82-65

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DEPARTMENT OF THE INTERIOR
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SUMMARIES OF TECHNICAL REPORTS, VOLUME XIII

Prepared by Participants in

NATIONAL EARTHQUAKE HAZARDS REDUCTION PROGRAM

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The research results described in the following summaries were submitted by the investigators on November 30, 1981 and cover the 6-month period from April 1, 1981 through October 31, 1981. These reports include both work performed under contracts administered by the Geological Survey and work by members of the Geological Survey. The report summaries are grouped into the four major elements of the National Earthquake Hazards Reduction Program:

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Earthquake Hazards Reduction Program

Seismicity and Related Data for Hazard Analyses

9950-02145

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No report received

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. D. Gordon has completed relocation of 240 instrumentally recorded earthquakes that occurred in the central U.S. (between 85° W. and 104° W.) in the period 1930-1980 and that had magnitudes (m_{blg}) of 3.0 or greater. The completeness of this catalog of instrumentally recorded earthquakes may be estimated by comparing it with catalogs of felt earthquakes, most of which would have had magnitudes greater than 3.0. For 1930-1960, only about 5 percent of felt earthquakes listed by Nuttli (1979, Geological Society of America, Reviews in Engineering Geology, volume IV, p. 67-93) could be located with instrumental data. For 1960-1969, we were able to instrumentally locate about 50 percent of the felt earthquakes reported by Nuttli, and we relocated over 75 percent of the shocks in Nuttli's list for 1970-1975. For 1976-1980, nearly 95 percent of felt earthquakes reported to the National Earthquake Information Service of the USGS could be located with instrumental data. For the entire period 1930-1980, the largest earthquakes that could not be instrumentally located occurred in the 1930's and had $m_{blg} \cong 4.7$, as estimated from the total felt areas reported in Nuttli's catalog.

2. Seventy-five percent of Gordon's reliably determined focal depths are shallower than 10 km. The percentage of shocks computed to be shallower than 10 km is nearly identical to that computed for the United States and adjacent Canada east of 85° W. (see report for this project in USGS Open-File Report 81-167, Summary of Technical Reports, National Earthquake Hazards Reduction Program, volume IX, p. 9-10). The focal depths computed for Central U.S. earthquakes are additional support for the hypothesis of Sbar and Sykes (1977, Journal of Geophysical Research, p. 5771-5786) that small and moderate shocks having depths greater than 10 km are atypical in eastern North America and may indicate the presence of deep-seated fractures capable of causing large earthquakes.

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

14-08-0001-19744

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Investigations

A program to establish a strong-motion recording capability in two seismic gaps has been implemented. A total of 12 stations in the Shumagin seismic gap, and one on Unalaska Island, eastern Aleutian arc of Alaska, are now operative since August 1981. In the seismic gap in the northeastern Caribbean a total of 5 SMA sites are operated since early 1981. In the Shumagin gap 10 strong motion instruments are now interfaced with the network to transmit exact SMA-trigger times to the central recording site. Furthermore, time-code generators were installed at a total of 12 sites that print internal time on any future records.

Results

A magnitude 5.3 event on August 23, 1980 provided a test for the then partly installed Shumagin Island strong motion network. Central monitoring of SMA operation indicated 4 triggered instruments from this event. A total of six records were retrieved from the remote stations during the summer field season of 1981.

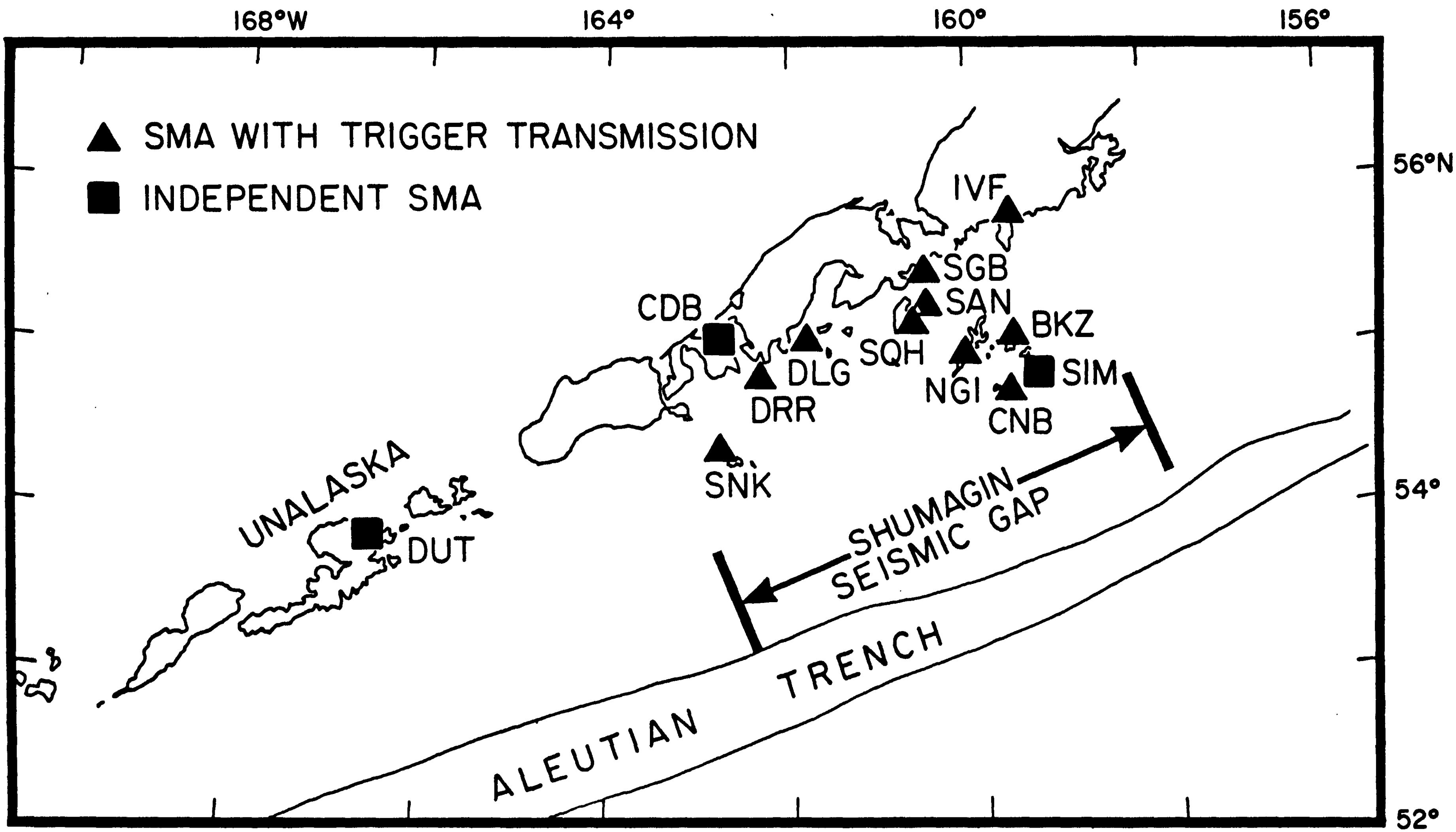

Figure 1. Distribution of strong motion stations near the Shumagin seismic gap, Alaska, as of August 1981. Stations indicated by triangles transmit trigger moment through telemetry of Shumagin seismic network to central recording site at Sand Point (SAN). Squares indicate strong motion sites unrelated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

National Earthquake Catalog

9920-02648

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Investigations

1. Coordinate the preparation of a national earthquake catalog.

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

3. Confirm locations and origin times and estimate magnitudes of poorly described western United States earthquakes that occurred between 1920 and 1960.

Results

1. The design and development of software for the project data base has advanced to the point where preparation of standardized files can begin during the next reporting period. W. H. K. Lee and J. N. Taggart discussed events list data bases at meetings in Golden, Colorado, in August, 1981. Lee uses the universal data base format available on the SLAC Computer at Stanford. Taggart designed a specific data base which can be used on VAX computers. Minor adjustments in parametric dimensions were made that will permit transfer of data between the data bases. The VAX data base, developed by Glen Reagor, contains a main character-string file of parameters, error estimates and references keyed chronologically to the combined date-origin time. The preferred data set for individual earthquakes is indicated by a flag. An editing program, developed to overcome many data entry errors, automatically replaces or deletes designated parametric substrings. More limited files, also keyed to date-origin time, contain comments, statistical data, focal mechanisms, source parameters and pointers to associated phase and waveform data.

Carl Stover and his coworkers (Project 9920-01222) continue to make excellent progress in the preparation of state seismicity maps. They have now published or have in review maps for all states east of the Rocky Mountains and are checking event lists for the tier of states from Montana to New Mexico. The event listings from the state seismicity maps, augmented by many additional parameters, will be the preferred data set for a majority of the earthquakes in the data base.

2. The collection, verification and correction of event lists for the catalog continues to be given the highest priority because the data base and research on estimation of errors depend upon these listings. Carol Thomasson and Frank Baldwin checked an additional 19,000 listings against original references during this reporting period, bringing the total number of verified earthquake listings to 41,000, exclusive of California. Taggart checked intensity references for about 3000 earthquake listings in the Rocky Mountains region. Karen Meagher assembled phase data for 200 California earthquakes with ML $\geq$ 5 that will be relocated by W. H. K. Lee.

3. Lee has made preliminary HYPO79 relocations of 200 California earthquakes with ML $\geq$ 5. These preliminary results should provide information on data quality and aid the development of schemes for weighting phase arrrival times and distribution of stations.

Taggart and Baldwin have identified nearly 400 earthquakes in a 1938 - 1939 sequence that occurred in southwestern New Mexico. Phase arrival times and amplitudes at the Tucson Observatory (TUO) were used to improve epicenter locations and origin times, and estimate magnitudes for more than 100 of the earthquakes. The TUO seismograms also were useful for separating spurious events from previous listings of the sequence.

Preparation of Isoseismal Maps and Summaries of Reported Effects for Pre-1900 California Earthquakes
Contract No. 14-08-001-19200

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This is the third annual report of a three year project to clarify the earthquake history of California for the period before 1900. One hundred and thirty seven earthquakes were studied. Nearly twelve thousand newspaper issues were searched for earthquake reports. About one quarter of the issues searched have provided earthquake reports. Summaries of these reports, emphasizing the information used to assign Modified Mercalli intensities, are appended to the report. The strength and spatial distribution of the reported earthquake effects were used to estimate the magnitude and epicentral location of the earthquakes. The report provides one hundred isoseismal maps showing the distribution of the intensity reports which control the estimates of magnitude and epicenter.

The epicentral distribution of pre-1900 earthquakes is generally similar to that of twentieth century earthquakes. Comparison with the Epicenter Map of California (Real et al., 1978), which displays post-1900 epicenters, shows that the following areas were more strongly affected by earthquakes before 1900 than after 1900:

AREA	DATE	MAGNITUDE	Imax
San Diego County	24 February 1892	6.7	VIII-IX
Santa Barbara Channel	21 December 1812	7.1	VIII
Los Angeles County	8 December 1812	6.9	VII
Los Angeles County	9 February 1857	7.9	IX+
Inyo County	26 March 1872	7.8	IX+
Western Stanislaus County	10 April 1881	5.9	VI
East San Francisco Bay	Jun.1836 & Oct.1868	6.8	VIII & IX+
Yolo and Solano Counties	19 April 1898	6.4	IX
San Pablo Bay	31 March 1898	6.2	IX
Mendocino County	15 April 1898	6.4	IX
Lassen and Plumas Counties	24 January 1875	5.8	VII
Del Norte County	23 November 1873	6.7	VIII

Other significant findings include information suggesting surface faulting, that was not previously recognized, during the following earthquakes:

DATE	M	Imax	POSSIBLE FAULT RUPTURE
11-31 October 1800	---	VII	San Andreas, Santa Cruz County
8 October 1865	6.3	IX	San Andreas, Santa Cruz County
2 February 1881	5.6	VIII	San Andreas, Monterey County
3 June 1887	6.3	VIII	Near Carson City, Nevada
19 May 1889	6.0	VIII	Antioch, Contra Costa County
24 February 1892	6.7	VIII-IX	Near Jacumba, San Diego County
19 April 1892	6.4	IX	Between Vacaville & Winters, Solano County
20 June 1897	6.2	VIII-IX	Calaveras, Santa Clara County
25 December 1899	6.6	IX	San Jacinto, Riverside County

Serious doubts have been raised as to the occurrence of an earthquake reported to have caused fault rupture on the Big Pine fault in southern California in 1852. The 1869 earthquake that was reported to have ruptured the Olinghouse fault in western Nevada about 30 kilometers to the northeast of Reno, appears from the felt effects to be centered about 20 kilometers south of Reno. The 1875 earthquake that was reported to have ruptured the Mohawk Valley fault zone in northeastern California appears from the felt effects to be centered about 50 kilometers to the north, near Honey Lake Valley.

Some earthquakes that were previously thought to be destructive were proven to be small, and other large earthquakes were identified for the first time.

Regional and National Seismic Hazard and Risk Assessment

9950-01207

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Investigations

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

   A. Finite fault rupture models

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

   B. Various published ground motion attenuation models.

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

2. Continued analysis of regional seismic source zones of the country with particular emphasis on the Pacific Northwest and Great Basin regions.

3. Continued investigation of the correspondence between average large-earthquake recurrence intervals developed from analysis of historical seismicity and those developed from field investigations of fault slip.

4. Collection of 1980 census data for economic loss studies in selected cities in the western and midwestern United States.

5. Refinement of data obtained from a field study of Modified Mercalli Intensities of the April 26, 1981 Westmorland, California earthquake.

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

7. Review of intensity data for earthquakes in central Washington is underway.

8. Intensity data for damaging earthquakes in the Mississippi Valley are being reviewed in connection with a FEMA supported disaster preparedness study in the Midwest. A maximum Modified Mercalli intensity map is being constructed for the Mississippi Valley.

Results

1. Sensitivity studies resulted in an improved probabilistic ground motion model for those regions in which fault ruptures are expected but where faults have an arbitrary location. The improved model was used in recalculation of ground motion values for areas east and west of the Wasatch fault, the Nevada Seismic Zone, central and southern California and western Montana. These recalculations have been incorporated into the new national seismic hazard maps.

Because of the controversy over ground motion attenuation in the east, tables were prepared comparing ground motion values for various attenuation functions and fault rupture models for the New Madrid and Charleston areas. These and other studies are contributing to an evolving text supporting the new national seismic hazard maps.

Two other related texts are in technical review; one describes a revised probabilistic ground motion computer program, the other is a detailed analysis of the consequence of fault-rupture models in ground motion hazard estimation.

2. A text that summarizes a series of meetings convened to provide the project with a consensus viewpoint on new information and other factors to be considered in seismic source zone determination is in technical review. Regionalization of the Basin and Range Province according to age of fault displacements has been revised and updated in a second text that is now in technical review.

The seismotectonic and geologic basis for the seismic source zones used in production of the new national probabilistic hazard maps is being compiled for publication. The neotectonic evolution of the Pacific Northwest is being studied, making use of additional data that has become available as a result of reactor siting investigations.

3. A series of maps have been prepared for the Basin and Range Province showing historical seismicity, strain-release, and probabilistic ground motion values. Comparison of these maps to such geologic information as age-of-faulting, geologic recurrence of faulting events and products resulting from field investigations of fault slip is in progress.

4. Data entry and development of utility programs for handling large files of census information have been developed.

5. Evaluation of Modified Mercalli Intensity for the April 26, 1981 Westmorland, California earthquake has been completed. The maximum intensity was VII (in Westmorland and Calipatria). The felt area did not differ significantly from the areas shaken in 1979 (M_L = 6.6) and in 1940 (M_L = 7.1).

6. Calculation and computer plotting of probabilistic seismic liquefaction intensity maps for return periods of 100, 500 and 2500 years has been completed and the maps have been turned over to project 9550-01629. These maps are expected to give a more complete description of liquefaction hazard than the liquefaction "opportunity" map technique.

7. Intensity attenuation in Washington east and west of the Cascades is being investigated. The intensity data from twelve Washington earthquakes and nine shocks from adjacent states have been studied. Preliminary results have not revealed any significant differences in areas shaken east and west of the Cascades.

Reports

Algermissen, S. T., and Steinbrugge, K. V., 1981, [abstract], Estimation of earthquke losses, in, Hays, W. W., ed., Proceedings of conference XIII, Evaluation of regional seismic hazards and risk, 25-27 August, 1980: U. S. Geological Survey Open-File Report 81-437, p. 162-163.

Algermissen, S. T., Thenhaus, P., Askew, B., 1981, [abstract], New Probabilistic hazard maps for the United States, in, Hays, W. W., ed. Proceedings of Conference XIII, Evaluation of Regional seismic hazards and risk, 25-27 August, 1980: U. S. Geological Survey open-file report 81-437, p. 137.

Barnhard, L. M., Thenhaus, P. C., and Algermissen, S. T., 1981, [submitted], Letter to the Editor, Earthquake Engineering Research Institute Newsletter, concerning the April 26, 1981, Westmorland, California earthquake.

Khattri, K. N., Rogers, A. M., Perkins, D. M., and Algermissen, S. T., A seismic hazard map of India and adjacent areas, [submitted], Bulletin of the Seismological Society of America.

Perkins, David M., 1981, Effect of changing return periods on probabilistic ground motion: Proceedings of the workshop on seismic performance of underground facilities, Augusta, Georgia, February 11-13, 1981, 23 p. (in press).

Perkins, D., Bender B., and Shedlock, K., 1981, Rules of thumb relating to issues in probabilistic ground motion mapping in Hays, W. W., ed., Proceedings of Conference XIII, Evaluation of Regional Seismic Hazards and Risk, 25-27 August, 1980: U. S. Geological Survey Open-File report 81-437, p. 107-110.

Reagor, B. G., Stover, C. W., and S. T. Algermissen, 1981, Seismicity map of the state of South Dakota, MF-1325.

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Reagor, B. G., Stover C. W., Algermissen, S. T., Steinbrugge, K. V., Hubiak, P., Hopper, M. G., Barnhard, L. M., 1980, Preliminary Evaluation of the Distribution of Intensity (for the October 15, 1979, El Centro, California earthquake), in, Rojan, C., ed., Selected Papers on the Imperial Valley, California, Earthquake of October 15, 1979: U. S. Geological Survey Open-File Report 80-1094.

Stover, C. W., Reagor, B. G., and S. T. Algermissen, 1981, Seismicity map of the states of Delaware and Maryland, MF-1281.

_____, 1981, Seismicity map of the state of Iowa, MF-1324.

_____, 1981, Seismicity map of the state of Minnesota, MF-1323.

_____, 1981, Seismicity map of the state of Nebraska, MF-1350.

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_____, 1981, Seismicity map of the state of Kansas, MF-1351.

Thenhaus, P. C., Ziony, J. I., Diment, W. H., Hopper, M. G., Perkins, D. M., Hanson, S. L., and Algermissen, S. T., 1981, Probabilistic estimates of maximum seismic horizontal ground motion on rock in Alaska and the adjacent outer continental shelf, in, Coonrad, W., ed., United States Geological Survey in Alaska: Accomplishments in Alaska during 1980: U. S. Geological Survey Circular 844 (in press).

Seismic Wave Attenuation in Conterminous United States

9950-01205

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Investigations

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

2. Data reduction and analysis of 29 NTS events recorded on strong-motion instruments in the near-field (1 to 20 km) is in progress.

3. Data analysis of the October 10, 1980, El Asnam earthquake is in progress.

Results

1. On a regional basis, for the Northeastern United States, 50 events in the magnitude range of 1.8 to 3.2 have been used to derive a mean γ-value. The distance range is between 30 to 400 km.

2. Preliminary results of the mean γ-value distribution for L_g-waves, with a period of 1 second, have been derived from the recordings on short period seismograph systems throughout the United States. The data base used in constructing the γ-distribution consists of 136 events with magnitudes from 2.0 to 6.4, and recorded in the distance range of 1° to 40°. Six magnitude scaling laws, on regional basis, have been derived from this data-base.

Reports

Espinosa, A. F., 1981, M_L determination and horizontal ground acceleration from strong-motion accelerograms: in the Imperial Valley, California, earthquake of October 15, 1979: U.S. Geological Survey Professional Paper, No. 1254.

Espinosa, A. F., and Michael, J. A., Tabulation and documentation of L_g-wave data recorded on the LRSM stations for 136 selected events: U.S. Geological Survey Open-File Report, [in preparation].

Espinosa, A. F., and Tongtaow, C., Aneslastic Q-distribution for L_g-waves in conterminous United States, for journal, [in preparation].

Investigation of Seismic Wave Propagation for Determination of Crustal Structure

9950-01896

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Investigations

1. Examined the potential of using a computer-generated Vibroseis© sweep to recorrelate and improve the original seismic reflection data in the Mississippi Embayment.

2. The track of hurricane Dennis of the 1981 hurricane season was plotted and the microseisms for a number of stations in South Carolina, Tennessee, and Virginia were recorded. This storm was not large enough to be recorded over an extensive area, but the data should be helpful to determine the feasibility of using hurricane generated microseisms as a zoning tool.

3. Worked with K. Shedlock in the processing and interpreting small boat reflection profile along the Mississippi River from Osceola, Arkansas, to Wickliffe, Kentucky.

Results

1. It was found that by using a computer-generated vibroseis® sweep on the seismic reflection data in the Reelfoot Rift, an improvement in reflection quality below the top of Paleozoic could be achieved. The poor quality of the original profiles seems to be more pervasive than previously thought.

2. A portion of the Mississippi River small boat survey was processed in collaboration with K. Shedlock. A number of features can be seen in this data including the extension of the Cottonwood Grove fault across the river south of Caruthersville, Missouri. Another feature which was crossed was a ancient deep river channel north of Caruthersville, Missouri.

Reports

Harding, S. T., D. P. Russ, and Norman Blubaugh, 1981, Need for optimized seismic reflection processing in active and higly disturbed fault zones [abs.]: Eastern Section Seismological Society of America, [in press].

Harding, S. T. and Kaye Shedlock, 1981, Mississippi River Seismic Survey [abs.]: Eastern Section Seismological Society of America, [in press].

Research Applications

9900-90027

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Investigations

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

Results

1. USGS joined with FEMA and DOE to sponsor the 1981 Summer Institute on Multiprotection Design, August 17-21, 1981, in Emmitsburg, Maryland. Lectures were given to the 25 university and college professors who attended the session on earthquake design. These lecturers focused on: 1) geologic hazards, 2) fundamentals of earthquake ground motion and the uncertainties associated with definition of the seismic input and site response in earthquake resistant design and 3) earthquake zoning research.

2. USGS and FEMA jointly sponsored a workshop on "preparing for and responding to a damaging earthquake in the Eastern United States," September 16-18, 1981, in Knoxville, Tennessee. The workshop brought together 75 participants representing officials of local and state governments, scientists, engineers, social scientists, economists, planners, and lawyers. A proceedings will be published in February 1982, containing recommendations for imporving the state-of-preparedness to deal with a damaging earthquake in the eastern United States.

Neotectonic Synthesis of U.S.

9540-02191

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Investigations

1. Work continued on earthquakes along the eastern seaboard of the U.S., including discussion and presentation at the special conference on eastern earthquakes in Knoxville, TN, in September of a unified model of earthquake generation along the eastern seaboard involving infrequent movement of scattered reverse faults under northwest-southeast compression (see report below, and Science, v. 214, p. 169, Assessing the risk of eastern U.S. earthquakes).

2. Work continued on analysis of topography for tectonic inference, particularly with respect to measures of relief and morphology of fault scarps.

3. Work continued on neotectonics in the southwest, and included preliminary compilation of a 1:2,500,000-scale map of Quaternary faults in the whole of the basin-and-range province (now being reviewed), and (with Paul Thenhaus) preparation of a map of seismic source zones of the same region, based on meetings of experts held in 1979-80. Revision to bring map up to date is now under way.

4. Work on neotectonics in central California was begun, directed particularly at the postulate that present topography represents Quaternary deformation of a subdued Pliocene landscape.

5. Coordinated the preparation of a proposal for deep-crustal reflection profiling across central California that was submitted to the Deep Crustal Studies Program of Geologic Division (Wentworth, C. M. (coordinator), 1981, Central California deep crustal investigation, U.S. Geological Survey Admin. Rept., 34 p.). The purpose is to explore the intermediate and deep lithosphere across the San Andreas fault system and Coast Ranges onto the Sierran crustal block. The initial phase proposed involves 140 km of deep reflection line extending from west of the Hayward fault across the Diablo Range by way of Livermore valley to the east side of the linear magnetic and gravity high along the center of the Great Valley near Modesto. Principal objectives of this phase are

a) to trace the Coast Range thrust to depth eastward beneath the Great Valley and explore its relation to the buried boundary between Franciscan and Sierran basements,
b) to explore the configuration and character of basement beneath the western Great Valley,

c) to explore the vertical extent and interrelations of contrasting Franciscan tectono-stratigraphic terranes and any associated oceanic crust, and

d) to begin to examine the subsurface expression of faults of the San Andreas system and search for any evidence of a midcrustal zone of subhorizontal decoupling and-or of the deep transform boundary.

Valuable information about shallow crustal structure along the profile line should also be obtained.

Results

1. Study of eastern earthquakes must address recent geologic or kinematic history as well as the dynamics represented by recent earthquakes. The interrelated low frequency of earthquakes in the region and lack of clear geologic expression of seismotectonic structures makes such effort particularly difficult, and tempts geologic associations for which little or no direct causal ties to earthquakes exists. East of the Fall Line, where Cretaceous-Cenozoic sediments raise the prospect of a record of fault offset through time, the accepted technique of seeking youngest faulted and oldest overlying unfaulted strata to date fault recency may be invalidated by incomplete propagation of small basement offsets up through the sedimentary cover.

Three types of models are now proposed to account for east-coast earthquakes: a) local structural features associated with historic concentrations of earthquakes, b) small infrequent movement of scattered reverse faults operating under a systemmatic regime of northwest-southeast compression across the continental margin, and c) infrequent movements of various parts of a subhorizontal Paleozoic decollement underlying the whole region now being driven seaward by gravity. Fundamental differences in geologic history, regional tectonic systems and earthquake sources are involved, but their resolution will require carefully designed studies, particularly because of the low deformation rate.

2. Rigorous definition of topographic relief for tectonic and geomorphic studies can be made by taking the altitude difference between the surfaces defined by two interdigitated, branching networks, the drainage network along the low points in the topography and the divide network along the high points. Strahler stream order and equivalent divide order can be used to specify the scale of relief. Inclusion of third and higher order elements defines a fundamental local relief between adjacent ridges and valleys. Outward termination of the networks at typical second/third order junctions maintains consistency of the relief measure across main ridges and trunk streams.

3. Major contrast between net deformation and true deformation history, as demonstrated in the Ventura Basin, California, by R. S. Yeats under this project, can pose serious problem in inferring deformation rates and styles from the geologic record. The rich stratigraphic record of the Ventura area allows reconstruction of a detailed displacement path for a 1-m.y.-old horizon now eroded from the crest of the Ventura Avenue anticline. Following marine deposition at a depth of about 250 m below sea level 1 m.y. ago, the horizon a) subsided at 0.9 mm/yr for 400,000 yrs accompanied by horizontal

displacement at 1.9 mm/yr across the Taylor thrust system, then b) subsided at a greater rate of 1.7 mm/yr without horizontal displacement for another 400,000 yrs, and finally c) was uplifted from well below sealevel at 11 mm/yr for the past 200,000 yrs. In contrast, simple comparison of initial and final positions of this geographically young marker yields a single monotonic uplift rate of 1.1 mm/yr and a rate of continuous horizontal displacement of 0.7 mm/yr. In the general case, where the geologic record is seriously incomplete, we are limited to determining net deformation of imperfect, imprecisely dated horizons. Within the resultant net deformation patterns and rates may be hidden many complexities important to seismotectonic interpretation. Time sequences of geologic horizons, even if of only local extent, are needed to test for such possibilities.

Reports

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Wentworth, C. M., and Mergner-Keefer, Marcia, 1981, Reverse faulting and the potential for large earthquakes along the eastern seaboard, in, Beavers, J. M., (ed.), Earthquakes and earthquake engineering: the eastern United States: Ann Arbor Science Publishers, Earthquake Engineering Research Institute and others, proceedings of conference, September 14-16, 1981, Knoxville, Tennessee, v. 1, p. 109-128.

Southern California Seismic Arrays

Contract No. 14-08-0001-19268

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Investigations

This semi-annual report summary covers the six-month period from 1 April 1981 to 30 September 1981. The contract's purpose is the partial support of the joint USGS-Caltech Southern California Seismographic Network, which is also supported by other groups as well as by direct USGS funding through its employees at Caltech. Other supporting groups include the California Division of Mines and Geology and the Caltech Earthquake Research Affiliates. According to the contract, the primary visible product will be a joint USGS-Caltech catalog of earthquakes in the southern California region; quarterly epicenter maps and preliminary catalogs are also required and have been submitted as due during the reporting period.

Results

Figure 2 shows the epicenters of all cataloged shocks that were located during the period; coverage above M = 3.0 is felt to be complete. Some of the seismic highlights in the southern California region during the six-month period are as follows:

Number of earthquakes located: about 11,000
Number of earthquakes currently entered in catalog: 2,756
Number of earthquakes of M = 3.0 and greater: 248
Number of earthquakes of M = 4.0 and greater: 17
Number of earthquakes of M = 5.0 and greater: 3
Number of earthquakes for which systematic telephone notification to agencies was made: 9
Largest earthquake: M = 5.8 (9-30-81, near Mammoth)

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

The largest earthquake of the reporting period, M = 5.8, was another of the continuing swarm of events near Mammoth, and its epicenter was close to those of the larger shocks of May 1980. Of greater interest in southern California was the M = 5.7 earthquake of 26 April near

Westmorland, which caused some local damage in the Imperial Valley. Aftershocks during a one-month period are shown in Figure 3, and the northeast trend of the activity is striking. Particularly interesting are those shocks at the northeast end of the alignment, which are on the projected southeastward trend of the San Andreas fault -- a segment that was conspicuously quiet prior to the 1979 Imperial Valley earthquake but "lit up" following both the 1979 and 1981 events. Kate Hutton and Carl Johnson are continuing studies of the Westmorland earthquake.

Sharply felt throughout the Los Angeles area was the M = 5.3 "Catalina earthquake" of 4 September, which was actually located much closer to Santa Barbara Island. Graduate student Edward Corbett has been studying this event, and epicenters of the main shock and principal aftershocks are shown in Figure 1. (Two aftershocks of M = 4.5 shook the Los Angeles area on 23 October, following the close of the reporting period). The marked northwest trend of the aftershock activity is consistent with the local geology as well as with the focal mechanism, which indicates right-slip on a vertical plane of this orientation. Although not in an area of high continuing activity, two earthquakes of magnitudes between 4 and 5 were located in the same area in 1952 and 1956.

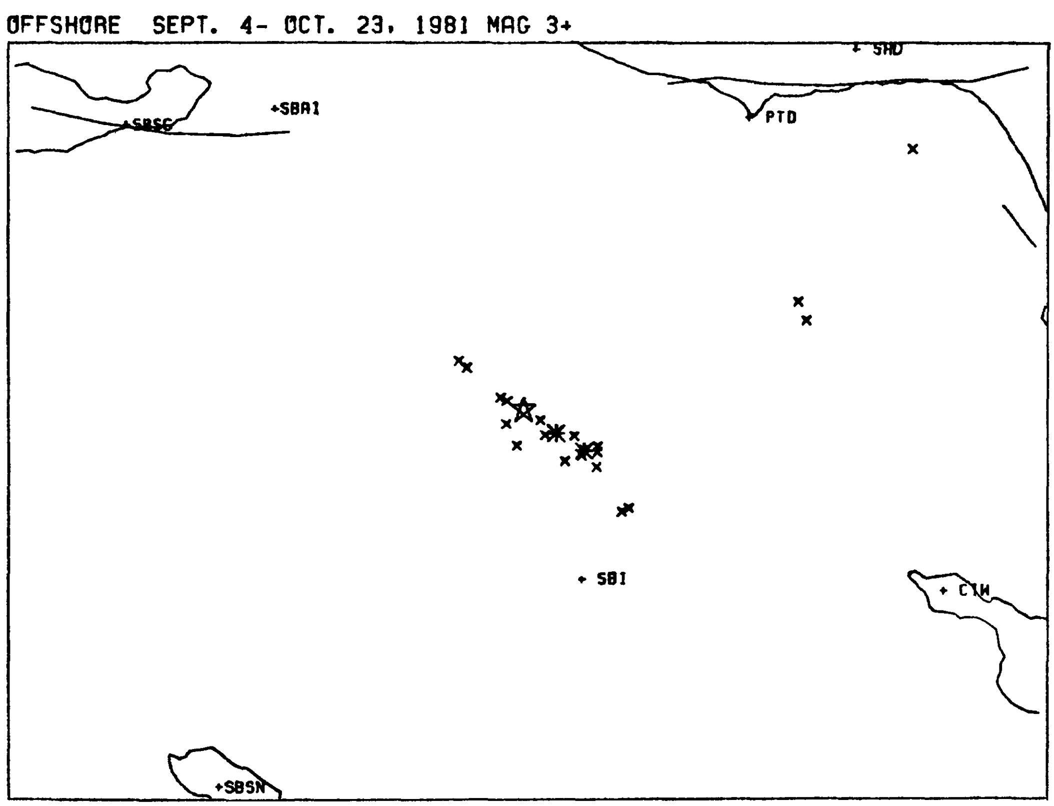

Fig. 1--Locations of larger Santa Barbara Island earthquakes of September-October 1981. Main shock (M = 5.3) is indicated by star, two M = 4.5 aftershocks of 23 October by asterisks. Santa Monica area is at upper right, Santa Catalina Island at lower right, San Nicolas Island at lower left, Santa Cruz Island at upper left.

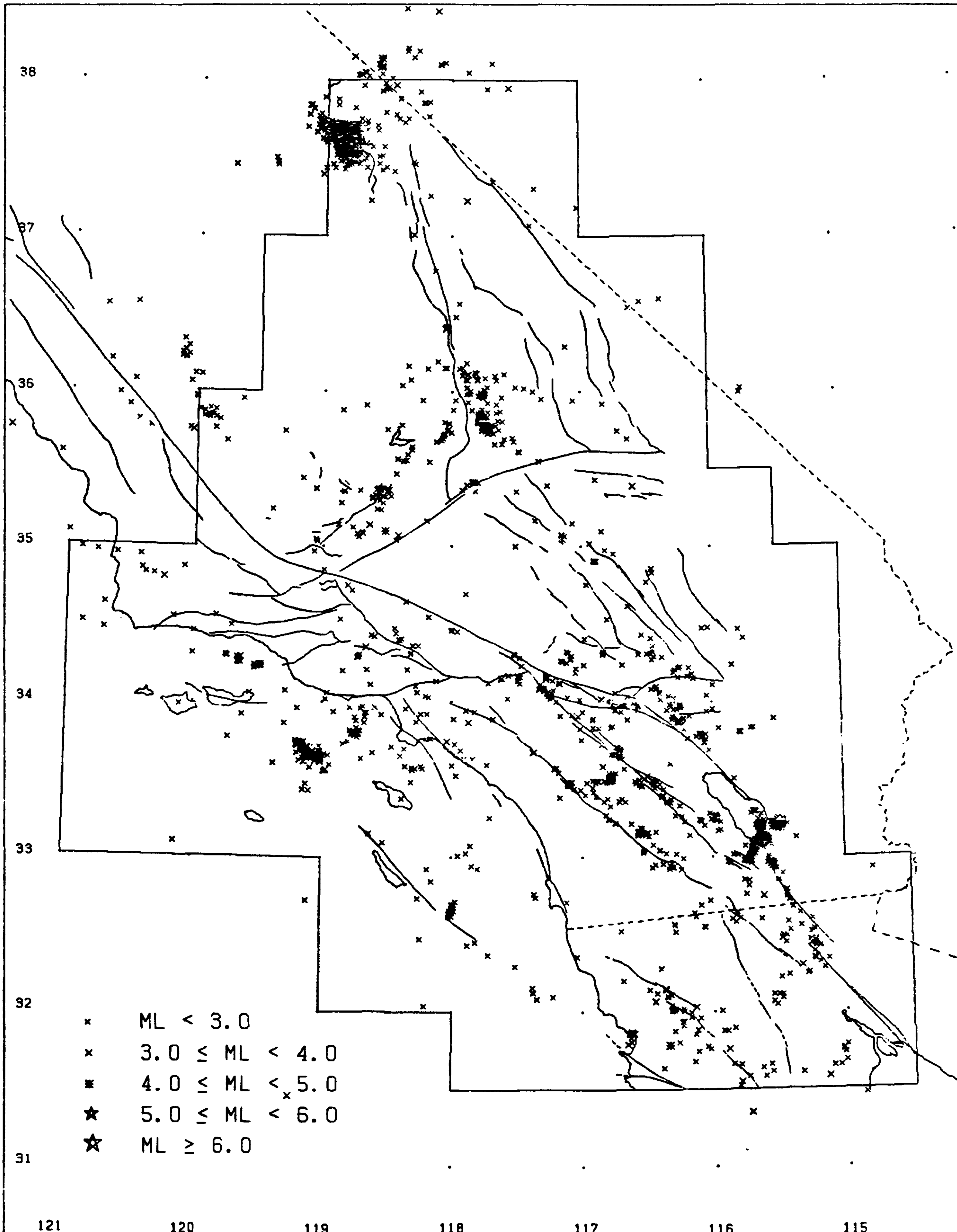

Fig. 2--Epicenters of larger earthquakes in the southern California region, 1 April 1981 to 30 September 1981.

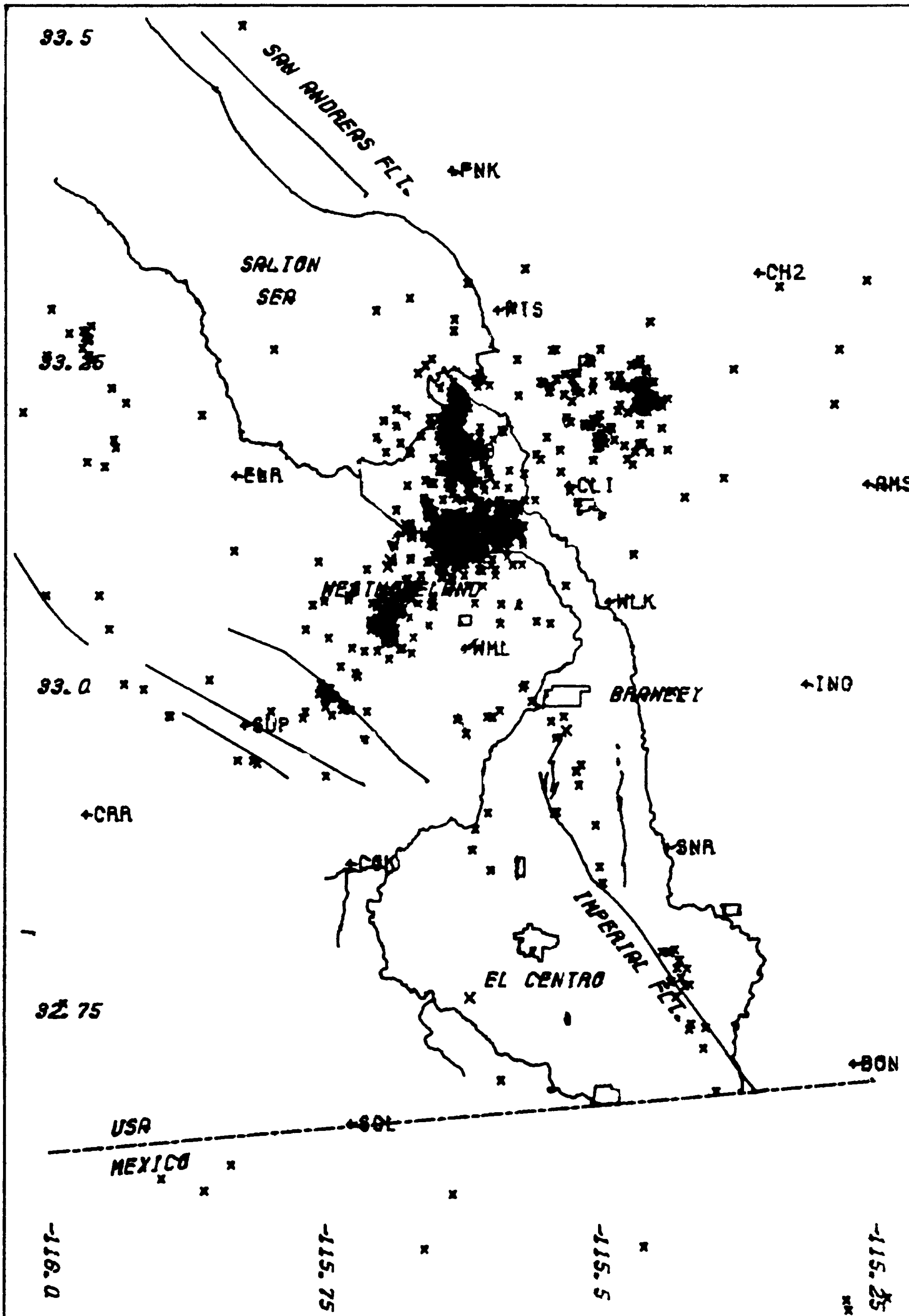

Fig. 3.--Epicenters of Westmorland earthquake of 26 April 1981 and aftershocks through 25 May 1981.

Tectonic Framework San Francisco Bay Region

9540-01618

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Investigations

1. Continued work on map of fault potential and epicenters for San Mateo County seismic zonation (I-1257) series (with Jean Olson).

2. Continued evaluation of different kinds of slope maps for San Mateo County (with Bob Mark and Evelyn Newman).

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

4. Continued work on surficial deposits and liquefaction potential of Monterey Bay area (Bill Dupre).

5. Continued work on map of flood-prone areas of San Mateo County (by WRD).

6. Conferred with Walter Mooney about best places for seismic refraction profiles in the Santa Cruz Mountains.

Results

1. Two maps dealing with faults and epicenters have been completed and given to the branch for Technical review, a map of faults and epicenters, by Brabb and Olson, and a map by Olson and Brabb showing focal mechanisms and discussing the seismicity in greater detail. The former map will be part of the I-1257 series and the latter map will be in the MF series.

2. Two miles of slope profiles in a variety of terrains near La Honda were recently surveyed to provide ground truth for a check of slope maps prepared from a digital elevation model (DEM) and from maps prepared by photomechanical methods. The profiles indicate that only about 55 percent of the slope categories are correct on the photomechanically-produced maps and about 50 percent are correct on a slope map prepared from the DEM. No consistent relations were observed between amount of slope, amount of vegetation and amount of error. Some areas on the slope maps were in error by as many as 4 of the 6 slope categories but almost 90 percent were correct to within ± one slope category. The significance of these errors is that slope maps presently available may not be accurate enough for slope stability studies.

3. The map showing direction and amount of bedding dip is finished and is in branch review. The map will be used in conjunction with maps of slope and landslide distribution to determine whether and how much the dip of bedded rocks contributes to the formation of landslides in San Mateo County.

4. The Seaside and Spreckles quadrangles are nearly finished but will not be completed until next summer when Professor Dupre will be available again.

5. The map showing flood-prone areas in San Mateo County is nearly finished, and will be submitted shortly for branch review.

6. Seismic refraction profiles are being obtained by Walter Mooney in a northeast direction from Davenport across the Santa Cruz Mountains to the Kaiser Permanente quarry in Cupertino, and northwest from Logan quarry to a quarry near Half Moon Bay. The profiles are being obtained to determine the character, depth, and configuration of basement rocks in an area of complex geology near the San Andreas, San Gregorio, and Zayante faults.

Project termination

This project has been terminated, effective October 1, 1981. Work that has not been completed may or may not continue under the sponsorship of other programs.

Reports

Kockelman, W. J., and Brabb, E. E., 1981, Two examples of seismic zonation in the San Francisco Bay region: Earthquake Information Bulletin, v. 13, no. 3, p. 80-84.

U.S. Geological Survey, 1981, Goals, strategies, priorities and tasks of a national landslide hazard reduction program: U.S Geological Survey Open-File Report 81-987, 97. p.

Brabb, E. E., 1981, Seismic zonation in the San Francisco Bay region <u>in</u> Jeremy Isenberg, ed., Social and economic impact of earthquakes on utility lifelines: American Society of Civil Engineers, p. 54-65.

Brabb, E. E., 1981, Preparation and use of a landslide susceptibility map for a county near San Francisco, California, U.S.A. (abs.): Abstracts for United Nations Educational, Scientific and Cultural Organization International Seminar on water-related exogeneous geological processes and the prevention of their negetative impact on the environment, Alma-Ata, U.S.S.R., 12-17 October, 1981, p. 4-6

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

Authors	Maps	Comments
Brabb, Pampeyan	Geology, I-1257A	In press
Wieczorek, et al.	Earthquake induced landslides	In TRU review.
Mark Newman Brabb	Slope	Elevation data in digital form. Need to compare with ground data.
Brabb, Taylor	Geologic, scenic and historic sites	Finished, in press.
Brabb	Dip direction and amount	In branch review.
Youd	Liquefaction potential	Almost ready for branch review.
Brabb, Olson	Fault potential and epicenters	In branch review.
Olson, Brabb	Focal mechanisms	In branch review.
Brabb, Pampeyan	Landslide inventory	Will be done when time available.
Brabb, et al.	Landslide susceptibility	Will be done by computer when landslide inventory and slope map finished.
Perkins (ABAG)	Building risk	In branch review.
Uncertain	Dam inundation	Available in digital form.
Fumal, Gibbs	Seismic units	Nearly ready for branch review.
Joyner, Gibbs	Ground velocity	Will begin in 3-4 months.
Uncertain	Tsunami	Data available in digitial form.
WRD	Flood prone areas	Nearly ready for branch review.
Uncertain	Land use	Data available in digital form.
Wentworth, Ellen	Hillside materials	In TRU review.
Uncertain	Vegetation	Available in digital form. May be used to make landslide susceptibility map.
Brabb	Composite hazards	Will begin when all other maps are finished

Seismic Hazards of the Hilo 7 1/2' Quadrangle

9550-02430

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Investigations

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

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

3. A text and accompanying map showing distribution and thickness of ash deposits, the thickness of the underlying clay bed, and the type of basement material in portions of the Hilo, Papaikou, Akaka Falls and Pi'ihonua quadrangles was prepared for review.

Results

Geologic mapping of the northwest section of the Hilo quadrangle was completed and a prelimlinary geologic map and report for the U S. Army Corps of Engineers was prepared. A detailed geologic map of the same area is in preparation. Reconnaissance geologic mapping of volcanic ash deposits in the greater Hilo area indicates a history of eruption, deposition, and severe weathering. Ash deposits believed to be erupted mainly from Mauna Kea Volcano are interbedded with Mauna Loa flows in the study area.

The ash has been divided into two types that reflect an expected difference in behavior when subjected to earthquake-induced shaking. A slight difference in grain size and water content was observed in ash deposits that, in general, overlie the severely weathered Mauna Kea lava flows and those overlying probable Mauna Loa flows. The finer-grained ash has higher sensitivity and natural water content than the coarser-grained ash. Slopes composed of the ash with the higher sensitivity are more likely to fail during seismically-induced shaking. Failure would be expected along road embankments and stream drainages where the material is unsupported. Generalized boundaries between the deposits with different sensitivities are shown on the map but further detailed work is needed to determine the precise distribution of the two ashes. The old part of the city of Hilo south of the Wailuku River is built on the less-sensitive ash deposit; the remainder of the city to the south, is built on lava flows. The clay bed that locally underlies the ash may also pose a geologic hazard during heavy rains as well as during earthquake shaking. Owing to its greater impermeability and finer particle size, it may cause water to accumulate at the base of the overlying ash thereby reducing the internal friction between particles and providing a surface along which the saturated ash could slide. No geotechnical tests were performed on the basement materials to determine their behavior during earthquake shaking.

Radiocarbon dating of charcoal found beneath lava flows indicates that deposition of the ash begain more than 23,000 C^{14} years before present and ended sometime between 9,000 to 3,400 C^{14} years ago.

Reports

Lockwood, J. P., and Buchanan-Banks, J. M., 1981, Preliminary geologic report for the Alenaio Stream flood damage reduction study area, Hilo, Hawaii: U.S. Geological Survey Open-File Report 81-791, 12 p., map scale 1:24,000.

Buchanan-Banks, J. M., 1981, Distribution and thickness of volcanic ash deposits in the greater Hilo area, Hawaii, and their seismic hazard potential (abs.): American Geophysical Union, Fall Meeting, Dec. 7-11, 1981, San Francisco.

Characteristics of Active Faults in the Great Basin

9950-01538

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Investigations

1. Completion of field studies on ten fault zones in unconsolidated sediments in the Tooele 2° quadrangle, Utah.

2. Completion of field studies on fault zones in unconsolidated sediments in the Elko 2° quadrangle, Nevada.

3. Collection of fault scarp profiles on faults in unconsolidated sediments in the Wasatch fault zone, Salt Lake Valley, Utah.

Results

1. Completed geomorphic and geologic investigations in the Tooele 2° quadrangle indicate that the most recent major scarp-forming earthquake events on ten fault zones in the quadrangle predate formation of the Bonneville shoreline scarp (abandoned between about 15,000-14,000 years B.P., Scott, 1981). Several sites in Rush Valley with reported post-Bonneville offset (Everitt and Kaliser, 1980) were visited with B. L. Everitt during final field studies (June, 1981). In three locations with some suggestion of post-Bonneville offset, lack of offset on the Bonneville shoreline scarp by adjacent fault scarps favors a pre-Bonneville age for the last event. Possible minor post-Bonneville or Holocene offset was located on one of the ten fault zones on the quadrangle, but the available evidence is equivocal.

Fault scarp profile data, collected in nine of the ten Tooele fault zones, were also used for relative dating of faults. Data in five zones was sufficient for statistical analysis using the methods described by Bucknam and Anderson (1979). Three of these zones, the Mercur, Twelve-Mile Pass, and Sheeprock (fig. 1) are relatively older than reference scarps of the Bonneville regression line. This supports relative age assignments for the zones based on crosscutting shoreline-scarp relationships.

Although regression lines on data from the Stansbury and Northern Oquirrh fault zones appear close on age to the Bonneville shoreline (fig. 1.), shoreline-fault scarp relationships indicate a pre-Bonneville age of last offset on these fault zones. The cause of this ambiguity is uncertain, but it may relate to multiple-event scarps in the data sets. On the five fault zones where profile data were insufficient for statistical analysis, relative ages were assigned based on general geomorphic character and fault scarp-shoreline cross-cutting relationships.

The results of mapping and profiling in the Tooele 2° quadrangle are currently being prepared for publication as an open-file report (Dodge, Bucknam, and Barnhard, 1981, in review). Future investigations of the characteristics of active faults in the Great Basin will be integrated with R. E. Anderson's Southwestern Utah Seismotectonic Studies (project number 9950-01738).

2. Geomorphic and geologic field investigations were completed on eight fault zones in the Elko 2° quadrangle. Geomorphic profiles were measured on six fault zones; scarp-height-slope-angle data were sufficient on four zones for statistical analysis and relative age comparison to the results of Bucknam and Anderson (1979). Results indicate that the most recent fault movement on these four zones predates formation of the Bonneville shoreline scarp (c. 15,000-14,000 years B. P, Scott, 1981). Geologic and geomorphic evidence, supported by limited profile data, indicates that the last event on other fault zones in the Elko quadrangle also predates 15,000 to 14,000 B. P. The final report and map for the Elko 2° quadrangle are in preparation for publication as an open-file report.

3. Scarp profiles were collected on fault scarps in unconsolidated sediments along the Wasatch Front, Salt Lake Valley, Utah. This data will be used to study the morphology of scarps on the Wasatch fault zone and the total offset along sections of the zone. Morphology-age relationships in this zone will be compared to those in other zones for relative dating, in conjunction with stratigraphic studies and surficial mapping being carried out by W. E. Scott under project number 9530-02174.

Reports

Bucknam, R. C., and R. E. Anderson, 1979, Estimation of fault-scarp ages from a scarp-height-slope-angle relationship: Geology, v. 7, p. 11-14.

Dodge, R. L., R. C. Bucknam, and T. Barnhard, 1981, Map of fault scarps on unconsolidated sediments, Tooele 1° x 2° quadrangle, Utah: U.S. Geological Survey Open-File Report 81- , [in review].

Everitt, B. L., and B. N. Kaliser, 1980, Geology for assessment of seismic risk in the Tooele and Rush Valleys, Tooele County, Utah: Utah Geological and Mineral Survey Special Study 51, 33 p.

Scott, W. E., 1981, Quaternary stratigraphy of the Wasatch Front: U.S. Geological Survey Open File Report 81-833, Summaries of Technical Reports, vol. XII.

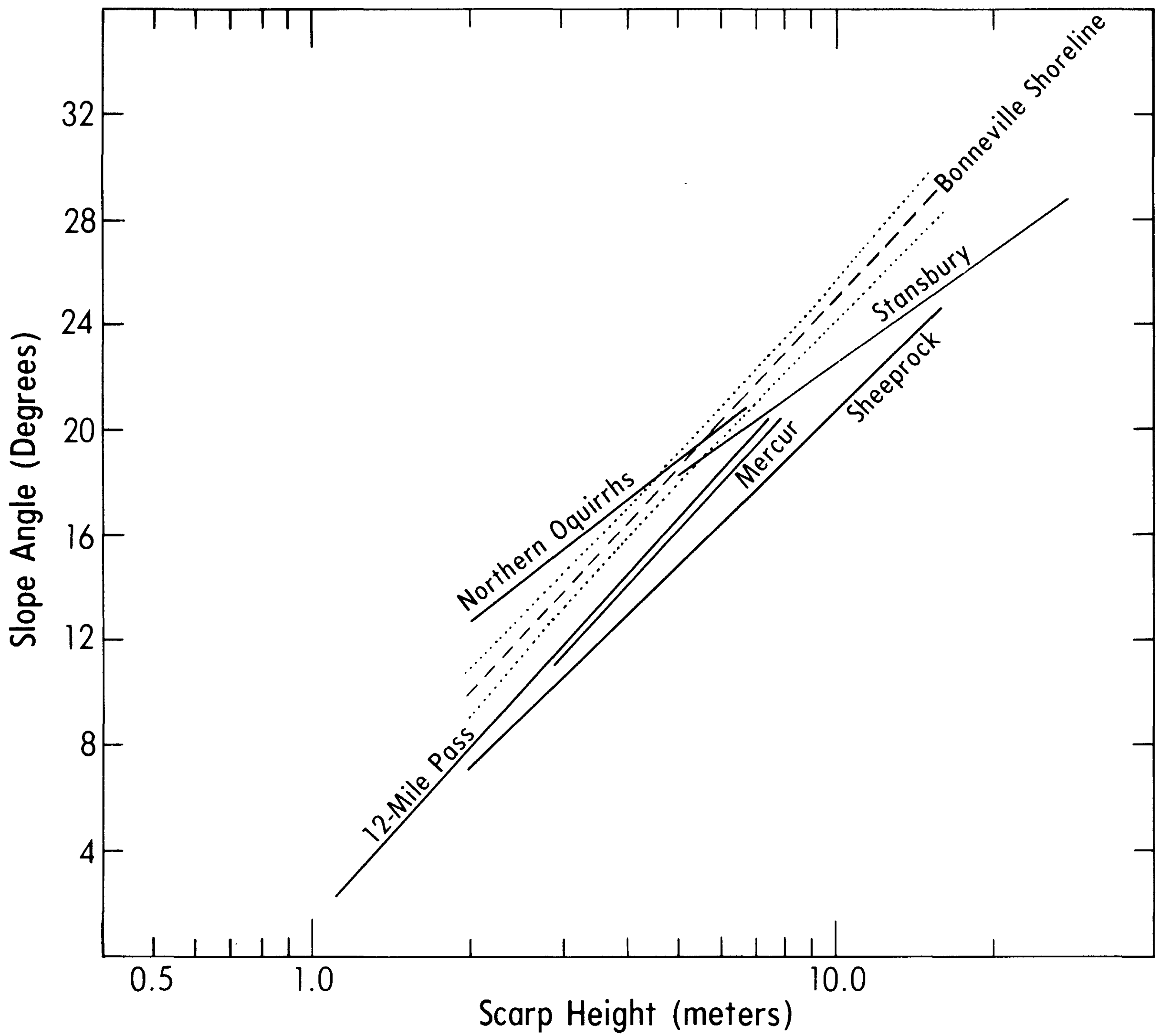

Figure 1. Regression lines for five fault zones in the Tooele 2° quadrangle, Utah. For comparison of relative age the regression line for the Bonneville shoreline scarp (c. 15000-14000 years old), and the 95% confidence interval (dotted line) are also shown.

Vertical Tectonics

9950-01484

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Investigations

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

2. Expanded investigations of the early 20th century uplift in southern California based on the recent discovery of early surveys propagated into southern California from stabler parts of the southwestern parts of the United States.

3. Accelerated our studies of the magnitude of the residual refraction error in observed elevation differences in southern California and elsewhere. Our assessment of the magnitude of this error is based on an examination of the tilt/slope ratio as a function of sight-length, network misclosures and such other parameters as are believed to influence the accumulation of the refraction error in geodetic leveling.

Results

1. Completed a brief report on a tectonic explanation for the maintenance of the divide between the Gulf of California and the Salton Basin.

Reports

Burford, R. O., Nason, R. D., and Harsh, P. W., 1981, Results of fault-creep studies in central California: U.S. Geol. Survey Earthquake Information Bull. (approved by Director).

Castle, R. O., Church, J. P., Elliott, M. R., Gilmore, T. D., Mark, R. K., Newman, E. B., and Tinsley, J. C., III, Comment on 'The Impact of Refraction Correction on Leveling Interpretations in Southern California' by William E. Strange (Jour. Geophysical Research, v. 86, p. 2809-2824, 1981): (approved by Director).

Castle, R. O., Elliott, M. R., The sea-slope problem revisited: (approved by Director).

Elliott, M. R., 1981, Digital vertical control data--past, present, and future: Proceedings of American Congress of Surveying and Mapping, Sept. 9-11, 1981, San Francisco, p. 232-237.

Evans, K. F., Burford, R. O., and King, G. C. P., 1981, Propagating episodic creep and the aseismic slip behavior of the Calaveras fault north of Hollister, California: Jour. Geophysical Research, v. 86, p. 3721-3735.

Mark, R. L., Tinsley, J. C., III, Newman, E. B., Gilmore, T. D., and Castle, R. O., 1981, An assessment of the accuracy of the geodetic measurements that define the southern California uplift: Jour. Geophysical Research, v. 86, p. 2783-2808.

Earthquake Hazard Studies in the Pacific Northwest

14-08-0001-19274

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Investigations

The seismicity, structure, and tectonics of the Pacific Northwest with emphasis on western Washington is investigated for earthquake hazard implications. A network of 25 stations is operated in western Washington under this project, complemented by additional stations on the Olympic Peninsula, near Mt. St. Helens, in the south Cascade range and in eastern Washington. Computerized recording, picking, and analysis of data are being accomplished and several subsidiary studies are undertaken, including the detailed study of two sequences of earthquakes in the central Puget Sound basin, a study of the application of pattern recognition techniques for identification of classes of earthquakes using the digital system, compilation of a complete historic earthquake data file, and a review of Mt. St. Helens local seismic activity over the last eight years.

Results

The renewal of volcanic activity at Mt. St. Helens is southwest Washington has dominated our activity for the last year, necessitating rapid growth in our seismograph station coverage of the south Cascades area and significant changes in recording and analysis procedures. To provide better future ability to acquire and analyze earthquake data on a regional basis, we are integrating data formats and analysis procedures for the UW networks on a statewide basis, under joint support of several projects. There has been an apparent regional increase in earthquake activity in the vicinity of Mt. St. Helens and two significant earthquakes have occurred recently -- one of magnitude near 5.5 on February 13, 1981 north of St. Helens, and a second of magnitude 5+ on May 28, 1981 southeast of Mt. Rainier. These earthquakes were both shallow and, with their aftershock sequences, promise to yield better understanding of the tectonics of the south Cascade Range of Washington. The analysis of two long duration swarms near Seattle prior to 1975 is not complete, but preliminary results indicate two very tightly clustered source areas. The swarms did not occur on any known fault(s) and are not easily understood on a regional basis. Toward the long-term goal of improved automated detection and analysis of digital network data, we have recently achieved some initial success with the application of linear predictive analysis (LPA) and pattern recognition theory to identification of certain classes of seismic events. The LPA is used for data compression and feature selection, and we have found that good separation can be obtained in preliminary attempts to distinguish between explosions and normal "tectonic" earthquakes. Ultimately, this approach should yield reliable automated identification and classification of seismic events by computer; however it is clear that a substantial period of development is required to achieve full utilization of the generality of this method. In collaboration with other investigators, a preliminary continental margin structure model has been proposed. The seismicity gap from 30 to about 40 km depth beneath Puget Sound is hypothesized as due to oceanic crust overlying a subducted lithoshphere dipping at about 6 - 7 degrees initially and somewhat steeper to the northeast. Compilation of a complete historical data base for the northwest region is being carried out jointly with separate support. This data base will be in a newly adopted standard format and will be compatible with our existing and planned software for all of our network data. This will allow efficient searching and plotting of historical and recent data in a uniform manner for the region. A review and careful comparison of the single station records from Mt. St. Helens and both Mt. Rainier and Mt. Baker is being undertaken in order to carefully document anomalous seismicity, if it exists, near St. Helens over the past eight years. Although this review is not yet complete, it appears that significant differences exist in the level and type of activity between all three volcanoes.

Reports

Noson, L.J., and R. S. Crosson, 1980, Compilation of earthquake hypocenters in western Washington - 1978, Department of Natural Resources, Geology and Earth Resources Division, Inf. Circ. 72., 18 pp.

Weaver, C.S., L.J. Noson, S.D. Malone, E.T. Endo, and R.S. Crosson, 1980, Eruption of Mt. St. Helens: Seismology, Nature, 285, 529-531.

Yelin, T.S., and R.S. Crosson, 1980, A significant sequence of earthquakes in south Puget Sound, Earthquake Notes, 50, 61 (abs.).

Anchorage-Susitna Lowlands Earthquake Hazards Mapping

9310-02078

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Investigations

1. Continued office compilation of surficial/engineering geologic maps and studies of Quaternary stratigraphy.

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

3. Completed field checking of critical localities with special emphasis on active faults and Pleistocene stratigraphy.

Results

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

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

3. Determined that a conspicuous lineament about 2.5 kilometers east of and parallel to the Little Susitna River is an active fault trace. It trends northeast-southwest and appears to splay out from the Castle Mountain Fault to the north and to extend under Cook Inlet to the south. The character of the fault trace is similar to that of the well-documented Castle Mountain Fault. Its west side is downthrown as much as 4 meters, and the truncated sediments are late Wisconsinan in age.

4. Found fossil barnacle shells in growth position at the top of the Bootlegger Cover Clay unit and immediately below the "Cover Sand" unit that blankets a large part of the Susitna Lowlands. These shells demonstrate a marine environment of deposition for the enclosing sediments and will provide a valuable radiocarbon age determination that should be younger than 14,000 years B.P.

Ground Response Along The Wasatch Front

9940-01919

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Investigations

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

Results

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

Reports

1. Hays, W. W. and King, K. W., 1981, Zoning of the Earthquake ground-shaking hazard along the Wasatch fault zone, Utah (ABSTRACT), International Conference on Microzonation, 3rd, Seattle, Washington, July, 1982.

Neotectonics of the San Francisco Bay Region, California

9540-01950

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Investigations

1. Work on the preparation of map syntheses (scale 1:250,000) and interpretive reports on active faults and earthquakes in the San Francisco Bay area was continued with W. L. Ellsworth (Proj. #9930-02103, Seismic Studies of Fault Mechanics)

Results

1. Extensive, youthful (certainly late Pleistocene, if not Holocene) imbricate thrust faults have been discovered in a number of areas in Santa Clara Valley and along the foothills flanking San Francisco Bay. A system of imbricate southwest-dipping thrust faults extending the entire length of the eastern foothills of the San Francisco Peninsula has now been documented. The thrust fault system includes the previously identified Serra, Monta Vista, and Berrocal faults, as well as a number of heretofore unknown thrust faults in the Menlo Park, Palo Alto, and Redwood City areas. The faults abut the San Andreas fault zone. Southeast of San Jose, a similar system of youthful, imbricate thrust faults have been found where the Hayward fault bifurcates from the Calaveras-Paicines fault. These thrust faults, which dip northeast, include the Evergreen, Silver Creek, and Coyote Creek faults that had been previously mapped. Near Hollister, two smaller systems of thrust faults have been found east and northwest of the town. To the northwest, there is a small system of north-dipping thrust faults that lie near the Sargent fault in the Lomerias Muertas hills. East of town, late Pleistocene fans are complexly faulted by a system of east-dipping thrust faults that occur between the Calaveras-Paicines fault and the Quien Sabe fault.

The thrust faults, like the Verona thrust fault in Livermore Valley, occur in areas where there are converging strike-slip faults. Apparently, the thrust faults permit the crustal blocks that are moving along the strike-slip faults to pass one another by shortening the width of the blocks.

2. A map synthesis of the subsurface stratigraphy of eastern Hollister Valley near the Calaveras fault has been completed and submitted to Branch technical review. Prepared by Catherine R. McMasters, Darrell G. Herd, and Constance Throckmorton, the report interprets the Holocene record of four 30- to 40-m-long cores recovered by auger drilling along the fault. The data suggest that there has been marked subsidence at San Felipe Lake, perhaps caused by folding of sediments near the fault. The report is accompanied by a description of the vegetative and climatic history of Hollister Valley that was prepared by Linda Heusser (Department of Biology, New York University) from an interpretation of pollen included within the core sediments.

3. Herd and Earl E. Brabb (Proj. #9540-01618) served as expert witnesses on surface faulting hazards at the General Electric Test Reactor (Vallecitos Nuclear Center, near Pleasanton, California) in a hearing before the Nuclear Regulatory Commission, Atomic Safety Licensing Board. The hearing was convened in San Francisco in June and July 1981.

Reports

Ellsworth, W. L., Lindh, A. G., Prescott, W. H., and Herd, D. G., 1981, The 1906 San Francisco Earthquake and the seismic cycle, in Earthquake Prediction--An International Review: American Geophysical Union, Maurice Ewing Series 4, p. 126-140.

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

9540-02685

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Investigations

1. Interpretive reports on surface faulting and ground failure in the Sonoran earthquake of 1887 were prepared.

2. An analysis of pre-1887 fault displacements on the Sonoran earthquake fault was continued with Robert C. Bucknam (Proj. #9950-1538, Physical and Mathematical Description of Active Faults) and William B. Bull, University of Arizona.

Results

1. A map of surface faulting in the Sonoran earthquake of 1887 (scale 1:50,000) was completed and submitted to Branch technical review. The map consists of 4 sheets (topographic quadrangles Canon de Guadalupe, Dieciocho de Agosto, Morelos, and El Tigre), which show the 76-km-long main fault rupture and secondary breaks thought to have been active in 1887. An accompanying text summarizes measurements of apparent dip-slip movement and throw that were made systematically along the length of the main 1887 fault rupture during field work in 1980 and 1981. The measurements are compared to those obtained by Mexican and American scientific expeditions that were dispatched to the epicentral area several weeks after the tremor (Aguilera, 1888; Goodfellow, 1887a, 1887b, 1887c, 1888).

2. A first draft of a journal article describing surface faulting and ground failure in the Sonoran earthquake of 1887 was completed. The article summarizes the pattern, extent, character, and amount of surface faulting in 1887, and discusses other fractures and faults observed in floodplains in 1887 that were undoubtedly ground failure. The article proposes that there may have been southward-directed rupture on the main 1887 fault. Intensity distribution maps prepared by Aguilera (1888) and more recently, by Dubois and Smith (1980) show that ground shaking persisted great distances south of the 1887 break. The intensity isoseismals are not uniformly distributed about the fault rupture, but are markedly skewed toward Mexico City. This apparent focusing of seismic energy, like that seen in the Guatemala earthquake of 1976 directed away from the shock's epicenter, suggests unilateral rupture propagation. If the 1887 rupture did propagate southward, then the epicenter of the earthquake must have been at the north end of the fault, near the U. S.-Mexican border. Interestingly, the greatest displacement on the 1887 rupture occurs near the north end of the fault.

3. A first draft of a journal article discussing recurrent movement on the Sonoran earthquake fault has been prepared by William B. Bull, Philip A. Pearthree, Robert C. Bucknam, and Darrell G. Herd. Several lines of evidence indicate that at least 10^5 years elapsed between the prior 1887 surface-faulting events.

Puget Sound Lowland Focused Geophysical Studies

9830-71110

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Investigations

1. Additional marine field work for this project was conducted in June 1981, aboard the University of Washington research vessel ONAR. Five sonobuoy refraction lines and ten ocean bottom seismometer deployments were successfully completed using a 300 cubic inch air gun. Line lengths ranged from 4.5 to 23.5 km; the data were collected in Lake Washington and the main basin of central Puget Sound.

Results

1. The sonobuoy data obtained using the 300 cubic inch air gun, the largest used so far on this project, revealed a 6.2 km/sec refractor at a depth of about 6.5 km beneath Puget Sound. This agrees very closely with the most recent results of the least squares gravity inversion model of the subsurface density distribution beneath Puget Sound. The data strongly suggest that this refractor represents the Eocene Crescent Formation.

2. The ocean bottom seismometer data are being processed at the Woods Hole marine geology office. Preliminary results indicate good data recovery from the hydrophone but noisy results on the internal geophone channel. The cause of this could be tape recorder noise and additional processing is being done in an attempt to evaluate this problem. The OBS hydrophone data should produce a more detailed picture of the velocity structure beneath Puget Sound because of superior signal-to-noise performance compared to the moored sonobuoys.

3. A revised Bouguer anomaly map for central Puget Sound has been prepared incorporating all land and marine gravity data collected on this project as well as all Washington State and Defense Mapping Agency data. This updated detailed map is now being used for final development of the gravity inversion modeling program and analysis of the subsurface density distribution across the large Seattle gravity gradient.

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

14-08-0001-19101

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Investigations

We have measured the secular variations of five cores from marine sediments of the Southern California Borderland. All cores were collected by the Scripps Institution of Oceanography. Of these, three (all gravity cores) were considered unsuitable for magnetic correlation due to their poor physical condition and a lack of age estimates. The remaining two cores (both piston cores) were collected recently from the Santa Barbara channel.

Results

The two Santa Barbara channel cores consist of Holocene sediments (younger than ≈8,000 years. Both cores show prominent horizontal varves so that we conclude the sediments have suffered little deformation subsequent to disposition. The magnetic intensity profile of the first core contains a number of prominent peaks (with $J_{nrm} > 10$ times the mean intensity). The intensity profile of the second core is comparatively constant, however, so that we conclude that the intensity variation is controlled by extremely localized variations in deposition and hence is unsuitable for magnetic correlation between sites. Some correlations between the cores can be made on the basis of the direction of magnetization (inclination and declination), but our confidence in this correlation is low. Age determinations (from C^{14} analysis and varve counting) on these cores are being conducted at Scripps and are scheduled to be completed soon. These determinations, and the measurement of additional cores, should enable us to increase the confidence of the apparent correlations.

Alaska Seismic Studies

9940-01162

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Investigations

1. Seismic data are collected and analyzed from a network of 54 stations extending across southern Alaska from Juneau to Cook Inlet and as far north as the Talkeetna Mountains. These data establish an important base of information for the study of the tectonic deformation, the potential for moderate-to-large earthquakes, and the nature of strong motion in southern Alaska.

2. A network consisting of one three-component and four vertical-component seismic stations began operation in November 1980 with Army Corps of Engineers funding to monitor the seismicity around the proposed Bradley Lake Hydroelectric project. In October 1981 a Kinemetrics SMA1 strong motion instrument was added to the array. Data from this network are being analyzed to determine the distribution and nature of the seismicity both within the crust and within the underlying Aleutian megathrust.

3. A network of 25 Kinemetrics SMA1 strong motion instruments is being operated in southern Alaska from Kodiak to Juneau. Sixteen of these instruments are located in or around the Yakataga seismic gap in order to insure that a high-quality suite of accelerograms will be obtained from the major earthquake(s) expected within the next two or three decades.

Results

1. During the past 6 months, data processing has remained on schedule, and preliminary earthquake locations have been obtained for March through August 1981. An average of 458 events were located each month. The catalog for July-September 1980 has received Director's approval.

2. From continued monitoring of the seismicity in and near the Yakataga seismic gap some interesting variations in the rates of activity over the past 2 years have been observed. The epicenters of the earthquakes which occurred between October 1, 1979, and September 14, 1981, are shown in Figure 1. As noted in earlier reports, the spatial pattern of the seismicity is remarkably stable. Most of the activity occurs at or near the perimeter of the Yakataga gap as defined by McCann and others (1980) and Lahr and others (1980), and is dominated by aftershocks from the 1979 St. Elias earthquake. In Figure 2, the rate of activity as a function of time is shown for various subregions of Figure 1. The most striking feature in these curves is an increase in the monthly number of located events that begins in about October 1980 for the Waxell Ridge, Copper River Delta,

Saint Elias, and Wrangell subregions. The elevated levels of activity continue for about 6 to 8 months and then, except for the Waxell region, return to near those observed during the earlier time period. The increased level of activity within the aftershock zone of the 1979 St. Elias earthquakes appears to be superimposed on a long-term decay in the rate of aftershock activity which approximates the expected time^{-1} decay for aftershocks. The offshore subregion experienced a gradual increase beginning about June 1980 and returned to normal in November 1980. A review of the data processing procedures and station operation history for the time period since October 1979 suggests that although these factors may introduce some apparent changes in activity rate they are not likely sources of systematic errors that could account for the observed long term variations in seismicity rates. The seismicity rates for the regions of Northern Prince William Sound and Yakutat Bay were also reviewed, but actual changes in the rates of seismicity cannot be reliably established due to systematic biases known to exist. In the case of Prince William Sound, a change in the timing criteria to reduce the number of small events to be located coincides with an apparent sharp decrease in activity beginning in October 1980. For the Yakutat Bay region, a reduction in the number of operating stations may have introduced the apparent decrease in seismicity beginning in August 1980.

These observations suggest that a perturbation occurred in the regional stress field in and around the Yakataga gap. The possible significance of the change in seismicity as a precursor to a gap-filling earthquake is being weighed.

3. Using data from the Bradley Lake network for December 1980 through July 1981, a preliminary review was made of the first motion data for crustal earthquakes which occurred beneath the southern Kenai Peninsula. This review was made in conjunction with Woodward-Clyde Consultants, who are under contract with the Army Corps of Engineers to assess the seismic hazards in the region of the proposed hydroelectric project. Composite focal mechanisms were made for a few of the clusters of earthquakes which occurred near the mapped surface traces of major faults. The focal mechanisms were clearly only consistent with normal faulting, notwithstanding the usual systematic errors in properly locating the first arrivals on the focal sphere caused by uncertainties in the velocity structure. The principal tension axis was constrained to be oriented within about 20° of east-west. This result, in a region of northwest-directed subduction, was not expected. One possible explanation is that the crust is locally in tension now, following the 1964 earthquake, but that the stress pattern will change to northwest-southeast oriented compression in the future as stresses build up prior to another large thrust earthquake.

4. With partial support from the USGS Volcano Hazards Program, seismicity in the vicinity of three active volcanoes--Spurr, Redoubt and Iliamna--west of Cook Inlet was examined in detail for the interval October 1980 through June 1981. Locations were determined for all shallow-focus earthquakes with four or more P and S phases recorded at three or more stations. During this interval no pronounced swarms of shallow earthquakes were observed within 20 km of any of the three volcanic centers. Epicenters of five shallow shocks, ranging in depth from 0 to 10 km and in magnitude from 0 to 1.0, were located within 3 km of the summit of Spurr. In addition, a cluster of 14

events scattered through time was located 10 to 20 km south of the summit. Spurr, which is the closest volcano to the Anchorage metropolitan area, last erupted in 1953 depositing about 5 mm of ash in Anchorage. On 9 September 1979 a swarm of 47 events as large as magnitude 0.7 occurred near the summit of Spurr in an 11-hour interval. No similar activity was observed during the recent 9-month interval. Sixteen earthquakes shallower than 20 km were located in a diffuse pattern within 20 km of Redoubt, the largest of which was magnitude 2.0. The most recent eruptions of Redoubt consisted of a series of explosive ash eruptions in 1966-1968. Fewer shocks were located in the vicinity of Iliamna Volcano, two events within 5 km of the volcano summit but no others within 20 km. Iliamna has been quiescent over the last three decades.

5. On August 1, 1981, a widely felt earthquake of magnitude 5.1 occurred 15 km east of Iliamna Volcano at a depth of 105 km. This earthquake is typical of deep events that have been occurring below Iliamna since our network was installed in 1971. A review of the NOAA earthquake data file for felt events in south-central Alaska discloses that the deep zone below Iliamna has been a prominent source of felt earthquakes since at least 1963. The average recurrence rate for magnitude 5 and larger events in the Benioff zone below Iliamna volcano has been 1.5 events per year since 1969. This is a remarkably high concentration of activity compared to that in the Benioff zone elsewhere beneath southern Alaska. The epicentral area of enhanced deep seismicity is approximately 70 km in diameter and is centered approximately 15 km northwest of Iliamna Volcano. It is not known whether the spatial relationship between the deep concentration of earthquakes and Iliamna Volcano is coincidental or if there is some causal relationship.

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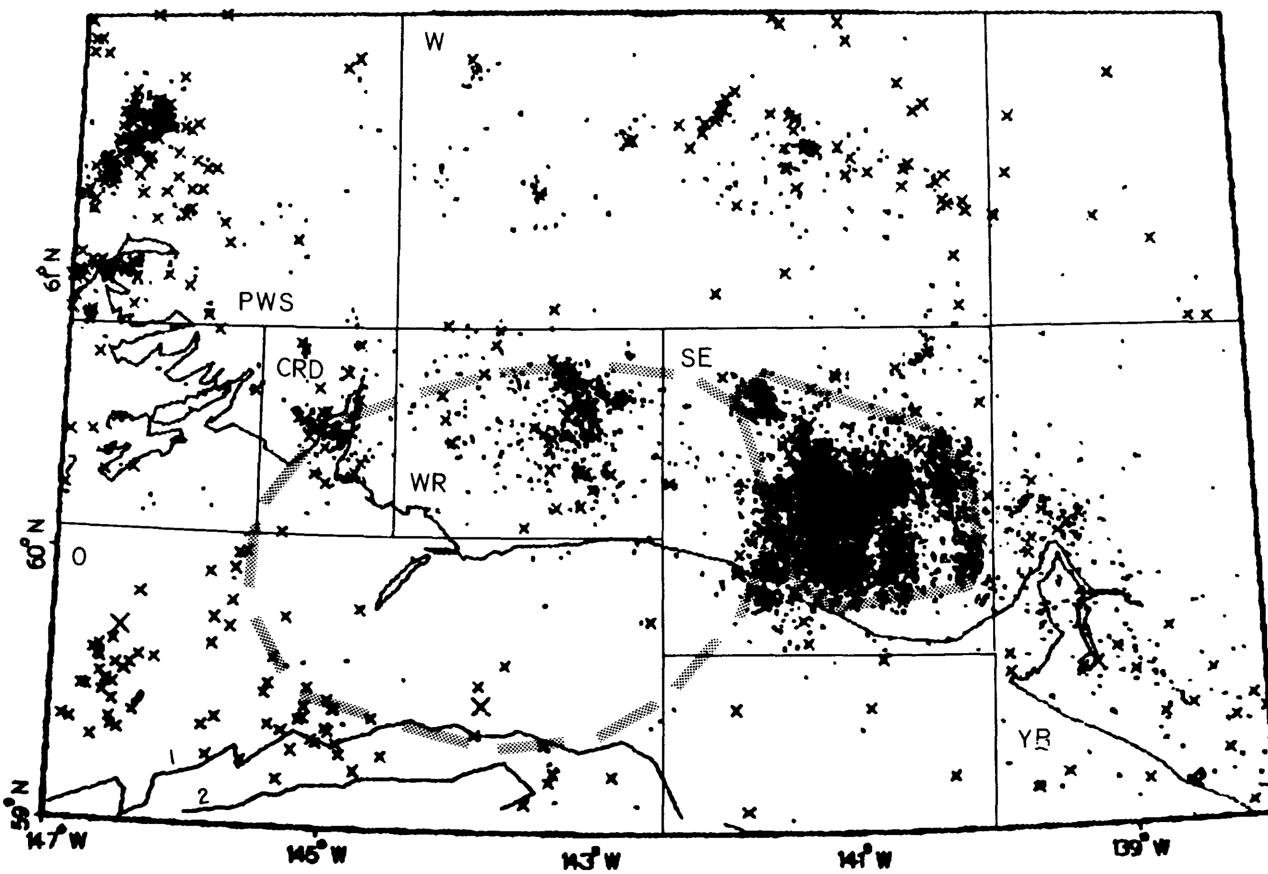

Figure 1. Epicenters of earthquakes which occurred in southeastern Alaska between October 1, 1979, and September 14, 1981. The three symbol sizes correspond to earthquakes in the magnitude ranges less than 2, 2.0 to 3.9, and greater than 3.9. The rupture zone of the 1979 St. Elias earthquake (M_S 7.1) is indicated by a solid line, and the Yakataga seismic gap is outlined by the light dashed line. Letters correspond to subregions of Figure 2 as follows: O) offshore, CRD) Copper River Delta, WR) Waxell Ridge, SE) St. Elias, W) Wrangell, YB) Yakutat Bay, PWS) northern Prince William Sound. Depth contours are in thousands of fathoms.

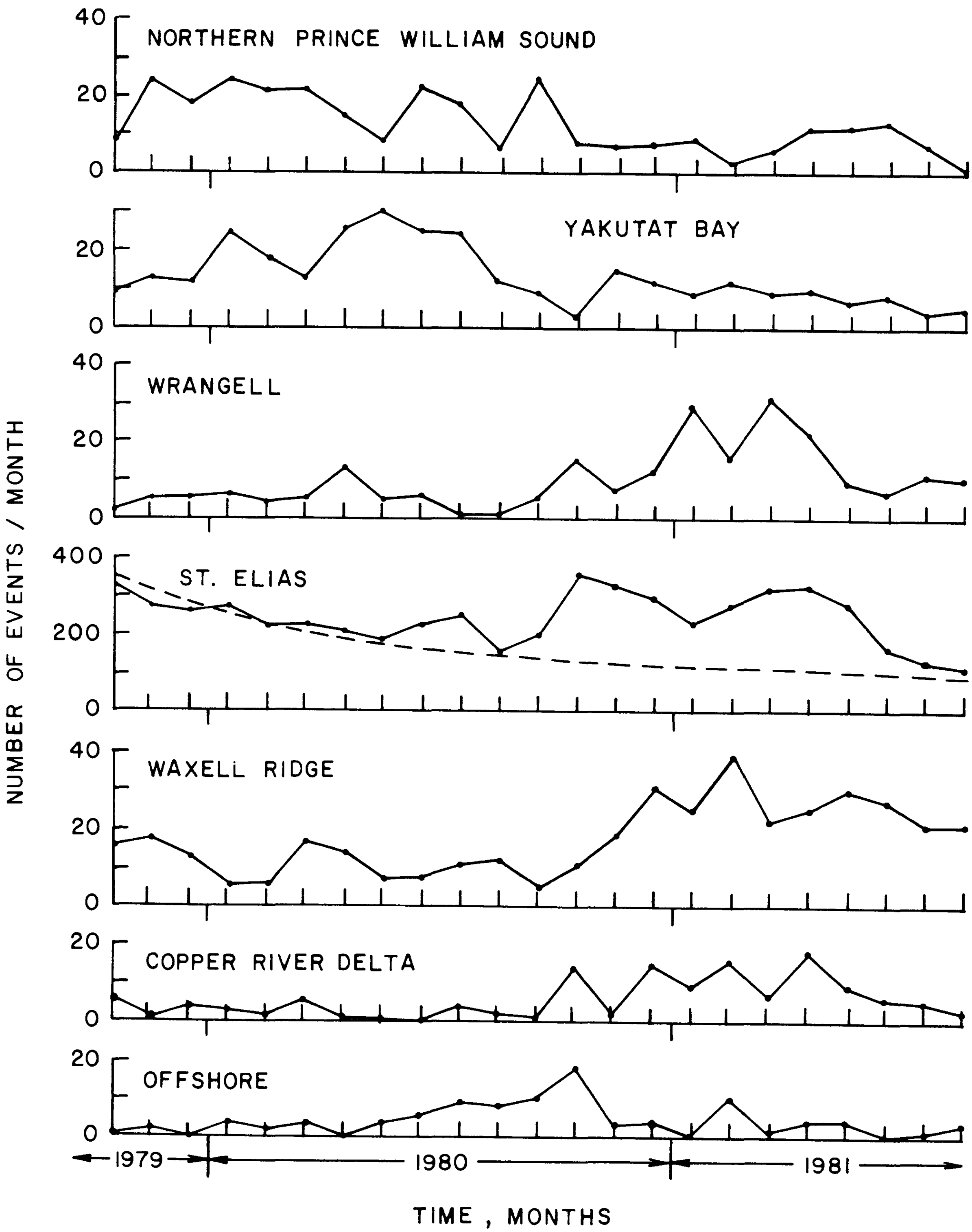

Figure 2. Number of located earthquakes as a function of time for the subregions indicated in Figure 1. The dashed line in the St. Elias graph represents a time^{-1} decay in aftershock activity. Note the difference in scale for the St. Elias region.

Study of Seismic Activity by Selective Trenching Along the Elsinore Fault Zone, Southern California

Contract No. 14-08-0001-19144

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Investigations

Published literature and engineering geology reports bearing on potential seismicity of the Elsinore fault zone were reviewed. A field reconnaissance was accomplished to locate promising sites where trenches might reveal datable Holocene fault displacement and possibly times between major seismic events. Nine sites which have the potential of revealing ruptured Holocene sediments across strands of the Elsinore fault zone have been identified. Sites S-1 (Fig. 1), S-6 (results presented in Lamar and Swanson, 1981) and S-8 along the Wolf Valley fault southeast of Temecula have been trenched.

Results

A test trench at Site S-1 across the Glen Ivy North fault revealed lake sediments in a partially filled sag pond faulted against alluvium and lake sediments (Fig. 2). Radiocarbon analysis of carbon residue and humic acids in a disrupted carbonaceous layer (Fig. 2) revealed ages of 710 $\pm$ 90 years and 480 $\pm$ 190 years B.P., respectively. The dated layer occurs as much as 2½ meters below the surface and is truncated by the base of the soil at an average depth of 1.0 meter. Thus, the event which ruptured the strata could be significantly younger than the dated layer. Disrupted beds and a possible local unconformity at -4.0 to -4.5 meters and 8 meters horizontal (Fig. 2) indicate an earlier event. Deeper trenching and additional radiocarbon analyses would be required to verify and date this event.

Trenches across a closed depression along the Wolf Valley fault (Site S-8) failed to reveal any fault-disrupted beds.

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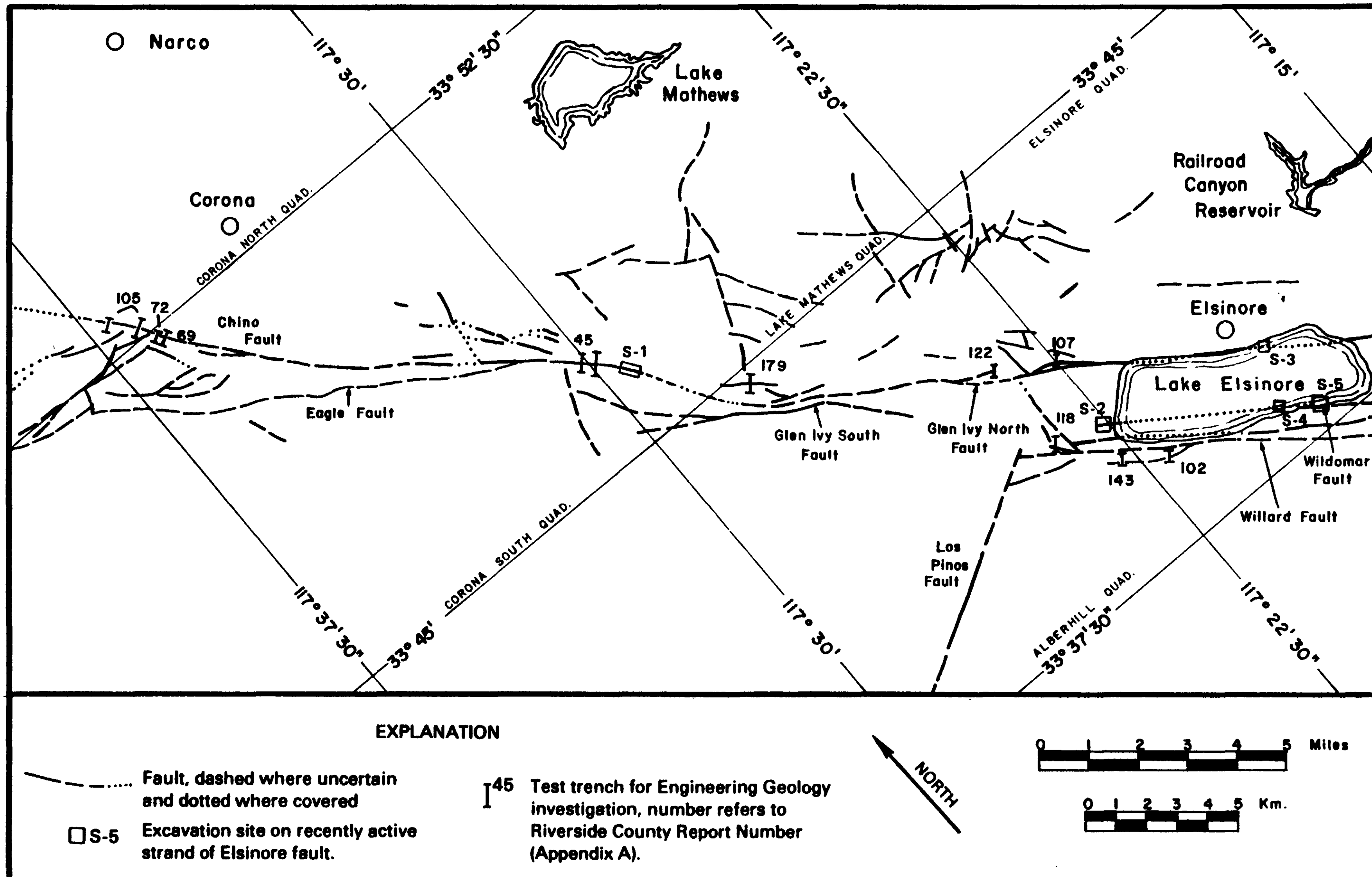

Fig. 1 - Map showing Elsinore fault zone between Corona and Lake Elsinore and excavation sites. From Rogers (1965) with modifications based on Weber (1977).

