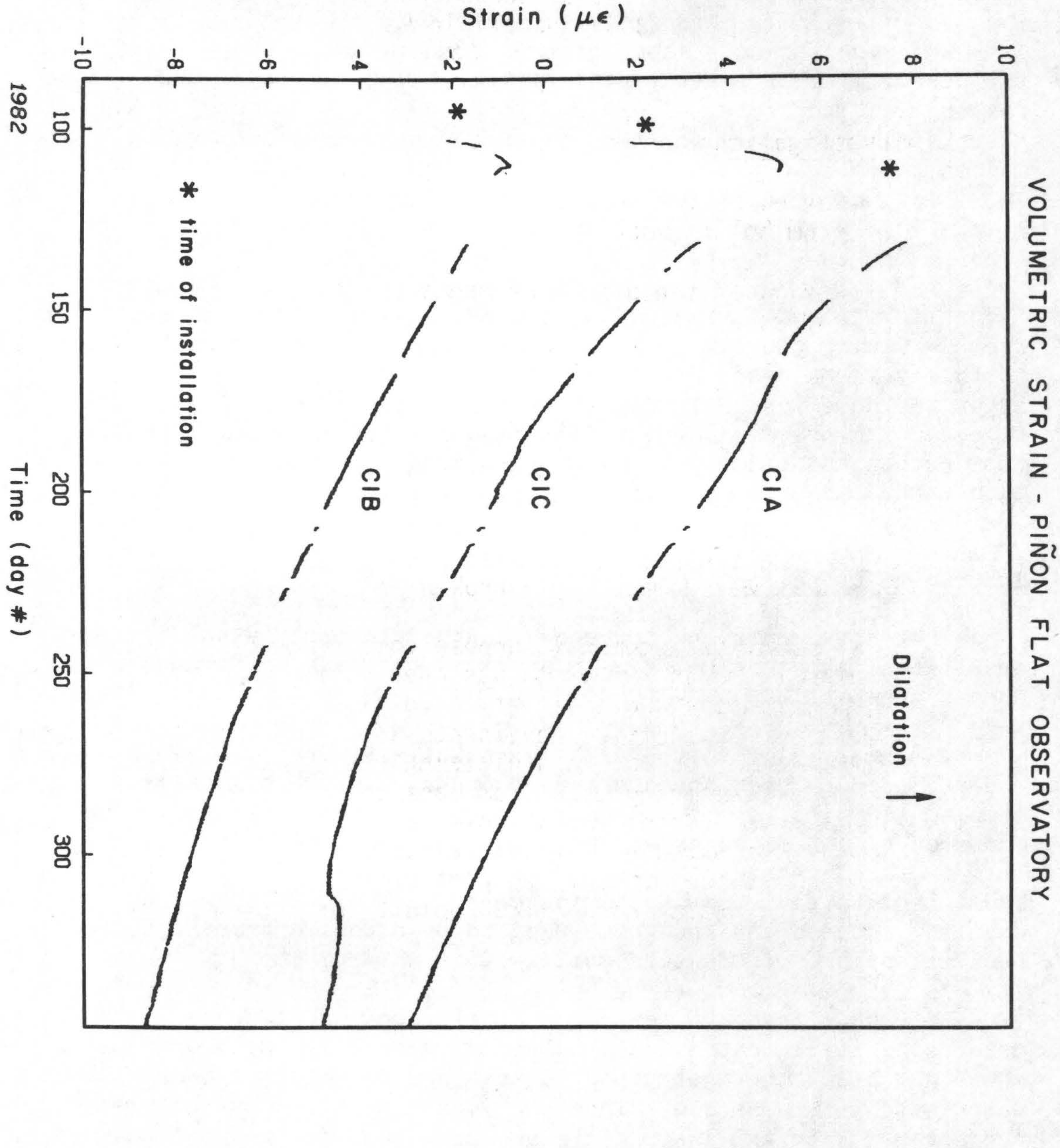
Hole CIA had a very bad section of rock at about 330 feet depth. During the few days between logging and our attempt to install, the hole bridged at this depth. This was some months after the hole was drilled. It was necessary to engage a driller to clear the hole. Material continued to enter the hole; it was then reamed and cased past the bad section. The instrument was then installed without further difficulties.

Instrument Operation

The instruments are now recording continuously with operational services being well provided by Frank Wyatt and Duncan Agnew of UCSD.

A summary plot of the data is shown in Figure 1. The data are recorded on slow speed chart recorders and are digitally sampled (12 bits) every 5 minutes. Strain rates at all sites are comparable. These rates are high but are decreasing with time. This is the expected behaviour for an installation of this type. The immediate environs of the instrument are disturbed by the drilling process and the grout used to bond the instrument to the rock takes some months to stabilize.

We expect that the instruments will continue to show decreasing strain rates. All holes are partially open, both above and below the instrument so that now transfer of heat via water motion is possible. Thus the settling period may be prolonged. When the instruments are equilibrated, we will be able to compare secular strain rates with other instrumentation at Pinon Flat, in particular with the long baseline laser extensometers.



VOLUMETRIC STRAIN - PIÑON FLAT OBSERVATORY
Dilatation
Strain (με)
10
8
6
4
2
0
-2
-4
-6
-8
-10
100
150
200
250
300
1982
Time (day #)
CIA
CIC
CIB
* time of installation

Crustal Changes North of San Francisco

9930-03353

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Investigations

1. Review of the feasibility of developing energy directly from molton rock.

2. Review of the origin of magma especially at mid-ocean ridges and at the sites of intra-plate volcanism.

Results

Close examination of anomalous ocean ridge crests gave me some new ideas about the origin of Iceland and the ocean floor from the Gibbs Fracture zone north to the Jan Mayen Fracture zone. The abnormal crustal structure seems related to old roots based on detailed pre-drift reconstructions. This work was delayed by a broken leg.

Geoplot is a general purpose computer graphics system written by me in 1980. It has been updated to include 20 map projections and a variety of digitized maps as well as utilities for plotting continents in place or drifted about a sequence of poles. A digitizing routine has been written to allow digitizing data from maps in any of the 20 map projections. Geoplot runs interactively under Geolab on Unix and is available to interested users. It is in Fortran and C and uses overlays. Geoplot utilizes two map files that give world coastlines in 5200 points and 81,000 points.

World-Wide Standardized Seismograph Network (WWSSN)

9920-01201

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Investigations

1. Technical and operational support was provided to the World-Wide Standardized Seismograph Network (WWSSN) as required. This was accomplished by exchanging modules and spare parts with the operating stations.

2. During this period, 187 modules or components were repaired, and 327 separate items were shipped to support the network. Regular and emergency shipments of photographic paper and chemicals were made to assure continuous operation of the cooperating stations. All stations are presently operating with regular photographic supplies.

3. The South Pole team of Mr. Russell Berry and Miss Loreen Utz was trained on identical equipment used at SPA. The team will winter over and operate this seismic station. They are also reporting the seismic activity recorded there.

Mr. Brian Davis, an employee for Nero and Associates of Portland, Oregon, was trained on the operation of a seismological and geomagnetic observatory. He is presently operating the Geophysical Observatory in San Juan, Puerto Rico.

Results

A continual flow of high quality seismic data from the network of 115 observatories for use by the seismological community.

Glen Canyon Dam

9920-01211

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Investigation

Glen Canyon Dam - Recorded, compiled, interpreted and reported local earthquakes in the vicinity of the dam and reservoir to attempt to determine whether there are detectable influences on the seismicity by the dam and/or reservoir.

Reservoir induced seismicity appears to have fallen off as very few earthquakes have been detected near the reservoir during recent report intervals.

Results

Glen Canyon Dam - Memorandum-type reports are being submitted to the Bureau of Reclamation periodically concerning status of local earthquakes recorded at seismograph station "GCA."