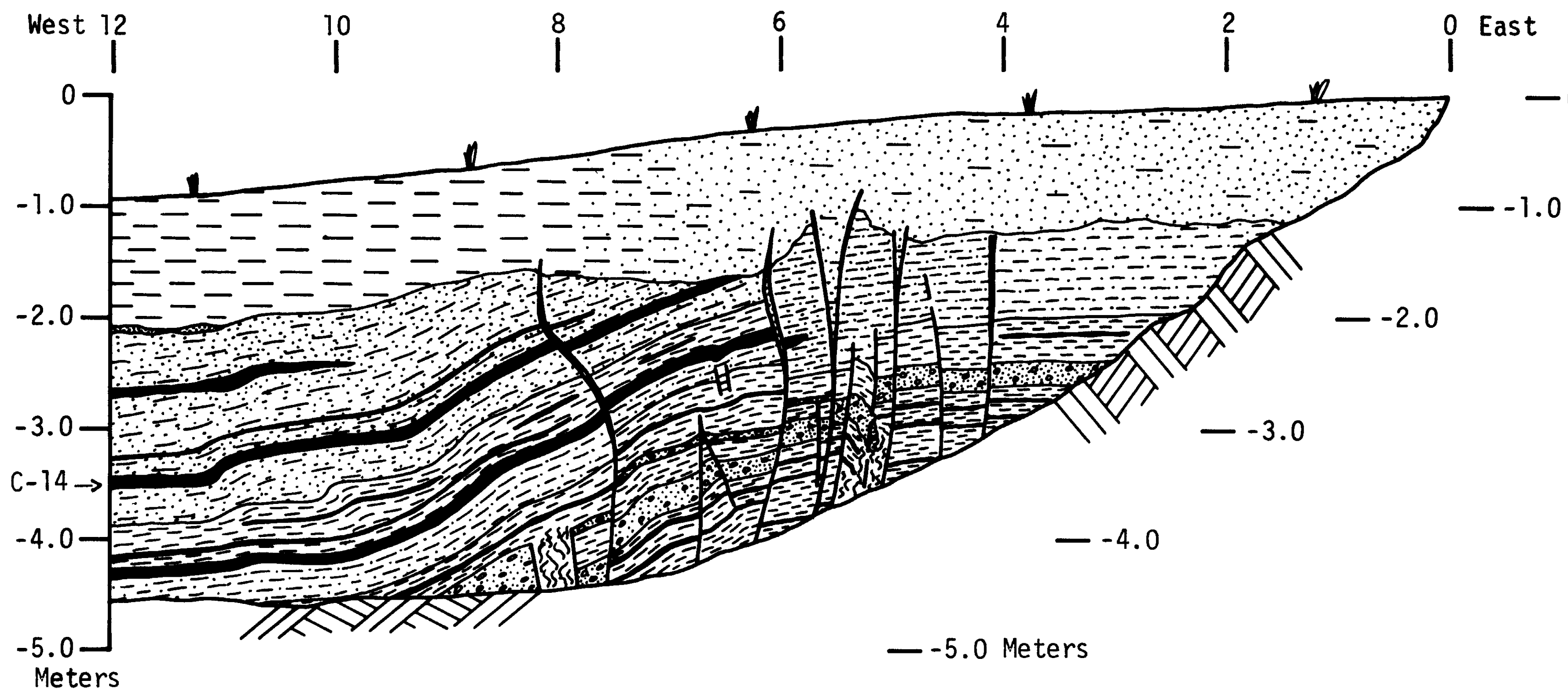

Fig. 2 - Log of test trench across Glen Ivy North fault (S-1 on Fig. 1). Lake deposits to west faulted against alluvial fan and lake deposits to east. C-14: layer dated by radiocarbon analysis.

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

9540-01616
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Investigations

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

2. Studies of neotectonic patterns within the Cucamonga Fault zone. The study has focussed mainly on faulting recurrence based on the morphology and distribution of scarps in multiple Holocene and late Pleistocene alluvial units. Together with J. C. Tinsley we have attempted to reconstruct possible seismic moments and vertical ground-surface displacements for ground-rupturing earthquakes within the fault zone.

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

Results

1. A depth-to-groundwater contour map for the entire upper Santa Ana River valley has been prepared utilizing California Department of Water Resoures water-well data. For each well we selected the shallowest reliable ground-water value recorded during the period 1972-1980. When contoured, these date show several zones of shallow (<50 feet) ground water: (A) Along the San Gabriel Mountain front west of San Antonio Canyon, and in the vicinity of Claremont and Cucamonga; (B) Within and marginal to the Santa Ana River channel from the San Jacinto Fault southwest to Prado flood control dam; (C) In the Arlington, Glen Avon, and southwest Riverside districts of Riverside county; (D) At several localities marginal to the South Branch of the San Andreas Fault north of San Bernardino and northeast of Redlands; (E) Underlying part of the San Bernardino metropolitan area northwest of the San Jacinto Fault groundwater barrier. We have not yet documented the presence or

distribution of materials susceptible to liquefaction in these areas of high water. However, preliminary examination of surficial deposits suggests that susceptible materials are present in the shallow subsurface of metropolitan areas of San Bernardino where shallow groundwater occurs.

2. The Cucamonga fault zone is a 1-kilometer-wide, east-striking thrust-fault complex that forms the southern front of the eastern San Gabriel Mountains. Faulting within the zone has recurred episodically throughout all of Quaternary and probably latest Tertiary time. The oldest faults occur within the northern part of the fault zone where some faults cut crystalline basement rock but do not affect even the oldest Quaternary units. Younger faults, Cucamonga Strands A, B, and C, occur farther south at the mountain front. Stand A breaks older Quaternary alluvial units but is concealed beneath younger Quaternary alluvial units. The youngest faults within the zone, Strand B and Strand C, occur farther south and form conspicuous scarps in young Quaternary alluvial fans. These relationships suggest that during late Pleistocene and Holocene time faulting within the Cucamonga Fault zone may have migrated southward.

We recognize four Pleistocene alluvial units (Qoa_{1-4}) and five Holocene alluvial units (Qya_{1-5}) within the Cucamonga fault zone. With respect to these alluvial units, Strands A, B, and C have experienced distinctive fault-movement histories that collectively constitute the neotectonic history of the fault zone. Confirmed displacements on Strand A occurred after the deposition of Qoa_2 and again after the accumulation of the oldest deposits of Qya_1, but not since that time. Strand B forms a prominent scarp throughout the entire length of the Cucamonga fault zone, but Strand C forms scarps that can be traced as discrete features only in the eastern part of the fault zone. Recurring displacements on Strands B and C disrupted evolving alluvial deposits of Qya_1 and Qya_2. Ground rupturing events on Strand B apparently ceased during the early stages of Qya_3 alluviation, but ground rupture continued to occur on the nearly pristine Strand C. The latest ground rupture on Strand C occurred prior to the deposition of 700 $\pm$ 200-year-old alluvium of Qya_3 that laps over the fault on Day Canyon fan.

Seismic-moment calculations, empirical fault-length/displacement relations, and limited field data suggest that vertical ground displacements of 2 m are reasonably expectable within the Cucamonga fault zone. Assuming a fault-movement model incorporating a succession of same-sized 2 m events, we calculate average recurrence interals of 1625 years for eight 2-m displacements on Strand C and 1000 years for ten 2-m events on Strands A and B during 13,000 years of late-Pleistocene and Holocene time. Assuming the faults ruptured independently of each other to produce eighteen discrete 2-m events during this 13,000-year period, these estimates for each strand suggest an arithmetic-mean recurrence interval of about 700 years for 2-m ground ruptures on all strands in the eastern part of the Cucamonga fault zone. Because the pristine-appearing Strand C apparently has not produced ground rupture since its truncation by 700 $\pm$ 200 year-old alluvium of Qya_3, a 700-year average recurrence for faulting within the Cucamonga Fault zone would suggest that the zone may be due for a magnitude 6 to 7 earthquake comparable to the 1971 San Fernando Valley event.

From west to east within the Cucamonga fault zone, late-Pleistocene and Holocene strain release has been distributed along increasing numbers of discrete fault strands: Strand A/B/C at the extreme west end of the zone, Strand A and Strand B/C in the central part of the zone, and Strand A, Strand B, and Strand C in the eastern part of the zone. Moreover, latest episodes of strain release may have occurred mainly on Strand C in the eastern 15 km of the Cucamonga fault zone, rather than throughout the entire 25-km length of the fault zone. The progressive increase in the number of discrete fault strands comprising the fault zone and the observed progressive youthfulness of faulting eastward within the fault zone suggest that both the timing and the distribution of faulting become more complex eastward along the Cucamonga fault zone toward its junction with the San Jacinto fault zone.

3. As summarized by Morton and Matti (1981), Quaternary reverse and thrust faults of the Banning Fault zone extend westward from San Gorgonio Pass only so far as the Calimesa area. Farther west, youthful faults in the vicinity of lower San Timoteo Canyon and Live Oak Canyon that are along strike with the Banning Fault zone have no connection with the Banning. Instead, these young structures are part of a family of normal faults that bound the generally northeast-trending Crafton Hills block that extends from San Timoteo Canyon northeastward nearly to the South Branch of the San Andreas Fault.

Preliminary mapping indicates that in lower San Timoteo Canyon the young faults have east-west orientations, but develop northeasterly orientations as they are traced from the Redlands Heights/Live Oak Canyon area northward through Yucaipa Valley. Along their courses these faults break young Quaternary alluvium, have downthrown blocks on the southeast, and form the southeastern flank of the Crafton Hills block. Their counterparts on the northwest flank of the Crafton Hills block are the Crafton Fault and the Redlands Fault (Morton, 1978). Together with the Chicken Hill Fault, all these normal-fault structures define a northeast-oriented horst-and-graben system that on the southwest interacts in some unknown way with the San Jacinto Fault.

The origin of the Crafton Hills horst-and-graben system seems to be related to interaction between the South Branch of the San Andreas Fault, the Banning Fault zone, and the San Jacinto Fault. The San Bernardino Valley presently is moving northwestward via right-lateral displacements on the South Branch. However, significant late Quaternary right slip on the South Branch may not have occurred efficiently along that portion of the fault that extends southeast from the vicinity of the Crafton Hills horst-and-graben complex. This interpretation is suggested by the absence of well-developed fault physiography along the South Branch between Mill Creek and Banning Canyon. We suggest that the Crafton Hills horst-and-graben complex has been forming during late Quaternary time as the San Bernardino Valley moves northwestward away from the region of the knot in the San Andreas Fault system. This knot region, centered in San Gorgonio Pass, is the site of Quaternary Banning-B and Banning-C reverse and thrust faulting that extend as far west as the Calimesa area (Morton and Matti, 1981). As the San Bernadino Valley moves northwestward away from the knot region, the crust appears to be breaking up and pulling apart in the vicinity of the Crafton Hills horst-and-graben complex.

By this interpretation the northwest-oriented triangle of the San Bernardino Valley, bounded by the San Andreas and San Jacinto Faults, at times must be welded or attached to the Perris block at about the latitude of lower

Bernardino Valley as a unit requires simultaneous operation of the following constraints: (a) northwestward right-slip along the San Jacinto Fault occurs south of the latitude of lower San Timoteo Canyon; (b) northwestward right-slip along the South Branch occurs northwest of the Crafton Hills horst-and-graben complex; (c) the Crafton Hills complex pulls apart in the wake of northwestward movement of the San Bernardino Valley; (d) if the San Bernardino Valley is attached to the Perris block, that portion of the San Jacinto fault that traverses the San Bernardino Valley intermittently must be locked up and quiescent in terms of large earthquakes. This hypothesis may account for the seismic-slip gap hypothesized for this portion of the San Jacinto Fault by Thatcher and others (1975).

When viewed in terms of the overall fabric of crustal-block boundaries in this part of southern California, the Crafton Hills horst-and graben system should be considered as a significant neotectonic element.

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

9940-03005

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Investigations

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

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

3. Continued investigation of crust and upper mantle velocity structure beneath southern coastal Alaska in cooperation with George Zandt at the University of Utah.

Results

1. Earthquakes for the interval April through July 1978 were timed, scaled, and located using the new four-film digitizing table and interactive mini-computer. A quarterly catalog of earthquakes for April-June 1978 is in preparation. Earthquakes from August 1978 are currently being processed.

Additional improvements to the four-film data processing system have recently been completed to facilitate and speed routine earthquake analysis. Prior to the recent improvements, about a factor of 1.5 increase in the speed of data processing has been realized using the interactive digitizing system.

2. As an initial step in the relocation of teleseismically recorded earthquakes in and around the Yakataga seismic gap, the resolution of the master event technique for precisely locating earthquakes is being investigated using a cluster of aftershocks of the 1964 Alaska earthquake, located on the western edge of the gap. A tape of phase data compiled by the International Seismological Center has been obtained for Alaskan earthquakes from 1964 through 1974.

3. P-wave arrival times were read for about 50 teleseisms recorded by the USGS southern Alaska seismograph network. About 30 of these events were sufficiently well recorded to be used in a three-dimensional block inversion of crust and upper mantle velocity structure. The arrival-time data were sent to George Zandt, who will perform the inversion.

Geologic Earthquake Hazards in Alaska
9310-01026

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Investigations

1. Carried out a reconnaissance study of surface features along the young-looking trace of the Anvik fault near Unalakleet (with W. W. Patton and T. Matsuda of EERI).

2. Made an examination of supposedly offset river terraces along the Healy Creek fault near Healy (with R. E. Wallace and T. Matsuda).

3. Examined selected shorelines that were uplifted during the 1964 Alaska earthquake to determine the nature and extent of post-quake vertical displacements (with R. E. Wallace and T. Kato of EERI).

4. Collected samples for comparative paleomagnetic study from Tertiary marine sedimentary rocks in the Prince William terrane and Yakutat block (with Jack Hillhouse and Sherman Grommé).

Results

1. The Anvik fault is a major north-northeast-trending dextral fault 175 km long that was mapped by W. W. Patton in an apparently aseismic region of western Alaska. It is bounded on the southwest by the Chirosky fault and on the northeast it appears to trend obliquely into the Kaltag fault. For part of its trace the fault is characterized by discontinuous southeast-facing steep slopes that have the appearance of fault facets as well as alined linear valleys, notches in ridges, and local closed graben-like topographic depressions. However, no definite offsets could be found in talus, alluvial cones, or other unconsolidated surficial deposits along the fault trace. Most of the surface features observed along the fault can be explained as due to stream and periglacial erosional processes controlled by the combination of a zone of weakness along the fault and the occurrence of relatively more resistant rocks on the northwest side of the fault. The possibility of Quaternary displacement cannot be ruled out, although any scarps that may have formed in the surficial deposits along the fault trace have been obliterated. A major unknown in this terrane, which is characterized by active permafrost processes in an area that was not subject to Pleistocene glaciation, is the rate at which scarps and other fault features are degraded.

One 3-km-long segment of the fault near the headwaters of the Anvik River in the Unalakleet C-3 quadrangle is particularly noteworthy for its youthful-looking topography. This part of the fault is marked by a strikingly linear and smooth southeast-facing slope 60-90 m high and a prominent bench at the base of the slope. Average slope angles are about 30°-33° with a local steepening in the lower 1.2-3 m to angles varying from 39° to 45°. The steeper lower part of the slope is strongly modified by ground squirrel burrows, by excavations made by bears while digging for ground squirrels, and by formation of nivation hollows at snowbanks that commonly form along the slope break. At the base of the slope there is a bench about 7 m wide that dips gently westward towards the steep ridge front. The bench locally has closed shallow depressions to 0.9 m deep that parallel the ridge. The initial impression is of a trace comparable to active normal faults in the Great Basin region. However, the localized extent of these features and their relationship to the topography suggest, instead, that this segment of the fault trace may be modified by northwestward gravitational sliding. In this area active downcutting by the Chirosky River has incised the area northwest of the fault some 120-180 m below the surface fault trace. As a consequence, a block of terrane about 4.8 km^2 that is bounded on the southeast by the Anvik fault appears to have moved roughly 7 m into the Chirosky River drainage on a westward-dipping slide plane. Sliding would account for the occurrence of the westward-dipping bench and related youthful features along this short segment of the fault trace. If correct, this interpretation suggests that the gravitational sliding accompanied or followed the last movement on the Anvik fault. The common occurrence of "sackung" throughout this region indicates that large-scale gravitational processes are extremely active.

2. In 1978, R. M. Thorsen of the University of Washington described in an unpublished report offset river terraces near Healy that he interpreted as evidence for recurrent late Quaternary movement along a fault he named the Healy Creek fault. Our levelling across the small gully in which these river terraces are exposed indicates that there is no clear evidence for offset of the terrace surface which is reported by Thorsen to be underlain by glaciofluvial deposits of Riley Creek II age (10,000-100,000 years B.P.). This suggests to us that there has been no Holocene movement on the Healy Creek fault. However, as noted by Thorsen, there is evidence in the north bank of the gully of progressive offset within the Riley II terrace deposits along a narrow zone trending N65E and dipping about 65°NW. Although the stratigraphic relationships across this feature are not entirely clear, they can best be interpreted as indicative of a reverse fault, rather than a normal fault as interpreted by Thorsen. Offsets in the terrace deposits suggest at least two episodes of displacement during Riley Creek time--an earlier one of 25 cm and a later one of 70 cm. Additional detailed work, including trenching, is needed along this fault to prove the apparent absence of displacements that postdate Riley Creek II deposits (post 10,000 years).

3. Analysis of level data near Anchorage indicates that as much as 29 percent of the 1.9 m coseismic vertical tectonic displacement that occurred during the 1964 Alaska earthquake was recovered in the decade following the earthquake (Brown and others, 1977, JGR, v. 81, no. 23, p. 3369-3378). Furthermore, an examination of tide gage records suggests that postseismic recovery may be a general phenomenon in the region that subsided during the earthquake, but that little or no change has occurred at the one permanent tide station in the uplifted region (Cordova).

A reconnaissance examination was made of shorelines in the area of coseismic uplift within Prince William Sound and westward to Kayak Island to determine the extent and magnitude of postseismic changes. Emphasis was placed on areas where large uplifts were measured in 1964. The data obtained were from measurements of 1) the difference in elevation between the upper limits of living barnacles and the in situ remains of barnacles killed by uplift in 1964, 2) the difference in elevation between the lower limit of 1964 terrestrial vegetation and post-earthquake vegetation, and 3) the elevation of post-earthquake tidal bench marks relative to known high tide levels.

Our data do not indicate any significant postseismic changes in the part of the uplifted region extending from Evans Island to Montague Island, Green Island, the Cordova area, Katalla, and Kayak Island. Although the measurement techniques are not as precise as those obtained with tide gages or levelling, the data definitely preclude changes of more than 5 percent of the coseismic displacements, and they do not require any postseismic changes.

4. The samples collected for paleomagnetic studies are in the process of being analyzed. Results are not yet available.

Reports

Bruns, T. R., Carlson, P. R., and Plafker, George, 1981, Structural deformation in northern Gulf of Alaska: Transition from transform to convergent plate motion abs. : American Association of Petroleum Geologists Bulletin, v. 65, no. 5, p. 907.

Jones, D. L., Silberling, N. J., Berg, H. C., and Plafker, George, 1981, Map showing tectonostratigraphic terranes of Alaska, columnar sections, and summary description of terranes: U.S. Geological Survey Open-File Report 81-792.

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Winkler, G. R., and Plafker, George, 1981, Tectonic implications of framework grain mineralogy of sandstone from the Yakutat Group, in Albert, N. R. D., and Hudson, Travis, eds., The United States Geological Survey in Alaska: Accomplishments during 1979: U.S. Geological Survey Circular 823-B, p. B68-B70.

SEISMIC ZONATION STUDIES IN LOS ANGELES BASIN

9940-01730

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Investigations

1. A manuscript entitled "a Comparative Ground Response Study Using Nuclear Explosions and the 1971 San Fernando Earthquake" was revised.

2. Work during this period was largely concentrated on the Southern Great Basin Seismic Studies program, a DOE funded study that is part of the Nuclear Waste Isolation program. This work included a year-end progress report, preparation of a talk for the annual Peer Panel Review, installation of a Dec 11-34 computer and software that does real time event detection for the seismic network, deployment of a portable digital network in the southern NTS region, and deployment of a permanent 6-station network on Yucca Mountain, the site that is currently under intensive study.

Results

1. No new results.

Reports

Rogers, A. M., Harmsen, S. C., and Carr, W. J., 1981, Southern Great Basin Seismological Data Report for 1980 and Preliminary Data Analysis, U.S. Geol. Surv. Open-File Rpt.81-1086, 148 p.

Khattri, K. N., Rogers, A. M., Perkins, D. M. Algermissen, S. T., 1981, A Seismic Hazard Map of India and Adjacent Regions (dir. approval).

Earthquake Hazard and Prediction Research in the Wasatch Front--Southern Intermountain Seismic Belt
14-08-0001-19257

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Investigations

1. Seismicity and elastic deformation associated with Basin and Range faulting in northern Utah.

2. Upper crustal structure of the Salt Lake Valley and the Wasatch fault from seismic modeling.

3. Subsurface geometry of major normal fault zones based on seismic reflection--and contemporary seismicity.

4. Reprocessing of seismic reflection line across Wasatch fault south of Ogden.

5. Seismic moment studies in the Utah region.

6. University of Utah seismic network: Network operations and seismicity through September 30, 1981.

Results

1. Continuing investigations relate observed seismicity in northern Utah to specific models of crustal deformation. Detailed seismicity data are provided by a special-study (10-20 km spacing) telemetry array covering the northern Wasatch and east Cache faults. Focal mechanisms reveal evidence for unexpected high-angle reverse faulting near Little Mt., 30 km NW of Logan. We have initiated testing the inversion of (SP/V) amplitude ratios to constrain focal mechanisms of local earthquakes.

In order to provide flexibility for representing complex fault structure and geometry,we are testing two methods of modeling elastic deformation for more realistic dislocation geometries and distributions. One method is a simple extension of the edge dislocation formulation of Freund and Barnett (1976) to allow curvilinear slip planes. We are using this technique to study deformation associated with listric normal faults. A focus of this research is the Ogden, Utah, region where geodetic data indicate anomalous E-W compression across the Wasatch fault zone. Preliminary results indicate the compression may be due to westward block motion of a portion of the adjacent Wasatch Mountains along a listric normal fault within the mountain block.

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*Final Technical Report includes contributions also from W.M. Bashore, D.I. Doser, G.M. Hathaway, P.J. Oehmich, T.J. Owens, G. Randall, and L.L. Sells.

In conjunction with Tom Soler and Richard Snay of the National Geodetic Survey a manuscript is in preparation summarizing the relationship of Cenozoic geology, earthquakes, and fault plane solutions to USGS-NGS geodetic data along the Wasatch Front. The geodetic data indicate E-W compression across the Wasatch fault near Ogden changing to E-W extension across the fault S of Salt Lake City.

2. In 1976 two unreversed seismic refraction profiles were recorded parallel and perpendicular to the Late Cenozoic structures in the Salt Lake Valley using large quarry blast sources. Three-component seismic data were modeled, principally using P-arrivals, utilizing an asymptotic ray tracing algroithm (McMechan and Mooney, 1980) for travel-times and synthetic seismograms in laterally inhomogeneous media. Modeling the line that crosses the Wasatch fault, suggests an asymmetrical eastward-deepening basin bounded on the east by a segmented normal fault that flattens in dip with depth (Figure 1). A narrow (∿3 km) lateral velocity gradient zone, east of the mapped fault, is necessary to satisfy the arrivals. Values of average fault dip (to 4 km depth) from 25° to 40° could be fit to the observed data (average station spacing, ∿2 km). Differing from other models of northern Utah, a high velocity (6.25 km/sec) laterally inhomogemeous layer at 5.1 to 7.0 km depth was necessary to fit arrivals east of the fault. These models are not sufficient to interpret the Wasatch fault as being listric; however, they do suggest that it has a significantly shallower dip with depth than is seen at the surface.

3. Epicenters in the Intermountain region, including those determined by JHD and inverse methods, generally show poor correlations with Late Cenozoic fault traces. Seismic reflection data from the Wyoming-Utah overthrust belt suggest that listric faulting may be intrinsic to current deformation of thrust-belt structure--providing a possible mechanism for accommodating extensional earthquakes. In an hypothesized model of listric faulting, rotation of valley fill (accentuated by erosion of nearby mountain blocks and by regional extension) may produce slip along a fault surface that flattens with depth and that may connect to a basal detachment surface. Behind the sediment prism, upfolding may accommodate the infill resulting in excessive bending moments that produce additional seismic release. Well determined focal depths cluster near 7 km and 80% of all events occur above an inferred upper-crustal low-velocity layer at ∿10 km--suggesting the correlation of a basal detachment with a zone of low rigidity. Results to date in central and SW Utah suggest the predominance of seismic slip on fault segments with moderate dip (40°-60°), either the upper portion of W-dipping downward-flattening faults, or related E-dipping antithetic faults. Five of 19 fault-plane solutions along the main seismic zone between 37°N and 40°N have one nodal plane dipping less than 30° (including 3 questionable cases). For the other 14 solutions the average dip of nodal planes is 53° (±17°). In one key study near the S end of the Wasatch fault, diffuse upper crustal seismicity appears to correlate in cross-section with imbricate curvilinear faulting, far more complex than typically envisioned for basin-range structure--but well familiar to petroleum geologists actively working the area.

4. A seismic reflection line that extends perpendicular from the Wasatch fault near Ogden, Utah, was recorded by the DOE and has been released to us for interpretation. These data suggest a shallow west-dipping reflector that extends beneath the valley of the Wasatch Front, perhaps representing the Wasatch fault dipping westward at a low

angle beneath Ogden. These data, because of strong lateral velocity variation, require migration before final interpretation. The reflection data are being reprocessed in conjunction with the Research Section of Western Geophysical Corp., Houston, Texas.

5. A completed manuscript entitled "Seismic Moment Rates in the Utah Region" has been submitted for publication in the Bulletin of the Seismological Society of America. An addition to the research since 1980 is an estimation of return periods for an earthquake of $6\frac{1}{2} < M_L < 7\frac{1}{2}$, from geologic moment rates, for four segments of the Wasatch fault. The return periods agree well with recurrence intervals estimated from trenching studies.

6. During the 12-month period of this contract, 464 earthquakes were located within the Wasatch Front study area (698 within the Utah region) including six shocks with $M_L \geq 3.0$. A new seismicity catalog Earthquake Data for the Utah Region, July 1, 1978 to December 31, 1980 will be disseminated in November 1981. The catalog includes 2,209 earthquakes ($M_L \leq 4.6$), of which 33 were reported felt, and extends our published earthquake record up to the point where computerized central recording of the University of Utah seismic network began. After a 3-month testing and debugging period, our PDP 11/34-11/70 computer system began routine event detection, recording, and processing on January 1, 1981. The system has proved considerably more reliable on the whole than our previous system of five Develocorders, allowing for efficient earthquake location processing and a data backlog of typically less than two weeks.

Reports and Publications

Arabasz, W. J. and R. B. Smith (1981). Earthquake prediction in the Intermountain seismic belt--an intraplate extensional regime, in Earthquake Prediction, An International Review, D. W. Simpson and P. G. Richards, Editors, American Geophysical Union, Maurice Ewing Series 4, 248-258.

Bashore, W. M., Jr. (1981). Upper crustal structure of the Salt Lake Valley and the Wasatch fault from seismic modeling, M.S. Thesis, University of Utah, Salt Lake City, Utah, 93 pp.

Doser, D. I. and R. B. Smith (1981). Seismic moment rates in the Utah region, Bull. Seism. Soc. Am. (submitted).

Hawley, B. W., G. Zandt and R. B. Smith (1981). Simultaneous inversion for hypocenters and lateral velocity variations: An interative solution with a layered model, J. Geophys. Res. 86, 7073-7086.

McKee, M. E. and W. J. Arabasz (1981). Microearthquake studies across the Basin and Range-Colorado Plateau transition in central Utah (abstract), Earthquake Notes 52 (1), 62. (Partially supported by USGS contract.)

Owens, T. J. (1981). Normal faulting and flexure in an elastic-perfectly plastic plate, Tectonophysics (submitted).

Richins, W. D., G. M. Hathaway, P. J. Oehmich, L. L. Sells, G. Zandt and W. J. Arabasz (1981). Earthquake Data for the Utah Region, July 1, 1978 to December 31, 1980, University of Utah Seismograph Stations, Salt Lake City, Utah.

Richins, W. D. and G. Zandt (1981). Seismicity and elastic deformation associated with Basin and Range fault blocks in northern Utah (abstract), Earthquake Notes 52 (1), 63.

Soler, T., R. A. Snay, and R. B. Smith, (1981). Geodetically derived strain near Salt Lake City, Utah, (abstract), American Geophysical Union, EOS 62, 394.

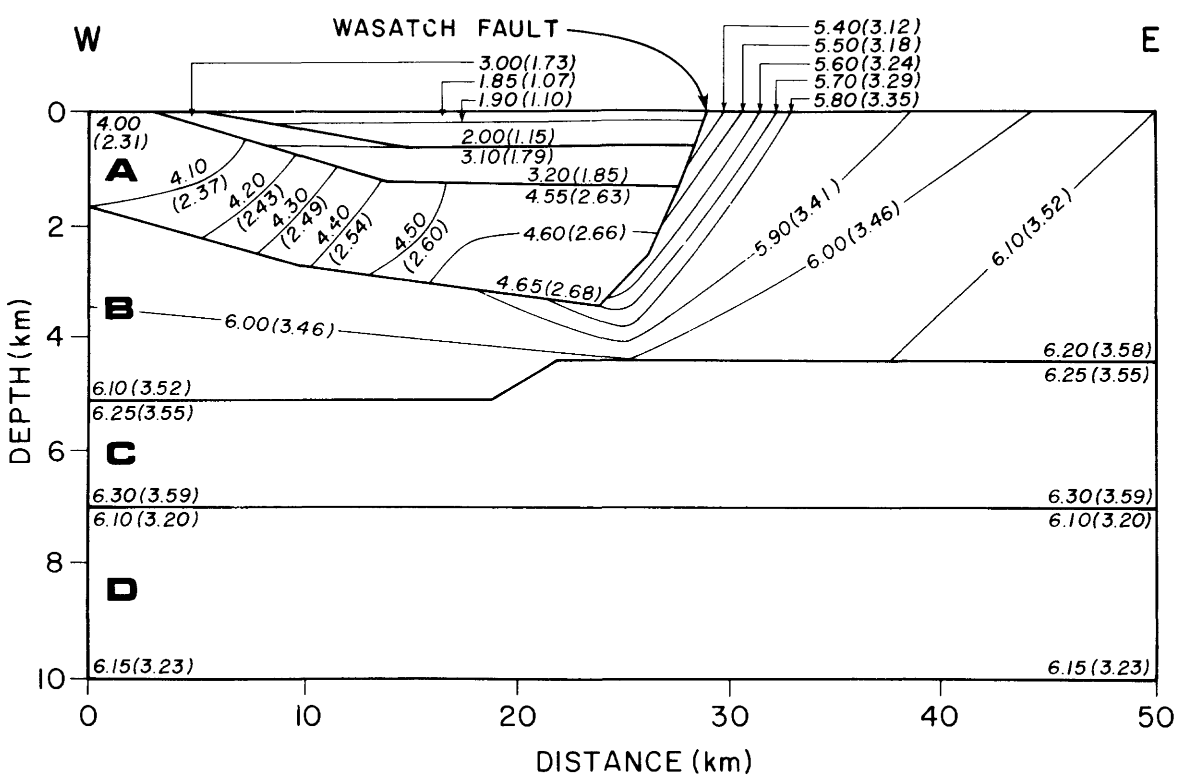

Figure 1. Velocity structure derived from modeling amplitude and travel-time data from seismic refraction profile (and from observed gravity) across the Wasatch fault 25 km south of Salt Lake City. Small numbers indicate P-wave and S-wave (in parentheses) velocities.

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

14-08-0001-19261

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

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

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

We are currently upgrading our network with the addition of six-eight new sites in the Los Angeles area. We are extending our coverage of the Newport-Inglewood fault south along the coast toward Laguna Beach. Many of the new sites will be located in boreholes at depths of 100 m or greater. This should significantly improve our detection threshold.

Quaternary Framework for Earthquake Studies
Los Angeles, California

9540-01611

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Investigations

1. Completed installing on the U.S.G.S. computer the geotechnical data base for the western part of the San Fernando Valley, California (J. Tinsley, M. Vivrette, D. Ponti, and K. Seals).

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

3. Commenced comparing geologic units with potential indicators of ground response such as shear wave velocity, void ratio, granulometric characteristics, and geologic age. Updated ground motion geotechnical data base. (J. Tinsley, A. M. Rogers, J. Gibbs, T. Fumol, and D. Ponti).

4. Initiated and completed an exploratory drilling program to obtain thickness measurements and geotechnical properties of near-surface geologic units in the western San Fernando Valley (J. Tinsley, T. L. Youd, C. Hastorf, S. Shaler, M. Bennett, and J. Sarmiento).

5. Continued analyzing and interpreting chemical and physical characteristics of pedogenic soils based on five chronosequences along a transect across southern California from the Los Angeles Basin and San Gorgonio Pass across the Mojave desert to the Vidal area (L. D. McFadden and J. Tinsley).

6. Revised reconnaissance soils-geomorphic study of the Cucamonga Fault Zone and forwarded manuscript to Technical Reports Unit, Menlo Park (J. Matti, D. Morton, and J. Tinsley).

7. Continued investigation and analysis of the Lompoc, California earthquake of April 7, 1981 (R. F. Yerkes, M. G. Bonilla, W. L. Ellsworth, A. G. Lindh and J. C. Tinsley).

8. Initiated and completed 1:125,000 compilation showing near-surface groundwater in the San Gabriel Valley and Coastal Basin areas of Los Angeles County. (J. Tinsley and B. Silverstein).

9. Assigned to separate investigations 15% of this reporting period.

Results

1. Analysis of physical and geotechnical properties of near surface geological materials in three dimensions in the western San Fernando Valley can commence upon completion of two computer programs currently in the last stages of debugging (D. Ponti and J. Tinsley).

2. Surficial geologic mapping is 80% complete.

3. Initial comparisons indicate sites on Holocene deposits have greater impedance contrasts, lower shear wave velocities, higher void ratios, and tend to have relatively higher amplification of ground motion as indicated by recordings of nuclear tests compared to sites located on Pleistocene deposits.

4. Fourteen exploratory holes were drilled to depths of about 20 m at 7 sites in the Canoga Park-Reseda area. Standard penetrometer tests, Dutch cone penetrometer tests and corkscrew (continuous-flight augering) techniques were used to examine, test, and sample near-surface geologic materials. In general, sediments in the interfluve areas are cohesive and not susceptible to liquefaction. Notable exceptions occur where fluvial channels traverse the area at depths of 3 to 12 m subsurface. These channel deposits contain well-sorted medium to fine-grained sand and silty sand, and locally are gravelly. Where daylighted by foundation excavations, these deposits are cohesionless and cascade into the open cut. Where water-saturated, the channel deposits commonly flow into the borehole and have SPT blow counts ranging from 2-8 blows per foot. Our studies indicate that cohesionless water-saturated deposits occur locally as channels in the western San Fernando Valley. Many of these deposits have relative densities sufficiently low that liquefaction ground failures may occur during earthquakes. In general, there are no clues in the surface morphology to indicate the presence of these buried channels in the subsurface. Site-specific studies would be required to evaluate the liquefaction susceptibility in any given instance.

5. A paper is in preparation to be included in the Geological Society of America D. E. Marchand Symposium Proceedings relating carbonate solution kinetics and rates and processes of carbonate accumulation in soils in the western Mojave region (L. D. McFadden and J. C. Tinsley).

6. The manuscript describing a reconnaissance study of the Cucamonga Fault Zone is now undergoing editing in the Menlo Technical Reports Unit.

7. Measurements of P-wave and S-wave velocities in the quarry exposures near the April 7, 1981 rupture using shallow refraction techniques showed V_P = 440-600 m/sec and V_S = 220 - 300 m/sec. (J. C. Tinsley and R. F. Yerkes).

Reports

Yerkes, R. F., Bonilla, M. G., Ellsworth, W. L., Lindh, A. G., and Tinsley, J. C., 1981, Reverse faulting and crustal unloading near Lompoc, Northwest Transverse Ranges, California: Geological Society of America Abstracts with Programs, vol. 13, No. 7, p. 586.

U.S.G.S./Alaska Division of Geological and Geophysical Surveys Cooperative Earthquake Hazards Project: Geotechnical Soils Investigations, Upper Cook Inlet, Alaska

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Investigations

The Upper Cook Inlet area of south-central Alaska, which includes the Anchorage and Matanuska-Susitna Municipalities, is the most populous area of the state and sustained considerable damage and loss of life as a result of the 1964 Prince William Sound Earthquake. Much of the resultant destruction was attributed to massive ground failure of Quaternary soils. Subsequent to the investigations conducted in the years immediately following that major event very little research has been conducted on earthquake hazards in the region. The present study involves (1) detailed evaluation of present-day susceptability for sensitive clay failure and liquefaction of Quaternary soils in response to a seismic event, (2) geotechnical characterization and three-dimensional mapping of soil units exhibiting failure potential modes, (3) mapping bedrock and surficial deposits along fault lineaments to determine Holocene activity, and (4) establishing an engineering soils data bank of geotechnical borehole logs and associated testing results for the Upper Cook Inlet region.

Results

(1) The engineering soils data bank which I initiated has now been on line for two years and is continuously being updated with information obtained from trenches and boreholes by municipal, state and federal agencies, and by industry. Presently the information for several thousand sites are being stored in the original report format with a Kardex catalogue file for data scope and acquisition reference.

(2) The Bootlegger Cove Formation, which underlies much of Anchorage, has been found to consist of seven discrete geologic facies which I have found to vary in their engineering characteristics based upon differing geologic histories and modern ambient conditions. I have been able to characterize these engineering geologic facies in terms of both static and dynamic behaviour. The Government Hill area of Anchorage (where lies the Port of Anchorage, major fuel depots, and Elmendorf Air Force Base) was used as a pilot study area for mapping these facies in three dimensions. This provides an engineering parametric characterization of the subsurface geology throughout the mapped area. The project was quite successful and a second mapping program in south Anchorage is now nearing completion, utilizing the

principles developed for the Government Hill area. Derivative maps of sensitive clay collapse and liquefaction potential have been made for each area. Multiple publications are in various stages of preparation and review for each area.

(3) Modern techniques of dynamic testing of the Bootlegger Cove Formation have been seriously lacking since the 1964 earthquake. I have initiated and am nearing completion of a site-specific test program that includes (a) resonant column testing of undisturbed samples of the five cohesive engineering geologic facies (b) cyclic trixial testing of companion samples, and (c) downhole seismic shear wave analyses. The results of this study can be applied conservatively to the three-dimensional mapping of the facies discussed above.

(4) Twenty-eight slope indicator casings have been installed in the major Anchorage landslides resultant from the 1964 earthquake. Of these, I have found that 13 still exist which I have subsequently been able to monitor with a Digitilt Inclinometer. I have been able to obtain the historic data for these casings and have completed a mathematical analysis of the strain history indicated by these casings for each of the three major landslides. The final report on this study is complete and in technical review.

(5) During the summer of 1981 I embarked upon mapping the bedrock and surficial geology of the Anchorage B-6NW (1:25000) and that mapping is now complete. Two goals were identified for this project: (a) to determine if active faulting can be located along the front of the Chugach Mountains near Anchorage, and (b) to quantify the liquefaction potential on the Knik River floodplain over which the highway and railroad transportation corridors to the interior of Alaska extend. Faults have been distinguished and mapped which have displaced middle to late Holocene glacial and periglacial deposits as well as the McHugh Group metavolcanic melange (Jurassic to Cretaceous age). Electric cone penetration testing of the floodplain deposits will begin in the spring of 1982, to better assess the liquefaction potential. Multiple reports will be forthcoming.

Geothermal Seismotectonic Studies

9930-02097

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Investigations

1. St Helens seismic zone (SHZ) studies: Earthquakes in southwestern Washington recorded by the University of Washington (UW) seismographic network since the May 18, 1980 eruption of Mount St. Helens are being studied in an effort to provide more detail of the zone than is available from using the data recorded prior to 1980. A network of radon detectors was established in August 1981 from the epicenter of the February 13, 1981 Elk Lake earthquake (M = 5.5) north to the Cowlitz River valley. A new seismographic station was installed near the Cowlitz River in May 1981 to help constrain focal depths for earthquakes along the northern end of the SHZ.

2. Olympic Peninsula-Washington Coast Range seismicity: The Olympic Peninsula subnet of the University of Washington statewide network continues to record low rates of local seismicity (one magnitude 3+ earthquake during the first 9 months of 1981). Focal mechanisms for small magnitude (2+) earthquakes are routinely calculated for the first time because of the increased station coverage. As with the SHZ studies, the contemporary data are now being compared with the pre-1980 data as this investigation moves to the reporting phase.

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

4. A teleseismic P-delay study, initiated earlier this year, has reached the analysis phase. The data set consists of approximately 60 well recorded teleseisms that have been read at all stations in the UW network.

Results

1. A crustal strike-slip seismic zone has been delineated from Mount St. Helens north-northwest approximately 70 km and this zone continues south of Mount St. Helens about 20 km (Figure 1). North of the Cowlitz River, seismicity for the period plotted (July 1, 1980 to September 30, 1981) has been sparse. A representative focal mechanism north of the Cowlitz River shows strike-slip motion with a normal component;

this contrasts to the representative mechanisms south of the Cowlitz (Fig. 1). A single mechanism calculated for an earthquake 30 km south of Mount St. Helens shows that strike-slip motion is occurring further south than earlier studies had indicated. The February 13, 1981 M_L = 5.5 Elk Lake earthquake was located at 46°21', 122°16' at a depth of 7 km along this seismic zone. The aftershocks define a north-northwest striking zone approximately 6 km long; the focal mechanism for the main shock is shown in Figure 1. These mechanisms are consistant with the focal mechanisms calculated for earthquakes that occurred near the Elk Lake mainshock in the weeks following the May 18, 1980 eruption of Mount St. Helens. 2. Earthquakes on the Olympic Peninsula for the period June 1, 1980 to September 30, 1981 are plotted in Figure 2. The majority of the events are near the Puget Sound-Olympic interface (near 123 degrees), but there are three other groups of earthquakes that are interpreted as significant. One group is near Willipa Bay (46°40'). On September 6, 1981, a magnitude 3.3 earthquake was felt near Raymond, Washington; the focal mechanism for this 35 km deep event indicates normal faulting with the two fault planes striking to the north-northeast. The second group is in the south-central Olympic Mountains (10 km east of station OLQ in Figure 2). These events are 35-40 km deep. The largest event located had a magnitude of 2.7; preliminary focal mechanisms for this group indicate normal faulting. The third group is near the northwest tip of the Olympic Peninsula.

Reports

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

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

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

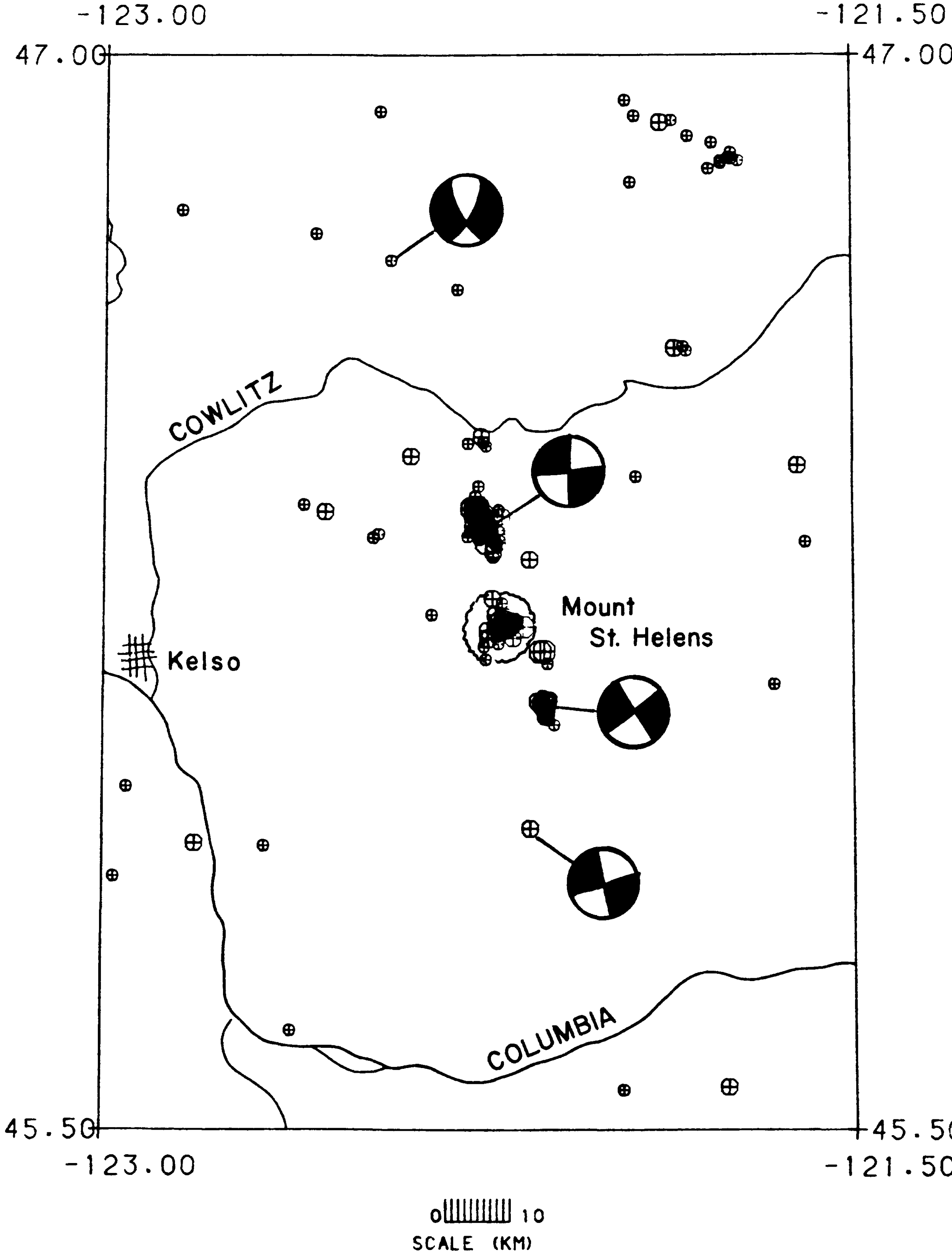

Figure 1: Seismicity in southwestern Washington, July 1, 1980 to September 30, 1981. Earthquakes are scaled by magnitude, between 1.5 and 5.5, with four symbol sizes (smallest, 1.5-2.5; small, 2.5-3.5; medium, 3.5-4.5; large, 4.5-5.5). Focal mechanisms are upper hemisphere, darkened quadrants compression, white quadrants dilatation.

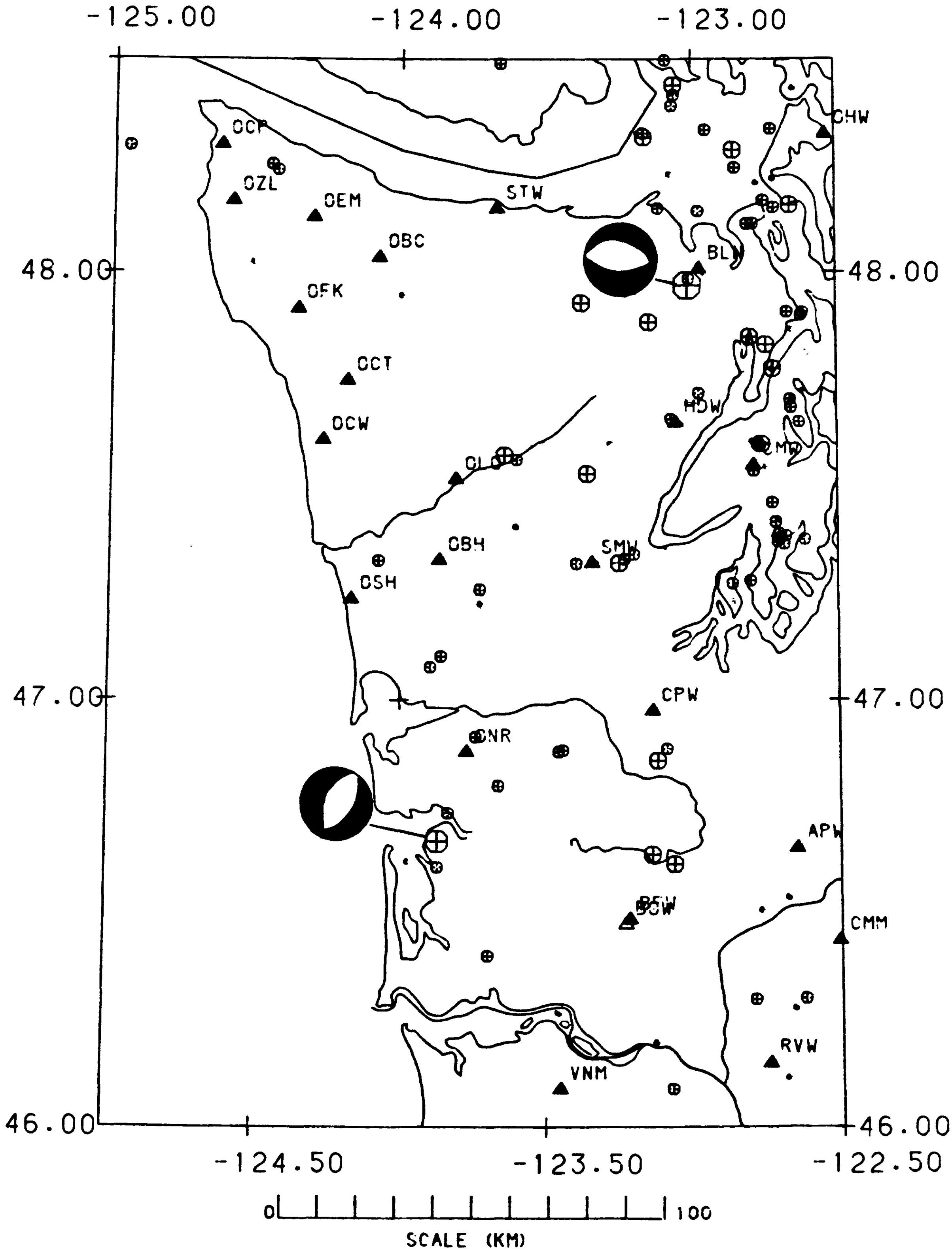

Figure 2: Olympic Peninsula seismicity, July 1, 1980 to September 30, 1981. Magnitudes 1.5 to 4.5. Focal mechanisms are upper hemisphere, with darkened quadrants compression, white quadrants dilatation. Solid triangles are operating seismographic stations.

Tectonic Tilt Measurements using Lake Levels

9950-02396

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Investigations

1. Established a level reference in August, 1981, across the southwest part of the Great Salt Lake and Utah Lake by simultaneous, 3-day recording of lake-levels at four points on each lake. Measurements are referenced to permanent bench marks. (Kirk Vincent)

2. Began investigations of early 20th Century and more recent leveling in the Salt Lake City and Provo area of Utah. (S. Wood)

3. Continued analysis and compilation of data of lake-level measurements in southern Alaska for open-file report. (S. Wood)

Results

Comparisons of measurements of lake levels made after the 1964 Alaskan earthquake in 1964 and 1966 with those made in 1979 and 1980 show no significant component of tilt between pairs of stations on eastern Iliamna, Skilak, and Klutina Lakes. A significant down-to-southeast component of tilt (200 $\pm$ 30 mm) occurred across Kenai Lake between 1966 and 1979.

Reports

Wood, S.H., 1981, Tectonic tilt derived from lake levels (abs.): Earthquake Notes, v.52, no. 1, p. 26.

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

9540-02907

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Investigations and results (W. H. K. Lee, K. M. Williams, R. F. Yerkes)

1. a. Historic earthquake data.--Phase data for earthquakes $\geq$M5 have been extracted from CIT card file for evaluation. CIT, USC, and USGS data for 1973-1975 earthquakes have been merged and preliminary locations derived in part. Results show that extensive clean-up and supplementary seismogram readings are required.

b. Fault map--Continued acquiring, evaluating, and compiling new mapping by USGS investigators and cooperators as available. Product will show latest results of recent Quaternary mapping-trenching investigations. Several segments of the Transverse Ranges frontal fault system appear to be relatively inactive on basis of geologic and seismic data.

2. Participated in planning/comprehensive summary report on earthquake hazards in metro Los Angeles region. Began evaluating data for chapter on seismotectonic setting.

3. Evaluated amd mapped fault-plane solutions for about 125 earthquakes of M 2-6 1/2 that occurred in Los Angeles basin during 1933-78 and located by others. Most are characterized by reverse or reverse-oblique mechanisms having low-plunge P-axes concentrated around N 25° E.

4. With M. G. Bonilla, W. S. Ellsworth, A. G. Lindh, and J. C. Tinsley, mapped, evaluated, modelled, and reported on new reverse fault (April 1981) and contemporaneous earthquake (M 2 1/2 CIT) in diatomite quarry near Lompoc. Laboratory measurements made after preparation of the abstract show that the natural bulk density of the removed diatomite was about 1.14 and the removed load accounts for a pressure reduction at the quarry floor of about 10 bars (instead of 6 bars); 90% of the load was removed after 1955 and 50% between 1970 and 1978, when quarrying ceased in the area of the fault. Landsliding was not involved.

5. With J. I. Ziony, H. G. Green, K. R. Lajoie, and J. C. Tinsley, appeared as subpoenaed witness at Federal and State hearings on Cojo Canyon site for proposed LNG terminal. Only result: lost time.

Investigations (A. M. Sarna-Wojcicki)

6. Continued chemical anlyses and identification of late Cenozoic ashes and tuffs in Transverse Ranges (Ventura, south Mountain, and Ridge basins), and the Los Angeles basin. Collected bone material (with T. A. Rockwell, UCSB), for dating of late Pleistocene terrace in the Ventura area.

7. Prepared chapter for guidebook and helped lead field trip for Friends of the Pleistocene, Pacific Cell, to examine the Quaternary stratigraphy, chronology, and tectonics of the Ventura area.

Results (A. M. Sarna-Wojcicki)

8. A bone fragment, collected from a deformed and faulted late Pleistocene marine terrace deposit near Sea Cliff, northwest of Ventura has been dated by J. L. Bischoff (BMG) by the uranium-series method. The $^{238}U/^{230}Th$ age on this bone is 48,600 ± 2000 yrs. b.p., but the $^{235}U/^{231}Pa$ age determination on the same material is 30,600 ± 2000 yrs. b.p.. The former age is in good agreement with a previous uranium-series age of about 50,000 yrs. b.p. on mollusk shells (Kaufman and others, 1971), and on numerous amino-acid racemization age estimates of about 45,000 yrs. b.p. by K. R. Lajoie and others. The $^{235}U/^{231}Pa$ age is much more likely to be in error because of the small amount of ^{235}U in the sample relative to ^{238}U. Because of the discordance, however, the $^{238}U/^{230}Th$ age can be used only as supporting evidence for the age of this terrace.

Reports

Sarna-Wojcicki, A. M., Lajoie, K. R., and Yerkes, R. F., 1981, Quaternary stratigraphy, chronology, and tectonics of the Ventura area: an informal field trip guide, Friends of the Pleistocene, Pacific Cell, July, part II, p. 126-159.

Yerkes, R. F., Bonilla, M. G., Ellsworth, W. L., Lindh, A. G., and Tinsley, J. C., 1981, Reverse faulting and crustal unloading near Lompoc, northwest Transverse Ranges, California: Geological Society of America, Abstracts with Programs, v. 13-7, p. 586.

Earthquake Hazards Puget Sound, Washington

9540-02197

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Investigations:

1. Determine the depth distribution of bedrock, Holocene alluvium or fill, and other poorly consolidated Quaternary sedimentary deposits in the Port Townsend 1:100,000 map area as a guide for explanations of ground shaking variations from observed earthquakes and as an aid in future location of instrumentation to measure strong ground motion.

2. Complete compilation of a bedrock geologic map of the Seattle 1:100,000 map area, emphasizing mapped faults and major geophysically-defined structures for purposes of clarifying the Tertiary tectonic framework from which today's observed seismicity in Puget Sound evolved.

3. Investigate the possible role that residual stress from past glacial loading may play on controlling the distribution of shallow (35 km) earthquakes in Puget Sound.

Results

1. Additional depth to bedrock data, derived mainly from 48-channel seismic reflection profiles in the eastern Straits of Juan de Fuca, Admiralty Inlet, and Saratoga Passage, help to clarify a rather strong relationship between thickness of Quaternary sediment and structural configuration of Tertiary basement. The Quaternary section thins by nearly 400 meters across the upthrown southwest side of a major northwest-trending gravity and aeromagnetic linear, which has been interpreted as a fault bounding the southwest side of the Marysville basin (Structure G; Gower and Yount, in press). The Quaternary section also thins markedly north of Oak Harbor, across a major east-west fault, the Northern Whidbey Island Fault, which makes up the northern boundary of the Marysville Basin (Structure B, Gower and Yount, in press). Such a strong relationship between Quaternary sediment thickness and Tertiary basin configuration suggests that the basin margin structures have been active during the last two million years.

2. Geologic mapping in the Gold Mountain-Green Mountain area east of Bremerton provides evidence for an east-west fault separating a complex of medium to coarse grained gabbro and associated minor tonalite bodies on the north (Green Mountain) from a series of subaerial basalt flows on the south (Gold Mountain). Both rock suites are cut by northwest and occasionally northeast trending andesite dikes previously dated at 42 million years. Theses dikes are intruded along joints that have a strong conjugate relation to the fault, and therefore most likely formed during movement on the fault.

Thus, faulting must predate or be contemporaneous with dike intrusion. The pattern of east-west faulting, parallels, and is on trend with similar faults making up the southern boundary of the Seattle basin.
3. Plots of earthquake epicenters against depth in profiles transverse and longitudinal to the past position of the Puget Lobe of the Cordilleran ice sheet show a remarkable coincidence of the ice sheet margin to the areas in Puget Sound exhibiting shallow seismicity (35 km deep). In addition, the pattern of seismicity, particularly in transverse profiles, mirrors ice thickness, with deeper earthquakes more abundant where ice was thickest, and earthquake foci becoming shallower near the ice margin. This coincidence suggests, but does not prove, that residual stress from past ice loading may play a role in triggering shallow earthquakes beneath Puget Sound.

Reports

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

Regional Syntheses of Earthquake Hazards in Southern California

9940-03012

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Investigations

The objectives of this project, which was initiated in May 1981, are to (1) determine the relative hazards (activity, earthquake potential, and expectable surface rupture) of faults in southern California from evaluation of their geologic and seismologic character, and (2) organize the preparation of comprehensive syntheses of other earthquake hazards for the major urban areas in the region.

Initial efforts were directed toward searching and assembling the large body of published and unpublished information on potentially active faults in the Los Angeles region. In addition, planning sessions were held and contributors selected for a major professional paper that will summarize the earthquake hazards of the Los Angeles region (between Ventura, San Bernardino, Palmdale, and San Clemente and including the offshore region).

Results

1. Comprehensive lists of information sources on known Quaternary faults in the Los Angeles region have been assembled. Compilation has begun of data files that summarize for each fault what currently is known about its geometry, age of latest displacement, seismicity, evidence for recurrent activity, late Cenozoic slip history, and rate of late Quaternary slip.

2. The scope and content were decided for a professional paper, aimed at planners and engineers, that will summarize current understanding of the earthquake hazards of the Los Angeles region and the methods available for their evaluation. Authors have prepared outlines of their contributions and are expected to submit their papers by July 1982. Topics to be covered in the volume are:

GEOLOGIC AND SEISMOLOGIC SETTING
R. F. Yerkes, C. E. Johnson
EVALUATING FAULT HAZARDS
J. I. Ziony, R. F. Yerkes, T. C. Hanks
PREDICTING EARTHQUAKE INTENSITIES
J. F. Evernden
PROPERTIES OF QUATERNARY SEDIMENTS THAT CONTROL EARTHQUAKE HAZARDS
J. C. Tinsley, T. E. Fumal, J. F. Gibbs, R. D. Borchert

RELATIVE SHAKING RESPONSE OF GEOLOGIC UNITS
A. M. Rogers, J. C. Tinsley, R. D. Borcherdt
PREDICTING REGIONAL STRONG-MOTION PARAMETERS
W. B. Joyner, T. C. Fumal
CALCULATING GROUND MOTIONS AT A SITE
P. A. Spudich, S. H. Hartzell
LANDSLIDES
R. H. Campbell, D. K. Keefer
PREDICTING SLOPE FAILURES FROM EARTHQUAKES
R. C. Wilson, D. K. Keefer, E. L. Harp
LIQUEFACTION POTENTIAL
J. C. Tinsley, T. L. Youd, D. M. Perkins
OFFSHORE FAULTS AND SUBMARINE LANDSLIDES
H. G. Greene, S. H. Clarke, M. P. Kennedy, M. R. Legg
TSUNAMI POTENTIAL
D. S. McCulloch
ASSESSING EARTHQUAKE LOSSES
S. T. Algermissen, K. V. Steinbrugge, M. G. Hopper, B. Askew
APPLYING EARTHQUAKE HAZARD INFORMATION
W. J. Kockelman

In order to demonstrate how the foregoing evaluation techniques can be applied in an integrated fashion, the professional paper also will include a scenario report on the predicted geologic effects of a postulated M6.5 earthquake along the northern Newport-Inglewood Zone.

Geophysical and Tectonic Investigations of the Intermountain Seismic Belt

9950-02669

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Investigations

1. Surveyed elevations for and measured 200 gravity values in Juab Valley, central Utah. The gravity data were collected along and in the vicinity of a recently purchased 30 km long seismic reflection profile which begins in the San Pitch Mountains east of the town of Nephi and crosses Juab Valley and the next range to the west. The gravity data will be used to aid in the interpretation of the seismic reflection data and to investigate the two-dimensionality of the valley structure observed on the seismic profile.

2. Analysis and interpretation (in conjunction with Ernie Anderson, USGS Denver) of publicly available seismic reflection profiles from numerous valleys in the Great Basin.

Results

1. The gravity data are currently in the process of being reduced, still requiring terrain corrections. By comparison with a previously published reconnaisance gravity survey in Juab Valley approximate terrain corrections can be estimated. The cross valley profile indicates a gravity low of 20-25 mgals corresponding to a maximum valley fill thickness of approximately 2.0-2.5 km. Gravity gradients on the east side of the valley suggest that the range front fault zone consists of at least two major step faults. Faulting probably occurs 1.5-2.0 km basin-ward of the range front suggesting an erosional origin for the reentrant in the range east of the town of Nephi.

2. Previously published and publicly available seismic reflection data from the northern Basin and Range have been reviewed in an effort to classify the subsurface geometry of major normal faults in the province. The primary criteria established for the classification of the normal faults is the dip of the strata in the sedimentary basin-fill sequence adjacent to the major bounding fault or faults. The geometry of slip on concave upwards (listric) normal faults requires horizontal extension in excess of that predicted from the steep near-surface fault dip and results, geometrically, in a potential void adjacent to the fault. To accommodate this space problem, major slip (typically 3-6 km) accompanying basin formation on master listric faults should be accompanied by a conspicuous pattern of reverse drag flexing of the basin-fill strata and/or antithetic

faulting as well as an associated growth fault pattern of sedimentation. Slip on major relatively steep, planar faults would not be expected to produce the reverse drag flexing.

Three major modes of faulting responsible for basin development have been identified. Faults of each mode are known to be active as evidenced by historic, Holocene, or latest Pleistocene surface rupture. The data indicate that some basins seem to form as relatively simple sags associated with one or more major steep relatively planar normal faults (Figure 1a), others as tilted ramps associated with moderately to deeply penetrating listric normal faults (Figure 1b), and others as assemblages of complexly deformed subbasins associated with sharply curving shallow listric faults that sole in a detachment surface at relatively shallow crustal levels (4-7 km depth) (Figure 1c).

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Hastings, D. D., 1979, Results of exploratory drilling northern Fallon Basin, western Nevada: Rocky Mtn. Assoc. Geol. and Utah Geol. Assoc., 1979 Basin and Range Symposium, p. 515-522.

McDonald, R. E., 1976, Tertiary tectonics and sedimentary rocks along the transition: Basin and Range province to plateau and thrust belt province, Utah: Rocky Mtn. Assoc. Geol., 1976 Cordilleran Hingeline Symposium, p. 281-317.

Reports

Anderson, R. E. and Zoback, M. L., 1981, Subsurface geometry of normal faults in the northern Basin and Range province inferred from seismic reflection data: abstract for American Geophysical Union Meeting, Fall 1981.

Anderson, R. E. and Zoback, M. L., 1981, The subsurface geometry of faults and the evolution of basins in the northern Basin and Range province: extended abstract for the Lunar and Planetary Institute Conference on the Physical Processes of Planetary Rifting, December 1981.

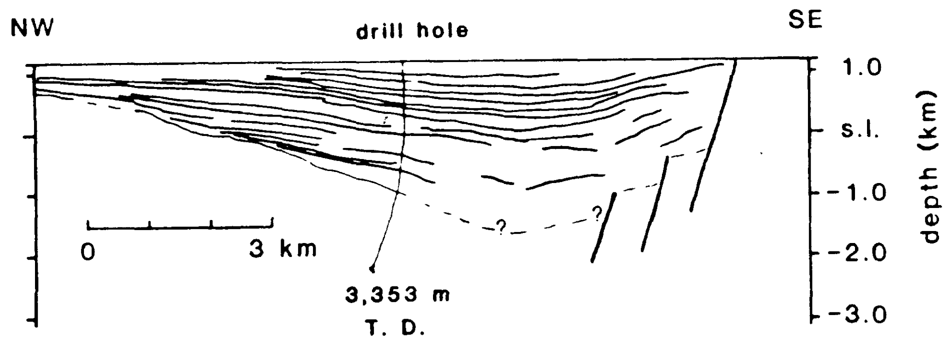

Figure 1a. Line drawing of a migrated depth section across the northern part of the Fallon Basin, Nevada showing major sag-like basin structure (modified from Hastings, 1979). Dashed lines and step-faulting pattern inferred from gravity data.

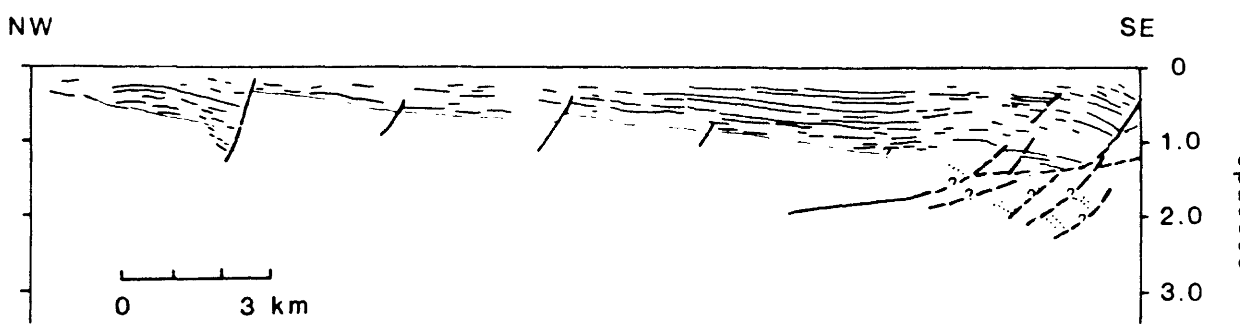

Figure 1b. Line drawing of a seismic section across Mary's River Valley, Nevada showing listric fault-tilted ramp structure (modified from Effimoff and Pinezich, 1981).

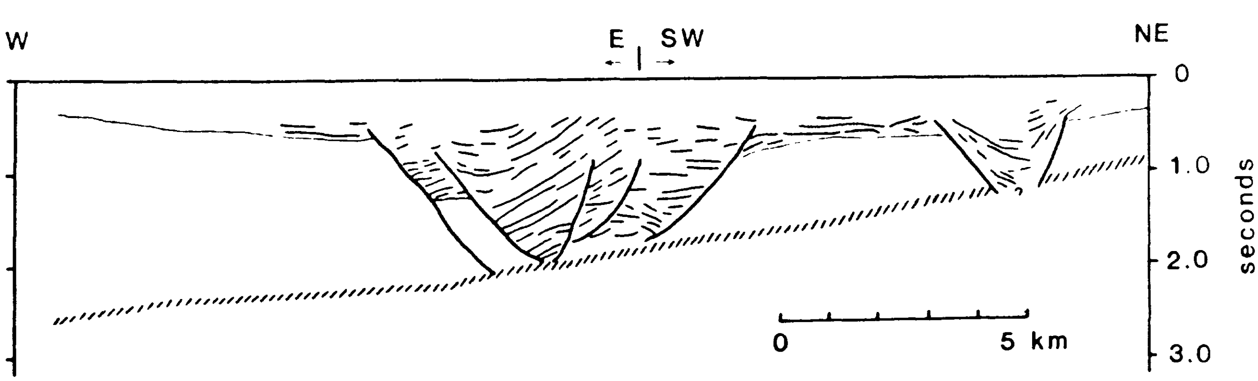

Figure 1c. Line drawing of a seismic section across the Sevier Desert basin, Utah showing sharply listric faults above a relatively shallow detachment surface (modified from McDonald, 1976).

Geophysical Studies in the Charleston Earthquake Area

9730-02083

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Investigations

1. Multichannel reflection data, recorded on 96 channels for 8 seconds and processed 24 fold, collected along a line from about 32°40′N, 80°03′W (near Johns Island, SC) to 34°30′N, 82°10′W (near Laurens, SC) were acquired by contract.

2. The data show evidence of a Triassic(?) basin 3-4 km deep at least 20 km across beneath the Coastal Plain sedimentary rock. As seen on the profile, the NW edge of the basin coincides with a steep magnetic gradient; a seismicity cluster exists near Bowman ~20 km to the NE. Reflections and diffractions are observed to depths as great as 12 km in several places beneath the Coastal Plain and piedmont including the general area of recent seismic epicenters near Summerville. Diffractions at similar depths have also been observed immediately offshore of the Charleston area and have been interpreted as evidence of a zone of detachment that may be related to seismic activity. Reflections and diffractions from depths of about 20 km indicate the presence of a discontinuity of an unkown nature within the crust. There is no apparent evidence of a decollement extending continuously from the foot of the Appalachians to the coast. Figure 1 shows the location of the line.

Reports

Behrendt, John C., and Hamilton, Robert M., 1981, Preliminary interpretation of a seismic reflection profile crossing the South Carolina Coastal Plain and piedmont including implications concerning the origin of the Charleston, 1886, Earthquake: Trans. EOS abstracts of fall AGU meeting 1981 (in press).

Figure 1.--Location of multichannel seismic reflection line (with shot point numbers indicated) superimposed on part of aeromagnetic map of Zietz and Gilbert, 1980.

Seismotectonics of Northeastern United States

9950-02093

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Investigations

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

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

Results

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

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

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

4. A continuing study of thermal convection in water-filled holes has begun to reveal some information on the nature of the fluid motions. This information may be useful in interpreting temperature-time data in terms of crustal strain. It may also be useful in assessing the accuracy of other in-hole measurements that are sensitive to small fluid motions.

5. Moved from Reston, Virginia to Golden, Colorado.

Reports

Diment, W. H., and Urban, T. C., 1981, An average elevation map of the conterminous United States (Gilluly averaging method): U.S. Geological Survey Map, GP-933.

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Muller, O. H., and Diment, W. H., 1981, In the Scranton gravity high part of the central North American rift system?: Geological Society of America Abstracts with Programs, v. 13, p. 516.

Muller, O. H., and Diment, W. H., 1981, Persistent zones of weakness in North America: EOS, American Geophysical Union Transactions, v. 63 (submitted).

Eastern U.S. Seismicity and Tectonic Studies

9950-02303

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Investigations

1. Review of geologic setting of central and eastern U.S. seismicity for the Conference of Earthquakes and Earthquake Engineering in the Eastern U.S., held in Knoxville, Tennessee, September 14-16, 1981.

2. Preliminary analysis of land seismic-reflection profiles obtained in the Charleston, South Carolina, area by Virginia Polytechnic Institute and State University during the 1980-81 Winter, and by Seisdata Services Inc. during the Spring of 1981.

3. Acquisition of marine seismic-reflection profiles off the coast of South Carolina during October 1981.

4. Completion of Science Advisory Committee report.

Results

The review of some of the areas of the eastern United States where intensity VIII and larger earthquakes have occurred shows that reactivation of older fault zones appears to be a plausible explanation for eastern seismicity. A fairly strong argument can be made in favor of this hypothesis for the New Madrid region, and limited data in other areas appear to be supportive of the idea. Whether these ancient fault zones are areas where stress is concentrated or whether they are zones that are weak within a fairly uniform stress field are important questions. The good evidence for uniformity of the stress field appears to favor the latter hypothesis. The persistent weakness of rifts may be due to their origin as fracture zones that broke completely through the brittle crust. The high volatile content of the alkalic rocks that occur in continental rifts may result in their having higher porosity and probably higher pore pressure compared with rocks outside the rift, which would also cause weakness. The association of intraplate seismicity with igneous intrusive rocks has been argued, and hypotheses concerning the role of intrusive bodies in concentrating stress have been proposed.

Another important consideration with regard to earthquake potential is the level of activity. It is quite a quandary that in the areas where the two largest earthquakes have occurred, New Madrid and Charleston, S.C., the pre-Late Cretaceous unconformity, a 100-million year old surface, is relatively smooth. Local relief has not been found greater than 80 m in either area on seismic-reflection profiles. This demonstrates that there probably has not been substantial net vertical fault movement in these areas. Even if the predominant movement in the New Madrid area in the Cenozoic were strike slip, there still would probably be some vertical movement associated with it, as is the case along the San Andreas fault zone, for example. One possible answer to this puzzle may be that fault displacement associated with an earthquake in these areas is very small. Another answer is that fault movement in these areas is actually very low and/or episodic; therefore, earthquake activity may occur only occasionally separated by long periods of quiesence. If this were the answer, then how good is the historic record for predicting future seismicity? Perhaps other favorably oriented zones of weakness that have not experienced historic seismic activity should be considered as places of potential earthquakes, particularly if they currently are sites of low-level seismicity. The Charleston, S.C., area experienced seismicity prior to 1886.

As new data accumulate about the geologic structure of eastern U.S. seismic zones, the importance of late Precambrian and early Paleozoic faulting increases. For example, this appears to be the case for the New Madrid, Ramapo, Giles County, St. Lawrence Valley, and Ottawa zones. The continuing weakness of these ancient fault zones is remarkable, and recognition of the phenomenon may provide a basis for mapping potential seismic areas. Such an approach would require mapping of rift zones to delineate the crustal blocks, examining their orientation in the present stress field to determine the potential for movement between them, and establishing criteria to evaluate which of the favorably oriented rifts are likely earthquake source regions.

Reports

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Tectonic Framework of the New Madrid Seismic Zone from Geophysical Studies

9730-01035

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Investigations

1. Modeling of the southeastern margin of the Mississippi Valley graben near Memphis, Tennessee from the interpretation of truck-magnetometer data.

2. Qualitative study of digital magnetic data of central United States.

3. Analyses of gravity and magnetic data to delineate features related to the complex faulting of western Kentucky.

Results

1. The geometry and magnetic properties of the southeastern margin of the Mississippi Valley graben were studied by analyzing detailed magnetic-anomaly profiles that are based on measurements made along roads near Memphis, Tennessee. The closely spaced data measurements were obtained with a truck-mounted magnetometer system developed by the U.S. Geological Survey. Modeling results suggest that the graben's margins represent both structural boundaries and conduits for ascending magma. Approximately 2 km of vertical offset associated with normal faulting occurs within an interpreted 5.5 km wide zone in which magnetic basement has an average dip of 20^{o} into the graben. This zone appears to contain several large normal faults formed during an extensional stage of rifting in late Precambrian or early Paleozoic time. Subsequent erosion of the scarps probably aided in forming the gentle northwestward slope of the buried Precambrian surface across the fault zone. The high apparent susceptibility (about 3×10^{-3} emu) of magnetic basement associated with this fault zone and with the upblock suggests either that ascending magma intruded the upblock or that the two blocks differed lithologically prior to the formation of the graben.

2. Major magnetic features of central U.S. are presently being studied to determine their relationship with earthquake-prone regions. Of particular interest is a pronounced northwest-trending anomaly that may extend for more than 1000 km from southeastern Tennessee to southeastern Nebraska. Structures corresponding to this anomaly, called the south-central magnetic lineament, may have influenced the tectonic development of major geologic features in the midcontinent. The south-central magnetic lineament coincides geographically with the northern boundaries of the Mississippi Embayment, Mississippi Valley graben, and the Ozark Uplift and the southern boundary of the Illinois Basin. The south-central magnetic lineament seemingly reflects a structural

boundary along which these downwarps and uplift developed or their growth was impeded. It also crosses the saddle between the Cincinnati Arch in Kentucky and the Nashville Dome in Tennessee, suggesting a structural influence in the formation of this saddle.

3. Western Kentucky is considered one of the most structurally complex regions in central U.S. Six major fault zones intersect this region and appear to be either bounding or central discontinuities of the Mississippi Valley graben, Rough Creek graben, and the Illinois Basin. The south-central magnetic lineament (discussed above), which also transects western Kentucky, is related to structures that have influenced the tectonic development of five of these fault zones. One fault zone lies along the trend of the south-central magnetic lineament: the remaining four fault zones bend or terminate in the vicinity of the magnetic lineament. As evidence from prominent magnetic and gravity highs, mafic or ultramafic bodies are present within the study area and are primarily located along the fault zones. Apparently, extension occurred along these fault zones which acted as conduits for the ascending magma.

Reports

Hildenbrand, T. G., Hendricks, J., and Kucks, R. P. 1981, Aeromagnetic map of central and northeastern Arkansas: U.S. Geological Survey Open-File Report 81-758.

Central and Eastern U.S. Earthquake Study

9730-02176A

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Investigations

1. Analyses are being made of wavelength-filtered gravity anomaly maps that separate to a first order sources in the earth's crust from those in the mantle. Derived structural features are being related to seismicity and geological models, including the recently developed McKenzie stretching model for sedimentary basins.

2. A report summarizing an evolutionary model for the Mississippi embayment and relating the seismicity to crustal structure was completed and accepted for publication in Geology.

Results

1. Gravity anomaly patterns of short to moderate wavelength (< 125 km half-wavelength) are being used to sketch a delineation of crustal structure in the Appalachian region. In the central (NY-VA) Appalachians suggested rift structures agree reasonably well with the disposition of sedimentary strata if the data are interpreted according to the stretching model of McKenzie. In the southern Appalachians the gravity patterns suggest a basinal region that is almost completely covered by allochthonous strata. The extent of the region if valid, gives an estimate of the minimum transport of the "thin skin" of this region (about 175 km). As reported previously the seismicity north of Virginia appears to be controlled by features of the mantle (or crust-mantle interface) gravity field whereas to the southwest the seismicity appears to be associated with features of the crustal gravity field.

2. A summary report describing an evolutionary model for the upper Mississippi embayment concludes that the contrasting tectonic styles of different ages are the consequence of a rotating horizontal stress field that has acted on a major crustal flaw that has existed since at least late Precambrian time and probably long before. The model invokes the McKenzie concept where sedimentary basins form because of lithospheric stretching and subsequent cooling and contraction of the hotter material raised below the stretched area. Of practical consequence is that the thinnest and most tectonically complex zone of the stretched region should lie near its center. Such a model would explain why the principal seismicity of the New Madrid region that is aligned parallel to the graben, lies in its central region and not along its boundaries as would be predicted by the classical graben model.

Reports

Kane, M. F., Hildenbrand, T. G., and Hendricks, J. D., A model for the tectonic evolution of the Mississippi Embayment and its contemporary seismicity: accepted for publication in Geology.

Kane, M. F., Gravity evidence of crustal domains in the United States: the Appalachian system (abs.): approved by Director; invited for presentation at the joint NE and SE GSA meeting for 1982.

Kane, M. F. Thin skin, rifts and sutures: new geophysical manifestations of the substructure of the Appalachians: approved by Director; invited for presentation at the AAAS meeting for 1982.

Quaternary Stratigraphy and Bedrock Structural Framework of Giles County, Virginia

9510-02463

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Investigations

1. Surficial deposits in Giles County and adjacent areas were trenched in a search for 1) seismic features such as faults and sand blows, and 2) textural and mineralogical data that can be used to establish age relationships, which may in turn be used to recognize neotectonic activity. A heavy-mineral analysis has been made, and organic material has been submitted for radiocarbon dating. Downslope motion rates of colluvial deposits were studied as a means of evaluating the effects of seismic shaking.

2. Structures in the Paleozoic bedrock have been studied by field checking, mapping, and air and satellite photo reconnaissance for features associated with the persistent seismic activity in the area.

Results

1. Trenching of surficial deposits yielded no structural features resulting from seismic or tectonic activity. Flood plain and terrace deposits were relatively featureless, with uniform textures; most of the sediment was in the coarse silt to fine sand fractions. Some woody material was recovered. Trenching of colluvial deposits provided fabric evidence of frost heave, presumably of Pleistocene age.

2. Evidence in surficial deposits for neotectonic activity has not been recognized.

3. The mean rate of downslope movement of surface clasts in colluvial deposits ranged from 3 to 673 mm per year over a two-year period with no significant seismic activity. Surface lowering by tree-fall erosion was calculated to be 13 mm/1000 yr, an order of magnitude lower than previous estimates.

4. Compilation of field data and previous, mostly unpublished large-scale mapping shows no direct effect of neotectonism, but documents interference structures related to late Paleozoic Appalachian tectonism. Elements of Central Appalachian trend are present in the Southern Appalachians in and near Giles County, and are parallel to

an active sub-Paleozoic fault trend as shown by seismicity monitored by G. A. Bollinger at VPI. No genetic relationship has been demonstrated, however.

Reports

McDowell, R. C., 1981, The Roanoke recess: an important geologic boundary [abs.]: Geological Society of America, Abstracts with Programs, v. 13, no. 7, p. 507.

Northeastern U.S. Seismicity and Tectonics

9510-02388

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Investigations

1. Relationship of ductile and brittle faults in southeastern New York and adjacent New Jersey and relationship to zones of seismicity.
2. Evaluation of exposures of faulted glacial pavement in southeastern New York as evidence for neotectonic activity.
3. Trenching of glacial lake Passaic deposits on Ramapo fault with Byron Stone.
4. Development of a Seismo-tectonic model for Ramapo seismic zone and the Lower Hudson River Valley that is testable by seismic reflection profiling.

Results

1. Fault and fracture mapping in Westchester County, N.Y., by Leo M. Hall and N. Ratcliffe in the White Plains, Ossining, Haverstraw, and Mohegan Lake quadrangles has determined that brittle faults of Ramapo fault character are not widely present in Westchester and do not explain either the distribution of epicenters nor the available fault plane solutions which suggest compressional faulting on northeast striking surfaces. Instead several Mesozoic type faults trend N to NW subparallel to the Hudson River perpendicular to the northeast trending regional grain. H. Helenek, in the West Point quadrangle, has defined several north and northeast trending zones of previously unrecognized brittle faults marking graben-like structures in Proterozoic gneiss that may be related to recent seismic activity near West Point and Cold Spring, NY. Ratcliffe has extended the mapping of Triassic-like brittle faults in the central Hudson River Valley area, northward to near Copake, New York. These zones of faults are spatially associated with exposures of faulted glacially polished surfaces (see below).

2. Exposures of faulted glacially polished pavement (20,000-16,000 years old) are spatially associated with zones of brittle faulting such as the Chatham fault and other block faults bounding outliers or horsts of Proterozoic Y basement gneiss in the aseismic area of Dutchess and Columbia County. Seven new and three previously identified (Oliver and others, 1970) exposures of faulted glacial pavement have been studied. In all instances the dominant faulting is southeast side-up reverse faulting with multiple faults each with 0.5 to 4 cm vertical net slip indicated.

The close spatial association of faulted glacial surfaces with zones of brittle faulting could suggest reactivation of these faults in the past 20,000 years. However, this conclusion does not appear warranted because the faulting may be explained by frost heaving and wedging acting on jointed and highly crenulated phyllite formed near these brittle faults of Mid-Paleozoic or Mesozoic age.

3. A trench dug in Pleistocene deltaic deposits near the ancient shoreline of glacial Lake Passaic (10,000-12,000 years old) revealed numerous faults along the up dip projection of the Ramapo fault as determined from core drilling in bedrock. Numerous southeast dipping vertical and northwest dipping high angle faults show predominant reverse movement with throws up to 2 cm. This is the first report of faulted Pleistocene deposits in the Ramapo seismic zone. Observations in the trench by Byron Stone and N. Ratcliffe indicate numerous faults terminate downward against bedding and may be entirely intrastratal. Structural data are being assessed.

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

Reports

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

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

Ratcliffe, N. M., The Cortlandt Beemerville magmatic belt: a late Taconic alkalic crosstrend in the central Appalachians: Geology, v. 9, p. 329-335.

Ratcliffe, N. M., 1981, Reassessment of the Ramapo fault system as control for current seismicity in the Ramapo seismic zone and the New York recess [abs.]: N.E. Sect. Meeting, Geol. Soc. Am., Geol. Soc. America, Abs. with programs 1981, v. 13, no. 3.

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

Ratcliffe, N. M., 1982, Tectonic vs. non-tectonic origin of faulted glacially polished surfaces in the Lower Hudson River Valley area, N.Y., [abs.], N.E.-S.E. GSA Meeting, Washington, D.C., 1982.

Mississippi Valley Seismotectonics

9950-01504

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Investigations

1. Preliminary processing of 62 km of seismic reflection data recorded by the R/V Neecho on the Mississippi River was completed. The new profile lies between Osceola, Arkansas, and Caruthersville, Missouri, and represents the southern one-third of the data collected during the boat-based program. Interpretation of the profile has begun.

2. Field and office investigations of Cenozoic faults and terraces in the Mississippi Embayment to establish structural framework and to determine the nature of Quaternary tectonism was continued.

a. A. Crone made a detailed analysis of vibroseis reflection profiles to identify and characterize pre-Quaternary faults.
b. D. Russ correlated late Quaternary terraces along streams in uplands east of the lower Mississippi River valley from topographic data and field mapping.

3. An intensive study of subsurface information in northeastern Arkansas, western Tennessee, and southeastern Missouri by A. Crone and E. Glick has been made to: 1) refine correlation of Mesozoic and Cenozoic stratigraphy, 2) construct improved structure contour maps, and 3) to document the history of movement along a northeast-trending fault in Crittenden County, Arkansas.

4. Sites of 1) confirmed and postulated Cenozoic faults, 2) significant post-Paleozoic stratigraphic exposures, and 3) Holocene earthquake-generated liquefaction and landslide features were studied and excavated in preparation for a field trip led by D. Russ and A. Crone for participants in a symposium on "Earthquakes and Related Features of the Mississippi River Valley" sponsored by the University of Tennessee at Martin.

5. Work continued on radiometric age-dating, petrologic, and geochemical studies of igneous rock cuttings from wells in the Mississippi Embayment. This study is a cooperative effort with R. Zartman of the Branch of Isotope Geology. It is being done to characterize the igneous history of the Mississippi Embayment and to determine its relationship to tectonics and seismicity.

6. A geologic and geomorphic analysis of the evolutiion of the stress field in the Mississippi Embayment was continued.

Results

1. Interpretation of part of the Mississippi River reflection profile shows that the Cottonwood Grove fault, a northeast-trending feature lying along the axis of Reelfoot Rift in an area of relatively intense seismicity, cuts across the Mississippi River about 5 km southeast of Caruthersville, Missouri. A zone of arched reflectors and angular unconformities is situated adjacent to the fault. Six kilometers north of Caruthersville, a probable Quaternary channel, 700 m wide and 200 m deep, is entrenched into Eocene sediments. The origin of the channel and its possible association with tectonic activity is currently under investigation.

2. Using data from the limited well control in the northern Mississippi Embayment several Tertiary reflectors on vibroseis reflection profiles have been correlated on the record sections; however, because the individual reflectors are laterally discontinuous, confidence in some of the correlations is reduced. Numerous faults with small vertical displacements have been identified, but it is difficult to trace the faults between adjacent profiles. Most of the faults are concentrated in the area of modern seismicity.

3. Subsurface information in northeastern Arkansas, western Tennessee, and southeastern Missouri has been carefully re-interpreted to construct a series of detailed structure contour and isopach maps. The maps provide a foundation for interpreting the late Mesozoic and Cenozoic depositional and tectonic evolution of the area. In addition, the subsurface information demonstrates recurrent movement in excess of 75 m along a northeast-trending fault that closely coincides with the southeast edge of the Reelfoot Rift. The subsurface data combined with detailed magnetic studies suggests that there may have been a reversal of movement on this fault.

Reports

Frederiksen, N. O., Bybell, L. M., Christopher, R. A., Crone, A. J., Edwards, L. E., Gibson, T. G., Hazel, J. E., Repetski, J. E., Russ, D. P., Smith, C. C., and Ward, L. W., 1981, Biostratigraphy and paleoecology of lower Paleozoic, upper Cretaceous, and lower Tertiary rocks in U.S. Geological Survey New Madrid test wells, southeastern Missouri: Tulane University Studies, [in press].

Harding, S. T., Russ, D. P., and Blubaug, Norman, 1981, Need for optimized seismic reflection processing in active and highly disturbed fault zones [abs.]: Seismological Society of America Eastern Regional Meeting, [in press].

Harding, S. T., and Shedlock, Kaye, 1981, Mississippi River seismic survey [abs.]: Seismological Society of America Eastern Regional Meeting, [in press].

Russ, D. P., 1981, Model for assessing earthquake potential and fault activity in the New Madrid seismic zone, in Beavers, J. E., ed., Earthquakes and Earthquake Engineering: the eastern United States: Ann Arbor Science, Ann Arbor, Michigan, v. 1, p. 309-335.

Russ, D. P., 1981, The structure of Reelfoot Rift and its relationship to some regional mid-continent features [abs.]: Geological Society of America Abstracts with Programs, 1981 Annual Meeting, [in press].

Russ, D. P., 1981, Structural framework of the New Madrid seismic zone [abs.]: Program and Abstracts, Symposium on Earthquakes and Related Features of the Mississippi River Valley, The University of Tennessee at Martin, p. 2.

Northeast Tectonics and Geophysics

9730-00364

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Investigations

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

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

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

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

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

Results

1. Colored gravity and terrain maps of the East Central U.S. are now on open-file. The maps include Bouguer gravity, free-air gravity, gradient maps, and wavelength filtered residual maps.

Reports

Simpson, R. W., and Godson, R. H., 1981, Colored gravity anomaly and terrain maps of the East Central U.S.: U.S. Geological Survey Open-File Report 81-846.

Earthquake Hazard Studies in Southeast Missouri

14-08-0001-19751

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Goals

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

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

Investigations

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. The seismic data is recorded on analog film and on a PDP 11/34 digital computer. Since the initial deployment of seismograph stations in July, 1974 1393 earthquakes have been located through the end of March, 1981. The locations of these are shown in Figure 1. Operation, analysis and publication of quarterly bulletins are an ongoing task.

The implementation of advanced analysis tools on the PDP 11/70 is progressing. Distributions of advanced analysis software were made to all USGS minicomputer system users. The new software includes a hypocenter location -- bulletin preparation program which uses data files generated by interactive trace analysis software developed by Carl Johnson (USGS). In addition, programs have been developed, or are being developed, to make the most out of the digital data, including graphic displays of P-wave first motion for focal mechanism studies and whole waveform analysis to obtain seismic moment, focal depth and fault plane parameters.

Mr. E. Haug, NRC effort project engineer, has made great strides in enabling the PDP 11/70 to perform real time seismic trace digitization when operating under the UNIX* operating system.