The goal of the Glen Canyon Project is to record, compile, interpret, and report local earthquakes in the vicinity of the dam and reservoir to accumulate data to aid in determining whether there are detectable influences on the seismicity by changes in water level in the reservoir.

U.S. Seismic Network

9920-01899

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Investigations

U.S. Seismicity. Data from the U.S. Seismic Network are used to obtain a preliminary location of significant earthquakes worldwide.

Results

As an operational program, the U.S. Seismic Network operated normally throughout the report period. Data were recorded continuously in real time at the NEIS main office in Golden, Colorado. At the present time, 80 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 was undertaken. As part of this, the network was converted almost exclusively to digital telemetry. This made possible the combination of several Long Lines into one as it is now possible to multiplex more than one data stream per Long Line. The use of digital data transmission will save at least $60,000 per year in Long Line charges. The conversion of the network to digital telemetry was completed in January 1983.

Also occurring in January was the initial operation of a real time seismic data link between the Pacific Tsunami Warning Center, Ewa Beach, Hawaii, and NEIS in Golden, Colorado. PTWC is funding the satellite link between Hawaii and Menlo Park where the data are merged into an existing data stream for transmission on to Golden. Nine channels of 20 samples per second data are being transmitted continuously in both directions.

Objectives

The U.S. Seismic Network is an operational program as the data generated are routinely used to support the NEIS operational requirement of timely location and publication of earthquakes worldwide. Also, the network data directly support the NEIS standby personnel who are responsible for locating and reporting to the media, disaster agencies and other organizations all significant earthquakes worldwide. Thirdly, support is given to the Alaska Tsunami Warning Center and the Pacific Tsunami Warning Service as network data are exchanged with both organizations.

Remote Monitoring of Source Parameters for Seismic Precursors

9920-02383

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Investigations

1. Teleseismic analysis of moderate-sized earthquakes. We are examining the rupture characteristics of important moderate-sized earthquakes using digitally recorded broadband waveforms. We have studied the New Brunswick earthquake of January 9, 1982, and are now studying the Yemen earthquake of December 13, 1982.

2. Broadband analysis of large earthquakes. We are developing methods of generating synthetic waveforms that correctly incorporate effects of propagation and source directivity to analyze the rupture process of large complex earthquakes (magnitude >7.0).

Results

1. From broadband waveforms we obtained strong constraints on static properties of the New Brunswick earthquake including depth (9 km), focal mechanism (thrust-faulting on a west-dipping fault plane), moment (5.0 x 10^{24} dyne-cm), rupture plane, rupture direction and associated stress drops (45-75 bars). Preliminary indications are that the Yemen earthquake can be described as a CLVD (compensated linear vector dipole) using long-period moment-tensor analysis. Broadband data show the event can be modeled as a sum of two events with different focal mechanisms.

2. We are examining the rupture process of the large (MS 7.8) Samoa earthquake of September 1, 1981. By using broadband waveforms, the depth of the initial nucleation has been determined. The rupture consisted of at least 6 subevents for which we have obtained individual focal mechanisms and relative locations.

Reports

Choy, G. L., Boatwright, J., Dewey, J. W., and Sipkin, S. A., 1983, A teleseismic analysis of the New Brunswick earthquake of January 9, 1982: Journal of Geophysical Research, v. 88, p. 2199-2212.

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 and other contributing stations are reviewed and checked for quality.

2. Network-Day Tape Program - Data from the Global Network of stations are assembled into network-day tapes which are distributed to Regional Data Centers and other Government agencies.

3. Event Detection Program for the Global Network - This program has undergone substantial revisions and upgrading and is presently being installed at all SRO/ASRO installations.

Results

1. Data processing for the Global Digital Seismograph Network - During the past 6 months, 402 digital tapes (177 SRO/ASRO, 189 DWWSSN, and 36 RSTN) from the global network and other contributing stations were edited, checked for quality, corrected when feasible, and archived at the Albuquerque Seismological Laboratory (ASL). The Global Network is now comprised of 11 SRO stations, 5 ASRO stations, and 14 DWWSSN stations which comprise the Global Digital Seismograph Network (GDSN) and are supported by the ASL. In addition, there are 6 contributing stations which include Glen Almond, Canada, and the 5 RSTN stations installed and supported by Sandia National Laboratories.

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 plus the contributing stations for a specific calendar day onto one magnetic tape. This tape includes all the necessary station parameters, calibration data, frequency response, and time correction information for each station in the network. A Network-Day Tape Newsletter containing information on all of the global stations plus the Network-Day Tape Program was distributed in October 1982. A third edition of this Newsletter will be issued in May 1983. Six copies of the network-day tapes are forwarded to various Regional Data Centers in this country and to other Government agencies. Long-Period digital data from the RSTN Network were added to the network-day tapes starting on December 12, 1982. Short-period and mid-period data were added on February 15, 1983.

3. Event Detection Program - This program is now working at the Albuquerque SRO stations, and it is also used to event detect the RSTN data. It is presently being implemented (effective 3 May 1983) on all of the SRO and ASRO stations. The continuous short-period data recorded by the SRO/ASRO network from October 1 to October 15, 1980, was processed to select the thresholds and other parameters of the detector for each station. This individual selection of parameters will result in fewer false alarms while detecting very small events.

Abstract

Engdahl, E. R., Hoffman, J., and Buland, R., Management of data from the Global Digital Seismograph Network: The Network-Day Tape Program. Accepted for presentation at IUGG, August 1983.

Newsletter

Hoffman, J. P., Buland, R., and Zirbes, M., Network-Day Tape Newsletter, October 1982, v. 1, no. 2, 16 p., available from Albuquerque Seismological Laboratory, Albuquerque, New Mexico.

Socorro Magma Bodies

9920-03379

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Investigations

1. Seismicity near Socorro, New Mexico.

2. Instrumentation.

3. San Juan Basin Studies.

4. Albuquerque Basin Seismicity.

Results

1. Al Sanford (New Mexico Tech) and I are contributing an article to the New Mexico Geological Society Guidebook (1983) on the early results obtained from the USGS/NMT seismic network. The data set will contain the hypocenters from 10 months (June 1982-March 1983) of recording and will include foreshocks and some of the aftershocks of the M_L 4.1 earthquake that occurred within the network on March 2, 1983. Preliminary studies of that earthquake suggest a focal depth of 8 km and a fault plane solution consistent with normal movement along a NS striking fault. A tech graduate student has taken on the responsibility of analyzing the entire earthquake sequence as a part of a master's degree study.

2. Frequency response tests run with L-4 seismometers suggest erratic seismometer output when driving frequencies exceed about 22 Hz. This result impacts a NMT Ph. D. study that seeks to determine seismic Q from an analysis of local microearthquakes recorded with L-4 seismometers.

The three component High Gain Long-Period System that Gary Holcomb (ASL) and I installed at NMT a few years ago has been put back into operation. The data are radio telemetered from Woods Tunnel to the NMT campus and recorded on three rectilinear writing helicorders.

3. Our paper summarizing crustal structure in the San Juan Basin, New Mexico, was rewritten after technical review and submitted to TRU.

4. Arrangements have been made with the BLM office in Socorro to use their FTS circuit "after hours" and on weekends. This allows us to work on the VAX computer in Golden, so seismicity data from the Albuquerque basin seismic net are again being analyzed.

Reports

Jaksha, L. H., and Evans, D. H., Reconnaissance seismic refraction-reflection surveys in N.W. New Mexico: U.S. Geological Survey Professional Paper (submitted to Central Technical Reports).

Evans, D. H., and Jaksha, L. H., Seismic refraction studies in the San Juan Basin, northwest New Mexico: U.S. Geological Survey Open-File Report (submitted to Central Technical Reports).