Results

*UNIX is a Trademark of Bell Laboratories.

A joint USGS, Saint Louis University, University of Wisconsin field project during August, 1981 deployed over thirty portable seismographs in the New Madrid Seismic Zone aone the north-south seismicity zone between 36.0°N and 36.5°N. Over fifty earthquakes have been located using the SLU and USGS data. Depth resolution is excellent. However, the spatial distribution of seismicity is complex.

A Ph. D. dissertation was completed by Singh (1981). This dissertation provides evidence for significant regional variation in 1-Hz crustal shear wave Q as well as frequency dependence in the Q operator. He was able to parameterize the frequency dependence of shear wave Q, Q(f), by

$$Q(f) = Q_o f^n,$$

where Q_o is the value of Q at 1-Hz. Figure 2 shows the variation of the exponent 'n' throughtout the continental U. S., while Figure 3 showns the variation of Q_o. An immediate implication is that western U. S. response spectra, whose shape is almost independent of epicentral distance, cannot be applied to other parts of the nation.

Publications

Singh, S. K. (1981). Regionalization of Crustal Q in the Continental United States, Ph. D. Dissertation, Saint Louis University.

Herrmann, R. B. and O. W. Nuttli (1982). Magnitude: the relation of M_L to m_{bLG}, Bull. Seism. Soc. Am. 72 (in review).

Herrmann, R. B., C. A. Langston, and J. E. Zollweg (1982). The Sharpsburg, Kentucky Earthquake of July 27, 1980, Bull. Seism. Soc. Am. 82 (in review).

Herrmann, R. B. (1981). The Relevance of Regional Seismic Networks for the Siting of Critical Facilities (working draft of a position paper).

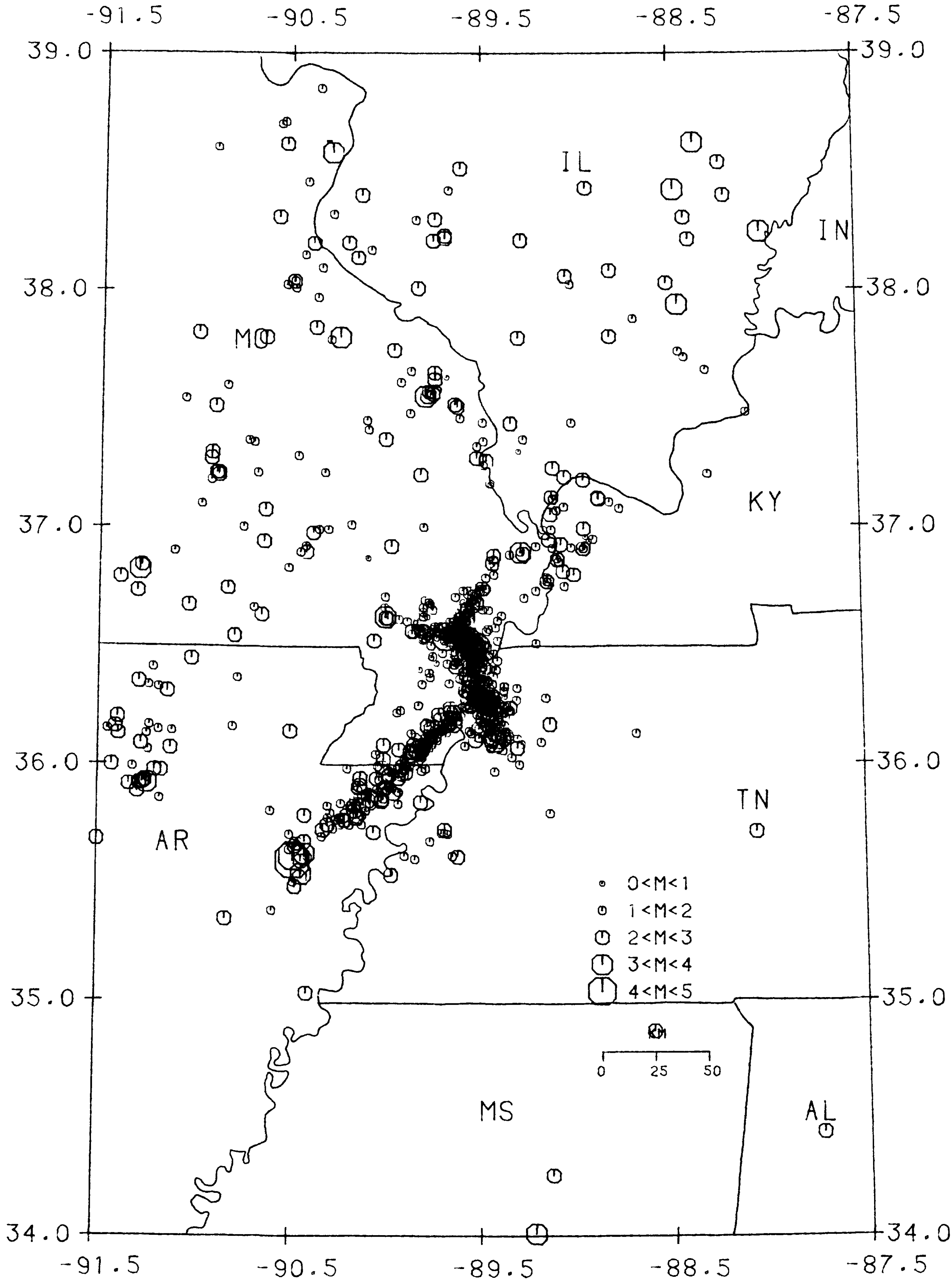

FIGURE 1

REPORTING PERIOD 01 JUL 1974 TO 31 MAR 1981

LEGEND . △ STATION ⊙ EPICENTER

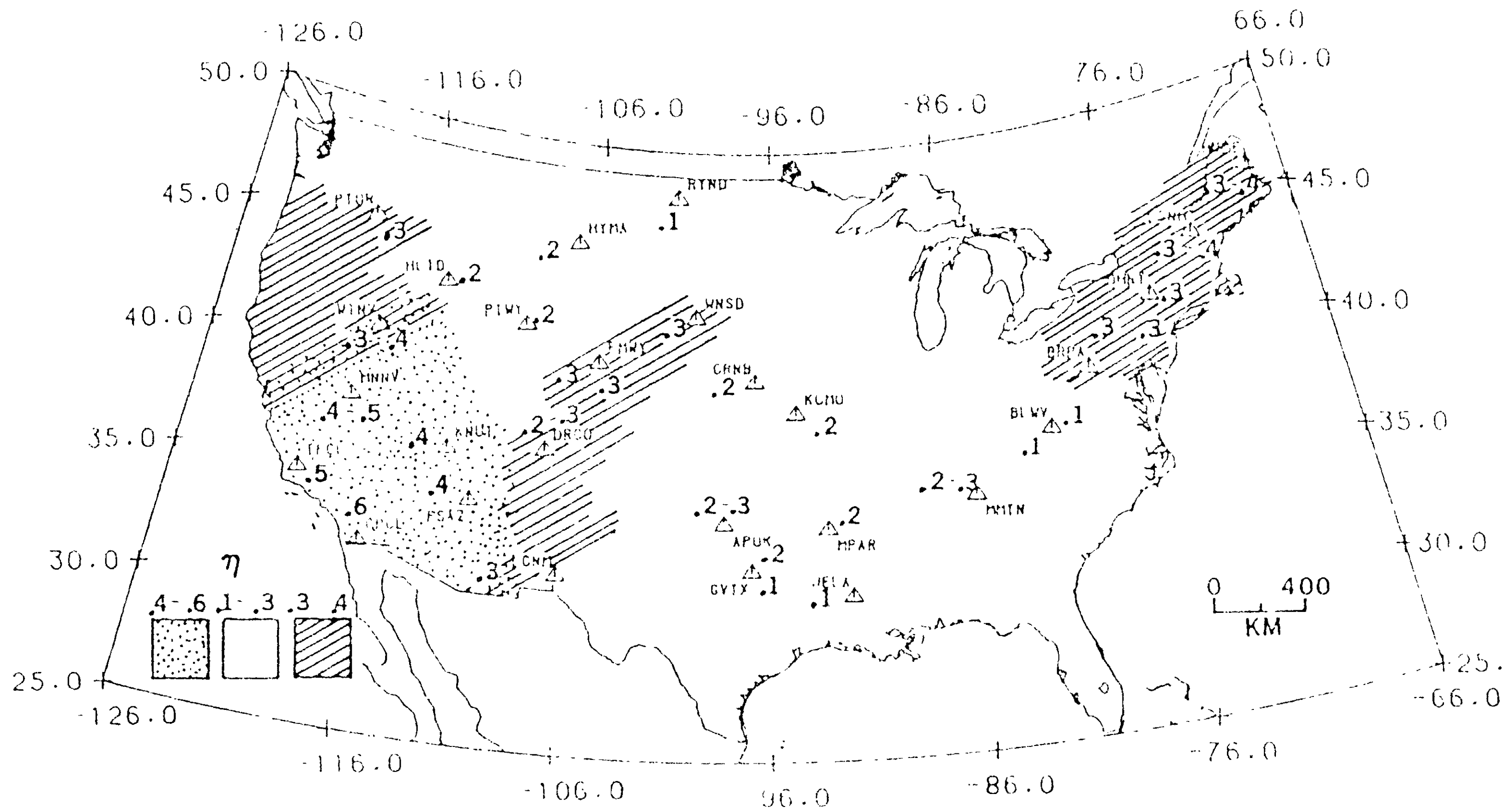

Figure 2. Distribution of η values throughout the continental United States.

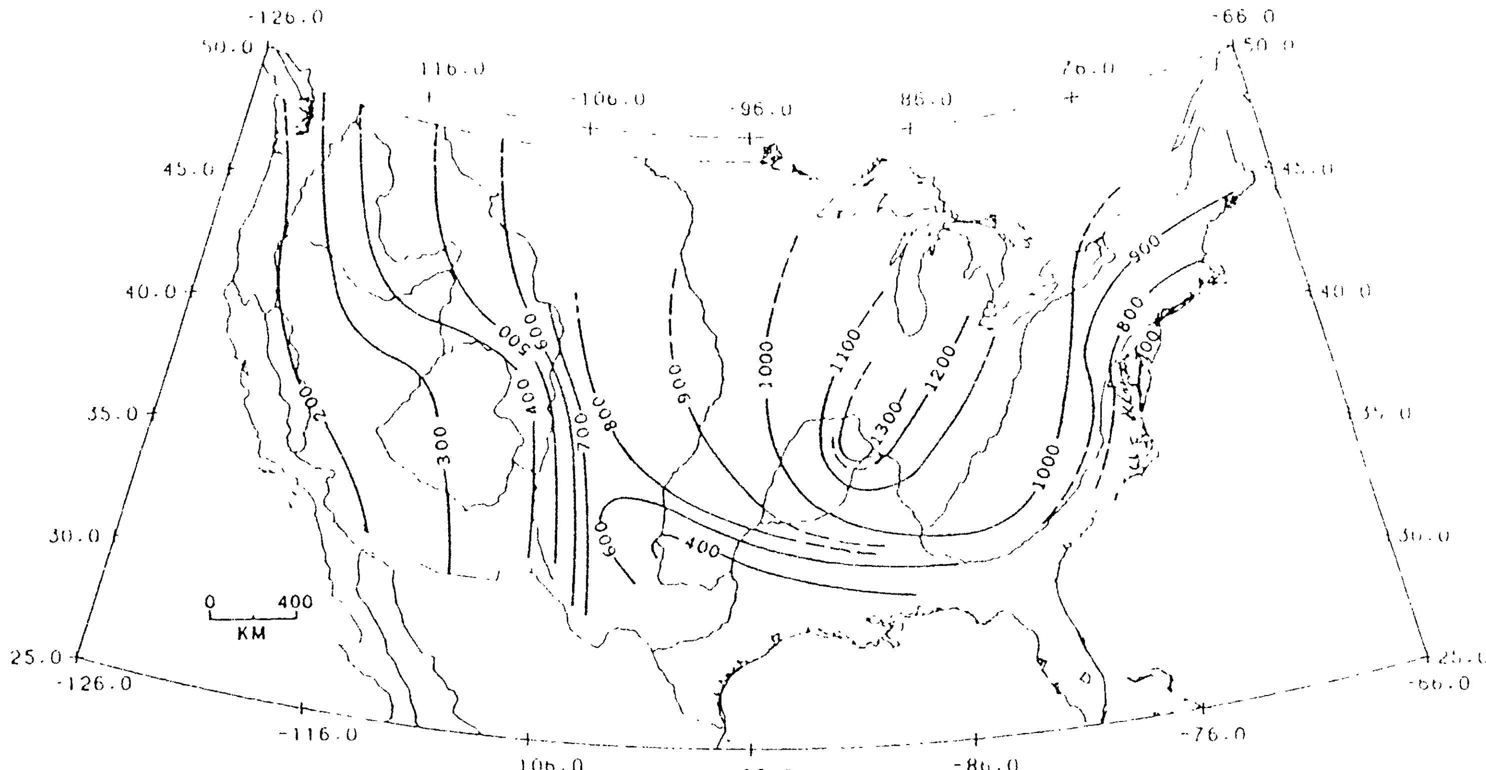

Figure 3. Contour map of crustal Q_o for the entire continental United States.

Glacial Lake Passaic

9510-02724

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Investigations

The project expanded in FY'81 to include detailed mapping (1:24,000) of the late-Wisconsinan terminal moraine in glacial Lake Passaic and reconnaissance mapping (1:125,000) north of the terminal moraine. Drilling and coring of lacustrine sediments southwest of the moraine were conducted along two transects; one to provide a distal to proximal series of cores, the other to provide a cross section proximal and parallel to the moraine. Drill holes were cased and geophysical logs were obtained.

Results

1. Mapping in the Chatham 7.5′ quadrangle delimited stratigraphic units in the vicinity of the Late Wisconsinan moraine. Units recognized are lacustrine clay-silt, lacustrine sand, glacio-fluvial sand and gravel, and till.

2. Cores of lacustrine sediments were obtained using Swedish foil sampler and wire line coring. Five core sites were drilled and cores were obtained along a transect perpendicular (distal to proximal) to the moraine. One core was obtained from the moraine to get the complete stratigraphic sequence at the ice-margin. Cores along a transect parallel and proximal to the moraine allowed for correlation of stratigraphic units. Correlation was aided by geophysical logging by Dick Walker (WRD, USGS, Trenton, N.J.). The ice-margin position was pinpointed including the southwestern limit of subsurface till.

3. Reconnaissance north of the moraine included measuring topset/foreset altitudes in deltas. These altitudes allow for calculation of tilt resulting from post-glacial crustal rebound. Tilt to the north between Moggy Hollow and Pequannock averages 0.6 m/km. A continuing problem in constructing this tilt history is the difficulty of recognizing beaches and other shoreline features mapped previously.

4. Description and sampling of soils developed in the lacustrine facies was initiated. Samples will be analyzed texturally, mineralogically, and chemically. Data from soils provide a basis for age correlation of post Late Wisconsinan deposits in the absence of other age criteria. Detailed soil descriptions have aided in recognition of remnants of pre-Late Wisconsinan weathering profiles on till and basalt in the vicinity of the moraine.

5. Oriented sections of cores have been studied by Joe Liddicoat (Lamont-Doherty Geological Observatory) using X-radiography and paleomagnetism. X-radiographs show couplets of silt/clay of uniform thickness which were not visible. These are interpreted to be varves. The silty "summer" layers show internal microlaminations which are apparently very thin ($\leq$50mm) fining-upward sequences which are possibly individual density flows. Paleomagnetic analysis of cores obtained in FY'81 shows progressive vertical trends of inclinaton and declination which may be useful in correlating varve sequences among cores.

6. A trench opened by Nick Ratcliffe across the Ramapo fault system near Riverdale showed sedimentary units recognized elsewhere in the basin which are interpreted to be younger than 20,000 ybp. Deformation of these lower delta foreset sediments included high angle reverse faults, normal faults and slumps. These structures may be due to intrastratal deformation as indicated by an unfaulted clay layer near the base of the trench. Reconnaissance along the trace of the Ramapo fault system showed no surface expression of late Quaternary differential movement. Evaluation of fault history must await more data from delta altitudes to assess post-glacial rebound and tilting.

FY'82 target activities are planned for the Fall of 1981 and Summer of 1982. These include:

1. Selecting transects for reflection and refraction seismic lines to be run cooperatively by the New Jersey State Geological Survey and USGS-WRD, Trenton. These seismic lines will be tied to existing drill holes or new holes to be drilled by the State of New Jersey.

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

3. Synthesis of subsurface data will continue. Emphasis will be placed on drawing detailed cross sections of subsurface units using geophysical logs and seismic reflectors for correlation.

4. Palynology and paleomagnetic studies of cores will continue.

5. Emphasis will be placed in obtaining near-surface peat samples from the lacustrine silt-clay facies both southwest and northeast of the moraine. Peat samples will be submitted for ^{14}C dating.

6. Clay mineralogy of varves and of pre- and post-Late Wisconsinan soils will be studied.

Structural Framework of Eastern United States Seismic Zones

9950-02653

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Investigations

1. Wheeler continued to use new and existing data and understanding of Appalachian structures and tectonics, to identify and map the most likely types of faults responsible for seismicity in and near Giles County, southwestern Virginia. Efforts were coordinated with faculty at Virginia Polytechnic Institute and State University (especially G. A. Bollinger), other USGS projects, and other pertinent investigators. See Result 1 and Report 2. Investigations included:

a. Work with Bollinger to prepare, and to revise after review, a manuscript that describes seismicity in and near Giles County and makes and evaluates structural interpretations of the seismicity.
b. Start of collection of maps and other data in preparation for compilation of a seismotectonic map of the region including Giles County.
c. Completion of analysis and interpretation of data bearing on stress orientations at seismogenic depths under Giles County.

2. M. Jones-Cecil continued work on the modification of a pattern-recognition technique for analyzing intraplate seismicity. See Result 2 and Report 1. Work included:

a. Continuation of investigations into statistical tests more appropriate than the binomial test for identifying significant associations of combinations of geological, geophysical, and topographic variables with the presence or absence of seismicity.
b. Continuing addition of new variables, updating of the earthquake catalogue, and minor changes to the pattern-recognition algorithm, for the application to the Southeastern United States.
c. Start of investigation of appropriate variables and identification of sources of data, in preparation for a similar pattern-recognition study of the Great Basin.
d. Giving a talk and participating in discussions at the Institute of Geophysics, University of Stuttgart. Work dealt with the pattern-recognition technique and the test application to the Southeastern United States.

3. K. M. Shedlock provided mathematical, statistical, and programming collaboration to other projects. See Result 3.

a. Shedlock continued processing and interpreting data from small-boat reflection surveys in the Mississippi embayment. Travel and computer work supported by projects 9950-01504 (D. P. Russ) and 9950-01896 (S. Harding).

b. Shedlock completed work on a manuscript with D. G. Herd and others on "The next great San Francisco Bay area earthquake", intended for Science. Travel and computer work supported by projects 9940-01950 (D. G. Herd) and 9930-02103 (W. L. Ellsworth).

Results

1. In and near the Giles County seismogenic zone of southwestern Virginia, the upper crust at seismogenic depths (beneath the Appalachian thrust faults) appears to be in roughly homogeneous, NE- to E-trending compressive stress. Analyses of 3 data sets support that conclusion. (1) We infer probable right-reverse motion in a steep, NE-striking zone under Giles Co., from the orientation and tabular shape of the seismogenic zone and from 6 impulsive P-wave first motions from the zone. (2) We infer SSE-trending, horizontal, least compressive stress, from orientations of fractures induced by coring of gas wells that were drilled 150 to 300 km NW of Giles Co. (3) We suggest failure in NE-trending compression for a shock (11/20/69, M = 4.6) that occurred about 12 km NW of the Giles Co. seismogenic zone, between the areas of (1) and (2) above. Herrmann used 9 P-wave first motions and surface-wave data to infer an easterly T axis for that shock (1979, Jour. Geophys. Res., v. 84, p. 3543-3552). That is not consistent with results of (1) and (2), which imply an easterly P axis. However by using orientations of geologically reasonable types of basement faults instead of the surface-wave data as constraints on a focal mechanism solution, we postulate nodal plane orientations and derive several focal mechanism solutions that are consistent both with the 9 P-wave first motions and with the results of (1) and (2).

The seismicity of (1) and (3) occurred deeper than the thrust faults of the Valley and Ridge province, in which Giles Co. is located. The coring induced fractures of (2) record stresses west of such thrusts, beneath them, or both. Thus the Midcontinent stress province of Zoback and Zoback (1980, Jour. Geophys. Res., v. 85, p. 6113-6156), which is characterized by NE- to E-trending compression, may extend eastward into the basement under the thrust faults of the Valley and Ridge province.

2. The test application of a version of the modified pattern recognition program to seismicity in the Southeastern United States was published, as Open-File Report 81-195. Further modifications to the statistical tests used in that study are needed to account more accurately for sample size and are underway.

3. Results obtained by Shedlock in collaborative work with other projects will be reported by the projects listed above under investigation 3.

Reports

Jones-Cecil, M., Wheeler, R. L., and Dewey, J. W., 1981, Pattern-recognition program modified and applied to Southeastern United States seismicity: U.S. Geological Survey Open-File Report 81-195, 137 p.

Wheeler, R. L., and Holland, S. M., 1981, Style elements of systematic joints: an analytic procedure with a field example, in O'Leary, D. W., and Earle, J. L., eds., International Conference on Basement Tectonics, 3d, Durango, Colorado, 1978, Proceedings: Denver, Colorado, Basement Tectonics Committee Publication No. 3, p. 393-404.

Southwestern Utah Seismotectonic Studies

9950-01738

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Trenching the Rose Canyon Fault Zone
San Diego, California

14-08-0001-19824

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Investigations

An approximately 70-meter long trench was excavated, logged, and the geology interpreted across the mapped projection of the Rose Canyon Fault zone in the La Jolla area of the City of San Diego, California.

Results

The inspection and analysis of the trench exposures indicate the fault to be located within a 3-meter wide zone separating the Cretaceous Point Loma and Eocene Ardath Shale. The main shear of the fault is approximately 23 cm wide, strikes generally N18°W and dips 70° southwest. A second shear about 5 to 12 cm in width striking about N20°W and dipping 60 to 80° northeast is located within 1.8 meters of the main shear. The rake of striations along the 3-meter wide fault zone dip at angles greater than 80° suggesting mainly a vertical component of displacement.

The main shear is overlain by an unfaulted Middle to Late Pleistocene deposit estimated to be approximately 75,000 to 128,000 years old. The secondary shear has an apparent vertical stratigraphic separation of 2.5 to 3 meters in the Middle to Late Pleistocene deposits. The strike and dip of the secondary shear in the Middle to Late Pleistocene deposits coincide with the strike and dip of the bedding of the Ardath Shale which underlies the Middle to Late Pleistocene deposits. Such an association does not discount tectonic faulting but also may suggest displacement due to adjustment along bedding planes within the Ardath Shale, consolidation of the younger sediments, or a combination of the two. A midden deposit radiocarbon dated as approximately 1,140±80 years old showed geologic evidence for no displacement.

Earthquake Hazards and Tectonic History of the San Andreas Fault Zone, Los Angeles County, California

14-08-0001-19193

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Investigations

The Division is in the final phase of a program of very detailed fault and geologic mapping of a 100-km stretch of the San Andreas fault zone in Los Angeles County. The purpose of the current project is to produce an analysis of the geologic history of the fault by bringing together all data collected during earlier phases of this program with newly collected data on minor gaps that remained and preparing a summary paper and series of strip maps. A better understanding of how fault behavior may be changing through time in offset history, recurrence interval, or in the physical location of ground rupture is the primary goal of this project.

Results

Geologic data, originally depicted upon orthophoto bases, are being transferred to topographic bases at a scale of 1:12,000. A total of eight contiguous sheets, each representing 12.5 km, form the detailed geologic strip map. Compilation and drafting of these maps is approximately 60 percent complete. Geologic cross sections for these maps are about 50 percent complete.

Eleven annotated fault activity maps, on orthophoto bases at 1:12,000 scale, are being prepared and/or revised. Drafting of these maps is approximately 80 percent complete.

The composite geologic column derived from six existing explanation sheets is being prepared through revision and simplification of the original nomenclature. The explanation depicts 108 units and subunits including 40 Quaternary units.

Surface Faulting Studies

9940-02677

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Investigations

The investigations were focused on the study of rupture fraction (surface rupture length/total fault length), in collaboration with J. J. Lienkaemper, and field examination of new surface ruptures.

Results

Tentative criteria for recognizing the termination or continuation of faults were prepared. The criteria, which are based on empirical, logical, and theoretical considerations, are being modified based on experience in applying them to the faults under study.

Acquisition of reports, maps, and other data was completed for the 1930 and 1943 Japanese events. Geologic, seismologic and geodetic data were all compiled at the same scale for direct comparison among the various kinds of data, and the events were discussed with Tokihiko Matsuda of Tokyo University. A first draft of a summary and conclusions regarding total fault length and rupture fraction for these two events was prepared.

Geologic and topographic maps were ordered for the area around the 1956 San Miguel, Mexico, faulting and the portion of the 1940 Imperial fault that was in Mexico. Corresponded with geologists of San Diego State University regarding a map that is being prepared of the San Miguel fault zone, and began search for data that may exist in addition to that already on hand.

New data on the 1968, 1970, and 1979 surface faulting in Australia were compiled and studied. Corresponded with J. D. Lewis of the Geological Survey of Western Australia regarding the origin, and possible field check by him, of geomorphic features that are visible on Landsat and 1/80,000 aerial photos north of the 1968 rupture.

Compiled and reviewed all pertinent published reports and other data on the 1950 Ft. Sage Mountains, California, fault area. Discussed unpublished information with members of the U.S.G.S., Nevada Bureau of Mines, and University of Nevada. Studied conventional black-and-white, color infrared, and low sun-angle aerial photographs of the area. Photointerpretation revealed some scarps that are not shown on existing maps, and these were confirmed as fault scarps by field examination. The height and slope angles of some of these were measured as an aid in estimating the age of the faulting. These faults are important in determining the length of the fault zone on which the 1950 faulting occurred.

Field investigation was made, in collaboration with others, of a new reverse fault rupture found in a diatomite quarry near Lompoc, California, a few hours after a magnitude 2 1/2 earthquake. Extrapolating empirical data, which are based on earthquakes of magnitude 6 or larger, the surface displacement (0.25 m) and length (0.57 km) were much greater than would have been expected for a M 2 1/2 earthquake; however, the displacement fits well with extrapolated empirical data relating logarithm of displacement to log length. An abstract was prepared on this event and submitted to Geological Society of America.

Field investigation was made of fractures reportedly formed within a 6-week interval on the south strand of the Los Positas fault near Lawrence Livermore Laboratory, California. The fractures have a right-stepping pattern suggestive of left slip and may be the result of creep on the fault. The fractures were mapped, the ends were marked with paint on June 24, and an alinement array was installed so that additional displacement can be detected.

Reports

Bonilla, M. G., in press, Surface faulting, Chapter 2 in Hays, W. W., ed., Facing geologic and hydrologic hazards--earth science considerations: Geological Survey Professional Paper 1240-B.

Yerkes, R. F., Bonilla, M. G., Ellsworth, W. L., Lindh, A. G., and Tinsley, J. C., 1981, Reverse faulting and crustal unloading near Lompoc, northwest Transverse Ranges, California [abs.]: Geological Society of America, Abstracts with Programs, v. 13, no. 7,p. 586.

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

9940-02090

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Beginning in FY82, investigations concerning Quaternary deposits and tectonics of the western Mojave area are being incorporated into the project entitled "Coastal Tectonics of the Western United States" headed by K. R. Lajoie (project no. 9940-01623).

Investigations

1. Work during the last half of FY81 included continued field mapping in the western Antelope Valley region near the intersection of the Garlock and San Andreas faults.

2. In situ shear wave velocity data from 11 holes drilled last year in cooperation with J. Gibbs and T. Fumal have been correlated with the stratigraphy in the central and eastern portions of the Antelope Valley.

3. Samples from a deformed 100 m thick lacustrine silty clay unit that underlies much of the central Antelope Valley basin (Rosamond Dry Lake) are currently being analyzed for paleomagnetic signatures (J. Hillhouse), diatoms (P. Bradbury), and ostracodes (R. Forrester).

Results

1. There is considerable geomorphic evidence for N-S compressional tectonics both to the north and south of the San Andreas fault, but unfortunately the uplifted surfaces have been stripped of gravels, making correlation and age estimates of the surfaces difficult. Amount of uplift of the northern flank of the Transverse Ranges within this areas has been at least 350 meters. This uplift has occurred over a span of time that could be as short as 50,000 years, but certainly no longer than 500,000 years.

2. The seismic velocities of the granular sediments (primarily sands and gravelly sands) appear to increase significantly with age of the deposit and, for a unit of a given age, do not vary significantly with depth of burial. The relationship between age and shear wave velocity may prove extremely useful for correlation and relative age dating. Velocity ranges for the alluvial units, based on our present sample, are as follows:

Early Holocene (6-10kA)	-	260-330 m/sec
Late Pleistocene (40-80kA)	-	400-440 m/sec
Pleistocene (100-150 kA)	-	470-520 m/sec
Pleistocene (~250 kA)	-	660-720 m/sec

We are currently reviewing shear wave data from granular sediments in Los Angeles and the San Francisco Bay area to see if similar clustering of velocities might exist in these regions as well.

3. No diatoms were found in the samples of silty clay at depths of 25 m and 45 m in Rosamond Dry Lake, but the presence of fresh-water algae and fresh- to brackish-water ostracodes confirms the lacustrine origin of the deposit. Results from the paleomagnetic analyses are still pending.

Reports

Ponti, D. J., Burke, D. B., and Hedel, C. W., 1981, Map showing Quaternary geology of the central Antelope Valley and vicinity, California: U.S. Geological Survey Open-File Map 81-737, scale 1:62,500.

Geomorphic Studies of Post Pleistocene Deformation Along the San Andreas Fault, West-Central Transverse Ranges, California

14-08-0001-17676

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Investigations

Geomorphic and structural details along a portion of the San Andreas Fault in the Central Transverse Ranges have been delineated at a scale of 1:12,000 on strip maps. In addition, several trenches have been dug across the active fault strand which last moved vigorously during the 1857 Fort Tejon Earthquake, in order to work out late Quaternary deformations. Evidence for at least three earthquakes has been recognized which will be datable when radiocarbon information is eventually forthcoming. The mapping at a scale of 1:12,000 shows such fault-zone features as scarps, sags, shutter ridges, displaced Quaternary surfaces, folds, drainage interruptions, and similar features superimposed or in addition to information on bedrock geology.

Results

1. Strip maps along the San Andreas fault zone delineating natural hazards related to the geologic setting, earthquake potential, and steep slopes between Interstate 5 on the south and the Temblor Mountains on the northwest. These maps are now completed and are in the process of being published by the USGS. Maps to the southeast of Interstate 5 are in preparation.

2. Documentation of times of movement (at least three) are forthcoming and will be more precise when radiocarbon samples have been dated. Soil sequences are adding information on timing which will lead to a sequence of dated deformational events.

3. Large-scale cross-sections showing the walls of trenches dug across the San Andreas fault zone provide information on both the sequence of events and on the intensity of earthquakes and associated phenomenon such as liquifaction.

4. Regional cross-sections and mapping of bedrock features has disclosed several reported older faults, such as mid-Miocene Caballo Canyon Fault.

5. Knowledge of the regional tectonics including information on the progressively northward folding of the San Emigdio Range toward the San Joaquin Valley, with time. This type of information along with data on regional relations will add to our understanding of plate tectonics.

Tectonics of Central and Northern California

9950-01290

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Investigations

1. Age dating of ancient oceanic terranes and timing of their accretion to western North America; in collaboration with D. L. Jones and B. R. Wardlaw.

2. Paleomagnetic orientation of terranes of the Klamath Mountains province; in collaboration with E. A. Mankinen and S. C. Gromme.

3. Tectonic relations of carbon dioxide discharges and seismicity; in collaboration with Ivan Barnes. Revision of map showing global distribution of carbon-dioxide discharges and major zones of seismicity continued.

Results

1. Most of the seismicity of North America is along the framework of tectonically accreted terranes that make up the western margin of the continent from Alaska to Baja California. Many of these accreted terranes include ophiolites whose distribution, age, and tectonic significance are described in a report by Irwin and Jones (in press). The various ophiolites are fragments of oceanic crust that formed during early and late Paleozoic, Triassic(?), and Jurassic time. Most of these fragments were accreted to western North America during the Jurassic. The ophiolitic components of the various terranes occur in three general modes: (1) as the depositional base for thick sequences of marine volcanic and sedimentary strata, (2) as tectonic blocks in melange, and (3) as nappes lying on rocks of continental affinity.

Geographic points of origin of most terranes of the western borderland of North America are not clearly known. Some terranes have doubtless traveled great distances to arrive at their present sites. In southern Klamath Mountains, several pods of limestone in melange of the Hayfork terrane contain a fauna of Late Paleozoic foraminifera that is foreign to North America (Nestell, Irwin and Albers, 1981). It is the youngest Permian Tethyan fauna found in the accreted terranes of western North America, and may also be the youngest Permian fauna reported in the Western Hemisphere. Similar Permian Tethyan foraminiferal faunas are found in southern China, Japan, and southeastern Siberia.

2. The Klamath Mountains province is a composite west-facing arcuate structure that consists of a series of nearly concentric accreted terranes.

In 1980, cores of Permian volcanic rocks were drilled in the northern part of the province where the regional trend of formational boundaries is east-northeast. Preliminary paleomagnetic measurements on these cores indicate that the Permain volcanic rocks have rotated clockwise through a large angle. During the present report period, additional drilling of the Permian volcanic rocks was done in the middle latitude of the province where the regional trend of the lithotectonic units is nearly north-south. Paleomagnetic measurement of these latest cores should aid in determining whether the Klamath Mountains province rotated clockwise as a single rigid block or whether the arcuate distribution of the Permian volcanic strata results from oroclinal bending. Laboratory work on the latest cores has not been completed.

Reports

Irwin, W. P., and Jones, D. L., 1981, Distribution, age, and tectonic significance of ophiolites of the western United States, in Ophiolites of the World: Wiley Co., in press.

Irwin, W. P., 1980, The Klamath Mountains, in Aubouin, J., Blanchet, R., and Rangin, C., eds., Réunion extraordinaire de la Société Géologique de France en Californie, 4 septembre-13 septembre 1979: Bulletin de la Société Géologique de France, v. 22, no. 4, p. 527-532.

Irwin, W. P., Wardlaw, B. R., and Kaplan, T. A., 1981, Conodonts of the western Paleozoic and Triassic belt, Klamath Mountains, California and Oregon: Director's approval.

Mankinen, E. A., and Irwin, W. P., 1981, Paleomagnetic study of some Cretaceous and Tertiary sedimentary rocks of the Klamath Mountains Province, California: Geology, in press.

Donato, M. M., Barnes, C. G., and Irwin, W. P., 1981, Northward continuation of the Hayfork terrane, north-central Klamath Mountains, California (abs.): Geological Society of America, Abstracts with Programs, v. 13, no. 2, p. 52.

Nestell, M. K., Irwin, W. P., and Albers, J. P., 1981, Late Permian (Early Djulfian) Tethyan Foraminifera from the southern Klamath Mountains, California (abs.): Geological Society of America, Abstracts with Programs, v. 12, no. 7, p. 519.

Tephrochronology of the Central Region

9530-02169

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

14-08-0001-19781

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Investigations

Development and refinement of a soil chronosequence for use in dating Quaternary tectonism and evaluating the earthquake hazard in the Western Transverse Ranges was continued along with mapping deformed fluvial terraces and alluvial fans. The style of tectonic deformation for major geologic structures in the central Ventura basin including the San Cayetano fault and the Ventura Avenue anticline, is also being investigated.

Results

Significant development has been made in the refinement of a soil chronosequence to be used as a Quaternary dating technique for the Western Transverse Ranges. Table 1 summarizes these results. Eight radiocarbon localities have been collected and submitted for analysis.

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

Faulting rates approach a maximum of 3.5 mm/yr near the central portion of the San Cayetano fault decreasing to about 0.5 mm/yr towards its western terminus. More than one strand has been active during the late Pleistocene and the Holocene as young alluvium has been faulted, but it cannot be demonstrated whether or not they move synchronously. Faulted Holocene alluvium along with Holocene footwall deformation indicate that deformation continues to the present.

Detailed mapping in the vicinity of Ventura to evaluate recent rates of uplift for the Ventura Avenue anticline suggest that fluvial terraces of late Pleistocene age have apparently been folded over the Ventura Avenue anticline. A terraced deposit on the anticlinal axis dated by radiocarbon at about 30,000 y.b.p. (Qt5b, Figure 1) provides a maximum rate of uplift of about 5 mm/yr. Older and higher terraces suggest that the rate of uplift during the period 30,000 y.b.p. to 80,000 y.b.p. was about 10 to 11 mm/yr. Folding of the Pleistocene bedrock dated by amino acid data at 200,000 y.b.p.

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

Geomorphic Surface		Brightest moist mixed color in B horizon: Hue	Chroma	Color Index[1]	Clay[2] $\overline{X}B/\overline{X}A$	Clayfilm Index[3]	Estimated Age in Years Before Present (BP)
Qt_1	Car body	AC profile, no B horizon			No B	0	10-20
Qt_2	Sespe	AC profile, no B horizon			No B	0	250
Qt_3	Orcutt 0	10 Yr	3	4	0.6	0	500-5000[4]
Qf_4	Orcutt 1	10 Yr	4	5	1.3	3.0	8,000-12,000[5]
Qf_5	Orcutt 2 (Bankamerica)	10 Yr	4	5	1.1	6.0	15,000-30,000[5]
Qt_{6a}	Oak View[7]	7.5 Yr	5	7	1.4	7.25	38,000[6]
Qt_{6b}	Apricot	7.5 Yr	6	8	1.5	5.5	>38,000
Qt_{6c}	La Vista[7]	7.5 Yr	7	9	1.6	7.0	>38,000
Qf_7	Timber Canyon[4]	5 Yr	6	9	ND	8.0	∿120,000[5,8]

1. Color index is computed by adding chroma number to hue (of moist mixed sample), where 10YR = 1, 7.5YR = 2, 5YR = 3. Indices from different profiles on same geomorphic surface are averaged. To determine color, a large air-dried bulk sample was passed through a 2mm sieve, then fractionated in a mechanical splitter, moistened, hand homogenized to a putty consistency and rolled to a sphere; the latter was then pulled into halves, and color noted from one freshly broken surface.
2. Ratio of the mean percent of clay in B horizon to that in the A horizon (computed from particle size graphs, Keller et al., 1980).
3. This index is based on clay film information contained in the profile descriptions and is computed by adding the percent frequency of clay film occurrence to their thickness, as follows: Percent frequency, very few = 1, few = 2, common = 3, many = 4, continuous = 5; Thickness, thin = 1, moderately thick = 2, thick = 3. For example, in the B_{22t} horizon of La Vista 2 there are "...many to continuous (4.5) moderately thick & thick (2.5) clay films..." The index would be 7.0.
4. This age estimate is collectively based upon tree rings of a number of mature oaks growing upon the Orcutt 0 surface, the degree of soil profile development, and a C-14 date [see Timber Canyon 1 profile description] on charcoal collected from a presumed buried soil in the lower part of the Timber Canyon profile.
5. Age estimate based in part upon relative amount of displacement on flexural-slip faults between older surfaces in Orcutt and Timber Canyons, and one C-14 date.
6. Based on two C-14 dates on charcoal collected at the base of the Oak View Terrace below Olíva 1.
7. These measures were taken from the buried soil portion of the profile; only the buried soil portion of the profiles of Olíva 1 and La Vista 3 are correlated to the Qt_6 geomorphic surfaces.
8. Older and more developed soils grouped with Qt_7 have been sampled and described. Thus, a 120 ka age estimate is a minimum for Qt_7 soils but appears correct for Timber Canyon 4 as discussed above.

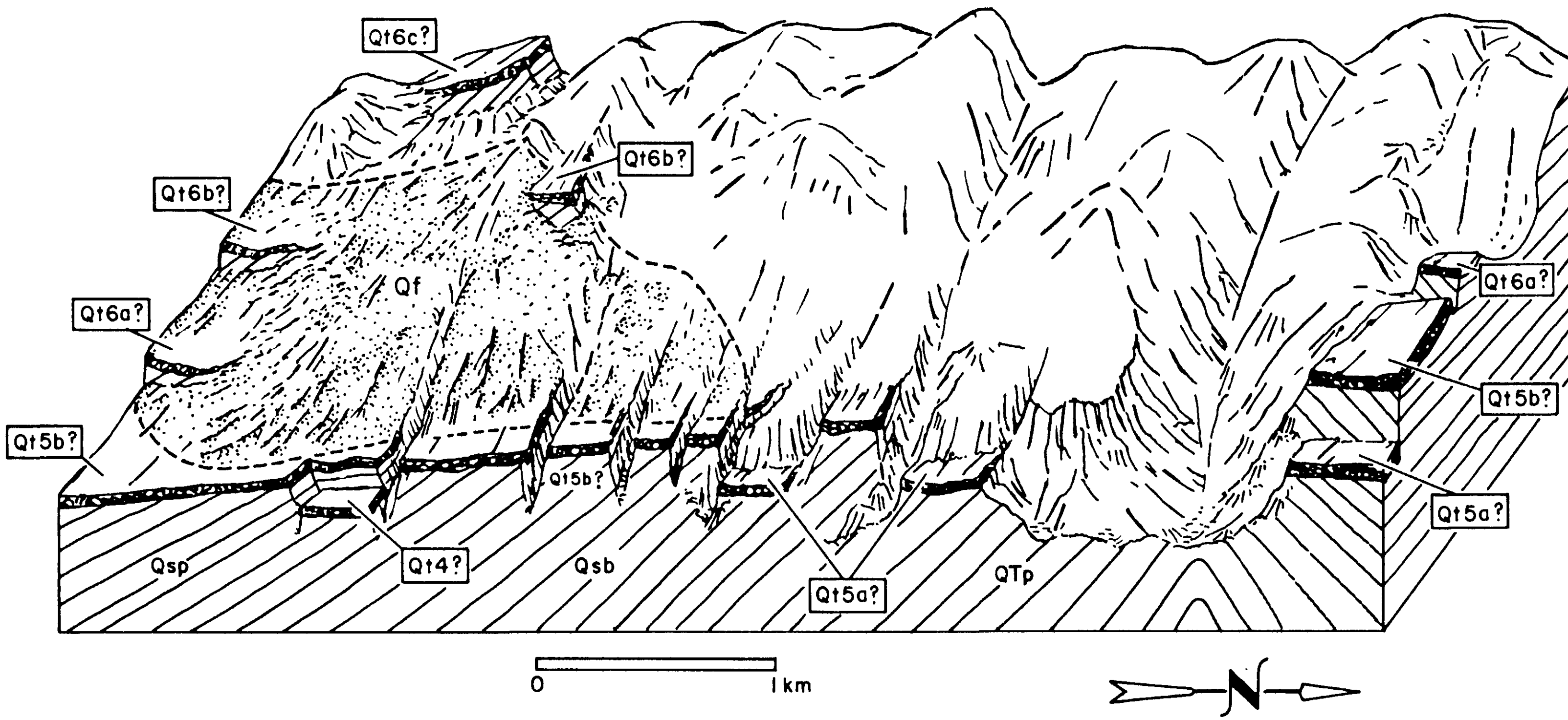

Figure 1. Idealized diagram of the Ventura Avenue anticline with deformed river terraces. The Qt5b (?) surface has been dated at about 30,000 radiocarbon y.b.p. The "?" indicates uncertainty in the assignment of the a, b, c designation in the Quaternary stratigraphy (see Table 1).

by U.S. Geological Survey personnel suggest that the uplift was even faster (15 to 16 mm/yr) during the period 80,000 y.b.p. to 200,000 y.b.p. Thus, during the last 200,000 years the rate of uplift may have been decreasing.

Reports

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Keller, E.A., Johnson, D.L., Rockwell, T.K., Clark, M.N. and Dembroff, G.R., 1981, Quaternary stratigraphy, soil geomorphology, chronology and tectonics of the Ventura, Ojai and Santa Paula areas, Western Transverse Ranges, California, Part I, Friends of the Pleistocene Field Trip Guidebook, p.1-125.

Correlating and Dating Quaternary Sediments by Amino Acids

9830-01996

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Investigations

1. Completed a study of amino acids in fragments of *Saxidomus giganteus* recovered from a borehole penetrating a shell bed overlying the Half Moon Bay marine terrace. The work provides a basis for the correlation of buried terrace deposits with exposed terraces.

2. In order to estimate ages of early man in France, completed studies of amino acids in hominid bones recovered from deposits at Caune de l'Arago, France.

3. To evaluate changes in the amino acid geochemistry of lacustrine sediments for the purpose of correlation and geochronology, initiated analyses of sediment samples from Clear Lake core CL-80-1.

Results

1. Shell fragments of *Saxidomus giganteus* recently recovered from a borehole (U.S.G.S. loc. M7814) near Princeton, California, on the Half Moon Bay terrace, were analyzed for amino acids in order to attempt to correlate this buried terrace with marine terraces exposed southward on the coast. Four specimens were selected for study. Total amino acid concentrations range from 6.7 to 7.3 micromoles per gram of shell (μm/g) suggesting that the fragments are of approximately the same age. Leucine D/L ratios range from 0.40 to 0.45. The average leucine D/L ratio of $\sim$ 0.42 correlates with values obtained from *Saxidomus* specimens collected from exposed Pleistocene marine terraces elsewhere along the coast that have a cool water faunal aspect. The age of the buried shell deposit is therefore estimated to be about 80,000 to 85,000 years old.

2. At Caune de l'Arago, France, an important transitional phase between *Homo erectus* and Neanderthal hominid fossils occurs during a time period difficult to date using radiometric methods. Amino acid analyses were conducted using l'Arago bone samples for geochronologic purposes and to enhance our ability to use bone for age estimations. In our analyses anomalously high extents of racemization of alanine and glutamic acid were measured, suggesting that excess D-enantiomers of these amino acids have become incorporated in the bones. For example, sample ZI22-III2 had an aspartic acid D/L ratio of $\sim$ 0.2, whereas the glutamic acid D/L ratio was $\sim$ 0.5. In uncontaminated bones aspartic acid

usually has the higher D/L ratio. Potential sources of D-alanine and D-glutamic acid are bacterial cell-wall proteins and soil humic acids. By assuming that the hydrophobic amino acid leucine is most likely indigenous to the bones, comparisons of the rate constants for the racemization of aspartic acid and leucine (kasp:kleu) can be used to reject contaminated samples. With this approach, bones at Caune de l' Arago are estimated by aspartic acid racemization to have ages ranging from ∿200,000 to 500,000 years.

3. Results of geochemical studies of amino acids in lacustrine sediment from core CL-80-1, taken during July 1980 from Clear Lake, California, are in general agreement with our recently published study of amino acids in core CL-73-4 (see Reports). Total concentrations of 14 amino acids are slightly higher in CL-80-1 than in CL-73-4, due probably to a modification of the analytical method. In core CL-80-1 total amino acid concentrations decrease from about 39,000 nanomoles per gram of sediment (nm/g) at a depth of 3.50 m to 31 nm/g at a depth of 155.50 m. Alanine D/L ratios of 0.19 at 123.00 m and 0.23 at 133.00 m bracket an oak pollen peak which occurs between 126 and 128 m in CL-80-1. In core CL-73-4, an alanine D/L ratio of 0.20 was measured at a depth of 79.55 m just above an oak pollen peak at 81 m. Oak pollen peaks characterize warm climatic intervals. The amino acid data essentially agree with the palynology and provide another means of correlation between both cores. Our results show that amino acids in bulk samples of clastic sediments behave in a consistent manner and therefore can be used for correlation.

Reports

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Coastal Tectonics, Western U.S.

9940-01623

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Investigations

1. Continued mapping and dating late Quaternary marine terraces and deposits in numerous coastal sites in western U.S. with emphasis on Humboldt, Santa Barbara, Ventura, Los Angeles and San Diego counties. Project personnel are George Kennedy (Paleontologist), Dan Ponti (Geologist), Scott Mathieson (Geologist), and Pat McCrory (PST).

2. Participated in investigative hearings conducted by California Public Utilities Commission to obtain data on the seismotectonic setting of the proposed site of a liquid natural gas facility near Point Conception, Santa Barbara County, California.

3. Participated in investigative hearings by the Federal Energy Regulatory Commission on the seismotectonic setting of the Point Conception LNG facility.

4. Investigated a new fumerole near Gaviota on the South Santa Ynez fault in Santa Barbara County, California.

Results

1. With R. McLaughlin mapped the late Quaternary alluvial and marine deposits at Point Delgada, Humboldt County, California. Slightly dipping alluvial fan deposits exposed on the south shore of Point Delgada are not tectonically deformed near an onshore projection of the San Andreas fault. The dips are primary depositional features associated with rapid alluvial fan formation, not tectonic deformation, as reported by previous workers. The 40kA(?) marine terrace that forms the low flat top of this headland dips slightly southward, but is not displaced across any faults.

2. A new molluscan fossil assemblage on lowest marine terrace at Point Arena has a temperature aspect that indicates an age of 85-105kA. The marine deposits on this terrace near the fossil locality are cut by a fault trending N40°W, roughly parallel to the San Andreas fault, which lies 7.5 km to the east. Other faults may cut this terrace 0.5 km east of the fossil locality. Corals in the fossil assemblage will yield absolute dates (U-series) that will provide local calibration for other dating techniques (paleontological and amino-acid racemization).

3. There is no evidence for the reported offsets of marine terraces at the mouth of Horno Canyon near San Onofre in San Diego County, California.

4. A new marine fossil locality at Shell Beach in San Luis Obispo County, California contains corals that will yield absolute dates (U-series) from which uplift rates along this section of coast can be obtained.

5. Dan Ponti compiled numerous well logs from the Los Angeles basin for computer modeling of earthquake ground shaking.

6. Numerous bedding-plane faults in well-bedded siliceous shales (Miocene) cut marine terrace platforms and deposits tentatively dated at 85-125kA at Point Conception in Santa Barbara County, California. Several fault strands cut overlying alluvial deposits, some of which may be late Pleistocene to early Holocene in age. The sudden bedding-plane displacement of similar rocks in the Lompoc Quarry about 20 km north of Point Conception may be a reasonable analog for some of the tectonic events associated with the faults that cut the marine terraces in this area.

7. With J. Slosson (consultant), R. Kovach (Stanford) and W. Evans (USGS) investigated a new fumerole 100 m from the South Santa Ynez fault near Gaviota, Santa Barbara County, California. The new fumerole activity (71°C-78°C) may indicate a change in tectonic stress in the region.

8. Paleontological and amino-acid data on fossil shells from a 20 m drill hole confirm an age of 85-105kA for the Half Moon Bay terrace (San Mateo County, California) derived from meager geologic data. This terrace is intensively warped and faulted, so the new dating control provides a firmer basis for deriving ages of faults and rates of tectonic deformation in the region.

Reports

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

14-08-0001-19746

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Investigations

1. Extend the magnetostratigraphy in the Neogene of the Atlantic Coastal Plain where the approximate age of sediments has been established using invertebrate fossils.

2. Date the Paleogene in the Atlantic and Gulf Coastal Plains using the paleomagnetic polarity time scale that is keyed to the marine faunal record (Napoleone et al., 1980).

Results

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

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

2. Paleomagnetic samples from the 40-meter Putney Mill core (New Kent County, Virginia, vertically oriented, split-spoon) were analyzed as a feasibility study for additional coring in central Alabama. The data for four samples following a.f. demagnetization identify reversed polarity near 20-meters depth and normal polarity near 40-meters depth. The

findings are encouraging that paleomagnetism can be used as a chronologic tool in paleontologic investigations of the Paleogene in the Atlantic and Gulf Coastal Plains. Among the objectives is an accuarate interpretation of temporal and spatial relationships between sedimentary deposits of marine, marginal marine, and non-marine origin.

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Soil Correlation and Dating, Western Region

9540-02192

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Investigations

Purpose: Establish data base and conduct fundamental research on the potential of soils as correlation and dating tools.

Strategy: Twelve numerically dated soil chronosequences from varied climatic and geologic environments have now been sampled and are currently being analysed to determine which soil properties are the most useful indicators of age and how rates of soil delevement vary in different environments. Analyses for soil profile and horizon samples include more than 100 physical, chemical, and mineralogical properties: 39 elements are determined by bulk chemistry, 25 properties by extractive chemistry, 25 properties by field descriptions, bulk density, particle size and mineralogical analysis by x-ray diffraction, thin section and grain mounts.

Personnel: M. N. Machette, J. W. Harden, E. M. Taylor, R. M. Burke, and M. C. Reheis (M. J. Singer, A. J. Busacca and P. Janitzky; U.C.-Davis, contract).

Investigations of the past six months include:

1. Continued laboratory processing of samples from the Honcut and Ventura, California chronosequences. (Singer, Busacca and Janitzky)
2. Interpreted newly acquired soil chemical, mineralogical and physical property data. (Harden, Taylor, Burke, and Busacca)
3. Completed geologic mapping of the Honcut Creek soil chronosequence area. Four of the eight 7 1/2' quadrangles are being compiled for Open-File release, the remaining four will follow soon. (Busacca)
4. Completed geologic mapping for Cowlitz, Washington soil chronosequence; laboratory analyses now complete. (Detheir, Bethel, and Ugolini)
5. Completed geologic mapping and sampling of soil chronosequences along Rock Creek, Montana and Cottonwood Creek, Wyoming. (Reheis)
6. Sampled soil chronosequence from flight of marine terraces near Santa Cruz, California. (Burke, Harden, Taylor, Machette, and Reheis)
7. Constructed a data management system for storage and statistical analysis of soils data. (Taylor)
8. Continued cooperative research with various projects needing soils expertise especially in applications towards dating unconsolidated Quaternary deposits. (Harden and Taylor)
9. Organized and chaired USGS internal workshop on current and future research needs in soils and weathering research as applied to late Cenozoic geology. (Machette, Chairman; Burke, regional cooridinator; Harden, workshop leader)

Results

1. Application of the profile index (PI) of Harden (1981) to the Honcut Creek chronosequence reveals a linear trend with time when plotted as $\log_{10}$ of PI versus $\log_{10}$ of soil age. This same relationship has also been shown for the Merced River chronosequence. These two chronosequences are developed on different parent materials but in similar climatic regimes, yet they show strikingly similar degree of development for soils of comparible age (fig. 1). This comparison provides an important test of the PI because correlation of geologic deposits and soils were carried out indepently by different workers in the two areas. We are now confident that the PI could become a fundamental field-mapping and correlation tool for Quaternary geologists. (Busacca and Harden)

	Honcut Creek		Merced River	
	PI	HI	PI	HI
Late Holocene (<1000 yrs)	12		12	
Middle Holocene (3,000 yrs)			20	
Holocene (undivided)		0.18		0.28
Upper Modesto Fm.	43	.31	27	
Middle? Modesto Fm.	45	.36		.41
Lower Modesto Fm.	56	.41	67	
Upper Riverbank Fm.	103	.52	102	.53
Middle Riverbank Fm.	107	.52	118	
Turlock Lake Fm.			148	.57
Laguna Fm.				
China Hat member			261	.84
Lower Laguna member	227	.77		

Figure 1. Soil Profile Index (PI) and maximum Horizon Index (HI) values for the Honcut Creek (Busacca, 1981) and Merced River (Harden, 1981) chronosequences.

2. The marine terraces of the Santa Cruz area are estimated to be from about 0.1 to 0.9 m.y. old on the basis of their elevations, tilt angles, and uniform uplift and tilt rates. The terraces are mantled by a thin blanket of marine sands and towards their back edges a progressively thickening wedge of locally derived colluvium or alluvium. For the most part the Santa Cruz terrace deposits are granitic sands, in contrast to the Año Nuevo and Ventura deposits which are reworked from Cenozoic shales. The soils formed on the Santa Cruz terraces show progressive development of structure, texture, color and mottling (percent and contrast) with increasing age. The terrace deposits are poorly preserved and in most cases the upper part of the solum has been eroded. Therefore, useful age-differentiation criteria will probably be based on maximum property development rather than the more preferred technique of cumulative property assessment. Samples from eight profiles were submitted for laboratory analysis at U.C.-Davis. (Burke, Harden, Taylor, Machette, and Reheis)

3. Detailed mapping of alluvial fans along Cottonwood Creek in the Kane 7 1/2' quadrangle (Wyoming) has shown that the Lava Creek Ash (0.6 m.y.) is in depositional continuity with the oldest fan (F7) rather than fan 5 as previously thought. Fan 3 alluvium overlies terrace deposits that upstream are overlain by a 100,000 (?) old ash. This chronsequence is characterized by semiarid soils with abundant gypsum; soils on fans 5, 6, and 7 are gypcretes. To the north, the soils of the Rock Creek, Montana chronosequence are a more typical suite having argillic and calcareous horizons. Several significant changes to the previous mapping are now warranted: 1) the Roberts terrace is formed by two separate and mappable deposits and 2) the lower Roberts terrace is overlain by the Lava Creek Ash (0.6 m.y.) near the town of Silesia, Montana. Samples from both of these chronosequences will be processed in the laboratory (University of Colorado) during FY 82. (Reheis)

4. Chemical analysis of major oxides, including zirconium and titanium, are important for determining relative elemental stability. For soil chronosequence studies, an accumulation series can determine the relative resistance of elements to leaching. Bulk analysis of the silt plus clay fraction is especially useful in stratified parent materials. In xeric soil moisture regimes of the California Central Valley, Zr oxide is the most resistant element in the accumulation series:
   Zr > Si,K > Al > Fe > Ca > Mg. Ti, a commonly used index element for leaching studies, is intermediate between Si and Al in mobility. Leaching and accumulation of other constituents can be more accurately determined once stable constituents are identified for a soil chronsequence. Relative to Zr, Ti accumulates faster in B horizons than in A horizons (figure 2). If Zr is truely stable, then Ti is either concentrated from coarse to fine fractions or it is translocated from the A into B horizons as soil development progresses. The differential concentrations of mobile elements are useful age indicators of soil development. For example, in figure 3 the difference in total iron in the B and A horizons from soils in a xeric soil moisture regime of the Central Valley is directly related to a logarithmic function of soil age. (Harden)

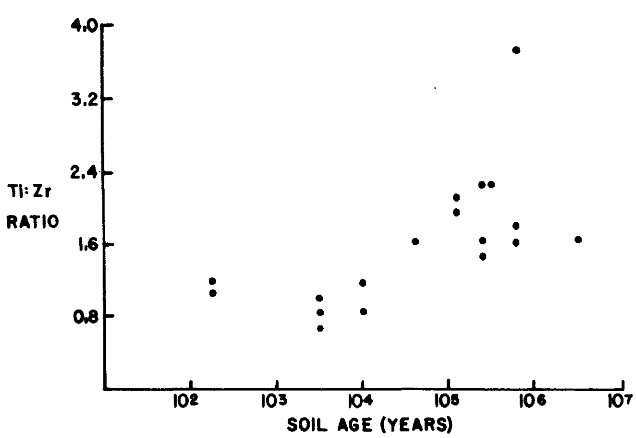

Figure 2. Ratio of weight percent Ti and Zr in A and B horizons vs. soil age plotted on a log scale. (Ti in B x Zr in A divided by Ti in A x Zr in B horizons)

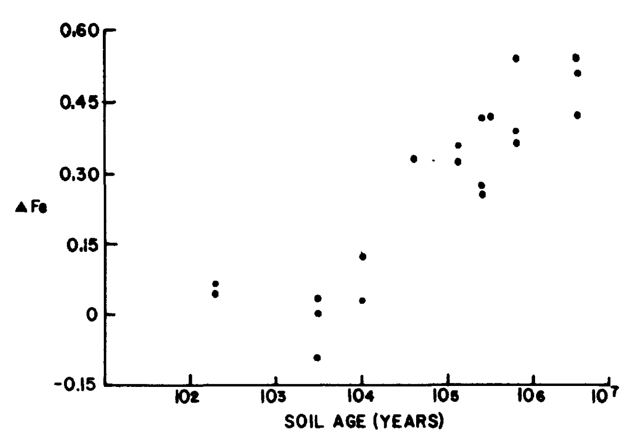

Figure 3. Horizon differential of iron (▲Fe) in silt and clay fraction vs. soil age plotted on log scale. (▲Fe: % Fe in B - % Fe in A divided by average % Fe in A and B horizons)

5. Experiments on the use of ultrasonic energy as a non-chemical dispersion pretreatment of soil samples for mineralogical and elemental analysis are now complete and a manuscript describing this technique is being prepared. This technique causes a decrease in the coarser sand and coaser silt fractions and an increase in finer sand and finer silt fractions relative to the more commonly used calgon pretreatment. However, the total sand and silt percentages are the same as those of calgon. A significant part of the weight reduction in the coarse fractions is, in fact, the result of pedogenic clay minerals being released from the surfaces and crevices of particles. With the exception of some destruction of coarse fractions, the ultrasonic technique poses no additional problems over the calgon pretreatment. The minerals are better-dispersed, cleaner, and free of excessive Na cations. We feel the pretreatment technique is superior to calgon for the types of soil analyses we are now preforming. (Singer, Busacca, and Janitzky)

6. We have completed development of a Multics data management system for field and analytical soil data. Currently over 10,000 pieces of data including physical properties, organically related extractive chemistry, Neutron activation and X-ray florescence analyses (bulk chemistry), and clay minerology are accessible by computer tapes or cards. Data are stored by unique USGS numbers and are accessable by soil properties. Once a property has been selected, optional choices may be made for any number of soil chronsequences, ages, profile numbers,and horizons. The system organizes the selected data for MINITAB, an easily applied statistical software package. Raw data with calculated means and standard deviations for each property are archived by chronosequence. (Taylor)

Reports

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Fault Scarp Morphology: Indicator of Paleoseismic Chronology

14-08-0001-19109

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Investigations:

1. Develop a simple and reliable technique for dating scarps formed by normal faulting of cohesionless material (morphologic dating).

2. Test morphologic dating technique on fault scarps and river terraces in the West Yellowstone, Montana, area.

3. Map the distribution of conical depressions in obsidian sand deposit south of Hebgen Lake, Montana, and assess the hazard they pose to the runway of the West Yellowstone airport.

Results:

1. Nash (1981) describes a simple analytical model for determining the change in elevation, y, with time, t, at some point on a hillslope profile,

$$\frac{\partial y}{\partial t} = c \frac{\partial^2 y}{\partial x^2}$$

where c is an empirically determined constant dependent on underlying material and climate and x is the horizontal coordinate of the point on the profile. When the model is applied to simple hillslopes consisting of a horizontal crest and base separated by a straight midsection inclined at an angle α, it is found that as the hillslope degrades with time, the basal concavity and crestal convexity become more rounded and the midsection is reduced to a new slope angle β. It is further found that a given value of $\tan\beta/\tan\alpha$ results uniquely from a single value of $(tc/H^2)\tan^2(\alpha)$ where H is the height of the hillslope measured vertically between the crest and base. The relationship of $\tan(\beta)/\tan(\alpha)$ to $(tc/H^2)\tan^2(\alpha)$, shown in Fig. 1, may be used to date some scarps produced by normal faulting of cohesionless materials as follows:

a. Measure β and H from a profile of the degraded scarp.

b. Estimate the initial angle of the scarp, α. For a fault scarp in cohesionless sands and gravels, α will generally be the angle of repose for the material.

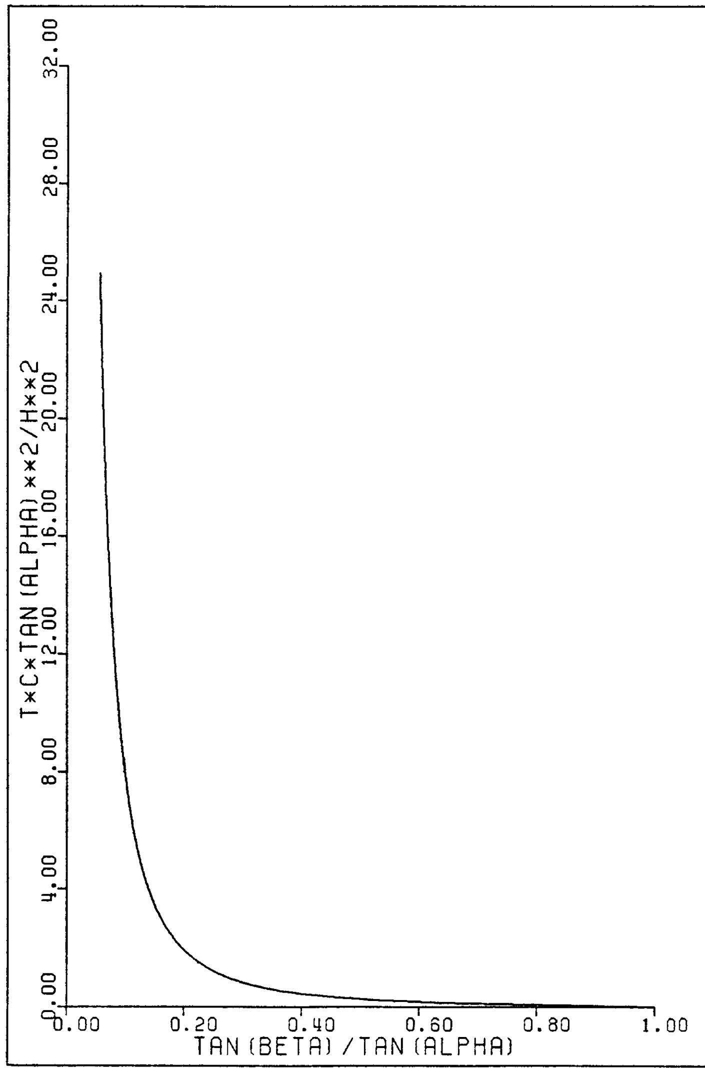

Fig. 1. Relation of $\tan(\beta)/\tan(\alpha)$ to $(tc/H^2)\tan^2(\alpha)$ for a simple hillslope where:

α = initial angle of scarp midsection
β = final angle of scarp midsection
c = diffusion coefficient (m /yr)
H = scarp height (m)
t = elapsed time (yrs)

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c. Calculate $\tan(\beta)/\tan(\alpha)$ and determine the corresponding value of $(tc/H^2)\tan^2(\alpha)$ from Fig. 1.

d. Calculate tc by multiplying the value of $(tc/H^2)\tan^2(\alpha)$ (found in the previous step) by $H^2/\tan^2\alpha$.

e. Determine the age of the scarp, t, by dividing tc by c. An appropriate value for c is best calculated by determining tc for a scarp of known age, t (using the procedure above), and dividing tc by t.

This morphologic dating technique has several limitations:

a. It only should be used for fault scarps in cohesionless materials (otherwise α is difficult or impossible to determine).

b. The initial morphology of the scarp must be a simple hillslope (i.e., it must be a single scarp formed in previously horizontal ground during a single movement of a normal fault.

Despite these limitations, morphologic dating provides a powerful means for determining the ages of many scarps in the Basin and Range.

2. In the study of fault scarps and terraces in the obsidian sand plain south of Hebgen Lake, Montana, a minimum value of $c = 1.49 \times 10^{-3}$ m^2/yr was calculated for a tenuously dated terrace along the Madison River. Although most fault scarps in the area are the results of multiple faulting events, one scarp near the South Fork Madison River probably was formed by a single pre-1959 faulting event. Morphologic dating of this scarp yields a value of $tc = 4.84 \pm 1.26$ m^2 or, using a value of $c = 1.49 \times 10^{-3}$ m^2/yr, the scarp formed 3,250 ± 850 years B.P.

3. Myers and Hamilton (1964) mapped seven conical depressions associated with fault scarps in the obsidian sand plain south of Hebgen Lake, Montana. I found twelve additional conical depressions. It is quite likely that at least one of these additional depressions (5.3 m wide and 1.6 m deep) formed, and may still be forming, well after Myers and Hamilton surveyed the area immediately following the 1959 earthquake. This depression (conical depression 4 in Fig. 2) is within 200 m of the runway of the West Yellowstone airport. Although Myers and Hamilton ascribe the depressions to collapse of sand into pits formed by giant sand boils, I suggest they originate by seepage of sand into fractures in the deeply buried (approximately 100 m) bedrock that were dilated by earthquake activity. If this hypothesis is correct, it is quite likely that one such open fracture system passes beneath the airport runway because it is flanked on either side by several conical depressions (Fig. 2). I believe that there is a danger of a depression forming beneath the runway causing it to subsude or perhaps to collapse suddenly.

References:

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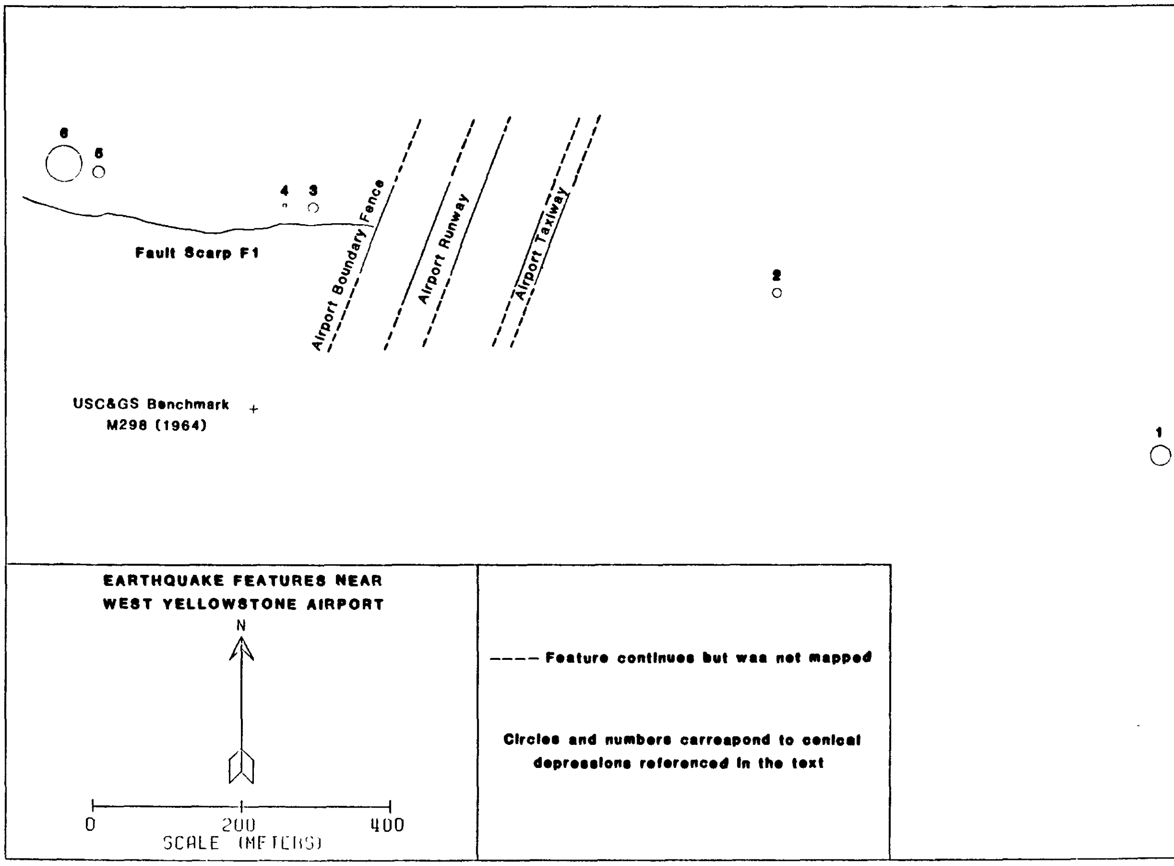

Fig. 2. Earthquake related features near the West Yellowstone airport. Conical depression 4 probably formed several years after the 1959 earthquake and may still be forming. Conical depressions may be produced by seepage of overlying sand into dilated fractures in the bedrock. There is a possibility of a conical depression forming beneath the airport runway.

Quaternary Dating and Neotectonics
9530-01559

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Investigations

1. Fission-track dating of volcanic ash offset by Arco fault, central Idaho (K. L. Pierce).

2. Completed compilation of Miocene and younger tectonic features in Colorado. These data are being prepared for publication as a 1:1,000,000 map of the state and a 1:125,000 map of the Rio Grande Rift in Colorado. Continued development of an explicit solution of a diffusion-type equation for a model of fault-scarp degradation with time (S. M. Colman).

3. Compiled eight 1:250,000-scale maps of the Rio Grande Rift area in New Mexico and western Texas showing faults that cut deposits less than 5 m.y. old, the distribution and age of volcanic rocks and extrusive features less than 5 m.y. old, areas of Miocene and older bedrock, and areas of unconsolidated Plio-Pleistocene deposits. Ages of deformed deposits and recency of fault movement are grouped into one of four categories: (1) Pliocene or younger, (2) middle Pleistocene (0.15-0.75 m.y.) or younger, (3) late Pleistocene (10,000-150,000 yr) or younger, or (4) Holocene (last 10,000 yr). Scarp height (or stratigraphic displacement) is categorized as either less than 5 m, 5-20 m, 20-50 m, 50-150 m, or greater than 150 m. Morphometric data for scarp profiles are presented in graphical and tabular form keyed to map locations (M. N. Machette).

4. Morphometric measurements were completed for late Quaternary fault scarps in the New Mexico portion of the Rio Grande rift. Data base now includes total scarp height (Hm), "single-event" scarp height (Hs), and maximum scarp-slope angle (θ) for 225 scarp profiles of 33 faults of middle Pleistocene to Holocene age. The data range from 0.5 to 60 m in height and 3° to 34° in maximum slope angle. Linear regression equations, coefficients of determination (r^2), and standard deviations for the scarp data were computed using MINITAB (M. N. Machette).

5. Continued field studies of the late Cenozoic stratigraphy, structure, geologic history, and potential uranium mineralization of the Beaver basin, south-central Utah. Logged upper 335 m of a 3,500-m-deep oil and gas test (Beaver Lulu No. 1 Federal, Badger Oil Co.) and field checked Beaver 15′ quadrangle (M. N. Machette).

6. Samples for thermoluminescence (TL) analysis were prepared from calcareous horizons of ten soils which are tectonically buried in a vertical sequence along the Sand Hills fault zone, about 20 km west of Albuquerque, New Mexico. These soils represent intervals of tectonic and geomorphic stability interrupted by discrete episodes of tectonism along the adjacent fault. Debris shed by the rapidly eroding fault scarp buried the soils under a wedge-shaped apron of scarp colluvium. This soil sequence, which may span the last 1-1.5 m.y., may provide a means to evaluate the potential age limits of calcium carbonate TL as a soil-dating technique (M. N. Machette).

7. Continued analysis of field and laboratory data for soil properties that are related to the age of surficial deposits that are offset by range-front faults along the Wasatch Montains between Kaysville and Scipio, Utah (R. R. Shroba).

8. Completed summary and analysis of data on soil properties that are useful for helping to date Quaternary deposits in the Western United States. The results of this study are summarized in a report (in press) on trends in late Quaternary soil development (R. R. Shroba).

Results

1. Along the Arco fault scarp, a thin volcanic ash was deposited on the downthrown side of the fault. Subsequent displacements have offset the ash about 8 m. Fission-track dates on glass by Nancy Briggs yielded an age of 76,000 ± 34,000 yr. This age is consistent with U-series ages on stratified carbonate rinds of about 170,000 yr for gravels offset 18 m by the fault and about 30,000 yr old for gravels that are offset 3 m. (Gravels slightly younger than 30,000 yr are not offset.) Based on the thickness of carbonate rinds in the soil above the gravel unit containing the ash, an age of about 80,000 yr is estimated. These dating methods suggest that the rate of fault movement, for intervals of several tens of thousands of years, has been about 1 m/10,000 yr. The fact that faulting has not occurred since about 30,000 yr ago suggests that movement in the order of 3 m might be expected in the relatively near future (K. L. Pierce, investigation no. 1).

2. Using an explicit solution of a diffusion-type equation describing the degradation of a fault scarp, a value of $t \cdot c$ can be obtained for individual fault-scarp morphometric profiles (t = time; c = rate coefficient). These data can then be used to calculate mean and standard deviation values of $t \cdot c$. Preliminary calculations on morphometric data for fault scarps in Colorado and New Mexico are consistent with independent age estimates of fault scarps within local areas; however, it appears that the value of the rate constant, c, varies markedly with climatic and lithologic factors between areas (S. M. Colman, investigation no. 2).

3a. Reconnaissance investigations along 33 of the most recent, continuous, or conspicuous faults within the Rio Grande rift of New Mexico and western Texas has been completed. None of approximately 250 observation sites have evidence for historic surface rupturing as suggested by several of the larger, recent seismic events (1906, Socorro, New Mexico; 1931, Van Horn, Texas). If historic surface rupturing occurred it must have been limited to short fault segments and very minor displacement, such that obvious surface manifestations have been obliterated.

3b. Considering the large number of faults that displace middle Pleistocene or younger deposits along the rift, there are few that have produced scarps during the past 10,000 yr. Based on their scarp's morphology, lateral continuity, and height in deposits of different ages, the following faults are considered to have segments which were active during the Holocene:

a) La Jencia fault (eastern flank of the Magdalena Range, New Mexico),
b) Caballo fault (western flank of the Caballo Mountains, New Mexico),
c) Cox Ranch fault (eastern flank of the Organ Mountains, New Mexico),
d) an unnamed fault (east side of the Pelloncillo Mountains, New Mexico),
e) Mayfield fault (eastern flank of the Sierra Viejo and Van Horn Mountains, Texas).

Of these Holocene faults, the Caballo, Mayfield, and Cox Ranch have abundant evidence of recurrent Pleistocene faulting. Scarps of up to 30-60 m in height are found along these and other recurrent faults in the rift. Holocene faults have scarps that are commonly 3-5 m in height; thus the composite fault scarps may be the product of ten or more discrete Quaternary surface ruptures (M. N. Machette, investigation no. 3).

4. New investigations of fault-scarp morphology now include the use of geometrically derived "single-event" scarp height (Hs) rather than total scarp height (Hm) when recurrent faulting is suspected at a site. In such cases, Hs is used to form hybrid data sets; these sets generally yield angle-height relationships more in accordance with those for scarps produced by known single-rupture events, have significantly higher correlation coefficients, and more accurately reflect recency of fault movement (M. N. Machette, investigation no. 4).

5. The Beaver basin contains two different yet coevil types of late Cenozoic deformation. The first and most extensive type is a north-trending, basin-center antiform formed by perhaps a hundred axially oriented normal faults that show progressively greater amounts of displacement in the older parts of the basin fill. The antiform is mainly expressed in the extensive middle Pleistocene Last Chance Bench gravels, but these faults also deform latest Pleistocene terrace deposits. The antiform is now considered to be driven by upward movement of the evaporitic facies of the Jurassic Arapiean(?) Shale coupled with basin extension. About 1400 m of overthickened sedimentary diapir and an equal amount of Miocene to early Pleistocene basin fill were recently encountered in a wildcat oil and gas test drilled along the antiform's axis. The second type of deformation is one of regional extension along the Colorado Plateau-Basin and Range margin. Within the eastern part of the basin there is a concentration of west-dipping normal faults with recurrent movement, some with up to 25 m of displacement, over the last 0.5 m.y. Latest Pleistocene alluvium has been displaced as much as 3 m in the town of Beaver (M. N. Machette, investigation no. 5).

6. Preliminary results of TL experiments on pedogenic calcium carbonate as a potential soil-dating technique by Rod May, Bill Lettis, and Michael Machette are extremely promising. These experiments have shown that soil $CaCO_3$ has progressively higher TL ratios for buried soils in a vertical section and for surface soils in a stratigraphic succession. The TL ratios of buried and surface soils reflect the average age of $CaCO_3$ accumulation (much like a mean residence ^{14}C age for soil humus). Because soils as old as 0.75 m.y. have progressingly higher TL ratios, this method could provide a means to differentiate, correlate, and estimate the ages of many Quaternary surficial deposits and would be directly applicable to a variety of geologic problems in arid and semiarid regions of the Western U.S. Toward these goals, the existing TL equipment has now been replaced by a Harshaw model 2000 TL analyzer and integrated picometer which will allow us to increase our precision and eliminate the downtime associated with our original apparatus (M. N. Machette, investigation no. 6).

7a. Recent studies of Holocene soils and surficial deposits along the Wasatch Front indicate the following: (1) Deposits of gravelly alluvium and colluvium, composed of sandstone and limestone, have soils with A1/Cca profiles that formed in about 1,000-2,000 yr and A1/cambic B/Cca profiles that formed in about 5,000 yr. The Cca horizons of these soils are greater than a meter thick and are characterized by thin (<1 mm), stage I carbonate coatings on the bottom and sides of stones. The cambic B horizon is a weakly developed, 30-cm-thick, color B horizon that lacks evidence of clay movement. (2) Deposits of gravelly, quartz monzonite-rich alluvium and colluvium that are probably a thousand to a few thousand years old have soils with A1/Cox profiles.

7b. Recent and previously reported studies suggest that selected morphologic and grain-size data for soil B horizons are useful criteria for establishing age estimates for range-front faults along the Wasatch Front that have been active during the Holocene and latest Pleistocene. Soils data indicate that Holocene deposits can be distinguished by the amount and type of B-horizon development: deposits of late Holocene age lack B horizons, those of middle Holocene age commonly have cambic B horizons, and those of early Holocene age typically have weakly developed argillic (textural) B horizons. Argillic B horizons of Holocene soils are usually discernible from those formed in deposits of latest Pleistocene age on the basis of horizon thickness, distribution and morphology of clay films, and relative increase in total clay (<2 μm) and fine clay (<0.5 μm) (R. R. Shroba, investigation no. 7).

8. Age-related properties of soils developed in Holocene tills and periglacial deposits in alpine areas of the Rocky Mountains include (1) sequence and thickness of genetic horizons, (2) increase in clay content of the B horizon, (3) depth of oxidation and color of the B and Cox horizons, and (4) degree of clay-mineral alteration. Morphologic data for these soils indicate that (1) weak A1 horizons can form in less than 300 yr, (2) Cox horizons form within 1,000-2,000 yr, (3) cambic (color) B horizons commonly form in about 3,000-5,000 yr, and (4) argillic B horizons generally form in about 5,000-10,000 yr. These rates of B-horizon development are more rapid than those for late Pleistocene tills at lower elevations in nearby forested areas. Much of the clay increase in the B horizons of the alpine soils is probably related to the amount of infiltration of eolian fines (R. R. Shroba, investigation no. 8).

Reports

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Radiocarbon Geochemistry & Geophysics

9740-01568

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Investigations

1. Determination of Holocene uplift rates for the Noto Peninsula of Japan (K. Lajoie).

2. Dating of the youngest event on the San Andreas Fault at San Emiglio Creek as younger than about 250 years (T. Davis).

3. Dating of the youngest slip event on the Plecto Fault as younger than 400 years (T. Hall).

4. Dating to provide chronological framework for studies of the Pleistocene history of the San Joaquin Valley (B. Atwater/D. Marchand).

5. Further dating to elucidate the chronology and tectonic history of the Mono Basin, California (K. Lajoie/S. Robinson).

6. Two investigations were undertaken to enable the refinement of radiocarbon dates for coastal tectonics studies where the sample material is usually marine mollusk shell. The first involves measurement of the effect of coastal upwelling along the west coast of the United States on the radiocarbon content of intertidal mollusk shell. It is found that the upwelling of water depleted in radiocarbon relative to surface water causes the shells to appear 650 to 800 years older than plants growing in the atmosphere and 250 to 400 years older than shells living in regions not affected by upwelling. The second study was to estimate the effect of contamination of shell radiocarbon with younger carbon atmospheric carbon dioxide or soil water bicarbonate. By analysis of shells known on independent grounds to be older than 60,000 years it was shown that carbonate materials younger than about 25,000 years can give radiocarbon dates not seriously affected by contamination if they have not been subjected to accelerated weathering either by exposure at the surface, or leaching in subsurface aquifers.

Reports

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Post-Earthquake Shaking Effects and Fault Creep

9940-03027

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Investigations

1. The disturbance caused by the seismic shaking in the regions adjacent to instrumental strong motion recordings was further investigated for the 1978 Santa Barbara earthquake (maximum recorded acceleration 0.38g), the 1980 Livermore earthquakes, and the 1980 Humboldt County earthquake.

2. Investigations in the development of reliable criteria for determining the seismic disturbance in earthquake shaking have continued.

3. Compilation of comprehensive reports on the extent of damage and hazards in the great California earthquake of April 1906 has continued.

Results

1. The store disturbance technique that has been developed for determining the seismic disturbance has shown excellent correlation with the instrumental strong motion measurements.

2. The historic newspaper records consistently show that the 1906 earthquake caused much more damage and disturbance in the towns east of San Francisco Bay than has been previously noted in scientific reports. The damage included major ground deformation effects, such as badly twisted streetcar rails, ground sinking, and liquefaction at the Oakland waterfront.

3. The historic newspaper records also show that significant damage occurred to buildings in inland hilly areas east of San Francisco Bay in the 1906 earthquake, which has previously been unreported.

Reports

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

Nason, Robert, 1981, The great San Francisco earthquake: U.S. Geol. Survey Earthquake Information Bull., vol. 13, no. 2, p. 40-42.

Nason, Robert, in press, Investigation of seismic intensity: Amer. Geol. Inst. Geologic Datasheets Series.

Uranium Series Dating

9740-00378
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Investigations

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

2. Uranium-trend dating of marine terraces is being tested on several sites collected in California, Virginia, North Carolina and South Carolina. It appears that separate calibration points, provided by marine deposits of known age, will be required before final uranium-trend ages can be calculated from analyses of the $^{238}U-^{234}U-^{230}Th$ system in these type deposits.

Results

1. Radioisotope analyses have been completed for uranium-trend dating of chronosequences in the Rio Grande Valley of New Mexico in cooperation with M. M. Machette and G. O. Bachman, USGS. This area appears to have the most suitable environment for uranium-trend systematics when compared to the previously investigated regions in the San Joaquin Valley and marine terraces in California and at Yellowstone, Montana. The results obtained from the investigation in the Rio Grande Valley are shown in the following table.

Uranium-trend model parameters and ages of deposition units

Unit	Description of Deposit	U-trend slope	Half-period of (F(O) (k.y.)	Age (k.y.)
24	Izaac's Ranch alluvium	+0.138	88	22 ± 15
25	Jornado II alluvium	+ .160	470	130 ± 20
26	Jornado I alluvium	+ .590	590	290 ± 20
27	Upper LaMesa alluvium	- .503	105	420 ± 120
28	Upper Santo Tomas alluvium	+ .240	390	150 ± 15
29	Lower Santo Tomas alluvium	- .355	190	540 ± 160
30	Anthony Gap blow sand	<- .303	570	>800

Basement Tectonic Framework Studies
San Andreas Fault System

9950-01291

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Investigations

1. Field Studies along the Vergeles fault zone (north side of the Gabilan Range) and Petrographic study of cataclastically deformed rocks in the fault zone.

2. Preparation of a manuscript detailing possible and impossible correlations of granitic and metamorphic basement rock units in the Salinian block with other California basement terranes, based on currently acceptable offsets on the San Andreas and San Greygorio-Hosgri fault zones.

3. Revision of Professional Paper manuscript on the metamorphic and plutonic rocks of the southernmost Sierra Nevada following technical reviews. The Professional Paper report on the metamorphic and plutonic rocks of the southernmost Sierra Nevada now has Branch approval and has been submitted to the Technical Reports Unit for editing and other processing. At this time I would like to make a "birth announcement". I will make preprints of the report available to those who have sufficient interest to make ozalid copies of the two plates and a xerox copy of the text, figures, and tables (a total of about 260 pages). Contact me in Room 8104 for loan of the mylars and text pages. For those outside of Menlo Park, I can be prevailed upon to make a reasonable number of copies and have them mailed to other Survey offices.

4. Further field studies in the area of the Kern Canyon-Breckenridge fault zone and study of basement rocks on both sides of the White Wolf fault to see if there are significant basement contrasts across this alleged continuation of the Kern Canyon-Breckenridge fault zone.

Results

Recent emphasis on widely traveled accreted terranes in continental California and documentation of significant lateral movement on the San Gregorio-Hosgri fault zone have caused me to restudy the basement rock data in the Salinian block and to reconsider possible correlations of those rocks with other California basement terranes. In essence, basement reconstruction based on currently acceptable right-lateral offsets of some 300 km on the San Andreas fault do permit basement correlations between the Gabilan Range and the southern Sierra Nevada. Correlations based on this offset, however, do raise significant, and possibly insurmountable, problems concerning how to accommodate the Barrett Ridge slice.

To be more specific, 300 km of reconstruction along the San Andreas fault superimposes at least 5 potentially correlative pairs of basement features between the Gabilan Range area and the southern Sierra Nevada. These are:

1) A granitic pair that both contain abundant sphene that has distinctive arabic- to rune-shaped magnetite inclusions.
2) Another granitic pair that both contain scattered red-cored hornblende crystals that bear skeletal clinopyroxene crystals.
3) The match between the unusual metagraywacke belt of Sierra de Salinas and similar rocks in the Portal-Ritter Ridge-Quartz Hill area.
4) Alinement of the anomalous east-trending granitic and metamorphic trends of the northern Gabilan Range with the similarly anomalously east-trending basement structures in the Sierra Nevada tail.
5) But most intriguing is the possible tie between the Pastoria and Vergeles fault zones. Both of these faults appear to juxtapose continental rocks on the south against oceanic basement on the north along what may be a significant suture or a paleo-continental margin.

Telescoping the northern Salinian block by reconstruction of currently suggested right-lateral offsets of more than 100 km on the San Gregorio-Hosgri fault zone brings the Point Reyes basement near similar basement rocks on Monterey Peninsula and also more nearly juxtaposes the similar tonalities of Bodega Head, Tomales Point, Ben Lomond and the northern Gabilan Range. On the other hand, such a reconstruction "strands" the K-feldspar arkose and granitic conglomerate beds of Gualala a considerable distance away from its postulated source area, the granitic terrane of the Salinian block.

In summary, basement correlations between the Gabilan Range and the southernmost Sierra Nevada look promising, particularly if it can be proven that the Pastoria and Vergeles fault zones mark a similar oceanic-continental margin or suture. Nevertheless, for the Salinian block as a whole, problems remain that are not resolved solely by reconstruction of Cenozoic offset on the San Andreas fault. These problems suggest that older, larger movements of the Salinian basement are called for and that possibly the Gabilan-Sierra Nevada basement tie is a coincidental "house of cards".

Reports

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Teprochronology of the Western Region

9540-01947

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Summary

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

Investigations

1) Continued tephrochronologic work in the following areas:

   a. Southern California (Ventura, Ridge, Los Angeles, Anza-Borrego, and Lake Tecopa basins).
   b. Central California (San Joaquin, Santa Clara, and Yosemite Valleys, and Sequoia National Park).
   c. Northern California (Humboldt basin).
   d. Central and Eastern Washington and northwestern Nevada.

2) Completed to technical review stage report on Holocene volcanism in the conterminous U. S. and role of silicic volcanic ashes in correlation of latest Pleistocene and Holocene deposits for 1982 INQUA Congress (with D. E. Champion, BP&RS, and J. O. Davis, Nevada Archeological Survey).

3) Completed to technical review stage study on hazards to nuclear reactor sites from volcanic ash erupted in the Pacific Northwest (with Susan Shipley, WAE, BWRG).