Sanford, A. R., and Jaksha, L. H., Seismicity near Socorro, New Mexico (June 1982 through March 1983): New Mexico Geological Society Guidebook (in preparation).

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.

During this reporting period, the Branch of Global Seismology and Geomagnetism issued a contract to Nero and Associates of Portland, Oregon, to supply one technical person to operate the San Juan Observatory. After training at ASL and Fredericksburg Geomagnetic Center, the technician began work at SJG on January 8, 1983.

Albuquerque Observatory

9920-01260

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Investigations

Recorded seismological data at Albuquerque Observatory, Albuquerque, New Mexico, on a continuing basis.

Results

Continued to send seismograms to the National Earthquake Information Service for use in ongoing USGS programs. Responded to requests from the public, interested scientists, state and federal agencies regarding geophysical data and phenomena.

Global Seismograph Network Evaluation and Development

9920-02384

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Investigations

Several proposed modifications to the hardware and software used at the SRO, ASRO, and DWWSSN stations were studied to determine the effect of the changes on bandwidth and operating range and to estimate implementation cost. The purpose of the modifications is to enhance GDSN data characteristics and station operation. They include adding horizontal-component, short-period recording, removing the notch filter section in the SRO long-period filter, extending the SRO long-period high-pass filter to 1200 seconds, replacing the event detection algorithm with a new version developed by Murdock and Hutt, and several hardware changes designed to improve operational reliability.

Results

Noise models were developed for quiet and noisy GDSN sites and used to predict the effects of changes in response on the system operating range. The proposed modifications to the transfer functions were made on a test system to verify conclusions based on modeling. The results of the investigation, together with estimated costs for the modifications, are summarized in an unpublished report entitled "GDSN Enhancement Studies." Included in the report are sections concerning transients in the long-period data, preliminary evaluation of the Streckeisen broadband seismometers, and the new event detector. A jointly sponsored USGS/DARPA meeting of data user representatives was held in Albuquerque on January 20-21, 1983, to consider the proposed modifications, provide guidance, and suggest other changes that would enhance the digital network. One change suggested at the meeting is to reduce the frequency of SRO calibration in order to improve the usefulness of the data for very-long-period studies; another is to split the network-day tape into two two tapes, one containing continuously recorded data and the other containing triggered data (when this becomes necessary because of data volume). The outcome of the investigation and the subsequent meeting is a prioritized listing of GDSN modifications that will be implemented in a schedule dictated by the availability of funds.

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 remains at one team leader and three technicians.

The final testing of the SRO event detector has been completed. The SRO Operation and Maintenance Manual has been revised and reprinted. New program tapes and manuals have been sent to the stations with an anticipated date of May 3, 1983, for all stations to put the revised software into operation. Special software testing has also been undertaken on the SRO system for recording three S.P. channels event detected and modified L.P. filters which remove the 6 sec notch for L.P. digital data and leave the notch in for the analog data.

The following station maintenance activity was accomplished:

Note: Due to budgetary limitations, no station maintenance activity was done in the quarter of October 1-December 31, 1982.

ANMO - Albuquerque - SRO (no maintenance).

ANTO - Ankara, Turkey - SRO (no maintenance visit).

BCAO - Bangui, Central African Republic - SRO (no maintenance visit).

BOCO - Bogota, Colombia - SRO (no maintenance visit).

CHTO - Chiang Mai, Thailand - SRO (one maintenance visit including installation of the new power system).

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 (one maintenance visit).

MAIO - Mashhad, Iran - SRO (out of operation).

NWAO - Mundaring, W. Australia - SRO (no maintenance visit).

SHIO - Shillong, India - SRO (no maintenance visit).

SNZO - Wellington, New Zealand - SRO (no maintenance visit).

TATO - Taipei, Taiwan - SRO (no maintenance visit).

ZOBO - La Paz, Bolivia - ASRO (no maintenance visit).

DWWSSN

COL - College, Alaska (one maintenance visit plus the digital calibration system was installed and put into operation).

GDH - Godhavn, Greenland (one maintenance visit).

One DWWSSN installation was completed during this period: HON - Honolulu, Hawaii.

ASL Repair Facility

The DWWSSN system for Honolulu, Hawaii, was tested, packed, and shipped. In addition, maximum effort was utilized in routine repair and testing of replaceable modules for SRO/DWWSSN systems.

Special Activity

A visit was made to Ahmadu Bello University in Zaria, Nigeria, in March to determine the feasibility of installing the proposed WWSSN/DWWSSN system at the university.

A 1-week training course on the operation and calibration of the WWSSN system was conducted by a contract technician in La Paz, Bolivia, at the request of CERESIS.

A 3-day training course was given on the operation and maintenance of the WWSSN system for the new operator of the WWSSN station in San Juan, Puerto Rico.

Results

Installation of the DWWSSN systems has expanded the digital network to a combined total of 30 SRO/ASRO/DWWSSN stations. This expansion has resulted in a much broader digital data base through the improved geographic coverage of the digital systems.

Seismic Review and Data Services

9920-01204

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Investigations and Results

Technical review and quality control were carried out on 527 station-months of seismograms generated by the Worldwide Standardized Seismograph Network (WWSSN). Ninety-nine station-months of the ASRO and SRO network analog seismograms were provided on a current basis to the National Earthquake Information Service (NEIS) for their PDE programs. These, as well as, the WWSSN recordings are forwarded to the microfilming service: weekly schedule for the WWSSN; and as released by the NEIS for the SRO and ASRO recordings.

Thirty-nine station-months of original microfiche seismogram copies were furnished to a special studies program monitored through this project.

Fifty-two WWSSN station performance reports were sent during this period. The overall standards in the WWSSN station operations remained at high levels. Reduction in the total number of recordings received is beginning to become evident. This drop is due to a shortage in photographic paper supplied to the stations necessitated by funding cutbacks and high paper costs. Stations run the vertical components only during short supply.

Consultations regarding station data and operations were provided to researchers and government officials as needed. Some attention is being directed toward microfiche short period seismogram copy to possibly improve their resolution.

Jerusalem (JER) has started sending in its backlogged seismograms. It is now directed by the Institute for Petroleum and Geophysics at Holon, Israel. The dispatch of the Addis Ababa (AAE) records through the State Department has been halted due to excessivly high shipping fees (air) and the lack of funds to cover these. Bulawayo (BUL) has been running its short periods on reversed polarity since July 29. Kipapa (KIP) was transferred to Honolulu (HON) and has been converted to digital (DWWSSN).

National Earthquake Information Service

9920-01194

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Investigations and Results

The weekly publication, Prelminary Determination of Epicenters (PDE), continues to be published on a weekly basis averaging about 60 earthquakes. The PDE, Monthly Listings, and Earthquake Data Reports (EDR) are all on the VAX and are continuing to work very well, with very little down time encountered. We continue to publish all earthquakes which have data available within 30 days of the earthquake on the PDE. We have had some improvements on rapid data flow from our foreign contributors.

These problems are still being worked on and some improvement is taking place. The personal contacts with many of our foreign visitors explaining the need for faster reporting of data have been helpful. We continue to receive telegraphic data from the U.S.S.R. on most 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 are being received in a very timely manner and in time for the PDE publication. The selectric typewriter on loan to the State Seismological Bureau (SSB) arrived in China late November 1982. Since that time we have been receiving 4 stations on a weekly basis. For the Monthly, we receive about 22 stations from SSB by mail.

The Monthly Listings of earthquakes are up to date. To date the Monthly Listings and Earthquake Data Report (EDR) have been completed through October 1982. Fault Plane Solutions continue to be determined when possible for any earthquake having a magnitude ≥6.5 and published in the Monthly Listing and EDR. Centroid Moment Tensor Solutions from Harvard University continue to be published in the Monthly Listing and EDR. Moment Tensor Solutions are being computed by the USGS at present. The first computations were published in the July 1982 Monthly Listing and EDR. Digital waveform plots are being published at present in the Monthly Listing, beginning in July. These plots provide an opportunity for graphically displaying focal parameters presented within the text of the Monthly Listing. Waveform plots will be published for selected events having MB magnitudes ≥5.8.

The Earthquake Early Alerting Service continues to provide services on recent earthquakes on a 24-hour basis in response to the ever increasing demands from scientists, news media, and the general public. Fifty releases were made from October 1, 1982, through March 31, 1983. The largest earthquake released during this time was a magnitude 7.8 in the New Ireland region on March 18, 1983.

Reports

Preliminary Determination of Epicenters (PDE) (25 weekly publications October 14, 1982, to March 30, 1983--Numbers 37-82 through 10-83). Compilers: W. Leroy Irby, Willis Jacobs, John Minsch, Waverly J. Person, Bruce Presgrave, William Schmieder.

Monthly Listing of Earthquakes and Earthquake Data Reports (EDR) (6 publications--June 1982 through November 1982). Compilers: W. Leroy Irby, Willis Jacobs, John Minsch, Russell Needham, Waverly Person, Bruce Presgrave, William Schmieder.

Seismological Notes, BSSA: Waverly J. Person
November-December 1981
January-February 1982
March-April 1982
May-June 1982

Earthquake Information Bulletin:
Vol. 14, no. 3, Earthquakes, Waverly J. Person, November-December 1981
Vol. 14, no. 4, Earthquakes, Waverly J. Person, January-February 1982
Vol. 14, no. 5, Earthquakes, Waverly J. Person, March-April 1982

United States Earthquakes

9920-01222

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Investigations

1. Seventy-nine earthquakes in 22 states were canvassed by a mail questionnaire for felt and damage data. Twenty-eight of these occurred in California. There were no particularly significant earthquakes during this reporting period, however, there were 8 events that caused minor damage; five in California and one each in New Mexico, New York, and South Dakota.

2. The United States earthquakes for the period October 1, 1982 to March 31, 1983, have been located and the hypocenters, magnitudes, and maximum intensities have been published in the Preliminary Determination of Epicenters.

3. The earthquake data files for Idaho, Utah, and Wyoming have been completed and Montana and Nevada are being compiled.

Results

The two events in South Dakota on November 15, 1982, and March 4, 1983, both of which caused slight damage (intensity VI), are significant because only 6 intensity VI earthquakes were reported within the state from 1872 to 1982.

United States earthquake data for July-December have been printed in a quarterly circular. The data for January-March 1982 are being printed.

Reports

Stover, C. W., Minsch, J. H., Dunbar, P. K., and Baldwin, F. W., 1982, Earthquakes in the United States, July-September 1981: U.S. Geological Survey Circular 871-C, 34 p.

Stover, C. W., Minsch, J. H., and Reagor, B. G., 1982, Earthquakes in the United States, October-December 1981: U.S. Geological Survey Circular 871-D, 27 p.

Stover, C. W., and von Hake, C. A., 1982, United States Earthquakes 1980: U.S. Department of the Interior, Geological Survey and U.S. Department of Commerce, National Oceanic and Atmospheric Administration, 182 p.

Digital Data Analysis

9920-01788

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Investigations

1. Moment Tensor Inversion. Apply methods for inverting body phase waveforms for the best point source description to research problems.

2. Computation of Free Oscillations. Develop practical methods for computing free oscillations of the Earth and combining them to construct synthetic seismograms.

3. Computation of Travel Times. Develop practical methods for computing body phase travel times directly from arbitrary, realistic Earth models.

4. Intermediate Period Band Studies. Use the LP channel of the DWWSSN instruments to study the frequency dependence of Q and mantle anisotropy.

5. Earthquake Location Technology. Study techniques for improving the robustness, honesty, and portability of earthquake location algorithms.

6. 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.

7. Special Event Reports. Contribute to NEIS publications pertaining to selected events.

8. NEIS Monthly Listing. Contribute both fault plane solutions (using first-motion direction) and moment tensors (using long-period body-phase waveforms) for all events of magnitude 5.8 or greater when sufficient data exist. Contribute waveform/focal sphere figures of selected events.

Results

1. Moment Tensor Inversion. The method has been fully tested by application to all events of magnitude 5.8 or greater from January 1, 1981, to the present. A highly automated version has been completed and is now in routine use. The technique is now being applied to understanding the role of extensional tectonics in the Mammoth Lake events.

2. Computation of Free Oscillations. The optimal spheroidal mode program has been modified to correctly compute Stoneley mode eigenfunctions. Also it has been extended to handle toroidal and radial modes. Work is proceeding on general testing, the I/O interface, and eigenfunction representation. Also work is commencing on extending the calculations to a visco-elastic media.

3. Computation of Travel Times. The tau table method is being specialized to phases of direct interest to the NEIS. Also the ellipticity correction is being redeveloped for the same phases, using a modern formulation which avoids approximations in current use.

4. Intermediate Period Band Studies. In preparation for this study, software has been developed for the analysis of seismic wave polarization.

5. Earthquake Location Technology. A linear method of finding a starting solution for the nonlinear iteration in local and regional problems has been developed. Also robust algorithms employing either linear programming or nonparametric techniques are being investigated.

6. Network-Day Tapes. Distribution of the third revision of the software and documentation is now imminent. The first version handled network-day tapes. The second version added capability for station tapes and old format network-day tapes. The third version handles network event tapes, corrects a few minor bugs and portability problems reported by end users, and handles the new RSTN data.

7. Special Event Reports. The mechanism of the Western Arabian Peninsula event of December 13, 1982, is being studied for a forthcoming special report.

8. NEIS Monthly Listing. Since May 1981, fault plane solutions for large events have been contributed to the Monthly Listing. Beginning in November 1982, moment tensors and waveform/focal sphere plots are also being contributed.

Reports

None.

Earth Structure and its Effects Upon Seismic Wave Propagation

9920-01736

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Investigations

1. Use of body wave pulse shapes to infer earth structure. Develop methods of generating synthetic waveforms that correctly incorporate the frequency dependent effects that arise from source directivity and from propagation through the earth. Apply these methods to infer the fine structure of velocity and attenuation at specific regions in the earth.

2. Source parameters from GDSN data. Extract source parameters from digitally recorded data of the GDSN by determining corrections to waveforms to distinguish source effects from propagation effects.

Results

The comparison of 8 digitally recorded PKP body waves from a deep earthquake with synthetic seismograms has permitted the resolution of the C and D cusps to better than $\pm 2^{\circ}$. Strong gradients in P-velocity, S-velocity and attenuation were inferred for the top 100-300 km of the inner core. An examination of the peak-amplitude method of inverting for core structure using long-period body-wave data shows that it systematically biases results toward structure with higher velocity contrast across the inner-outer core boundary. This bias is caused by incorrect assumptions about the simplicity of the source function of earthquakes.

2. After correcting broadband waveforms for propagation effects, we obtained strong constraints on the static and dynamic properties of the New Brunswick earthquake of January 9, 1982. We also have developed programs to model the large (MS 7.8) Samoa earthquake of September 1, 1981. This was a very complex rupture consisting of at least 6 subevents. Because of the large size of this earthquake, many conventional instruments at P-wave distances were saturated. Two stations at distances for diffracted P and PKP were able to provide crucial azimuthal control on the rupture process after consideration of propagation effects.

Reports

Choy, G. L., and Cormier, V. F., 1983, The structure of the inner core inferred from short-period and broad-band GDSN data: Journal of the Royal Astronomical Society, v. 72, p. 1-21.