4) Continued analysis of areal distribution, thickness, and stratigraphy of ash erupted from Mount St. Helens, 1980, and reworking of ash as models for interpretation of primary and secondary stratigraphic features in pre-historic tephra layers (with Susan Shipley).

Results

1) An ash in Pleistocene Lake Tecopa beds of southeastern California, previously correlated with the Huckleberry Ridge ash (Pearlette type B) of the Yellowstone area, has been dated by C. E. Meyer and M. J. Woodward (BWRG, Tephrochronology Project) at 1.58 ± 0.08 m.y. by the fission-track method on zircons. This age is somewhat younger than ages reported by others (1.6 to 2.0 m.y.) for the Huckleberry Ridge ash. Chemical composition of the ash in the Tecopa lake beds strongly indicates that its source was indeed the Yellowstone area. Consequently, the discrepancy in ages can be attributed to

one or more of the following: 1) our fission-track age of the ash in the Tecopa lake beds is too young owing to analytical error, 2) the ages of the Huckleberry Ridge ash (K-Ar and fission-track) are in error owing to contamination or analytical error, or 3) there are two, or possibly, several ashes that are attributed to the Huckleberry Ridge ash, with differences in ages of several tens of thousands to several hundreds of thousands of years.

2) An ash obtained from a core sample in south San Joaquin Valley near Wasco, previously identified as the Bishop ash (Davis and others, 1977), is identified by us as a Pearlette type ash, probably the Lava Creek ash (Pearlette type O, 0.6 m.y. in age). Shard morphology typical of Pearlette-type ashes (clear, solid, angular bubble-wall glass shards) and energy-dispersive X-ray fluorescence spectrochemical analyses of the glass indicate this ash belongs to the Pearlette ash family. Highest similarity coefficients obtained (0.98, where 1.0 represents identity) are between the Wasco-core ash sample and Lava Creek ash samples.

3) An ash found in new road cuts for the extension of U. S. Highway 101 in Santa Clara Valley, central California, interbedded with deformed and faulted alluvium of the Santa Clara Formation, has been identified as the Rockland ash (also known informally as the Maidu ash, 0.45 m.y. in age), based on electron probe and energy-dispersive X-ray fluorescence spectrochemical analyses of the volcanic glass (C. E. Meyer and M. J. Woodward). This identification makes it possible to temporally correlate parts of the Santa Clara Formation southeast of the Bay area, with the Woodside "member" of the Santa Clara Formation, part of a fault-bounded block situated along the San Andreas fault near the town of Woodside, west of south San Francisco Bay, where the same ash has been found previously.

Quaternary Stratigraphy of the Wasatch Front

9530-02174

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Investigations:

1. Completed field mapping of an area along the Wasatch fault in Salt Lake County in conjunction with R. L. Dodge and R. R. Shroba.

2. Collected and submitted additional radiocarbon samples from Lake Bonneville deposits.

3. Continued work on reports on Lake Bonneville stratigraphy and history.

Results:

1. The Wasatch fault zone south of Bells Canyon is composed of several scarps that displace surficial deposits on a broad piedmont area lying above the Bonneville shoreline. Deposits of several ages are mappable: (a) alluvium that predates the last cycle of Lake Bonneville (probably 150,000 yr old), (b) alluvium and debris-flow deposits of about the same age as the regression of Lake Bonneville during its last cycle (10,000 to 15,000 yr old), and (c) alluvium and debris-flow deposits of middle(?) and late(?) Holocene age. These ages are based on stratigraphic and geomorphic relations to deposits of Lake Bonneville and on the soils work of R. R. Shroba. Some preliminary conclusions about ages and rates of faulting can be made.

   On the upthrown side of the fault zone, alluvial surfaces that are probably about 150,000 yr old do not occupy a much higher topographic position than do faulted surfaces that are about 10,000 to 15,000 yr old. This suggests that average rates of faulting during latest Pleistocene and Holocene time may, on the average, be higher than rates in the interval from 50,000 to 150,000 yr ago. This observation is in accord with more equivocal evidence from farther north in the valley (Scott, 1981).

   The amount of recurrent offset of latest Pleistocene and Holocene deposits may suggest an apparent linear rate of offset during the period; however, the ages of these deposits are too poorly known to say precisely. For example, at the mouth of the canyon of the South Fork of Dry Creek, the levees of a late Holocene debris-flow deposit are displaced about 3 to 4 m along a scarp that displaces early(?) to middle(?) Holocene fan deposits about two to three times that much.

In addition, this documentation of faulting of probable late Holocene deposits is significant in that this has only been possible in a few other areas in Salt Lake County.

2. Several additional radiocarbon dates on deposits of the last cycle of Lake Bonneville are in accord with other dates obtained in this study. The transgressive phase of this cycle is now dated from 25,000 to 16,800 yr B.P. At 25,000 yr B.P. the lake level was about 30 m above present Great Salt Lake. By 16,800 yr B.P. the lake level was probably within 30 m of the altitude of the outlet at Red Rock Pass, Idaho. The formation of the Bonneville shoreline (the highest in the basin) therefore postdates 16,800 yr B.P. The Bonneville shoreline was abandoned about 14,000 to 15,000 yr ago during the rapid lake-level fall that was caused by the Bonneville flood.

Reports:

McCoy, W. D., 1981, Quaternary aminostratigraphy of the Bonneville and Lahontan basins, Western U.S., with paleoclimatic implications: Unpublished Ph. D. dissertation, University of Colorado, 603 p.

Scott, W. E., 1981, Field trip guide to the Quaternary stratigraphy and faulting in the area north of the mouth of Big Cottonwood Canyon, Salt Lake County, Utah: U.S. Geological Survey Open-File Report 81-773, 12 p.

Scott, W. E., Pierce, K. L., Bradbury, J. P., and Forester, R. M., in press, Revised Quaternary stratigraphy and chronology in the American Falls area, southeastern Idaho, <u>in</u> Bonnichsen, William, and Breckenridge, R. M., eds., Cenozoic geology of Idaho: Idaho Bureau of Mines and Geology.

Salton Trough Tectonics and Quaternary Faulting

9940-01292

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Investigations

1. Field investigation of surface faulting associated with the Westmorland, California, earthquake of 26 April, 1981.

2. Recently active traces of San Andreas fault between Salton Sea and Whitewater River-Mission Creek, California.

3. Continuing creep along Garlock fault in Fremont Valley, California (with T. L. Holzer and E. H. Pampeyan).

Results

1. Parts of the Imperial and the Superstition Hills faults moved right-laterally at the ground surface at the time of or shortly following the M_L 5.6 Westmorland earthquake of 26 April 1981 (see Fig. 1). The displacements occurred prior to any significant aftershocks on either fault and thus are classed as sympathetic. Although the main shock was located in an exceptionally seismogenic part of Imperial Valley, about 20 km distant from either fault, no clear evidence of surface faulting has yet been found in the epicentral area. Horizontal displacement on the Imperial and Superstition Hills faults, southeast and southwest of the epicenter, respectively, reached maxima of 8 mm and 14 mm, and the discontinuous surface ruptures formed along approximately equal lengths of northern segments of the two structures (16.8 km and 15.7 km, respectively). The maximum vertical component of slip on the Imperial fault, 6 mm, was observed 3.4 km north of the point of largest horizontal slip. Vertical movement on the Superstition Hills fault was less than 1 mm. No new displacement was found along the traces of the Brawley fault zone, the San Andreas fault, or the part of the Coyote Creek fault that slipped during the 1968 Borrego Mountain earthquake. A careful search in the epicentral area of the main shock failed to locate any definite evidence of surface faulting. Concentrations of late aftershocks north and northeast of Calipatria near the southeastward projection of the San Andreas fault occurred mostly after our field check; this area was not investigated.

2. Surface expression of the most recently active traces of the San Andreas fault between Salton Sea and Whitewater River-Mission Creek in the San Bernardino Mountains varies widely with location. In parts of the Indio Hills on the northern branch (Mission Creek fault) and southeast of Thermal Canyon on the combined branches are segments with abundant and

well-preserved scarps and offset channels, along with sharp vegetation boundaries in late Holocene deposits. In contrast, elsewhere and between some of these segments are areas up to several kilometers long with little or no evidence of recent movement. In addition the southern branch (Banning fault) lacks clear evidence for Holocene displacement for more than 15 km in and northeast of Indio Hills. South of Thermal Canyon almost all of the scarps, bends and other evidence for recent displacement coincide with intermittent ground rupture triggered by distant earthquakes in 1968 and 1979. The very close association between locations of triggered creep and evidence for Holocene offset, particularly below the high shoreline of pre-historic Lake Cahuilla suggests:

a. Triggered creep may locally contribute a significant fraction of total Holocene surface displacement.

b. No large earthquakes and associated major, through-going ground ruptures have occurred along the portion of the fault that was uncovered by the lowering of Lake Cahuilla since lowering 200-300 years ago.

c. Intermittent segments of the fault northwest of the zone of triggered creep in 1968 and 1979 that also show clear evidence of Holocene displacement may experience triggered creep during other distant earthquakes.

Three zones of active normal faulting in Quaternary sediments that lie northeast of and adjacent to the San Andreas fault in and southeast of Indio Hills are concentrated in elongate hills that are undergoing active uplift, increasing southeastward in each zone. These normal faults record repeated displacement, are clearly related to the San Andreas fault, and represent a locally very large increase in the width of the zone subject to surface rupture along the San Andreas fault.

Seven broad, incised channels in the Indio hills southwest of and beheaded by the northern branch of the fault appear to date from the first uplift of the hills. The channels record kilometers of horizontal displacement from their original upstream sections. Possible matches to different groups of seven incised channels northeast of the fault that might be the beheaded upstream sections indicate a range of plausible minimum right-lateral offset from 2 1/2 to 11 km since initiation of uplift.

3. Continued monitoring of vertical deformation across creeping traces in the Garlock fault zone in Fremont Valley by Holzer and Pampeyan give further support to the association there of creep with ground water pumping. Displacement rate is seasonal, with maxima during summer maximum pumping, and minima, or locally, reversal in displacement, during winter when little pumping occurs. Protruding well casings and obvious tilting of the Koehn Lake playa surface toward the area of maximum pumping provide further strong evidence that removal of groundwater is causing subsidence and associated faulting.

Reports

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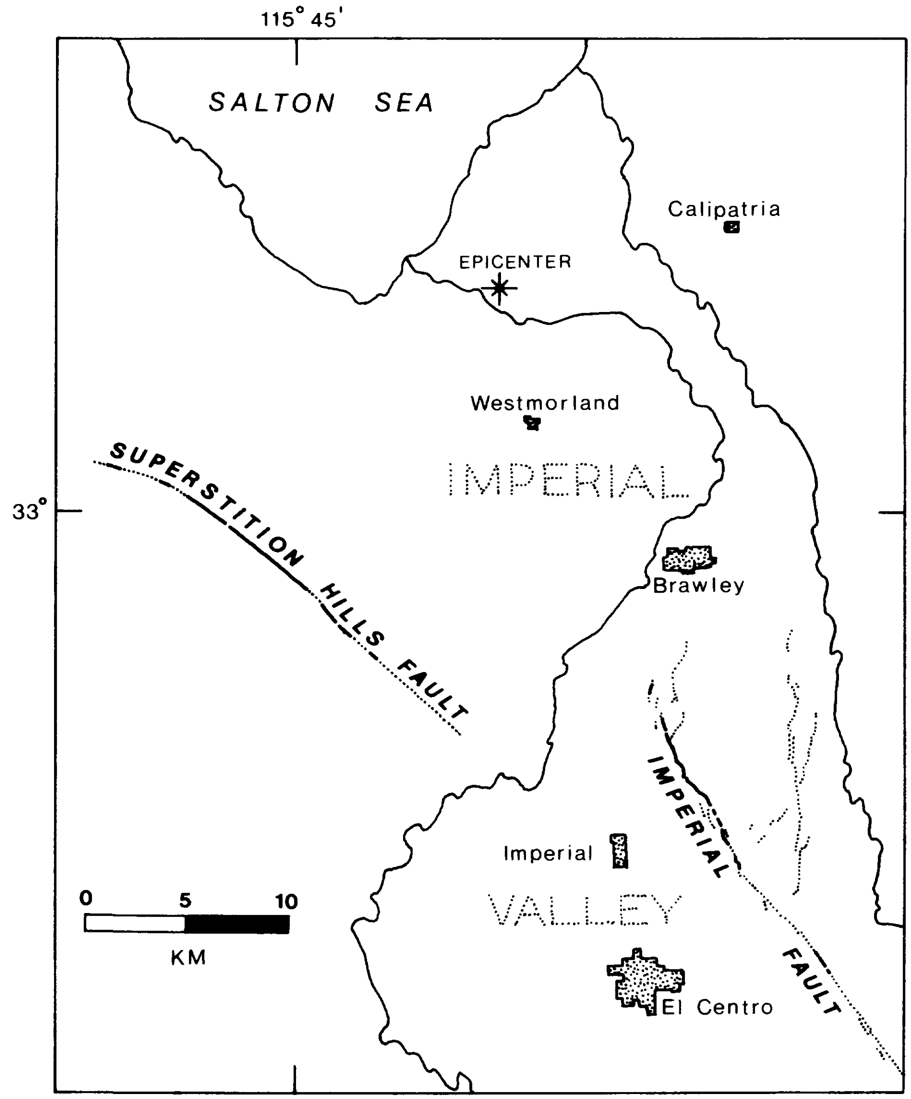

Figure 1. Map of new surface faulting associated with the Westmorland earthquake of 26 April 1981. Solid lines indicate fault segments where new ground rupture was observed. Dotted lines indicate fault traces from previous surface movements or mapping of geologic and geomorphic features.

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

14-08-0001-19756

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

Data from several sites is beginning to enable a more detailed view of the long-term behavior of the San Andreas fult. Our latest progress, from March through October of 1981 is outlined below:

1) Near Indio, final ^{14}C dates can now be plugged into the stratigraphic sand structural context described in 1980. The latest large earthquake involving slip along the fault here apparently occurred more than 560 years ago (Sieh, 1981). Creep at a rate of ~2 mm/yr may have been continuous for this time period.

2) At Ray Weldon's site near Cajon Pass, at least two and probably more large slip events have occurred within the past ~700 years (Weldon and Sieh, 1981). These may represent two or more of the latest 4 events recognized at Pallett Creek, which is about 30 km to the northwest. Our best estimate for the Holocene slip rate here is now 25 mm/yr. Based upon these and data reported in previous years, the fault segment(s) southeast of the San Bernardino Mountains appears to have a much longer recurrence interval than the fault to the northwest. The question of which segment will generate the next great earthquake remains open, however.

3) Efforts to dendrochronologically date the last prehistoric large earthquake prior to the 1857 event are continuing, but we can report no conclusive results at this time.

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

5) Work on a MS describing my studies with Dick Jahns at Wallace Creek, in the Carrizo Plain, is progressing slowing.

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

7) Howard Shifflett has completed a rough draft describing our studies of fault slip rates using old fences in the creeping central of the San Andreas fault.

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

Detailed Geologic Studies: San Andreas Fault Zone

9950-01294

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Investigations:

1. Detailed mapping and investigation of surficial and bedrock deposits in and adjacent to the San Andreas Fault Zone in the:

   a) Cholame Valley and Cholame Hills quadrangles (Sims).
   b) Hepsedam Peak and Priest Valley quadrangles (Rymer).
   c) Bickmore Canyon and San Benito quadrangles (Perkins).

Results

1a) Detailed geologic studies in the Cholame Valley and Cholame Hills quadrangles (fig. 1) are concentrated on identifying detailed relationship between strands of the San Andreas fault and its subsidiary fault, the Gold Hill fault. An ophiolite-like assemblage of rocks is exposed between these two faults and mapping shows that serpentinite was thrust over Franciscan clastic volcanic rocks prior to being deformed in the present deformational cycle. In addition, the distribution Holocene surficial deposits and geomorphic features in the broad valley of Cholame Creek may be interpreted as resulting from tensional tearing to produce a small basin at the step in the San Andreas fault south of the Jack Ranch. This feature has been known for several years but with detailed mapping it can be better documented and understood.

1b) Geologic mapping at a scale of 1:12,000 in the Hepsedam Peak and Priest Valley 7-1/2-minute quadrangles reveals that the wedge-shaped diapir mapped in the Monarch Peak quadrangle (Rymer, in press) is present in these quadrangles also. The diapir consists of Franciscan rocks and serpentinite, and contains the fault zone. To the northeast of the fault zone there are Neogene marine formations and, to the southwest, Neogene and Quaternary marine and continental formations. Locally present on the Franciscan rocks of the diapir are allochthonous rock units (klippen) of the Great Valley sequence transported from areas east of the fault zone. In the Hepsedam Peak quadrangle there is also an allochthonous block of sheared granitic rock.

In general, the San Andreas fault zone consists of the main trace and boundary faults in the southern part of the area mapped; a main trace, oblique subsidiary faults, and boundary faults in the central part; and two parallel main traces, subparallel subsidiary faults, and boundary faults in the northern part of the area mapped. Also present in the northern part of the area mapped to date are faults that separate Neogene and Quaternary rock units on the southwest side of the fault. These latter faults have sheared Franciscan rocks along the fault planes. The mapping shows that the tectonic setting of the San Andreas fault zone in the region is more complicated than previously thought.

1c) Geologic mapping at a scale of 1:24,000 of a 3 km wide strip along the San Andreas fault zone (SAFZ) in Bickmore Canyon quadrangle is nearly complete. A continuous main trace is found throughout the area mapped. Locally Miocene age rock units, present along the southwest side of the fault, are also present along the northeast side of the main trace, which suggests a westward shift of the main trace. At these locations marble breccia and chert, possibly derived from the Franciscan assemblage, is also near the main trace. The main trace of the SAFZ offsets three Holocene(?) terrace deposits found along the San Benito River. Charcoal was collected from the highest (= oldest) terrace and submitted for radiocarbon dating. Numerous subparallel subsidiary faults are found within the fault zone, most of which offset Plio-Pleistocene(?) gravel deposits in the Santa Margarita Formation found southwest of the fault. Geomorphic expression of these faults also suggests Holocene activity.

Reports

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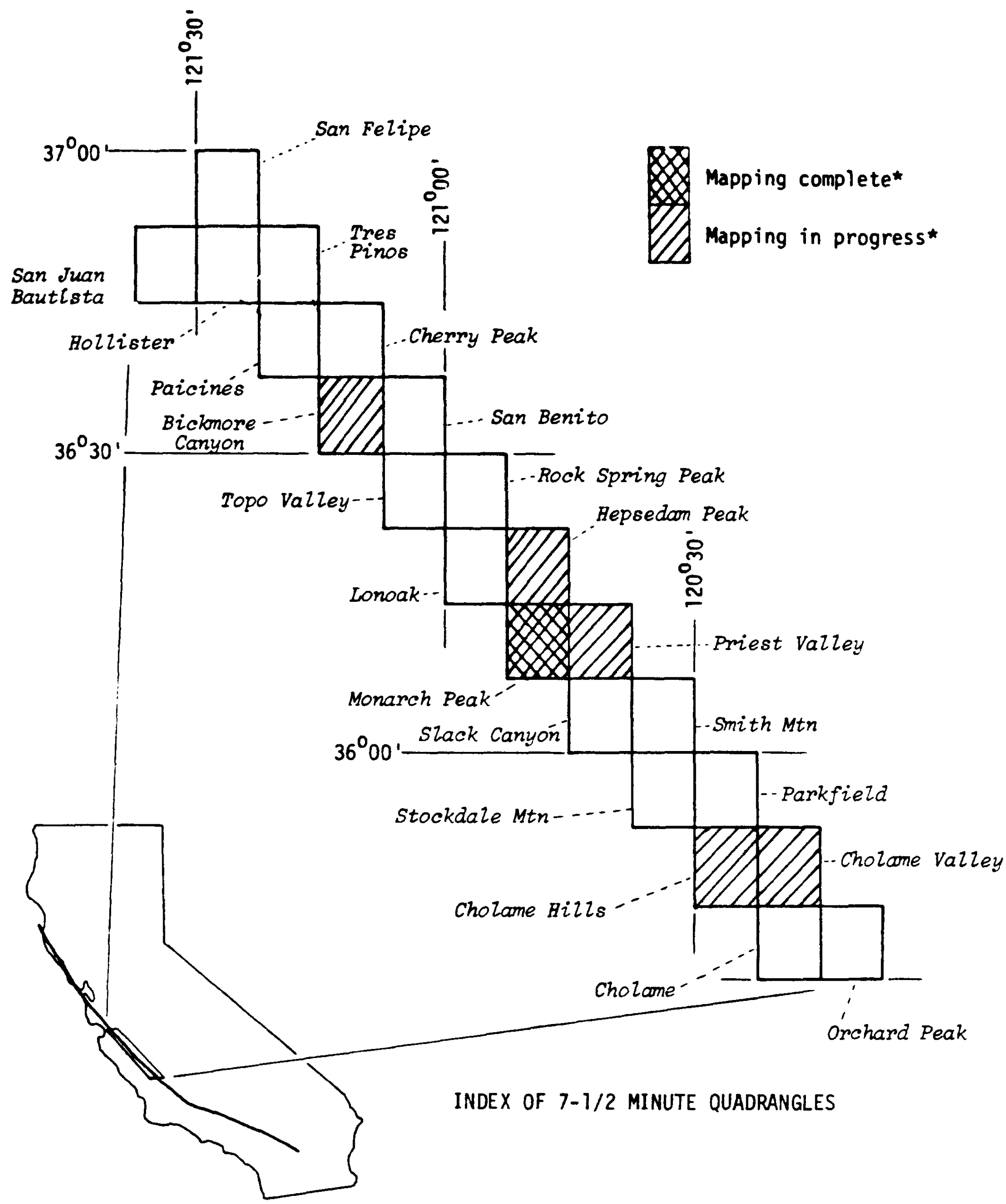

Figure 1. Progress of detailed geologic mapping and geologic studies along the San Andreas fault zone between San Juan Bautista and Cholame, California.

Quaternary Reference Core, Clear Lake, California

9950-02394

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Investigations:

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

2. Distribution of samples for continued geochemical and paleontological analyses of cores CL-80-1 and CL-80-2.

3. Seismic reflection and side scan sonar study of lake bottom geomorphic features in cooperation with the Branch of Pacific-Arctic Marine Geology.

Results

1. X-ray mineralogical analysis of cores CL-80-1 and CL-80-2 are complete. The X-ray data has been reduced but not yet fully analyzed. The clay mineral suite of the two cores is composed of the following minerals in decreasing order: Chlorite, Illite, Smectite, Kaolinite and mixed layer clay minerals. The preliminary interpretation of the clay mineral data suggests that the areas underlain by Franciscan Assemblage rocks have been constant major producers of chlorite-rich detritus to Clear Lake over the past 2000,000 years the contribution of the Franciscan Assemblage has remained about constant. The Clear Lake volcanics has been a less prolific contributor of smectite-rich detritus to Clear Lake.

Grain-size analysis of the two cores is still underway. However, preliminary interpretation of the incomplete data suggests that core CL-80-2 resembles strongly the data set from core CL-73-4, as was suspected. The mean grain size in core CL-73-4 ranges between 7.73 and 9.21ϕ (4.8- 1.7 μm) and there is no apparent systematic variation in the core (fig. 1). Grain size variation in core CL-80-1 is much greater than in core CL-80-2, with the mean ranging from 5.69 to 8.44ϕ (19.39 to 2.87 μm). At present the data is too sketchy to allow a meaningful interpretation.

2. Preliminary analysis of ostracods from Clear Lake cores CL-80-1 and CL-73-4 by Richard Forester [U.S.G.S.-Denver] shows that ostracods are not abundant. The general lack of abundance of ostracods is the result of continuous predominance of anoxic conditions or low dissolved oxygen in the lake and the presence of a fluid or unstable substrate. The ostracodes in both cores suggest that the dominant anion in Clear Lake has been Cl^-. Water analyses of Clear Lake show that HCO_3^- is the dominant anion.

3. Preliminary analysis of Uniboom seismic reflection and side-scan sonar records shows that there is a lake bottom textural difference across the mouth of Konocti Bay, where gaseous springs had been used to infer the presence of a fault. The seismic reflection profile and a fathogram show that, at least locally, this fault breaks the lake bottom, indicating that the fault has been active in the Holocene. The reasons for the textural differences across the fault are believed to be due to phreatomagmatic volcanic explosions, which formed the bay. Seismic reflection profiles across the main basin of the lake show no interpretable record. Apparently the shallowness of Clear Lake in the main basin (<10 m) and the thick pile of homogenous mud make seismic studies using a Uniboom system inapplicable.

Reports

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Blunt, D. J., Kvenvolden, K. A., and Sims, J. D., 1981, Geochemistry of amino acids in sediments from Clear Lake, California: Geology, v. 9, p. 378-382.

Perkins, J. A., and Sims, J. D., 1981, Relationships between varve thickness and climatic parameters and paleoclimatic reconstruction: U.S. Geological Survey Open-File Report 81-952, 36 p.

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Sims, J. D., 1981, Late Quaternary Paleolimnology and paleoclimate, Clear Lake, California: Geological Society of America Abstracts with Programs, v. 13, p. 555.

Tectonic Analysis of Active Faults

9900-01270

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Investigations

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

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

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

4. Evaluation of lichenometry techniques for dating prehistoric events along fault scarps.

5. Development of prediction terminology in connection with Southern California Earthquake Preparedness Project of FEMA/Seismic Safety Commission

Results

1. Between the south end of surface faulting that developed in 1915 in Pleasant Valley, NV and the north end of surface faulting that developed in 1954 in Dixie Valley is a "gap" 40 km long along the Stillwater Range in which no historic faulting has occurred. Inasmuch as surface faulting has occurred in the central Nevada seismic belt on the average every 18 years during the last 109 years, the Stillwater seismic gap appears to be a candidate for surface faulting in the next few decades.

Whether or not the fault bounding the Stillwater Range in the gap is more permanently locked than were the segments that broke in 1915 and 1954 has been tested by an evaluation of young fault scarps in the gap. Preliminary analysis shows no conspicuous difference between the historically faulted segments and the segment unfaulted in historic time.

2. A draft of a set of terms suggested for use in expressing earthquake prediction was prepared for the Southern California Earthquake Preparedness Project by Robert E. Wallace, James F. Davis and Karen C. McNally. Terms from the draft report are shown in table 1 (below) and comments or discussion will be appreciated.

Table 1

TERM TO CONVEY PROBABILITY OF A EARTHQUAKE DAMAGING IN AN AREA	PROBABILITY OF A DAMAGING EARTHQUAKE
LONG-TERM EARTHQUAKE POTENTIAL	Less than 2% chance per year
EARTHQUAKE PREDICTION	
LONG-TERM PREDICTION	
Earthquake watch or forecast	2-10% chance per year
INTERMEDIATE-TERM PREDICTION	
Earthquake warning stage 1	10-50% chance per year
Earthquake warning stage 2	50-100% chance per year
SHORT-TERM PREDICTION	
Earthquake alert	50-100% chance per 10 days
Imminent earthquake alert	50-100% chance per day

Reports

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Physical Constraints on Source of Ground Motion

9940-01915

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Investigations

I am examining digital records obtained by this Branch during the May-June 1980 Mammoth Lakes, Calif., earthquake sequence. My goal is to find how source spectra scale between events of different size.

Results

Coda waves are strongly excited in the Mammoth Lakes records, and direct S waves cannot be clearly isolated. In order to examine source effects in a situation in which propagation effects are constant, I have selected seven events with hypocenters at nearly the same location. Integrated records of displacement as a function of time at nearby hard-rock sites are complex and show conspicuous arrivals that are consistent among different events. This indicates that scattered waves are arriving close behind the direct S wave.

To try to separate source from propagatioon effects, spectra of S coda waves were examined at five stations for the seven events. Velocity power spectra for each pair of horizontal components were summed and then smoothed. Each observed spectrum was assumed to be the product of a source spectrum and a propagation spectrum. Logarithms of smoothed spectra were inverted to find a source spectrum for each event and a propagation spectrum for each station. At each frequency the inversion left one degree of freedom undetermined: all the propagation spectra may be divided by an arbitrary factor if all the source spectra are multiplied by the same factor, and so only ratios of the source spectra are meaningful. One might say that relative site effects have been determined, but not the regional scattering spectrum for coda waves.

The source spectra have consistent trends at high frequency. The spectral ratios are consistent with similarity scaling with constant apparent stress, but only if the regional scattering spectrum is a decreasing power-law function of frequency.

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

9940-02674

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Investigations

1. Based on a data set that includes 1500 earthquakes from the 1980 May-June Mammoth Lakes sequence, we have determined locations, fault plane solutions and source parameters, namely, seismic moment, source radius and stress drop.

2. Using the accelerograms recorded during the 1979 Imperial Valley earthquake we have been investigating possible constraints on the earthquake mechanism.

3. We have been developing a numerical method that would incorporate both a realistic earth model and a finite fault to be used in generating synthetic seismograms.

Results

1. A paper "Source parameters of the 1980 Mammoth Lakes, California, earthquake sequence" has been completed and submitted to the Journal of Geophysical Research. The main conclusions are summarized in the June 1981 Summaries of Technical Reports, vol. XII.

2. The 1979 Imperial Valley earthquake has a rather surprisingly low stress drop, about 8 bars, considering the peak velocities of 115 cm/sec (Meloland) and 109 cm/sec El Centro Array stations 6 and 7. The rupture velocity is between 0.80 and 0.85 times the local shear wave velocity.

3. The vertical component of motion has been added to the Discrete Wavenumber/Finite Element (DWFE) code developed by Allen Olson for computing Green's functions in a vertically heterogeneous earth. An efficient method of combining Green's functions from a finite fault and the slip function on the fault has been completed. Using this method synthetic seismograms for the 1979 Imperial Valley earthquake have been computed.

Reports

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National Strong Motion Data Center

9940-02085

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Investigations

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

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

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

Results

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

a. Hardware: Considerable effort has been expended to improve terminal access to the CPU by concentrating editing terminals in a general work area, adding a 16-line DMA terminal interface, and modifying a locally developed high speed interface to be compatible with DR11-W DMA parallel interface.

The two reel-to-reel magnetic tape drives on the system were exchanged for high speed (125 ips), triple density (800/1600/6250 bpi), auto-load/auto-thread drives to simplify and speed up overall data storage management.

b. Software:

(1) Application software: Several seismogram processing programs were modified to take advantage of the large Virtual arrays available from Fortran (up to 32,767 points per array), and to use high-speed block I/O instead of record I/O.

(2) System software: The following commands were written or modified:

EMOde/GMOde--Toggles the Tektronix compatible VT100 terminals between editing mode and graphics mode.
STTY--Modified to display as well as modify terminal characteristics.
SYU/SAC--Extracts and formats detailed or summary usage reports from the system collected accounting information.
WHO--Modified to obtain user identification data from the in-core accounting data base, if possible.

The following system modifications were made:

Multi-user F11ACPs--The FILES-11 ACPs were modified to be completely non-overlaid, with all read-only code and data shared between multiple copies, resulting in an overall increase of 16 to 20K words of memory available for user programs.
Virtual disk support--Successful implementation of the virtual disk driver, VD:, on RSX-11M-Plus required modifications to the system programs MOUnt, DMOunt, and the FILES-11 ACPs to properly handle foreign disk devices without error-logging support.
MCR--The system command dispatcher, MCR, was modified to be completely non-overlaid to eliminate service delays due to disk overlay loading.
Plotting libraries--Enhancements were made to add new features or improve overall convenience for users.

Several new software components were added to the Center:

The Oregon Software Pascal-2 compiler.
EDT V2, an upgrade to the standard RSX system editor that combines line-by-line editing with a VT100 full-screen editor.
The IMSL subroutine libraries were upgraded to version 8.1.
DEC's SORT-11 sorting package.
DECnet/M-Plus V1 and DECnet-RT were received, but have not yet been incorporated into the production systems.

Project No:	14-08-0001-19135; Earthquake Hazard Evaluation of the Helena Valley Area, Montana
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Between April 1, 1980 and June 30, 1981, the geology of the Helena Valley and surrounding foothills was mapped with emphasis on the Quaternary deposits and faulting. Mapping was completed on 1:12,000 scale low-sun-angle aerial photography and transferred to a topographic base map with a scale of 1:24,000. The results of this study, summarized below, are incorporated in a geologic map of the Helena Valley and in this final technical report.

The Helena Valley, site of the state capitol, is a rapidly growing urban area located in seismically active central-western Montana. A series of several thousand earthquakes (including two destructive events with magnitudes of 6¼ and 6) in 1935-36 and small to moderate sized earthquakes which have occurred up to the present time demonstrate substantial seismic hazard in the Helena Valley. Unconsolidated Quaternary deposits underlying parts of the Helena Valley may be subject to severe ground shaking and/or liquefaction during future large earthquakes in the area. The geologic mapping conducted during this study delineates hazardous faults and areas subject to potential ground failure or severe shaking during earthquakes.

The majority of the bedrock exposed east, north and west of the Helena Valley consists of red, green and brown argillite and pink, brown and white feldspathic quartzite of the Belt Supergroup. Paleozoic and Mesozoic rocks made up of brown to white quartzite and sandstone, black to brown shale and bluish grey to tan limestone and dolomite outcrop along the southern valley margin. Granodiorite and related rocks of the late Cretaceous/early Tertiary Boulder Batholith, including its satellite stocks and plugs intruded and metamorphosed sedimentary rocks along the south and west margins of the Helena Valley. A major volcanic pile, the Elkhorn Mountains Volcanics, overlies sedimentary and intrusive rocks at the southern edge of the Helena Valley in the northern Elkhorn Mountains.

The Helena Valley is a northwest-trending structural and topographic basin which began to form in early or middle Tertiary time by block faulting, possibly along pre-existing zones of basement weakness. The oldest recognized Tertiary clastic deposits include well bedded olive-grey to yellowish clay, tan siltstone, light grey, poorly sorted arkosic sand, rounded to subangular pebble gravel and thin lignite beds of probable Oligocene age. Rocks with similar ages outcrop along the southern valley margin and include white to grey well-indurated volcaniclastic rocks which contain pumice fragments and rhyolite pebbles. The Tertiary deposits which cover about 80 percent of the eastern Helena Valley consist of tan, micaceous siltstone with interbedded sandy pebble and cobble gravel. This deposit is generally coarser grained than the previously described deposits and are probably middle Miocene to Pliocene in age.

Early Pleistocene and possibly latest Tertiary alluvial deposits cap ridgetops along the southern valley margin and form eroded and faulted hills along the northeast portion of the Helena Valley. A thin veneer of poorly sorted, silty gravel covers extensive pediment surfaces, of probable middle Pleistocene age, developed along the northwest and southwest perimeter of the Helena Valley; most of the city of Helena is built on such a deposit. Late Pleistocene to Holocene alluvial plain deposits underlie the western Helena Valley and probably do not exceed 40 m in thickness. Other unconsolidated deposits which outcrop over relatively small areas include channel and terrace alluvial deposits, loess deposits, strath terrace remnants along the Missouri River, and fine sand, silt, clay and minor gravel deposits of Great Falls Glacial Lake which flooded the Helena Valley to an elevation of at least 4,000 feet during Wisconsin(?) time.

Two major northwest-trending fault zones bound the Helena Valley. The Prickly Pear fault zone roughly parallels the southwest valley margin and exhibits down-to-the-northeast offset. A 15 km segment, half the total trace length of the Prickly Pear fault zone, lies buried beneath young alluvial deposits in the western Helena Valley. Seismological evidence indicates that this buried section of the fault was probably the source of the destructive 1935-36 earthquake sequence. The Helena Valley fault zone consists of five segments which bound the northeast valley margin and exhibit down-to-the-southwest offset. The northwest segments are remarkably linear and appear to offset middle Pleistocene deposits. The last movement along fault segments further to the southeast is somewhat older. Numerous small faults, with trace lengths less than 15 km, near the southern Scratchgravel Hills and along the northwest valley margin, have offsets as young as late Pleistocene but do not appear to define an extensive fault zone.

Major fault zones within the Helena Valley showing a long history of movement which continues into historic time point to a high seismic hazard for the area. The trace lengths of segments of the Helena Valley and Prickly Pear fault zones suggest that earthquakes in the magnitude 5.0 to 6.5 range are possible along any segment. Simultaneous rupture of the Helena Valley fault zone might produce an earthquake with a magnitude as large as 7.5. Unconsolidated deposits in the western half of the Helena Valley may be subject to severe ground shaking and liquefaction, especially those which are fine grained and water saturated.

Teleseismic Determination of Earthquake Source Parameters

9940-03011

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Ground Motion Prediction at Selected Strong Motion Sites

9940-01168

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Investigations

1. Study directivity in the peak accelerations from the 1980 Livermore Valley earthquakes (with J. Boatwright).

2. Study relative scatter in peak acceleration (PGA) and root-mean-square acceleration (RMSA) for records from the 1971 San Fernando earthquake (with M. McCann).

Results

1. The peak horizontal accelerations from the two largest events in the 1980 Livermore Valley earthquake sequence showed clear evidence of directivity, both in each event individually and in the ratio of motions at common recording sites. The azimuthal variation of the motions, corrected for distance-attenuation, was as much as a factor of 5. Theoretical predictions of the directivity, based on the simplest model available, gave a good fit to the data. Although Mach numbers between 0.7 and 0.9 gave equally good fits to the data, it would be hard to fit the data with Mach numbers much below 0.7.

Directivity in these earthquakes was also observed in longer period motions, including Wood-Anderson seismographs and broadband recorders (Bolt et al., 1981; Schechter, 1981). The low-magnification Wood-Anderson equivalent at Berkeley gave magnitudes of 5.5 and 5.9 for the first and second events, respectively. If the magnitudes had been based on peak accelerations, the theoretical curve predicts that the difference between first and second events would have been -0.5 to -0.7 units, depending on Mach number. This is a greater difference than observed (-0.4), which is not surprising given the longer predominant periods in the Wood-Anderson records (not to mention scatter of up to 0.2 log units due to local site geology). The relative amplitudes of the broadband recordings at Berkeley are reversed with respect to the Wood-Anderson amplitudes, with the first event having much more long period motion (Schechter, written communication, 1981); this is expected from the relative amplitudes of the moments for the two events ($\approx 6\times10^{24}$ and 2×10^{24} dyne-cm).

2. PGA and RMSA descriptors of strong ground motion have similar scatter after the distance attenuation is removed. The scatter of motion within small areas ($\approx$ 1 km radius) is comparable to that from the scatter about the distance regression line, suggesting that local effects (due to

variations in building size and in local geology) are responsible for a majority of the scatter. Further analysis, incomplete at this writing, suggests that building size has a significant influence on the ground motions.

Reports

Fletcher, J. B., Zepeda, R. L., and Boore, D. M., 1981, Digital seismograms of aftershocks of the Imperial Valley, California earthquake of October 15, 1979: U.S. Geological Survey Open-File Report 81-655.

Global Accelerograph Program (GAP)

9940-02689

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Investigations

The objective of this program is to obtain critically needed records of damaging levels of ground motion close to the source of earthquakes of magnitude M6.5 and greater; the purpose is to improve engineering design standards and to address a number of fundamental scientific questions regarding earthquake mechanisms and the generation of damaging ground motion.

During the last half of FY81 the following activities were carried out:

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

(2) Nine additional countries were identified as desirable locations for GAP-type agreements: Argentina, Columbia, Indonesia, Italy, New Zealand, Philippines, Romania, Taiwan, and Venezuela. OIG was requested to send to each of these countries a description of the program and an inquiry regarding interest.

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

(4) Discussions were held with officials from counterpart agencies in the following countries: Greece, Italy, and Romania.

Results

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

A preliminary agreement with the appropriate counterpart agencies in Italy was formulated; that agreement has been approved by management in Italy and is currently (October 1981) being reviewed by U.S.G.S management.

Preliminary agreements were also formulated with counterpart agencies in Greece and Romania. Those agreements are still being reviewed by management authorities in the those countries; the agreements have not yet been reviewed by U.S.G.S management.

Compilation of Regional Geological and Seismic Site Characteristics

9940-02087

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Investigations

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

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

Results

1. For the Los Angeles-Ventura areas, 68 sites have been logged to a depth of approximately 30 m for P- and S-wave velocities. Most of these sites are on Quaternary sedimentary deposits or soft Tertiary bedrock. During the report period, data reduction was completed for sites 47-68, located in the Los Angeles Basin and Antelope Valley areas. Test holes were drilled at an additional 17 sites, mostly on hard bedrock in the Tehachapi, San Gabriel and San Bernardino Mts. A preliminary comparison of the S-wave velocity data with the physical property and age characteristics of the unconsolidated to semiconsolidated deposits shows:

a. Five of the six seismically distinct units defined for sedimentary deposits in the San Francisco Bay region on the basis of physical properties can also be delineated in the Los Angeles-Ventura areas. Velocities in these units generally range higher in Los Angeles-Ventura than in the San Francisco Bay region. No equivalent of the bay mud (thick deposits of soft clay) was sampled in the Los Angeles area.

b. For Los Angeles-Ventura, Holocene and Pleistocene sediments show distinct velocity ranges. The division occurs at about 260 m/sec in the near-surface and increases to 300 m/sec below 15 m.

c. In the Antelope Valley, where a more detailed comparison between velocity and age was made (Ponti, D. J., personal communication), the Pleistocene map subdivisions show distinct S-wave velocity ranges:

Q4 (~40,000-80,000 yrs. B.P.)	395-430 m/sec
Q3 (~100,000-150,000 yrs. B.P.)	470-515 m/sec
Q2 (~250,000 yrs. B.P.)	680-715 m/sec

2. All of the 17 sites drilled during the report period were located at strong motion stations which have recorded time histories from the Kern County (1952), Lytle Creek (1970), or San Fernando (1971) earthquakes. A hole was also drilled at Coyote Lake dam near the epicenter of the Coyote Creek earthquake (1979). The shear wave velocity logs, geologic logs and physical property data will provide a comprehensive definition of site properties. From data of this type ground motion prediction equations can be developed. These can be used for predicting the parameters of strong motion in future earthquakes given local magnitude, source distance, and site conditions.

Theoretical and Empirical Studies of Strong Ground Motion

14-08-0001-19835

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Investigations

1. Computer Code Development

Simulation of strong-ground motion requires extensive computations of transfer functions for a layered earth. We have obtained a very efficient code for plane-layered media and have modified the code for optimum use on our computer. This package significantly reduces the labor and computer expense associated with strong-ground motion studies.

Lateral velocity structures such as geologic basins have major effects on the amplitude and duration of strong-ground motion. Over the last year we have been developing a computer code for modeling lateral structures using the Kirchhoff technique. An example of a wave incident at a shallow angle at the base of a small basin, for the acoustic case, is shown in Figure 1. Note the factor of 3 amplication across the basin.

2. Mammoth Lake Earthquakes

We are modeling both the near-field strong ground motion records and the teleseismic body waves from the four $M_S \sim 6$ Mammoth Lake earthquakes of May, 1980. Preliminary results indicate that the first, third and fourth events are primarily dip-slip along NNW trending faults, while the second event is primarily strike-slip. Although vertical surficial motion was observed on the Hilton Creek fault, the dip-slip events are located west of the fault (Cramer and Toppozada, 1980) and cannot be simply associated with it (unless the fault dips west). The strike-slip event is located along the boundary of the Long Valley Caldera and slightly to the northwest of the dip-slip events. The spacial relationships and the focal mechanisms suggest tear-faulting along the East-West trending southern boundary of the caldera with normal faulting on an intersecting North-South trending structure.

3. Publications

The paper "Peak Acceleration Scaling Studies" has been completed and submitted for publication in the Bull. Seis. Soc. Am.

References

Cramer, C.H. and T.R. Toppozada, 1980, Seismological study of the May, 1980, and earlier earthquake activity near Mammoth Lake, California, Cal. Div. Mines and Geology Special Report 150.

Hadley, D.M., D.J. Helmberger and J.A. Orcutt, 1981, Peak Acceleration Scaling Studies, Bull. Seis. Soc. Am., submitted and revised.

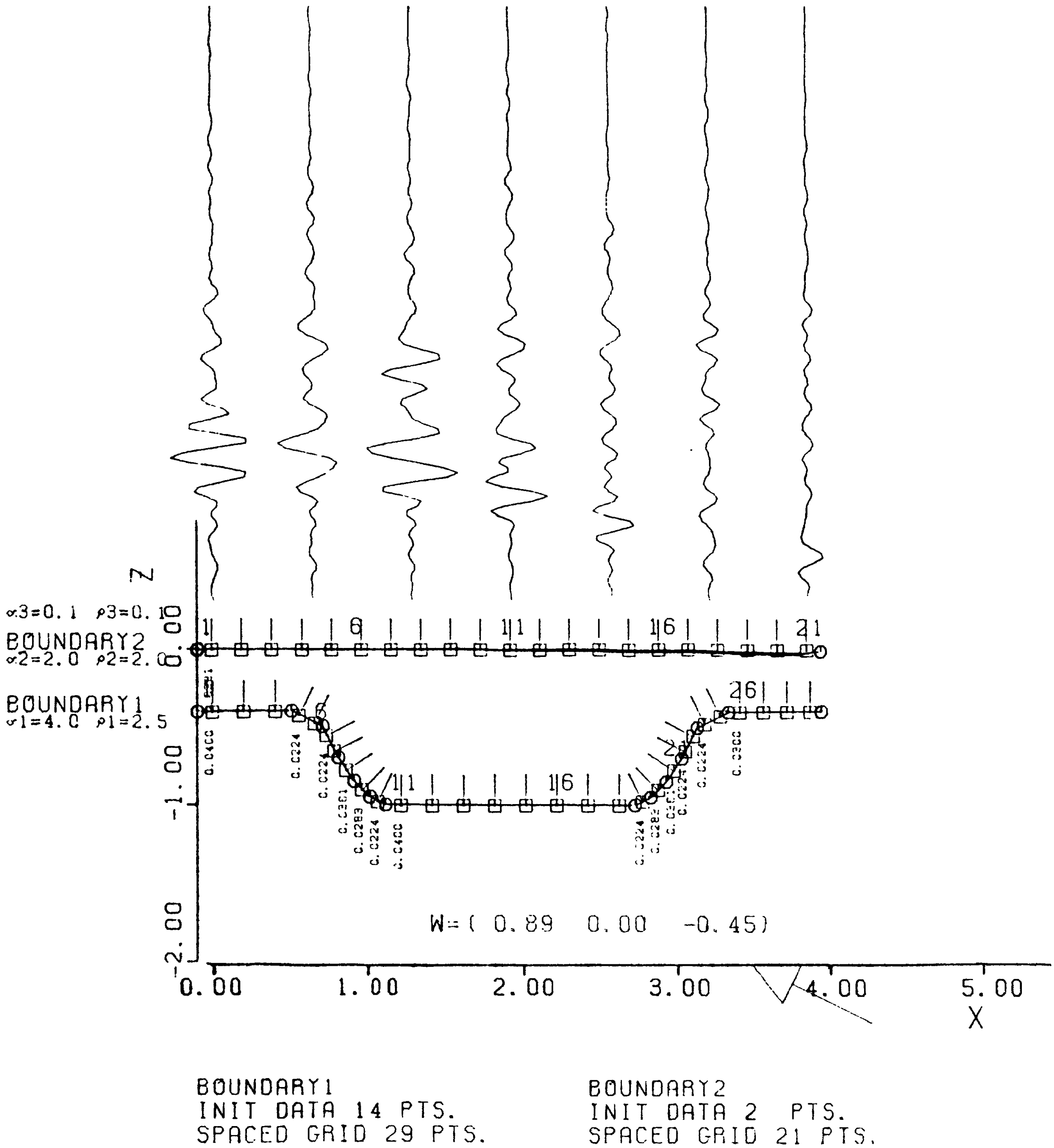

Figure 1. Waveforms and relative amplitudes for a wave incident at a shallow angle from the right (arrow). The synthetic time histories have been calculated with a Kirchhoff technique and includes two multiples within the basin. Note the factor of 3 increase in amplitude caused by structure.

STRONG GROUND MOTION STUDIES

14-08-0001-19131
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In recent years significant progress in theoretical and observational aspects of the mechanics of earthquakes have greatly increased our understanding of the various physical processes involved. Concurrent advances in the calculation of synthetic ground motion provide a powerful tool for studying the effects of a particular earth structure, source orientation, or rupture processes. Although a large number of accelerograms are now becoming available, when compared with the wide range of possible source orientations, source-site separations, magnitude and crustal site conditions, the actual data set is rather limited.

Currently neither purely computational nor strict empirical techniques provide optimal guidelines for the prediction of site-specific strong ground motion characteristics. Our approach has been to develop hybrid techniques that draw upon the strengths of each field. During the last year our principal goal has been to use computational techniques for constructing scaling relationshps that are compatible with and provide for the extrapolation and further utilization of the existing data.

The simulation of strong-ground motion can be viewed as the end product of a series of filters that describe the transfer of energy from the fault to the site:

$$ACC(t) = S*R*E*Q$$

Where S is the source time function, R represents rupture over a finite fault, E is the elastic propagation through the earth and Q is the path attenuation, assumed to be linear. If these operators were exactly known, a deterministic approach to predicting strong ground motions would be straightforward. In these studies E was computed from a velocity model of the Southern California crust. A range of realistic rupture velocities have been obtained by other investigators and have been simply incorporated into the simulations. Assumptions of the path averaged attenuation, Q, can be tested by comparing with observational data, as a function of distance, the parameters peak acceleration and computed M_L. This provides a check on both the high frequency (5-10 hz) and long period ($\sim$1 sec) behavior or E*Q. Using this technique, an average crustal shear wave Q_β of 300 has been found to be compatible with observational data (M_L = 4.5-5.0). Assumptions of S can be avoided by using real sources derived from accelerograms recorded at small epicentral distances (epicentral distance/source depth < 1). Using these operators, accelerograms have been simulated for four magnitudes: 4.5, 5.5, 6.5, 7.0; at eight distances: 5, 10, 15, 20, 30, 50 and 70 km; for five different rupture geometries. From these simulations an attenuation relationship for strike-slip events for peak acceleration has been developed for each of the above magnitudes. These results are discussed in detail in our final Technical Report, Appendix A.

The shear wave attenuation factor (Q_β) discussed above strongly affects the behavior with distance of both peak acceleration and the computed values of M_L. If Q_β is too large, the computed value of M_L will increase with distance. Conversely, if Q_β is too small M_L decays with distance. Although the value of Q_β was adjusted to correctly predict the observed behavior of peak acceleration and M_L, we systematically found that the computed values of M_L in the distance range of about 20 km was $\sim$0.2 units small, relative to the value predicted on the basis of Richter's Attenuation Curve. In recent studies of computed M_L from near-field accelerograms, Kanamori (personal communication) has also found a dip in the measured value of M_L at about 20 km. These modeling studies combined with the observational results suggest a revision of the attenuation curve for M_L at short epicentral distances may be in order. As this parameter is quite significant for engineering and design, this conclusion should be verified by examining the effects of a wider range of fault orientation and crustal velocity models.

Accelerograms from the recent Imperial Valley earthquake have generated considerable interest in the scaling with distance and the relationship between the vertical and horizontal components of motion. From the time separation and decoupling between the vertical and horizontal components, it is clear that the high vertical motion results from near vertically incident P-waves. Our modeling studies, described in detail in our final Technical Report, Appendix B, suggests that this phenomenon results from focusing or triplications caused by faulting at a shallow depth in a sedimentary structure where velocity is rapidly increasing with depth.

Seismological Field Investigations

9950-01539

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Investigations

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

2. Argentina aftershock study--regional investigation of the magnitude - 7.4 (M_S) earthquake.

Results

1. The upper Mississippi Valley earthquakes of 1811-1812 caused considerable damage and represent the most widely felt earthquakes in the United States within historical time (Nuttli, BSSA, 1973, p. 227). A multi-disciplinary group of scientists from several organizations is currently investigating the upper Mississippi Valley seismic source region. The seismotectonic study that is being conducted by the Seismological Field Investigations Project is designed to address some of the important questions related to a key portion of this seismogenic area.

The predominate feature in the seismicity pattern of the upper Mississippi Valley is a northeast-trending alignment of epicenters which is offset by approximately 20 km to the northwest in the area between New Madrid, Missouri, and Ridgley, Tennessee. Within this offset area is a zone of intense, low-magnitude seismicity (greatest seismic activity in the region) that trends to the north-northwest. The geology and tectonics of the north-northwest seismic zone are not well understood (W. Stauder, USGS Prof. Paper, edited by F. A. McKeown, in TRU); therefore, this study will use recent seismic activity to better define the causative structures and also the tectonic framework.

During the month of August, Dave Carver, Richard Dart, Susan Rhea, Tom Bice, and Ron Henrisey participated in the installation and operation of a temporary seismograph network that covered the north-northwest seismic offset zone. The USGS network consisted of 16 single-component portable analog recording (smoked paper) systems and five portable three-component digital systems. The digital instruments were collated with five analog systems to facilitate in tuning the detection algorithm because of the high cultural background noise. In addition to the USGS seismographs, Saint Louis University installed and operated five portable analog systems and the University of Wisconsin deployed 15 of their digital instruments.

During the 27-day field exercise, 52 microearthquakes were recorded by three or more stations. Of these, 36 were locatable with data obtained from not less than five stations. Preliminary analysis indicates that the microearthquake epicenters define a north-northwest zone of seismicity, however, depth profiles have not been completed. Digital data from the USGS instruments have been entered into the computer and are in the process of being analyzed.

2. A preliminary draft of the aftershock study of the magnitude - 7.4 (M_S) western Argentina earthquake that occurred on November 23, 1977, has been completed. Results indicate the presence of a source volume rather than a planar or tabular-shaped source. There are extensive north-northwest and north-northeast fault systems as well as a cross-cutting east-northeast fault system present in the Sierra Pie de Palo and the surrounding region (refer to Open-File Report 81-833, Summaries of Technical Reports, volume XII, p. 219). Movement on the main shock's causal fault could have perturbed the local stress regime to the extent that strain release occurred on all of these fault sets. A voluminal, rather than a planar, source volume would thereby result. Also, the main shock causal fault probably exhibited unilateral propagation to the south from the initial point of rupture at the north end of the Sierra Pie de Palo.

Strong Ground Motion Data Analysis

9940-02676

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No report received.

Data Processing, Golden

9940-02088

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Investigations

1. The purpose of this project is to provide the day to day management and systems maintenance and development for the Golden Data Processing Center. The Center supports Golden based OES investigators with a variety of computer services. The systems include a PDP 11/40, a PDP 11/70, three PDP 11/03's and a PDP 11/23, a VAX/780 and a PDP 11/34. Total memory is 2.4 Mbytes and disk space will be approximately 1.8 G bytes. Peripherals include three plotters, eight mag-tape units, an analog tape unit, three line printers, 5 CRT terminals with graphics and a Summagraphic digitizing table. Dial-up is available on all the major systems and hard-wire lines are available for user terminals on the upper floors of the building. Operating systems used are RSX11 (11/40 and 11/34), Unix (11/70), RT11 (11/03) and VMS (VAX).

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

Results

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

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

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

In Ground Motion and Faulting, the data center supports equipment for on-line digital monitoring of Nevada seismicity. Also it provides capability for processing seismic data recorded on field analog and digital cassette tape in various formats.

Reports

A. M. Rogers, Covington, P. A., Park, R. B., Borcherdt, R. D., and Perkins, D. M., 1981, Nuclear event time histories and computed site transfer functions for locations in the Los Angeles Region: U.S. Geological Survey Open-File Report (in press).

Using Earthquake Hazard Maps for Lifeline Systems
San Francisco Bay Area
Contract No. 14-08-0001-19831

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INTRODUCTION

In this project, ABAG is extending the computer-based earthquake hazard mapping capability developed in two earlier contracts to the highly urbanized central San Francisco Bay Area. The earlier contracts focused first on San Mateo County, and second on the rapidly developing areas of the East Bay ridgelands and Petaluma.

Ways are being explored to use the resulting maps for analyzing lifeline systems in the Bay Area, including water, sewage, and solid waste systems, major highways and railways, electrical and gas networks, and communications systems. Since lifeline problems are associated largely with existing urban development, this project should be a logical complement to the last project which focused on areas undergoing rapid new development. The results will be made available in forms useful to a variety of people working for and with local governments and lifeline systems.

PROJECT COMPONENTS

1. Selection of target areas and key lifeline systems

2. Map file development and manipulation

3. Lifeline networks and facilities analysis

4. Communication and use of the project's findings

DISCUSSION OF RESEARCH PROGRESS

1. Target Selection

Although many of the basic data map files and hazard map files previously developed were for the entire nine-county Bay Area, several were developed only for or only in detail for San Mateo County, the East Bay ridgelands, and the Petaluma area. The first task of this project was to choose those urban areas where expansion of the detailed hazard mapping work should occur. These areas were limited by cost to approximately fifteen 7-1/2 minute quadrangles. The sixteen quadrangles chosen, when added to the areas mapped in detail in the earlier two contracts, form a contiguous area that extends from Santa Rosa in the north, to Morgan Hill in the south, and east to Walnut Creek.

Next, various lifeline systems were examined to determine those most appropriate for analysis. The decision has been made to concentrate on sewage, water and highway systems. Less emphasis will be placed on other transportation, solid waste disposal, power, and communications systems. The analysis of these will extend to the entire nine-county Bay Area whenever practical, rather than limiting all work to the 46 quadrangle area where detailed hazard information will be available.

2. Map File Development and Manipulation

Information on bedrock geology, existing landslides, and topography has been added for the sixteen central urban quadrangles chosen for additional analysis. Also, the bedrock geology and landslide data have been added for those portions of five quadrangles which are outside of San Mateo County. (These data had been entered for the portion of the quadrangles within San Mateo County as part of an earlier contract.)

These upgraded basic data map files of bedrock geology, landslides, and topography will be used to produce more refined ground shaking intensity maps for the central urban area. (Both a maximum ground shaking intensity map and several risk of damage maps will be produced using new data on the relationship between geologic materials and intensity). In addition, these data, together with information on vegetation and precipitation, will be used to produce both rainfall-induced and earthquake-induced landslide susceptibility maps for these central urban areas. Finally, new information on fault location prepared by the California Division of Mines and Geology as part of the Alquist-Priolo Special Studies Zones Act program is being incorporated into the fault file to use in upgrading the earthquake intensity maps for the entire region. Other information on damage to buildings and lifelines and on earthquake recurrence intervals also is being examined for possible inclusion in the intensity map revision process.

3. Lifeline Network and Facilities Analysis

These revised hazard maps--as well as maps of liquefaction, dam failure, and tsunasmi hazard areas completed as part of earlier contacts--should be useful in assessing the earthquake hazards associated with the three main lifeline system components: the networks, key facilities, and service areas. Analysis techniques to be used include simple overlay maps, area tabulations of hazard level by lifeline type or link, identification of points of concern on networks, a printout of hazards associated with the location of key facilities, an assessment of development patterns on utility service areas, and estimates of damage. The first step in this analysis process, collecting data on the location of lifeline system components, has been initiated.

4. Communication of the Information

Much effort is being made to ensure that the findings of the lifeline analysis work are effectively communicated to a variety of professionals working for and with local governments and lifeline systems in the San Francisco Bay Area.

- o A series of fifteen working papers previously developed to document the hazard mapping capabilities is being extended to include the documentation of this contract.
- o Contracts with local government personnel made in the two previous contacts are being expanded.
- o Discussions are being held with key staff working with lifeline systems to design the analysis techniques so that they will be more interested in the project's findings.

Rupture Process and Wave Propagation Effects of the Coyote Lake Earthquake and its Aftershocks

9940-03010

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Investigations

1. We have applied collocation methods to the calculation of complete theoretical seismograms in laterally homogeneous media.

2. We have studied computational methods for combining wave-propagation methods with earthquake source models.

3. The effects of local velocity structure upon amplitudes of body waves in Coyote Lake earthquake aftershocks were studied.

4. An analytic solution was sought to the coupled P-SV equations in vertically inhomogeneous elastic media.

Results

1. In collaboration with Dr. Uri Ascher, we have written a computer code which uses a collocation method to solve the wave propagation equation $du/dz = A(z)u$, where u is a stress-displacement vector, z is depth, and A(z) is a matrix of coefficients dependent on the velocity structure. The P and S velocity structures, and the attenuation structure, may be arbitrary functions of depth. We are currently comparing synthetic seismograms generated by this method to those generated by other methods.

2. We have written a computer code which will combine arbitrary kinematic fault rupture descriptions with Green's functions generated using the discrete-wavenumber finite-element method of Olson. We have used this code to calculate near-source seismograms from extended earthquake sources in laterally homogeneous earth structures having arbitrary velocity-depth profiles. Currently, the method can be used for strike-slip earthquakes on faults having any dip. We are checking our results against other methods, and are adding the small additional code necessary to do earthquakes of any mechanism.

3. Using the 2-D velocity structure obtained for the Santa Clara valley by Luetgert and Mooney, we have investigated the effect of the low P and S velocities found in the Calaveras fault zone on body waves from Coyote Lake aftershocks. By calculating raypaths from aftershocks to the surface, we have shown theoretically that the low-velocity fault zone causes triplications in the P and S waves observed near the fault trace, i.e., in the

fault zone not one, but three P or S wave arrivals should be observed. This prediction is verified by Coyote Lake aftershock records collected by J. Fletcher showing multiple P arrivals at station CAN, which was in the Coyote Lake fault zone. This result indicates that ground motions in fault zones may be more complicated and have longer durations than those observed outside fault zones. In addition, analysis of the P and S triplications may enable the detailed measurement of velocity structure within fault zones.

4. An attempt was made to expand the solutions to the coupled P-SV equations in series of spherical Bessel functions (a Neumann expansion). The resulting expressions involved a 5-term recurrence relation among the expansion coefficients of the two series. From this recurrence relation a stable algorithm for generating the expansion coefficients was derived, but it was determined that the Bessel function series did not converge. A less straightforward approach to this problem is currently under consideration.

Reports

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

14-08-0001-19823

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Investigations

The goals of this study are to prepare and publish earthquake hazards maps for the Mt. Rose NE and Reno NW quadrangles in western Nevada. In order to accomplish this goal, the following tasks will be completed:

1) Collection, review, and compilation of existing geotechnical data from federal, state, and local sources.

2) Measurement of seismic velocities to aid in determination of ground shaking characteristics.

3) Measurement of *in situ* density for those geologic units lacking bulk density information.

4) Preparation of depth-to-groundwater maps for use in determining liquefaction potential.

5) Trenching of youthful faults to examine the stratigraphy and determine the age of last movement.

6) Categorization of the seismic response of geologic units according to rigidity products (product of shear wave velocity and bulk density) and depth to groundwater.

The geologic maps of these quadrangles provide the base from which the earthquake hazards maps will be derived. The eastern half of the Mt. Rose NE quadrangle consists mainly of Quaternary sediments of alluvial fans, floodplain and lake deposits, and glacial outwash. In the western half of the area, Tertiary extrusives and intrusives predominate. In contrast, much of the Reno NW quadrangle is comprised of Tertiary lacustrine and basin fill deposits overlain in the east-southeast and southwest by varying thicknesses of Quaternary alluvial fan, floodplain, beach and playa deposits. Mesozoic granitic and metavolcanic rocks protrude from the basin fill in the northwest, central and south-central parts of the quadrangle.

Results

More than 119 geotechnical reports were reviewed. Data on bulk density, standard penetration blow counts, and depth to groundwater were compiled from over 850 borehole logs (641 in Mt. Rose NE; 207 in Reno NW) and 377 test pit logs (299 in Mt. Rose NE; 89 in Reno NW). Thirty standard sand cone density tests were performed in Quaternary deposits which lacked density data (21 in Reno NW; 9 in Mt. Rose NE). The geotechnical data are currently being evaluated in order to select representative bulk density values for determination of the rigidity products.

Shear (SH) wave and compressional (P) wave velocities were measured in the upper 9 m (30 ft) of material at 39 locations on 14 geologic units in Mt. Rose NE quadrangle and at 33 locations on 16 geologic units in the Reno NW quadrangle. Time-travel plots have been completed for each of the 72 seismic sites.

Studies have shown that geologic materials having a low shear wave velocity generally have a greater response to earthquake shaking (Seed and Schnabel, 1972). Based on SH-wave velocity measurements, it is apparent that several units in each quadrangle may be susceptible to some degree of ground shaking. Floodplain and alluvial bajada deposits, and siliceous sinter may be prone to ground shaking in Mt. Rose NE quadrangle. Playa, beach, floodplain, and some alluvial fan deposits in the Reno NW quadrangle may also be susceptible to shaking. However, the depth to groundwater must also be considered with the rigidity product in categorizing the ground shaking characteristics of these geologic units.

In general, those areas in which the groundwater table is within 3 m (10 ft) of the ground surface may be subject to possible severe liquefaction potential. For this reason depth to groundwater maps are being prepared for the Mt. Rose NE and Reno NW quadrangles. Data plotted thus far indicate that the water table is within 3 m (10 ft) of the surface in the northeast (floodplain deposits) and east-central (alluvial bajada deposits) parts of Mt. Rose NE quadrangle. Near-surface groundwater conditions also exist in the Reno NW quadrangle beneath the two playa lakes, White Lake and Silver Lake, and in associated beach deposits. Those geologic units in which the groundwater table is within 3 m (10 ft) of the surface, also tend to have low seismic velocities in both quadrangles. Therefore, it is suspected that these materials will be in the category of greatest severity of shaking and possible severe liquefaction. Further evaluation of the depth to groundwater and the rigidity products (shear wave velocity and bulk density) will be necessary to properly categorize the geologic units.

Trenching across selected fault traces is being planned to: 1) determine the spatial relationship of the fault scarp to the fault trace, 2) examine subsurface expression of the fault (zone), 3) examine the soil profile and determine stratigraphic relations in order to estimate the age of last fault movement, and 4) possibly collect material suitable for age dating by relative and absolute methods. Selection and trenching of faults will be completed in the coming months.

Faults will be categorized according to the age of most recent fault displacement (i.e. Holocene [<12,000 years], late Pleistocene [12,000-35,000 years], mid- to late Pleistocene [35,000-100,000 years] and early to mid-Pleistocene [100,000-1.8 m. years]) on the basis of several factors including geology, soil development, and trenching results. The age of most recent fault movement is considered indicative of the potential for surface rupture; thus, the young (Holocene) faults are considered to have the greatest potential for surface rupture in the future.

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Development of General Earthquake Observation Systems

9940-03009

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Investigations

This project will develop, debug, and produce several low powered, wide dynamic range digital recording systems. The system is software base for easy use in a wide variety of applications.

Results

Modifications have been completed on all hardware. All circuit boards have been converted to P. C. with the exception of the tape controller circuits. Three production model units are being assembled. Almost all software modifications have been completed and tested including automatic WWVB time sync and various record options. The first 3 production units are scheduled for testing in December.

Instrument Development and Geotechnical Studies

9940-02089

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Investigations

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

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

Results

1.a. The DR-100 systems were maintained and/or installed and/or operated by E. D. Sembera in these activities:

Microearthquake survey on Nevada Test Site (A. Rogers)
Anza activity survey with L. Carroll (J. Fletcher)
Building vibration survey (A. Schiff)

1.b. E. D. Sembera also performed the 500 hour maintenance on all DR-100 systems plus:

Modification of two DR-100's for sample synchronization for precise arrival time studies (H. P. Liu)

Revision of power unit wiring to decrease the possibility of catastrophic failure because of improper cable connections

Frequency response tests for Mammoth Lakes H.E. tests (E. Cranswick)

2.a. A reversed shear and compressional wave refraction profile was conducted at the location of the piezometer near Convict Lake where events of the Mammoth Lakes sequence were recorded. The near surface shear wave velocity was necessary for E. L. Harp to complete the analysis of the piezometer recordings. The water saturated shingle beach yielded a shear wave velocity of 130 meters/sec. through the depth of interest.

2.b. Gary Maxwell and Allen Walker are collaborating in adapting the Nimbus system digital magnetic tapes to the 11/70 system.

2.c. The display of the L.P. three-component signals from Jamestown was started with the completion of the telemetry links by J. R. Van Schaack and associates. Tests of different signal bands are proceeding.

Behavior of Weakly Cemented Sands Under Static and Seismic Loading

14-08-0001-19763

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Investigations

A small degree of cementation in sands has a profound effect over sand behavior especially in seismic events. The weakly cemented sand is highly resistant to failure either under drained or undrained conditions. This investigation is directed towards quantifying the effects of cementation, and determining the appropriate techniques for measuring in-situ levels of cementation.

Results

Laboratory tests have been performed on a number of cemented sands obtained from the San Francisco Bay Area which allow a qualitative as well as quantitative assessment of their behavior. Levels of cementation are found to vary with agents of cementation, density, age of deposit and weathering effects. In terms of static behavior, cemented sands exhibit a cohesion intercept on a Mohr diagram, but otherwise their characteristics are similar to those of uncemented sands. Under dynamic loading cemented sands show little development of cumulative strain with repeated cycles of loading; instead they fail suddenly. Cycled tension loads degrade the strength of cemented sand, a finding important in view of the fact that tension stresses develop in the steep slopes found naturally to exist in cemented sands.

Determining the degree of cementation in sand deposits has proven to be a major problem. In this research a number of conventional procedures were attempted but the sand structure was found to be disturbed by the sampling or sample preparation process. The most promising method to date appears to be by in-situ pressuremeter testing of cemented sands which is found to provide useful qualitative indications to cementation levels. As yet quantitative methods for reducing the data are only crudely developed since the failure mode under this type of loading is not fully understood.

In addition to the lab and in-situ testing, an extensive series of studies have been made of the behavior of slopes in cemented sands. This includes field mapping, aerial photo studies, and analytical studies. Failures in homogeneous cemented sands are found to be generally shallow and sudden, with a complete disintegration of the sands. In some cases, deep failures can occur if the underlying structure causes unusual seepage conditions. The final results of all the analytical studies have been set into the form of charts which can be used to assess stress conditions under static and dynamic loading in steep cemented soil slopes.

Reports

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Seismic-Induced Ground Failure

9550-01452

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Investigations

1. Continued processing and analysis of seismic pore-pressure records obtained during May 1980 Mammoth Lakes, California earthquake sequence; conducted geotechnical and geophysical site investigation of lake sediments where seismic pore pressures were obtained.

2. Conducted site studies of engineering properties of rocks in source areas of rockfalls and rockslides from May 1980, Mammoth Lakes, California earthquake sequence.

Results

1. Preliminary analysis of seismic pore-pressure records gathered from lake sediments at Convict Lake during the May 1980 Mammoth Lakes earthquake-sequence aftershocks and comparison with corresponding strong motion accelerograms obtained from the same site shows that the pore-pressure records are very similar in waveform to the acceleration traces. The pore-pressure records have well-defined waveform components that closely correspond to respective p-wave and s-wave components of the accelergrams. The "p-wave" components of the pore-pressure records appear in-phase with p-wave portions of corresponding accelergrams. The "s-wave" components of the pore pressure appear to be slightly out-of-phase with corresponding acceleration components and also appear to sustain a comparative loss of higher frequency components. Site studies measuring material properties of the lake sediments will allow a comparison of existing theory of seismic pore-pressure generation with actual measured values. A report is in preparation.

2. Studies of engineering properties of rocks at source areas of rockfalls and slides from May 1980 Mammoth Lakes earthquakes indicate that many different measurable properties such as, joint spacing, number of joints per unit volume of rock, joint roughness, widths of joint openings, chemical weathering, and joint orientation, all play an integral part in determining the seismic stability of rock slopes. Various engineering classifications using the above properties have been used to compare classification values from various sites versus intensity of rockfall occurrence. Several classifications appear to show good correlation and may be a good predictive indices of seismic slope stability, however, refinement and comparison of data are needed to separate the effects due to physical and chemical nature of

rocks from other site effects such as distance from epicenter, topographic amplification, and slope.

Reports

Harp, E. L., 1981, Factors affecting the concentration and distribution of rock falls and slides from the May 25-27, 1980 Mammoth Lakes earthquake sequence, Geological Society of America Annual Meeting, Abstracts with Programs, p. 468.

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Use of Long-period Surface Waves for Fast Evaluation of Tsunami Potential of Large Earthquakes

Contract No. 14-08-0001-19755

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Investigations

We investigated several methods to determine the mechanism and seismic moment of large earthquakes accurately and very quickly (e.g. within 1 hour after the earthquake) using long-period seismic waves.

Results

During the period from December 1, 1980 to May 31, 1981, we developed a method which uses long-period Rayleigh waves from the IDA network. The method has been tested and used for several large events, (e.g. 1979 Colombia earthquake, 1979 Montenegro, Yugoslavia earthquake, 1978 Tabaz, Iran earthquake). This part of the study has been completed and a paper is now in press in Physics of the Earth and Planetary Interiors.

We also tested our method for Love waves recorded by the SRO network. Although the results are still preliminary, use of Love waves seems to enhance the resolution and the reliability of the method significantly.

As a test of the method for routine application, we attempted to determine the mechanism and the seismic moment of all the events in 1980 with $M_s \geq 6.5$. Out of 28 events listed in Table 1, we could obtain the solution for 25 events with the constraints $M_{zx} = M_{zy} = 0$. These solutions are listed in Table 2. After all the seismograms have been retrieved from the tape file, the solution could be obtained in about 10 minutes for most events.

Reports

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Table 1
List of Large Earthquakes (M_s > 6.5) in 1980

EVENT NO.	DATE		TIME	LATITUDE	LONGITUDE	DEPTH	M_s	REGION
1	1	1	$16^h42^m40.0^s$	38.815N	27.780W	10G	6.7	Azores
2	1	2	20 58 44.2	5.984N	126.188E	63		Mindanao
3	2	7	10 49 16.0	54.158S	158.890E	10	6.5	Macquarie Is.
4	2	23	5 51 3.2	43.530N	146.753E	44	7.0	Kurile
5	2	27	21 17 20.2	6.017S	150.189E	53	6.6	New Britain
6	3	8	22 12 10.3	22.673S	171.357E	38	6.7	Loyalty Is.
7	3	24	3 59 51.3	52.969N	167.670W	33	6.9	Fox Is.
8	6	9	3 28 18.9	32.220N	114.985W	5G	6.4	Cal-Mex Border
9	6	18	10 49 10.0	15.268S	173.570W	43	6.5	Tonga
10	6	18	17 14 54.5	9.475N	126.657E	54	6.8	Mindanao
11	6	25	23 18 20.4	5.233S	151.686E	49	6.5	New Britain
12	7	8	23 19 19.8	12.410S	166.381E	33	7.5	Santa Cruz
13	7	9	20 56 53.2	12.689S	166.004E	33	6.7	Santa Cruz
14	7	14	16 15 1.7	29.273S	177.154W	49	6.6	Kermadec
15	7	17	19 42 23.2	12.525S	165.916E	33	7.9	Santa Cruz
16	7	29	3 11 56.3	13.101S	166.338E	48	6.7	Vanuatu Is.
17	7	29	14 58 40.8	29.598N	81.092E	18	6.5	Nepal
18	9	26	15 20 37.1	3.225S	142.237E	33	6.5	Papua
19	10	10	12 25 23.5	36.195N	1.354E	10G	7.3	Algeria
20	10	24	3 25 34.4	21.989S	170.165E	33N	6.7	Loyalty Is.
21	10	25	7 0 7.9	21.982S	170.025E	33N	6.7	Loyalty Is.
22	10	25	11 0 5.1	21.890S	169.853E	33N	7.2	Loyalty Is.
23	10	25	16 20 4.8	22.313S	170.380E	33N	6.5	Loyalty Is.
24	11	8	10 27 34.0	41.117N	124.253W	19D	7.2	No. Calif (Eureka)
25	11	11	10 36 58.2	51.422S	28.796E	10G	6.7	So. Africa
26	11	23	18 34 53.8	40.914N	15.366E	10G	6.9	Italy
27	12	17	16 21 58.8	49.479N	129.496W	10G	6.8	Vancouver Is.
28	12	31	10 32 11.0	46.060N	151.453E	33N	6.5	Kurile

Table 2
Moment Tensor, Scalar Moment and Fault Parameters
($M_{zx} = M_{zy} = 0$)

Event No.	M_{xy}	$M_{yy} - M_{xx}$ (10^{27} dyne-cm)	$M_{yy} + M_{xx}$	M_o	δ_1 (deg.)	λ_1 (deg.)	ϕ_1 (deg.)	δ_2 (deg.)	λ_2 (deg.)	ϕ_2 (deg.)	2nd D-C (%)	Depth (km)	To (sec)
1	−0.14±0.02	−0.56±0.07	0.027±0.021	0.33	90	0	148	90	180	58	8	16	15
2	−0.061±0.038	−0.68±0.09	−0.50±0.04	0.60	45	90	5	45	90	−175	16	62	10
3	0.17±0.034	−0.29±0.10	−0.055±0.032	0.25	90	180	−160	90	0	70	22	16	0
4	−0.24±0.06	−0.34±0.11	−0.48±0.05	0.53	45	90	−153	45	90	27	10	43	20
5	0.006±0.020	0.12±0.06	−0.22±0.02	0.22	45	90	93	45	90	−87	21	53	15
6	0.14±0.06	0.27±0.26	−0.49±0.07	0.49	45	90	−66	45	90	114	9	33	15
8	0.0078±0.0084	0.088±0.017	0.013±0.007	0.051	90	180	140	90	0	−130	25	16	15
10	0.013±0.042	−0.22±0.08	−0.27±0.04	0.27	45	90	177	45	90	−4	9	53	20
11	−0.034±0.012	0.081±0.035	−0.093±0.012	0.10	45	90	−110	45	90	70	7	43	15
12	0.44±0.15	−1.9±0.4	−2.0±0.1	2.10	45	90	168	45	90	−12	3	33	33
13	0.049±0.017	−0.13±0.04	−0.14±0.02	0.15	45	90	161	45	90	−19	6	33	12
14	−0.037±0.013	−0.092±0.029	−0.12±0.01	0.12	45	90	−161	45	90	19	0.5	43	15
15	1.3±0.6	−4.52±1.46	−6.1±0.5	6.1	45	90	165	45	90	−15	8	33	60
16	0.058±0.018	−0.17±0.06	−0.17±0.02	0.19	45	90	163	45	90	−17	9	43	15
17	0.021±0.011	0.065±0.025	−0.062±0.009	0.070	45	90	−73	45	90	106	11	16	15
18	0.12±0.02	−0.079±0.038	−0.093±0.015	0.17	45	90	144	45	90	−36	46	33	15
19	−0.51±0.17	0.77±0.37	−0.67±0.14	0.97	45	90	63	45	90	−117	32	16	30
20	0.098±0.011	−0.033±0.026	−0.18±0.01	0.19	45	90	140	45	90	−40	5	33	15
21	0.26±0.05	0.024±0.105	−0.53±0.04	0.53	45	90	−46	45	90	134	0.7	33	15
22	0.84±0.14	−0.36±0.32	−1.7±0.1	1.7	45	90	141	45	90	−39	1	33	25
24	0.23±0.12	2.1±0.3	0.072±0.106	1.1	90	180	142	90	0	−129	6	16	30
25	0.091±0.024	−0.18±0.05	0.11±0.02	0.18	45	−90	−112	45	270	68	41	16	15
26	−0.14±0.03	−0.062±0.067	0.28±0.03	0.28	45	−90	−51	45	270	129	2	16	20
27	0.040±0.015	0.27±0.08	0.041±0.026	0.16	90	180	143	90	0	−127	25	16	18

Ground Failures Caused by Historic Earthquakes

9550-02161

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Investigations

1. The project was completed with submittal of the final paper "Landslides caused by earthquakes." This paper culminates a comprehensive study of landslides in 40 selected earthquakes and a study of landslide-related intensity data from several hundred others.

2. Reconnaissance was conducted in the Mammoth Lakes, California, area to plan a study of earthquake-induced landslides there next summer.

Results

1. Fourteen types of landslides occur in earthquakes. Whereas rock falls, rock slides, and disrupted soil slides are the most numerous, catastrophic rock avalanches and soil avalanches cause the greatest number of deaths.

Numbers and areal extent of landslides in an earthquake show a strong correlation with magnitude. Logarithmic straight line functions have been derived to relate magnitude to the farthest distance from the epicenter or source zone at which landslides occur.

A wide variety of geologic materials are involved in earthquake-induced landslides. These materials are described in the final paper.

Reports

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Interactions Between Ground Motion and Ground Failure

9550-01628

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Investigations

1. Developed a procedure for estimating earthquake design curves given the magnitude of the design earthquake and its distance from the site.

2. Developed mapping criteria for seismic slope stability study of Hilo, Hawaii (with G. Wieczorek and J. Buchanan-Banks).

3. Prepared results, of project investigations for publication in preparation for termination of project.

Results

1. In the first half of FY 81, a normalized "seismic slope stability design curve" was developed which estimates the displacement of a landslide mass versus the critical displacement, given the peak acceleration and the duration of the design earthquake. This normalized design curve was based on similar curves calculated from a suite of actual strong-motion records, using a modification of Newmark's analysis. In the latter half of FY 81, this work was extended with the development of a method for preparing similar seismic slope stability design curves, given the magnitude of the postulated design earthquake and its distance from the site, using the peak acceleration versus magnitude-distance relationship of Joyner and others (1981).

2. Drained direct-shear tests performed on samples of the Pahula ash collected near Hilo, Hawaii (in late FY 80), yielded a mean friction angle, $\emptyset = 41^{o}$, and a mean cohesion, c = 25 kPA. Using the lithology/slope criteria developed for the San Mateo County seismic slope stability map, these strength values would classify the Pahula ash as an "A" unit (weathered bedrock). However, the very high water content (200 - 300%) and the sensitivity (4 - 8) would be more compatible with a "C" unit (clays and weathered shales). When the low bulk density (80 pcf) and high pore pressures under saturation (pore pressure/overburden = 0.6 - 0.8) is factored into the analysis, the Pahala ash is more likely to behave as a C unit under seismic conditions.

Seismic design curves of displacement versus critical acceleration were also derived for the Hilo area using the techniques discussed on 1) above. The "upper-bound" curve was calculated using a postulated M 8.5 event on the south coast (50 km) and a local (10 km) M 7.5 event. The "lower-bound" curve was based on a local (10 km) M 6.0 event. The upper bound curve yields displacement, $u > 10$ cm for slopes with critical acceleration, $a_c < 0.22$ g;

lower-bound, $u > 10cm$ for $ac < 0.08g$. From the geotechnical measurements of the Pahula ash, these critical accelerations may be "back-calculated" as slopes steeper than 10% (upper-bound) and 25% lower-bound. These slope values thus become mapping parameters for a seismic slope stability map of the Hilo quadrangle.

The geotechnical data, seismic design curves, and slope criteria have been forwarded to J. Buchanan-Banks of the Hawaiian Volcano Observatory who will perform the field mapping.

3. Because this project terminates with FY 1981, the final six months were largely devoted to writing up the results of investigations conducted during the life of the project (since FY 1978). The principal product of the project was the "Seismic Slope Stability Map of San Mateo County, California" (I-Series Map) (Wieczorek, Wilson and Harp). Another significant product is the journal article, "Dynamic Analysis of a Slope Failure from the 1979 Coyote Lake, California Earthquake (Wilson and Keefer) which presents an improved version of Newmark's (1965) dynamic slope stability analysis and describes a physical test of this analysis against an actual seismic slope failure. The final manuscript prepared during this period was an MF-Map and text describing ground failures from the January, 1980, Greenville/Mt. Diablo (Livermore) earthquake sequence. This map represents the latest in a continuing series of post-earthquake ground failure investigations in which this project has participated since FY 1976.

For FY 1982, this project has been combined with two other USGS projects investigating seismic ground failures (Harp, 9550-01452 and Keefer, 9550-02166) into a new project, "Seismic Slope Stability" with D. K. Keefer as chief. The new project will continue and extend several of the investigations begun by the present project, particularly improving methods for regional mapping of seismic slope stability.

Reports

Wieczorek, G. F., Wilson, R. C., and Harp, E. L., Seismic slope stability map of San Mateo County, California: U.S. Geological Survey Misc. Geologic Investigation I-Map, 1:62,500 (submitted for Director's Approval).

Wilson, R. C., and Keefer, D. K., Dynamic analysis of a slope failure from the Coyote Lake, California, earthquake: Seismological Society of America Bulletin (submitted for Director's Approval).

Wilson, R. C., Wieczorek, G. F., Keefer, D. K., Harp, E. L., and Tannaci, N. E., Ground failures from the Greenville/Mt. Diablo earthquake sequence of January, 1980: U.S. Geological Survey MF-Series Map, 1:62,500 (in technical review).

Experimental Mapping of Liquefaction Potential

9550-01629

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Investigations

1. Compilation continued of a liquefaction potential map for San Mateo County, California.

2. With John Tinsley, Branch of Western Regional Geology, conducted subsurface investigations including cone and standard penetration soundings and auger sampling at several sites likely to contain liquefiable sediments in the San Fernando Valley, California.

3. With Ricardo Dobry, Rensselaer Polytechnic Institute, Kenneth Stokoe, University of Texas, and Richard Ladd, Woodward Clyde Consultants, investigated the usefulness of measurements of shear modulus as an indicator of liquefaction susceptibility for sands.

4. Completed compilation of geotechnical logs for holes and soundings beneath strong motion instrument sites in the Imperial Valley, California.

5. Made reconnaissance investigations of secondary ground effects caused by the April 26, 1981 Westmorland, California earthquake.

Results

1. The 1981 Westmorland earthquake (M_S=6.0, M_L=5.6) generated liquefaction and other secondary ground effects at many places in a 150 km^2 area. These effects which included sand boils, fissures, slumps, lateral spreads, and

ground settlement disrupted roadway pavements, canal linings, and fields. Secondary ground effects developed only in areas of recent (late Holocene) deposition, primarily in those areas inundated by the 1905-1907 flooding along the New and Alamo Rivers and the concurrent rise of the Salton Sea. All except one of the liquefaction sites were within 5.6 km horizontal distance from the zone of seismic energy release which was inferred from first-day aftershock epicenters. The one exception was slight rejuvenation of several sand boils that previously erupted during the 1979 Imperial Valley earthquake. Those sand boils were 11 km from the estimated 1981 energy source zone. The types of sediments affected and the distribution of liquefaction effects about the energy source zone agree well with behavior noted during past earthquakes.

2. A method was developed for evaluating liquefaction susceptibility of saturated sands during earthquakes using measurements of insitu shear wave velocity (V_s) and threshold shear strain to calculate the threshold acceleration required to initiate pore-water pressure build up in the soil. Experimental evidence indicates that the threshold strain for most sands varies between about 1×10^{-2} and 3×10^{-2} percent. Insitu measurements of V_s in unconsolidated sands commonly vary from 100 m/s for loose, young sediments to 1000 m/s for old, compact units. The method predicts that the threshold acceleration for such sands can vary from less than 0.05 g to more than 0.5 g. The method correctly predicts the decrease of liquefaction susceptibility with age that is observed in nature. The method also predicted a threshold acceleration of 0.06 g for an instrumented site in Japan where measured pore-water pressures and surface accelerations during two earthquakes yielded a threshold acceleration consistent with the 0.06 g value

<u>Reports</u>

Dobry, Ricardo, Stokoe, K.H., Ladd, R.S., and Youd, T.L., 1981, Liquefaction susceptibility from S-wave velocity *in* In situ Testing to Evaluate Liquefaction Susceptibility: American Society of Civil Engineers, 1981 Annual Convention Preprint No. 81-544, 15 p. (unpaginated).

Youd, T.L., and Bennett, M.J., 1981, Liquefaction site studies following 1979 Imperial Valley earthquake *in* In situ Testing to Evaluate Liquefaction Susceptibility: American Society of Civil Engineers, 1981 Annual Convention Preprint No. 81-544, 14 p. (unpaginated).

Seismic Hazard Evaluation for Commercial Buildings in Memphis

14-08-0001-19829

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Investigations

The geology and seismicity of the Memphis area have been investigated on the basis of the available literature. Microzoning of the region was recently done by Sharma and Kovacs. They identified potentially hazardous soil conditions in the locations shown in Fig. 1.

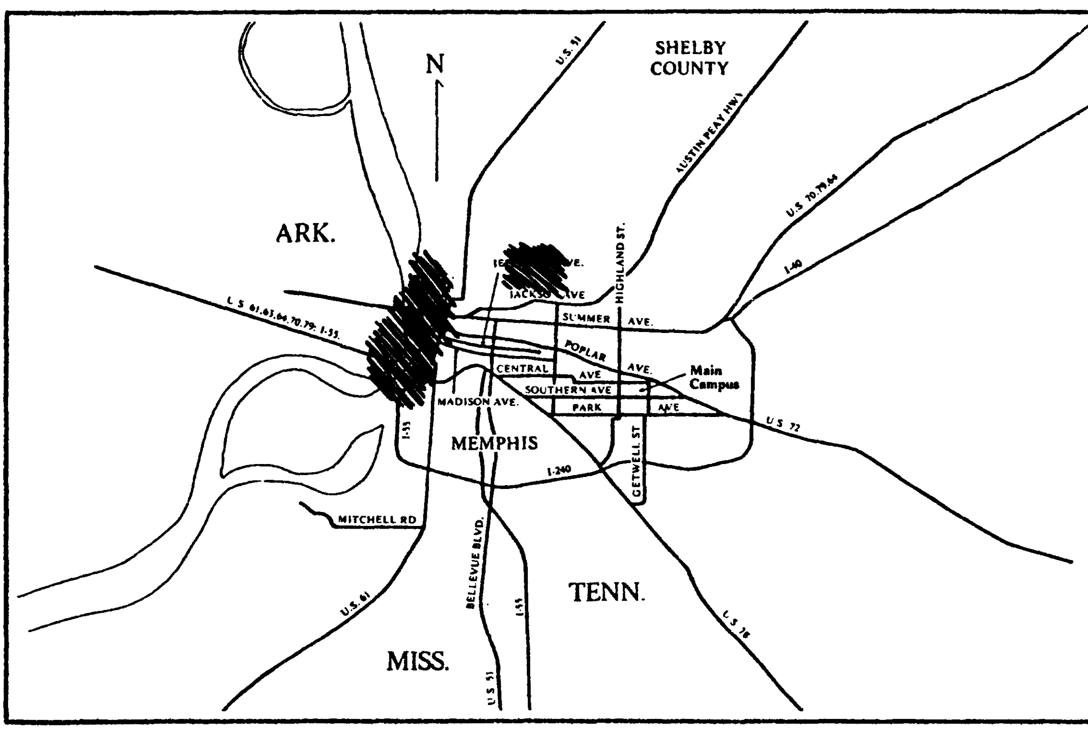

Fig. 1 Locations of potentially hazardous soil conditions

Commercial buildings in Memphis were put into categories with regard to type of structure, age, height, assessed value and location. The statistical analysis was performed on the basis of data stored in the files of the Shelby county assessor's office. The histograms of number of stories and intensity of construction (number of buildings per 10 year period) are shown in Fig. 2 and 3, respectively.