Choy, G. L., Boatwright, J., Dewey, J. W., and Sipkin, S. A., 1983, A teleseismic analysis of the New Brunswick earthquake of January 9, 1982: Journal of Geophysical Research, v. 88, p. 2199-2212.

Systems Engineering

9920-01262

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Investigation

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 technical requirements for the Uphole Digital System and the Remote Recording System, which are part of the Global Telemetered Seismograph Network, were completed. The Uphole Digital System will interface with the satellite Remote Earth Terminal, Remote Recording System, and the Downhole-Seismometer System. All commands from the Data-Receiving terminal and data transmitted to the Data-Receiving terminal, via the satellite network, will be processed by the Uphole Digital System. The Uphole Digital System will also control the Downhole Seismometer System as well as transmit data and commands to the Remote Recording System. The Global Telemetered Seismograph Network will be developed under contract.

2. The Digital Recording System and the Depot Repair Instrumentation Plans for the China Digital Seismograph Network (CNSN) have been completed. This large program will be developed during the next 12 to 24 months. The China Digital Recording System will be based on the DWWSSN Digital Recording System with additional tasks and features required by the China Digital Seismograph Network. Initially, two prototype Digital Recording Systems will be built at the Albuquerque Seismological Laboratory. After final testing and evaluation of the two prototype systems, additional systems will be constructed under contract.

3. The DWWSSN Laboratory Microprocessor Simulation System (LMSS) was completed. Initial programs for the China Digital Seismograph Network such as the "Murdock Event Detector" program will be evaluated using the LMSS.

4. The 2400/9600 Baud Digital Telemetry System (DTS) design and assembly have been completed. Two Digital Telemetry Systems were assembled. Final software and firmware for the DTS control programs are being developed and tested. Assembly for the third DRS has started.

Reports

Clark, H. E., 1983, Digital recording system for telemetered DWWSSN stations: U.S. Geological Survey Open-File Report, 146 p.

Seismicity and Tectonics

9920-01206

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Investigations

Studies carried out under the project focus on detailed investigations of large earthquakes, aftershock series, tectonic problems, and earth structure. Studies in progress have the following objectives:

1. Interpret seismicity associated with the great Colombia-Ecuador earthquakes of 1942, 1958, and 1979 (C. Mendoza and J. W. Dewey).

2. Provide tectonic setting for and analysis of the 1974 Peru gap-filling earthquake series (W. Spence and C. J. Langer).

3. Determine the maximum depth and degree of velocity anomaly beneath the Rio Grande Rift and Jemez Lineament by use of a 3-D, seismic-ray tracing methodology (W. Spence, R. S. Gross, and L. H. Jaksha).

4. Provide tectonic setting for and analysis of the 1977 Sumba earthquake series (W. Spence).

Results

1. The method of Joint Hypocenter Determination (JHD) has been used to relocate shallow earthquakes along the Colombia-Ecuador subduction zone. The seismicity suggests that "fracture energy" barriers, distributed along that portion of the Nazca-South American plate interface that had previously broken in 1906, were responsible for arresting rupture propagation in 1942 and 1958. The barrier that arrested failure in 1958 is relatively small and corresponds to the point of initial interplate rupture of the 1979 earthquake. The 1942 barrier is not as well defined, but may be related to the interaction of the now-extinct Malpelo rift-Yaquina graben spreading system with the zone of shallow subduction. The difference in size of the aftershocks that followed each of the 1942, 1958, and 1979 earthquakes implies that a complete episode of strain release along the Colombia-Ecuador portion of the plate boundary must involve failure of the entire segment that ruptured in 1906.

2. The space-time history of the aftershock series of the great 1974 Peru main shock shows two primary features: a) Two highly active aftershock clusters that show abrupt beginnings and endings, and b) Abrupt alternation of aftershock activity between two major segments that comprise nearly the entire aftershock zone. These abrupt, systematic changes in the space-time character of the 1974 aftershock sequence imply that the aftershock clusters and segments interact

elastically. It is concluded that the process of stress release throughout the entire aftershock zone is an elastically coupled process, which continues until no significant aftershock subzone is stressed to its local fracture energy density.

3. To a depth of about 160 km, the upper mantle P-wave velocity beneath the Rio Grande rift and Jemez lineament is 4-6 percent lower than the corresponding upper mantle velocity beneath the High Plains Province. The 3-D, P-wave velocity inversion shows scant evidence for pronounced low P-wave velocity beneath the 240-km-long section of the Rio Grande rift covered by our array. However, the inversion shows a primary trend of 1-2 percent lower P-wave velocity underlying the northeast-trending Jemez lineament, down to a depth of about 160 km. The Jemez lineament is defined by extensive Pliocene-Pleistocene volcanics and late Quaternary faults. The upper mantle low-velocity segment beneath the Jemez lineament is at most 100 km wide and at least 150-200 km long, extending in our inversion from Mt. Taylor through the Jemez volcanic center and through the Rio Grande rift. A Backus-Gilbert resolution calculation indicates that these results are well-resolved.

4. The great Sumba Island earthquake of August 19, 1977, is the largest earthquake (M_S = 8.3, M_o 4 x 10^{28} dyne-cm; Given and Kanamori, 1980) to occur globally since the great Rat Island, Aleutian earthquake of 1965. The normal-faulting main shock was neither preceded nor followed by thrust-faulting earthquakes in the Sunda subduction zone. Because the buoyant Australian continental lithosphere is at the mouth of the Sunda Trench (minimizing any 'push' forces into the subduction zone), the best hypothesis for the origins of stresses producing the main shock is related to the gravitational instability of already subducted oceanic lithosphere. The method of joint hypocenter determination is being used to relocate the extensive aftershock series to this earthquake.

Reports

Langer, C. J., and Spence, W., Deformation of the Nazca plate related to the gap-filling earthquake series of October-November, 1974. Approved for publication by the Director, U.S. Geological Survey.

Mendoza, C., and Dewey, J. W., Seismicity associated with the great Colombia-Ecuador earthquakes of 1942, 1958, and 1979: Implications for barrier models of earthquake rupture. Submitted to outside journal. Approved for publication by the Director, U.S. Geological Survey, on March 28, 1983.

Needham, R. E., Buland, R. P., Choy, G. L., Dewey, J. W., Engdahl, E. R., Sipkin, S. A., Spence, W., and Zirbes, M. D., 1982, Special earthquake report for the September 1, 1981, Samoa Islands region earthquake: U.S. Geological Survey Open-File Report 82-781, 71 p.

Spence, W., and Langer, C. J., The seismic-gap-filling, 1974 Peru earthquake series represents an ordered process of stress release. Approved for publication by the Director, U.S. Geological Survey.

DEVELOPMENT OF IMPROVED HYDROFRACTURING INSTRUMENTATION AND ITS APPLICATION AT A SITE OF INDUCED SEISMICITY

Contract No. 14-08-0001-20537

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The objective of this project was to improve the existing technique of field hydrofracturing so as to render it substantially cheaper and faster than the present norm, and then use it at one or more sites of induced seismicity. It is primarily the high costs that have kept hydrofracturing stress measurements from being conducted at many sites of induced seismicity.

The major improvement in the field technique was its conversion from a drillrod to a wireline method using separate hydraulic lines for the packer and for the hydrofracturing interval. The new tool is not unlike a geophysical logging instrument and employs a 7-conductor wireline and an appropriate hoist. The lowering and lifting time of the equipment is thus drastically cut as are expenses, since a tripod over the testhole head is sufficient for "tripping" the tool and the need for a drill rig and crew have been eliminated.

During the past year the design and fabrication of the major components of the wireline hydrofracturing equipment were completed. These included a hoist and instrument truck, tripod, wireline impression-orienting tool, and straddle packer pressure transducer housing assembly. Safety devices were incorporated which should compensate in part for the major disadvantage of the wireline, i.e., its inability to push or twist the downhole probe.