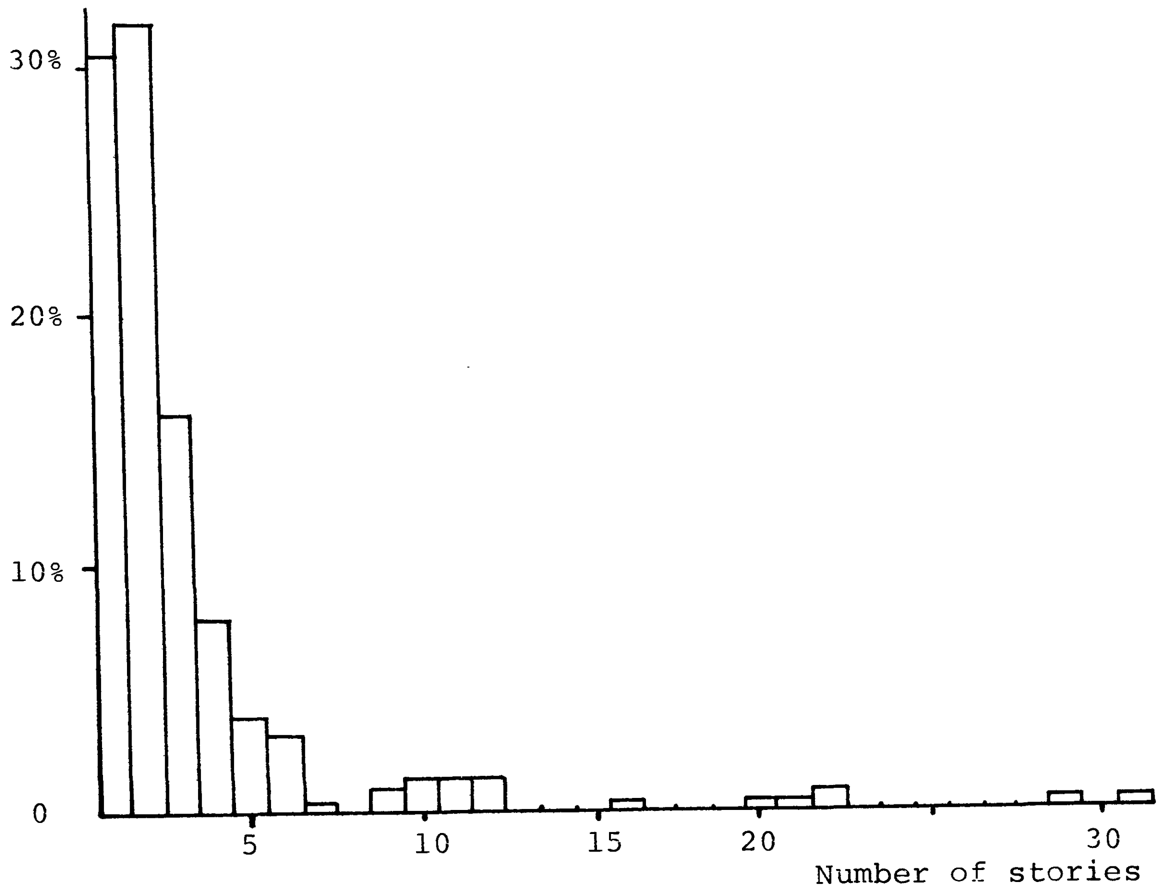

Fig.2 Histogram of Number of Stories

Ten buildings were selected as representatives of the different categories. They included high rise structures with the number of stories up to 29 and low-rise with 2 to 4 stories. The year of construction varied from 40 to over 100 years ago. The selected buildings were examined to determine their resistance, especially with regard to lateral forces. The most important parameters considered in the examination included configuration of columns and beams, and beam-to-column connections.

Results

The potentially hazardous seismic zones cover the downtown area, where most of high-rise buildings are located. Low-rise (one or two story) commercial structures are scattered throughout the city, in particular they are concentrated along major thoroughfares. There are very few taller buildings outside of the downtown area.

Examination of the selected older structures revealed a surprisingly good quality of design, materials and construction. On the basis of visual inspection it seems that in most buildings the lateral strength is sufficient to prevent extensive structural damage and collapse in case of an earthquake. A very low seismic resistance was observed in one three story unreinforced brick bearing wall building.

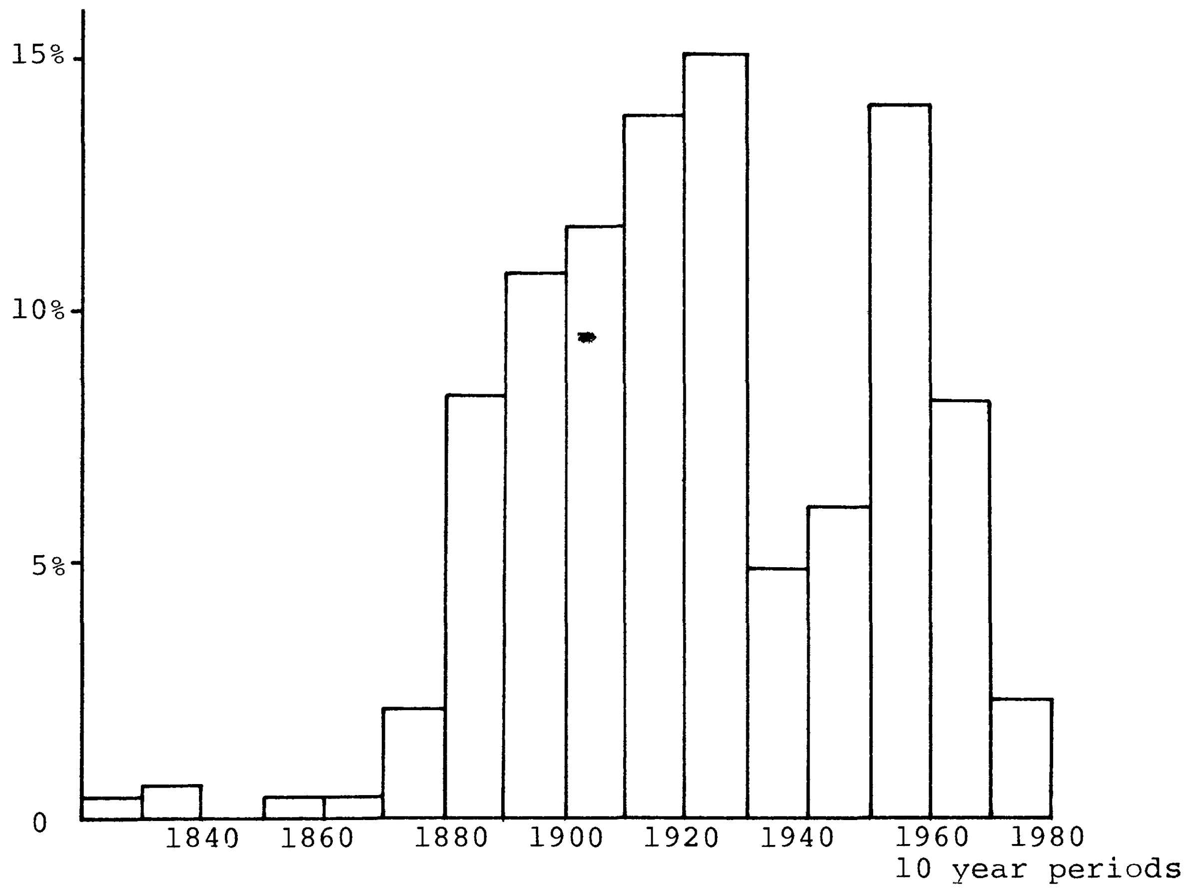

Fig. 3 Histogram of Construction Intensity

A new hospital building was also examined. It is a precast concrete structure, with precast concrete columns, beams and floors and roof, with interior partitions of sheetrock on metal studs. The precast materials were of a high quality. A potential for trouble was observed in the sparsity of shear walls. In the bottom story, for example, the shear walls between the exterior columns were all capped with windows the full width. Structurally, they are partial height shear walls. Though the design may satisfy the seismic code requirements, there seems to be a potential for damage that might have been lessened by using full height shear walls in some of the bays.

A Multi-Purpose Crustal Strain Observatory at the Dalton Tunnel Complex, San Gabriel Mountains

Contract No. 14-08-0001-19753

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This project involves the installation, calibration and maintenance of short baseline tiltmeters in the Dalton Geophysical Observatory, located in the San Gabriel Mountains, Glendora, California. The major purpose of these tiltmeters is to detect possible tectonic tilts associated with deformation of a major block of basement rock adjacent to the San Andreas fault.

Previous surface and near surface short baseline tiltmeters have suffered from noise and drift. The Dalton Tunnel is particularly well suited for detecting contemporary tectonic movement in the bedrock west of the San Andreas and for the testing of new ideas and techniques relative to geophysical instruments.

Two types of gravity-sensing electrolytic (spirit level) tilt transducers are being operated, investigated and improved. One is the biaxial bubble level detector from the Kinemetrics TM-1 tiltmeter but with improved signal conditioning electronics. The other is a single axis spirit level detector manufactured by the Fredericks Company, Part No. 7614. The units are bench tested to determine their transfer functions and then operated side by side on the same pier in the Dalton Tunnel using identical electrical and mechanical systems to make a comparison of their sensitivity, noise and drift.

Tests of the electronic systems involved placed the long term drift at less than 10^{-9} rad/day and put an upper limit on the rms noise of the equivalent of 10^{-9} rad. Drift of the pier and mechanical systems which was 5×10^{-6} rad/day in January of 1981, is now of the order of 10^{-7} rad/day. It is too early to tell however if this represents continuing curing of the pier which was poured in the summer of 1980, stabilization of the mechanical system, intrinsic drift in the sensors, or true tectonic tilt. Redundant data from several instruments will hopefully answer this important question in the next year. Semi-diurnal tidal signals at the level of 10^{-7} radian are recorded with a good signal to noise ratio.

Creep and Strain Studies in Southern California

Contract No. 14-08-0001-19269

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Investigations

This semi-annual report summary covers the six-month period from 1 April 1981 to 30 September 1981. The contract's purpose is to maintain and monitor creepmeters and alignment arrays across active faults in the southern California region . Primary emphasis focuses on faults in the Coachella and Imperial Valleys.

Results

Imperial Valley. -- Continuously recording creepmeters at HARRIS ROAD, ROSS ROAD, HEBER ROAD and TUTTLE RANCH were each serviced twice during the six-month reporting period, and no significant creep episodes were noted. Similarly, resurveys of alignment arrays at HIGHWAY 80 (2 times), WORTHINGTON ROAD, and SUPERSTITION HILLS, as well as 2 resurveys each of nail-file arrays at ROSS ROAD, ANDERHOLT ROAD, and WORTHINGTON ROAD, revealed no large movements, although minor creep may be continuity. The dial-gauge-reading creepmeter at SUPERSTITION HILLS was observed twice and it, too, revealed no movement during the reporting period. It is somewhat unusual to have a period of as long as six months in the Imperial Valley when no sudden displacements are observed.

Coachella Valley. -- Keller and others (1978) suggested that creep was taking place along the San Andreas fault in the Coachella Valley area, on the basis of repeated surveys of our alignment arrays there. Because these data were debatable, and because many resurveys have been made since 1978, graduate-student Steven Cohn has re-examined all of the data from alignment arrays at INDIO HILLS, DILLON ROAD, RED CANYON, and BERTRAM, as well as the creepmeter data from NORTH SHORE. Data from RED CANYON and INDIO HILLS are shown in Figure 1. It is now apparent that Keller's preliminary conclusion was correct, and that episodic creep is indeed taking place along this segment of the San Andreas fault at an average rate of 2-3 mm/yr as measured over a 10- to 12-year time span. This is in sharp contrast to continuing evidence for the absence of creep along segments of the fault farther northwest. Small abrupt displacement, or accelerated creep, has been observed along the San Andreas fault opposite the Salton Sea in association with both the 1968 Borrego Mountain earthquake and the 1979 Imperial Valley earthquake. It is possible that all of the right-lateral "creep" observed in our alignment arrays in the Coachella Valley area has taken place in discrete episodes, but, if so, the episodes have not been correlated in time between the various localities. It is particularly significant that episodic creep at a significant rate is taking place along a segment of the fault that otherwise is recognized as a distinct seismic gap.

During the reporting period, the alignment array at INDIO HILLS was resurveyed once. The NORTH SHORE creepmeter was serviced twice, and no changes were observed. The new continuously recording creepmeter at MECCA BEACH went into operation on 7 April 1981 and has as yet shown no significant movement. It has been our plan to telemeter this signal directly to Pasadena, but we have been hung-up on a disagreement between the BLM and California State Park System as to whose land the telephone line will cross -- despite earlier assurances that all was in order. As of this writing, it appears the situation has finally been resolved and that telemetry will commence shortly.

Other Areas. -- The alignment array across the San Jacinto fault at ANZA was resurveyed twice during the reporting period, and the monuments appear remarkably stable; this is in contrast to earlier suggestions of continuing creep. Alignment arrays across the San Andreas fault farther northwest and across the Garlock fault are normally resurveyed once a year, and no resurveys were made during this reporting period.

Publications

Cohn, S. N., Allen, C. R., Gilman, R., and Goulty, N. R., in press, Creep on the Imperial and Brawley faults preceding and following the 1979 Imperial Valley earthquake: U. S. Geol. Survey Prof. Paper.

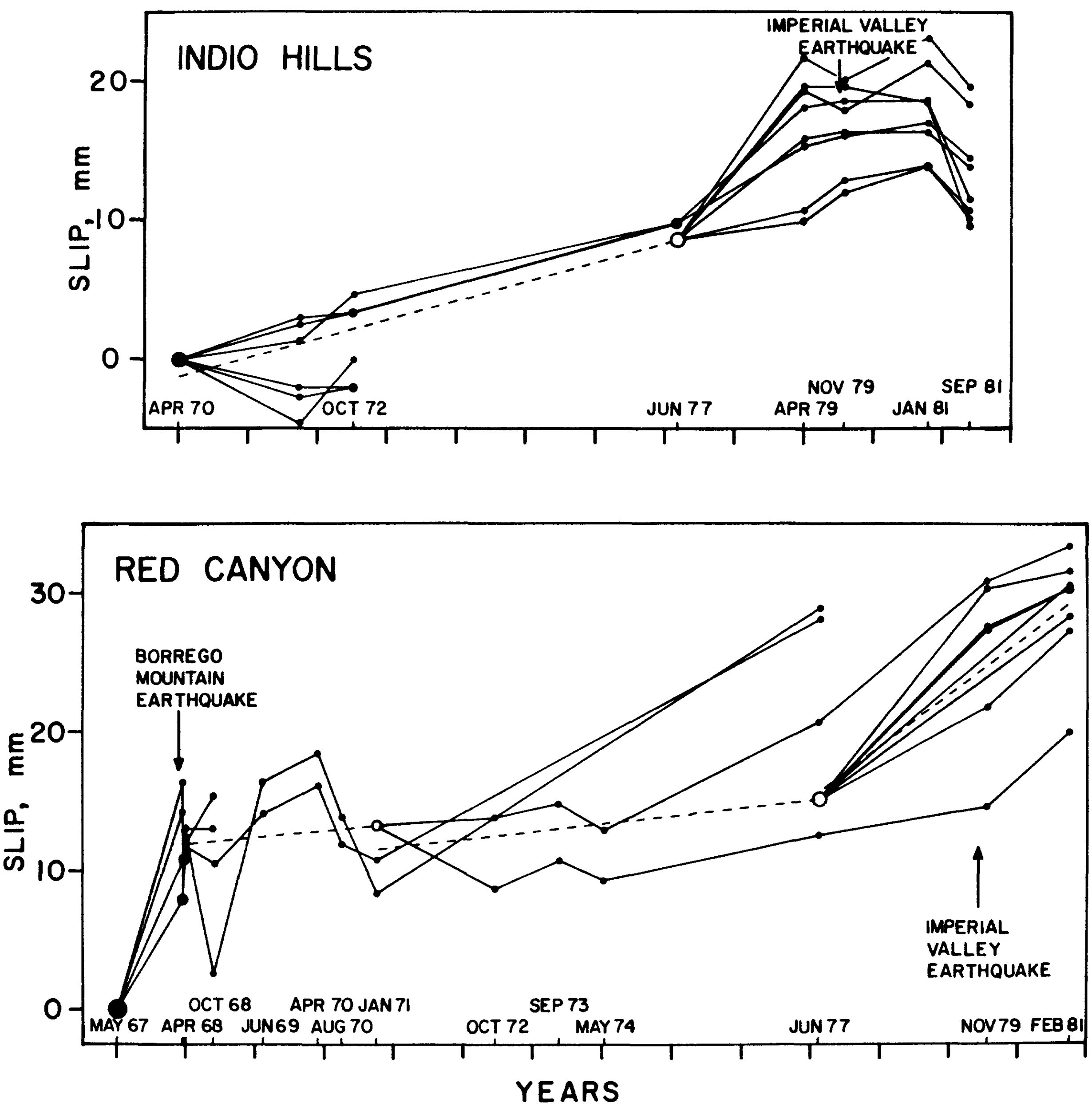

Fig. 1.--Results of resurveys of alignment arrays across San Andreas fault at INDIO HILLS (6 km N Indio) and RED CANYON (21 km SE Indio). Positive slip is right-lateral. Filled circles represent individual measurements between pairs of stations on opposite sides of the fault, usually within 300 m. Open circles represent assumed new values, based on averages of earlier readings, following loss of monuments and/or establishment of new monuments. Apparent left-lateral displacement from latest measurement at INDIO HILLS could result from disturbance of the base monument. Creep rate along the segment of the fault, based on these and two additional alignment arrays, is 2-3 mm/yr averaged over a 10- to 12-year period.

Red River Fault Study, Yunnan Province, China

Contract No. 14-08-0001-19271

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Investigations

This study is being carried out under the Protocol between the State Seismological Bureau of the People's Republic of China and the National Science Foundation and the U. S. Geological Survey of USA for scientific and technical cooperation in earthquake studies. The principal Chinese investigators include Zhang Buchun of the State Seismological Bureau and Han Yuan and Zhu Chengnan of the Bureau of Seismology of Yunnan Province. Reported herein is progress between 1 April 1981 and 30 September 1981.

Results

The principal investigators spent six weeks in China in February and March of 1981, and preliminary results of field work along the Red River fault were summarized in the previous semi-annual report. Since that time, and as anticipated in the original proposal, our effort has been devoted entirely to completing a manuscript for publication. That manuscript, "Quaternary activity of the Red River fault, Yunnan Province, China," is currently about 75% complete, including maps and illustrations. After modification by our Chinese co-authors, it will be submitted for publication in China, and perhaps elsewhere as well.

On-Line Seismic Processing

9970-02940

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Investigations and Results

During the reporting period we have again worked at improvements on the existing (Real Time) picker without major changes in the system hardware. Jim Ellis identified failure modes which explained most of the system problems, and was able to remedy these problems with minor field changes in wiring and replacement of IC's. As a result, our estimated mean time between failures (MTBF) for soft failures of the Menlo Park RTP has increased from 2-3 weeks to something over two months. This estimate is hazy because there have been no failures since the changes were made.

The RTP's measure of coda length of an observed events was changed to conform to the "hand-pick" standard of 1 cm amplitude on 16 mm film image, and the measured magnitudes are now in satisfactory agreement with Calnet hand picks up to a magnitude of about 3.5. We are continuing work on other magnitude rating schemes, but this will allow us to use RTP data in the usual way in Calnet analysis.

As of early October about 1/3 of all Calnet phase cards processed are from the RTP. This proportion will increase as more of the Calnet stations go on the RTP and as we gain more experience in using the output.

The RTP software has been modified to provide a daily report on observed status of the seismic net as seen by the system. This report is generated each morning during the quiet time at 5:00 a.m. and includes for each station the observed values of discriminator offset and average background seismic noise. The reports have proved to be of considerable value to the technicians maintaining the seismic telemetry system, since these critical parameters can be checked at a glance and maintenance activity planned accordingly.

The 120-station RTP for the University of Washington has been delivered and is operating satisfactorily.

Seismic Source Mechanism Studies in the Anza - Coyote Canyon Seismic Gap

14-08-0001-18397

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The complete design of the Anza digitally telemetered seismic network has been finalized. The design calls for up to 16 three component stations each sampling each channel at 250 times per second with a 16 bit resolution. The data from these 16 remote stations are telemetered via a 215 MHz FSK modulated carrier to a mutually visable mountain peak. Here, all 48 channels are multiplexed into a single bit stream that is transmitted some 110 km to our laboratory via a 1.6 GHz microwave link with a repeater atop Mt. Soledad in La Jolla.

Prototypes of the remote and relay stations were delivered and tested, and orders were placed for a complete 10 station three component network. Some initial delays were encountered in obtaining both VHF and microwave frequency assignments but eventually channels in the government bands were obtained. Delays were also encountered in installing the microwave link but finally, on October 15, communication was established between Toro Peak and our La Jolla lab. Currently, one prototype station is operating on Mt. Soledad in a test mode.

Meanwhile, the Telemetry Interface Unit (TIU), developed by Systems, Science and Software and based on a 6809 microprocessor, was debugged, tested and interfaced to the PDP 11/34 that will serve as the detection and recording machine. The software detection and record system was written by Larry Baker (USGS, Menlo Park) during the summer, and tested and debugged during several sessions at La Jolla during the summer and fall.

Current status is that all hardware is on order with delivery scheduled before the end of the year. Exact station locations have been chosen, site noise surveys conducted, and initial site preparation is planned for December.

Fault Slip Measurements

9960-02943

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Investigations and Activities.

Alinement-array surveys. A network of 11 alinement arrays distributed along 45 km of the San Andreas fault trace in the Parkfield-Cholame area was resurveyed during May, 1981. Prior to 1978, the network consisted of only 4 sites along the fault section between Slack Canyon and Water Tank (near Cholame), but 7 new sites were added along this section during the period 1978-80. The expanded alinement-array network has been resurveyed about three times per year since late 1978 to augment information concerning the southeastward decrease in average slip rates in the Parkfield region documented during the previous 10 years of monitoring. The specific purpose of increasing the density of sites and the frequency of repeat surveys is to examine apparent step-like southeastward decreases in slip rate and their possible relations to broad asperities evident in the geometry of the active trace and the associated nucleation zones of minor to moderate earthquakes.

Rainfall and fault creep. The effects of rainfall on fault creep activity in central California are currently being investigated through analysis of 3 data sets: 1) continuous records from creepmeters for the period 1969-1980, 2) results from repeated alinement-array surveys obtained since 1967, and 3) rainfall records from a number of weather-monitoring stations in the study region. The purpose of these investigations is to develop simple criteria for recognizing and evaluating the effects of the normal yearly wet and dry seasons as well as longer, generally 2-to 3-year periods of drought and/or above-average rainfall. Recognition and removal of surficial rainfall effects from the fault creep data as well as evaluation of potential tectonic effects, if any, of short and long-term variations in amounts of rainfall are essential steps leading toward more meaningful interpretations concerning the tectonic significance of both short and long-term fluctuations in rates of fault slip sensed at the surface.

Earthquake hazards conference. Plans for a conference on earthquake hazards in the eastern San Francisco Bay Area to be held during March 24-27 at California State University, Hayward, have undergone considerable development during the past several months. The conference theme of "engineering, geologic, and tectonic problems of the Hayward, Calaveras, and related fault zones in the East Bay Area" is to be treated by considertion of 7 distinct topical categories ranging from geologic and tectonic settings of the active faults, through levels of historic and contemporary activity and analysis of present-day risks, to the roles of various local, state, and federal agencies concerning responses to potential earthquake hazards and related questions concerning determination of land-use policy in high-risk environments. The conference is sponsored by U.S.G.S., California State University at Hayward, California Division of Mines and Geology, East Bay Council on Surveying and Mapping, and the San Francisco Section of the Association of Engineering Geologists.

Results

Parkfield alinement surveys. The 45-km section of the San Andreas fault between Slack Canyon and Cholame contains 3 distinct changes in fault strike. The alinement-array survey results show that step-like southeastward decreases in slip rate associated with these asperities contribute significantly to the previously recognized regional slip-rate decline from the Slack Canyon site (28 km northwest of Parkfield) toward Cholame and the Carrizo Plain segment. Activity at all monitoring sites within a few kilometers to the southeast of each asperity is dominated by occurrences of large episodes of creep, in contrast to the nearly steady-state activity noted at most of the other sites. The changes in modes and rates of aseismic slip in relation to changes in fault strike provide strong evidence that deep-seated effects of fault geometry at the asperities exert a significant level of control over the characteristics of slip along the fault trace. Careful examination and analysis of the surface slip records thus may yield clues concerning the nature of temporal variations of slip deeper on the fault within and near the nucleation zones of minor to moderate earthquakes.

Effects of rainfall on creep. Several noticable effects of the variations in rainfall on fault creep activity have been documented, and these range from immediate instrumental or surficial soil responses associated with individual rain storms, through apparent triggering of creep events caused by storms, to possible long-term influences on average slip rates. Despite large variations in total annual rainfall from year to year, however, a few of the creepmeter records show that there is a consistent relation between total annual creep and the amount of annual creep occurring as events, implying that creep-event occurrences at these sites are controlled by conditions other than wetting or drying determined by temporal distribution of rainfall. Nevertheless, alinement-array records, in particular, indicate that long-term changes in slip rate may be related to the amount of rainfall received in the region in the immediately preceding few years.

Earthquake hazards conference. Response to the conference announcements has been encouraging. The potential number of participants currently stands at about 300, and about 70 presentations well distributed across the range of proposed topics have been offered. Over half of the proposed contributions deal with subjects concerning contemporary tectonic activity, analysis of specific earthquake hazards, or problems of engineering, planning, and development along active faults. A proceedings volume for the conference will be published during the summer of 1982 as a Special Report of the California Division of Mines and Geology.

Reports

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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, in press.

Burford, R. O., R. D. Nason, and P. W. Harsh, Results of fault-creep studies in central California, U. S. Geol. Surv. Earthquake Info. Bull., in press.

Evans, K. F., R. O. Burford, and G. C. P. King, Propagating episodic creep and the aseismic slip behavior of the Calaveras fault north of Hollister, California, Journ. Geophys. Res., vol. 86, pp. 3721-3735 (1981).

Central California Network Processing

9930-01160

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Investigations

Signals from 300 stations of the multipurpose Central California SEismic Network are telemetered continuously to the central laboratory facility in Menlo Park where they are recorded, reduced, and analyzed to determine the origin times, magnitudes, and hypocenters of the earthquakes that occur in or near the network. Data on these events are presented in the forms of lists, computer tape and mass data files, maps, and cross sections to summarize the seismic history of the region and to provide the basic data for further research in seismicity, earthquake hazards, and earthquake mechanics and prediction. A magnetic tape library of "dubbed" unprocessed records of the network for significant local earthquakes and teleseism in prepared to facilitate further detailed studies of crust and upper mantle structure and physical properties, and of the mechanics of earthquake sources.

Results

1. Summary catalogs of earthquakes located by the network from 1969 through December 1977 have been published. Preliminary results for January 1978 through June 1980 are accessible in various forms, and work on completing and publishing the summary catalogs for these years has high priority. Results for July through December 1980 are being finalized.

2. Routine analysis of the network data has been transferred from the MULTICS system to the PDP 11/70 computer under the UNIX system. Processing procedures have been revised to include the merging of P-phase data provided by the real-time picker system developed by Rex Allen and Jim Ellis. The addition of these data has substantially decreased the amount of time required to process earthquakes to catalog quality. On a daily processing basis emphasis is placed on completing, to catalog quality, each day's earthquakes. This approach to the processing was initiated in May 1981 and has been reasonably successful.

3. A detailed study of the locations and first-motion patterns of the November 8, 1980, Eureka, Calif., earthquake and its aftershocks

indicates that they were generated by a process that is systematically disrupting the southeast corner of the Gorda plate. The main shock and most aftershocks occurred on a large left-lateral strike-slip fault that strikes about N 50° E across the southeast corner of the Gorda plate. The northeast third of the 140-km-long 1980 break passes between the Eel and Klamath submarine plateaus and ends at the continental shelf. Near the southwest end of the 1980 break, aftershock-epicenter alinements and first-motion patterns suggest that the end of the main break is connected to the Mendocino Fracture Zone by short northwest-trending (conjugate) right-lateral strike-slip faults. Prominent ridges on the sea floor in that area correspond approximately in position and trend to the faults suggested by the aftershocks.

The northwest edge of the principal zone of aftershocks is sharply defined, but the southeast edge is not. Locally, the alinement of epicenters extending southeastward from the principal zone suggest movement on additional conjugate right-lateral faults between the main break and the Mendocino Fracture Zone.

4. Events from the May-June 1980 Mammoth Lakes, California earthquake sequence were used as sources for a seismic-refraction study of the upper-crustal structure of the Sierra Nevada and its western foothills. The earthquakes used in this study were located by using U.S. Geological Survey and local permanent University of Nevada, Reno, stations. A total of 14 earthquakes were measured, with depths ranging from 1.0 to 11 km. For the refraction study, portable smoked-drum seismographs were deployed over a distance of 140 km at 10 sites along a line extending west-southwest of the Mammoth Lakes events, roughly perpendicular to the axis of the Sierra Nevada. In addition, a portable magnetic-tape seismograph was set up at Edison Lake, approximately midway between the earthquakes and the closest smoked-drum recorder. A modeling of this unreversed refraction data indicates an apparent P-wave velocity of 5.45 $\pm$ .15 km/s for the first 50 km. Within a range of 50 to 100 km the apparent velocity is 6.13 $\pm$ .15 km/s. The westernmost three stations which lie in the Great Valley, indicate an apparent velocity of 5.6 $\pm$ .1 km/s. If the first two apparent velocities are assumed to be the true velocities, the two layers are separated by a boundary at 11 km. The final, lower apparent velocity may be modeled by either a 5° (lower boundary) wedge of sediment with a velocity of 3 km/s or a 3.5° wedge with a velocity of 2.5 km/s that thickens to the west over a shallow structure otherwise similar to that inferred under the Sierra. The results of this study are most consistent with models by Eaton (1966) and Bateman and Eaton (1967).

5. On May 19, 1981 (1644 UTC), an earthquake of coda magnitude 2.8 occurred in northern California approximately 59 km west of Red Bluff (130 km east of Cape Mendocino). No foreshocks or aftershocks were recorded. A well-constrained hypocentral solution places it at a

depth of 55 km. This is the deepest reported earthquake in California and one of the three deepest events in the contiguous United States. The hypocenter was calculated with the HYPO 71 program from clear short-period P- and S- wave arrivals at 59 stations, of which 4 stations were within one focal depth; 2 of these 4 station records showed clear S-wave arrivals. The HYPO 71 standard errors of horizontal epicentral location and focal depth are 0.7 and 1.3 km, respectively; the root-mean-square traveltime residual is 0.3 s. Three facts heavily support the 55-km focal depth: (1) the apparent P-wave velocity is approximately 10 km/s (much greater than typical crustal or upper-mantle velocities) out to an epicentral distance of 100 km; (2) S-P times at stations out to 60-km distance range in duration from 7 to 10 s; and (3) contraining the focal depth to be shallow (i.e., 5 to 15 km) results in the closest stations having P-wave residuals as long as 3 s. A P-wave focal-plane solution indicates NNE-SSW horizontal compression; the nodal planes strike N. 68° E. and N. 30° W., and dip 70° SE. and 70° NE., respectively. The faulting is predominately strike-slip (right lateral on the northwest-striking plane) with a minor reverse component. Two regional tectonic implications of this earthquake are that: (1) the thermal structure at depth in this region allows brittle failure, and (2) the dip angle of the subducting Gorda plate must be greater than the 10° inferred from gravity data.

Reports

Cockerham, R. S., A well recorded 55-km deep earthquake in western north-central California (abs.): American Geophysical Union, Fall Meeting, 1981.

Eaton, J. P., Detailed study of the November 8, 1980, Eureka, Calif., earthquake and its aftershocks (abs.): American Geophysical Union, Fall Meeting, 1981.

Mavko, B. B., A refraction line through the Sierra Nevada using the 1980 Mammoth Lakes earthquakes: submitted to the Bulletin Seismological Society of America, 1981.

Use of a Transportable VLBI Electronics System to Monitor the Rotation of the Earth and Transcontinental and Intercontinental Strain Accumulation

14-08-0001-18388

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The transportable very-long-baseline interferometer (VLBI) electronics system that we constructed under a previous contract with the USGS has been used in four sessions of observations: November 1979, July 1980, September 1980 and October 1980. The observations obtained from these sessions have been analyzed to estimate distances from radio telescopes in the U.S. to the two European radio telescopes at which the transportable terminal was located (Effelsberg, F.R. Germany and Chilbolton, England). The observations in September and October 1980 were made as part of the international "MERIT" program (Measurement of Earth Rotation and Intercomparison of Techniques). The data from the October 1980 session were also analyzed to yield estimates of the solid earth tide parameters h and ℓ and the tidal lag angle. During the July 1980 session, we took special observations to determine the precision of our corrections for the propagation delay in the ionosphere.

Seismic Studies of Fault Mechanics

9930-02103

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Investigations

The analysis of seismicity in central and southern California continues to be the primary focus of our work. The earthquake history of California is being examined to determine if there are regional-scale variations in seismicity associated with major earthquakes. Contemporary microseismicity studies are now underway to seek further our understanding of fault interactions through the detailed examination of earthquake sequences. The knowledge gained from these and other studies should improve our ability to assess the results of the real-time earthquake monitoring system that is now in routine use.

Results

1. Simple recurrence calculations based on measured displacement in 1906 and long-term loading rates allow us to speculate that sufficient time has elapsed since 1906 for a M 6 - 6.5 earthquake to occur on the San Andreas fault north of San Juan Bautista. Detailed studies show that the San Juan Bautista and Parkfield regions, transition zones between the creeping segment of the San Andreas fault and adjoining locked segments, share a characteristic seismicity pattern that may outline likely sites of future large earthquakes. The Parkfield region has produced four M 5.5 - 6 earthquakes this century, while the San Juan Bautista region produced three or four M 6 - 7 events in the nineteenth century, and none in this century. At both San Juan Bautista and Parkfield, shallow diffuse microseismicity is associated with creeping segments of the fault, while deeper clusters of earthquakes charcterize the transition to locked segments. At Parkfield, M 6 events nucleate at the junction between shallow and deep activity. We suggest that a large earthquake northwest of San Juan Bautista will conform to this pattern, initiating near Pajaro Gap and rupturing into the locked zone. Although speculative, this long-term forecast of a M 6+ event serves to focus our attention on careful monitoring of this region in the coming years. Real-time loction of microearthquakes is one such activity that has already been in practice for the past nine months.

2. Daily monitoring of seismicity with the Allen/Ellis Real-Time Picker (RTP) has been in routine operation for the past six months. Phase arrival time data transferred from the RTP to the UNIX 11/70 computer are used to produce a daily log of earthquakes in central and northern California. Earthquakes that locate in selected study zones (including San Juan Bautista) are further reprocessed with specialized crustal velocity models. The resulting high-precision relocations are examined on a daily basis for changes in the background activity pattern.

3. The earthquake catalog for 1977 is now virtually complete. Open-file reports for the first three quarters of the year have been published, and the fourth quarter report will be released in early FY82.

4. Study of the aftershocks of the 1979 Coyote Lake earthquake continues. Aftershock hypocenters define two narrow, vertical planar zones that are offset by an _en echelon_ right step near their facing tips. Mechanisms of earthquakes in each zone suggest simple dextral slip on a planar surface. Mechanisms in the diffuse zone of activity within the _en echelon_ step are rotated 30 degrees clockwise, on average, from the two main zones. The orientation of these mechanisms agree well with the predictions of the theoretical models of interesting shear cracks of P. Segall and D. Pollard. The details of the temporal development of the aftershock zone suggest that the dimension of the mainshock rupture was less than half the length of the ultimate aftershock zone. Seismicity observed in the 10-year period prior to the event defines a dense cluster of activity immediately adjacent to the mainshock hypocenter. This limited source zone appears to have been obliterated by the mainshock.

Reports

Marks, S. M., and Fluty, L., 1981, Catalog of earthquakes along the San Andreas fault system in central California, July-September 1977: U.S. Geological Survey Open-File Report 81-462, 43 p.

Ellsworth, W. L., Lindh, A. G., Prescott, W. H., and Herd, D. G., 1981, The 1906 San Francisco earthquake and the seismic cycle, _in_ Simpson, D. W., and Richards, P. G., eds., Earthquake prediction - an international review: American Geophysical Union Maurice Ewing Series 4, p. 126-140.

Ellsworth, W. L., Lindh, A. G., and Moths, B. L., 1981, Evidence for a cyclic pattern associated with great earthquakes in California, _in_ Joint Meeting of the U.S.-Japan Panel on Earthquake Prediction Technology, 2nd, Menlo Park, 1981, Proceedings, 7 p.

Garm Source Mechanism Studies

9930-02100

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Investigations

This project terminated at the end of September 1981.

USGS participation in this joint US-USSR program was limited to the evaluation of data previously collected in Garm.

Equipment for the continued maintenance of the Garm telemetered seismic network was delivered to Garm. Other tools for network maintenance and data reduction were refined for use back in the US and in China.

Results

The paper describing initial USGS spectral studies in Garm continues to undergo extensive revision. No temporal variations in spectral parameters which might have been useful as earthquake predictors have yet been found.

Recent side effects of the Garm work, however, have been more fruitful: A very low-power portable frequency counter for audio frequencies is now in use in California. A revised BASIC version of the HYPOINVERSE earthquake location program is now in use in China as well as the USSR. Also, and 80 KHz narrow band LF receiver to monitor radio background noise was obtained to supplement our 62 KHz receiver. Based on a Russian study, these receivers may show an increase in radio noise minutes before local earthquakes of magnitude 5 or larger.

Reports

There were no reports this period.

Theodolite Measurements of Creep Rates on San Francisco Bay Region Faults

Contract No. 14-08-0001-19767

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

We presently have theodolite measurement sites at 19 localities on faults in the Bay region. Most of the distances between our fixed points on opposite sides of the faults range from 75-215 meters; consequently, we can monitor a much wider slip zone than can be done using standard creepmeters. The precision of our measurement method is such that we can detect with confidence any movement more than a millimeter or two between successive measurement days. We measure most of our sites about once every two months.

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

Hayward fault - We began monitoring the Hayward fault in September 1979 and we presently have five measurement sites. I believe I have detected a pattern in the changing rates of creep along the Hayward fault based on U.S.G.S. creepmeter data and our theodolite results. Creepmeter data indicate the Hayward fault was creeping at the rate of only a few millimeters per year in 1976 and 1977. Slip behavior apparently changed beginning in 1978. A pulse of about one-half centimeter of relatively rapid right lateral slip began in Fremont in mid-1978 and progressed northwestward along the fault, arriving in the City of Hayward in late 1978. Similarly, another half-centimeter pulse occurred during the later half of 1979, again starting in Fremont and arriving several months later in Hayward. A third pulse of about five to eight millimeters of movement occurred in Fremont in early 1980 and progressed northwestward to the City of Hayward by late 1980-early 1981. Since the passage of this third pulse of rapid creep, the Hayward fault has not moved very much, only a few millimeters or less in Fremont and Union City in the past year (since the summer of 1980). We intend to continue monitoring the Hayward fault to see if any more pulses of movement occur and progress from southeast to northwest along the fault.

Concord fault - We began monitoring the Concord fault at our two measurement sites in September 1979. The Concord fault slipped about a centimeter in a right lateral sense during October and November 1979, probably the first significant movement on this fault in the past two decades. Virtually no additional slip has occurred in the last one and one-half years.

Antioch fault - We presently have two sites on the Antioch fault where we began our measurements in January 1980. About a centimeter or more of right lateral slip occurred on the Antioch fault from May through October 1980, probably the first significant movement on this fault since 1965. Virtually no additional slip has occurred since.

Seal Cove fault - After several months of apparent left lateral slip of a few millimeters, the Seal Cove fault has slipped about a centimeter in a right lateral sense since February 1980.

San Andreas fault - Our site on the San Andreas fault in South San Francisco shows about two millimeters of right lateral slip in the past year. Additional measurements will show whether the fault is indeed creeping very slowly or whether the results are a normal variation to be expected within the precision limits of our measurement method.

Calaveras fault - We began monitoring the Calaveras fault at two sites in the Hollister area in September and October 1979. Virtually no slip occurred in late 1979; however, about one-half centimeter of right lateral slip occurred during the first two months in 1980. One of the sites shows no additional slip in 1980, whereas the other shows more than a centimeter. We established an additional site in November 1980 in San Ramon that has shown virtually no movement during the first half year of measurements.

West Napa fault and Rodgers Creek fault - We began monitoring these two faults in the northern San Francisco Bay region in the summer of 1980. Both sites show a few millimeters of left lateral slip. Continued measurements on these faults will determine whether this left lateral movement predominates or whether it is a seasonal effect.

Relationships Regarding Recent Movements on East Bay Faults - The increased rate of movement on the Hayward fault in the San Francisco Bay region in 1978 and 1979 may have initiated certain slip events on other East Bay faults. Following the first two pulses of relatively rapid slip on the Hayward fault for a total of about a centimeter of right lateral movement, the Concord fault slipped about a centimeter in a right lateral sense. Following this rapid slip in late 1979, moderate earthquakes with accompanying right lateral surface displacement on the Greenville fault occurred in late January 1980. Following these events, the Antioch fault slipped about a centimeter or more in a right lateral sense in mid-1980.

In summary, this sequence of events began on the Hayward fault and systematically progressed in a landward direction to the Concord, Greenville, and Antioch faults. The movements described are probably the most significant ones to have occurred on any of these faults for at least the past decade. This hypothesis regarding movement relationships will continue to be tested.

Central California Network Operations

9970-01891

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Investigations

Maintenance and recording of 405 seismometers, 30 tiltmeters, 16 magnetometers, 8 strainmeters, 43 creepmeters, and 17 radio receiver sites located in northern California and in Oregon, totaling 454 data-gathering field sites. The area covered is approximately 101,000 square miles.

Results

1. The Stanwick Corporation, under contract 14-08-0001-1945, is responsible for the maintenance of seismic, tiltmeter, magnetometer, creepmeter, and strainmeter data; inside maintenance of low frequency digital equipment; installation of new seismic stations and final testing of J402 VCO/AMP units.

2. More than 95 percent of the J302 VCO units have been converted to lithium batteries to increase the length of time between battery changes. Radio sites are being converted to solar power where possible.

3. The Stanwick team consisting of ten members has far exceeded the maintenance goals set by the reference contract (95 percent operational).

4. Eleven new seismic stations were installed:
   - 1 site in the Melones/Merced area.
   - 1 site in the Lake Isabella area.
   - 1 site in the Lassen area.
   - 2 sites in the Hollister area.
   - 2 sites in the San Juan Bautista area.
   - 4 sites in the Williams area.

5. One Develocorder was reconditioned and installed to record data from the Shasta/Lassen area.

Central American Seismic Studies

9930-01163

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Investigations

1. Seismograph records from stations near Four Volcanoes in Central America were examined in order to describe the characteristics of volcanic seismicity and to identify the origins of this seismicity.

2. Historians were contracted to search for and collect first-hand detailed accounts of earthquake damage and volcanic eruption damage. The search is continuing at the Colonial Archives for Central America located in Guatemala City; and has been completed in Chiapas, Mexico, (once part of Guatemala) and at the Archives of the Indies located in Seville, Spain. About one-third of the accounts has been translated at this time. The goal of this work is to estimate locations and magnitudes of historical earthquakes in Central America in order to determine recurrence intervals, identify active faults, and determine seismic risk.

Results

1. There are three main sources of seismic activity at Central American volcanoes. These include regional earthquakes with hypocentral distances greater than 80 km, earthquakes within a few tens of kms from each volcano, and seismic activity originating at the volcanoes due to eruptive processes. Regional events are the major source of seismicity and are generated on the Central American Subduction Zone. Nearby earthquakes occur on shallow tectonic faults around each volcano. The signatures of seismic events at the volcanoes vary greatly and are closely related to magma movement and eruptive activity.

2. Preliminary results indicate that useful isoseismal maps can be constructed from archival data for many large earthquakes. These data are composed of primary accounts such as sworn notarized testimony in church reconstruction petitions and tax relief petitions to the king of Spain, death records, and mayorial records.

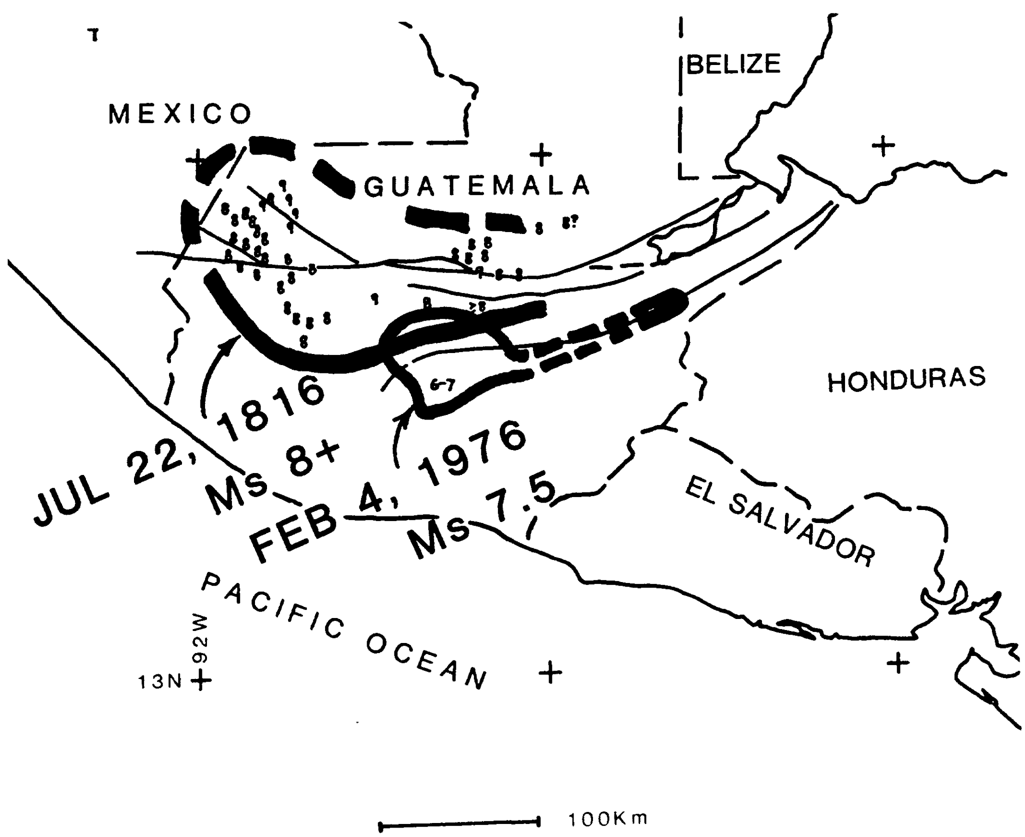
One of the most interesting "finds" was an earthquake not previously mentioned in any of the historical literature. On July 22, 1816 an earthquake occurred on the Chixoy-Polochic Fault Zone near Huehuetenango. This left-lateral strike-slip fault can be traced for several hundreds of kilometers across central Guatemala but no large historical earthquakes have previously been reported on it. The figure, shown below, shows preliminary minimum MM intensities and the intensity VIII contour. For comparison, we show the intensity VIII contour for the Feb. 4, 1976 Guatemala earthquake, Ms = 7.5, which occurred on the Motagua fault. The area within the intensity VIII contour is about ten times greater for 1816 and indicates a surface wave magnitude Ms = 8 to 8 1/4.

Another interesting result is that there have not been any other large earthquakes on either the Chixoy-Polochic or Motagua Faults since at least 1700 and probably since 1600.

Reports Received

Rubio Sanchez, Manuel, 1981, Collected post-colonial earthquakes and eruptions in Guatemala.

Cristol, Susan, 1981, Collected colonial earthquakes in Chiapas, Mexico.



Southern California Repeat Gravity Studies
9730-03074

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Investigations

Parts of the southern California high-precision gravity network, established during the fall of 1976, were remeasured during May 1981. This survey constitutes the eighth partial reoccupation during the past 4.6 years. As in previous surveys, 12 stations of the secondary reference station network were remeasured. This network extends from Amboy and Cottonwood Pass on the east (~115.5°W) to Tejon Pass on the west (~119°W) and from Riverside on the south (~34°N) to Barstow and Mojave on the north (~35°N). In addition, stations in the vicinity of Lucerne Valley and Homestead Valley were remeasured.

Results

1. Results from the May 1981 survey in the vicinity of Lucerne Valley and Homestead Valley indicate that the temporal gravity anomaly described in the previous technical report is continuing to evolve. In this area, gravity decreased systematically between the fall of 1976 and May 1980 with the maximum change (-60 μGal with respect to assumed invariance at Riverside) at Homestead Valley. Gravity at nearby stations decreased by 20-40 μGal during the same period. Surveys during November 1980 and February 1981 showed that the temporal gravity anomaly reversed sign sometime between May 1980 and November 1980. The most recent survey indicates that the gravity in this area again decreased during the three months following the February 1981 survey but in general did not reach the levels attained in May 1980.

2. Analysis of long-term trends of gravity change at stations of the secondary reference network suggest that the gravity field over most of the network has been stable with respect to that at Riverside during the 4.6 year interval covered by the measurements. Linear regression analyses were performed on temporal gravity data from 13 stations scattered over the Mojave Desert and Transverse Ranges. The largest gravity change (+68 μGal between the fall of 1976 and February 1981) occurred at a station 3 km south of Whitewater. This gravity change most likely was caused by ground-water recharge in the adjacent alluvial-filled basin where water-level measurements indicate that the water table elevation increased by approximately 30 m during the period of gravity observations. For the other stations the analyses yielded rates of change of less than 2 μGal/yr at seven stations, between 2 and 3 μGal/yr at three stations, and greater than 3 μGal/yr at two stations. The only station that showed a rate of change significantly different from zero at the 95 percent confidence level (+4.1 μGal/yr) is located in the mountains just south of Palmdale.

Assuming a Bouguer relationship of $-2\ \mu Gal/cm$ between gravity change and elevation change, these results suggest an upper limit of 10 cm (with respect to Riverside) on broad-scale changes of elevation in the Mojave Desert and Transverse Ranges during the past 4.6 years.

Interpretation of Data

8-0001-17687

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Southern California Leveling

We have continued to analyze leveling data for southern California. We still find evidence for height-related systematic errors on the leveling profiles Los Angeles-Saugus, Saugus-Palmdale, and Saugus-Lebec. Except for the uplift caused by the 1971 San Fernando earthquake, we do not see evidence for tectonic motions in the leveling data.

Our theoretical model includes both tectonic motions and systematic errors. Comparing two surveys, we have

$$\frac{\Delta^2 h_i}{\sigma_i} = \frac{\alpha_j \Delta h_i}{\sigma_i} + \frac{\beta_\kappa \Delta \chi_i}{\sigma_i} + \frac{e_i}{\sigma_i}$$

where i is a distance index, Δh_i is the height difference between successive benchmarks, $\Delta \chi_i$ is the horizontal distance between them, e_i is an unknown random error, σ_i is the estimated standard deviation of this error, and $\Delta^2 h_i$ is the difference between the later and earlier measured values of Δh_i. Then, α_j is an unknown value representing a systematic error proportional to height; such errors could result from rod miscalibration or from atmospheric refraction. The index j signifies a profile in which rod usage did not change in either the earlier or later survey. Similarly, β_κ is an unknown value representing average tilt, presumably of tectonic origin, and κ is an index signifying a region in which tectonic tilt could be assumed constant.

We used estimates of σ_i of the form $\sigma_i^2 = a^2 + b\Delta\chi_i + c\Delta\chi_i^2$, and determined the coefficients χ and β by linear regression. The estimated values of χ and β depend only slightly on the choices for a, b, and c. The values a = 1.2 mm, b = 1.4 mm /km, and c = 0 were consistent with the data from Saugus-Lebec. For graphical simplicity, we plot tilt $(\Delta^2 h_i/\Delta\chi_i)$ and slope $(\Delta h_i/\Delta\chi_i)$.

Data for the profile Burbank-Saugus-Palmdale are shown in Figure 1. Clear correlations between tilt and slope are obvious for each of three surveys (1955, 1961, and 1964) when compared to 1965. Note the reversal in sign of this correlation between 30 km and 40 km in the 1965-1964 data. This change suggests that rod miscalibration is to blame for the major part of the correlation, because a rod change occurred at 36 km in the 1964 survey. The large random tilts between Burbank and the Santa Suzana thrust are probably caused by benchmark instability.

Absolute values of the tilt/slope ratio α exceed 100 ppm in every case, and are significant at the 95% confidence limit in every case. The regional tilt β is not significant at the 95% confidence limit for any case.

Publications

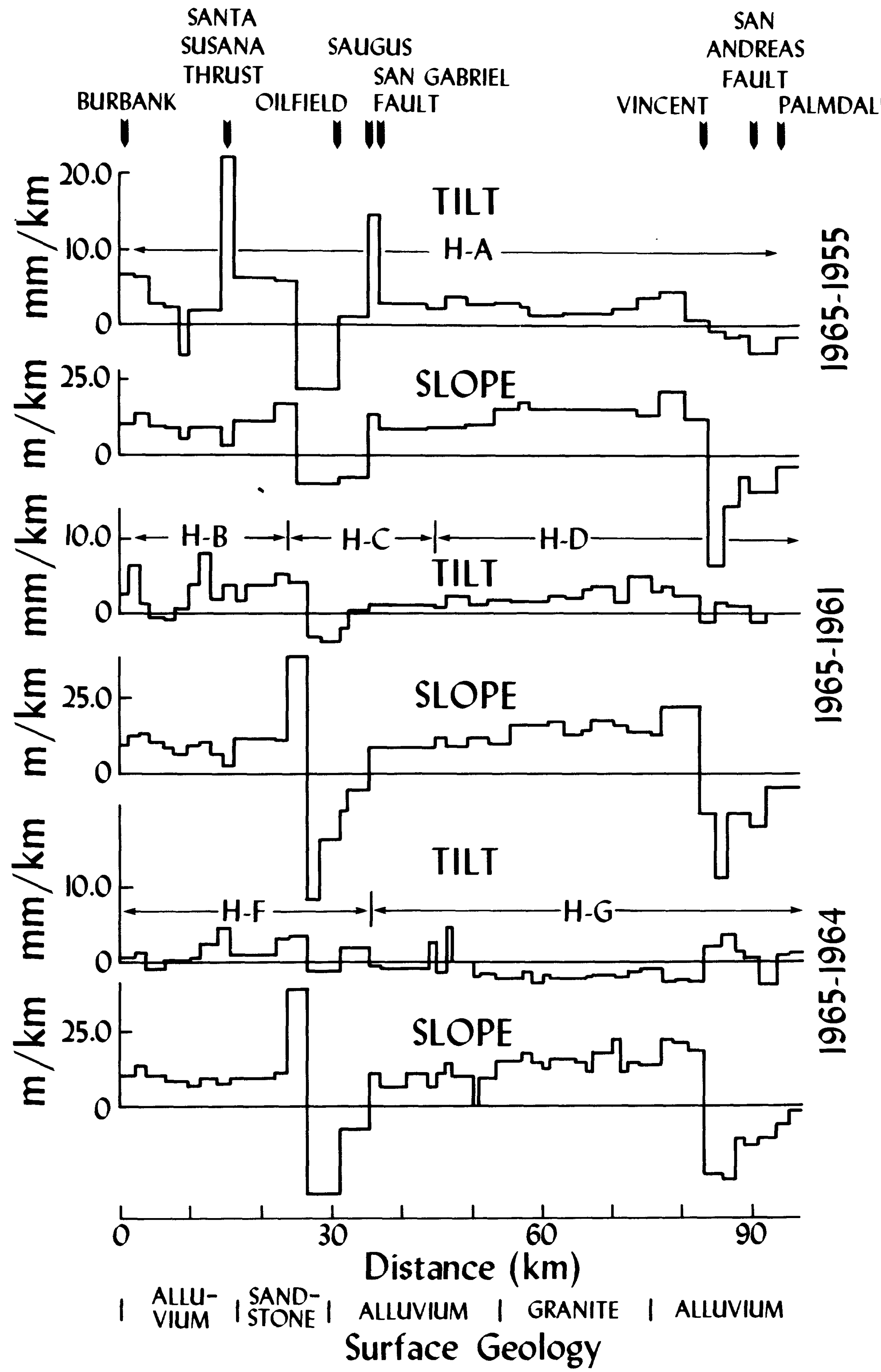
Jackson, D.D., Lee, W.B., and Liu, C.C., Aseismic Uplift in Southern California: An Alternate Interpretation. Science, 210, 534-536, 1980.

Papers submitted

Davis, P.M., Jackson, D.D., Searls, C.A., and McPherron, R.L., Detection of Tectonomagnetic Events Using Multichannel Predictive Filtering. Submitted to Journal of Geophysical Research.

Jackson, D.D., Lee, W.B., and Liu, C.C., Height Dependent Errors in Southern California Leveling in Earthquake Prediction: Proc. Fourth Annual Ewing Conference on Geophysics, 1981.

Ergas, R.A., and Jackson, D.D., Spatial Variations of Crustal Seismic Velocities in Southern California. Submitted to Bulletin Seismological Society of America.


SANTA SUSANA THRUST
SAUGUS
SAN GABRIEL FAULT
BURBANK
OILFIELD
SAN ANDREAS FAULT
VINCENT
PALMDALE
mm/km
m/km
20.0
10.0
0
25.0
TILT
SLOPE
H-A
H-B
H-C
H-D
H-F
H-G
1965-1955
1965-1961
1965-1964
0
30
60
90
Distance (km)
ALLU- VIUM
SAND- STONE
ALLUVIUM
GRANITE
ALLUVIUM
Surface Geology

Interpretation of Data

8-0001-19246

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Southern California Leveling Data

We have analyzed data for the profile Saugus-Lebec to estimate regional tilting and height dependent systematic errors. Height dependent systematic errors are statistically significant, but regional tilting is not. Apparent tilt from 1964 to 1965 and slope are shown as functions of distance N of Los Angeles in Figure 1; rod usage is shown in the boxes. For the shaded region the benchmarks are on crystalline rock, and subsidence from fluid extraction is not expected. The apparent tilt is strongly correlated with slope, suggesting that the data are subject to height dependent systematic errors. Such errors include rod calibration errors and atmospheric refraction errors. The rod change at 90 km in 1964 coincides with a reversal of the tilt/slope ratio, suggesting that rod calibration errors dominate in this region. Furthermore, atmospheric refraction is expected to be small on this profile because the steep slope forces short sight lengths. The large random tilts from 0-40 km mask any tilt/slope correlation in this region. The random tilts are probably caused by benchmark instability. A detailed analysis of these data are contained in Jackson _et al._ (1981).

Magnetic Data Analysis

High precision geomagnetic measurement depends on eliminating variations of ionospheric and magnetospheric origin. Taking differences between total field magnetometers is only partially successful. We use multi-channel Wiener filters to predict the total field difference between two sites from the total fields at other sites, and the field components at one site. Filter lengths and number and choice of input channels are determined using statistical methods. The resulting filters, defined on short noise free record sections, are found to be effective over the remainder of the record. The two components orthogonal to the total field direction are essential, but the other component is redundant with the total field. Thus, the field aligned component may be omitted from a vector station, simplifying the instrumentation considerably. For the UCLA array, the standard deviation of the residuals (0.1 nT for hourly averages) is eight times that expected from digitization noise alone. It appears that measurement noise is about three times the digitization interval (0.25 nT) and that higher precision measurements are required for further improvement. This has been confirmed by tests on the instruments at close spacing. We applied the method to data from Central California and Hawaii and found tectonomagnetic effects that are otherwise hidden in noise. Wiener filters are especially suitable for real time analysis, an important factor in earthquake prediction.

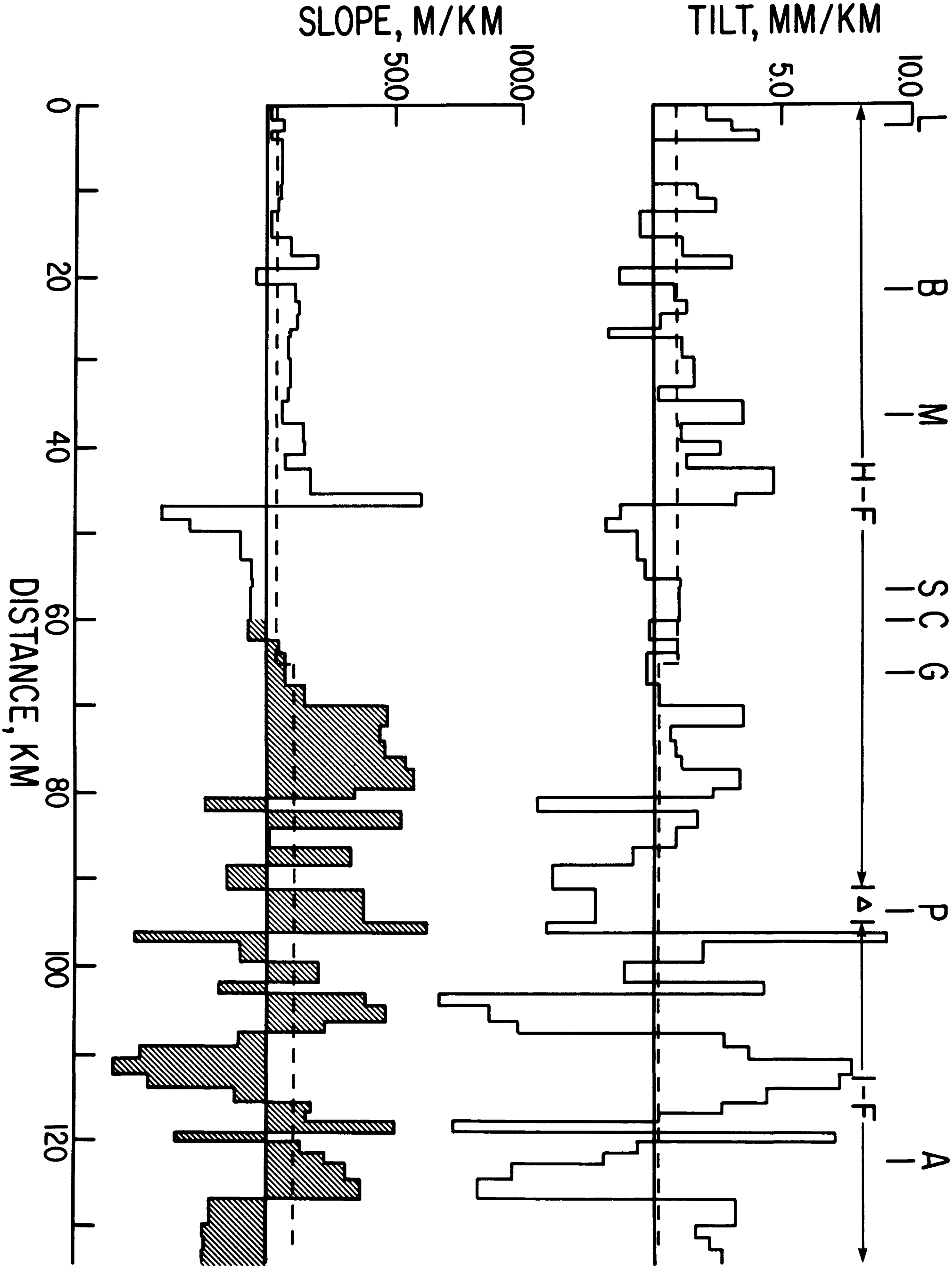
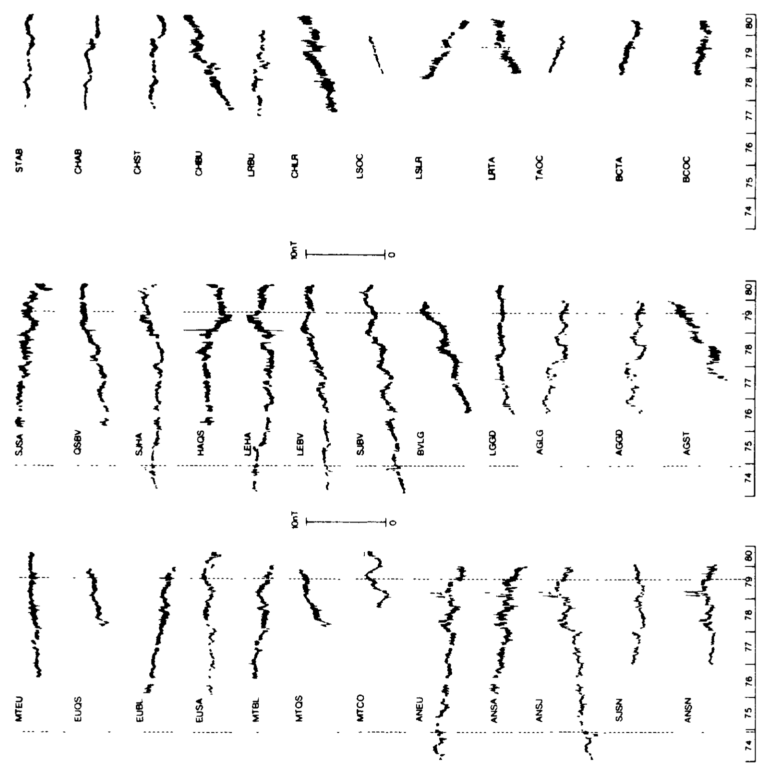
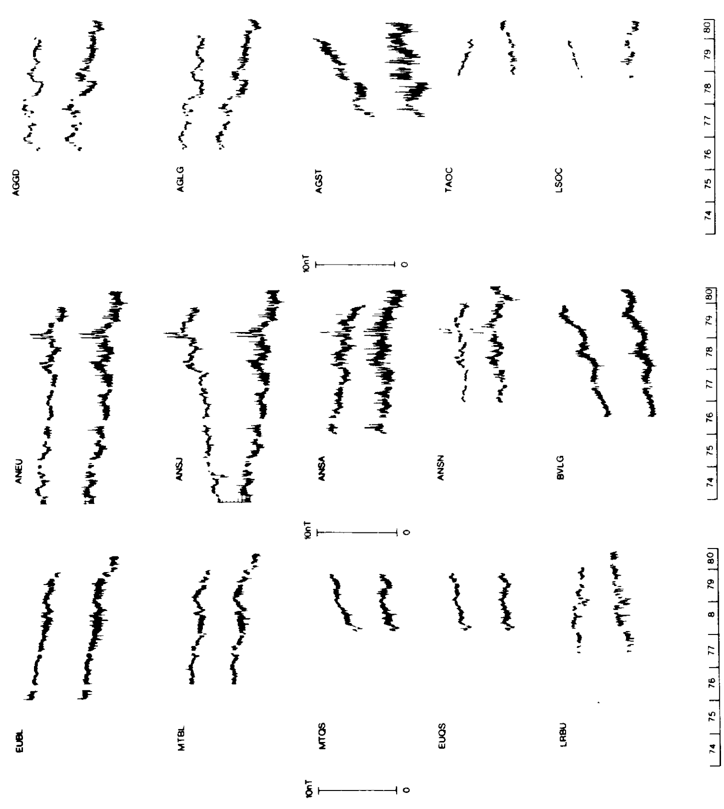

SLOPE, M/KM
TILT, MM/KM
50.0
100.0
5.0
10.0
0
20
40
60
80
100
120
DISTANCE, KM
L
B
M
H-F
S
C
G
P
A
I-F

FIGURE 1



STAB
CHAB
CHST
CHBU
LRBU
CHLR
LSOC
LSLR
LRTA
TAOC
BCTA
BCOC
SJSA
QSBV
SJHA
HAQS
LEHA
LEBV
SJBV
BVLG
LGGD
AGLG
AGGD
AGST
MTEU
EUQS
EUBL
EUSA
MTBL
MTQS
MTCO
ANEU
ANSA
ANSJ
SJSN
ANSN
10nT
0

FIG. 3



AGGD
AGLG
AGST
TAOC
LSOC
ANEU
ANSJ
ANSA
ANSN
BVLG
EUBL
MTBL
MTQS
EUQS
LRBU
10nT
0

FIG. 2

Crustal Deformation Observatory, Part A

14-08-0001-18364

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Vertical control benchmarks have been installed and surveyed four times by Art Sylvester of University of California, Santa Barbara. We tested for elevation dependent systematic errors; there is no evidence of such errors, but the test is not conclusive because of the lack of significant topography. We estimated regional tilts using the equation,

$$\Delta h_2 - \Delta h_1 = T_x \Delta x + T_y \Delta y + e$$

where Δh_1 is the height different between two benchmarks on an early survey, ΔH_2 is the same quantity on a later survey, T_x and T_y are east and north tilt, Δx and Δy are differences in the east and north coordinates of two benchmarks, and e is a random error. With over 30 benchmarks, there is a large degree of redundancy. Results for the first four surveys are as follows:

Survey date	East tilt, μ rad	North tilt, μ rad	RMS residual, μm
13 Oct 79	-	-	-
26 Jan 80	-1.7 ± 2.1	0.6 ± 2.3	326
28 Jul 80	-1.2 ± 3.1	-1.2 ± 3.5	498
28 Aug 80	-0.8 ± 3.0	1.5 ± 3.3	469

From this we conclude that the precision of the technique is about ±3 microradians tilt between surveys, and that no tilts greater than this have taken place.

A study of the residuals indicate that benchmark instability is the dominant source of error. For this reason, some benchmarks are being established in 30 m boreholes.

We have studied some possible causes of error in electromagnetic distance measurements. Curvature of the line of sight due to atmospheric refraction is not a factor for lines under 50 km; the effect goes as the square of the line length, and is greatest when κ, the gradient of the index of refraction, is perpendicular to the line of sight. The relative error is less than 10^{-8} for a 36 km line with typical atmospheric structure.

We analyzed some test data collected with an HP 3808 electronic distance meter by Al Lindh of U.S.G.S. Apparent distance and endpoint temperatures, pressures, and humidities were recorded for several days over a 10 km line. We made a standard correction for the index of refraction of air, then examined the data for residual atmospheric effects using linear regression. The regression reduced the rms residual from 4 mm (for the standard correction) to about 2.5 mm. Residuals appear to be uncorrelated in time. The standard error of the mean is only 0.4 mm, corresponding to a relative error of 4×10^{-7}.

Crustal Deformation Observatory, Part A

14-08-0001-19254

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Tilt Measurements at Pinon Flat, California

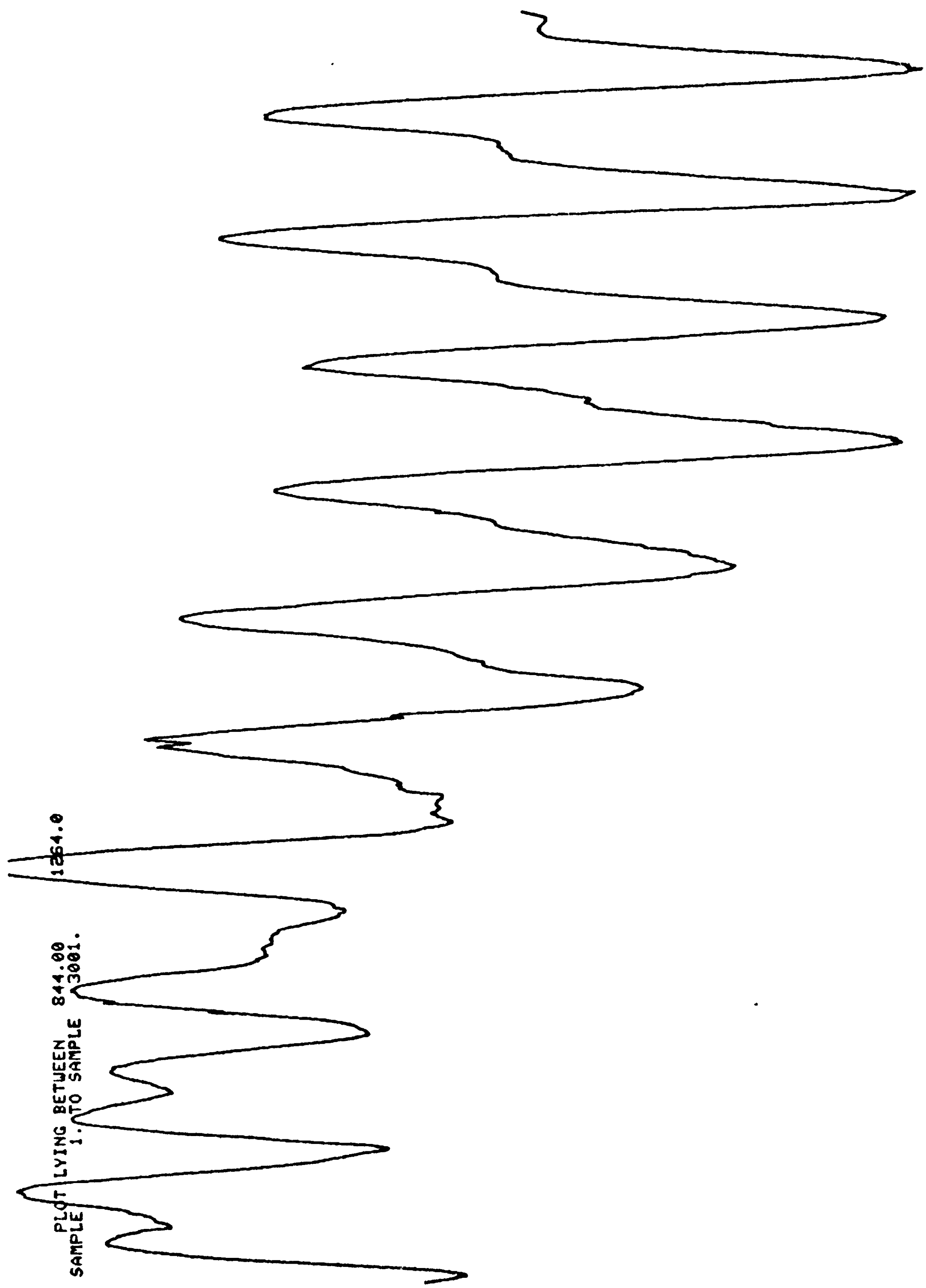
Three different 532 m fluid tiltmeters (operated by the University of California--San Diego, Lamont Doherty and Cambridge University) have been installed and operating intermittently since 15 June 1981. Ten days of data for the UCSD and Cambridge instruments are shown in the figures. Omission of data from the Lamont tiltmeter is not intentional. I could not find the figures at press time. Analysis of the data is just beginning.

A two-component borehole tiltmeter operated by the Air Force Geophysics Laboratory has been operating since March 1981. Tilts from this instrument over a 43-day period show clean tidal signals. Amplitudes of the daily and semidiurnal tides are within a factor of two of the theoretical values; phases are within 15° of theoretical.

The Pinon Flat leveling line has been expanded to 60 benchmarks. The original 30 benchmark portion has been surveyed six times since 13 October 1979. The extended portion has been surveyed twice.

Accuracy of EDM Measurements

We carried out a field study to examine the sources of error in electronic distance measurement techniques. We surveyed a 3 km line near Pearblossom approximately 100 times during four consecutive nights (00:00 - 06:00, April 1-4, 1981) with an HP 3808. Temperatures were measured at 7 m and 17 m above ground level at each endpoint. First order environmental corrections were made using averages of the endpoint temperatures. Higher order corrections were then estimated by linear regression of first order residuals on the temperature observations. We observed a nighttime inversion layer that caused the endpoint temperatures to underestimate the average temperature on the path. The observed temperature gradient was significantly correlated with the first order residuals. After regression, the standard error of the estimated line length was 4.5 mm, or about 1.2 ppm.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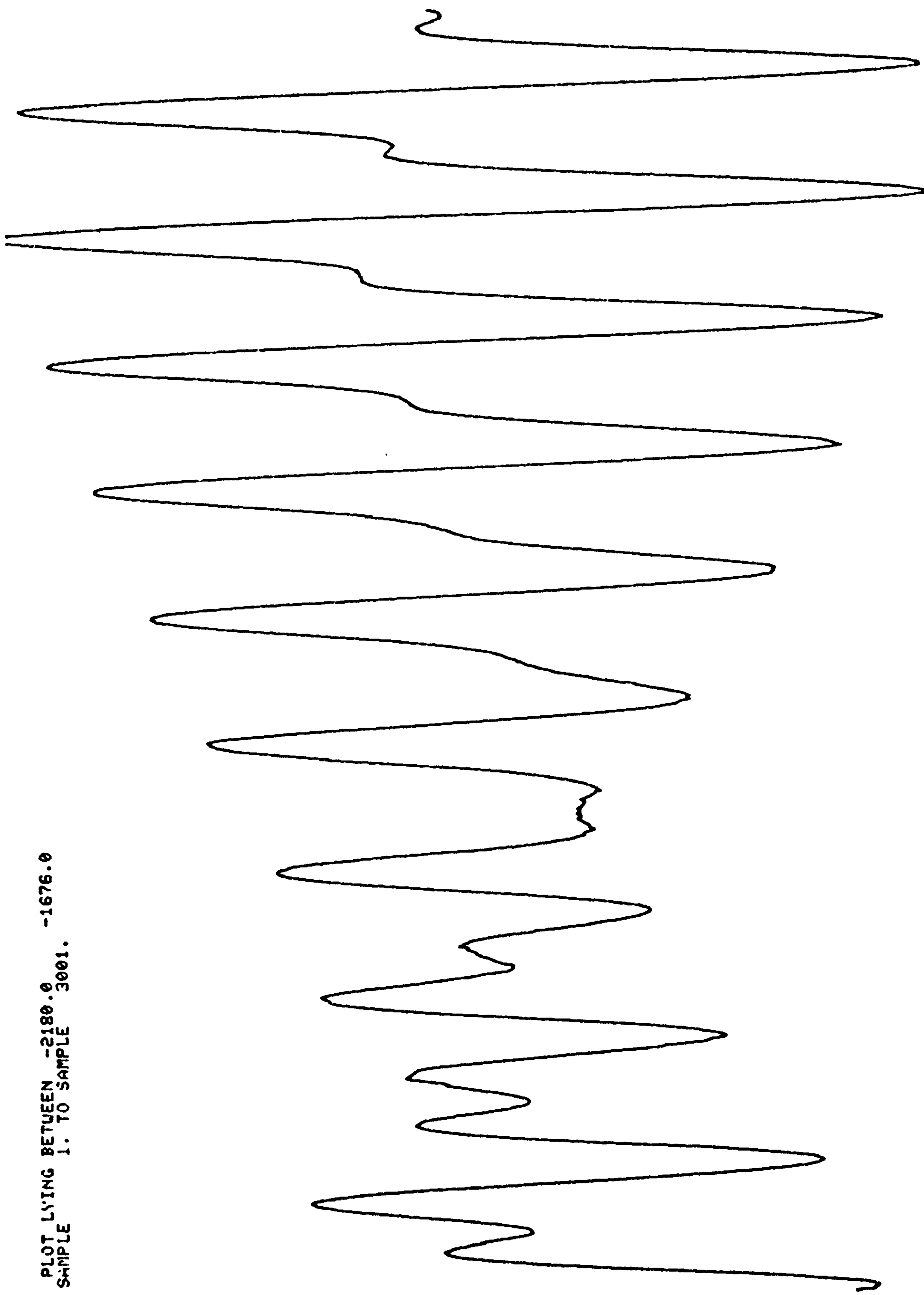
SAMPLE 1. TO SAMPLE 3001.


PLOT LYING BETWEEN -2180.0 -1676.0
SAMPLE 1. TO SAMPLE 3001.

INSTRUMENT DEVELOPMENT AND QUALITY CONTROL

9970-01726

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Investigations

This project supports other projects in Office of Earthquake Studies by designing and developing new instrumentation and by evaluating and improving existing equipment. During this period some personnel from this project were assigned to the GEOS project (9940-03009) and the Central California Seismicity project (9930-02392).

Results

One of the largest undertakings during this period was moving much of the equipment in Calnet Playback Center to a new location. This was the first part of an extensive reorganization of the playback and computer centers necessitated by the installation of several new computers. Planning and preparation for electrical power and data signal rerouting and equipment placement has been completed. A Tustin 512-channel A/D converter has been interfaced to the Calnet PDP-11/34 event digitizer and will soon replace the original 128 channel system.

The 100 recording instruments and the playback equipment of the Seismic Cassette Recorder system have been maintained in operation during several field programs this season. Production of radio-controlled triggers for these recorders is nearing completion.

Eighty new discriminators have been tuned, calibrated and installed. Alignment and repair of 125 radio transmitters and receivers was completed as well as calibration of approximately 100 seismometers. Construction of 150 new seismic VCO/preamp field units has been completed.

Southern California Cooperative Seismic Network

9930-01174

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Investigations

1. Routine processing using stations of the southern California cooperative seismic network were continued for the period April through September 1981. Routine analysis includes the timing of phases, event location and preliminary catalog production using the newly developed CUSP analysis system. Events with magnitudes exceeding 5.0 have continued in abundance with three (26 April, M_L = 5.7, Westmoreland; 4 September, M_L = 5.2, offshore near Catalina Island; 30 September, M_L = 5.7 Mammoth Lakes) occurring during the reporting interval. The increase in moderate seismicity still is not reflected in a concommitant increase in background rate. For a detailed discussion of the results of this investigation refer to C. R. Allen, Southern California seismic arrays, 14-08-0001-16719.

2. We are proceeding with the development of a southern California earthquake prediction data base. Geophysical data (e.g., seismicity, strain, tilts, radon, water levels) are collected from a variety of researchers in southern California. These data are cataloged and included in a computer data base. Plots of these data are made on a common time scale and copies are made available to other workers. Progress in this program is presently at nearly a standstill due to an irremediable decrease in staffing.

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

4. Two field teams were dispatched to establish in situ monitoring of the 26 April event near Westmoreland in the Imperial Valley. A five-station local network, run from 6 hours after the mainshock, was replaced 4 days later by a network of six FM field recorders. Close coverage was maintained for two weeks.

Results

1. The CUSP (Caltech-USGS Seismic Processing) system has been implemented on a PDP 11/70 minicomputer under the RSX-11M operating system with all source code written in FORTRAN. This approach provided a substantial improvement in throughput, analysis features, system integrity, and simplicity of overall design as compared to the UNIX-based, "C"-coded system developed during FY80 under this project and presently in routine use at Menlo Park, the University of Washington, and St. Louis. Running in southern California, the CUSP system, with a 5-person staff, provides a production rate of 80-120 events per day, substantially exceeding the background seismicity of roughly 35 detections per day. This system has been operational during the past six months and permitted the timing and analysis of more than 10,000 local events that occurred in southern California during that interval. The detection rate of nearly 20,000 events annually is marginally within the throughput capabilities of the present system, although further enhancements in efficiency and integrity checking are an abiding concern.

2. Preliminary investigations of the 26 April 1981 sequence near Westmoreland has provided some surprising insights into the complexities of Imperial Valley sequences. The aftershocks (Fig. 1) manifested a remarkable, progressive development with time both north along the Brawley seismic zone, as well as along a northeast-trending lineation that appears to be the fault trend associated with left-lateral motion during the main event. A vigorous foreshock sequence consisting of hundreds of small events near the mainshock focus occurred sporadically during the week preceding.

3. A set of FORTRAN subroutines for the plotting of seismicity patterns as stereo pairs was developed and tested. The routines which are being distributed as an open-file report should greatly facilitate the analysis of complex sequences.

4. Analysis of the tidal stress tensor at the time of moderate-to-large earthquakes fails to confirm the earlier hypothesis of Heaton (1975) that shallow dip-slip earthquakes occur near times of maximum tidal shear stress. In our latest study, we computed the tidal shear stress for 68 shallow dip-slip earthquakes,and no obvious correlation with earthquake occurrence was found. In addition, the time history of tidal shear stress has been computed for 135 deep and 19 shallow strike-slip earthquakes. No obvious correlations could be seen in these data sets. Combining the results of the earlier study and this study, we conclude that no obvious correlations between either shear stress or normal-to-the-fault compressive stress are seen for a total earthquake sample of 330 moderate-to-large earthquakes.

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*Heaton, T. H., 1975, Tidal triggering of earthquakes: Geophysical Journal of the Royal Astronomical Society, v. 43, p. 307-326.

Reports

Given, D. G., 1981, Seismicity of the San Jacinto fault zone, in Unruh, M. E., and Ruff, R. W., eds., Geology of the San Jacinto Mountains; South Coast Geological Society Field Trip Guidebook, October 10-11, 1981.

Heaton, T. H., 1981, The 1971 San Fernando earthquake: A double event?: Seismological Society of America Bulletin (in press).

Heaton, T. H., 1981, Tidal triggering of earthquakes (abs.): EOS, American Geophysical Union Transactions, v. 62 (in press).

Hutton, L. K., and Johnson, C. E., 1981, Preliminary study of the Westmoreland, California earthquake swarm (abs.): EOS, American Geophysical Union Transactions, v. 62 (in press).

Johnson, C. E., and Hutton, L. K., 1981, Imperial Valley seismicity and the San Andreas fault (abs.): EOS, American Geophysical Union Transactions, v. 62 (in press).

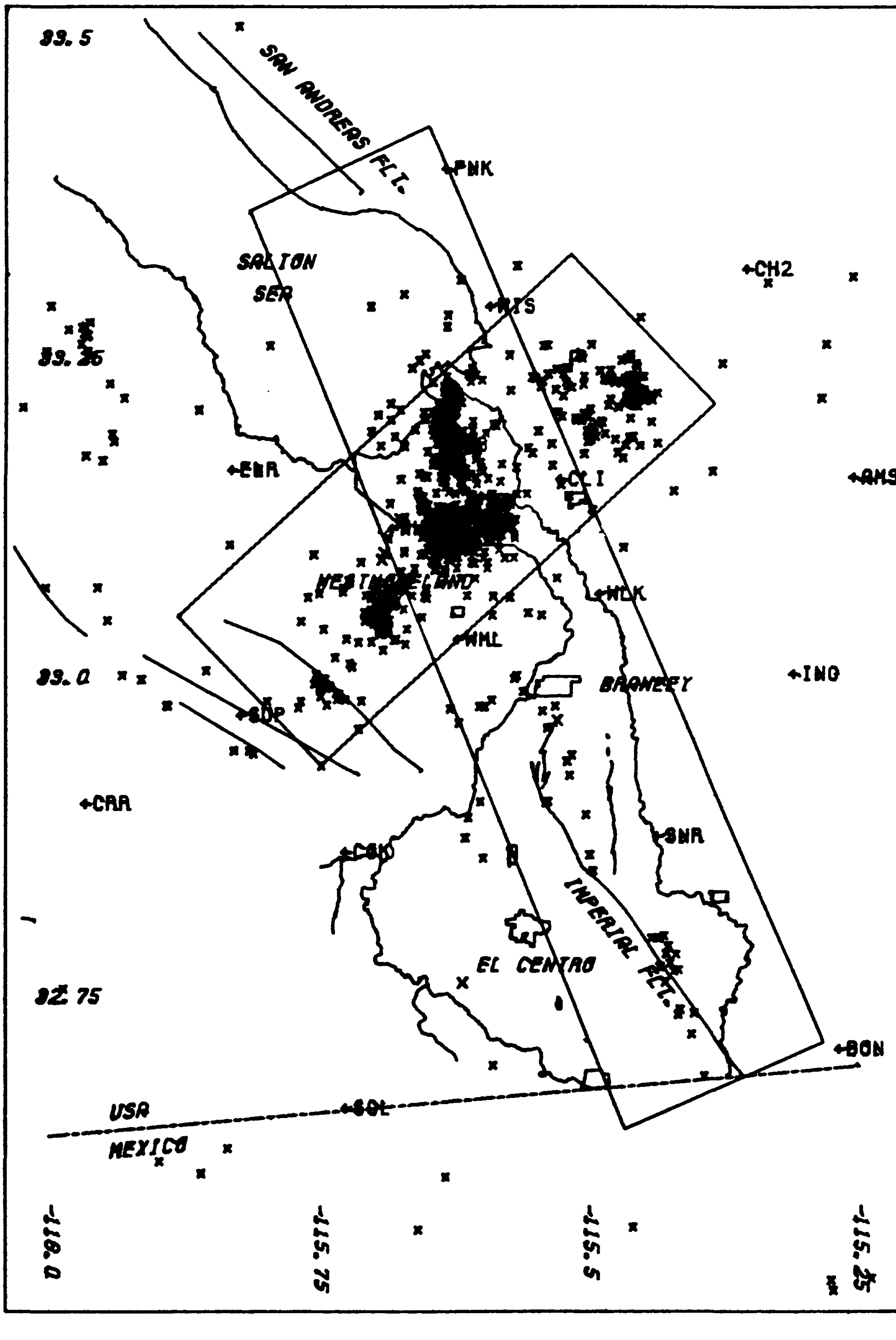
33.5
SAN ANDREAS FLT.
PNK
SALTON SEA
CH2
RIS
33.25
ENR
CLI
AMS
WESTMORELAND
WLK
WML
33.0
BRAWLEY
IMO
SUP
CRR
SNR
CSI
INPERIAL FLT.
EL CENTRO
32.75
BON
USA
SOL
MEXICO
-116.0
-115.75
-115.5
-115.25

Figure 1

Adequate and Timely Data Processing

9930-02392

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Investigations

Computer data processing is essential in modern seismological research; digital seismic data can be analyzed in no other way, and problems of earthquakes and seismic wave propagation usually require numerical solution. On the other hand, the interface between computers and people usually makes data processing unnecessarily difficult. The purpose of this project is to develop and operate a simple, powerful, well human-engineered computer data processing system and to write general application programs to meet the needs of scientists in the earthquake prediction program.

Results

The PDP 11-70 UNIX system has reached a state of stability and has operated smoothly for the last several months, performing a large amount of computing for program projects. Some current statistics:

164	registered users
1,733	directories
36,962	files
490,099	1024-byte disk storage blocks used
120	logins per weekday
42	different users per weekday

Recent events of particular importance include:

Hardware. An Able DMAX terminal multiplexor has been installed, adding 12 new terminal ports. This gives us a total of 48 ports, 36 of which are of the efficient direct-memory-access (DMA) type.

UNIX Operating System. We are now running a version of UNIX that is similar to the most recent release (2.8BSD) of the Computer Science Department at the University of California at Berkeley. It is much faster and more robust than the standard Bell Labs version, and has performed well for several months. One noteworthy feature of this system is its support of memory overlays, which increase the virtual address space of programs written in any language, including FORTRAN. A device driver has been written for the LPA11 laboratory data acquisition controller. This direct-memory-access device can, in real time, obtain digital data from external analog devices such as data lines and tape playback units. We are now turning on a new system feature that monitors the disk usage by different projects and enforces quotas.

Manuals. Because many software changes have occurred since the manuals were issued, they are being extensively revised. Volumes 1 and 2 will be reprinted in full, and corrections and updates will be issued for volumes 3 through 8.

Software. The earthquake location program HYPO71 has been optimized. It is now about 35 percent faster. In addition, driver files have been written that enable the make command to control the running of an earthquake location program. Make can automatically keep track of which of many input files have been modified since they were processed, and greatly simplifies the routine processing of large numbers of earthquakes. Geoplot has been modified and extended, and can now operate the Calcomp plotter through the RSXNET program (see below). In addition, several new software packages have been obtained and installed:

— A package of programs for digital signal processing assembled and distributed by the Institute of Electrical and Electronics Engineers (IEEE).

-- Leroy, a high-level device-independent graphics language developed at the Cooperative Institute for Research in Environmental Sciences (CIRES) of the University of Colorado for producing publication-quality plots.

-- Extended Fortran Language (EFL), an elaborate preprocessor for FORTRAN compilers that greatly extends the power of the language and at the same time makes programs more transportable between different machines.

-- Error, a program that takes the error messages produced by all the language translators and compilers and inserts them as comments at the appropriate places in the source files. This greatly speeds up the process of writing and debugging programs.

-- Style and diction, word processing programs that locate probable cases of poor usage in written documents. These programs complement the existing program spell, which finds spelling mistakes.

-- RSXNET, a file-transfer and remote-job-entry facility connecting UNIX and the RSX-11M system operated by the Branch of Ground Motion and Faulting. RSXNET provides UNIX users access to the Calcomp pen plotter attached to the RSX system.