In the coming year the equipment which was initially designed for 76 mm holes, will be converted to fit larger size holes such as 140-170 mm diameters, and will be tested in one of the existing drillholes near the Monticello Reservoir, a suspected site of induced seismicity.

INDUCED SEISMICITY - SLEEPY HOLLOW OIL FIELD

14-08-0001-20544

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BACKGROUND.

To investigate the possibility of induced seismicity in the Sleepy Hollow Oil Field in southwestern Nebraska, the U.S. Geological Survey is currently funding operation of an eight-station seismic network. This study began in April, 1982 and is scheduled to end December 12, 1983. Numerous equipment failures have occurred since the installation of the network. Most of the problems have been due to power failures at the radio repeater site. USGS engineers, who have been maintaining the network, have apparently remedied the problem which was due to defective solar panels.

RECORDED SEISMICITY.

During the first eight and one-half months (April 1 to December 12, 1982) of the operation of the Sleepy Hollow Seismic Network thirty-one earthquakes of magnitude -0.6 to 1.7 were detected. Of these, 15 were recorded well enough to locate. Details of the seismicity are given in the accompanying figure. The epicenters are preliminary, as we are in the process of determining station delays and refining the velocity model.

None of the earthquakes located by the Sleepy Hollow Network are deeper than 5 kilometers. At this time it is not clear if any of the earthquakes previously located in this area (Rothe et al., in review) were deeper than 5 kilometers.

Most of the located earthquakes occurred within, or just west of the lease limits of the Sleepy Hollow Oil Field. There does appear to be a linear northeast-southwest trend of seismicity through the oil field.

EXPLOSION REFRACTION STUDY.

On November 26, 1982 we conducted a refraction experiment to test our velocity model, determine station adjustments, and determine station polarities. Data from this exeriment suggest that the velocity model used heretofore should be slightly revised. Further adjustments to the velocity model will be made using a group hypocenter program.

FOCAL MECHANISMS.

Focal mechanisms for the Sleepy Hollow earthquakes remain one of the most important, yet elusive aspects of this study. The station polarities are all fouled up, preventing the determination of accurate focal mechanisms.

Further experiments are necessary on a station-by-station basis to determine station polarities. This will be a high priority of the study in the coming months.

Although the actual focal mechanisms are unknown, the data thus far suggest that the earthquakes in the oil field are of two different mechanisms. Until station polarities are known little more information can be gleaned from the earthquake first motions.

FLUID INJECTION.

Detailed injection records for the Sleepy Hollow sandstone for the months of March to November were recently obtained from Amoco. Injection is accomplished using four groups of wells, each fed by a separate battery of supply tanks. The temporal correlation between injection parameters must be examined with some caution since the network was "down" or not operating at full efficiency for several extended periods of time.

DIRECTION OF CONTINUED EFFORT.

Work which should be completed by the time current funding expires in December, 1983 includes refinement of the velocity model, station delays, and hypocenters, the determination of station polarities, the acquisition of more of the details of the injection, and possibly the modeling of the flow of fluids in the Sleepy Hollow sandstone.

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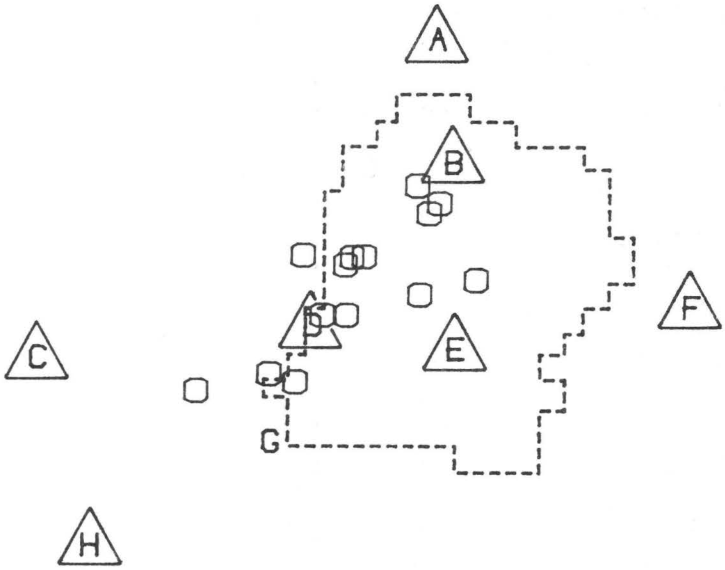

Figure 1. Epicenters of earthquakes with satisfactory locations - April 1, through Dec. 12, 1982. Letters designate seismic stations and circles epicenters. Line trending N40°E is "eyeball" fit to selected epicenters.

TABLE 1. EARTHQUAKES DETECTED BY THE SLEEPY HOLLOW SEISMIC NETWORK — APRIL 1, 1982 TO DECEMBER 12, 1982

NO	YRMODY	HRMN	N.LAT (DEG)	W.LONG (DEG)	DEPTH (KM)	MAG	RMS (SEC)	ERH (KM)	ERZ (KM)	REMARKS
1	820401	2234	40.1575	100.3860	2.6	1.7	0.08	0.5	0.8	P+S,H71
2	820403	1145				0.1				3 STNS
3	820403	1931	40.1828	100.3533	2.0	1.3	0.07	0.3	0.7	P+S,H71
4	820405	0144	40.1808*	100.3173*	3.5	0.4	0.20	1.8	4.7	H71
5	820408	1500	40.1700	100.3552	3.2	0.4	0.05	0.6	1.7	P-ONLY;H71
6	820411	2105	40.1562	100.3807	3.8	0.4	0.06	0.3	0.4	P+S;H71
7	820413	1151	40.1668*	100.3752*	2.5	0.1	0.18	1.3	1.1	H71
8	820413	1314	40.1700*	100.3890*	2.0	-.2	0.00			H71
9	820414	0211	40.1668	100.3752	2.5	-.2	0.10	0.5	0.6	P+S;H71
10	820415	1104	40.1872	100.3557	2.2	0.3	0.04	0.4	0.7	H71;P-ONLY
11	820421	1349	40.1308*	100.4208*	4.0	-.2	0.18			H71;3STNS
12	820421	1845	40.1548	100.4008	0.5	0.1	0.06	0.3	0.3	H71;P-ONLY
13	820421	1846	40.1502*	100.4112*	5.0	0.1	0.32			H71;???
14	820422	0425	40.1725*	100.3498*	1.2	-.1	0.11	0.4	8.8	H71;???
15	820422	1147	40.1792*	100.3852*	1.8	0.2	0.10	1.4	1.6	H71;4STNS
16	820507	1058				-.2				2STNS
17	820509	1026	40.1668	100.3702	3.2	0.7	0.13	0.7	1.2	H71;P+S
18	820517	0648				-.2				2STNS
19	820526	2021				0.5				3STNS
20	820527	1227				0.1				3STNS
21	820605	1251				-.5				2STNS
22	820616	0532				-.6				2STNS
23	820616	1907				-.5				2STNS
24	820806	0655				-.4				3STNS
25	820915	0943	40.1759	100.3691	1.8	0.2	0.10	0.4	0.2	APH
26	820915	1220	40.1747	100.3705	2.5	-.1	0.08	0.1	0.2	APH
27	820915	1402				-.3				2STNS
28	820915	1452	40.1760	100.3666	3.8	0.7	0.11	0.1	0.5	APH
29	820927	0651	40.1723	100.3437	2.2	0.5	0.10		0.3	APH
30	821016	1119	40.1844	100.3512	2.0	-.5	0.05	0.2	1.6	APH
31	821105	1344	40.1762	100.3791	2.2	0.3	0.10	0.3	0.7	APH

* UNSATISFACTORY SOLUTION; EVENT NOT PLOTTED
H71: EVENT LOCATED WITH HYPO71
APH: EVENT LOCATED WITH APHYD

IS

Continuation of Geological Studies in an Area of Induced Seismicity At Monticello Reservoir, South Carolina

14-08-0001-19833

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INVESTIGATIONS AND RESULTS

This study provides geological background information necessary for an evaluation of the earthquake hazzard in an area of induced seismic activity at Monticello Reservoir, South Carolina. This region contains an 8 km thick sequence of Proterozoic Z (?) and Cambrian metavolcanic and metasedimentary rocks that are interpreted to have accumulated in association with a volcanic arc. In the early to middle Paleozoic, this sequence was recrystallized and penetratively deformed under conditions that ranged from greenschist to amphibolite facies, and experienced at least two episodes of folding. The region has been intruded by late kinematic to post kinematic granitoid plutons of Silurian and Carboniferous ages and by numerous northwest trending diabase dikes of Late Triassic and Early Jurassic age.