TOTAL RUPTURE PROCESSES ALONG GREAT STRIKE-SLIP MARGINS
14-08-0001-19796

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INVESTIGATIONS

1. Investigation of directional and asymmetric processes preceding significant earthquakes.
2. Study of seismo-tectonic blocks associated with the pre-earthquake loading sequence.

RESULTS

Spatial patterns before some mainshocks appear skewed to one side or toward one end of the pending surface of rupture. Several examples of thrust-type earthquakes, for example, indicate a stronger pattern of prior seismicity within the overthrusting block. Similarly some aftershock patterns appear skewed to one side of the rupture surface or in a direction away from the location of prior seismicity. For some earthquakes, therefore, the zones of most significant activity before and after the mainshock do not coincide and, thus, are difficult to explain in terms of loading processes that are completely symmetric about the plane of rupture. These observations appear to be explainable in terms of either: a) an asymmetric distribution of rock properties about the fault zone with consequent asymmetric seismic response to stress accumulation, or b) a fundamental directionality to the process of tectonic loading resulting possibly from earlier crustal or plate movement in a nearby region. These two explanations are not incompatible and may in fact be related.

PUBLICATIONS

KELLEHER, J. and B. ISACKS, Directional Hypotheses: Late Stage Pre-earthquake Loading May Often Be Asymmetric, *J. Geophys. Res.*, (in press), 1981.

TECHNICAL REPORT

Our current investigation is focused on the regions of quiescence adjoining strike-slip earthquakes, some portion of whose common boundary forms the rupture surface. During the years preceding the mainshock the quiescent zones are bounded and defined by swarms, clusters and other seismicity. These regions of quiescence are interpreted as seismotectonic blocks closely associated with the pre-earthquake loading process. Patterns of prior seismicity appear to be more directly associated with these tectonic blocks rather than with the rupture surface itself. This distinction is significant because it removes in part some of the confusion and inconsistencies in the interpretation of seismicity patterns preceding earthquakes.

Following is a discussion of our work on asymmetric or directional loading plus an expansion of these comments on our current work.

Directional or Asymmetric Loading

Late stage pre-earthquake loading may often be asymmetric in the sense that different kinds of loading processes appear to occur at various azimuths from the fault surface.

The patterns of seismicity that precede and accompany significant earthquakes appear to provide some clues to the processes of tectonic loading leading to earthquake ruptures. The zones of strongest activity before some earthquakes have become quiet abruptly at the time of rupture. Similarly the zones of strong aftershock development sometimes fall in directions away from the zone of prior activity, and aftershock epicenters are sometimes distributed asymmetrically with respect to the surface of faulting. Furthermore there is some evidence that these kinds of asymmetric phenomena may tend to repeat in given locations or in nearby locations. These observations are difficult to explain by patterns of tectonic loading that are totally symmetric with respect to the rupture surface. Rather, the observations would be more consistent with some asymmetry either in seismic response of the crust to stress or else in some fundamental aspect of tectonic loading or possibly with both. Certainly many active faults separate regions of varied geology and structure and it is reasonable to expect that such different regions might exhibit different seismic responses to similar levels of tectonic stress. Alternatively, the process of tectonic loading may sometimes be itself asymmetric or directional. That is, tectonic loading may result from the movement of a stress front that may require months or even years to propagate across the fault region. Thus, tectonic loading may be asymmetric or directional in the sense that applied stress or deformation pulses may originate in a nearby region from crustal or plate movement and migrate toward the fault zone.

Neither of these explanations is uniquely required by the observations and certainly some other process not considered could also be involved. The investigation, therefore, is not an attempt to develop and present a comprehensive model of tectonic loading. We discuss specific features that may be important in future models and we emphasize the potential importance of viewing tectonic loading as an area-wide phenomenon rather than a process confined to a narrow zone of faulting. That is, in preparation for an earthquake, tectonic strain energy is stored in some volume of rock surrounding the pending surface of rupture. Realistic progress toward earthquake prediction probably will require fundamental understanding of the spatial dimensions of the volume of stored energy and the pattern in time of energy accumulation within the volume. A narrow focus concerned only with the fault surface, therefore, may view only peripheral effects of a complex process. A major objective in our investigation, then, is to examine seismicity over a wider area to develop some understanding of how tectonic strain actually accumulates in the region about the fault surface.

Seismo-tectonic blocks

The patterns of seismicity before many strike-slip and thrust-type earthquakes appear to delineate tectonic blocks which adjoin either one or both sides of the pending rupture surface. That is, the rupture surface forms some portion of the common boundary of two seismo-tectonic blocks. The tectonic blocks are defined by regions of relative quiescence bounded by swarms, clusters, and other seismicity. Some significant portion of the stress energy released during the mainshock is probably accumulated within the tectonic block prior to rupture. An important result, therefore, is that pre-earthquake loading develops within large tectonic blocks adjacent to the fault surface and that the sequences of phases of stress accumulation within these blocks must be understood for successful earthquake prediction. Our emphasis then is on a wider regional examination of the area surrounding the earthquake zone rather than a more narrow focus on the rupture surface itself. In this study we compile observations which provide some indication of the spatial dimensions and orientation of these tectonic blocks and which may provide marginal evidence of the timing of pre-earthquake loading.

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

14-08-0001-19272

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Recent Seismicity

The spatial distribution and rates of occurrence of local earthquakes fit the same general patterns as observed in the past by the Adak Seismic Network. 406 local earthquakes were located with network data during January through June 1981. Five events large enough to be located teleseismically and reported in the PDE (m_b 4.4 to 5.5) were locatable by the network during January through July (one, in July, is not shown on the seismicity map).

The first intense earthquake swarm detected by the network since its inception in July 1974 occurred just outside of the region within which events can be well-located, on May 17-19, 1981. 47 swarm events were recorded at ADK. Because of the location, just southeast of the area of network coverage, only two events, the westernmost, were located during routine processing of the data. Because the swarm is unique during almost seven years of observations, the site will be watched for any further interesting activity.

The P-velocity model used in the location procedure at Adak is based on refraction data for the uppermost layers and a Herrin upper mantle below. There have been no S-wave data at all and the S velocities have been derived from P by assuming a ratio of $\sqrt{3}$. A preliminary study of wave velocities to a depth of 135 km has been carried out using a technique by which the earthquake origin time is determined from the Wadati diagram and the focal depth and average P and S velocities from the hypocenter to the surface are found. Only 15 events have been used so far, but the results show the feasibility of the method and tend to confirm that the velocity model in use is a good one. Below 50 km, the P velocities are found to be greater than the standard model by about 2 percent, S velocities by about 4 percent. A gentle gradient in both velocities is suggested. The method, suggested by A.L. Hales and his colleagues, is a valid means of getting focal depths that are velocity-model independent, as well as independent measures of the velocities.

Recent Earthquakes of Special Interest

Shallow earthquakes in the back-arc region, far above the main subduction zone, are regularly recorded by the network and some have been studied in the past. In March, 1980, the rate of occurrence of such events appeared to increase markedly and a study of this unusual behavior was undertaken. The data show that the increase is due to a shallow-focus swarm in the neighborhood of the dormant volcano Adagdak, the northernmost point of Adak Island.

The question under investigation is whether this swarm is truly volcanic in origin or is a tectonic phenomenon localized by the presence of the volcanic structure. Seismicity patterns, focal mechanisms and spectral characteristics are being analyzed as means of exploring the origin of the earthquakes. The principal result so far is that the localized swarm is a real phenomenon, characterized by four bursts of activity between October, 1978 and December, 1980.

The sub-region SW2 was the site of second $m_b 5$ event, on July 10, 1981, almost exactly one year after a similar event that has been studied for precursors. Regions SW1 and SW2 are providing opportunities to repeat retrospective "prediction" experiments, because of the repetition of similar events. The space-time distribution of earthquakes near the July 10 event, before and after it, has been examined and a study of the behavior of focal mechanisms before the event has been started. A brief interval of quiescence seems to precede events in this source zone. This event is one of several for which clear, coherent co-seismic tilt events have been observed on Adak Island since the tiltmeter installations were upgraded.

PUBLICATIONS

Papers

Billington, S., Method to objectively sort P-wave first-motion data for composite focal mechanism solutions, submitted to *Bull. Seism. Soc. Amer.*, 1981.

Kisslinger, C., J.R. Bowman, and K. Koch, Procedures for computing focal mechanism from local $(SV/P)_z$ data, *Bull. Seism. Soc. Amer.*, *71*:1719-1729, 1981.

Kisslinger, C., J.R. Bowman and K. Koch, Determination of focal mechanisms from SV/P amplitude ratios at small distances, submitted to *Tectonophysics* for special issue on Earthquake Algorithms, 1981. Paper presented at IASPEI Assembly, London, Ontario, July, 1981.

Morrissey, S.T., A 50 milliwatt power converter to replace mercury batteries in seismic amplifier/VCO systems, submitted to *Bull. Seism. Soc. Amer.*, 1981.

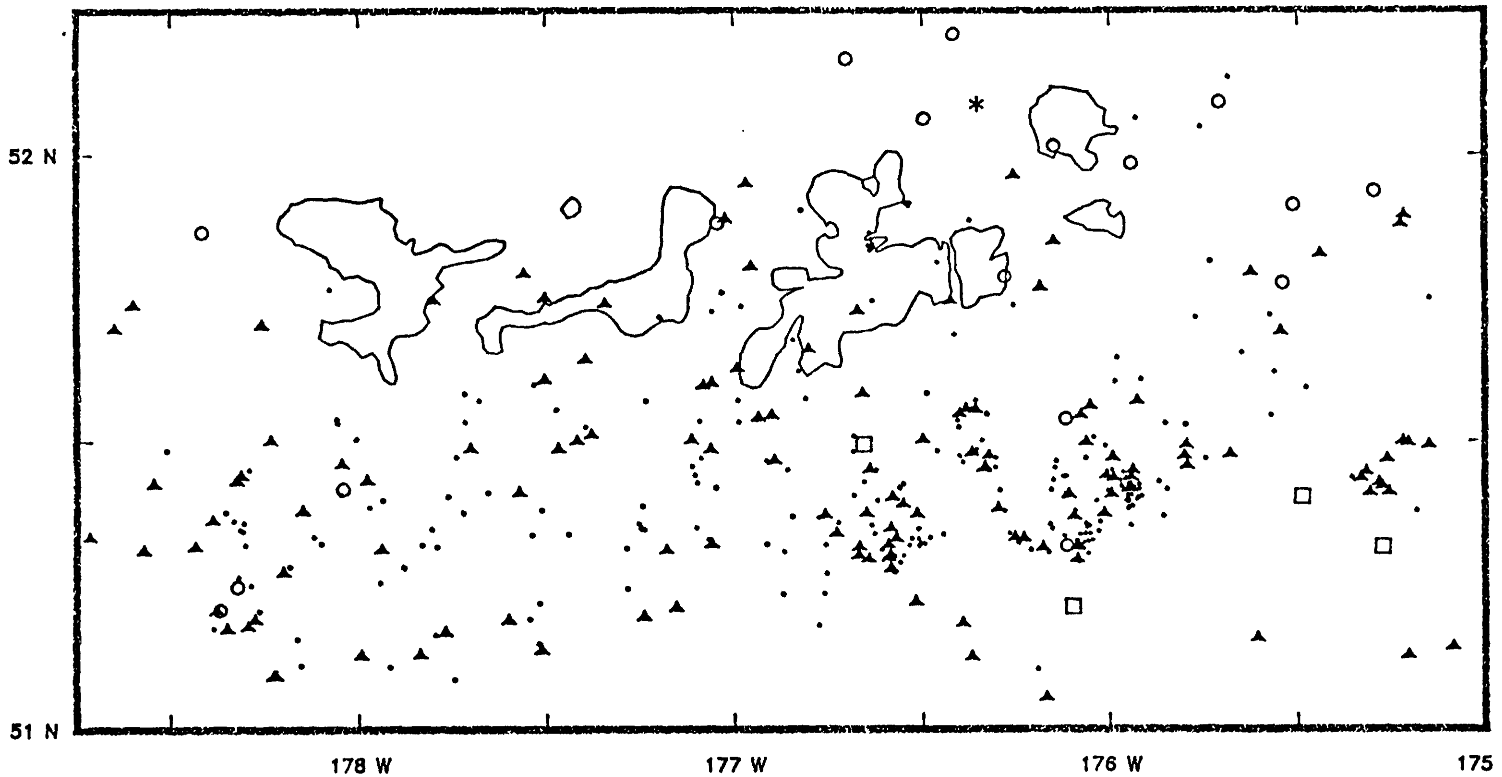
Morrissey, S.T., A frequency selective voltmeter for seismic telemetry network servicing, submitted to *Bull. Seism. Soc. Amer.*, 1981.

Abstracts

Frohlich, C., S. Billington, and E. R. Engdahl, Final results from the OBS experiment in the central Aleutians in 1978 (abstract), *EOS*, *62*: 335, 1981.

Kisslinger, C., J.R. Bowman, and K. Koch, Procedures for computing focal mechanisms from local $(SV/P)_z$ data (abstract), *EOS*, *62*: 330, 1981.

Meertens, C.M., and S.T. Morrissey, A tidal and secular tilt study at Adak Island, Alaska (abstract), *EOS*, *62*: 263, 1981.



LEGEND

m_d • = 2.2 and below
▲ = 2.3 to 3.0
○ = 3.1 to 3.9
$*$ = 4.0 to 4.9
m_b □ = TELESEISMIC

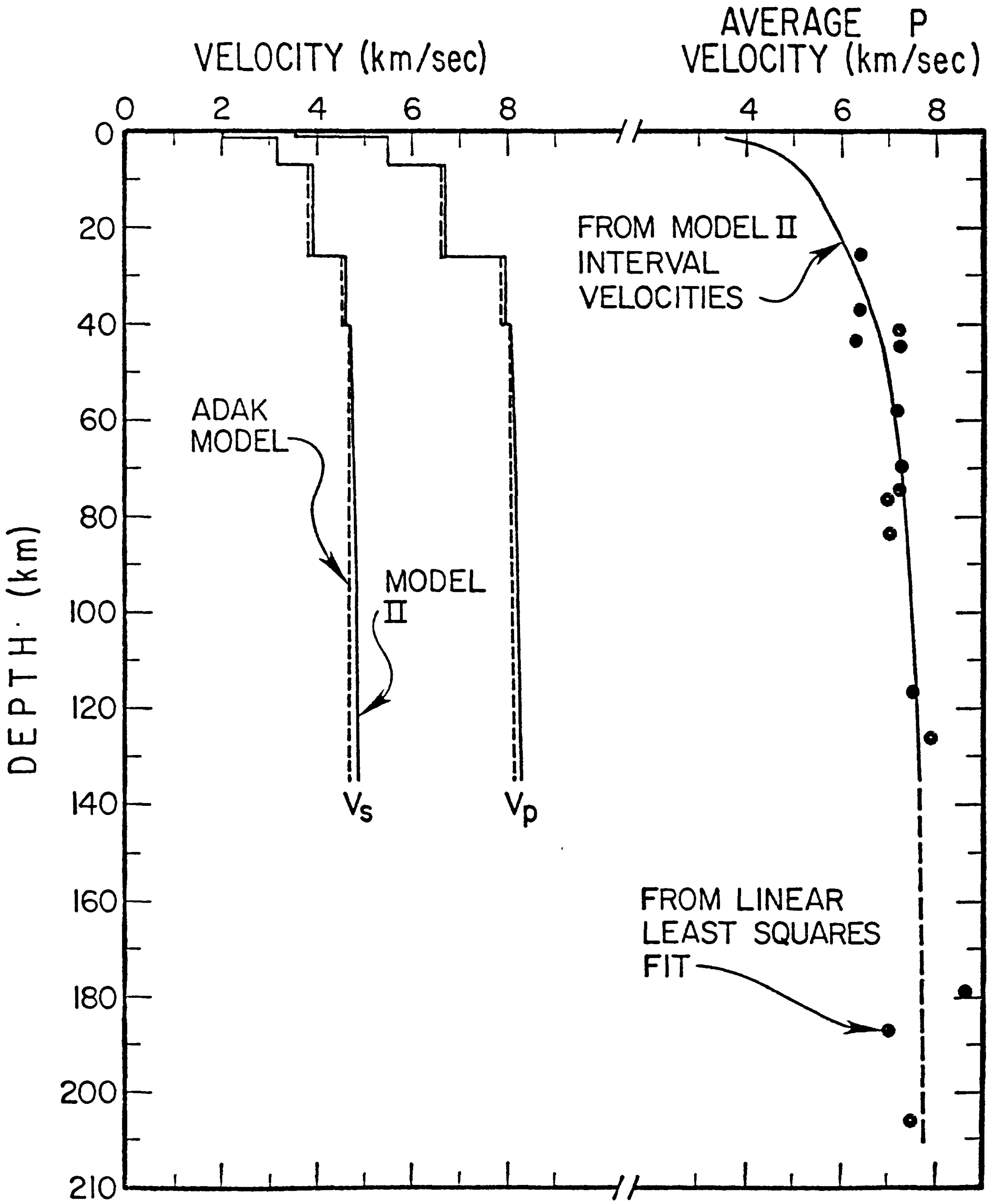
ADAK SEISMICITY – JANUARY TO JUNE 1981

|====|
15 km

UNIVERSAL TRANSVERSE MERCATOR PROJECTION

406 EVENTS

Map of seismicity near Adak which occurred during the first half of 1981. All epicenters were determined from Adak network data. Events marked with squares are those for which a teleseismic body-wave magnitude has been determined by the USGS; all other events are shown with symbols which indicate the duration magnitude determined from Adak network data. The islands mapped (from Tanaga on the west to Great Sitkin on the east) indicate the geographic extent of the Adak seismographic network.



The modified velocity model derived in this study.

CARBON FIBER STRAINMETER STUDIES NEAR PALMDALE, CALIFORNIA

Contract No. 14-08-0001-19760

Peter C. Leary, Peter E. Malin, Thomas L. Henyey
(213) 743-8034

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UNIVERSITY OF SOUTHERN CALIFORNIA
LOS ANGELES, CALIFORNIA 90007

Summary

A new array of six carbon fiber strainmeter sites is currently under construction in cooperation with Roger Bilham of Lamont-Doherty Geological Observatory in the Central Tranverse Ranges of southern California. The sites are listed in Table 1 below and shown in Figure 1.

To date, end station piers at all sites have been built. Three sites (including one with orthogonal components) have been installed with the carbon fiber curing at this time (a 2-3 month process). The remaining sites will be installed in the late Summer of 1981 with all sites coming on line for recording in the Fall of 1981.

Table 1
Location of New Strainmeter Sites in the San Gabriel Mountains

Site Name	Location	Comments
L.A.A. Tunnel	34°32'01.0" 118°31'12.0"	Access tunnel to L.A. Aqueduct
Three Sisters	34°32'01.0" 118°19'35.5"	1 km N of fault near Elizabeth Lake
Jackson #1 and #2	34°30'54.5" 118°17'46.0"	Two orthogonal components at this site
Monte Cristo	34°21'04.5" 118° 5'22.0"	
Big Horn #1	34°21'24.0" 117°44'38.0"	1 km N of Big Horn #2
Big Horn #2	34°21'39.0" 117°44'36.5"	1 km S of Big Horn #1

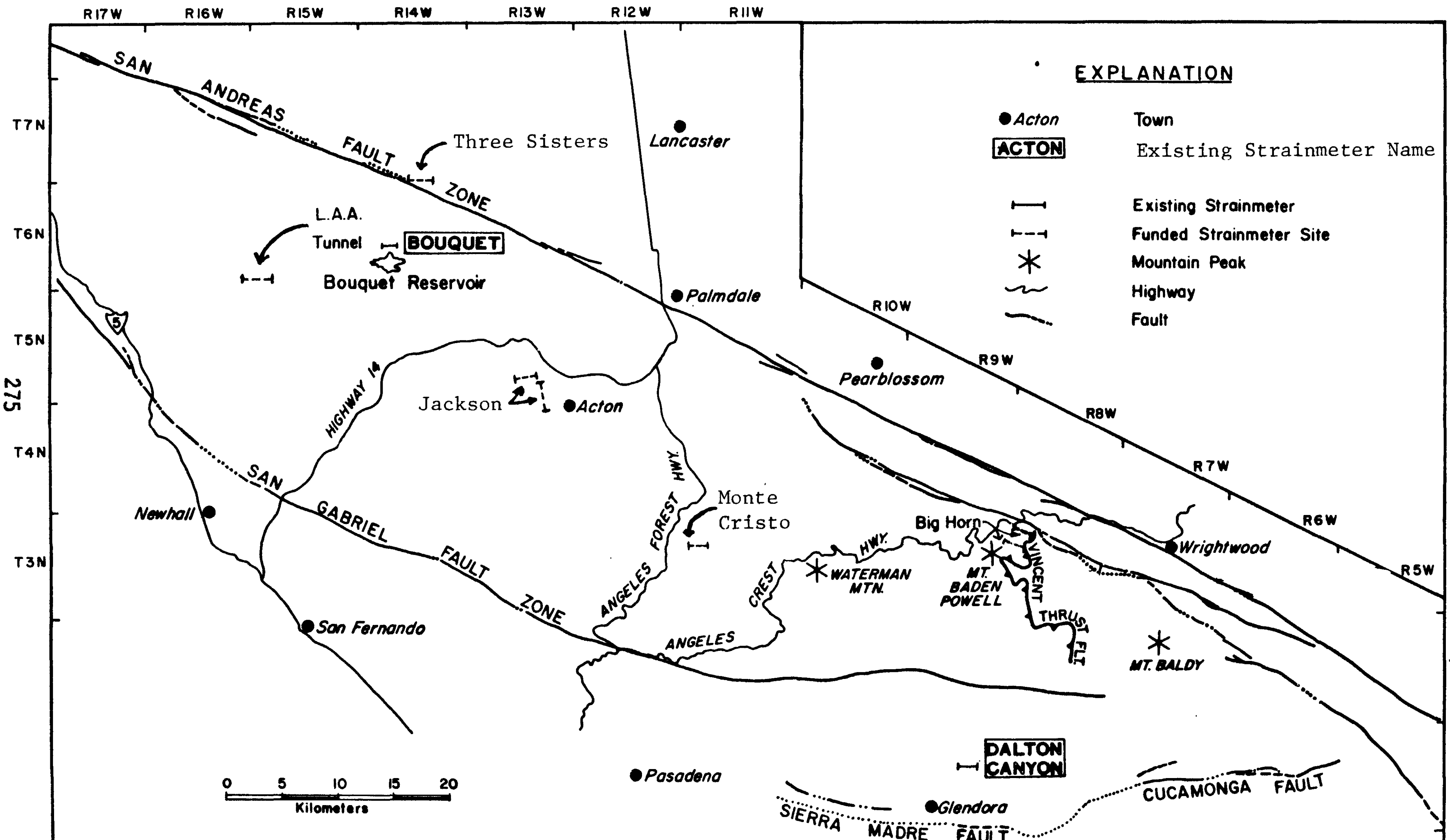

Figure 1. Location map for existing and new carbon fiber strainmeter near Palmdale, California.

Microearthquake Data Analysis

9930-01173

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Investigations

The primary focus of this project is the development of state-of-the-art computation methods for analysis of data from microearthquake networks. Two major topics are investigated:

1. During the first three months, the principal effort has beên devoted to see the book, "Principle and Applications of Microearthquake Networks", by Lee and Stewart through the press.

2. During the second three months, the principal effort has been devoted to investigate and improve interpolation of seismic velocity and its spatial derivatives for seismic ray tracing in 3-dimensional models.

Results

1. In Lee and Stewart (1981), a review of the fundamentals of microearthquake networks is presented. This book contains nine chapters: (1) Introduction, (2) Instrumentation systems, (3) Data processing procedures, (4) Seismic ray tracing for minimum time path, (5) Generalized inversion and nonlinear optimization, (6) Methods of data analysis, (7) General applications, (8) Applications for earthquake prediction, and (9) Discussion. It also includes a glossary of abbreviations and unusual terms, a list of over 700 references, author index, and subject index. A considerable amount of practical material relevant to earthquake seismology has been brought together in this book, and it is intended for seismologists in general. It will also be useful for geologists, geophysicists, and engineers who wish to learn more about microearthquake networks and their applications.

2. In 3-dimensional seismic ray tracing, a set of 6 first-order differential equations is to be solved. Numerical solutions of the ray equations require values of seismic velocity and its first and second spatial deviatives in arbitrary points of a 3-dimensional model. Since a model is specified at grid points, interpolations must be performed. Although tensor product splines provide smooth interpolation, they have the tendency of generating artificial high and low values, especially in regions of rapidly varying seismic velocities. Applying tension to splines will minimize this effect, but the spatial deviatives will tend to be discontinuous, and the cost of computing is greatly increased. By a series of numerical experimentations, we found that these difficulties could be largely overcome if we perform local Hermite interpolation with Hermite polynomials constructed from tensor product splines.

Reports

Lee, W. H. K., and S. W. Stewart, 1981, "Principles and Applications of Microearthquake Networks": Advances in Geophysics, Supplement 2, Academic Press, New York, 293 pages.

Seismic Data Libraary of WWSSN Seismograms

9930-01501

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This is a nonresearch project, and its main objective is to keep the WWSSN seismograms up to date and properly filed. Everything is now up to date. In addition to the WWSSN seismograms we are also filing microfilm copies of seismograms produced by the Historical Seismogram Filming Project (jointly operated by NOAA and USGS).

Worldwide Earthquake Research Database

9930-02104

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Investigations

The main goal of this project is to provide up to date information which will facilitate research on earthquakes. Three major topics now under investigation are:

1. Establishment of a seismogram library of significant earthquakes, especially those before 1963.
2. Organization and maintenance of a bibliographic data base and retrieval system on current earthquake literature.
3. Developement of a simple archiving and retrieval system for earthquake data.

Results

1. Under contract from this project, the National Geophysical and Solar-Terrestrial Data Center, NOAA, has been filming seismograms from key U.S. stations. Please see Glover and Meyers (1981) for current activities.
2. The Current Earthquake Literature (CEL) database has been maintained and kept up to date. The 1980 Annual and 1981 Quarterly indexes are being distributed on schedule.
3. A simple archiving and retrieval system for handling massive amounts of earthquake data has been designed and developed. The archiving computer medium is high density (6250 BPI) magnetic tapes which can hold about 150 megabytes of data. A basic data unit (BDU) is defined as the smallest unit of data to be transferred. A label (containing indexes and pointers) is added to each BDU during the archiving process. Label information are then incorporated into a database under the SPIRES database management system for later data retrieval. Data are retrieved by first generating pointers in response to users' querries. Pointers are then sorted, and the data are recovered by a single pass of the archival tapes. Several sets of data are now being implemented: (a) strong motion data of about 300 megabytes, (b) phase data of Central California Microearthquake Network of about 200 megabytes, and (c) Wave-form data of selected earthquakes from Central California of about 5,000 megabytes.

Reports

Glover, D. P. and Meyers, M., 1981, Historical seismogram filming project, Third Progress Report: U.S. National Oceanic and Atmospheric Administration, Environmental Data and Information Service, World Data Center A for Solid Earth Geophysics, Report SE-28, 76 p.

Hayashida, B. S., Kauffmann, M. L., and Lee, W. H. K., 1981, 1980 Annual Index of Current Earthquake Literature: U.S. Geological Survey Open-file Report 81-454, 386 p.

Parkfield Prediction Experiment

9930-02098

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Investigations and Results

The 430-km-long segment of the San Andreas fault that ruptured in the great 1906 earthquake (M 8) has been seismically quiet at the M 6 level for the last 75 years (Ellsworth et al., 1981). The historic record of earthquakes in the 19th century for the southernmost 100 km of the rupture, extending from San Francisco to just north of San Juan Baustista, indicates that it was the site of three or four M 6 or greater earthquakes in the 110 years preceding 1906: 1800?; 1838, M 7?; 1865, M 6.5; 1890, M 5.9 (Toppozada, 1980). We believe that these earthquakes are plausibly accounted for by repeated slip on the southernmost 50 km of fault, just to the northwest of San Juan Bautista (Figure 1).

Geodetic data indicate that strain is currently accumulating across this zone at a rate (0.6 μstrain/a; Prescott, 1980) which can be explained if the right lateral displacement across the fault is 2 cm/a, and the upper 10 km of the fault are locked. This rate of strain accumulation is consistant with short and long term geologic determinations of displacement rates in the region, and is sufficient to account for a magnitude 6 1/2 earthquake every 30 years (Figure 2), a close approximation to this segment's behavior in the nineteenth century. The long interval without a large event since 1906 can plausibly be accounted for by the 1 1/2 m of slip that occurred on this portion of the fault in the 1906 earthquake. If this model (Bufe et al., 1977; Shimazaki and Nakata, 1980; Sykes and Quittmeyer, 1981) is correct, it suggests that a large (M 6+) earthquake could occur in this region at any time. This idea is reinforced somewhat by the pattern of lower magnitude seismicity following 1906. Quiescence extending down to the M 4 1/2 level lasted for forty years, with activity resuming in the mid-1940's (Figure 2). These variations are suggestive of a small scale, stress modulated "seismic cycle".

Since 1979, a sequence of M 4 earthquakes have occurred on the San Andreas in the region northwest of San Juan Bautista. Microearthquake hypocenters associated with each of these larger events map out nonoverlapping areas on the fault plane and highlight two portions of the fault where future large events might reasonably be expected (top, Figure 3). One is a 10-15 km long zone between San Juan Bautista and Pajaro (0-15 km on the horizontal scale at the top of figure 3) that has not ruptured in the past twelve years. The other is a 40 km zone northwest of Pajaro (15-55 km, top Figure 3), which not only has been anomalously quiet in the last twelve years, as compared to the preceding eighteen (Figure 2), but also was the probable location of at least some of the large earthquakes of the nineteenth century.

In cross section, the pattern of microseismicity on the fault plane at San Juan Bautista strongly resembles that at Parkfield, some 150 km to the southeast (bottom, Figure 3). Lindh and Boore (1980) have determined that fault slip during the M 5 1/2-6 1966 Parkfield earthquake, (dashed line, bottom, Figure 3), started near a dense cluster of activity at the leading edge of the seismically active zone (left side, bottom figure 3), and propagated 20-25 km southeast to a single deep cluster (right side, bottom, Figure 3). By analogy, we speculate that the 1865 earthquake near San Juan Bautista occurred within the dashed line shown in the top of Figure 3. Furthermore, several of the recent M 4 earthquakes have occurred at the ends of the 40 km long zone on which we believe a M 6+ event is possible today.

Further similarities exist between the San Juan Bautista and Parkfield regions. Each region contains the terminus of a historic rupture zone for a great earthquake on the San Andreas fault, 1906 to the north and 1857 to the south. In both cases the transition for locked to creeping behavior is accompanied on the east side of the San Andreas by a change from a high density, high velocity basement (gabbroic and/or greenstones) to a low velocity, low density crustal section of predominantly graywacke character. The transition from locked to creeping behavior is also accompanied by the appearance of a high level of microseismicity on the fault plane that persists along the length of the creeping zone, by geometrical complexities in the fault zone, and by the occurrence of moderate (M 5-6) earthquakes. We believe that the distribution of rock types along the fault plays a major role in determining whether or not a given section of fault slips seismically or aseismically, in determining the character of the microseismicity, and in determining where large earthquakes will occur. Thus we believe that an integrated study of the geology, tectonics, seismic velocites, densities, and seismicity of a region forms a rational basis on which to build an earthquake prediction program.

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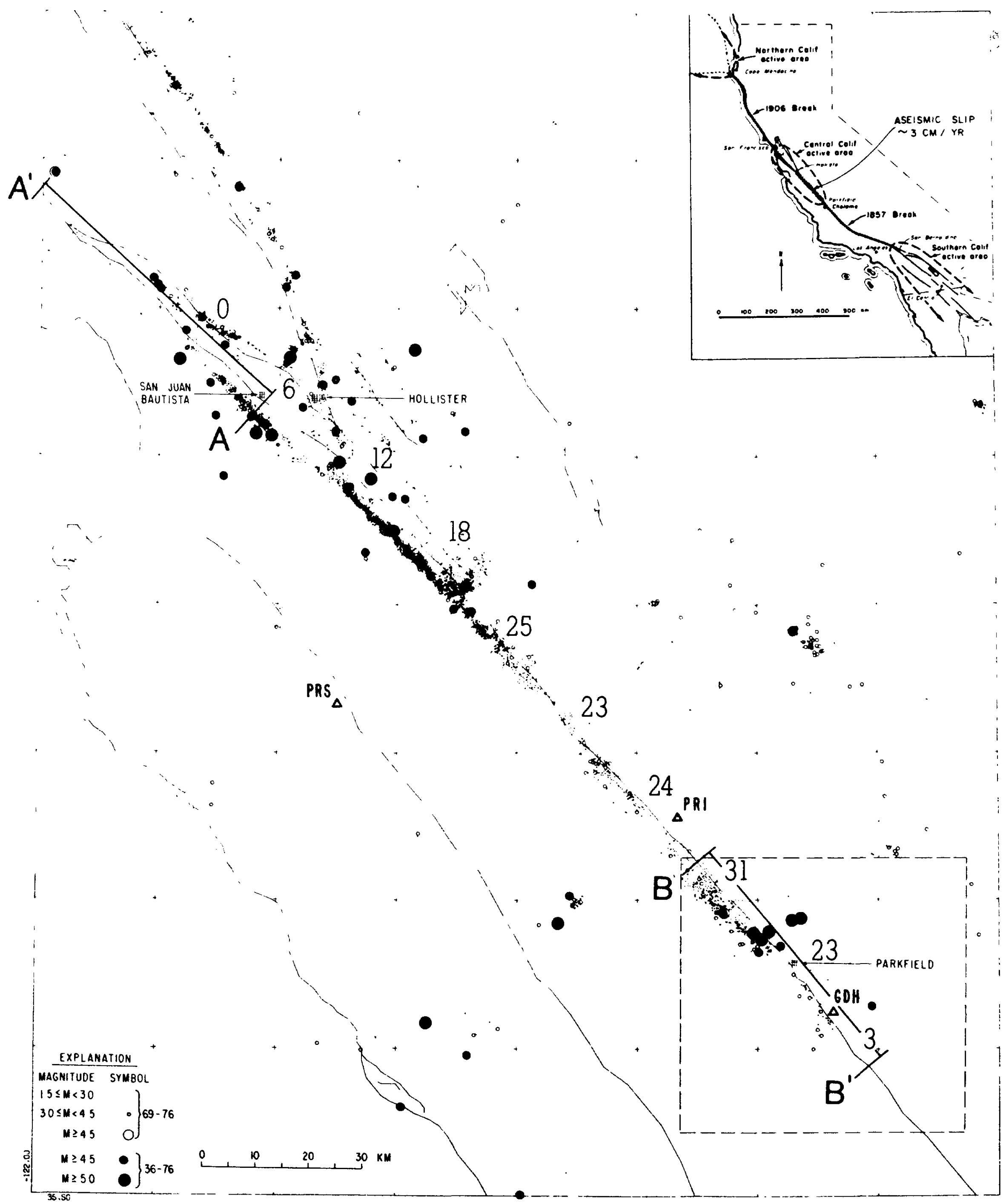
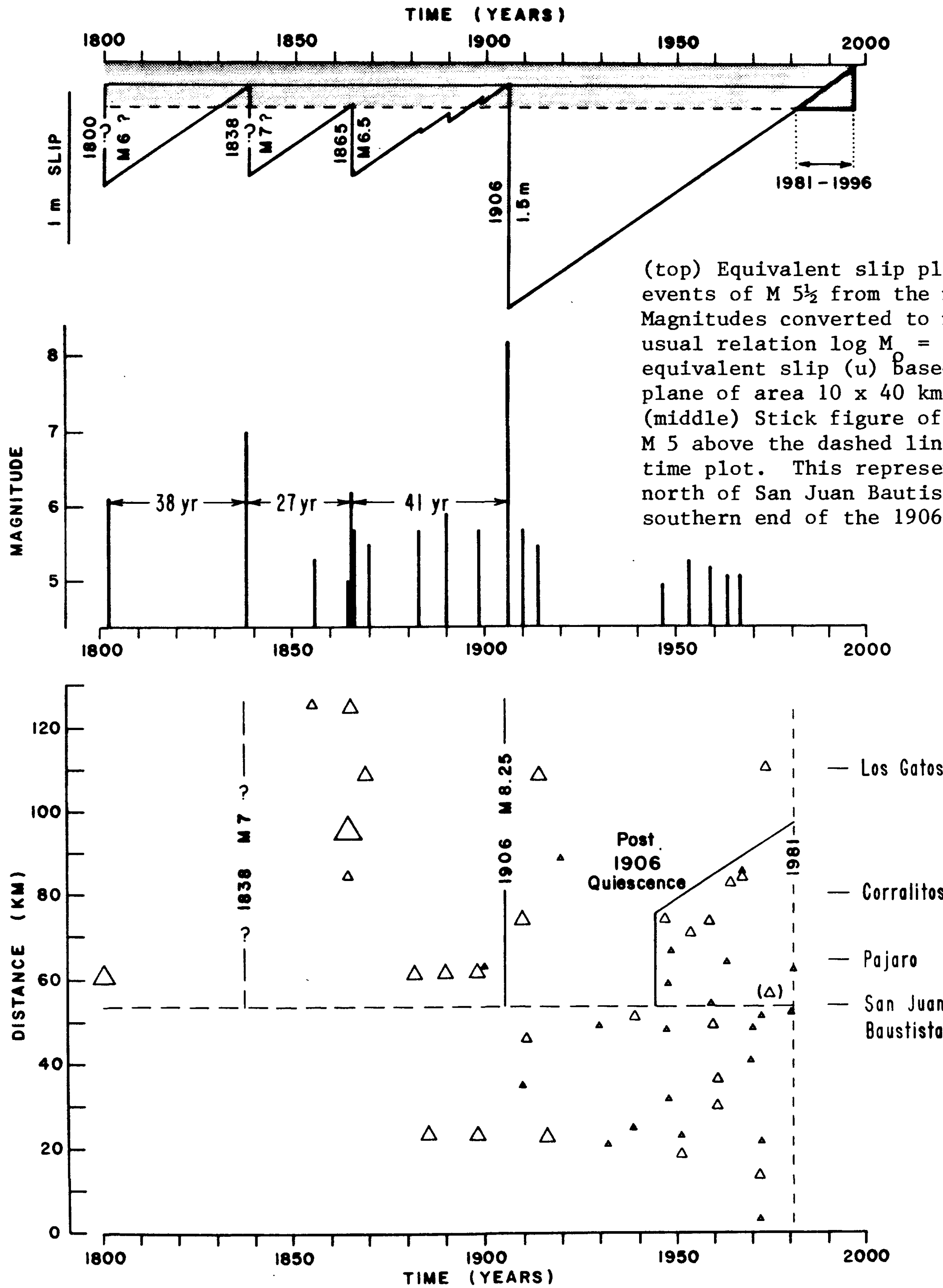


A'
A
0
6
12
18
25
23
24
31
23
3
B
B'
SAN JUAN BAUTISTA
HOLLISTER
PRS
PRI
PARKFIELD
GDH
ASEISMIC SLIP ~3 CM / YR
Northern Calif active area
1906 Break
Central Calif active area
1857 Break
Southern Calif active area
EXPLANATION
MAGNITUDE SYMBOL
1.5≤M<3.0
3.0≤M<4.5
M≥4.5
69-76
M≥4.5
M≥5.0
36-76
0 10 20 30 KM

Figure 1



(top) Equivalent slip plot of the events of M 5½ from the middle figure. Magnitudes converted to moment by the usual relation log $M_o = 16 + 1.5M_L$, equivalent slip (u) based on a fault plane of area 10 x 40 km (A) and M = Au. (middle) Stick figure of the events of M 5 above the dashed line in the space time plot. This represents activity north of San Juan Bautista along the southern end of the 1906 break.

Figure 2

(bottom) Space time plot of the seismicity along the San Andreas from Bear Valley to Los Gatos. M 5 prior to 1900, M4½ since that time.

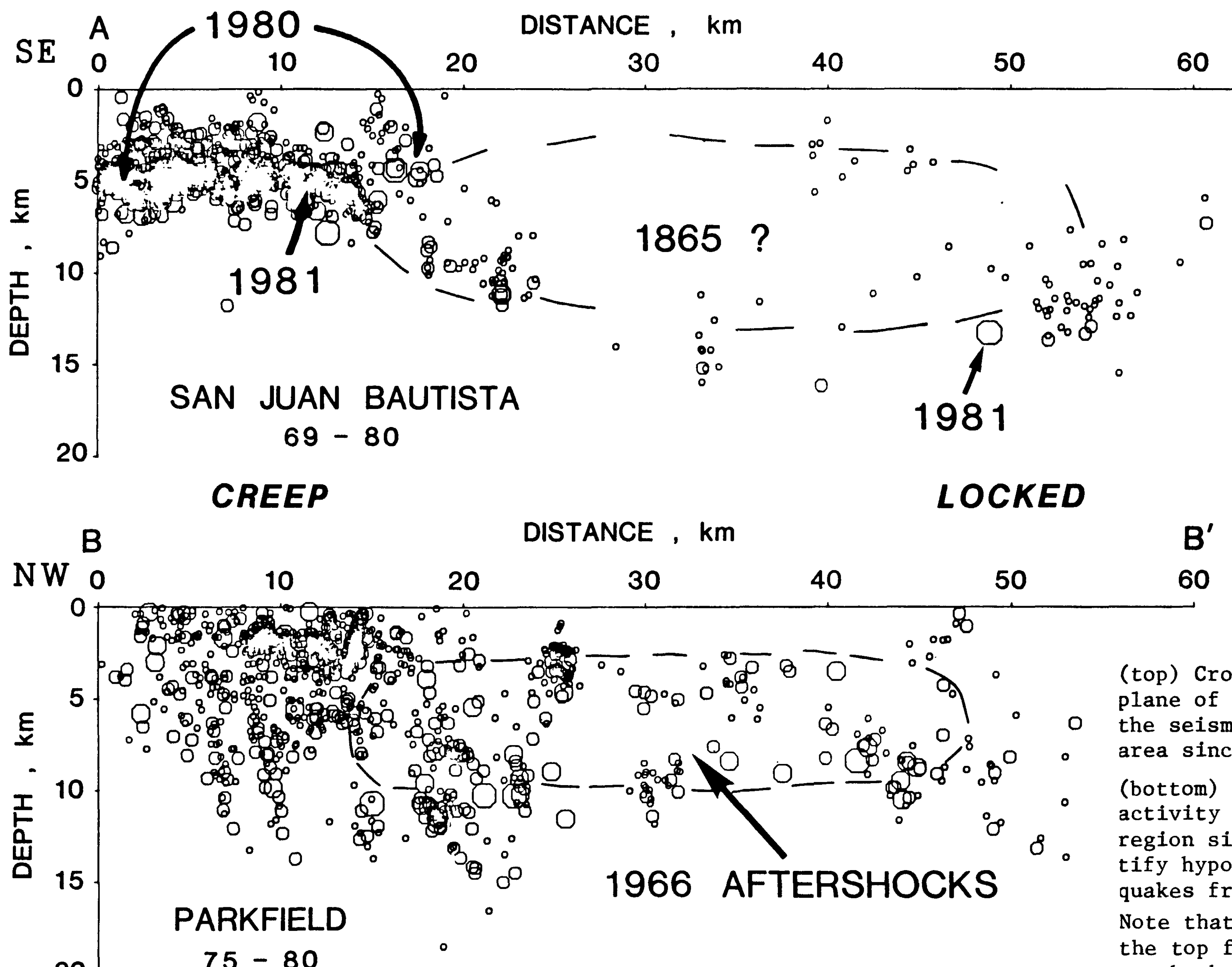


Figure 3

(top) Cross section in the plane of the San Andreas, of the seismicity in the Parkfield area since 1975.

(bottom) Similar plot of the activity in the San Juan Bautista region since 1969. Arrows identify hypocenters of M4 earthquakes from 1980-1981.

Note that NW is to the right in the top figure, but to the left at the bottom thus both cross sections are oriented such that the creeping portions of the fault are to the left in each case, and the locked portions to the right. The locations of the two cross sections are shown in Figure 1.

STUDY OF EARTHQUAKE PREDICTION AND TECTONICS OF NORTHEASTERN CARIBBEAN:: CONTINUING EXPERIMENT IN TWO MAJOR SEISMIC GAPS

USGS 14-08-0001-19748

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Lamont-Doherty Geological Observatory has continued to operate the 17 seismograph stations in the northeastern Caribbean. Since March 1979 our main recording device has been a digital recording system (DRS). The DRS presently records 32 channels of information from the 17 stations. Each channel records information at a rate of 100 samples per second and has a dynamic range of 72 db. As the dynamic range of the telemetry links is about 46 to 52 db, the DRS does not limit the information gathered.

The response of the VCO at the St. John station has been changed from a velocity to a displacement response. This change was undertaken on an experimental basis only. It was felt that the velocity response was providing too much gain in the high frequency band leading to saturation of the system for events of relatively small magnitudes. It was hoped that a successful conclusion of this experiment would lead to modifying the response of all the 3 component stations. The results of this experiment have thus far been very encouraging. We, therefore, plan to convert all 3 component stations to a displacement response in October, 1981.

2. Focal Mechanisms and Depths of Two Earthquakes North of the Virgin Islands

We have been processing teleseismic (WWSSN) Rayleigh wave data recorded from an earthquake (m_b = 5.1) which occurred north of the Virgin Islands on January 22, 1979 to help constrain its focal mechanism and depth. The Rayleigh wave radiation pattern from this event will be compared to that of a larger nearby earthquake which occurred on May 23, 1963 using the event pair technique of Weidner and Aki (1973).

The Rayleigh wave amplitude data which have been processed so far are consistent with a depth of 10 km for this event as obtained from local network data. For periods greater than about 30 sec the Rayleigh wave data show very little scatter and are consistent with the starting model chosen. The additional scatter of the observed data at periods shorter than 30 sec is common in surface wave studies and is probably caused by the greater degree of lateral hetereogeneity in the earth on a scale comparable to that of the wave lengths of the shorter period data (<100 km).

The nearby event which occurred in 1963 was studied by Molnar and Sykes (1969) and they obtained a thrust mechanism. The depth reported by them for the 1963 earthquake was 51 km. If this earthquake is in fact that deep and if the 1979 event is as shallow as 10 km then the comparative event method of Weidner and Aki (1973) should be very helpful in constraining both the depth and mechanism of the two earthquakes. This method requires two events located very near each other with different source properties (i.e., different mechanisms and/or depths). In order to fully investigate the focal mechanism and depth of these two events more Rayleigh wave records from additional WWSSN stations are being digitized and analyzed.

3. Studies of Precursory Phenomena

On February 14, 1980 a magnitude 4.8 earthquake occurred about 45 km northeast of St. Thomas. The waveforms of earthquakes that were located within about 15 km of this event were studied using the records from the digital recording system for the 10 months previous to the event to investigate possible precursory phenomena (Frankel, in preparation). For this period of time, a spatial clustering of five events ($M \approx 2$), unique for this region, occurred near the site of the impending shock. Four of these events were produced in two pairs with each event followed by a second one within two days. Cross correlation studies of the waveforms of these earthquakes indicate that the events in each pair were located within about 150 m of each other, such that each pair could be considered as one multiple event. One other pair of events occurred about 8 km north of the February event, well outside of its rupture area, starting about 7 hours before the mainshock.

Changes in first motions at one station and P-SV ratios indicate that the focal mechanisms of shocks that occurred within 2 months of the mainshock differ from the normal focal mechanism of earthquakes in the region. The mainshock exhibited the normal set of first motions. However, no significant changes in the spectra of earthquakes preceding the mainshock was apparent.

4. Character of the Plate Boundary

Magnetic lineations, topographic trends and sites of uplift indicate that two clusters of seismic activity on the inner wall of the trench may lie near parts of a large fracture zone (i.e., the Barracuda ridge) that has been overridden by the northeast corner of the Caribbean plate. Over the last few million years plate motions have carried the Barracuda and Tiburon ridges into the subduction zone of the northern Lesser Antilles. The interaction of these ridges with the arc has deformed the sediments on the inner wall of the trench, uplifted the frontal arc, and dramatically increased the seismicity in the vicinity of the interaction. There appears to be a dichotomy in the mode of seismic energy release between the up-island and down-island clusters of seismiity. Whereas, the down-island cluster is characterized by mainshock-aftershock sequences, the up-island cluster is characterized by swarms. To date no swarms have been observed in the subduction zone of the northern Lesser Antilles. Numerous swarms have been observed, however, north of the Virgin Islands. These swarms are primarily concentrated in the region where the Main ridge interacts with the crustal portion of the Caribbean plate and they are not evenly distributed in time. A typical surge in the seismic activity north of the Virgin Islands is characterized by the occurrence of a swarm followed by at least one additional swarm within a few tens of days and not more than about 40 km from the initial swarm. This type of sequence is very common when the swarms contain earthquakes of magnitude 4.0 or greater.

5. Rates and Directions of Plate Motion

Accurate computation of the rate and direction of motion between the North American and Caribbean plates is essential if we are to estimate the seismic potential for the northeastern Caribbean. The length of the downgoing seismic zone in the northeastern Caribbean has been measured at 100 km intervals along the seismic zone. Previous investigators have shown that the length of the seismic zone is a function of the age of the subducted seafloor and the rate of convergence if the length is measured along the slip vector between the plates. The age of the seafloor and the rate of convergence do not vary significantly along the Caribbean arc so seismic zones of equal length will be observed in cross sections parallel to the relative slip direction. Our investigations indicate a slip direction of about S70°W+10°. This southerly component to the slip vector is useful for explaining the previously enigmatic downgoing seismic zone beneath Puerto Rico and the Vrigin Islands.

The rate of relative plate motion has also been estimated. Rates of seafloor spreading have been estimated for the Cayman Trough region from magnetic anomalies to be about 2 cm/yr. The seismicity of the region indicates, however, that the observed rate may not fully represent the motion between the North American and Caribbean plates. To the west of the spreading center seismic activity is concentrated along the more southerly Swan fracture. To the east, however, activity is rather evenly divided along two transform faults indicating the presence of a buffer block between the North American and Caribbean plates. We therefore qualitatively estimate the rate of Caribbean - North American plate motion to be about 4 cm/yr+1 cm/yr.

Geodetic Strain Monitoring

9960-02156

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Investigations

1. A portable two color laser geodimeter (Terrameter) was ordered in 1978 for the purpose of high resolution trilateration surveys in selected areas of the San Andreas fault system.

2. A cooperative program is underway with Dr. Larry Salter of the University of Colorado, CIRES, to observe crustal deformation near Pearblossom, California which is near the center of the "Palmdale Bulge".

3. 18 km of level lines were benchmarked and double run to 1st order standards so as to obtain some vertical geodetic control within the two-color geodimeter network at Pearblossom. The intention is to relevel these lines approximately twice per year.

4. A suite of measurements of *in situ* stress, obtained using the hydrofrac technique by Zoback, Hickman, Tsukahara, and Healy, is the basis of an elastic analysis of the state of stress in the Mojave desert adjacent to the San Andreas fault.

Results

1. The terrameter, ordered in 1978, was accepted during July, 1981, and since that time, has been used to measure lines from various benchmarks within the Pearblossom network. These measurements provide closure for, and generally augment, the line length data acquired using the University of Colorado two-color instrument at the center of the network. A reconnaissance was made of the Palmdale network, where measurements have been made by Savage *et al.*, with the intention of beginning a program of frequently repeated surveys there using the terrameter.

2. Since the beginning of November, 1980, 13 baselines within a geodetic network 13 km in dimension and straddling the San Andreas fault about 30 km to the southeast of Palmdale (Figure 1), have been repeatedly measured using a two-color geodimeter to a precision of 0.1 ppm. The data set, consisting of about 1300 line length measurements as of the middle of October, 1981, has been analyzed with the assumption of homogeneous strain accumulation within the network and the results indicate a nearly uniaxial

compressional strain change at a rate of 0.27 ± 0.03 μstrain/a oriented N47°W ± 3°. The orthogonal component extends at a rate of 0.05 ± 0.03 μstrain/a. Because the strike of the San Andreas fault within the network is about N70°W, the rate of dextral shear strain accumulation is 0.11 ± 0.02 μstrain/a, which is approximately 3/4 of the average rate over the last 10 years determined by Savage _et al._, within a geodetic network just to the west of Palmdale. On a time scale of two weeks (Figure 2), the accumulation of shear strain shows no significant departures from the secular rate. The components of strain parallel and normal to the fault, however, showed substantial excursions from their linear trends in December, 1980, March and early June 1981. The amplitudes of these fluctuations, lasting about a month, approach ± 0.4 μstrain for the normal component and about half that amount for the parallel component.

3. A preliminary analysis of the levelling data indicates that 1st order standards were, in fact, met. The first relevelling over these lines will be performed, hopefully, during January and February, 1982.

4. The stress measurements, made at depths extending from 80 and 849 m and at distances from the fault between 2 and 34 km, indicate a state of deviatoric stress typical for continents in that the inferred gradient of shear stress with depth is about 7.6 MPa/km. The state of stress does not appear to vary significantly either with distance from the San Andreas fault or along the strike of the fault. The average shear stress in the upper 14 km along the fault is about 54 MPa, a result that is incompatible with recently proposed estimates of shear stress based on the analysis of heat flow data.

Reports

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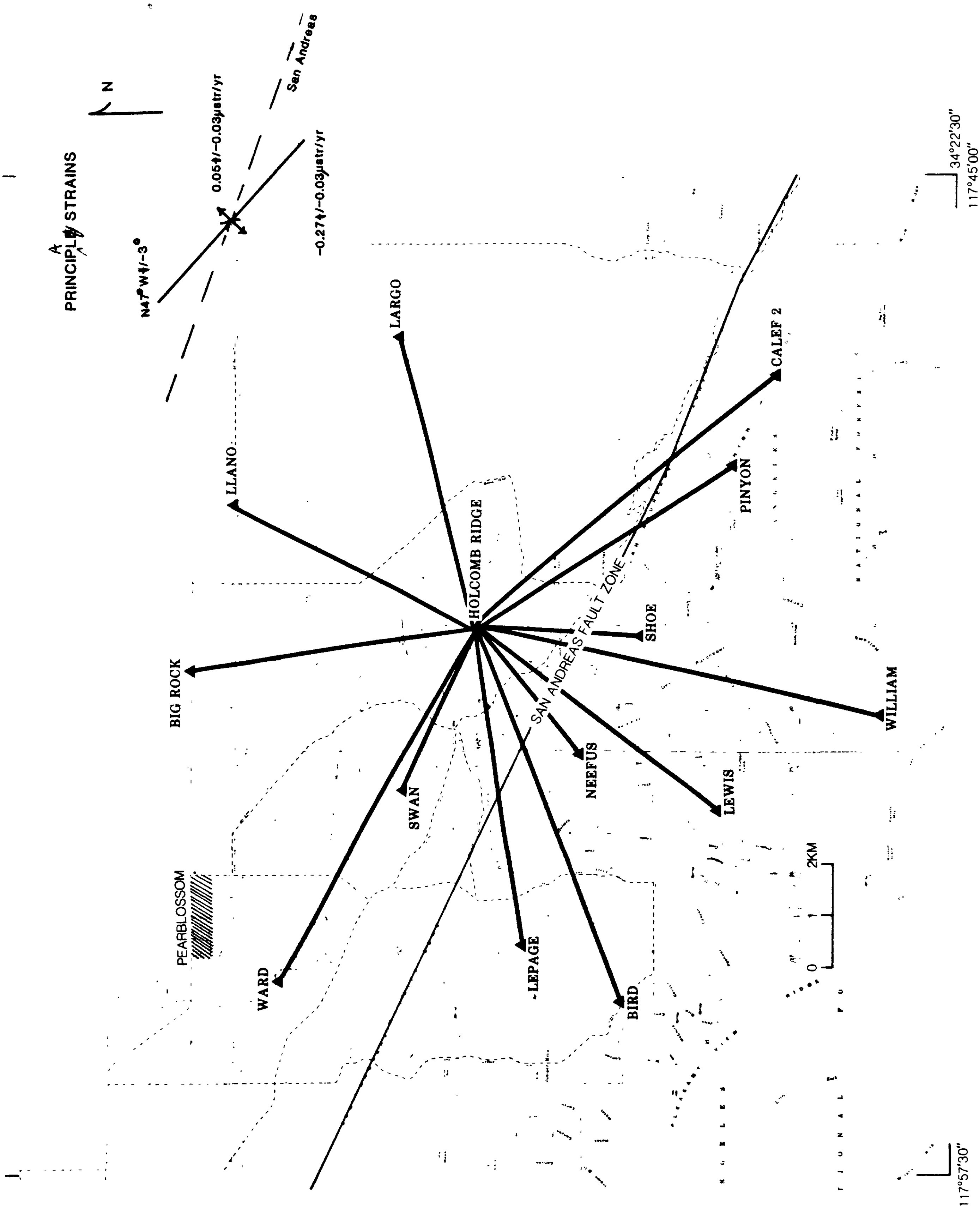
PRINCIPLE STRAINS
N
N47°W+/-3°
0.05+/-0.03μstr/yr
-0.27+/-0.03μstr/yr
San Andreas
LARGO
LLANO
CALEF 2
PINYON
HOLCOMB RIDGE
SAN ANDREAS FAULT ZONE
SHOE
BIG ROCK
WILLIAM
NEEFUS
SWAN
LEWIS
PEARBLOSSOM
WARD
LEPAGE
BIRD
2KM
1
0
34°22'30"
117°45'00"
117°57'30"

Figure 1

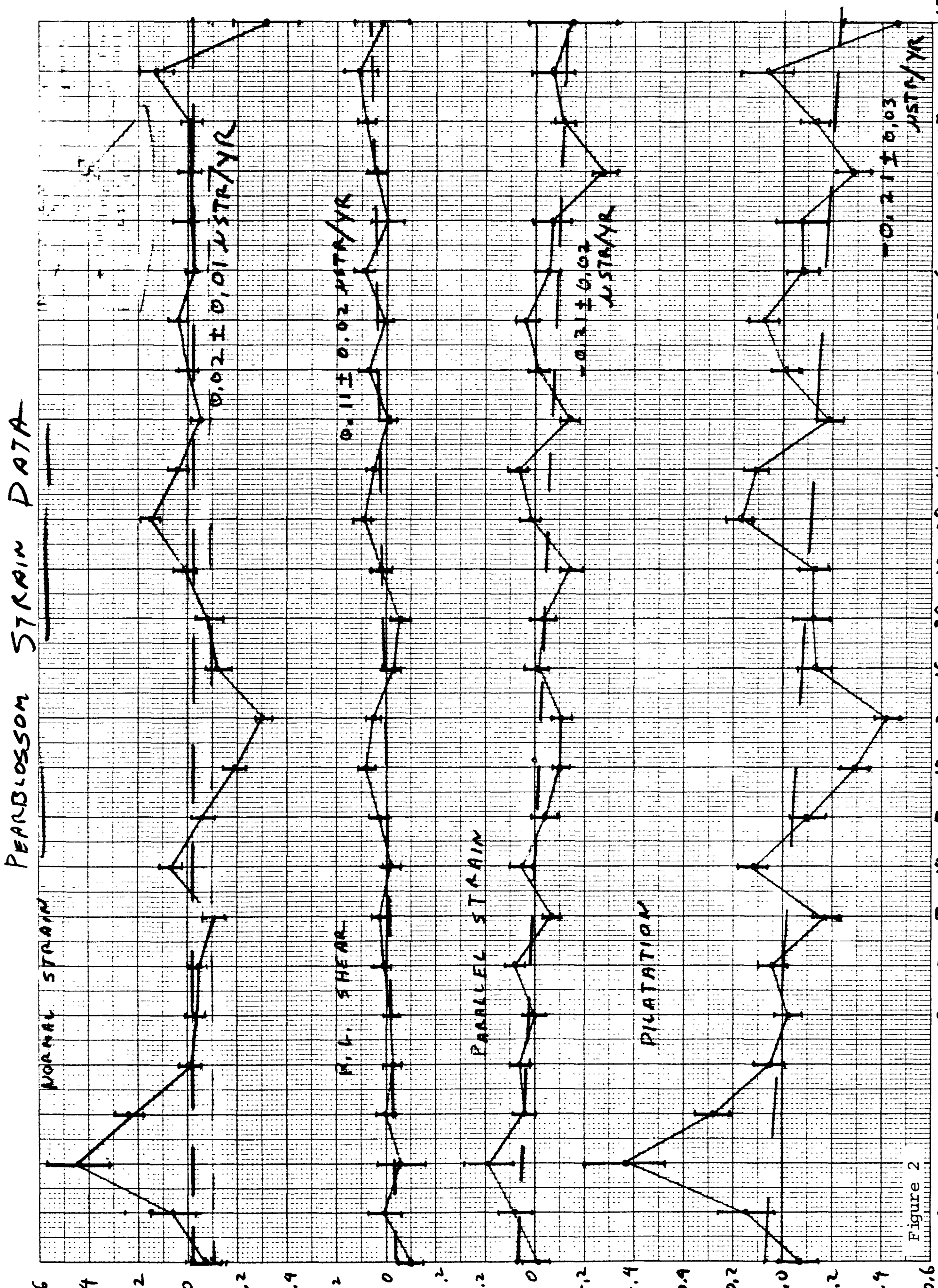
PEARBLOSSOM STRAIN DATA
NORMAL STRAIN
R.L. SHEAR
PARALLEL STRAIN
DILATATION
0.02 ± 0.01 μSTR/YR
0.11 ± 0.02 μSTR/YR
-0.31 ± 0.02 μSTR/YR
-0.21 ± 0.03 μSTR/YR
.6 .4 .2 0 -.2 -.4
.2 0 -.2
.2 0 -.2 -.4
0.4 0.2 0.0 -0.2 -0.4 -0.6
30 13 27 11 25 8 22 5 19 5 19 2 16 30 14 28 11 25 9 23 6 20 3 17 1 15

Figure 2

Variable Rupture of Seismic Gaps and the Relation to Foreshock-Mainshock-Aftershock Sequences

14-08-0001-19265

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We are investigating the nature of the failure process in seismic gaps and its relation to seismicity patterns, foreshocks, and aftershocks. Specifically we are investigating the variability of the rupture mode of seismic gaps. Several examples (e.g. the Colombia-Ecuador sequence) clearly indicate that the same seismic gap sometimes breaks in a single great earthquake, but at other times breaks in a number of smaller events which are separated in time. Our investigations to date indicate that the regional variations of rupture mode and seismicity patterns can be explained in terms of regional variations of fault-zone heterogeneity. Such heterogeneity, characterized by asperities, appears to be reflected in the complexity of body waves from large earthquakes originated from the individual subduction zones. We are conducting further investigations on this subject for subduction zones off the coast of Mexico, Guatemala, Colombia-Ecuador and the Kurile islands, by studying spacio-temporal patterns of seismicity, body-wave form complexity, spectra, and mechanism.

Middle American Trench

The largest shallow earthquakes ($M_s \geq 7.0$) which have occurred along the Middle American trench since the installation of the WWSSN network are the 1965, 1968, and 1978 Oaxaca events, the 1970 and 1973 events and the 1979 Petalan event. All have been studied to identify similarities and differences that may lead to a better understanding of fracture and subduction processes with relationship to precursory seismicity patterns. The events have seismic moments ranging from 1.0×10^{27} dyne-cm for the 1968 event to 3.2×10^{27} dyne-cm for the 1978 Oaxaca event. All events are of predominantly thrust type, consistent with subduction of the Cocos plate to the northeast. Body waves of the 1965, 1968, 1978 and 1979 events along the trench indicate rather simple faulting processes. These events all had focal depths of 15 to 20 km and stress drops on the order of 10 bars. The 1970 and 1973 events, the eastern- and westernmost, respectively, of the events studied here, show greater complexity in their body waves, perhaps representing a transition to regions of more complicated tectonics (Chael et al. 1981).

The earthquakes in 1965, 1973, 1978 and 1979 were preceded by relative seismic quiescence of $\geq$24 months, in contrast with those in 1968 and 1970. Short term "foreshock type" activity occurred 28 days and 73 days before the 1970 and 1979 events, respectively. The rates of background activity are about double in the regions with no prior seismic quiescence; this correspondence suggests the possibility of predicting the type of precursory pattern for different regions. Seismic quiescence has prevailed for more than three years near Acapulco, Mexico (McNally, 1981).

At roughly 18.5°N, 104.5°W, the trend of the Rivera Fracture Zone intersects the Middle American trench. This fracture zone represents the boundary between the Rivera plate, subducting under North America at about 2.1 cm/yr, and the Cocos plate, subducting under North America at about 5.4 cy/yr. A segment of the East Pacific Rise intersects the Rivera Fracture Zone from the south at 18°N, 106°W, so that the western branch of the fracture zone represents the boundary between the Pacific and Rivera plates. Seismicity near the western branch of the Rivera Fracture Zone follows the trend of the fracture zone, but along the eastern branch approaching the coast of Mexico it is more diffuse. Earthquakes near the eastern Rivera Fracture Zone were jointly relocated in an attempt to clarify the location of the late boundary as determined by the seismicity. The great earthquake of 1932 in Jalisco, Mexico, is the largest historic event of that area. The seismic moment of the main shock on June 3, M_s=8.2, is 1.5×10^{28} dyne-cm. A more accurate epicenter for the 1932 event was found in order to locate the Jalisco earthquake on either the Rivera plate or the Cocos plate. Since the subduction rates of these plates are different, the results of the location of the 1932 event is crucial for estimating the repeat time and current seismic potential for an earthquake of this size in the Jalisco area. We conclude that this earthquake was north of the extension of the Rivera Fracture Zone and was probably caused by subduction of the Rivera plate under North America. Hence, the repeat of a 1932 type event may not be likely in the immediate future (Eissler and McNally, 1980).

Colombia-Ecuador Region

A great earthquake (estimated M_w=8.8, M_t 8.7) occurred off the coast of Ecuador-Colombia in 1906. During the past 38 years, three large earthquakes (1942, M_s=7.9; 1958,M_s=7.8; 1979, M_s=7.7) occurred abutting to each other with approximately the same rupture zone as the 1906 event. This sequence represents one of the best examples of the variable rupture mode. One of the important conclusions of the current investigation is that, despite the fact that the 1942-1958-1979 sequence and the 1906 event ruptured over the same segment, the sum of the seismic moment of the 1942, 1958 and 1979 events is only 20% of the seismic moment of the 1906 earthquake. Also, the amount of slip which occurred in the 1942, 1958 and 1979 events is about half the slip for the 1906 event. This result can be interpreted in terms of an apserity model. In the framework of this model, a "small" earthquake such as the 1942, 1958 and 1979 event represents failure of one asperity, and the rupture zone is pinned at both ends by the adjacent asperities. A great earthquake (e.g., the 1906 event) represents failure of more than one asperity and involves a larger effective width, slip and seismic moment per unit length of the rupture zone.

Kurile Island Region

A sequence of earthquakes occurred in March 1978 in a region of the Kurile Islands near Etorofu. There were two main shocks. The first on March 23 with M_s=7.5, and the second on March 24 with M_s=7.6. There was extensive foreshock activity immediately preceding these events. The earthquakes were located in the same section of the Kurile trench as the 1958 Etorofu earthquake, M_w=8, although they occurred closer to the trench. The aftershock zones of the 1978 events substantially overlap that of the 1958 event. The repeat time of large earthquakes in this region is considered to be about one hundred years. Thus, the occurrence of these two earthquakes after an interval of only twenty years seems anomalous. The 1958 earthquake was, itself, considered unusual. Fukao and Furumoto (1979) determined a stress drop for the 1958 event which was very high in comparison to events in surrounding areas of the Kurile trench.

Extensive foreshock activity occurred near the southwestern end of the rupture zone of the March 23 event (M_s=7.5). Then, about 24 hours later another M_s=7.6 event (March 24, 1978) occurred rupturing from the foreshock area to the southwest. Few aftershocks occurred within the foreshock area. It is suggested that the initial stress concentration occurred near the foreshock area to cause the extensive foreshock activity. Many large earthquakes in the Kurile Island region tend to have distinct foreshock activity, which seems to reflect the highly heterogeneous stress distribution in the region.

The foreshock area may represent a strong spot (asperity) along the subduction zone. When this asperity failed, the rupture initially extended to NE in the main shock of March 23, and subsequently to SW during the main shock of March 24.

If this model is correct, we may expect a difference in the event characteristics between the aftershocks and foreshocks, and more importantly between the early foreshocks and the late foreshocks.

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Foreshocks and Other Short-Term Precursors

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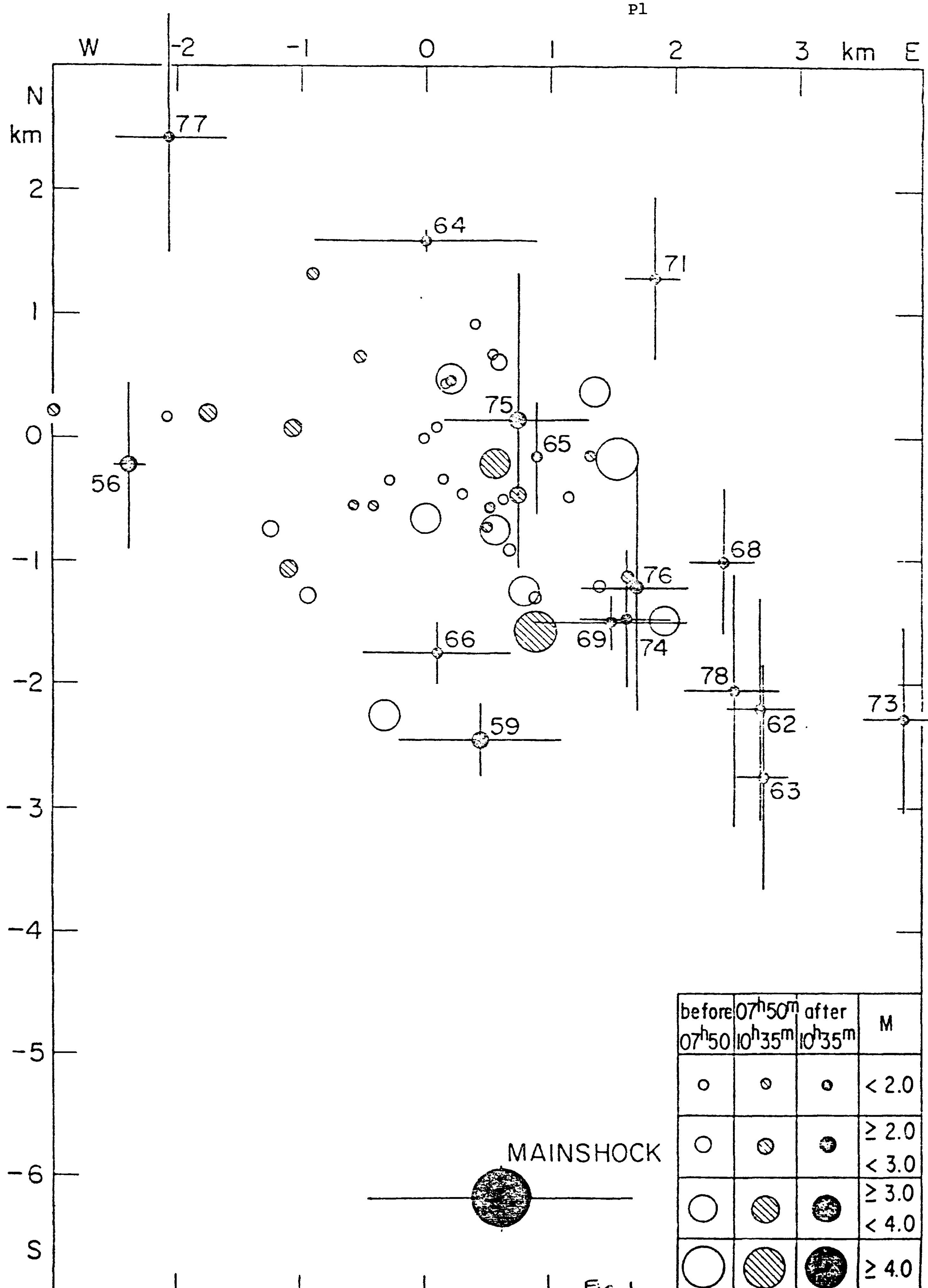
We have examined the locations and radiation patterns of the foreshocks of the 4 February 1975 Haicheng earthquake (M = 7.3). Using arrival times from six local seismic stations, the foreshocks and mainshock were located relative to a master event. The foreshocks occurred in a tight cluster that elongated with time. Before the largest foreshock, the activity was located within a small, approximately equi-dimensional volume with a diameter of about two kilometers. After the largest foreshock, the activity spread northwest and southeast, forming a six kilometer long, northwest trending zone (Figure 1). First motions and ratios of P to S amplitudes indicate that two different faulting mechanisms occurred during the foreshock sequence. The two radiation patterns can tentatively be correlated with different parts of the zone. The hypocenter of the mainshock was not located on the same fault as that defined by the foreshock's hypocenters but rather was located six kilometers south-southwest of and several kilometers shallower than the foreshock cluster. We think this large separation between foreshocks and mainshock in a direction perpendicular both to the plane of rupture of the mainshock and to the trend of the foreshocks might be the result of an en echelon step in the fault that slipped during the mainshock. An analysis of the change in stress due to slip on the possible foreshock faults shows that the increase in shear stress on the mainshock fault caused by the foreshocks can be no more than 4% of the stress drop associated with the foreshocks.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after 10h35m
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< 2.0
≥ 2.0 < 3.0
≥ 3.0 < 4.0
≥ 4.0

Fig. 1

Crustal Strain

9960-01187

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Investigations

The principal subject of investigation was the analysis of deformation in a number of tectonically active areas in the Western United States.

Results

1. A dislocation model of strain accumulation and release at a subduction zone. Strain accumulation and release at a subduction zone is attributed to stick-slip on the main thrust zone and steady aseismic slip on the remainder of the plate interface. This process can be described as a superposition of steady-state subduction and a repetitive cycle of slip on the main thrust zone consisting of steady normal slip at the plate convergence rate plus occasional thrust events that recover the accumulated normal slip. Because steady-state subduction does not contribute to the deformation at the free surface, deformation observed there is completely equivalent to that produced by the slip cycle alone. The response to that slip is simply the response of a particular earth model to embedded dislocations. For a purely elastic earth model, the deformation cycle consists of a coseismic offset followed by a linear-in-time recovery to the initial value during the interval between earthquakes. For an elastic-viscoelastic earth model (elastic lithosphere over a viscoelastic asthenosphere) the postearthquake recovery is not linear in time. Records of uplift as a function of time indicate that the long-term postseismic recovery is approximately linear, suggesting that elastic earth models are adequate to describe the deformation cycle. However, the deformation predicted for a simple elastic half-space earth model does not reproduce the deformation observed along the subduction zones in Japan at all well if stick-slip is restricted to the main thrust zone. As recognized earlier by Shimazaki, Seno, and Kato the uplift profiles could be explained if stick-slip were postulated to extend along the plate interface beyond the main thrust zone to a depth of perhaps 100 km, but independent evidence suggests that stick-slip at such depths is unlikely.

2. Magmatic resurgence within the Long Valley caldera: Possible cause of the 1980 Mammoth Lakes earthquakes. Geodetic measurements of deformation near Mammoth Lakes, California in the interval 1975 to late 1980 suggests that

the magma chamber beneath the resurgent dome within the Long Valley caldera may have expanded due to the injection of new magma in late 1979 or early 1980, inducing stresses around the caldera that may have caused the 1980 sequence of earthquakes southeast of Mammoth Lakes. Changes in elevation of benchmarks along the 37 km segment of US Hwy 395 from Toms Place to Crestview indicate a broad uplift reaching a maximum of 0.25 m near the center of the old resurgent dome. This uplift coincides quite closely with what would be expected from a 0.15 km^3 inflation of a spherical source (diameter not specified) at a depth of 11 km. Deformation of a trilateration network between Mammoth Lakes and Bishop also indicates significant displacements roughly consistent with the inflation of a magma chamber at 11 km depth, but this deformation is contaminated to some extent by the effects of the Mammoth Lakes earthquake sequence. The fact that no significant deformation was observed in the trilateration network prior to July 1979, suggests that the inflation of the magma chamber occurred in late 1979 or early 1980.

3. <u>Deformation near the epicenter of the 1980 Victoria, Mexico, earthquake.</u> A trilateration network around the nothern end of the Cerro Prieto fault and across the adjacent Laguna Salada Valley in northern Baja California was measured in 1978, 1979, and 1981. The precision of the measurements is a few parts in 10 million. Between 1978 and 1979 the principal strain rates were an east-west extension of 0.7 ± 0.2 μstrain/year and a north-south extension of 0.3 ± 0.2 μstrain/year. Relative station motion between 1979 and 1981, the period containing the M_L=6.2 earthquake occurring on 9 June 1980 near Victoria, Mexico, amounted to as much as 0.3 m. A dislocation model for the earthquake indicates that 0.5 ± 0.1 m of fault slip between 0 and 10 km depth are required to explain the geodetic observations.

4. <u>Time dependence of strain accumulation rates since 1906 along the 1906 rupture of the San Andreas fault.</u> Examination of a number of determinations of strain accumulation rate along the San Andreas fault system between San Francisco and Point Arena indicates that there is no hard evidence of any changes in rate. Data published by Thatcher for Point Reyes and Fort Ross indicate the largest changes in rate and even here the rate change is not significant (Fort Ross) or is barely significant (Point Reyes) at the 95 percent confidence level. In the vicinity of San Francisco Bay the evidence for a change in rate is also unconvincing on a case by case basis. Nevertheless the fact that 5 different comparisons of strain rate covering a variety of time periods since 1906 all indicate a decrease in strain rate suggests that in general strain rates may be declining. Finally, it is unlikely that the increase in magnitude 5 and greater earthquakes that started about 1955 was accompanied by an increase in deformation rates.

5. <u>Strain accumulation in the Shumagin Islands, Alaska.</u> A trilateration network of 38 lines located on the Shumagin Islands, Alaska was measured in 1980 and 1981. The network spans an area 30 km wide along the plate boundary and covers the region between 150 km and 250 km northwest of the Aleutian trench along which subduction of the Pacific plate occurs. The

network has 18 angles in common with a 1913 third-order triangulation survey and 5 angles in common with a 1954 first-order triangulation survey. Twenty-two of the length measurements made in 1980 were repeated in 1981. Comparison of observations over the 1913-1980 time period gave shear strain rates with a standard deviation of 0.10 μstrain/year (engineering). The 1954-1980 comparison had a standard deviation of 0.10 μstrain/year, and the 1980-1981 comparison 0.20 μstrain/year. The increased precision of the newer observations is offset by the shorter time periods. The only significant strain rate observed was for the period 1954-1980. Over this time period γ_1 (which measures left lateral shear parallel to the southwest-northeast striking plate boundary) changed at a rate -0.25 ± 0.10 μstrain/year indicating a right lateral component of slip on the thrust. Compression or extension normal to the plate boundary would be reflected in γ_2 which had a rate of 0.10 ± 0.13 μstrain/year during the period 1954-1980, not significantly different from zero. Comparisions for other time periods indicated that the strain rates are below the noise level in the observations.

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

USGS USDI 14-08-0001-19163

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Primary emphasis has been on the reduction and analysis of digital and analog data collected following the 15 October 1979 Mexicali and the 9 June 1980 Victoria earthquakes. Research has been directed toward an understanding of the differences and similarities of these two events. The most obvious differences were in the surface ruptures. The 1979 Mexicali event produced a surface rupture 30 km long, with a maximum displacement of almost 80 cm. The Victoria event, while almost of equal magnitude, produced no extended surface rupture; short segments with both small left and right lateral slip were observed, but these were perhaps associated with local ground failure. One interesting similarity between the two sequences is that in each case the rupture appears to have begun at the southern end of the zone, more or less in mid-transform fault, and propagated toward a nearby spreading center segment. Also, in each event, most aftershocks occurred in the vicinity of the spreading center, as a swarm-like sequence, while the main-event rupture zone was relatively quiescent.

Other analyses of the data from both aftershock sequences include source mechanism studies, computation of S-wave spectra for stress drop, and determination of seismic attenuation with distance in the Imperial Valley. A strain network installed just south of the Victoria main shock epicenter a few months before the event was resurveyed shortly thereafter to determine displacement at the time of the event. Study of the seismic moments released by historical earthquakes on the Cerro Prieto fault suggests that there is probably considerable strain energy still stored along its northern part.

Analyses have been made of teleseismic data from the 29 November 1978 Oaxaca and the 14 March 1979 Petatlan earthquakes. The SRO LP recordings of both events are quite similar, suggesting similar rupture processes.

Crustal Deformation Observatory
Part G

14-08-0001-19758

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Investigations

This effort consisted of a portion of the initial field testing and evaluation of a new 2-fluid tiltmeter. Because of the new concept and design of this instrument it was decided that it would be advantageous to consider a detailed comparison of the 2-fluid tiltmeter with as many other types of vertical deformation monitoring instruments as possible. The number of such instruments at Pinon Flat made that location an obvious choice. It was anticipated that this instrument would provide a measure of relative height differences between monuments 500 meters apart to an accuracy of better than 0.1 millimeters.

Results

New thermally-stable monuments have been constructed and installed at the Pinon Flat site. These monuments consist of three concentric metal tubes of approximately 7 meters length. The inner and outer tubes are of steel while the intermediate tube is of aluminum. The tubes are connected to each other in a method such that the thermal expansion of the steel tubes is offset by the thermal expansion of the aluminum tube. We installed one additional monument for an intercomparison of this new design with more conventional benchmarks that are also utilized in the area.

We have not yet begun measurements using the 2-fluid tiltmeter at Pinon Flat Observatory. Initial field tests of 2-fluid tiltmeter in central California revealed daily variations in relative height measurements as large as 1-2 centimeters. These variations have been traced to several effects, some of which have since been eliminated. The correction of the sampling sequence and more accurate calibration of reference heights and trigger levels have reduced the measurement errors to less than 1 millimeter.

The remaining error sources appear to be dominated by an effect that has, heretofore, been underestimated. The basic assumption in the 2-fluid theory is that the temperature of both fluids at any given point along the tiltmeter profile is the same. It is NOT sufficient to assume that this assumption is satisfied when the air or soil surrounding the fluid tubes is nearly uniform in temperature. Since the 2 fluids have different thermal "masses" any significant temporal gradient in the temperature of the surrounding material will result in different temperatures of the 2 fluids.

There are 2 reasons for this difference in thermal " mass ". There is a significantly different mass of each fluid per unit length of the tiltmeter, this is due to different tubing diameters that are used to provide similar dynamic responses of the fluids. There is also a difference in the specific heats of the 2 fluids and this difference changes in a nonlinear fashion with changing temperature.

There appears to be some hope that these 2 effects can somewhat offset one another by modifying to some extent the tube diameters selected. It does seem to be required that the instrument be buried to a depth sufficient to reduce temperature variations to acceptable rates. Preliminary results suggest that this depth is approximately 1 meter. If this analysis is correct the original claim for the 2-fluid tiltmeter is only partially correct; the instrument does not require level installation but it will require burial at a modest depth.

Crustal Inhomogeneity in Seismically Active Areas

9930-02231

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Investigations

The USGS Central California Microearthquake Network was established in the late 1960's. The primary mode of recording the data is on analog magnetic tapes and 16 mm Develocorder films, and the primary mode of processing these data is by visual scanning and timing of the films. The growth of the network to more than 250 stations, and the need for digital representations of the waveforms for many types of analysis, has led us to seek computer-based methods for recording and analyzing the microearthquakes that occur within the network. As reported here previously, we are using a PDP 11/34 computer system with an analog-to-digital converter to monitor various sub-areas within the larger network, and to write out to digital magnetic tape those events detected by the computer. The computer programs for this work were developed largely by Carl Johnson of the USGS Pasadena office. During this report period we have monitored routinely a 61-station configuration within the larger network, have ordered and received various types of computer hardware to increase the speed and capacity of the PDP 11/34 computer, and have made some program changes for special purposes.

The digital tapes written by the 11/34 have been processed on the UNIX PDP 11/70 computer, largely by and under the direction of Bob Dollar. It has long been apparent that, for a network configuration larger than 61 stations, more computer time would be needed for the data processing task. By the latter part of this report period, a PDP 11/44 system was delivered and installed. It will be dedicated to processing the earthquake data that is recorded by the 11/34 computer.

W. H. K. Lee and S. W. Stewart completed the final details on their book "Principles and Applications of Microearthquake Networks".

Results

Although the PDP 11/34 online computer has been dedicated to monitoring the seismic stations around the Parkfield area, during the summer of 1981 we also monitored a 14-station array around The Geysers region for Dave Oppenheimer. The computer detection algorithm worked particularly well for this region, particularly when the telemetry lines into Menlo Park were relatively noise-free. This may be due in large part to the impulsive nature of the events, and the close station-spacing. Significant upgrading of the capability of the 11/34 computer is underway. The 512-channel, high-speed Tustin analog-to-digital converter was received. Grey Jensen checked it out and interfaced it to the computer. I wrote a simple test routine for it, and now we are in the process of bringing it online and into routine operation. The initial plan is to monitor about 150 stations, using Carl Johnson's more recent version of the earthquake detection and recording program.

The memory capability and execution speed of the 11/34 will be enhanced by adding more memory boards, and a 2 kbyte high-speed cache memory system. These items were recently received, but are not yet installed. I have been delving into the innards of the RSX-11M operating system by writing and adding some simple options to the online program, and by taking some specialized programming courses offered by the computer manufacturer.

Reports

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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 field experiment, carried out co-operatively with the National Geodetic Survey (NGS), to investigate the effect of unequal refraction on geodetic leveling measurements from southern California.

2. A model study on the surface deformation effects of periodically recurring earthquakes in subduction zones.

Results

1. A field test was conducted in Southern California during May and June of 1981 to study differential refraction over a 50 km long leveling line with a 1.5% grade. Sections were double-run with 42 and 24 m average sight lengths (L). Temperatures at 0.5, 1.5, and 2.5 m above the ground were recorded during every set-up, along with ground type, cloud cover, and wind velocity. The mean temperature was 28°C, and the mean 0.5-2.5 m temperature difference ($\overline{\Delta T}$) was 1.07°C, and the vertical temperature gradient was consistently non-linear.

   The cumulative divergence between long (ℓ) and short (s) sight length height differences, (dh_ℓ-dh_s), was -40.2 mm over the maximum height difference of 612 m. Testing for linear height-dependence of dh_ℓ-dh_s showed a weak benchmark-to-benchmark correlation. For forty-six sections where the ground type was gravel or sand, Kukkamaki's balanced sight equation without slope corrections,

$$dh_\ell - dh_s = \gamma(\overline{\Delta T_\ell}\,\overline{L}^{\,2}_\ell - \overline{\Delta T_s}\,\overline{L}_s^{\,2}), \qquad (1)$$

   provided an excellent fit, with $\gamma \simeq 1.3 \times 10^{-8}$ °C^{-1} m^{-2}. Observations obtained under clear and cloudy conditions showed no significant departure from (1). For the fifteen sections leveled over sparesely vegetated ground, soil, concrete, and asphalt, the fit to (1) was poor. This may be caused by unmodeled air stratification, or a larger component of random error for some of these sections. ΔT was not correlated with observed wind velocity, which ranged from 0-5 m/s. This test demonstrates that in southern California atmospheric refraction can accumulate with a magnitude significantly in excess of random leveling errors. [R. S. Stein, W. Thatcher (USGS); W. E. Strange, S. R. Holdahl, C. T. Whalen (NGS)].

2. Vertical displacements due to periodic thrust earthquakes (recurrence interval T) in an elastic plate (thickness H, shear modulus μ) overlying a Maxwell half-space (viscosity η, relaxation time $\tau = 2\eta/\mu$) are computed and compared with observations. Strain is accumulated essentially via the elastic dislocation mechanism proposed by Savage et al (EOS, 62, 404, 1981), but effects due to asthenospheric flow are included as well. The cumulative deformation between successive earthquakes is the same for both elastic and viscoelastic models, but for the latter the movement history through the cycle depends sensitively on T/τ and D/H (D is the maximum depth of faulting). For T/τ small ($\lesssim 1$), viscoelastic and elastic cycles are similar. However, disparities grow for increasing T/τ, with greater viscoelastic movements relative to the elastic solution early in the cycle and correspondingly less in its later stages. Early postearthquake deformation occurs in contrasting modes depending on whether or not the entire lithosphere ruptures coseismically. For D/H $\lesssim$ 0.8 deformation above the lower edge of the coseismic fault shows subsidence early in the cycle and uplift later. For D/H $\simeq$ 1 the reverse is true, and strong postseismic downwarping occurs further "inland" as well. The second case corresponds better to movements observed landward of subduction zones. Comparison with the observed deformation cycle in southwest Japan (~1890-1980) suggests viable alternatives to our earlier models for the 1946 Nankaido earthquake. One such alternative includes lithosphere-wide faulting, postseismic uplift due to asthenospheric relaxation, and $T/\tau \simeq$ 20, implying an asthenospheric viscosity of 10^{20} Poise or less. (W. Thatcher and J. B. Rundle).

Reports

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Stein, R. S., 1981, Discrimination of tectonic displacement from slope-dependent errors in geodetic leveling from southern California, Proceedings, Fourth Maurice Ewing Symposium on Earthquake Prediction, 441-456.

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Thatcher, W., 1981, Crustal deformation studies and earthquake prediction research, Proceedings, Fourth Maurice Ewing Symposium on Earthquake Prediction, 394-410.

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Field Experiment Operations

9970-01170

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Investigations

This project performs a broad range of management, maintenance, field operation, and record-keeping tasks in support of seismology and tectonophysics networks and field experiments. Seismic field systems that it maintains in a state of readiness and deploys and operates in the field (in cooperation with user projects) include:

a. 5-day recorder portable seismic systems
b. Smoked paper-recorder portable seismic systems
c. Seismic refraction trucks
d. "Cassette" seismic refraction trucks
e. Portable digital event recorders

This project is responsible for obtaining the required permits from private landowners and public agencies for installation and operation of network sensors and for the conduct of a variety of field experiments including seismic refraction profiling, aftershock recording, teleseism P-delay studies, volcano monitoring, etc.

This project also has the responsibility for managing all radio telemetry frequency authorizations for the Office of Earthquake Studies and its contractors.

Results

Seismic refraction. A major seismic refraction study was done in the Mt. Shasta - Modoc Plateau area in extreme northern California. Five profiles were shot; one east-west and four northwest-southeast. A total of 26 shots were fired and recordings were made at 600 sites using the seismic cassette recorders. Approximately 2,600 records were obtained. Another seismic refraction study was completed in the San Joaquin Valley. One profile was shot between Stockton and Los Banos and the record profile extended from Mt. Hamilton to the Sierra foothills just north of Yosemite Valley.

Portable networks. Six 5 day recorders were deployed in the Imperial Valley for an aftershock study lasting 2 weeks. All seventeen 5-day recorders were operated in the Mt. Shasta - Modoc Plateau area from early June through mid-October. Sprengnether digital recorders and 11 Terra Tech digital recorders were operated in a 6-week experiment in the Sargeant Fault - San Andreas Fault area near San Juan Bautista.

Data Processing Center Operations

9970-01499

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Investigations

This project has general housekeeping, maintenance and management authority over the Earthquake Prediction Data Processing Center. Its specific responsibilities include

1. day-to-day operation and performance quality assurance of 5 network tape recorders,

2. day-to-day management, operation, maintenance, and performance quality assurance of 2 analog tape playback stations,

3. day-to-day management, operation, maintenance and performance quality assurance of the USGS telemetered seismic network event library tape-dubbing facility (for California, Alaska, Hawaii, Oregon, and Yellowstone National Park), and

4. projection of usage of critical supplies, replacement parts, etc., maintenance of accurate inventories of supplies and parts on hand, and 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.

Study of San Pablo Bay-Suisin Bay Seismic Gap

9930-02938

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Investigations

Distribution of earthquake clusters was mapped, and one cluster at the east end of Suisin Bay was studied for geometry and for variation in source properties with depth at the base of the seismogenic zone.

Results

Most earthquake clusters occur south of the bays in clusters less than 6 km deep. Four clusters deeper than this are on a northeast trend terminated on the northeast end by a deep cluster on the Antioch fault. This cluster is in the shape of a line about 30 degrees from vertical extending from 13 to 23 km in depth. No variation in pulse width was observed.

Studies of the Seismic and Crustal Deformation Patterns of an Active Fault: Piñon Flat Observatory

14-08-0001-18398

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Investigations

Studies of crustal deformation at Piñon Flat Observatory were continued in an effort to understand better the mechanics of faulting in southern California. Four long baselength instruments and several shorter baselength instruments were operated throughout this period, each providing complementary information. The remote facilities were maintained and field assistance provided for several different geophysical instrumentation development programs.

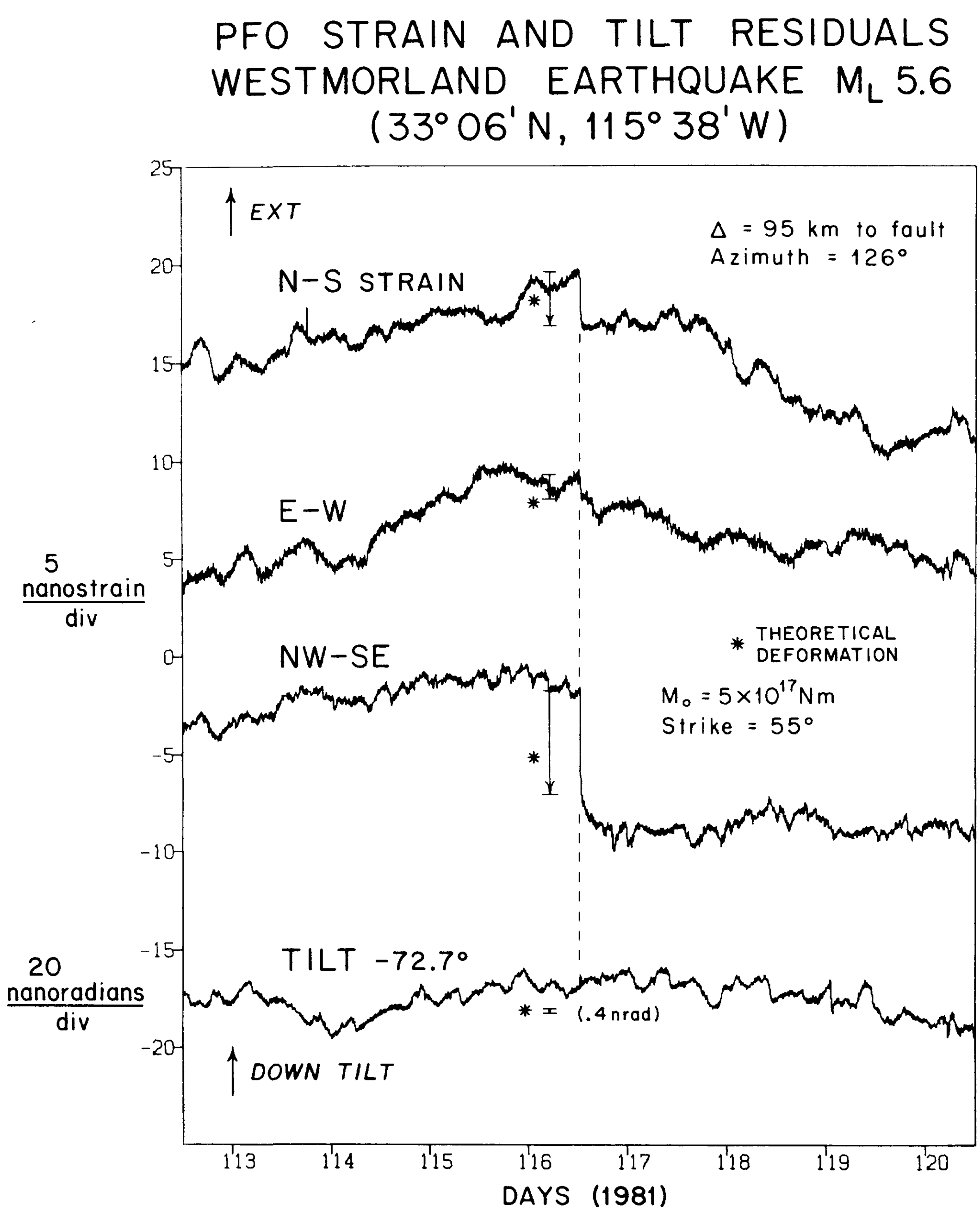
Results

A long fluid tiltmeter (LFT) began operating at the site in January, 1981. The first six months of data from this instrument have been analyzed, as well as those records from three nearby shallow (4.5 m) borehole tiltmeters, and a deeper (26 m) borehole tiltmeter. The LFT observations show a uniform down-tilt rate of nearly 1. μrad/yr towards the ESE with fluctuations no greater than .02 μrad (excluding the tidal signals). Evidence suggests that this tilt is primarily due to a gradual adjustment ($\sim$ .1 mm) of one of the reference monuments. Very shortly we will be monitoring this motion relative to the material at a depth of 27 m, using a vertical optical anchor. None of the other tiltmeters displayed tilt rates as low as that of the LFT.

On April 26, 1981, a moderate earthquake, M_L 5.6, occurred near the town of Westmorland, in the Imperial Valley, California. Though the event was some 95 km distant from the observatory, static deformations were readily observed using the long baselength instruments. Figure 1 shows the records from these instruments after removing the tidal signals (tidal amplitude $\sim$ 20 nano strain). The magnitude and sign of the coseismic strains vary considerably among the records. This pattern is remarkably consistent with a reasonable estimate of the seismic moment and fault strike as illustrated in the figure.

Figure 2 shows the long term strainmeter records from 1971 through 1980. Also displayed are the strains calculated from the records of a USGS geodetic array centered at Pinyon Flat. Both techniques indicate similar strain rates for the North-South and East-West components up to the end of 1978. At that time the strainmeter records show an offset and a change in trend. While the significance of the offset is questionable, we believe the increased strain rates are meaningful. In 1979 the Northwest-Southeast strainmeter was modified, with the addition of an optical anchor at the northwest end. (We are currently installing a similar device at the southeast end.) The agreement between the two techniques is very good since that time. Efforts are continuing to reduce the low frequency instrumental noise to allow more accurate determination of crustal deformation.

Figure 1.



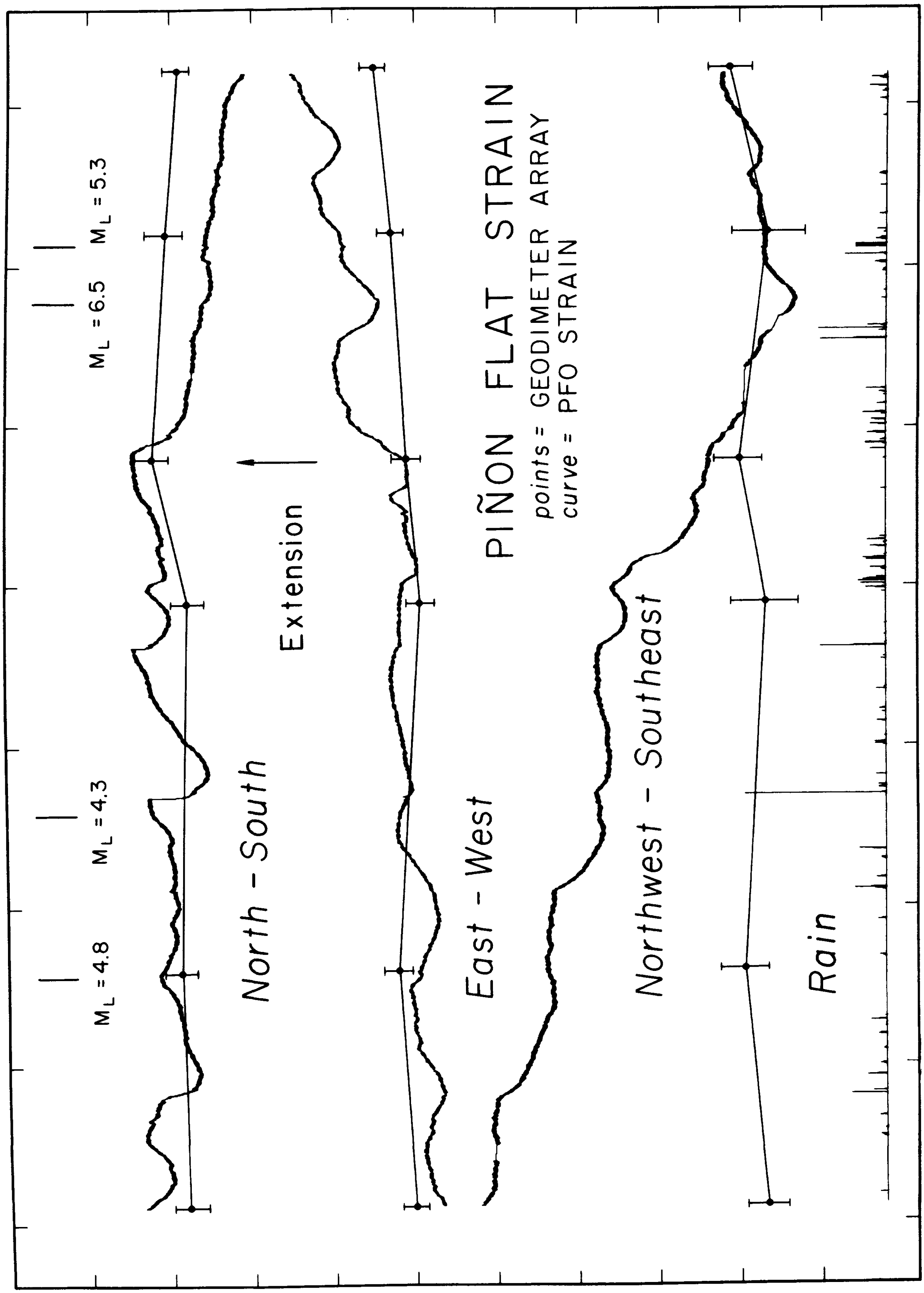

PIÑON FLAT STRAIN
points = GEODIMETER ARRAY
curve = PFO STRAIN
North - South
East - West
Northwest - Southeast
Rain
Extension
$M_L = 4.8$
$M_L = 4.3$
$M_L = 6.5$
$M_L = 5.3$
$10^{-6} \frac{\epsilon}{div}$
$10 \frac{cm}{div}$
1974
1975
1976
1977
1978
1979
1980
1981

Figure 2.

Crustal Deformation Observatory
Part D - Data Logging Facilities

14-08-0001-19762

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Under this contract support was provided to independent investigators conducting research at Piñon Flat Observatory and to record the observations.

Accomplishments (November 1980 - May 1981)

1. In cooperation with Dr. Gerald Cabaniss, of the Air Force Geophysics Laboratory, an Arthur D. Little biaxial borehole tiltmeter was installed in a 26 m deep borehole. Signal and power wiring, preamplifiers, amplifiers, and temperature sensors were connected through to the data logging facility.

2. Dr. Roger Bilham, of Lamont-Doherty Geological Observatory, completed the fabrication of an equipotential-surface long fluid tiltmeter. Three large A frame enclosures were constructed above the existing instrument vaults. Assistance was provided in maintaining the instrument on a weekly basis.

3. Under the direction of Leighton and Associates, nine holes were bored for Dr. Bruce Clark, Dr. Arthur Sylvester and Dr. Larry Slater.

4. NASA sponsored the construction of an ARIES/JPL observation platform. The work was conducted by UCSD personnel. Following the completion of this facility it was occupied by a Satellite Doppler Survey team of the National Geodetic Survey and the 3 m ARIES antenna.

5. Dr. Larry Slater was aided in the installation of three temperature compensated (6 m deep) reference monuments for a two-fluid tiltmeter. Pads were built for the instrument enclosures.

6. Tim Owen, Cambridge University, installed the final components of a pressure-differential long fluid tiltmeter. Preamplifiers and receivers were connected to the recording equipment.

7. Negotiations were conducted to secure the funds necessary to drill three 244 m deep boreholes at PFO for Dr. I. Selwyn Sacks' (Carnegie Institution) volumetric strainmeters.

8. Data from three field recorders were decoded, inspected, and stored on 9-track magnetic tape in our La Jolla Laboratories. One of the recorders was upgraded to accept 32 channels of data. Instrument records were forwarded to appropriate investigators.

Precursory Seismicity Patterns

14-080001-19757
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The world catalogue of earthquakes is not homogeneous for the time period 1963-1980. We found that more small events were reported during 1963-1968 per unit time, than at any time thereafter. In recent years 50% fewer earthquakes are reported for $M<4.5$ compared to 1963-1968. This decrease of detection capability causes problems in research aimed at detection of seismicity rate changes. We therefore made a detailed study of the homogeneity of the world seismicity catalogue.

The discovery that man made seismicity decreases contaminated the catalogue forced us to re-analyse the seismicity in some of the areas we had studied. In each region the minimum magnitude which was not affected by the detection decreases was determined by the use of magnitude signatures. Then rate fluctuations were studied using only those events with $m \geq m_{min}$. The areas in which reexamination of the data were done are: Kurile, Tonga, Aleutian and New Hebrides island arcs.

Earthquake and Seismicity Research Using SCARLET and CEDAR

Contract No. 14-08-0001-19270

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Investigations

Research supported wholly or in part by this contract during the six-month reporting period has concentrated on:

1. Waveform studies of preshocks and aftershocks of the 1979 Imperial Valley earthquake.

2. Analysis of variations in the depth of the seismic zone in Southern California.

3. Relative array diagram analysis of upper mantle lateral velocity variations in Southern California.

4. Studies of the 4/26/81 Westmoreland earthquake (M_L 5.7) and the 9/4/81 Santa Barbara Island earthquake (M_L 5.3)(See reports by C. R. Allen, Contract No. 14-08-0001-19268 and C. E. Johnson, Contract No. 9930-01174 for a summary of results).

Results

1. Waveforms of M_L 2.0-2.8 preshocks of the 10/15/79 Imperial Valley earthquake (M_L 6.6) recorded digitally since 1977 show that in comparison to aftershocks with similar magnitudes and locations, the preshocks originated from a relatively small number of highly localized sources. 8 preshocks from a 4-1/2 by 1-1/2 km box centered 4 km SE of the mainshock epicenter have remarkably similar waveforms over the entire record length ($\sim$30 sec), with an average correlation between seismograms of consecutive events of 0.74 (Fig. 1a). This suggests similar source mechanisms and hypocenters within 1/4 of the dominant wavelength, i.e. < 250-500 m (Geller and Mueller, 1980). 5 aftershocks from the same box show an average correlation between seismograms of consecutive events of only 0.24. Any associated changes in mechanism must be small because they are not reflected in the first motion data.

Ten preshocks from a 1-1/2 by 2 km source area centered along the fault 16 km NW of the mainshock epicenter were also studied. Three of these

*Semi-annual Technical Report includes contributions from J. C. Pechmann, E. J. Corbett, T. M. Hearn, M. C. Walck, J. B. Minster, L. K. Hutton and C. E. Johnson.

occurred in a swarm on 2/24/78 and 6 occurred in a swarm on 12/7-12/9/78. The events within each swarm have very similar waveforms (correlations $\geq$ 0.6) and first motions, but different from those of the other swarm and a 9/14/77 preshock (Fig. 1b). The 24 aftershocks from this area recorded without interference from other events exhibit a variety of waveforms and some variability in first motions. Although there are groups of like events, no more than 2-3 consecutive aftershocks have correlations $\geq$ 0.6. These observations are consistent with the hypothesis that small earthquake activity is concentrated along fault asperities which decrease in number as the weaker ones fail under increasing stress during the intervals between large earthquakes.

2. Earthquake locations with quality "A" designation determined using the CEDAR system (1977-1981) have been used to study the depth distribution of earthquakes in Southern California. We find that the bottom of the seismic zone varies between 10 and 20 km. North-dipping structures are evident within the western Transverse Ranges. Areas of deeper seismicity (15-20 km) include San Bernardino Valley-San Gorgonio Pass, the northern San Jacinto fault, and the Malibu area. In contrast to this the Mojave has very little activity deeper than 10 km and none deeper than 15 km. An abrupt change in the depth of the seismic zone from 20 to 10 km occurs beneath the San Bernardino Mountains. We tested the quality of the data set in this region by creating synthetic travel times using various flat-layered velocity models and applying the location procedure to them. These tests suggest that most quality "A" locations are within 1 km of the true epicenter and 2 km of the true depth. Although possible systematic errors due to lateral velocity variations still need to be investigated, we believe it is unlikely that location errors can account for the major features found in this study.

3. Spatial averaging of short-period teleseismic P-wave arrivals across SCARLET constrains upper mantle lateral velocity variations beneath southern California. We compared $dT/d\Delta$, back-azimuth and averaged arrival time estimates determined from the entire network for 154 events to the same parameters derived from small subsets of SCARLET. The resulting relative array diagrams and plots of "net subarray delays" computed for 171 overlapping subarrays exhibit large anomalies that vary smoothly as a function of subarray position, implying substantial lateral heterogeneity under the network. Patterns of mislocation vectors for more than 100 subarrays permits identification of an east-west striking high-velocity antiform beneath the Transverse Ranges. Further constraints on both the lateral configuration and depth of the anomaly are obtained through thin lens analysis of the net delay data, where all the time perturbations are assumed to originate at a single depth. Projection of 2798 net delays requires a lens deeper than 100 km. A representative lens at 150 km depth features low velocities beneath the Salton Trough as well as a concentrated high-velocity zone between 116.3° - 118.3°W and 33.7° - 34.8°N, consistent with the relative array diagrams and the PKP-delay contours of Hadley and Kanamori (1977). Therefore the bulk of the high-velocity material observed by Hadley and Kanamori may in fact lie at or deeper than 150 km rather than 40-100 km. This possibility prompts renewed speculation regarding the relationshp of this body to the plate tectonic history of the region.

Reports

Walck, M. C., and J. B. Minster. A Thin Lens Model of Upper Mantle Lateral Velocity Variations, Southern California, EOS 62 333 (abstract).

Walck, M. C., and J. B. Minster. Relative Array Analysis of Upper Mantle Lateral Velocity Variations in Southern California. Submitted to J. Geophys. Res.

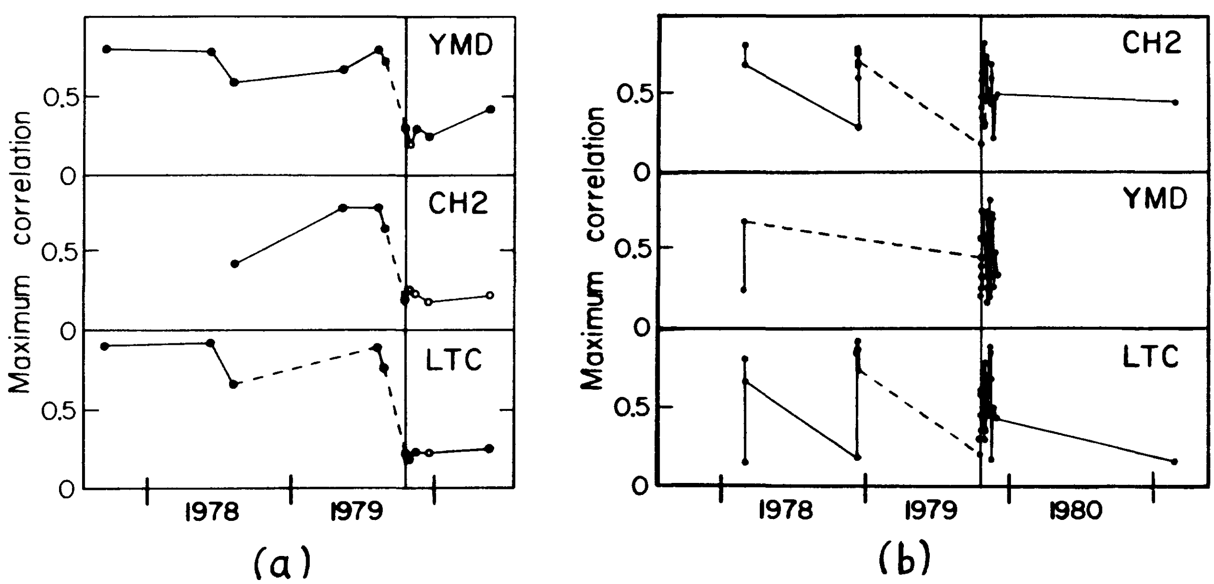

Fig. 1. Maximum correlation between the seismogram of an event and that of the previous $M_L \geq 2.0$ event within two small source areas along the Imperial fault: (a) a 4-1/2 by 1-1/2 km box centered 4 km SE of the 1979 mainshock epicenter (b) a 1-1/2 by 2 km box centered 16 km NW of the mainshock epicenter. The vertical bars mark the time of the mainshock. Approximate station distances and azimuths are: (a) YMD, 68 km, 95°; CH2, 76 km, 355°; LTC, 99 km, 11° (b) CH2, 60 km, 8°; YMD, 85 km, 105°; LTC, 88 km, 22°. Dashed lines indicate intervals containing earthquakes that could not be included in this analysis because the records were unavailable or unuseable due to interference from other events. Thirty seconds of record was used in the cross-correlation calculations. The instrument response was deconvolved in the passband 1-16 Hz from the records used for Fig. 1a.

REAL TIME MONITORING OF RADON AS AN EARTHQUAKE PRECURSOR IN ICELAND

Contract 14-08-0001-19774

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Investigations

We report radon data collected during June 1980 to May 1981 from geothermal wells in Iceland. Discrete radon samples are being collected weekly from nine stations in the Southern Iceland Seismic Zone (SISZ) and two stations in the Northern Iceland-Tjörnes Fracture Zone (TFZ) to determine the potential for earthquake prediction. We also monitor volume ratio of gas to water, wellhead temperature and chloride content of the water to enable us to constrain the possible mechanism involved in radon anomalies. One continuous radon meter installed by LDGO in 1980 is operated in the Southern Iceland Seismic Zone.

Results

The outbreak of a volcanic eruption in the Hekla Volcano was accompanied by a strain step in the SISZ recorded by the seven borehole strain meters installed within the zone. One of these is near to our radon sampling station Laugaland, where we observed a distinctive positive anomaly in both radon and chloride. Historic data indicate that eruptions of Hekla are often followed by earthquakes in the western part of the SISZ. No large earthquakes have occurred in the report period but there has been a noticeable increase in swarm activity, consisting of weak earthquakes accompanied by minor radon anomalies. We suggest that the volcanic activity of the Hekla Volcano as well as the swarm activity and radon anomalies in the SISZ are induced by a regional strain event.

Several positive radon anomalies were found to accompany swarms of earthquakes with maximum magnitudes in the range of 3 to 5 in the Tjörnes Fracture Zone.

Reports

Einarsson, P., Bjornsson, S., Foulger, G.R., Stefansson, R. and Skaftadottir, Th. (1981). Seismicity pattern in the South-Iceland Seismic Zone. Amer. Geophys. Un., Maurice Ewing Series, in press.

Hauksson, E., Goddard, J.G. (1980). Short-term radon anomalies that preceded some earthquakes in Iceland (Abstract), Third Memorial Maurice Ewing Symposium, New York.

Hauksson, E., Goddard, J.G. (1981). Radon earthquake precursor studies in Iceland, J. Geophys. Res., in press.

REAL TIME MONITORING OF RADON AS AN EARTHQUAKE PRECURSOR IN ICELAND

Contract # 14-08-0001-19747

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We present the first seven months of data from our ALOKA-continuous radon meter at Fludir. The data show no anomalies and no earthquakes have been reported. Since the deployment of instruments for continuous monitoring of eight different variables at the radon station, Fludir was recently completed. We describe in our report the instrumentation and how the data are computerized for detailed analysis.

No moderate size or large earthquakes occurred in the SISZ or the TFZ during the report period and no large changes in radon emission were observed at any of the eleven radon stations. In the SISZ the tectonic activity consisted of a minor lava eruption at Hekla in April, 1981. In the TFZ an earthquake swarm (M~2.5) occurred 25 km north of Dalvik in late January and possibly was preceded by a radon anomaly at the Dalvik station. At Krafla a minor deflation took place at the end of December and a major deflation with an accompanying eruption took place late January and early February 1981. The radon data collected during these events are presented.

INVESTIGATION OF RADON AND HELIUM AS POSSIBLE FLUID-PHASE PRECURSORS TO EARTHQUAKES

14-08-0001-19227

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This report presents new data on radon, helium, and other dissolved gases (N_2, Ar, CH_4) in thermal wells and springs along our Southern California network, for the period October, 1980, to September, 1981. Graphs of data measured from 1975 to the present can be found in the Final Technical Report (Chung et al, 1981, S.I.O. reference number 81-37).

Four monitoring sites have been of particular interest in the last two years. They are Hot Mineral Well (HMIN-2W) and Bashford's Bath Well (BASH-1W) at the south end of the San Andreas fault in the Salton Sea area, Robison's Well (ROBI-1W) on the San Jacinto fault, and Murrieta Hot Springs on the Elsinore fault.

At HMIN-2W and BASH-1W, radon increased by about 35% above the previous baselines in February, 1980. These increases were previously reported as precursory to three small earthquakes (M = 3.3, 2.9, 3.0), which occurred nearby these wells in April 1980. Since the February increase, radon at HMIN-2W has been staying at about 20% above the baseline except for two brief drops. The first drop occurred after the Imperial fault earthquake (M = 6.1) about 150 km south of the Salton Sea on June 9, 1980. The second drop in March 1981 occurred prior to the April 26 Westmorland earthquakes (a swarm of foreshocks and aftershocks with the main shock, M = 5.6, occurred at 5:09 AM local time). The radon drop took place one month before these seismic events. The radon values observed a few days before the main shock and one day after were, however, about the same, both at about 20% above the baseline. About 6 months prior to these shocks, temperature was decreasing continually while methane showed a large fluctuation. At BASH-1W, radon showed two successive peaks which might have been precursory to the Imperial fault shocks and the Westmorland earthquakes respectively. These anomalies were not observed in helium, nitrogen or argon.

At Frink Spring, helium concentration which has been increasing monotonically since 1975 at about 5% per year, now appears to have reached its "plateau". This variation pattern is not observed in other gases which have been essentially constant over the monitoring years.

Along the San Jacinto fault, Robison's Well (ROBI-1W) showed a significant increase in both helium and conductivity during June 1981. This increase was followed by two earthquakes (M = 4.0, 3.8) which occurred near Julian in the San Felipe Valley on September 3, 1981. No significant radon or nitrogen variations have been observed throughout the monitoring period although radon decreased somewhat in June. On the Elsinore fault, radon and helium variations at Murrieta Hot Springs are quite similar to each other. A peak about 20% above baseline was observed prior to the Julian earthquakes.

During December 1980 and January 1981, two Chinese scientists (Shi Huixin and Mu Song Lin) visited our laboratory and participated in our field work as well as sample analysis in laboratory. In July 1981, another Chinese scientist (Cai Zuhuang) joined us for six weeks. He has studied and worked on our earthquake prediction program for future collaboration and mutual benefits. He and H. Craig have also concluded their preliminary joint study on the geothermal fluids of the Yangbajin geothermal field, Tibet.

DEEPWELL MONITORING ALONG THE SOUTHERN SAN ANDREAS FAULT

Contract No. 14-08-0001-19759

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Water level monitoring continues at twelve deepwell sites along the San Andreas Fault between Gorman and San Bernardino. All variations in water level can be related to meteorological effects. Groundwater turbidity is being monitored at three sites. No anomaly in groundwater turbidity has been observed. Bottom-hole temperature monitoring is underway at the same twelve sites that are being monitored for water level, plus two additional deep well sites. Bottom-hole temperatures have remained stable at the 0.01°C level at all sites except Del Sur where there is a minor fluctuation. Figure 1 is a plot of recent data from Del Sur.

We have recently completed development of a new water level monitoring package using the Foxboro pressure transducer. This new unit, ∿ 25% of the cost of our original sensors, is now being deployed at several new sites near Palmdale.

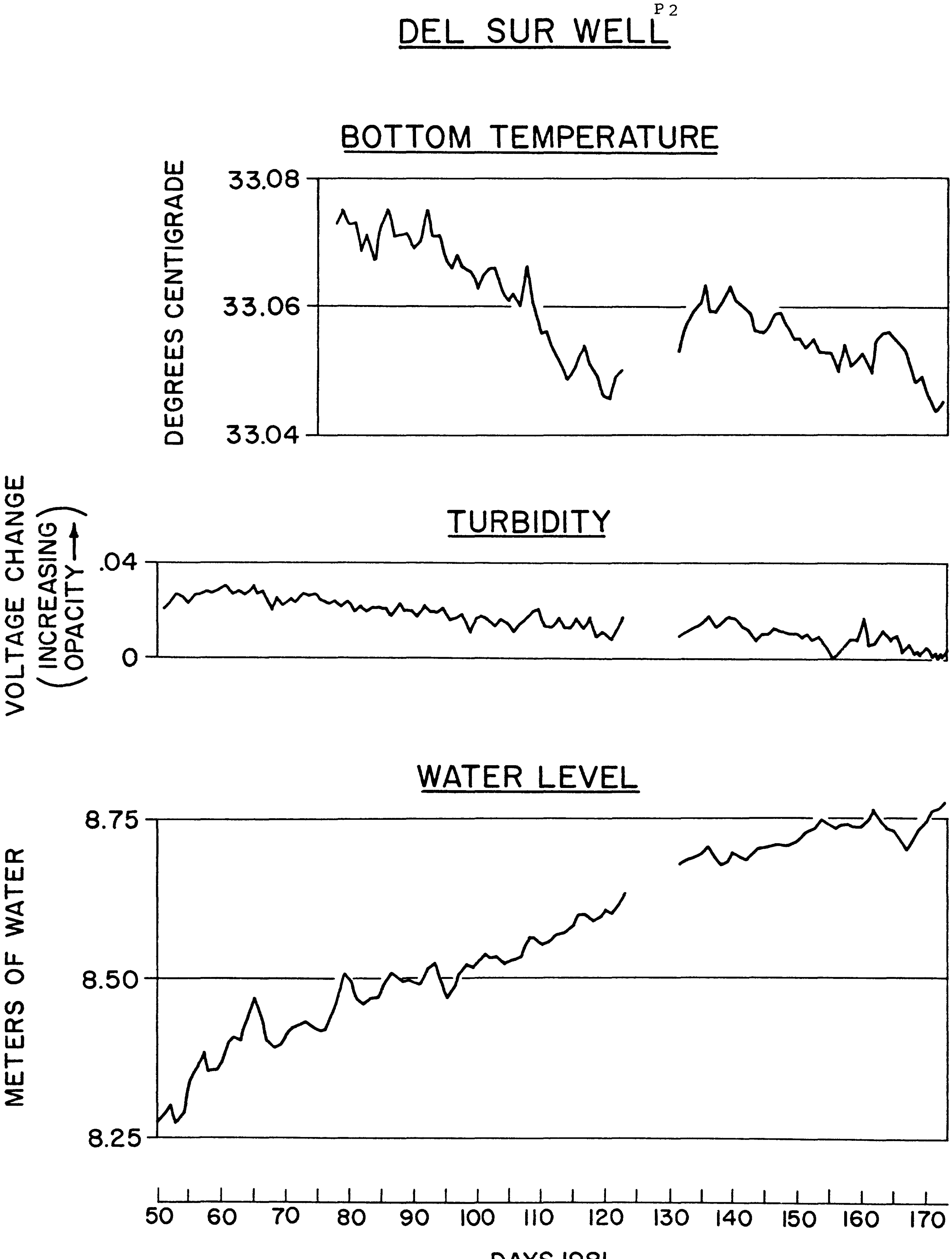

Figure 1. Groundwater level, groundwater turbidity, and bottom hole temperature at the Del Sur site near Palmdale during days 50-175,1981.

Low Frequency Data Network

9960-01189

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Investigations

1. Continued collection, 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. Development and enhancement of innovative computer controlled monitoring and telemetry systems.

3. Further development of interactive research tools.

Results

1. Data from low frequency instruments in both Southern and Central California have been collected and archived using the Low Frequency Data System. In the last six months six million measurements from 230 channels have been received and subsequently transmitted on the OES 11/70 UNIX computer.

2. 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.

3. The working prediction group of the Branch has made extensive use of the timely plots which are produced routinely by the data system.

4. A new algorithm for removing non-geophysical signals from the data which was developed earlier in the year is now has now been installed on the system. Data can now be "cleaned", removing telemetry noise and offsets due to field adjustments, and archived on a routine basis.

5. Current data is now being processed using this new algorithm in order to produce near-error-free daily records of each of the tilt and strain instruments on a timely basis.

6. Most of the necessary hardware has been procured for the expansion of the 11/03 based real-time system. A PDP 11/44 will be added along with hard disc storage devices. This will facilitate access to long term data.

7. Development has been proceeding on algorithms for detecting earthquake precursor signals in real time. An early version of such an algorithm is being installed on one of the 11/03 machines.

8. A new graphics program has been developed on the Unix 11/70 computer making possible rapid display of low frequency data on interactive graphics terminals such as the tektronix 4014. This program provides quick convenient access to all or any part of raw and processed data sets. Finished plots with scales in time and physical units may also be produced.

Reports

Cutler, R., S. Silverman, M. J. S. Johnston, and J. Herriot, 1981, Real-time Crustal Monitoring -- the On-line acquisition, Display, and Testing of Low-Frequency Geophysical Measurements along the San Andreas Fault, Earthquake Note, 52, 16-.

Magnetometer Array

8-0001-17688

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Investigations

We have carried out a laboratory program to identify and remove sources of noise in fluxgate and proton precession magnetometers.

We have cooperated with USGS and USC to carry out a field test to compare the performance of two types of vector magnetometers and two modifications of commercial scalar magnetometers within a 30 m radius.

The UCLA fluxgates are "field aligned," with the z component along the main field, the y component E-W, and the x component perpendicular to the z-component in a N-S plane. The USC cryogenics were oriented E, N, and up. Each magnetometer had its own recording system. Temperature was monitored at most of the sensors and recording packages, and temperatured was controlled by active heating for UCLA fluxgate #2.

We operated an array of three commercial proton precession magnetometers on the San Andreas fault in southern California. The array was operational from August 1978 through February 1980.

Results

We expect that the stress release during earthquakes, and possibly before and after earthquakes, should cause measureable tectonomagnetic effects. However, there have been no unambiguous observations of tectonomagnetic effects associated with earthquakes to date. One reason may be unexpected noise in the magnetometer measurements. Such noise may be of instrumental or cultural origin, or may be caused by inadequate modeling of natural geomagnetic variations. To evaluate these sources of noise, the University of California at Los Angeles has designed and tested a magnetic observatory for earthquake monitoring applications. The observatory includes a proton procession magnetometer, a vector fluxgate, a microcomputer control and data acquisition system, and a digital cassette recording system. Two complete systems were built and evaluated in conjunction with several other instruments in a closely spaced array test at a remote magnetic test facility. The commercial proton magnetometers used in the system could not measure natural variations at periods shorter than 500 seconds because of internal white noise of order 0.1 nT rms. Furthermore, these instruments are sensitive to

We have applied the multichannel prediction method to most of the USGS magnetometer array data for California through 1979. The vector data came from the magnetic observatory at Boulder, Colorado. Figure 2 shows the effect of the filtering for 15 pairs of stations. The lower trace of each pair is the unfiltered total field difference. The upper trace is the result of multichannel prediction filtering. The noise level is reduced dramatically in several cases, and the trend is significantly altered in some cases. Filtered data for 36 station pairs are shown in Figure 3. Each of the 23 USGS stations is represented in the differences. Annual variations in several of the traces is apparently caused by temperature sensitivity of the magnetic observations at some sites. The dashed vertical line indicates the time of the Coyote Lake Earthquakes in 1979. No significant coseismic anomaly is observed. There are apparent offsets of as much as 1 nT at several sites within the year prior to the earthquake, and isolated offsets of similar size at other times. The spatial coherency of these events is not sufficient to suggest that widespread geophysical phenomena cause the effects.

Publications from This Project

Ergas, R.A. and Jackson, D.D., Spatial variation of crustal seismic velocities in Southern California, Bull. Seis. Soc. Amer., 71, p. 671-689, 1981.

Davis, P.M., Jackson, D.D., Searls, C.A., and McPherron, R.L., Detection of tectonomagnetic events using multichannel prediction filtering, J. Geophys. Res., 86, p. 1731-1737, 1981.

Davis, P.M., Jackson, D.D., and Johnston, M.J.S., Further evidence of localized magnetic field changes before the 1974 Thanksgiving Day earthquake, Hollister, California, Geophys. Res. Lett., 7, p. 513-516, 1980.

Jackson, D.D., Lee, W.B., and Liu, C.-C., Height dependent errors in southern California leveling, in Proceedings of the Fourth Maurice Ewing Conference: American Geophysical Union, p. 457-472, 1981.

temperature with a peak-to-peak diurnal variation as high at 0.3 nT. Normally, these effects are masked by a residual diurnal variation in station differences as large as 0.5 nT. Effects of temperature and diurnal field variations may be removed by linear prediction filtering using the measured temperature and vector magnetic field.

We evaluated the absolute accuracy of the two field aligned vector fluxgate magnetometers. The field aligned components were sensitive to the temperature of the sensor feedback coil and the temperature of the electronics driving the coil. Both effects were easily removed by linear prediction filtering. Transverse components of the vector field are more sensitive to tilt than temperature. Linear prediction filtering from electronically measured tilts enabled us to predict the transverse components of one instrument from the field of the other to better than 1.0 nT rms. over a two week interval.

Our results suggest that near-term efforts in the monitoring of magnetic precursors of earthquakes should be devoted to improvements in instrumentation. Use of modern circuitry and microcomputer control can significantly reduce the noise level in both total field and vector measurements.

Publications Under This Contract

Davis, P.M., and Searls, C.A., Magnetic field measurements in the aftershock zone of the Coyote Lake earthquake, J. Geophys. Res., 86, p. 927-930, 1981.

Tilt, Strain, and Magnetic Measurements

9960-02114

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Investigations

Rapid changes in deformation parameters are expected before moderate to large earthquakes. We are attempting to develop a prediction capability from the analysis of continuously monitored tilt, strain and magnetic field perturbations that occur as a result of fault activity within the San Andreas fault system.

Results

1) As a result of the increased seimsic activity in the San Juan Bautista area a program of upgraded monitoring is being implemented. The includes

a) An extensive medium range geodetic network across the transition zone between the locked and creeping section of the fault. Fifty-four lines with lengths from 2 to 10 km cover the fault between San Juan Bautista and Hecker Pass. Benchmarks were installed and the majority of these lines were measured during the summer.

b) The paration for the installation of several Carnegie dilatometers in an array designed to show the two-dimensional strain gradient. Permits have been obtained for five holes. Drilling is preceeding on the third hole. Improved quality control on maintanence of existing monitoring instruments. Data is presently displayed and reviewed at least every few days.

2) The resolution of the differential magnetometer array is presently being limited by tidal contamination. The fitting and removal of tides from the magnetometer data typically improves standard deviations by a factor of two from about 0.5 nT for hourly means to about 0.25 nT.

3) The first six months of data from Carnegie dilatometers in the Mojave desert show strain rates (estimated by least squares linear regression) of 0.06×10^{-8}/day for CCSS (3 km from fault), 1.3×10^{-8}/day for BBSS (17 km) and 3.8×10^{-8}/day for AMSS (35 km). Compression is positive. These long term rates probably still reflect curing of the grout used to install the instruments.

4) As part of the U.S.-China Exchange Program, the design of the magnetometer arrays and construction of the first four sets of equipment is now complete. Installation is planned for late fall.

5) Cyclic ground loading caused by fluctuations in level of the New Melones Reservoir is being used to test whether tectonomagnetic effects are observable for conditions encountered near the San Andreas Fault System. Significant magnetic anomalies of about 1 nT were observed after nearly three years at the magnetometer site closest to the point of peak load. A significant correlation of -0.04 $\pm$ 0.02 nT/m (95 C.L.) exists between the differential magnetic field and the reservior height. Neither the piezomagnetic or the electrokinetic effect can yet be ruled out as a possible mechanism. It may be possible to determine the relative importance of the two tectonomagnetic mechanisms with future magnetic observations taken at higher water levels. Piezomagnetism should produce a negative amomaly near the entire loaded region while the electrokinetic effect should create both positive and negative anomalies of shorter wavelength.

6) At least two centers of dilation of the Mogi (1963) type appear necessary within Mount St. Helens prior to the May 18, 1980, eruption in order to satisfy deformation and magnetic measurements from April 1980 to the present. Similar overall patterns of inflation (+30 μradians) and magnetic field increase (+20 nT) occurred at distances of 5 km and greater from the center of the volcano until the first indications of extrusive dome building in mid June 1980. General deflation (-20 μradians) and magnetic field decrease (-30 nT) have subsequently occurred at this distance while intense localized deformation occurs within the crater area with each episode of dome building. Stress perturbations in excess of one kilobar from a source at a depth between 5 and 10 km could explain these data. A second, partly-coupled, shallow source in the present crater area appears to be necessary to explain the pre-May 1980 bulging (Moore and Albee, 1981) and features of the blast itself (Kieffer, 1981).

7) A linear regression of differential proton magnetometer measurements at distances from a few meters to 800 kilometers indicates a standard deviation of daily means that varies with site separation as $\sigma = a + bL$ where $a = 0.46 \pm 0.13$ nT, $b = 0.006 \pm 0.001$ and L is the site separation in kilometers. At a few meters separation, at sites with low cultural noise, the standard deviation of hourly mean data ranges from 0.06 to 0.10 nT. The present theoretical measurement limitation is 0.07 nT. For typical site separations of 10 to 15 kilometers throughout the San Andreas fault, estimates of σ for daily mean data range from 0.25 to 0.5 nT depending on the local magnetization characteristics. Correction for some local response differences can be made using Wiener filter techniques. Spectral density estimates indicate that the M_2 and other tidal components are clearly evident in all station differences and must be removed to increase the measurement precision further.

Reports

Cutler, R. and M.J.S. Johnston, 1981, An Interrogable Data Collection Node (D.C.N.): A Microprocessor Based System for Collection and Transmission of Law=Sample Rate Geophysical Data, U.S. Geological Survey Open File Report 81-762.

Dvorak, J., A. Okamura, M.J.S. Johnston and C. Mortensen, 1981, Tiltmeter and Magnetometer Measurements at Mount St. Helens, Washington: 1980-1981. I.A.V.C.E.I., Tokyo, Japan.

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Van Bruggen, C., and M.J.S. Johnston, 1981, Tectonomagnetic changes casued by dam loading - a control experiment. Trans. A.G.U. (in press).

Fault-Zone Water and Gas Studies

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Investigations

The following studies were conducted in a continuing search of hydrological and geochemical precursors to earthquakes: (1) Radon content of soil gas was monitored by the Track-Etch method at about 100 sites in California. Ten of these sites were recently abandoned. A thermoluminescence technique for radon measurement has been tried and found to be less usefull and less convenient than the Track-Etch method, and will thus not be adopted for regular usage. (2) The Continuous groundwater radon monitor at the Mission Farm Campground in San Juan Bautista has been moved to a new water well because the previous well is needed by the land owner. A second radon monitor has been returned from southern California and is being installed at the San Francisco Retreat a few kilometers southeast of San Juan Bautista. (3) Water level was continuously recorded at eight wells. (4) Water quality and chemistry were periodically measured in situ and by laboratory measurements of water samples taken from the wells. (5) Soil gas samples were periodically collected at 9 stations for M. Reimer of U.S. Geological in Denver for helium measurement. (6) Mercury content of soil gas was monitored at 9 stations (with Arizona State University).

Results

1. Large water-level increases (1.5m) were recorded at the Chabot well in Oakland, California about 5 weeks before and 3 weeks after a magnitude 4.4 earthquake on March 3, 1981 in Fremont, about 35 km from the well. Comparable water-level changes were recorded at about the same times at another well in Oakland, where water quality showed significant changes before the quake also.

2. Water level recorded at a water well in the Mammoth Lakes area showed some unseasonal increases beginning in early August, 1981, before the magnitude 5.8 Mammoth Lakes earthquake on September 30, 1981. Two of the three soil-gas radon stations in the area recorded large pre-earthquake increases in radon emanation.

3. Increased radon emanation has been recorded since late 1980 at many soil-gas radon stations deployed along the San Andreas fault system in both southern and central California, particularly along the locked segment between Frazier park and San Bernardino.

Reports

King, C.-Y., 1981, A special collection of reports on earthquake prediction: Hydrologic and geochemical studies, Geophys. Res. Lett., v. 8, P. 421-424.

King, C.-Y., Evans, W. C., Presser, T., and Husk, R. H., 1981, Anomalous Chemical Changes in well waters and possible relation to earthquakes, Geophys. Res. Lett., v. 8, p. 425-428.

O'Neil, J. R. and King, C.-Y., 1981, Variations in stable-isotope ratios of groundwater in seismically active regions in California, Geophys. Res. Lett., v. 8, p. 429-432.

King, C.-Y., 1981. Do radon anomolies predict earthquakes?, Nature v. 293, p. 162.

Water-Level Monitoring Along San Andreas and San Jacinto Faults, Southern California, During Fiscal Year 1981

14-08-0001-19253

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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 three wells and barometric pressure at one well were monitored by the Caltech Remote Observatory Support System (CROSS). Another ten wells were monitored continuously with Stevens Type F recorders, two being maintained by W.R. Moyle, Jr. of the Geological Survey. The remaining wells were probed monthly, weekly, semi-weekly or daily with the aid of volunteers. Water-level data are displayed on computer-generated hydrographs for each well. Rainfall and earthquakes are plotted on the graphs for direct comparison with water levels.

Geochemical parameters, including radon utilizing the track-etch technique, temperature, salinity and conductivity, were measured in ten selected wells at the time the water-level charts were changed. Telephone lines and protective housings have been installed on five additional wells for CROSS to monitor water level, barometric pressure, water temperature and conductivity.

Results

Several wells along the Palmdale-Valyermo segment of the San Andreas fault showed water level changes during 1979 which appear unrelated to seasonal rainfall. In previous discussions of these changes (Merifield and Lamar, 1980, 1981 ab) it was suggested that they could either be the result of a delayed response to rainfall or anomalous and perhaps related to changes in the strain pattern (Savage et al, 1981), radon activity and other geophysical phenomena (Shapiro et al, 1980) observed during 1979. With the longer term hydrographs now available, it is possible to compare seasonal rainfall and water-level changes for an additional season and better interpret the possibly anomalous water-level changes.

The solid lines in Figure 1 are the hydrographs for the wells in the Palmdale-Valyermo area which showed possibly anomalous water-level changes during 1979; the dashed lines represent the hydrograph which would have been predicted. In early 1979 water levels on the lower four hydrographs on Figure 1 rose more than would have been predicted based on seasonal rainfall variations and the long-term hydrographs. Water levels appear to have returned to normal in late 1979 and early 1980, although the possible anomalies are superimposed on long term rises of water level which persisted until middle and late 1980. In contrast, the upper two hydrographs show that water levels in these wells were lower than expected during 1979. The drops in water level during the rainy season of early 1979 appear particularly anomalous. As previously noted (Merifield and Lamar, 1980, 1981b) the wells which show an unexpected rise in water level are located west of the earthquake swarm that occurred in 1976-77 (McNally et al, 1978), whereas those which show water levels lower than would have been predicted are located east of the earthquake swarm.

No unusual water-level fluctuations associated with earthquakes were observed during the past six months. Unusual fluctuations possibly associated with a M3.6 event 3.5 km (2.2 mi) west of well 7S/3E-23B1 in Anza were reported previously (Merifield and Lamar, 1981a). No anomalous measurements of temperature, salinity, conductivity or radon activity have been recognized during the past six months.

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Merifield, P. M. and D. L. Lamar, 1980, Water-level monitoring along San Andreas and San Jacinto faults, southern California, during fiscal year 1980: Lamar-Merifield Tech. Report 80-2, Final Report, U. S. Geological Survey Contract No. 14-08-0001-18358, 77 p.

Merifield, P. M. and D. L. Lamar, 1981a, Water-Level monitoring along San Andreas and San Jacinto faults, southern California, during the first half of Fiscal Year 1981, Summaries of technical reports, volume XII, U. S. Geological Survey Open-File Report 81-833, p. 377-380.

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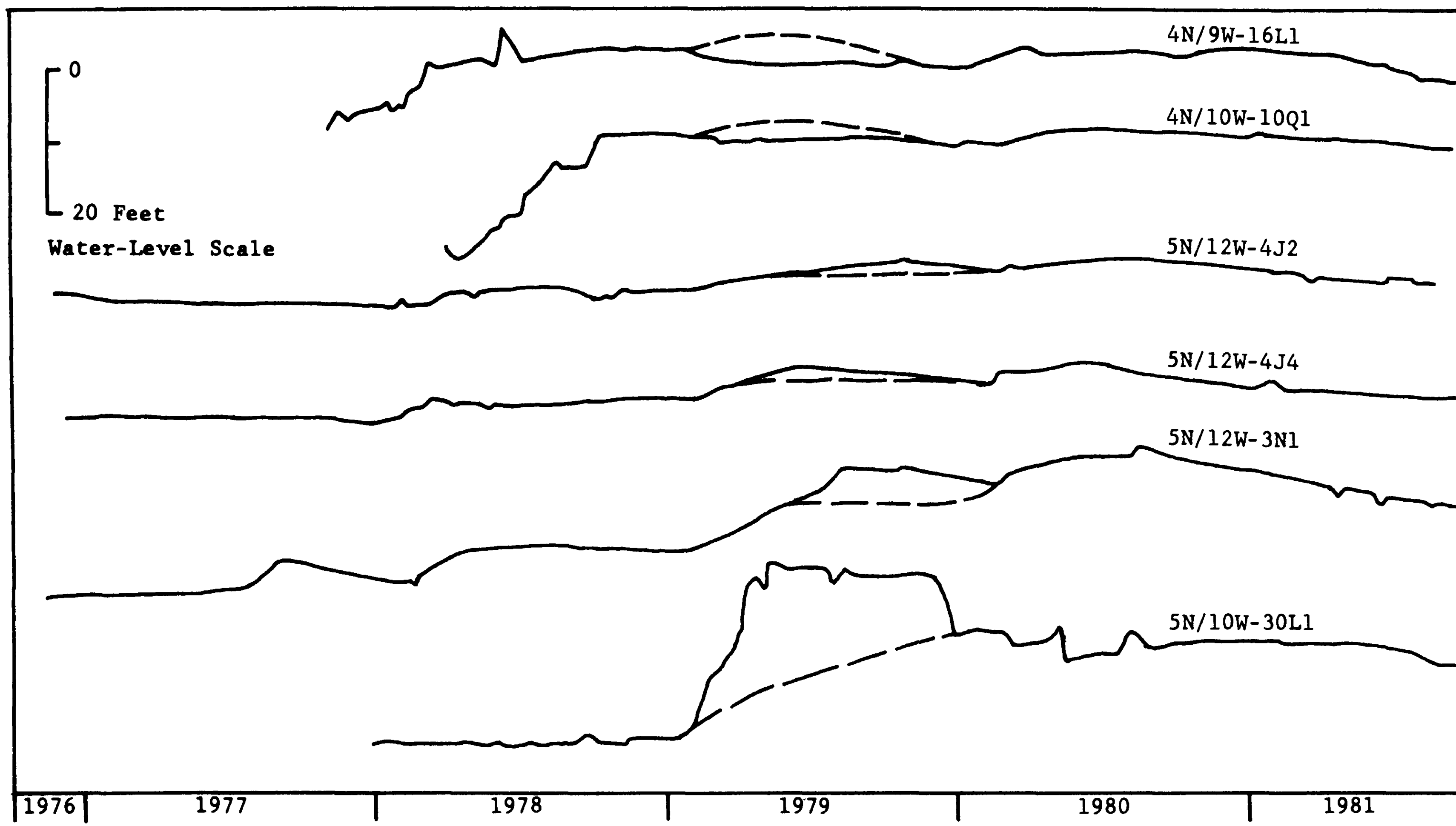

Figure 1 - Comparison of actual (solid lines) and predicted (dashed lines) water-level changes in observation wells, Palmdale-Valyermo area.

Air-gun Seismic Velocity and Attenuation Measurements in the San Andreas Fault Zone

9960-02413

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Investigations

1. Effect of tidal stress on seismic wave velocity in fractured granitic rocks adjacent to the San Andreas fault zone near Hollister, California.

2. Laboratory measurement of rock internal friction. For a detailed discussion of the results of this investigation, refer to Rocks under Geothermal Conditions, 9960-01490.

Results

Digitally recorded seismic waveforms were collected along a 600-m baseline located along a fractured granitic mass 2 km west of the San Andreas fault near Hollister, California. A 40 cubic inch air gun fired in a mud-filled pit 2 m deep provided a repeatable seismic source. The recordings from two vertical-component geophones (natural period, 0.5 s) were digitized at a rate of 600 samples/s by two Sprengnether DR100 cassette recorders modified to allow for precise synchronization of data sampling against a master clock. Relative timing is then achieved between the two instruments to within 0.04 ms for seismic data gathered during one 14-hour period, chosen to coincide with a maximum in the fortnightly tidal cycle. First arrivals of the air-gun shots were clearly recorded. Analysis of phase velocity is done by timing of amplitude extrema in a wave train constructed from the digital data by a cubic-spline interpolation. The single-shot accuracy and repeatability of traveltime is $\pm 0.04\%$ for the first high-frequency arrival after the arrival of body waves. The traveltime over the 600-m baseline achieved a maximum about half-way through the 14-hour period, and the maximum and minimum traveltimes differed by 1.7 ms (0.4% of the traveltime). Additional data will be collected over 14-hour periods at different points of the fortnightly tidal cycle to verify the tidal origin of this traveltime variation.

Report

Liu, H.-P., R. E. Westerlund, and J. B. Fletcher, 1981, Precise measurement of seismic traveltime; Variations from tidal stress?, submitted to EOS, Trans. Amer. Geophys. Union, 1981.

High Sensitivity Monitoring of Resistivity and Self Potential Variations in the Palmdale and Hollister Areas for Earthquake Prediction Studies

Contract No. 14-08-001-19249

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We are now able to detect some real changes in our telluric arrays, and it is necessary to be able to interpret these changes in order to study their relevance to the earthquake problem.

We have made a formal analysis of the comparative telluric measurement system. We have also modelled the Palmdale array sensitivity using a crustal conductance distribution that is reasonably constrained by the regional geology and which predicts the observed telluric magnitudes. Based on this analysis we plan to reprocess our entire data set, and hopefully improve our resolution as well as more clearly define the nature of the resistivity changes. Data involving dipole B in Palmdale, which was our noisiest dipole, has been reprocessed to test out these ideas as well as to test some noise editing schemes. Figure 2 shows the analysis results. Noise effects on dipole B are still evident, but a trend is now visible which could not be ascertained from the older analysis.

We have also initiated smaller-scale measurements to test their applicability as alternatives to the large arrays which need telephone lines as antennas. Four local three-dipole arrays have been set up at both Palmdale and Hollister. At these sites only the holes which locate the electrode positions are permanent. Repeat measurements are made using portable equipment. Since shorter-period telluric fluctuations are recorded, reasonable statistics can be obtained in one half hour to one hour of recording. We seem to be obtaining data of equivalent quality to that obtained on the large arrays. We will be comparing the small array results with those of the surrounding large arrays.

Reports

LaTorraca, G.A., 1981, Differential tellurics with applications to mineral exploration and crustal resistivity monitoring. Ph.D. thesis, M.I.T., Department of Earth and Planetary Sciences.


Hollister Telluric Array
W
D
B
ST
E
H
F
C
A
OS
B
P
SALINAS
20 STATUTE MILES
30 KILOMETERS
CONTOUR INTERVAL 200 FEET
DOTTED LINES REPRESENT 100 FOOT CONTOURS
DATUM IS MEAN SEA LEVEL
DEPTH CURVES IN FEET—DATUM IS MEAN LOWER LOW WATER
Bakersfield
KERN
COUNTY
Mojave
Barstow
M
O
J
Fp
Go
A
Lc
Lancaster
B
D
E
Pd
Palmdale
C
Cs
H
D
Pb
E
Cpl
LOS ANGELES COUNTY
Su
F
Az
VENTURA
COUNTY
Ojai
Santa Paula
Santa Barbara
Ventura
Oxnard
CHANNEL
0 10 20 30 40 50 km
Palmdale Telluric Array

Fig 1

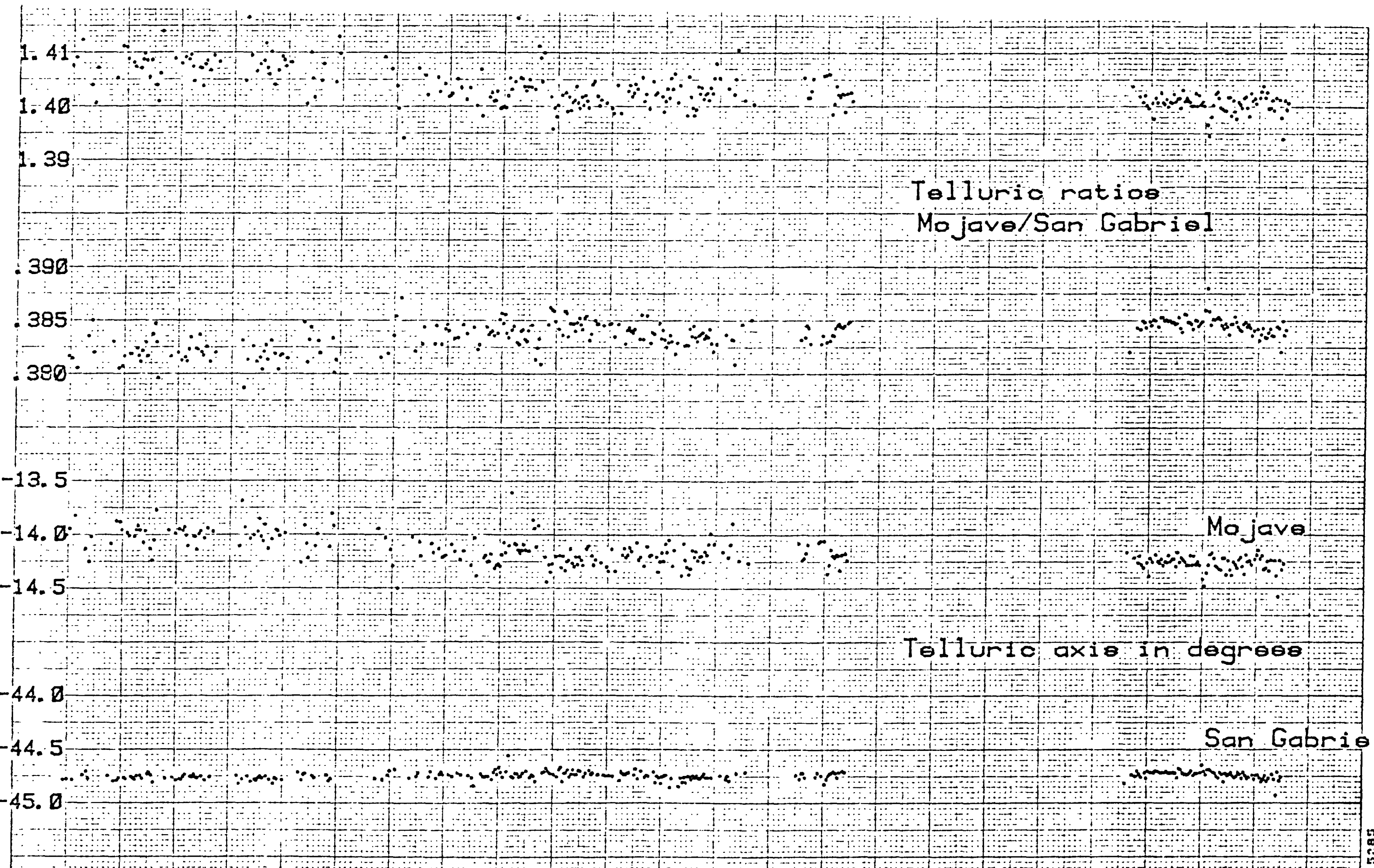

Fig 2 TELLURIC EIGENSTATE ANALYSIS on PALMDALE ARRAY

A SEARCH FOR PRECURSORY SEISMIC VELOCITY ANOMALIES NEAR PALMDALE, CALIFORNIA OVER FIXED BASELINES

#14-08-0001-19262

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Using a repeatable airgun source, we have monitored the travel times of several seismic phases along 13 and 18 km baselines from Bouquet Reservoir to boreholes on the San Andreas fault near Palmdale, California. The first arriving phases refract at a depth of 2-3 km, while one later arrival is possibly a reflection from 10 km. The majority of some 200 travel time determinations for the most prominent phases were made between August 1979 and March 1980; isolated measurements were made in November 1978 and March 1981. There exists ample geodetic and other evidence for significant strain changes during this period. Allowing for source variation due to fluctuating reservoir water levels, we, however, observed no travel time changes to the limit of our precision of ± 1-2 msec for the first arrivals and ± 3-5 msec for secondary arrivals, or about .1% of the total travel time. An earlier study which monitored rays penetrating only 500 meters into the crust found that travel times varied by up to .3% over a period of several days. The variations showed some correlation with strain changes due to local seismic activity and were not permanent. To understand this different behavior of crustal rocks between 500 and 2000 m, we investigate the depth dependence of their velocity-strain sensitivity. Using our measured P and S velocity profiles for the region to gauge the rate at which confining pressure increases velocity, we find that 1 bar of transient over-pressure at 500 meters can vary the P-velocity by .1% while 1 bar at 2000 meters will vary the velocity by only .01%. Applying the O'Connell-Budiansky physical model for cracked rock to the same velocity depth profiles we can further characterize the local crust as having a high crack density, a mobile fluid component and an average crack aspect ratio of 2.5×10^{-3}. The combination of a mobile fluid content and high crack density suggest that fluids play a role in the transient velocity anomalies observed at a depth of 500 meters.

Fault Zone Tectonics

9960-01188

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Investigations

1. Maintained and upgraded creepmeter array in California.

2. Updated archived creep data on PDP 11/70 computer.

3. Searched for large-scale coherent patterns in fault slip.

4. Studied the effects of rainfall and ground water on creep observations.

Results

1. Extensive renovations were done at creepmeters XMR1 and MRW1 at Melendy Ranch, XGH1 and XWT1 at Parkfield, and SJN1 at San Juan Bautista. Electronics were installed or upgraded at creepmeters SHR1, WRT1, and HLC1 near Hollister. Potential creepmeter sites were indentified at Hayward and Berkeley. Currently 39 extension creepmeters operate; 25 of the 39 have on-site strip chart recorders; and 19 of the 25 are telemetered to Menlo Park.

2. Fault creep data from all 39 USGS creepmeter sites on the San Andreas, Hayward, and Calaveras faults have been updated (through September, 1981) and stored in digital form (1 sample/day). A report of all data from recently operating creepmeters was completed and submitted for publication.

3. Detrended fault creep observations on the San Andreas and Calaveras faults provide evidence of spatial and temporal coherence. A pronounced increase in right-lateral slip rate beginning during 1972 is observed over approximately 70 km (perhaps as much as 90 km) of the San Andreas fault south of San Juan Bautista. The increase has been associated with several moderate (magnitude greater than 4) earthquakes between San Juan Bautista and Bear Valley, but it extends 20-40 km farther to the south. A second increase in slip rate in late 1977 - early 1978 is observed over 50 km of the San Andreas fault between Bear Valley and Parkfield, closely following two magnitude 4 earthquakes near Parkfield. Possible explanations for the large scale spatial coherence of the changes in slip rate are that:
   (1) The San Andreas fault between Bear Valley and Parkfield is freely slipping and surges ahead when the more seismically active regions to the north and south are unpinned by moderate earthquakes.
   (2) The earthquakes and creep were both caused by some kind of large regional slip or strain event.

(3) The increases in slip rate are caused by a combination of earthquakes and rainfall.

A second kind of coherence is seen over shorter distances, but between separate faults. Slip histories on the San Andreas and Calaveras faults after 1973 show similar increases and decreases in slip rate and some apparently correlated creep events. Before 1973 creepmeter records on the two faults appear to be out of phase, with the Calaveras decreasing in slip rate when the San Andreas increases in slip rate.

4. There is an apparent correlation between creep rates and rainfall at some sites. In addition, large summer creep events are seen at stations located near agricultural pumping, and it is suggested that at least some of the movement being interpreted as right-lateral in fact contains a component of either vertical and/or horizontal movement caused by subsidence or shrinkage related to dessication.

Reports

Schulz, S. S., G. M. Mavko, R. O. Burford, and W. D. Stuart, Long term fault creep observations in central California (submitted to J. Geophys. Res.).

In-Situ Seismic Wave Velocity Monitoring

14-08-0001-19251

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Investigations and Equipment Changes

Monitoring has continued of 1) first arrival travel times on nine paths crossing or adjacent to the San Andreas fault in central California, and 2) down-hole travel times in boreholes at the ends of most of the paths, to account for near-surface seasonal variations. The measurements have been made approximately twice per month with the University of California VIBROSEIS* system.

Several significant equipment repairs and changes were made in May and June 1981 to eliminate observed spurious variations in signal delay through the geophone amplifier, and suspected phase errors in the vibrator baseplate motion. In addition, an amplifier/filter system has recently been designed and built which will provide 1) much improved filtering of the geophone signal, and 2) precise matching of phase shifts induced in the geophone and reference signals prior to correlation.

Results

The measurement effort undertaken has proven to be practical with a two-man field crew in addition to scientific personnel.

The equipment improvements stabilized the travel times in June of this year, significantly reducing the 1 msec or so of scatter previously evident. Preliminary field measurements show that the new filter system will significantly decrease measurement time, due to reduction of types of noise that previously caused data collection to cease, while improving travel-time precision. Travel-time precision and accuracy approaching one part in 10^4 appear to have been achieved.

Attempts to monitor a deep crustal reflection at sites adjacent to the San Andreas fault in the Bear Valley region have been frustrated to date by severe noise problems peculiar to the site and to the geophone array used. Initial field trials of the new filter package and improved vibrator usage indicate that these measurements can now begin on a regular basis.

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* Trademark of Continental Oil Company

Experimental Tilt and Strain Instrumentation

9960-01801

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Investigations

1. Project investigators continued to operate and monitor tiltmeter and strainmeter arrays in central and southern California, totaling 56 sites, and a tiltmeter array in Alaska consisting of three doubly instrumented sites. The purpose of these networks is to provide a continuous monitor of crustal deformation near active faults in order to contribute to a thorough understanding of fault mechanics. Observed signals in the records are checked against meterological and other data to assure validity, are compared with other records to determine coherence and possible correlation with seismicity, and are tested against various fault models to estimate source parameters.

2. A number of experiments and tests, including the operation of a cluster of tiltmeters near Parkfield, California, have been completed and the capabilities and limitations of short-baseline instruments installed in shallow boreholes determined. A revised experimental strategy consistent with these results has been proposed and a substantial reduction in the numbers of instruments deployed is planned in order to accomodate a reduced budget.

3. Pairs of instruments at Icy Bay, Cape Yakataga and Yakutat, Alaska were serviced. These instruments provide an opportunity to monitor crustal deformation in an important tectonic setting.

4. The properties of various fluids were researched and tested to determine the best fluid to serve as a viscous damping medium in the long-baseline tiltmeters. After much testing the fluid selected was a high viscosity alginate with thixotropic rheology. Water softener and formaldehyde were added to sequester calcium ions and to prevent the growth of bacteria, which can precipitate the algin. This damping fluid was introduced into the prototype long-baseline tiltmeter at Stone Canyon with satisfactory results and will be introduced into the 52 m long instrument at San Juan Bautista.

Results

1. Installation of telemetry was completed for the three volumetric strainmeters in the Mojave Desert. Various tests to isolate the cause of small, transient "glitches" that appear in the records from these instruments were carried out in conjuction with Malcolm Johnston's project. To date these tests have been inconclusive.

2. Parallel data from the prototype extended-baselength tiltmeter at Stone Canyon, which is approximately 8 m long, and the adjacent short baseline instrument, demonstrate that substantial improvement in long-term stability can be achieved even with such a minor extension of the baselength. However, "ringing" of the vertical reference column in the extended baselength instrument causes a worstening of the signal-to-noise ratio for short period signals. The inertia of this column is sufficient that emersion in wate results only in an under dampened condition. Following the installation of the high viscosity damping fluid the smoothness of the data indicates that the desired degree of overdamping has been achieved.

3. Energy at tidal frequency appears in the data recorded by the tiltmeter with 52 m baselength at San Juan Bautista. However the short data set and underdamped condition of this instrument prevent good resolution. The viscous damping fluid is to be added to this instrument soon.

Stable Isotope Analyses

9740-00383

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Investigations

1. Analyses of D and ^{18}O are made of ground waters collected bimonthly at several sites along active fault systems in California with the aim of tracing changes in local hydrological regimes that precede or accompany earthquakes.

2. In a search for geochemical precursor phenomena, soil gases at several sites along the San Andreas fault are analyzed for amount and isotopic compositions of CO_2 and H_2.

3. The isotopic compositions and water contents of fault gouge are analyzed with the aim of learning the physical chemical conditions of formation and the porosity of such material.

Results

1. The most dramatic isotopic effects yet observed were seen in a suite of water samples collected biweekly from a well located on the Chabot College Campus (Hayward fault). At some time between collection periods one month and two weeks before the occurrence of a local earthquake of magnitude 3.9 on 8-15-80, the δD and $\delta^{18}O$ values dropped about 20 and 3 permil, respectively (Fig. 1). The δ-values remained fairly constant for a little over a month and then gradually increased over a four-month period to the original values. This recovery is in contrast to the lowering of δ-values that occurred at Mission Farm Campground (San Juan Bautista) prior to a magnitude 4.8 event (O'Neil and King, 1981). After over a year this latter water has not begun to return to the original isotopic ratios.

   Such changes in isotopic ratios are most easily explained as arising from aquifer mixing. Some large scale forces must create a temporary connection between two aquifers of quite different isotopic (and chemical) compositions. The "normal" δD and $\delta^{18}O$ values of -40 and -6.0, respectively, are typical of modern ground waters in this area. However, the δD and $\delta^{18}O$ values of -60 and -9.0 for the other ground water are characteristic of waters from a colder climate (Pleistocene waters?). We shall continue to analyze water samples from this "sensitive" well and search for others.

2. For over a year now we have made weekly collections and analyses of the amount and isotopic compositions of CO_2 in the soil gas from the Mission Farm Campground location in San Juan Bautista. From the $\delta^{13}C$ values of -22 $\pm$1 we know that the CO_2 is derived from decay of organic matter as expected. Not expected, however, are the extremely large variations in the amount of CO_2 with time. The samples are collected at the same time of day in an 150 cc. flask, and the data are reported as the number of micromoles of CO2 per flask of soil gas. In Figure 2 these variations are shown along with occurrences of earthquakes of magnitude >2.5 within 25 km. of the sampling site. The two earthquakes with magnitudes >4.0 (6-8-81 and 8-13-81) occurred a few days after the amount of CO_2 had gone to very low values, although more dramatic changes in CO_2 content occurred without obvious relations to seismic activity.

   The large variations cannot be caused by changes in local production rates of CO_2 and must be related to some kind of opening and closing to a source of CO_2. We shall investigate the magnitude of variations over short periods of time and continue the routine analyses for the next several months.

   Periodically we look for H_2 in these soil gases with gas chromatography. To date we have not seen any H_2, in agreement with the results of Sato and McGee.

3. Analyses of fault gouge are in progress and will be discussed in the next report.

Reports

O'Neil, J. R., and King, C.-Y. (1981) Variations in stable-isotope ratios of ground waters in seismically active regions of California, Geophys. Res. Lett., vol. 8, p. 429-432.

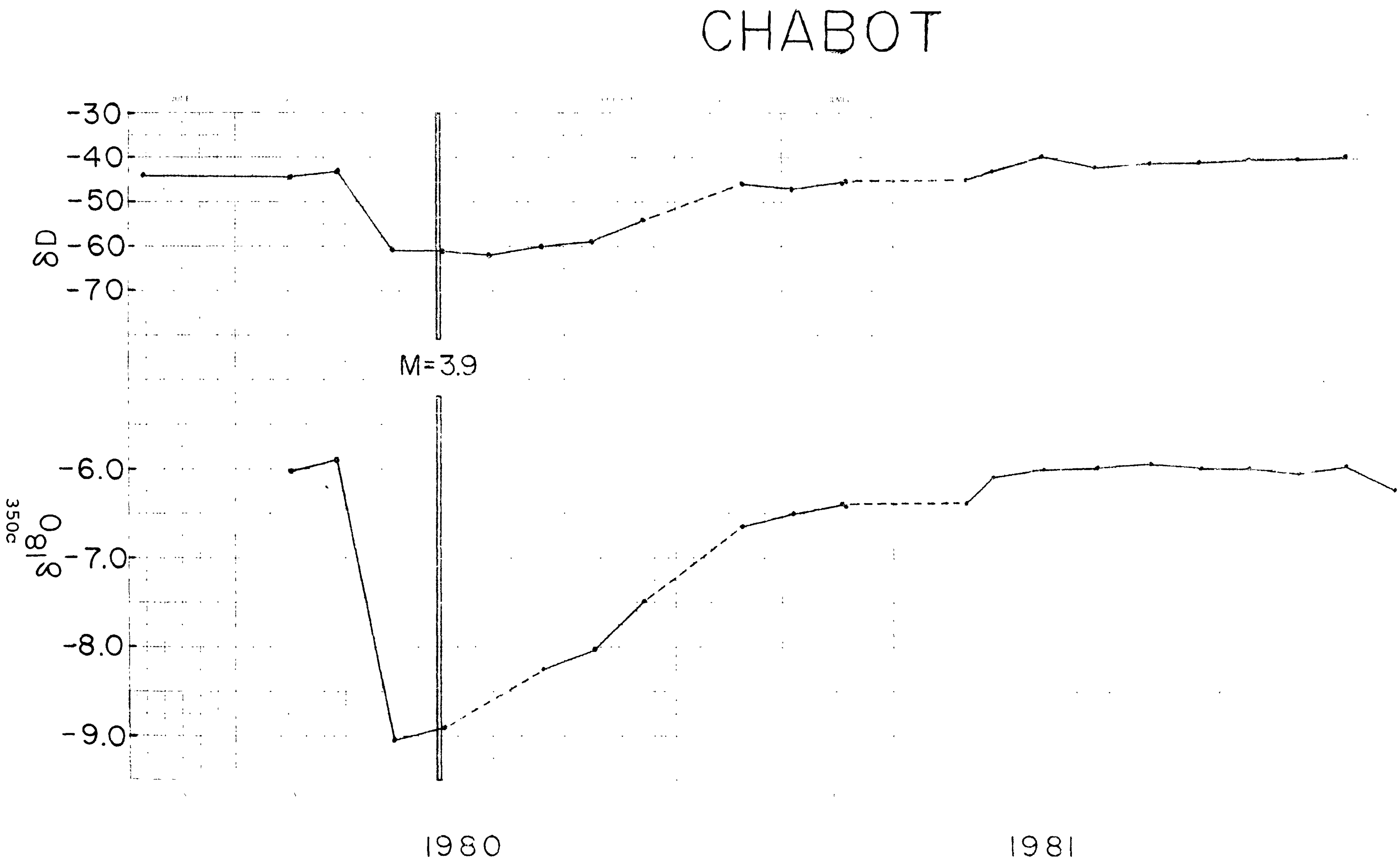

Fig. 1. Time series of δD and $\delta^{18}O$ of well waters from Chabot College. The vertical line indicates the date of a local earthquake of magnitude 3.9.

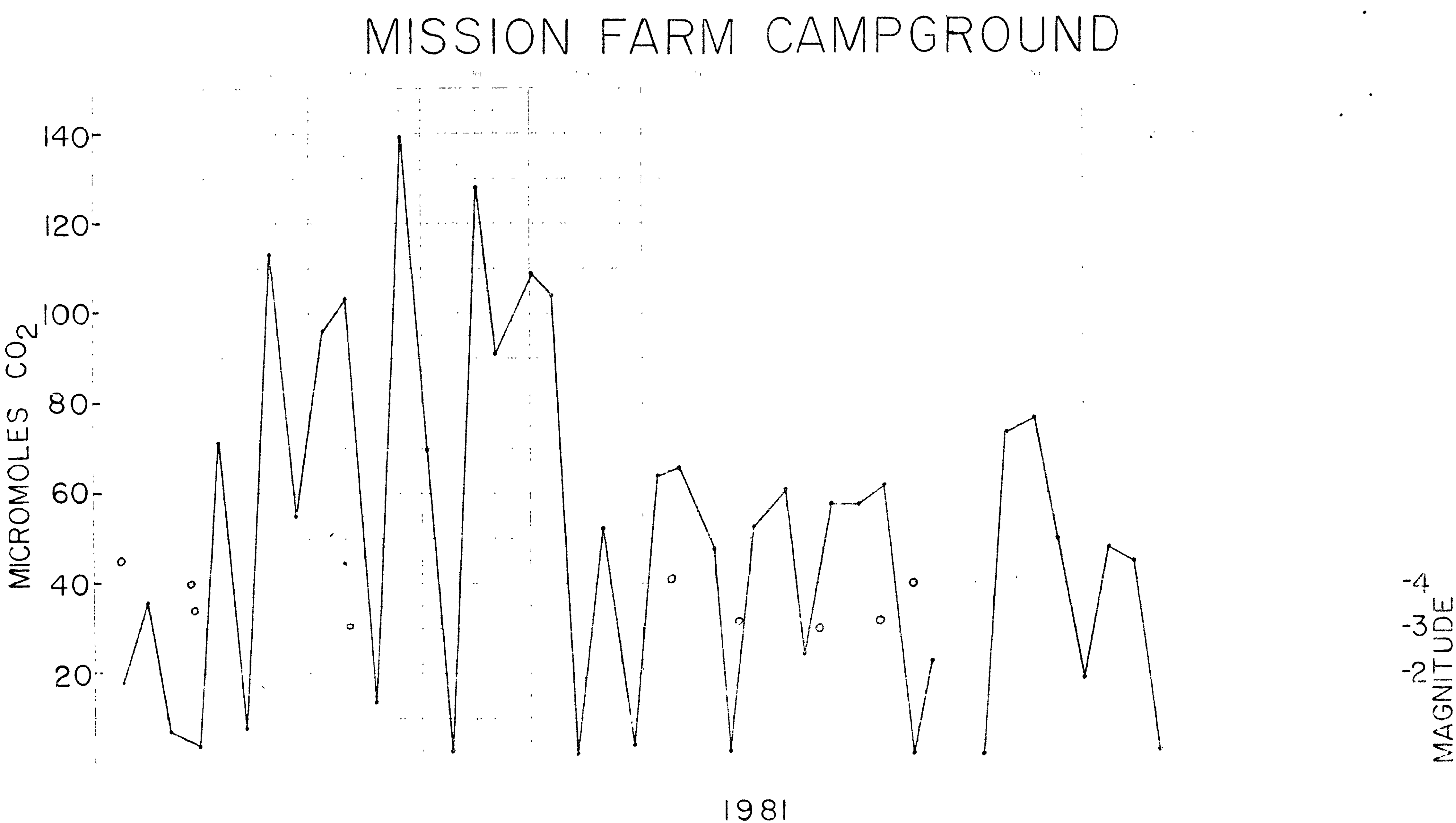

Fig. 2. Time series of relative CO2 contents of soil gas from Mission Farm Campground, San Juan Bautista, CA. Dates of earthquakes of magnitude >3.0 within a 25 km. radius are shown by the open circles.

Analysis and Evaluation of Strainmeter and Tiltmeter Data

9960-02942

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Investigations

1. Data from several taut wire strainmeters have been collected in Central California over the past 6 years. Analysis of the data is encumbered by frequent data loss and several instrumental defects. The instrument output, once cleaned of equipment effects, must be examined for meteorological and geologic-site effects. If identified such effects must be extracted as well as possible in order to observe the residual tectonic effect on datum trace. The resulting residual trace is interpacted with the goal of recognizing such patterns via physical models.

2. Surface tiltmeter data are being collected under external research contract with St. Louis University at or near sites where the USGS is collecting data from dilatometers installed at depth. These data are analyzed, much along the lines described above, in the attempt to integrate the tiltmeter data into a coherent picture of the local tectonics.

Results

Due to budget limitations the installation of tiltmeters in southern California by SLU has been postponed. At present, experiments are being carried out in St. Louis to devise a more inexpensive method of installation. Attempts are being made to install the instruments in boreholes that are narrower than what was originally anticipated. The experiments should be completed in the near future. It is hoped that instruments can be installed near Palmdale by January 1982. Attempts will be made to install the meters at about ten meters depth. The resulting records will be examined for tectonic signals that can be correlated with records from other types of instruments located nearby.

Helium Monitoring for Earthquake Prediction

9440-01376E

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Investigations

This current year will see a decrease in this project's activities because of fiscal constraints. For the present time, however, soil gas helium analyses are continuing for the the monitoring stations that have been established along the San Andreas Fault. A data base accomodating the seasonal variations has been established and all helium concentrations in the Hollister area are being compared to this base. Monitoring of helium in water from a well at the Mission Farm Campground near San Juan Bautista has begun. This is at the same well presently being monitored for radon by Chi-yu King.

Results

Helium analyses of samples taken from stations located along the San Andreas fault on the San Francisco Peninsula do not show the same variation (range) as samples collected from the Hollister area. The San Francisco area showed very little variation during the last six months compared to the Hollister region. This difference could be a reflection of a different ground water mixing pattern especially as related to changes in local crustal stresses in the two individual areas.

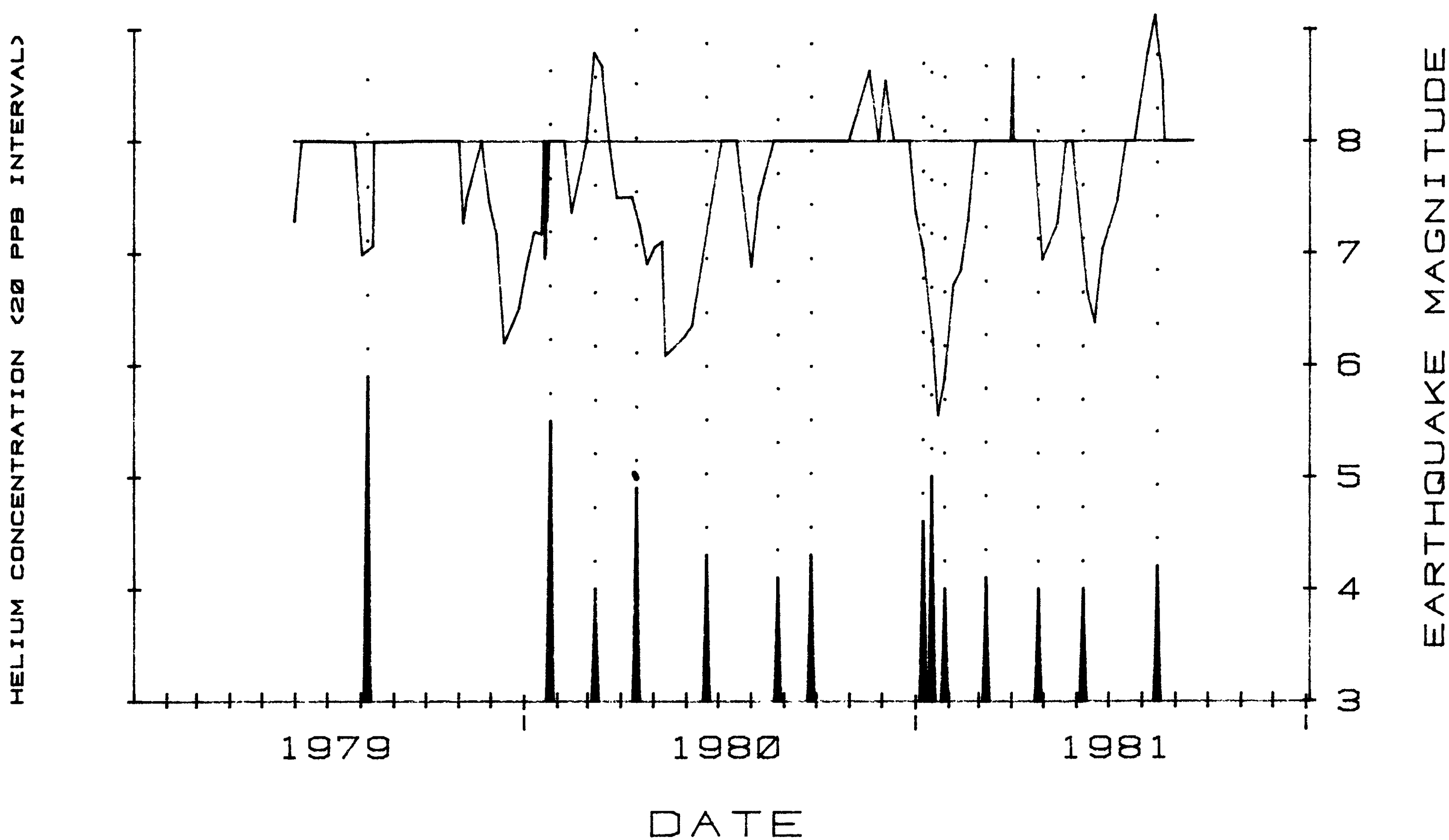
A rapid increase in the helium concentration occurred in late July and August near Hollister. A subsequent decrease has returned the concentration level to the seasonal norms anticipated from the data base collected the previous two years. This type of pattern has not been observed before and interpretation is difficult. At this time, we don't believe that change was related to the Mammoth Lake earthquake of September 30, but may be related to changes in crustal stress that may or may not be evidenced by later seismic activity.

The accompanying graph shows helium variations from the seasonal baseline and earthquakes magnitude 4 and greater that occurred within a 160 km radius of our stations during our two and one-half year sampling period. The baseline was established by first using a best-fit harmonic line for the skewed sinusoidal variation, averaged for two years. Then only the helium concentrations that exceeded a ±10 part per billion difference from the baseline were plotted. The result is a rather conservative picture considering that ±10 ppb is the analytical precision. It shows many decreases either preceding or remaining low during seismic activity. There are several increases, as well. These and the decreases may be a result of changes in crustal stress that affects ground water mixing, and in turn, is revealed as changes in the soil gas helium concentration.

Reports

Reimer, G. M., 1981, Helium soil-gas variations associated with recent central California earthquakes: Precursor or coincidence?: Geophysical Research Letters, v. 8, no. 5, pp. 433-435.

Graph showing variations from a baseline of averaged helium concentrations for soil gas samples collected near Hollister, California. The helium concentration is in parts per billion (ppb) with respect to the baseline. Also shown are earthquakes of magnitude 4 or greater that occurred within 160 km of the sampling stations. The dotted line is for convenience to reference the earthquakes to the helium concentration line.



Hydrogen Monitoring

9710-02773

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Investigations

Hydrogen gas could be generated by the reaction of rock-forming minerals with ground water when frictional stress facilitates hydration reactions of these minerals by increasing temperature or surface area. Hydreogen is extremely mobile and relatively non-reactive at ambient temperatures, and thus may prove to be one of the best geochemical indicators of the highly stressed state of the crust. We explore techniques for reliable and economical monitoring of hydrogen emission along active faults and test the techniques in the field. Ultimately, we hope to examine if anomalous emission of hydrogen occurs prior to an earthquake.

Results

During this reporting period, we have installed 5 additional hydrogen monitoring stations on the San Andreas and Calaveras faults. They are located at Carr Ranch (in Cholame Valley), Parkfield, Slack Canyon, Wright Road (in Hollister), and Shore Road (NW of Hollister), in California. Figure 1 shows the geographic locations of these stations and the first pilot station at Melendy Ranch which was established in December 1980.

The stations are all equipped with a hydrogen sensor which is a small H_2/O_2 fuel cell and which generates several millivolts per 100 ppm H_2. The stations at Carr Ranch, Parkfield, Slack Canyon, and Melendy Ranch use a solar panel to power an air pump which supplies atmospheric oxygen to the sensor. The stations at Wright Road and Shore Road use bottled oxygen to operate the H_2 sensor. The latter stations do not require electrical power, but the oxygen tank must be replaced or refilled every 6 months or so. The voltage outputs of the H_2 sensors are telemeterd to Menlo Park via the digital telemtry network maintained by the Branch of Network Operations, Office of Earthquake Studies.

At present, the data are extracted from the OES Unix computer system and plotted once a week by Sandy Schults, Branch of Tectophysics, in Menlo Park. An example of such plots is shown in Fig. 2. Attempts have been made to transfer the data stored in the Menlo Park Multics sytem via a phone line to Reston for data processing, but a few wrinkles still need be ironed out.

Sato visited the Yamasaki fault and the Negoro fault in central Japan with Prof. H. Wakita and the members of his group at the University of Tokyo in September 1981 at their invitation. Dr. Wakita published a paper in Science (1980) about abnormally high concentration of hydrogen (up to 3 %) found along the Yamasaki fault. His group had also found similarly high concentrations of H_2 along the Negoro fault and other active faults in Japan. Sato had not found such a high concentration of H_2 along the Californian faults, and was curious to find the reason for the difference.

Working with the Wakita group, Sato directed the installation of a hydrogen monitoring station on the Yamasaki fault in an underground tunnel dug for the explicit purpose of conducting scientific studies of the fault. The sensor output was telemetered to Kyoto University via a phone line.

It turned out that the H_2 concentraion was extremely high (at least several hundred ppm) when a hole was dug in the tunnel using a power drill, but then the concentration declined steadily to tens of ppm within a day. Further examinations on other sites on and off the fault appeared to have indicated the following. (1) Hydrogen may be generated, partly, by the drilling operation itself. The fast drilling produces a considerable amount of heat and freshly ground surfaces of rock-forming minerals and of the metallic drill bit. The reaction of water with the minerals and the drill bit can produce hydrogen.
(2) The faults in Japan are very wet and clayey, due to the wet climate of the country. Wet clay is impervious, and could retard the escape of hydrogen ascending from a depth, creating a high H_2 concentration zone near the surface. The Californian faults are dry and full of cracks in many places at least near the surface, making the escape of hydrogen relatively easy at shallow depths.