Initially, detailed field work was conducted in the region around Monticello reservoir. The induced seismic activity is occurring in a heterogeneous quartz monzonite pluton of Carboniferous age. Although laterally extensive faults have not been found in the region of seismic activity, the pluton does contain large enclaves of country rock and is cut by numerous diversely oriented small faults and joints. These local inhomogeneities, together with an irregular stress field are interpreted to control the diffuse seismic activity around the reservoir.

Recent detailed field investigations have focused on the Wateree Creek fault zone which occurs in the Carolina slate belt several kilometers south of the Virgil C. Summer nuclear station. The Wateree Creek fault zone was originally recognized as a north trending high angle reverse fault zone which cut stratigraphic units and fold axes in the central part of the Chapin quadrangle and which appeared to abruptly terminate in the northern part of the Chapin quadrangle. However, recent work indicates that in the northern part of the Chapin quadrangle the Wateree Creek fault zone abruptly changes strike to N45^{o}E and continues on to the northeast at least as far as the Winnsboro plutonic complex in the Rion quandrangle. The Wateree Creek fault zone is characterized by brittle deformation and it offsets both earlier F_1 and F_2 fold axes and an east trending silicified fault zone. The ^{40}/Ar/^{39}Ar whole rock plateau age for phyllite outside the Wateree Creek fault zone is 331 $\pm$ 6 m.y., whereas within the Wateree Creek fault zone, the ^{40}Ar/^{39}Ar release spectra are moderately disturbed, suggesting that the latest episodes of movement are more recent that 331 m.y. Significant movement has probably ceased by mid-Mesozoic time because the Wateree Creek fault zone is cut by a diabase dike of probable Late Triassic or Early Jurassic age.

In view of the apparent antiquity of the Wateree Creek fault zone and the apparent absence of lengthly faults in the region of active seismicity, 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.

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Induced Seismicity at Nurek, Toktogul and Aswan Reservoirs: Seismicity, Geology and Tectonics

USGS-14-08-0001-21278

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Investigations

1. Seismological and geological studies of induced seismicity at Nurek and Toktogul Reservoirs, Soviet Central Asia.
2. Seismotectonics and geology of Central Asia.
3. Induced seismicity studies at Aswan Reservoir, Egypt.

Results

1. An enhanced, false-color Landsat image for the area around Nurek Reservoir is being used by W. Leith in his geological studies of the northeastern part of the Tadjik Depression. The image provides a 1:250,000 base map on which geological data from Soviet publications and our own field work are being compiled, using the improved resolution of the enhanced image to extend the coverage into unmapped areas. This work complements the seismicity studies at Nurek and a study of the stratigraphy and subsidence of the Tadjik Depression (Leith, 1983).
2. Soviet catalogs of earthquakes for Central Asia show much more resolution of tectonic features and provide more complete coverage for $M<4$ than the ISC or PDE catalogs. Major faults, that have produced earthquakes of $M>7$ this century, show relatively low levels of microearthquake activity, while regions such as the Tadjik Depression have high levels of microearthquakes, but rarely have events $M>5$ 1/2.
3. On November 14, 1981 a magnitude 5 1/2 earthquake occurred at Aswan Reservoir, shortly after the seasonal maximum in water level. The seasonal peak in November 1982 remained 5 m below the peak level in 1981, and no events of $M>4$ occurred in November-December 1982. The largest events July 1982-April 1983 were of magnitude 4 in August 1982 (shortly after the seasonal minimum in water level) and in March 1983.

Reports 1982-1983

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Deep Hole Desalinization of the Dolores River

9920-03464

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Investigations

This desalinization project will pump approximately 30,000 barrels/day from brine-saturated rocks beneath the Dolores River through a borehole to the Madison-Leadville limestone formation of Mississippian age, some 15,000 feet below the surface. There is a possibility of seismicity being induced, especially in the long term, by this desalinization procedure. The project objectives are to establish a pre-pumping seismicity baseline and, during the pumping phase, to closely monitor the discharge zone for possible induced seismicity. If induced seismicity does occur it should be possible to relate it to formation characteristics and to the pumping pressure and discharge rates. This project is being performed under joint sponsorship of the U.S. Bureau of Reclamation and the USGS Induced Seismicity program.

Results

Currently in progress is the installation of a ten-station seismograph network, centered on location of proposed pumping station and well. Seismic data are to be brought to Golden, Colorado, via microwave and phone line. These data will be fed through an A/D converter and through an event detector. Earthquakes so detected will be located and further analyzed on an individual basis.

IN-SITU STRESS DETERMINATIONS BY HYDRAULIC FRACTURING: A LABORATORY RE-EVALUATION

Contract # 14-08-0001-197771

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A knowledge of the in situ state of stress and of changes in these stresses is of major importance in understanding earthquake mechanisms and in predicting future seismic events. Of the two main methods currently used to determine in situ stresses (i.e., stress relief and hydraulic fracturing), hydraulic fracturing is presently the only method which is feasible for determining stresses at depths greater than 200 meters.

Most investigators assume that straddle packers (a downhole tool used to isolate a section of a wellbore for testing) have no influence on the stresses determined by hydraulic fracturing. However, recent research has shown that straddle packers may have, under certain conditions, a significant influence on the magnitude of the stresses as determined by hydraulic fracturing. There is a substantial degree of disagreement, nevertheless, among investigators as to the extent of this effect and the conditions under which it may be significant.

A laboratory investigation of in situ stress measurements by hydraulic fracturing was conducted with an emphasis on the effects of the inflatable packers. A straddle packer assembly using two standard production injection packers was inflated in a series of three pipe sizes. Packer pressure was monitored as pressure was applied to the interval.

Typical test results are depicted in Figure 1. These tests, in general, show that pressures in liquid-filled straddle packers rise when pressure is applied to the fracture interval. The pressure rise generally is sufficient to maintain a positive pressure differential. This differential pressure depends somewhat on the clearance between the packer and the pipe's inside diameter; a greater clearance results in a higher differential pressure.

A series of laboratory hydraulic fracturing tests were conducted on cubes of cement and hydrostone. These cubes were placed in appropriate test chambers and loaded in triaxial compression to simulate typical in situ conditions (Figure 2). They were then hydraulically fractured using various packer configurations and fluid types.

A typical pressure-time record is seen in Figure 3. These records were analyzed and values of breakdown pressure, re-opening pressure, and instantaneous shut-in pressure (ISIP) were determined. The inflection point method was used for determining the ISIP.

Results of these tests were difficult to evaluate with regard to the effect of the packer inflation pressure. Values of the ISIP range from 30% below to more than 30% above the known value of σ_{Hmin}. Values of σ_{Hmax} calculated from the values of reopening pressure demonstrate even greater variance from the known values.

The source of these large differences between applied and measured stress is not clear. Consistently high or low values of ISIP and σ_{Hmax} might be explained more readily. Possible sources of error include 1) size effects resulting from fracture length relative to block size and hole diameter, 2) specimen inhomogeneity, 3) fluid viscosity and, 4) lack of uniformity in applied stress field.

Several packer failures occurred during this investigation which required that better sealing element materials be identified. Three of the sealing materials identified were tested on a packer inflated in a one-inch diameter pipe. The packer that was made using a proprietary elastomer compound provided superior performance and was used on all remaining tests.

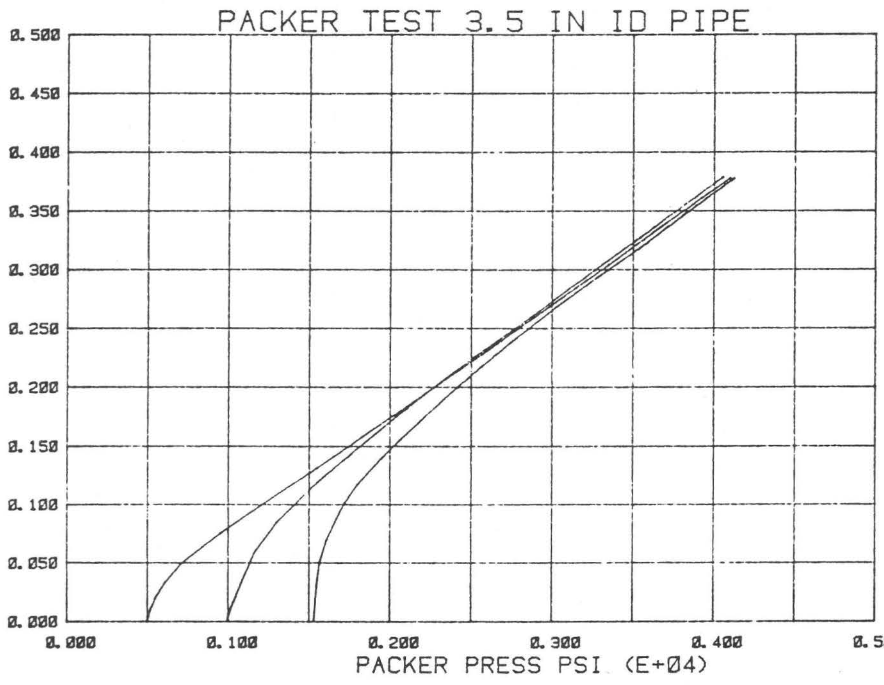

Figure 1 - Interval Pressure Versus Packer Pressure in 3.5 Inch Pipe with Initial Inflation Pressure as a Parameter.

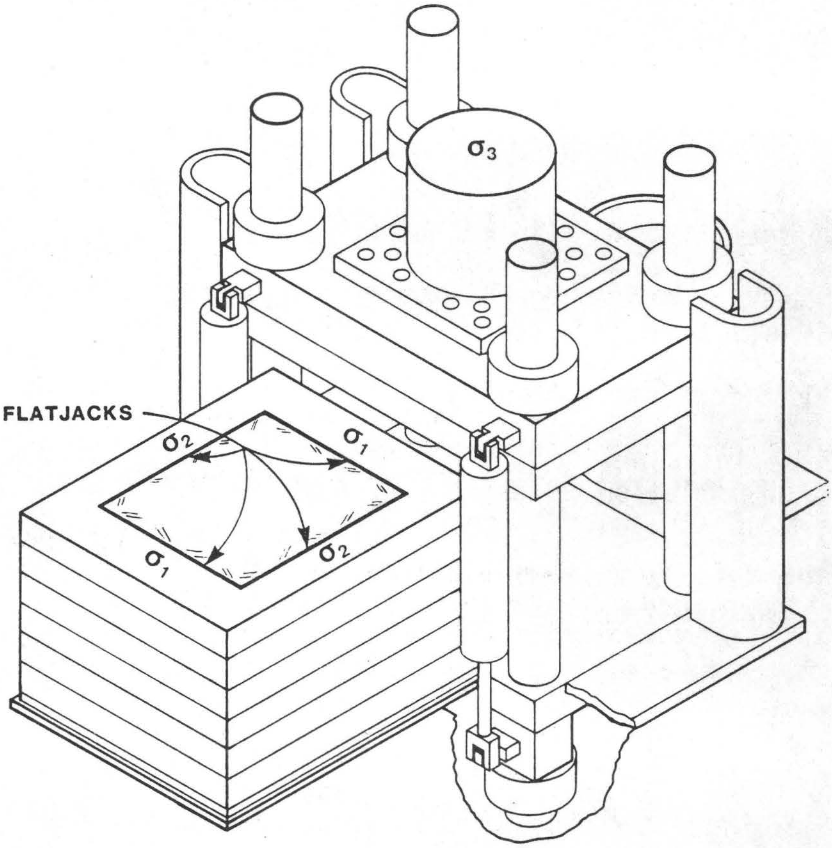

Figure 2 - One Cubic Meter Polyaxial Test Facility

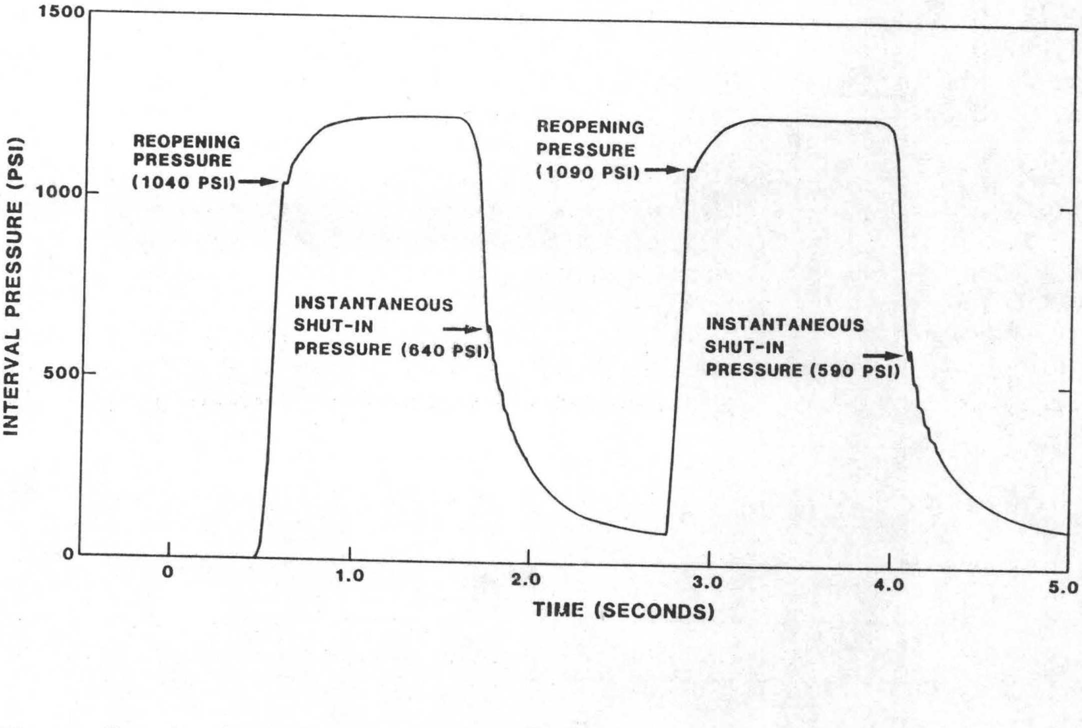

Figure 3 - Typical Pressure-Time Record for Hydraulic Fracturing in 1.5 Cubic Foot Block of Cast Hydrostone

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