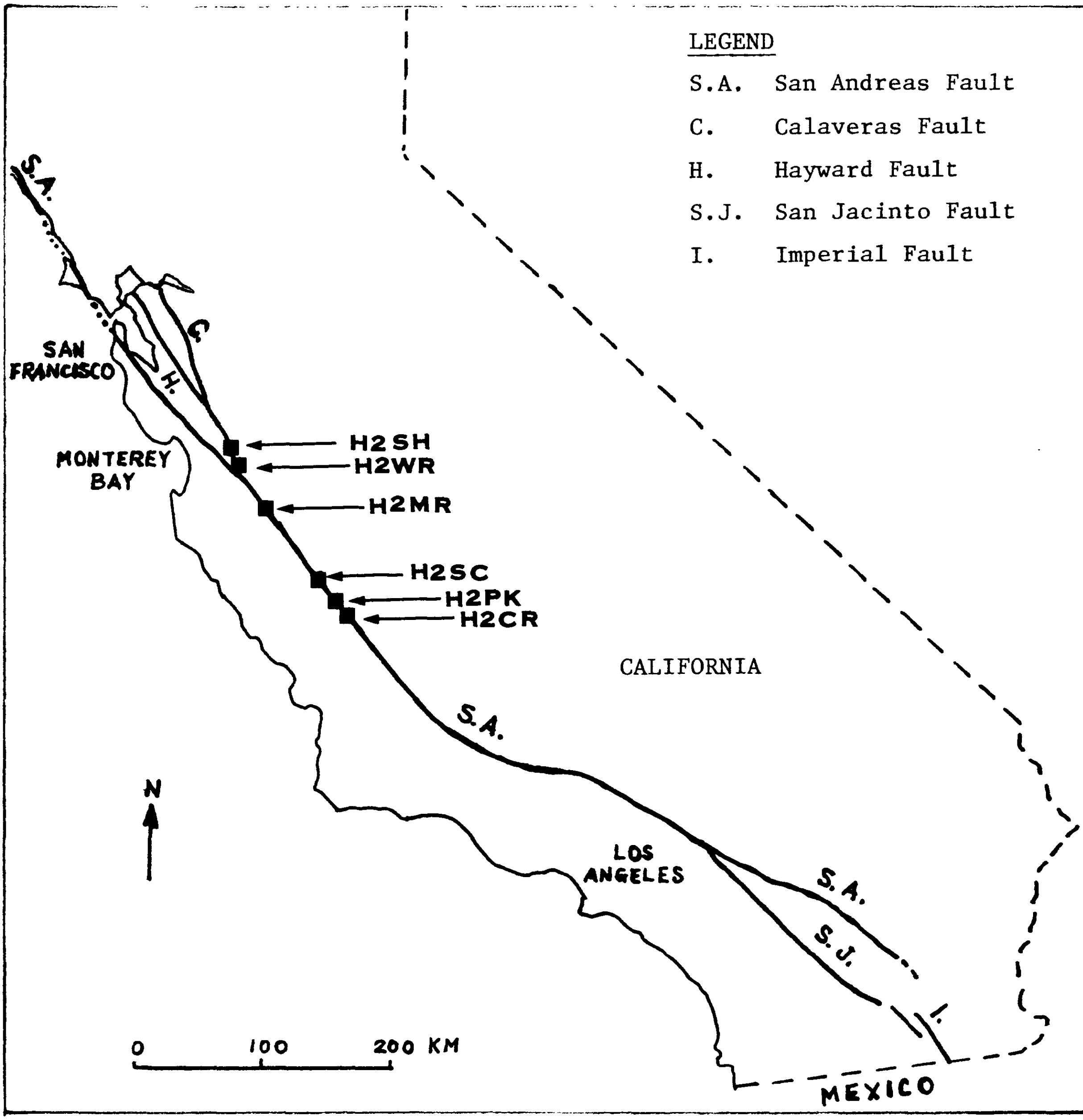

Fig. 1. A map showing the locations of USGS hydrogen monitoring stations on active faults of California. The code names for these stations start with H2 followed by 2 characters designating the location; SH: Shore Road, WR: Wright Road, MR: Melendy Ranch, SC: Slack Canyon, PK: Parkfield, and CR: Carr Ranch.

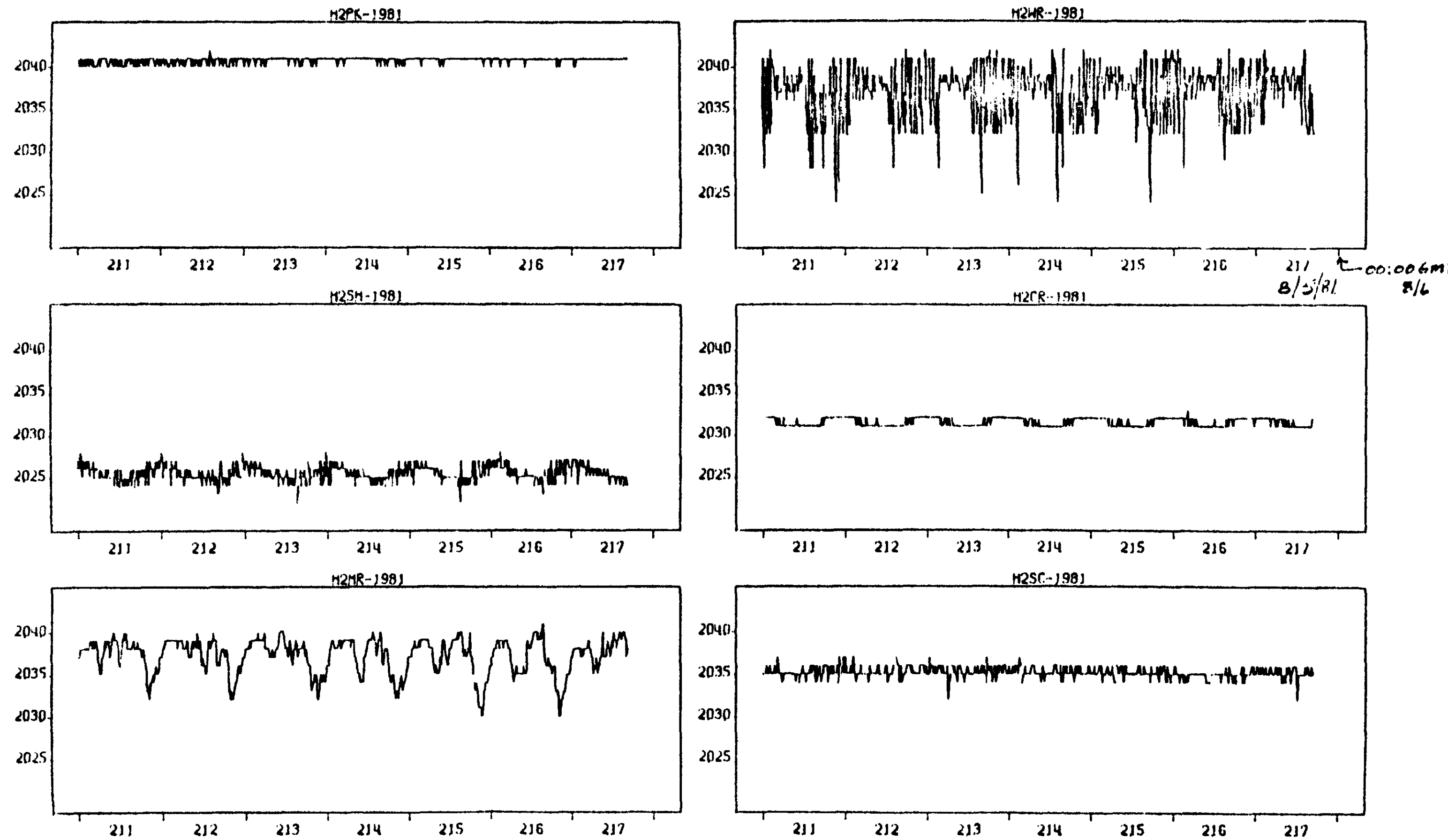

Fig. 2. An example of weekly plot of the hydrogen sensor outputs from six monitoring stations shown in Fig. 1. The horizontal axis is the time scale where the numerals indicate julian days. The vertical axis is the voltage scale where the voltage is expressed as the number of counts in the digital telemetry system. One count change corresponds to a change in voltage of about 2.44 mV. The abolute number is not important.

THE EXTENSION AND OPERATION OF A COMPUTER-CONTROLLED RADON MONITORING NETWORK FOR EARTHQUAKE PREDICTION, INVESTIGATIONS OF ENVIRONMENTAL EFFECTS ON SUBSURFACE RADON, AND COMPARISON OF RADON MONITORING TECHNIQUES

14-08-0001-19752

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INVESTIGATIONS

During the first half of FY81, our efforts were devoted mainly to (1) the analysis of data from the radon-thoron monitoring network, (2) completion of upgraded software for the fully automatic analysis of data from the network, (3) the installation of a VAX-750 computer which will be used for much of the automated analysis, (4) an expanded program of geochemical characterization of the sites at which radon is monitored, (5) the analysis of hydrogen and helium data from the Pacoima site, (6) completion of site work at Ft. Tejon, and (7) field work associated with the selection of three new sites in Riverside County.

RESULTS

Most of the stations on the network continue to record anomalous radon spectra. This is particularly true of those station located on the frontal faults of the Transverse Ranges. A qualitative correlation has been observed between the character of the radon data at these sites and geodetic measurements of strain and strain rates in the Transverse Ranges. For the past two years rapid changes in strain of considerable magnitude have been measured in the vicinity of Palmdale. It appears that during those times when the strain has been predominantly compressional, fluctuations in the radon levels have been relatively small. At times when the strain has appeared to be tensional large fluctuations in radon level have been noted. It appears that the regional strain event which began about two years ago is continuing, and is responsible for the increased level of seismicity in the region. Recent data from five of our monitors is shown in the figure.

Software improvements now allow fully automatic merging of data files from the new version units in operation at Pacoima, Lake Hughes, and Sky Forest. The Kellogg Laboratory VAX-750 computer is now in operation and the process of producing regular data updates will be transferred to that machine in the near future.

In collaboration with visiting scientists from the China, an expanded program of hydrogeological field work and geochemical analysis has been undertaken with the aim of determining hydrological and geochemical profiles of existing and future monitoring sites. Water samples were taken from all of the boreholes on the network both before and after the rainy season. Complete geochemical and radiological analyses of these samples are in progress.

Early problems encountered with the Gulf Research gas chromatograph have been solved, and the instrument now is recording hydrogen and helium levels in the Pacoima borehole on a regular basis. This data is transmitted to Caltech through the radon-thoron monitor at the site. Generally, very low levels of hydrogen and helium have been observed; however, one large hydrogen spike was recorded in late April of this year.

REPORTS

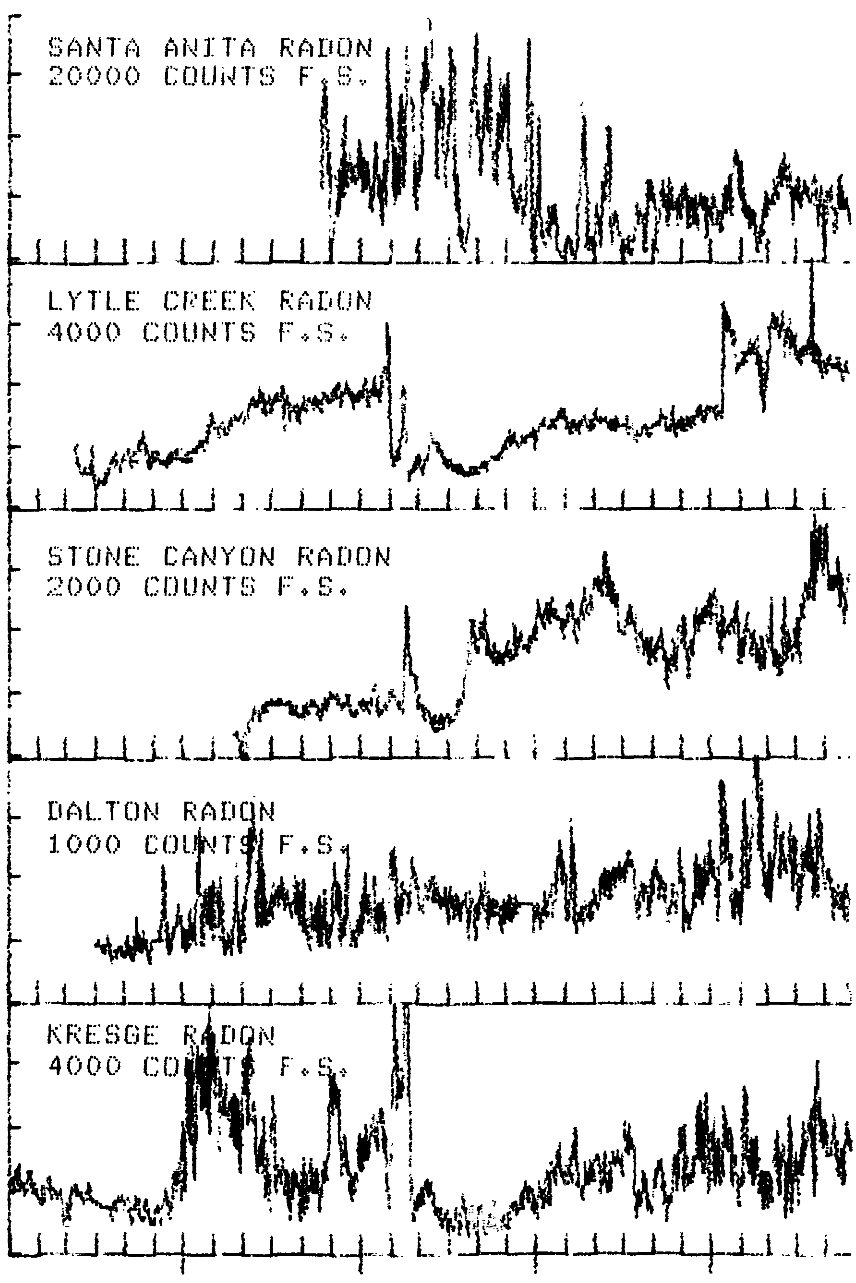
M.H. Shapiro, J.D. Melvin, T.A. Tombrello, M.H. Mendenhall, P.B. Larson, and J.H. Whitcomb, Relationship of the 1979 southern California radon anomaly to a possible regional strain event, J. Geophys. Res., 86, (1981) 1725-1730.

Jiang Fong-liang and Li Gui-ru, The application of geochemical methods in earthquake prediction in China, Geophys. Res. Lett., 8, (1981) 469-472.

Jiang Fong-liang and Li Gui-ru, Experimental studies of the mechanisms of seismo-geochemical precursors, Geophys. Res. Lett., 8, (1981) 473-476.

M.H. Mendenhall, M.H. Shapiro, J.D. Melvin, and T.A. Tombrello, Preliminary spectral analysis of near-real-time radon data, Geophys. Res. Lett., 8, (1981) 449-452.

M.H. Shapiro, Radon and earthquake prediction, 1982 McGRAW-HILL YEARBOOK OF SCIENCE AND TECHNOLOGY, in press.


SANTA ANITA RADON
20000 COUNTS F.S.
LYTLE CREEK RADON
4000 COUNTS F.S.
STONE CANYON RADON
2000 COUNTS F.S.
DALTON RADON
1000 COUNTS F.S.
KRESGE RADON
4000 COUNTS F.S.
1-JUL-79
1-JAN-80
1-JUL-80
1-JAN-81

GROUNDWATER RADON AND CHEMISTRY STUDIES FOR EARTHQUAKE PRECURSORS

#14-08-0001-19264

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The University of Southern California is monitoring groundwater radon content at 13 sites in the Central Transverse Ranges of Southern California. In addition, methane, helium and other gases are being monitored at four sites. Radon monitoring has been underway since 1974, while monitoring of methane began in the spring and summer of 1981. Helium measurements began in August, 1981.

There have not been any groundwater radon anomalies at our 13 monitoring sites during the six month period from April to September, 1981. Data for methane and helium do not have adequate baselines to draw conclusions at this time.

We are currently building 12 continuous radon monitoring devices and plan to deploy them in the Spring of 1982.

PUBLICATIONS

Teng, T. L., L. F. Sun, and J. K. McRaney, Correlation of Recent Groundwater Radon Anomalies with Earthquakes in the Greater Palmdale Bulge Area, Geophysical Research Letters, vol. 8, no. 5, p. 441-444, 1981.

Hammond, D. E., T. L. Teng, L. G. Miller, and G. Haraguchi, A Search for Co-variance Between Groundwater Radon, Groundwater Chemistry and Seismicity in Southern California, Geophysical Research Letters, vol. 8, no. 5, p. 445-448, 1981.

Local Changes in the Gravity and Magnetic Fields Due to Tectonic Strain

Contract No.14-08-0001-19792

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I have been analyzing changes in the earth's gravity and magnetic fields resulting from tectonic strain. During the past six months, I completed a manuscript describing an analysis of gravity changes due to changes in topography. This manuscript is now being revised. I have been collaborating with J.R. Rice of Brown University on a study of changes in the earth's magnetic field. We have made no forward progress during the past reporting period.

STOCHASTIC SIGNAL PROCESSING AND ANALYSIS OF WATER LEVEL DATA

Contract No. 14-08-0001-18379
Co-Principal Investigators:
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Dr. J. A. Dracup

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INVESTIGATIONS

This Final Technical Report describes the work completed under U.S.G.S. Contract #14-08-0001-18379 with Environmental Dynamics, Inc. This contract was entered into with the intention of demonstrating that contemporary stochastic processing techniques can enhance the usefulness of ground water level data by isolating any water level earthquake precursors that might occur against a background of other influences which might otherwise mask these precursors.

A complete software system which performs this task has been generated and is listed in this and previous Technical Reports. A large quantity of well level and barometer records has been digitized and processed into a form suitable for multiple regression processing. Three component tidal attraction data has been generated covering the period April, 1977, to January, 1981, for the Palmdale area and for shorter periods of time for other Southern California locations. All of the processed data, amounting to approximately 9,000,000 bytes, is available on archived magnetic tapes. This contract has demonstrated on limited data that these techniques are potentially capable of isolating any earthquake water level precursors that might occur against a background of masking influences.

EDI received records from twelve wells in Southern California in which the water levels are continuously recorded. An additional 40 wells were sampled for water level on the average of once a week.

The following was used as input:

1) Water level.
2) Barometric pressure.
3) Three component land tidal attractions (calculated from a NOAA Fortran program).

The water level and barometric pressure records are digitized prior to processing. Details of the various procedures involved in this digitizing, subsequent file preparation and the difficulties encountered are covered in this Final Technical Report and in EDI's Semi-Annual Report dated August, 1980.

This program has also generated a method and appropriate software for testing the effectiveness or information "bandpass" of our procedures. This is done by generating artificial precursors of various shapes, time durations and amplitudes which are then added into the current water level data. The data is then processed with the current multiple regression model and plots of the output residuals are examined for evidence of the artificial precursor. Examples demonstrated herein demonstrate the effectiveness of these methods.

Three difficulties loomed large in the performance of this contract. They were: 1) The complexity of the digitization of the data with its many exceptional cases and the consequent complexity of the related file preparation, 2) The sparse availability of experienced programmers within the budget constraints, 3) The recent massive software change-over at U.C.L.A.

Two major conclusions have arisen from this contract. One is that it is essential that this data limited to the continuous monitoring of only twelve wells be processed by contemporary stochastic processing techniques in order to make it more comparable to the Chinese experience of monitoring at least 70-80 wells per province. The second is that it is urgently necessary to simplify these procedures as much as possible in order to make timely use of this enhanced data. This means, at least, standardization in-so-far as feasible and the necessity for digitization of the bulk of any data at the well head as soon as feasible. Fully 50% of the difficulties associated with this contract arose in the digitization phase with the consequently required additional preprocessing of the resulting error containing and out-of-order files. The existing procedure introduces inaccuracies, is error prone and costly.

Magnetic Field Monitoring of Tectonic Stress in Southern California

14-08-001-18335

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Investigations

Magnetic field measurements have been taken on a regular basis at 43 field sites across Southern California from the vicinity of Tejon Pass on the NW to Indio on the SE. Starting with 10 sites distributed along the San Jacinto fault zone in 1973, the project now consists of an extensive 2-dimensional array. The purpose of the investigation is to monitor tectonic stress change in the crust via the piezomagnetic effect.

The field procedure involves the taking of a series of discrete measurements of the earth's total magentic field strength at two adjacent sites simultaneously. Usually about 76 readings are taken over a 10-minute interval of time. Means, standard deviations and ranges are determined for the 76 values and the mean values for the two sites are differenced. The time variations of these differences of means are in large part due to tectonic stress change in the crustal rocks beneath the site pair. This simple differencing procedure needs refinement but for the present time error is assessed by conducting repeat measurements and by totaling differences of means around loops of field sites. One large loop monitors all fault zones in and around the San Bernardino Mountains and another large loop extends around the Santa Rosa Mountains, with sites situated along the San Andreas and San Jacinto fault zones.

Results

With reduced data in hand that spans the time interval from 1973 to 1981 it is possible to make the following observations:

a) Tectonomagnetic effects were documented by the survey when measurements were taken before, during and following a swarm of moderate earthquakes that occurred at the east end of the San Bernardino Mountains near Landers beginning mid-day on March 15, 1979. It is believed that the magnetic changes that occurred were closely associated in time with the fault displacements and associated deformation rather than being precursor events associated with the build-up of elastic strain.

Results (continued)

Differences of mean values between nearby site pairs changed by 2 to 3 gammas during the week of March 17-24, an unusually rapid rate of change when compared with measurements conducted elsewhere in the array.

b) Errors in the simple differencing method make interpretations of apparent magnetic field change difficult for short time intervals, such as the intervals between successive surveys. Rapid magnetic field changes were detected at sites near Wrightwood between April 12 and June 25, 1979. On August 28, 1979 a magnitude 3.7 earthquake occurred that plotted almost directly in the center of this location. A resurvey conducted two months after the earthquake indicated that the deviation had disappeared.

Regions that have repeatedly indicated marginally significant change between surveys can be distinguished from other areas that are producing less change. One to three gammas changes between successive surveys have been most commonly observed for the area between Wrightwood and the Cajon Pass.

c) The simple differencing technique is sufficiently precise to identify magnetic field changes of from 8 to 12 gammas, as occurred in the Wrightwood-Cajon Pass area between 1973 and 1976.

If this amount of change had occurred over a shorter period of time a large earthquake might have been indicated. Earthquakes are likely to be associated with large and rapid rates of change. For this reason the project should be directed to identifying these larger changes.

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Development of a Quantitative Model of Stress in a Seismic Region as a Basis for Earthquake Prediction

Contract No. 14-08-0001-19150

Principal Investigator: Keiiti Aki
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Goal

To develop a method which determines the distribution of incremental stress in the earth associated with a precursory surface deformation. This method will provide a quantitative basis for the understanding of stress-induced precursory phenomena.

Investigations

Mathematical formulations for an elastostatic inverse problem to determine incremental stresses in the earth were recognized as a Cauchy problem for elliptic equations and the uniqueness and stability of solutions were investigated. A general approach for this inverse problem is (1) to define a body (domain) under the earth beneath an area over which displacements are known, (2) to apply eigenfunction expansions to operators, (3) to reduce the problem to ordinary differential equations, and (4) to convert two point boundary value problems into initial value problems as is done in a shooting method for ordinary differential equations. The necessary initial values, i.e. the Cauchy data are obtained from stress free conditions at the surface and displacements measured on the surface by means of geodimeter networks and levelling surveys.

Results

The solution for the two-dimensional elastostatic inverse problem is obtained by expanding Airy's stress function into polynomials along a horizontal axis and by imposing stress free conditions to determine coefficients of the reduced system of linear equations. Remaining coefficients are determined by matching the displacements expanded into polynomials on the surface with an integrated form of the stress function. For the three dimensional inverse elastostatic problem the solution is obtained via the Galerkin vector instead of Airy's stress function. By expanding the Galerkin vector into polynomials, we obtain a system of linear equations, which can be solved by imposing stress free conditions and known displacements on the surface.

Results

The solution for the two-dimensional elastostatic inverse problem is obtained by expanding Airy's stress function into polynomials along a horizontal axis and by imposing stress free conditions to determine coefficients of the reduced system of linear equations. Remaining coefficients are determined by matching the displacements expanded into polynomials on the surface with an integrated form of the stress function. For the three dimensional inverse elastostatic problem the solution is obtained via the Galerkin vector instead of Airy's stress function. By expanding the Galerkin vector into polynomials, we obtain a system of linear equations, which can be solved by imposing stress free conditions and known displacements on the surface.

The analytic method of inversion is then applied to the geodetic data obtained in southern California where anomalous uplift called Palmdale bulge has been observed between 1959 to 1974 along the San Andreas fault. Results of inversion for stress show that the principal stresses at 10km depth have significantly different patterns from the horizontal stresses obtained at the surface. At the surface the principal stresses are the nearly N-S horizontal compression of 3.5 to 4.5 bar, the nearly E-W horizontal compression of 0.0 to 0.1 bar and vertical stress of zero magnitude. At 10km depth the nearly N-S compression reaches to 12 bars and the nearly E-W compression reaches to 6 bars under the central region of the Palmdale Bulge. Thus the incremental shear stress along the fault at 10km depth near Palmdale is only slightly greater than at the surface, but the incremental normal compressional stress increases with depth considerably, suggesting a locking mechanism on the San Andreas fault during the period of Palmdale uplift. This result is consistent with the swarm of microearthquakes which occurred in this area during 1977 to 1978 after the uplift stopped and then turned to downwarp. It is shown that while our method of inversion is quite useful in earthquake prediction researches, currently obtainable geodetic data are not satisfactory for our inversion scheme. We need a matched data on vertical and horizontal components of displacement vector at the same points, but the current geodetic measurements are independent and unmatched between the vertical and horizontal components. The use of new methods based on space technology such as VLBI, ARIES and GPS which enable matched 3-component measurements at all points is required for an adequate application of our inversion method to the determination of the incremental stress in the Earth.

SYNTHESIS OF SEISMICITY AND GEOLOGICAL DATA IN CALIFORNIA

USGS USDI 14-08-0001-19766

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INVESTIGATIONS

(1) Compile as complete as possible a set of slip rates for major faults in California.

(2) Compare the historical seismicity on each of these faults with activity rates which are needed to maintain the slip rate.

(3) Determine if this information will be useful for predicting earthquakes.

RESULTS

At the present time, work is underway on these topics, but no significant results are yet available.

A study has been made of the analytical tools which are available to analyze the results of this study for earthquake prediction purposes. Collins (1977) used a simple Bayesian procedure to find the revised probability of an earthquake after a precursory observation, but this model is inadequate for realistic applications (Anderson, 1981A). A better model has been formulated (Anderson, 1981B). This gives a rigorous procedure for determining whether or not a particular observation is useful as a precursory observation, and if so, how an observation of the phenomena affects the probability of earthquakes in the subsequent time period. The model fully accounts for the magnitude distribution of earthquakes.

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Digital Signal Processing of Seismic Data

9930-02101

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Investigations

Seismograms from main shocks of earthquake sequences in 1922, 1934, and 1966 on the San Andreas fault near Parkfield, California were compared to deduce differences in source characteristics, in particular their relative seismic moments.

Results

The ratio of seismic moment determined for seismograms recorded at Berkeley, Ca. for the main shock of Parkfield, California sequences in 1922 and 1934 (1:3) is nearly equal to the ratio of time intervals to the subsequent Parkfield earthquake sequence (12 years: 32 years), consistent with the "time-predictable earthquake recurrence model". If this seismic moment-time interval proportionality holds, the relative seismic moment of the main shock of the Parkfield sequence in 1966, determined from recordings at Berkeley, implies that the next Parkfield sequence will occur between 1994 and 2003.

Reports

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THERMODYNAMIC DETERMINATION OF HYDRATION BOUNDS FOR WEAK CLAYS AND RECONSIDERATION OF THEIR FRICTION

14-08-0001-19795

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Investigations

1. Pilot study of the affinity of a sodium-montmorillonite for water by means of vapor-pressure measurements.

2. Extrapolation of the hydrated/dehydrated clay boundary into the laboratory and geologic pressure ranges.

3. Measurement of friction of both hydrated and dehydrated clays in the absence of pore water.

Results

1. A montmorillonite from Clay Spur, Wyoming (API Standard #26) with formula $(Na_{.42},Ca_{.02})$ $(Al_{3.08},Fe_{.32},Mg_{.66})$ $(Al_{.18},Si_{7.82})$ $O_{20}(OH)_4 \cdot nH_2O$ was investigated. At low humidity it equilibrates to n=0 ("dehydrated") and at high humidity to n=6 ("hydrated"). X-ray diffraction shows the volume change to be 13.2 cc/mole-H_2O. Equilibrium between phases was attained at a steam (partial) pressure of 1500 Pa at 22 C. From the rate of increase of this pressure with temperature, the dehydration enthalpy was found to be +9.77±0.1 kcal/mole-H_2O (gas).

2. Using the generalized Clapeyron equation, this boundary can be integrated through three-dimensional (T,P,P_{H_2O}) space by changing ΔH and ΔV at the water/steam phase boundary. The figure shows results for the laboratory and geologic cases; the dehydration is expected to occur within the domains of common frictional testing and shallow crustal earthquakes, respectively.

3. Single samples of hydrated and dehydrated clay deformed at room temperature and 6×10^{-5} cm/sec showed a factor-of-two difference in frictional strength. However, because the pressures in the experiment were not high enough to cause dehydration of the hydrated clay sample, it had a higher coefficient of friction (0.2) than has been previously reported. This value is believed to be relevant to the mechanical behavior of sodium montmorillonite down to 6 km in permeable strike-slip fault zones.

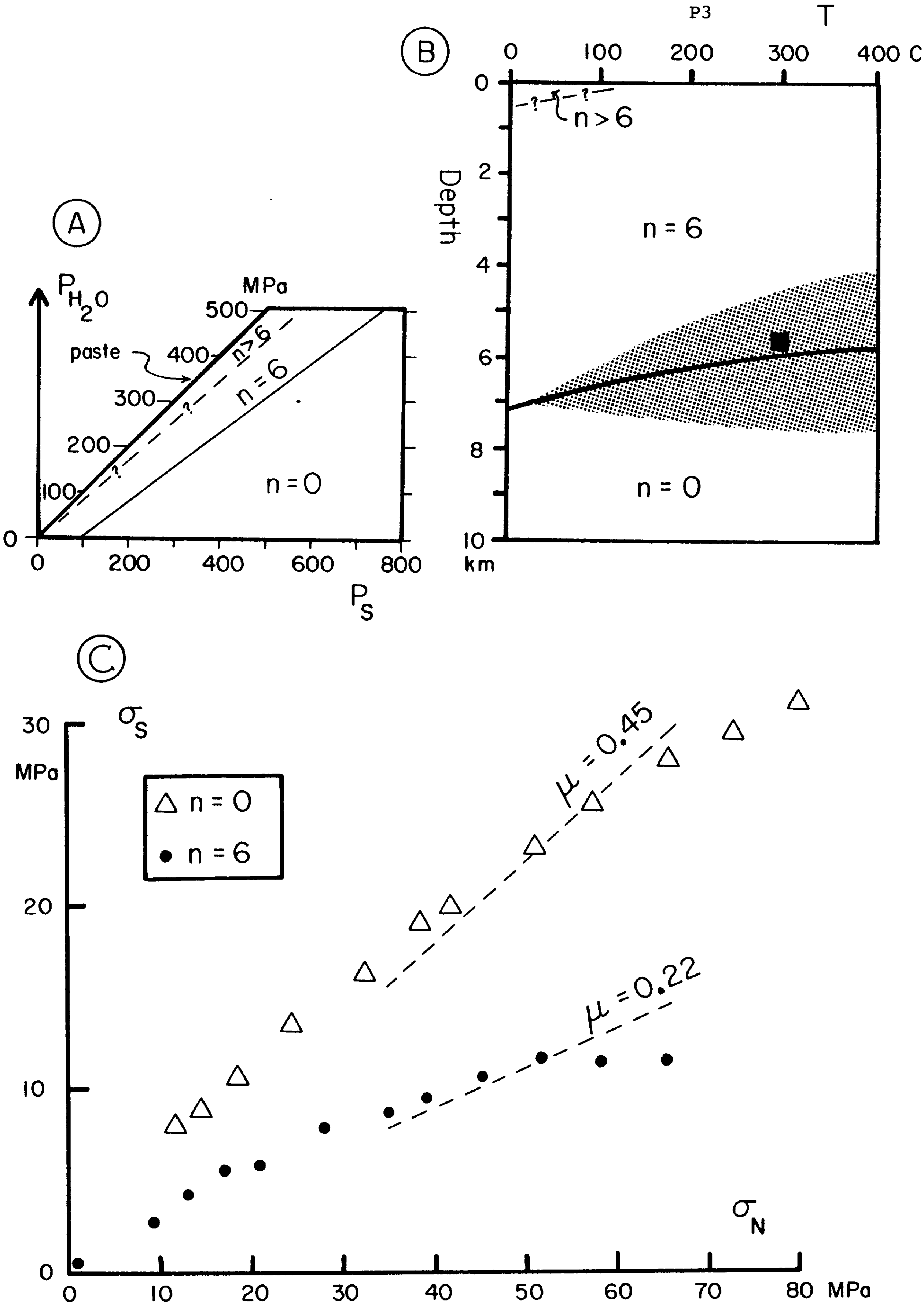

Figure 1: Properties of sodium montmorillonite (API Standard #26).
A: Hydration boundary at T=22 C, with variable solid and water pressures.
B: Hydration boundary with lithostatic solid pressure and hydrostatic water.
C: Shear stress at sliding versus normal stress for both phases.

Rock Mechanics

9960-01179

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Investigations

Laboratory studies are carried out to determine the physical properties of rocks at temperatures, pressures and fluid pressures that occur at depths of 5-15 km in the earth's crust.

Results

Frictional sliding experiments at confining pressures up to 400 MPa were performed on thin layers of clay-rich fault gouges from locations along the San Andreas and Hayward faults. Both saturated and dry samples showed a strain hardening that increased at higher confining pressures for the same gouge, or with increased strength among different gouges. Tests with various lubricating mediums at the sample ends, and different jacketing materials showed that these possible mechanical constraints on frictional sliding had no effect on the strain hardening process. Therefore the observed strain hardening was a real material property of the fault gouges.

The strength of the gouges did not correlate well with mineral composition, grain size distribution or creeping vs. "locked" locations along the San Andreas fault. The presence of water lowered the strength, friction and amount of strain hardening of the samples. Very low deviatoric stresses in the gouge, on the order of the low shear stresses inferred from heat flow data along the San Andreas, were achieved in undrained (high pore pressure) shearing experiments.

Reports

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Recrystallized Grainsize in Ductile Fault (Mylonite) Zones as an Indicator of Palaeostress Magnitudes During Faulting

14-08-0001-19797

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Investigations

1) Theoretical modelling of dynamic recovery and recrystallization processes was continued, with a view to developing stress/subgrain size and stress/ recrystallized grain size equations which reflect the dynamics of the creep process and the details of dislocation substructure formation. The model is based upon TEM observation of substructures developed in naturally deformed quartz and feldspar, and experimentally deformed pyroxene.

2) Construction of the deformation apparatus is now complete, and experimental work has begun to test and calibrate the theoretical models.

Results

1) The transmission electron and optical microscopy of experimentally and naturally recrystallized materials is complete. It confirmed that the subgrain structure formed during creep provides the nuclei for dynamic recrystallization, and that the development of this subgrain structure must be modelled before a stress/grainsize relationship can be derived. However, the dynamic recrystallization process seems to involve growth and coalescence of subgrains as well as simple rotation.

2) The behaviour of the substructure during creep has been modelled to allow for variation in misorientation between, and size of, subgrains, and a preliminary stress/subgrain size equation has been formulated.

$$\dot{\theta} - \theta\frac{\dot{d}}{d} = \frac{2}{3}\,\frac{D\mu b}{kT}\left[A\left(\frac{\sigma}{\mu}\right)^{n} - bc_j\,\frac{6m_c\theta}{\pi(1-\nu)}\left(\frac{b}{d}\right)^{2}\right]$$

where θ = boundary misorientation
d = subgrain size
D = coefficient of self diffusion
μ = shear modulus
k = Boltzmann's constant
T = temperature
σ = stress
c_j = concentration of jogs on dislocations
ν = poisson's ratio
m_c = dimensionless geometrical parameter
and A, n are dimensionless creep constitutive equation parameters.

This equation predicts that the relationship between stress and subgrain size will depend on the details of the creep process (e.g., the stress exponent, n, and the effective diffusion constant D), and may thus vary with temperature and chemical environment. We are in the process of refining this equation and comparing its predictions with published data on a wide range of materials.

3) The Griggs-type deformation apparatus has been constructed and commissioned. However, we have had to experiment extensively in order to find a sample assembly design that overcomes the dual problems of large non-hydrostatic stress during pressurization and large errors in load (stress) measurement. The first of these problems induces microstructures under unknown conditions prior to intentional deformation of the sample, and the second makes calibration of any stress/grainsize relation very imprecise. A sample assembly consisting largely of NaCl has proven most suitable, and further testing of this assembly is in progress.

4) Experimental testing of the stress/subgrain size model has just begun. We have succeeded in introducing a hydrogen defect into natural Brazil quartz at 700°C and 0.5 GPa, and will investigate its phase equilibria and effect on mechanical properties. Synthetic quartz single crystals with a range of well characterized chemical defects have been ordered from Sawyer Research Ltd., and we will be deforming these at pressures from 0.1 to 2.0 GPa, and temperatures from 600° to 1000°C in order to test and calibrate the theoretical model.

Earthquakes and the Statistics of Crustal Heterogeneity

9930-03008

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Investigations

The size of an earthquake is determined by the processes that stop rupture growth, namely propagation into a region of either great strength or low stress. Therefore, earthquake statistics must depend on the statistical distribution of stress and mechanical properties in the earth, a subject about which we are almost totally ignorant. This investigation uses earthquake mechanisms and the scattering of seismic waves as tools for studying crustal heterogeneity.

Results

I am conducting a theoretical analysis of the scattering of seismic waves by anisotropically distributed inhomogeneities. Such a theory is needed to understand the propagation of local earthquake waves in stratified and foliated crustal rocks. This theory will also be helpful in interpreting coda-length magnitudes, and how they may depend on such variables as focal depth.

In cooperation with Steve Hartzell, I have written computer programs to calculate the frequency and impulse responses of any seismograph system and to deconvolve digital seismograms to remove instrumental effects. This ability is needed in studying earthquake mechanisms.

I have recently begun a theoretical study of the stress distribution within a randomly inhomogeneous medium. I hope to be able to understand from this how stresses are concentrated and oriented as functions of the strength, length scale and correlations of inhomogeneities in bulk modulus and rigidity. Such knowledge would have obvious application to the understanding of rupture initiation and termination.

Large Scale Laboratory Contained Fracture Experiment

9960-02941

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Investigations

1. Determination of source parameters during unstable sliding on a fault.
2. Producing contained fracture events by altering the stress field along the fault.
3. Measuring heat generated during unstable sliding on a fault and relating this to the total energy released during sliding.

Results

1) Experiments have been conducted at normal stress up to 6.4 MPa on a 200 x 40 cm simulated fault. By injecting water onto the ends of the fault while applying shear stress, the ends of the sample were pre-slipped up to 50 microns while the center of the sample remained locked. Then, by removing water pressure and continuing to raise shear stress, the pre-stressed central portion of the fault failed unstablly. Ruptures produced in this manner were successfully contained by the low-stressed ends of the fault. Results for eight events produced by this method are as follows. Total fault slip measured at the center of the slipped zone ranged from 8.5 to 38.9 microns. Slip velocity increased with increasing dynamic stress drop. Dynamic stress drop increased with increasing normal stress with a ratio of approximately 0.09. Seismic moments for these events ranged from 6×10^7 to 3×10^8 dyne-cm. This technique will now provide a powerful tool for studying source parameters related to the stopping phase of ruptures as well as in studying the effect of fault inhomogeneity.

2) Temperature rises have now been measured for slip along the fault while dry, wet and with a layer of simulated gouge. For the dry fault, the frictional heating of the fault during unstable slip is 88 $\pm$ 6% of the total energy released. From this observation, a seismic efficiency between 5 and 10 percent is inferred. When water was injected on the fault, no significant change in the heating of the fault was detected. Wetting of the fault does tend to increase both the yield strength and the relative stress drop for these conditions of low stress and finely ground surface. Sliding of the fault with a 1.5 mm thick layer of Ottowa sand suppressed 'stick-slip' behavior. Heat generated on the fault was found to be approximately proportional to sliding rate and normal

stress. For all these low normal stress events, with energy densities up to 10^5 erg/cm^2, the temperature rise on the fault was less than a few degrees Celsius. Even for relatively small earthquakes having an energy density 1000 times greater than this, heating of water in the fault zone could become important.

Reports

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Laboratory Studies of Premonitory Slip Under Hypocentral Conditions

14-08-0001-19293

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Investigations

The overall objective of this project is to investigate fault mechanics of gouge-host rock systems through controlled laboratory experiments with emphasis on understanding the operative physical principles that govern shallow-focus earthquakes. The emphasis of this research is to study premonitory slip and its application to earthquake prediction. In this report we discuss the results of investigations into four areas: (1) dehydration of simulated gypsum gouge and its effect on frictional sliding; (2) preliminary measurements of preseismic slip in a triaxial apparatus; (3) fault motion upon fluid injection; and (4) fault zone studies in Southern California.

Results

Dehydration of simulated gypsum gouge and its effect on the frictional sliding of Tennessee sandstone. The effects of gypsum dehydration on the sliding behavior of Tennessee sandstone are studied experimentally to gain a better understanding of how the dehydration of fault gouge influences fault movement. Cylindrical specimens (4.0-4.1 cm in length and 1.84 cm in diameter) of Tennessee sandstone with 0.5 mm thick gypsum gouge or 0.3 mm thick anhydrite gouge along a 35° precut are deformed dry in a triaxial gas-apparatus equipped with an internal furnace, at temperatures to 300°C, with a shortening rate of about 5×10^{-5}/s, and at confining pressures to 150 MPa. In most experiments, specimens are open to air through a thermocouple hole.

Gypsum gouge shows only stable sliding at room temperature and at 300°C, but it does show stick-slip at 100 and 150°C. At 150°C, both gypsum and anhydrite show stick-slip at and above 30 MPa pressures, but the behavior of gypsum gouge during dehydration is notably more unstable than that of anhydrite gouge. This suggests either that a small amount of moisture derived from the dehydration produces more unstable behavior or that the behavior of hemihydrate--dehydration product of gypsum at 100 to 170°C (Heard and Rubey, 1966)--is more unstable than that of anhydrite. Isolation of specimen leads to no marked change in the stick-slip of gypsum gouge. To date, no evidence suggesting the generation of high pore pressure in the gouge has been obtained. Gypsum should receive attention as a destabilizing agent of fault motion especially when country rocks are fairly porous.

Preliminary measurements of preseismic slip in a triaxial apparatus. If stick-slip is a mechanism of majority of shallow earthquakes, preseismic slip is perhaps the most crucial in understanding the processes that leads to unstable fault motion. We have attempted to detect preseismic slip in a triaxial apparatus by measuring the change in length of a precut specimen very accurately. An internal LVDT that attached to the upper and lower pistons is used for the measurement, and the sensitivity of displacement measurement as low as several hundredths of a micron has been attained. Seven specimens of Tennessee sandstone with 35° precut (4.8 cm in diameter and 9-10 cm in length; two with 1 mm thick quartz gouge and others with no gouge) are deformed at room temperature, at confining pressures of 70 to 80 MPa, at a pore pressure of 10 MPa (except for a dry run), and with a shortening rate of 3×10^{-4}/s to 1.5×10^{-5}/s. Over 100 stick-slip events have been recorded, but experimental data have not yet been analyzed completely. The major results from our preliminary analysis are as follows:

1) The force-dispalcement curve during stick-period for a specimen with no gouge is characterized by a slight knee at a differential stress about half way up to the peak stress, at which local slip probably begins to occur on the sliding surface. Above this point, the curve is often composed of a few portions in which a small nearly-linear segment is followed by gradual bending of the curve. This suggests that a sequence of yielding-type phenomena occurs after the onset of local slip, although the exact nature of this yielding is presently unknown. Immediately prior to seismic slip, the differential stress often, but not always, drops slightly.

2) During the frictional sliding of a specimen with no gouge, the displacement becomes notably accelerated in a few tenths of a second prior to seismic slip. The duration of this accelerating period is almost independent of strain rate, and stiffness and mass of apparatus are perhaps the major controlling factor of this period. When a specimen contains quartz gouge, the accelerating period becomes slightly longer. Laboratory experiments relevant to immediate precursors must be directed to this accelerating slip.

3) The accelerating slip diminishes with increasing strain rate for specimens deformed under pore pressure. Based on our experimental results from water injection experiment, it is suggested that the rate of pore-pressure increase and consequent rate of change in the effective pressure within a specimen is the major controlling factor. For a specimen deformed at a rapid rate, the effective pressure is expected to decrease at a rapid rate resulting in a rapid reduction of friction, and this will enhance the fault instability to reduce the amount of accelerating slip. For quantitative analysis of our experimental data, it is desirable to establish constitutive property of fault, especially its normal stress dependence.

Fault motion upon fluid injection. Water injection experiments are performed in conjunction with stick-slip experiments described above in order to see how fault behaves in general upon injection of water into fault zone. The differential stress supported by the specimen is released mostly by a sequence of unstable slip. In this report, an emphasis is placed on the preseismic slip of these unstable slip events. Important results are summarized below.

1) The onset of unstable slip is very abrupt when pore pressure within a specimen is increasing at a rapid rate, whereas unstable slip is preceded by well-defined preseismic slip for a slow rate of increase in the pore pressure in a specimen. The present injection experiments have brought about a marked effect of changing effective-normal-pressure on friction in a simpler test than in ordinary friction experiments. However, the normal-stress dependence of constitutive property of faults has to be evaluated to explain the observed behavior quantitatively.

2) The magnitude of stress drop at unstable slip tends to be smaller as the differential stress is removed more by water injection. But the magnitude of this stress drop depends on various factors such as the amount of displacement, presence or absence of gouge, confining pressure, etc., and there is no unique relationship between the stress drop and the differential stress. Some implications of our results on earthquake control are discussed briefly in the text.

Fault zone studies in Southern California. Field studies in Southern California have concentrated on locating well exposed fault zones that would support an integrated field and experimental study of the mechanical behavior of the rock materials in the fault zone and the development and significance of rock fabrics produced by the faulting process. As this investigation is in its preliminary stages, this report summarizes (1) the criteria used in evaluating faults for a study which combines field and experimental methods, (2) observations of the better fault exposures investigated during the past summer, and (3) discusses strength contrasts across fault zones, fabric studies of fault zones, and experimental studies of mylonites.

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Theoretical Mechanics of Earthquake Precursors

9960-02115

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Investigations

1. Studied theoretical models of one-dimensional and two-dimensional faults, incorporating fault zone constitutive laws inferred from laboratory measurements of frictional sliding.

2. Studied the theoretical relations between static stress drop, slip, and moment on 2-D heterogeneous faults.

Results

1. These model simulations were made to explore the effect of laboratory-inferred friction laws on the sliding behavior of in situ-scale faults. The fault zone "frictional" strength is characterized by two competing effects: an instantaneous dependence of fault strength on velocity (strength increases with velocity); and also an inverse dependence of strength on velocity that takes full effect only after a finite amount of slip has occurred. 2-D simulations in a plate predict recurring rapid strike-slip events, similar in size to the 1906 San Francisco earthquake, separated by periods of strain accumulation. The initial results were obtained using a simplified form of the law developed by A. Ruina. The emphasis during this reporting period has been to incorporate the more complete form of the law developed by J. Dieterich. It is hoped that this will introduce finer resolution features into the simulations (eg., creep events).

2. Simple analytical techniques were found for computing static stress-slip solutions on two dimensional faults. For a single rupture zone an infinite number of analytic solutions can be obtained by expanding the stress drop over the rupture zone in terms of Chebyshev polynomials. The expansion allows the corresponding slip to be written in terms of the same coefficients used to describe the stress. The condition that determines whether or not the solution is finite everywhere reduces to whether or not the first two coefficients are zero. The seismic moment is shown to depend only on the first and third coefficients.

Reports

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Mavko, G., Easy computation of static stress drop, slip, and moment on 2-D heterogeneous faults, (submitted to B.S.S.A.).

Bounds on Lower Crustal Rheology

9960-02414
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Investigations

The Pacific coast of the United States is composed of an assemblage of tectonic units with varying ages, modes of formation, surficial expression, and physical properties. A systematic investigation of the gravity anomalies associated with the various tectonic provinces was begun for the purpose of clarifying the depth extent of individual units, the contrasts in rheological properties, and the mechanical interaction between provinces. Results from this analysis will be interfaced with refraction work underway within the Office of Earthquake Studies in order to better constrain the models. Rheological parameters derived from this study may provide future input for comprehensive models of stress and strain accumulation in the western U.S.

The first area considered covers the upper two degrees of the state of California and includes such diverse features as the Klamath Mountains, the northern tip of the Great Valley, two prominent peaks of the Cascade Range, and the northernmost section of the Sierra Nevada. The isostatic response function derived from the correlation between Bouguer gravity anomalies and topography in this region was calculated in order to investigate the isostatic compensation of surface features, which in turn gives clues to the relationship between the underlying tectonic source of the features and the strength of the upper lithosphere.

Results

The isostatic response function for the entire region indicates very local compensation (i.e., low flexural rigidity) at 20-25 km depth. However, the residual isostatic gravity anomalies are large with prominent highs over the Klamath Mountains and distinct lows correlated with the Cascade volcanoes, Shasta and Lassen. The magnitude of the residual anomalies can be significantly reduced by calculating separate response functions for the eastern and western sections of the grid. The short-wavelength information in the western response function indicates that the surface topography in the Klamath Mountains is 5 to 10 percent higher than the 2670 kg/m3 used in the Bouguer correction. In the eastern grid it appears that the density of the Cascades is less than 2670 kg/m3 by a similar percentage. The long-wavelength response estimates show that compensation for the Klamaths is more regional (i.e., higher flexural rigidity) and deeper than the compensation for the Cascades.

These observations are consistent with the surface geology and recent tectonic history of these two distinct mountain ranges. The greater surface density for the Klamath Mountains is the result of the more mafic composition of the rocks. The lower rigidity in the lithosphere beneath the Cascade volcanoes could well be the result of lithospheric reheating accompanying the volcanism since rock strength in the lower crust is highly temperature dependent. By comparison, the orogenic event responsible for the formation of the Klamaths involved less heating of the lithosphere.

Reports

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McNutt, M.K. and H.W. Menard, Constraints on yield strength in the oceanic lithosphere derived from observations of flexure, submitted to Geophys. J. Roy. Astr. Soc., July 1981.

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Internal Friction and Modulus Dispersion in Rocks at Seismic Frequencies

9960-01490

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Investigations

The objectives of this investigation are to determine the internal friction (1/Q) and the relative elastic modulus in rocks. Measurements are to be made in the range of frequencies and strain amplitudes characteristic of seismic waves. Such data can be used for correcting observed seismic travel times, and may provide a means for determining the physical properties (e.g., state of stress, anisotropy) in seismically active regions.

Results

The laboratory apparatus for determining the internal friction (1/Q) from direct observations of the stress-strain hysteresis loops was experimentally and theoretically investigated for systematic errors. Measurements were made on fused quartz, Lucite, steel and air dry Westerly granite at 0.01 to 2 Hz and 10^{-8} - 10^{-7} strain amplitude. Q is independent of frequency for the granite, fused quartz and steel samples. The Q for Lucite is highly frequency dependent, similar to the results of Spencer [1981]. Table 1 gives the comparison of available low frequency Q data in air-dry rocks at seismic frequencies. This table is part of two manuscripts presently in preparation: Investiagations of Internal Friction in Fused Quartz, Steel, Lucite and Westerly Granite from 0.01 - 2 Hz at 10^{-8} - 10^{-7} Strain Amplitude; Part I Experimental, Part II Theoretical Considerations.

Reports

L. Peselnick, The hybrid method for determining pressure derivatives of elastic constants of solids. Submitted to J. Geophys. Research.

References

Spencer, J.W., Stress relaxation at low frequencies in fluid-saturated rocks: attenuation and modulus dispersion, J. Geophys. Res. 86, 1803-1812, 1981.

TABLE 1. COMPARISON OF LOW FREQUENCY Q DATA FOR AIR OR VACUUM DRIED ROCKS AT OR NEAR STP.

ROCK	FREQUENCY*	STRAIN (10^{-6})	Q	DEPENDENCE OF Q ON FREQUENCY	LOOP SHAPE	DEPENDENCE OF Q ON AMPLITUDE	REFERENCE
Granite	0.5 to 50	>10	QE~50	Independent	Sharp corners	No data	Gordon & Davis [1968]
Quartzite	0.5 to 50	>10	QE~200	Independent	Sharp corners	No data	Gordon & Davis [1968]
Granite, Basalt, & Sandstone	3 to 100	1 to 10	QE~100	No data	Cusped ends	No data	McKavanagh & Stacey [1974]
Basalt	1 to 500	2.6	QS=590	No data	Elliptical	No data	Brennan & Stacey [1977]
Granite	1 to 500	2.9	QS=320	No data	Elliptical	No data	Brennan & Stacey [1977]
Sandstone, granite, & Limestone (all vacuum dry)	4-400 Hz	~0.1	QE>500	Independent	No data	No data	Spencer [1981]
Westerly granite (air dry)	0.2 Hz	~1.0	QE=90	No data	Elliptical	No data	Peselnick & Liu [1979]
Westerly granite (air dry)	0.01 to 2.0 Hz	~0.01 to 0.1	QE>1000	Independent	**	No amplitude dependence	Present results

* Frequency in millihertz unless otherwise noted.
** The observation of details of the loop shape for Q > 1000 is beyond the resolution of the present apparatus.

Mechanics of Geologic Structures Associated with Faulting

9960-02112
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Investigations

1. Field mapping and thin section investigation of strike-slip faults and related structures in granitic rocks of the Sierra Nevada.

2. Investigation of the geometry of strike-slip and normal faults, and the nature of geometric discontinuities along fault zones (with Atilla Aydin).

3. Theoretical investigation of the process of echelon cracking in rock.

4. Theoretical and field investigation of solution surfaces in deformed rock (with Ray Fletcher).

5. Microscopic investigation of deformation structures within a strike-slip fault (with Y.-N. He and Steve Kirby).

Results

1. On the nucleation and growth of strike-slip faults in granite: A detailed study of small strike-slip faults in granodiorite of the Sierra Nevada was undertaken to determine how faults in granitic rock nucleate and grow. A subparallel array of fractures within the upper Cretaceous Lake Edison granodiorite strikes N 50°-70° E, and dips steeply to the south. Some of these fractures are identified as joints because they cross-cut, but do not offset, aplite dikes and mafic inclusions. In thin section, the joints are found to be filled with underformed, hydrothermal precipitates. Other fractures are identified as faults because they display left-lateral offsets of up to two meters. The faults occur parallel to, and in the same outcrop with, the joints. The faults contain plastically deformed hydrothermal precipitates and in some cases deformed granodiorite. The joint-filling precipitates thus predated the faulting. We conclude that the joints formed prior to the faulting, and that a later shear deformation concentrated on the pre-existing joints, nucleating small faults.

Secondary extensional-fractures, oriented N 20°-60° E, are found at the ends of some faults. These fractures formed contemporaneously with left-lateral slip on the faults. There is no evidence to indicate that faults extended in their own planes as shear fractures. Rather, secondary fractures linked together adjacent sheared-joints, thereby increasing the effective fault lengths. Locally, extensive secondary fracturing between sheared joints produced fault zones 0.5-2 meters in width, which display 5-15 meters of left-lateral slip. As deformation progressed, faulting evolved from relatively short, closely spaced faults to longer, more widely spaced fault zones.

2. On the deformation microstructures within a strike-slip fault in granodiorite: We studied a E-W striking, subvertical strike-slip fault in the granodiorite of Lake Edison, central Sierra Nevada, to determine the variation in deformation microstructures as a function of perpendicular distance from the fault. Field and thin section observations (described above) indicate the fault formed on a pre-existing, quartz-filled extensional fracture. This fracture forms the center of the mapped fault. Within approximately 20 centimeters of the central fracture the granodiorite is strongly foliated and the offset dike clearly deformed. Outside this zone the dike is undeformed and the granodiorite not visibly foliated. We have studied the deformation microstructures in the granodiorite, aplite dike, and quartz-rich fracture filling. Selective chemical etching was used to reveal grain-, subgrain-, and twin-boundaries and dislocation etch pits. Quartz in granodiorite outside the deformed zone is not syntectonically recyrstallized and displays large subgrains. In contrast, quartz within 20 centimeters of the central fracture is highly recrystallized and contains significantly smaller sub-grains. These observations demonstrate strong variations in deformation microstructures with distance from the center of the fault. We believe these results cast doubt on uncritical use of recrystallized grain size- and subgrain size-paleopiezometers, which would suggest significant variations in the apparent magnitude of the tectonic stress. Important effects of strain and/or environmental fluids on the micro- structures are suggested by our observations.

3. On inferring the state of stress from echelon crack geometry: Echelon cracks form over a great range of lengths (μm - km) and in a variety of materials (e.g., metals, rock, soil, ice). Their ubiquity attests to their importance in fracture processes. An analysis of a distinct class of echelon cracks, those that emerge as smoothly twisting segments from the breakdown of a parent crack, suggests that crack geometry reveals aspects of the state of stress. The parent crack lies in a principal stress plane with maximum tension as its normal. Crack segments approximate helicoidal surfaces that twist out of the parent-crack plane about the propagation axis. Steps in the fracture surface bound these segments and trend in the propagation direction. The sense and magnitude of the twist indicates a spatial rotation of two remote principal stresses about the propagation axis. This rotation introduces a shear stress on the parent crack acting parallel to the crack front. A smooth breakdown indicates a relatively great ratio of tensile to shear driving stress and/or a small Poisson's ratio.

In sections perpendicular to the propagation axis, crack segments have the echelon arrangement. The distribution of dilation along these segments is used to deduce the ratio of tensile driving stress to elastic stiffness and the fracture toughness of the host rock. Some segments do not link together, but overlap with straight tips. Others follow curving paths that slightly diverge, then strongly converge, and may link at tip-to-plane intersections leaving a step in the fracture surface. The former examples indicate a relatively great compressive stress acting in the crack plane. The mechanical interaction of adjacent echelon cracks introduces shear distortions to the crack wall and to nearby markers that may be misinterpreted as caused by remote shear loading. The analysis indicates the sense and magnitude of these local distortions.

Reports

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THEORETICAL STUDIES OF RUPTURE PROCESSES IN GEOLOGICAL MATERIALS

14-08-0001-19146

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During the year May 21, 1980 to May 20, 1981 we have accomplished some work in each of the three areas proposed for study: (i) interaction of slipping zones on faults; (ii) inception of shear rupture; and (iii) effects of coupling between deformation and pore fluid diffusion on rupture.

Interaction of Slipping Zones

Rudnicki and Kanamori (1981) have used existing quasi-static solutions for collinear shear cracks to examine quantitatively the effects of fault slip zone interaction on determinations of moment, stress drop, and static strain energy release. In addition, these calculations provide specific numerical examples of the general relations between moment and stress drop derived by Madariaga (JGR, 84, 2243-2250, 1979) and illustrate the extent to which small strong asperities or barriers can control the pattern of stress release.

As a preliminary to an examination of the dynamic effects of slip zone interaction, Rudnicki and Freund (1981) have reexamined the relationships among various expressions for the energy radiated by elastodynamic seismic sources. Both farfield representations and Kostrov's (Izv. Earth Physics, 1, 23-40, 1974) representation of radiated energy in terms of fault surface traction and particle velocity are examined. In particular, Kostrov's representation is arranged in various forms to reveal the source of radiated energy as the deviations of the fault surface tractions and particle velocities from the values that would occur during quasistatic fault motion between the same end states. Moreover, the excess of the static strain energy change over the work done by the fault surface tractions, called W_0 by Kanamori (JGR, 82, 2981-2987, 1977), is shown to be a good approximation to the radiated energy when fault propagation speed is near the Rayleigh wave velocity and the time rate of change of fault surface tractions is small. Because Kanamori has shown that for large earthquakes W_0 is approximately equal to the Gutenberg-Richter energy, one possible inference is that the conditions for which W_0 is approximately equal to the radiated energy are satisfied for large earthquakes.

Inception of Shear Rupture

Our work in this area has concentrated on an extension of Rice's (JGR, 80, 1531-1536, 1975) analysis of the stability of dilatant hardening for a layer subjected to simple shear. In particular, we are examining the response in the case of a finite-size nonuniformity in the form of a sublayer already weakened, perhaps by past faulting. An analysis that linearizes the response of the weakened layer and that of the surrounding material about undrained (no change in fluid mass content) homogeneous deformation demonstrates the competing effects of increasing tectonic stress and pore fluid diffusion in aggravating and mitigating, respectively, the tendency for the deformation to concentrate in the weakened layer. A graduate student, G. L. Bowers, has been formulating a direct numerical solution of the problem. Numerical solutions demonstrate that dilatant hardening can delay failure by comparison with its occurrence in dry rock. Moreover, although Rice's (1975) analysis demonstrated that homogeneous undrained response became unstable, in the sense that local nonuniformities grow exponentially in time when the underlying drained response passes peak, the numerical results suggest that at higher rates of boundary displacement the material can be driven to a load maximum instability before significant growth of these nonuniformities can occur. However, for imposed strain-rates representative of tectonic processes ($\sim 10^{-14}$ sec^{-1}) essentially drained conditions prevail until very near instability and dilatant hardening appears to be ineffective at increasing either the maximum stress or the maximum average strain of the layer. Consequently, the analysis does not yield evidence that dilatant hardening of an existing fault zone can transfer inelastic deformation and cracking to a much larger volume and cause accompanying precursory changes in material properties.

Coupled-Deformation Diffusion Effects

In addition to the above-mentioned work on dilatant hardening, which also involves coupled deformation diffusion effects, we have accomplished some additional work in this area.

Rudnicki (1980) has reviewed predictions for processes preparatory to earthquakes based on an inclusion model of earth faulting (Rudnicki, JGR, 82, 844-854, 1977; Rice and Rudnicki, JGR, 84, 2177-2193, 1979) for both dry and fluid-saturated rock masses. This review includes an interpretation of recent experimental results by Martin (GRL, 7, 404-406, 1980) on the stabilization by dilatant hardening of failure in Westerly granite.

Rudnicki (1981) has also obtained a useful rearrangement of Cleary's (Int. J. Solids Struc., 13, 785-808, 1977) solution for the sudden application of a point force at the origin in a linear fluid-infiltrated porous elastic solid. In particular, the stress and displacement fields are demonstrated to comprise a time independent portion, the classical elastic solution based on the undrained (short-time) moduli, and a time dependent portion, the solution for a continuous fluid mass dipole. A corollary of this result is that the time dependent functions entering the point force solution can be obtained from a single function entering the displacement solution for a fluid mass source. Rudnicki has used singlular solutions constructed from the point force solution to reconstruct, by placing appropriate point singularities at the origin, the solution of Rice, Rudnicki, and Simons (Int. J. Solids Struc., 14, 289-303, 1978) for the response of a fluid-infiltrated porous elastic solid containing a spherical cavity or inclusion. It is hoped that this technique may be used to obtain solutions for more complex geometries.

Publications

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AN EXPERIMENTAL STUDY OF THE RHEOLOGY OF CRUSTAL ROCKS

Contract 14-08-0001-15247

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The purpose of our study is to gain a more fundamental understanding of the deformation of crustal rocks by determining the grain-scale deformation mechanisms operative at different pressures, temperatures, strain rates, differential stresses, and water contents; to determine both the microscopic and the macroscopic brittle-ductile transition for these rocks as a function of these variables; and to determine flow laws for these polyphase rocks within the fully ductile regime so that it is possible to make extrapolations to natural conditions and to evaluate the depth range within which earthquakes are to be expected. Our approach is to deform samples of polyphase crustal rocks such as granites and diabases, as well as monomineralic aggregates of their constitutent phases, in the laboratory at controlled conditions; to do detailed petrographic and transmission electron microscope (TEM) analysis of the deformed specimens in order to determine the operative deformation mechanisms; to determine flow laws within the regime of dislocation creep; and to use a finite element computer program to determine how the flow laws of monomineralic aggregates should be summed into that of a polyphase aggregate in order to be extrapolated accurately to natural conditions.

During the first 6 months of the project this year, we have worked on a number of studies related to this project, including:

1. Experimental study of the effect of water on the deformation behavior and flow law of quartzite (Jaoul et al., 1981).

2. Theoretical computer modelling study of the flow law for polyphase aggregates in relation to those for the constituent phases, as tested against our experimental flow law data (Horowitz et al., 1981).

Our results are summarized below.

Effect of Water on Quartzite Deformation

We have undertaken an experimental study to determine the effect of water on the flow law and deformation mechanisms of quartzite as a function of water content. Heavitree quartzite was deformed 'as-is' (water content about 0.15 wt %), after vacuum drying at 685°C for 12 hours (water content about 0.03 wt %), after vacuum drying at 1000°C for 3 days (zero water content), with 0.15 wt % water added, and with 0.35 wt % water added. Stress and temperature stepping creep experiments were done at 15 kb within the alpha quartz field to determine flow laws, and constant strain rate experiments were done for observations of textures and deformation mechanisms.

There is a progressive weakening of the quartzite with increased water content; at 800^{o}C and 10^{-6}/sec, for example, the strengths (in order of increasing water content) are 6.8, 5.5, 3.6, 2.5, and 1.2 kb. The creep data were fit to a power law. The creep activation energy decreases somewhat with increasing water content, from 46 kcal/mole for the driest sample to 35 kcal/mole for the wettest. The stress exponent also decreases with increasing water content, from 2.93 for the driest to 1.40 for the wettest.

Textural observations were made on samples deformed at constant strain rate to 20% strain. The vacuum dried samples show no grain boundary recrystallization and the original grains show deformation bands and sharp, patchy undulatory extinction. The 'as-is' sample shows somewhat limited grain boundary recrystallization with an average size of .02 mm; the original grains are flattened and show continuc undulatory extinction and abundant deformation lamellae. The water-added samples show a more continuous layer of grain boundary recrystallization, with a smaller grain size (.01 mm) than in the 'as-is' sample; the original grains remain quite equant, with little undulatory extinction and few deformation lamellae.

Thus it appears that the dried samples deformed by inhomogeneous dislocation glide with limited climb; that the 'as-is' samples deformed by fairly homogeneous dislocation glide with easy climb and some accomodations taken up by grain boundar recrystallization; and that the water-added samples deformed by grain boundary sliding within the layer of recrystallized grains along the boundaries of the original grains. This would be consistent with the observed decrease in stress exponent.

We do not yet have any measure of the water actually within the crystal struc ture after the experiments, but we have sent some of our samples to Dr. S. Kirby who has kindly agreed to attempt IR measurements on them. We are also experimentir with using ^{18}O enriched water in the water-added samples and using the ion microprobe to analyze the penetration of this water into the grains (with the help of Dr. B. Giletti).

Finite Element Models of Polyphase Aggregate Flow Laws

Most crustal rocks of interest are composed of a number of phases with different rheology. If the constituent phases of such a rock have (non-linear) power law flow laws with different activation energies and stress exponents, then it is invalid to fit experimental data for the polyphase rock to a simple power law at all, and certainly such a low cannot be extrapolated outside the experimental conditions. For such materials, one must determine the flow laws of the constituent phases separately and formulate a model that correctly sums their contributions, taking account of the volume proportions of the phases as well as their geometrical arrangement.

One of the main goals of this project has been to experimentally determine flow laws for two of the most common crustal rock types, granitic and gabbroic rocks, and for the monomineralic aggregates of their constituent phases (quartz, albite, clinopyroxene, and intermediate plagioclase). That program has been completed (Shelton and Tullis, 1981; Shelton, 1981). In order to actually make use of these data and allow extrapolations to natural crustal conditions it is essential to develop a theoretical model which will allow one to express the behavior of the polyphase aggregate in terms of the properties, proportions, and arrangements of its constituent phases. It is this problem that we have been working on for the first half of this year.

A finite element model for incompressable power law creep of a single phase material has adapted to allow for multiple phases having different power law parameters. The program assumes that each phase behaves as a continum; that is, it ignores grain boundary sliding effects and dislocation/grain boundary interactions. Testing of the modified program with Chen and Argon's (1979) self consistent power law method and with Jaeger and Cook's (1969) linear elastic solutions, both for simple geometries, demonstrated that the problem solves the mixing problem correctly.

As a first test of the program we chose diabase, a two-phase aggregate on which we have done much experimental work. As input to the program, we digitized the actual texture from a photomicrograph of our Maryland diabase starting material, and we used the power law flow laws determined by Shelton (1981) for anorthosite and for clinopyroxenite. We numerically deformed this sample under plane strain using constant strain-rate boundary conditions. The results matched Shelton's best fit power law for the diabase reasonably well at the high end of the strain rates examined. Other sets of experiments were run using input textures digitized from a second photomicrograph of the starting material and from a photomicrograph of a diabase sample experimentally deformed to high strain, so that it had a prominent foliation. These three sets of experiments produced almost identical results, indicating that the volume fractions and the flow properties of the constituent phases are more important than their geometrical arrangement. In general, the predicted aggregate response tends to follow the constant strain rate bound for the stress and strain rate regimes investigated.

In the final 6 months of the project we plan to use this model to more systematically test the effect of varying volume proportions and varying geometrical arrangements of the phases on the strength of polyphase aggregate, and we also plan to apply the model to the aplite system, for which we also have extensive experimental results. This general method is somewhat cumbersome and time-consuming, so when we have determined the most important variables we hope to formulate a relatively simple function which approximates the aggregate response. We believe that the self-consistent solution of Chen and Argon (1979) offers the best approach.

Reports

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A STUDY OF MYLONITIC ROCKS FROM MAJOR FAULT ZONES

14-08-001-17757

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Investigations

1. Samples of mylonitic rocks and other cataclastic rocks were collected from exposed zones in central and southern California. Most of the work has been in southern California, focused on the the Punchbowl fault zone in the San Gabriel Mountains and the eastern Peninsular Ranges mylonite zone near Borrego Springs. Samples were also collected from the Carthage - Colton mylonite zone in the NW Adirondacks of New York.

2. Thin sections have been prepared from collected samples; these have been petrographically examined to determine the minerals present and whether any reactions accompanied mylonitization. Suites of rocks from the different zones have been analyzed for whole-rock chemistry using rapid silicate analysis methods. Selected samples have been analyzed with the electron microprobe.

Results

1. The analytical data from the mylonitized plutonic rocks of the eastern Peninusular Ranges mylonite zone have demonstrated two contrasting responses of the rocks to mylonitization. One group shows addition of $K2O$ and $H2O$ relative to unmylonitized equivalent rocks, whereas another group of mylonites seems to have lost $K2O$ and gained $H2O$. Other elements are affected to lesser degrees. Retrograde hydration reactions involving primary igneous minerals accompanied the mylonitization in much of the volume of the zone. The reactions probably occurred over a wide range of temperatures. The results show that an $H2O$-rich fluid phase was an important factor in the EPRMZ.

2. The Punchbowl fault zone is a complex volume of deformed rock slices that parallels, and joins at its ends, the San Andreas fault zone. The Punchbowl zone rocks have been strongly affected by the presence of an $H2O$-$CO2$ fluid phase during fault activity. The results of hydration and carbonation reactions are pervasively present throughout the zone. The fault rocks exposed were formed at a great variety of depths and, consequently, a considerable range of metamorphic grade conditions. Compositions of key phases, in

particular of Ca-amphibole, show that the relative ratio of P/T was consistently appropriate to intermediate to intermediate-high baric types. The results are compatible with measurements of present heat flow in the region; therefore one can extend back in time the applicability of the present thermal regime. No evidence has been found which would suggest that any different thermal regime ever prevailed near the zone.

Reports

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Experimental Study of Ultra Fine-Grained Granular Fault Gouge
(Contract No. 14-08-0001-19789)

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Investigations

(1) Preparation of ultra fine-grained (UFG) quartz and feldspar powder for the study of frictional and sintering properties of granular fault gouge.

(2) Measurement of frictional properties of the UFG gouge over a range of strain rates, confining and pore pressure.

(3) Investigation of the sintering of granular gouge at high temperature and pressure.

Results

(1) UFG quartz powder with different grain size distribution was prepared by separating commercially available silica sand into five different fractions. Median values of the grain-size distribution were 1, 3, 7, 15 and 25 μm. Size distribution curves for the finest and coarsest fraction determined by the sedigraph technique are shown in Figure 1. The preparation of UFG feldspar is now in progress.

(2) Shearing experiments have been performed on three sizes of the UFG quartz (of median grain size 1, 7 and 25 μm). The frictional strength data are summarized in Figure 2.

The UFG powder was introduced as a thin (~1 mm) layer along 35° sawcuts in solid cylinders of Berea sandstone and Westerly granite. The experiments were performed in triaxial compression, at axial strain rates ranging from 10^{-4} to $10^{-6}s^{-1}$. Confining pressure was fixed at 50 MPa (for "dry" experiments) or at 60 MPa with a fixed pore pressure of 10 MPa (for "wet" experiments). Two runs were also made on over-consolidated gouge prepared by leaving the whole assembly overnight under 200 MPa pressure before the shearing experiment.

The frictional data all fall along a straight line with a frictional coefficient of about 0.8 (Figure 2) which is close to the upper bond value of 0.85 suggested by Byerlee for such pressure conditions. "Dry" experiments on a Berea sample with 1 μm gouge at strain rates of 10^{-4} and $10^{-5}s^{-1}$ show frictional behavior identical to "dry" runs on a Berea sample without gouge along the sawcut and on a Westerly sample with 7 μm gouge at strain rates from 10^{-4} to $10^{-6}s^{-1}$. We conclude that unlike certain clay minerals of similar particle size which can apparently reduce the frictional strength, the UFG quartz under our test conditions has frictional properties identical to other granular gouge.

Although the stress-strain curves and the pore volume changes could be different, frictional coefficients for the "wet" and "dry" experiments on Berea samples with the finest and the coarsest quartz gouge and deformed at strain rates of 10^{-4} and $10^{-5}s^{-1}$ are almost identical. Neither did we observe any appreciable difference between the normally- and over-consolidated 1 μm gouge. "Holding" tests at different stages of deformation show that pore pressure transients were insignificant. Evidently no anomalous pore pressure developed in the gouge, and the sample assembly was deformed under fully-drained condition at the condition of strain rate, gouge thickness and porosity we chose.

(3) To have a better understanding of the effects of composition on frictional properties of UFG gouge, we will perform a few selected experiments on feldspar powder and one clay. We will also begin the investigation of sintering behavior of the UFG quartz.

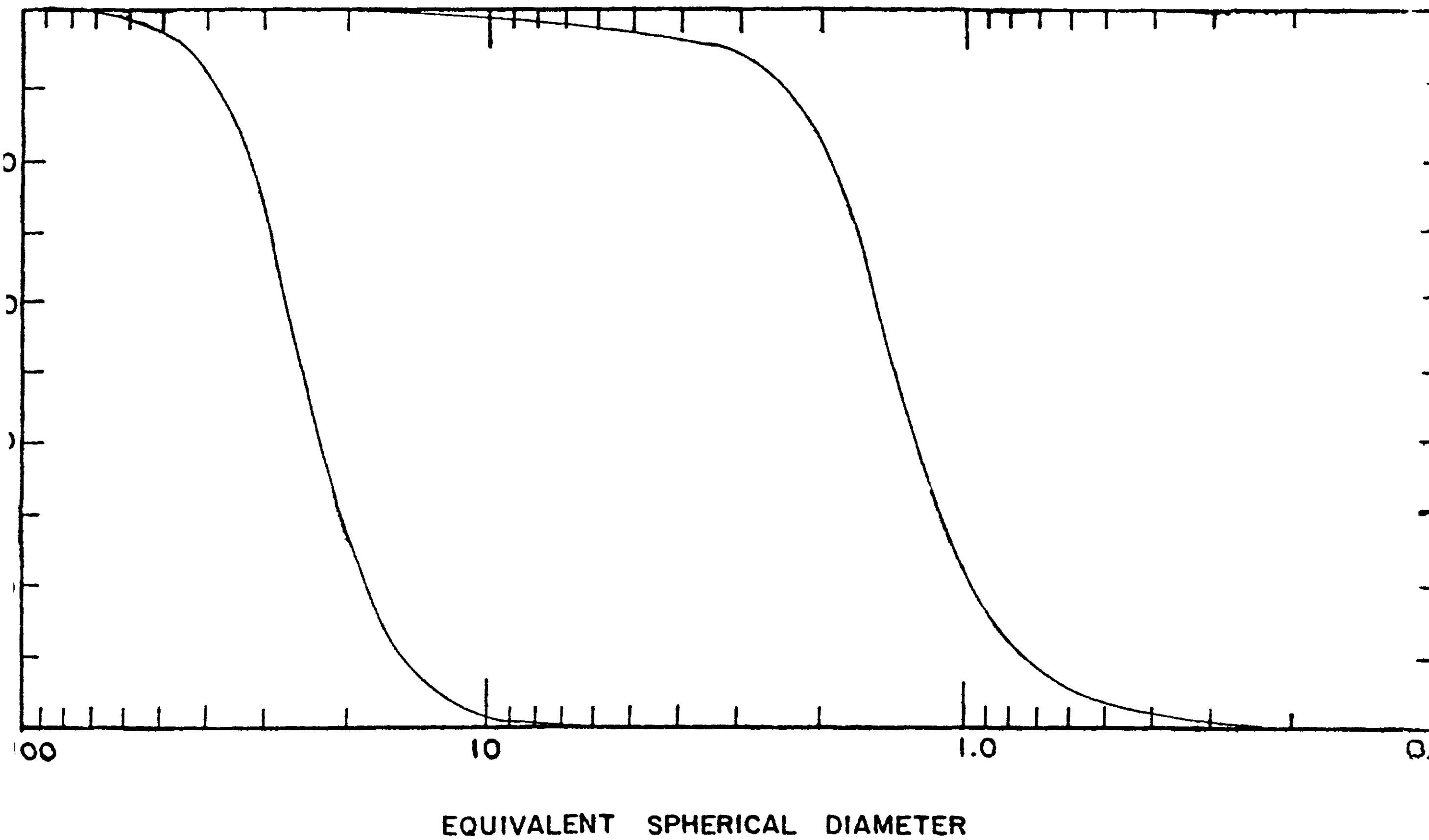

Figure 1: Particle size distribution for the finest and coarsest type of quartz gouge

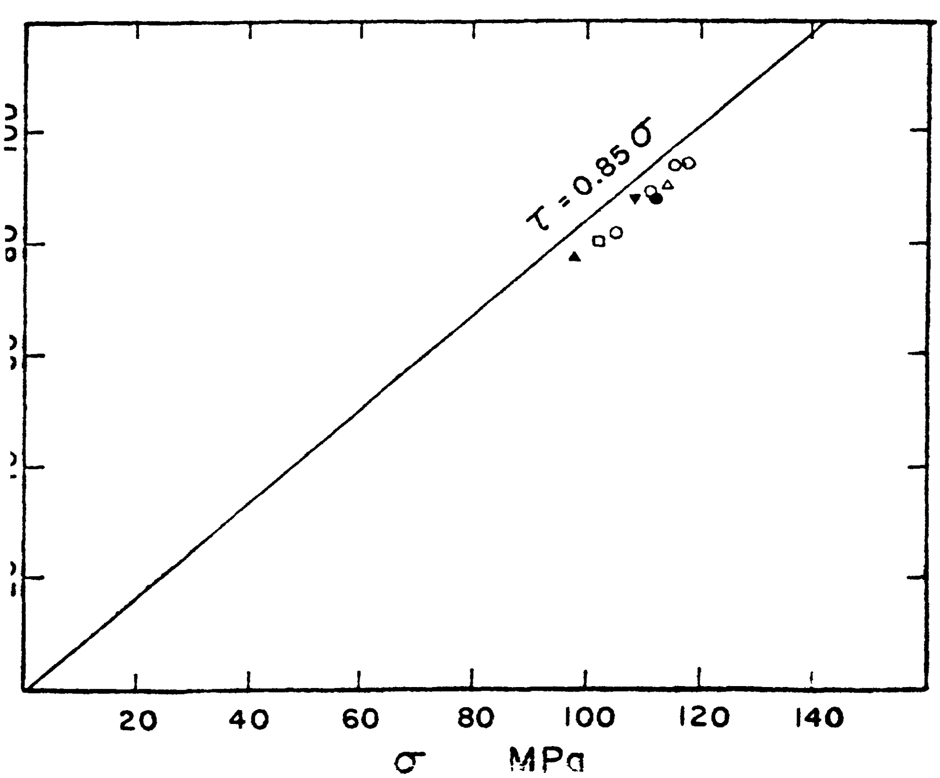

Figure 2:

Shear stress (τ) plotted as a function of normal stress (σ) at the maximum friction for different types of quartz gouge. Light symbols indicate that the samples were deformed "wet", whereas dark symbols are data from "dry" experiments.

□ = 25 μm gouge; ∇ = 7 m gouge; o = 1 m gouge; Δ = without goug

Contract No. 14-08-0001-19297

CONTINUED OPERATION OF STRESSMETER NET ALONG ACTIVE FAULTS IN SOUTHERN CALIFORNIA

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Investigation

During the first half of FY 1981, the following investigations were performed as a part of this contract:

1. Stressmeter readings were collected manually on approximately a bimonthly basis at seven active sites, three in the San Andreas Net and four in the Sierra Madre Net. The Lytle Creek I and San Antonio II arrays were also activated.

2. Site selection was completed for five sites in the newly authorized San Jacinto Net. Permitting was completed for use of two of the five new sites in the San Jacinto Net and in progress for the other three sites. Drilling of installation boreholes was completed at the new Pinyon Flat Observatory site and partially completed at the new Anza site.

3. Independent contractors were hired and trained to take Stressmeter readings in both the San Andreas and Sierra Madre Nets. These workers are trained geotechnical personnel who live within the boundaries of the Nets and thus can make the measurements at each site in a minimum of time and cost. As a part of this program, the frequency of measurements was increased to once per week.

4. Laboratory and field evaluations were completed on a new readout unit which contains a 250 khz reference oscillator in place of the original 100 khz oscillator. This increases the sensitivity of the vibrating-wire sensors by a factor of 2.5.

5. Work continued on new methods of defining and evaluating anomalous behavior in the Stressmeter measurements. A linear regression method is now being employed on a trial basis for evaluating long-term Stressmeter trends.

6. Work also continued on methods to install the sensors at greater depths and in rock of poor quality.

7. One manuscript was published in Science, and a second manuscript was essentially completed during the period and submitted in July for publication to the Journal of Geophysical Research.

Principal Findings

1. Long-term stress changes were shown to be consistent among individual sites and with regional tectonic stress-change patterns for southern California. Although an alternative explanation of the data as slow drift within the instruments remains possible, several independent lines of evidence make this explanation highly unlikely.

2. Weekly data collection confirm the excellent stability of the instruments. The data points generally follow linear trends developed during the previous recorded history of the sensor. No installed sensors were lost or failed during the period.

3. No significant short-period anomalies have been recorded during the first half of FY 1981. Long-term trends continue about as they had been, except that at San Antonio Dam, we determined that a change in the long-term trend had occurred in the Autumn of 1979, a few months before the 1979 Lytle Creek earthquake. The new trend, which was noted in earlier reports, is now quite linear and well-established.

4. Weekly data collection and analysis appears to be both feasible at reasonable cost and scientifically useful. The weekly results began to be collected in the last month of this period.

5. Drilling procedures continue to be a problem, largely because of the heterogeneity of rock quality near major fault zones. In the process of drilling in the San Jacinto Net, we are attempting to complete the holes with a rotary-pneumatic rig, using a specially designed carbide cross bit for the installation zone in the hole.

6. Use of a stainless steel tube in which the sensors are installed at the ground surface, and which could be grouted into place in a deep hole or a hole in poor-quality rock, appears promising. The system will require carefully chosen grouts, however. Laboratory testing is continuing.

Reports and Papers

Clark, B. R., 1980, Criteria for Distinguishing Anomalous Behavior in Stressmeter Data; EOS, Vol. 61, p. 1,053.

———, 1981, Stress Anomaly Accompanying 1979 Lytle Creek Earthquake, Southern California; Science, Vol. 211, pp. 51-53.

———, 1981, Monitoring Changes of Stress along Active Faults in Southern California; submitted to Jour. Geoph. Research, July 1981.

Heat Flow and Tectonic Studies

9960-01176

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Investigations:

1. Heat flow and tectonics of the western United States: Drilling activity subsided markedly with only seven holes (average depth, about 200 m) being drilled specifically for heat flow during the report period. Current field investigations are centered on the Cascades-Modoc Plateau area of northern California, the Salton Trough, southern San Andreas fault zone, the Sierra Basin and Range transition and the southern Colorado Plateau, the latter in cooperation with WRD and the Arizona Bureau of Geology and Mineral Technology. Laboratory and interpretive work has been focused on the Sonoran Desert and northern California during the report period.

2. Heat flow and tectonics of Alaska: Additional temperature data were obtained at 24 sites on the Alaskan North Slope. Laboratory investigations of thermal conductivity on core and cuttings from the National Petroleum Reserve - Alaska continued, as did interpretive studies of this region and Prudhoe Bay.

3. Thermal studies related to nuclear waste isolation: Temperature logs were made at all available sites in the proposed Yucca Mountain Repository, located astride the western boundary of the Nevada Test Site. Temperature logs were also obtained from wells at Salt Valley and Gibson Dome within the Paradox Basin in southeastern Utah. Measurements of thermal conductivity and interpretive studies were conducted primarily to provide information on regional tectonic and hydrologic settings and local hydrology. The detailed temperature and thermal conductivity data should also prove useful for engineering purposes.

4. Thermal studies related to "Geopressured" geothermal resources: A series of commercial temperature logs is being studied in conjunction with thermal conductivity measurements made in our laboratory in an attempt to construct equilibrium temperature profiles to determine regional heat flux and possibly to identify vertical fluid movement within or adjacent to the geopressured zone.

5. Data management: A concerted effort is being made to streamline our massive collection of data and to make the data readily available for a variety of interpretive procedures.

6. Equipment development: Work continues on development of an ultra-sensitive ($\sim 10^{-4}$ °C) probe for monitoring temperatures near the fault and on a rugged lightweight digital temperature recording system compatible with our present portable logger and computer system.

Results:

1. Heat flow and tectonics of the western United States: Recent field, laboratory, and interpretive work have served mainly to confirm and document the preliminary results and conclusions published previously. An open-file report documenting the work in deep wells in west-central Arizona was published (Sass and others, Open-File 81-1089), and an open-file report by Mase and others documenting previously published interpretations of the thermal regime of the California Cascades - Modoc Plateau is nearing completion.

2. Heat flow and tectonics of Alaska: Analysis of temperature measurements through permafrost in 14 petroleum-industry holes near Prudhoe Bay, Alaska, yields a general understanding of the geothermal regime of the region. The heat flow is 1.3 HFU, and the anomalously thick permafrost (600± m) is explained by the anomalously high thermal conductivity of the silicic ice-rich sediments. A rapid climatic change in the last 100 years resulted in a net accumulation of ∿5 $Kcal/cm^2$ by the solid-earth surface and a rise in its temperature of ∿2°C. A theoretical model accounting for recent shoreline transgression implies that ice-rich permafrost close to its melting point extends to depths ∿500 m throughout much of the offshore region overlying prospective petroleum resources. Such permafrost causes engineering problems for extraction and transportation of oil. The study provides confirmation for a simple model of the conductivity of an aggregate in terms of the conductivity of its constituents, and for its application to frozen and thawed sediments.

3. Thermal studies related to nuclear waste isolation: The Colorado Plateau, once thought to be a province of uniformly low-to-intermediate heat flow, has been shown recently (by D. Chapman and colleagues) to be comprised of a number of distinct thermal subprovinces. Preliminary estimates of heat flow from Salt Valley and Gibson Dome in the Paradox Basin confirm that this part of the Colorado Plateau is a province of low-to-normal heat flow. Detailed temperature profiles in the caprock indicate the possibility of local hydrologic disturbances to the thermal regime, but there is no evidence for vertical water movement within the salt sections. Heat-flow data from the Nevada Test Site region generally confirm the previous location of the southern boundary of the "Eureka Low" (defined by the 1.5 HFU contour). They also indicate a complicated plumbing system in the upper 2 km or so with large local variations in conductive heat flux caused by water movements with a vertical component of seepage velocity of 10 mm y^{-1} or less. Equilibrium temperature profiles in the rather thick (300-500 meter) unsaturated zone near Yucca Mountain exhibited puzzling reversals and large lateral variations of temperature over distances of a few hundred meters. One explanation we have considered for these unusual temperature excursions involves steady-state two-phase water flow with abrupt changes in the liquid/vapor ratio occurring at stratigraphic boundaries. A testable theoretical model of the process has been developed (Lachenbruch, Open-File 81-1220).

4. Thermal studies related to "Geopressured" Geothermal Resources: From temperatures and thermal conductivities in two wells (Dow Sweezy #1 and AMOCO Fee #1) in the Louisiana Gulf Coast, the average thermal gradient is

between 20 and 25°C/km. Gradients are higher (35 to 40°C/km) in the impermeable shale overlying the geopressured zone and correspondingly lower (15 to 20°C/km) in the sands. This is consistent with a regional heat flux of about 1.5 HFU (60 mWm^{-2}).

5. Data management: All data presently are in computer files, either archived on the USGS Multics system or in active disk storage. The bulk of our present effort is now devoted to cross-referencing the data files on the basis of several attributes (e.g., geographical location, tectonic province, rock type, etc.) in order to facilitate analysis and interpretation of the data.

Reports:

Lachenbruch, A. H., 1981, Temperature effects of varying phase composition during the steady vertical flow of moisture in unsaturated stratified sediments: U.S. Geological Survey Open-File Report 81-1220, 11 p.

Lachenbruch, A. H., and Sass, J. H., 1981, Corrections to 'Heat flow and energetics of the San Andreas fault zone' and some additional comments on the relation between fault friction and observed heat flow: Journal of Geophysical Research, v. 86, p. 7171-7172.

Mase, C. W., Sass, J. H., Brook, C. A., and Munroe, R. J., 1981, Shallow hydrothermal regime of the East Brawley and Glamis KGRA's, Salton Trough, California: U.S. Geological Survey Open-File Report 81-834, 57 p.

Sass, J. H., 1981, Review of Terrestrial heat flow in Europe, edited by V. Cermak and L. Rybach: Earth Science Reviews, v. 17, p. 293-294.

Sass, J. H., Munroe, R. J., and Stone, Claudia, 1981, Heat flow from five uranium test wells in west-central Arizona: U.S. Geological Survey Open-File Report 81-1089, 42 p.

Fault Zone Structures

9930-01725

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Investigations

1. In June 1981 a nuclear shot at the Nevada Test Site was recorded on 100 portable seismic cassette recorders in an ongoing attempt to determine the feasibility of nuclear waste storage in the vicinity of Yucca Mountain, Nevada. The data collected have been digitized and record sections produced. Analysis of traveltime delays in terms of near-surface structure is continuing at this time. Planning for two future profiles in the area continues; a preliminary survey across Yucca Mountain was carried out to determine shot point sites, location of deployment profile lines, and deployment vehicle needs. Also, a new remote radio turn-on system is being added to each recorder which will allow the successful recording of nuclear events by removing problems caused by pre- and reprogramming.

2. The final report describing the Saudi Arabian refraction profile and the interpretation of the data collected has been technically reviewed and is in its final preparation stages. The record sections have been improved and are ready for publication. A volume on the Proceedings of the CCSS (Committee on Controlled Source Seismology) meeting in Park City, Utah, in August 1980 has been compiled and is now in review.

Results

1. The data recorded along the profile from Yucca Mountain to Death Valley Junction (fig. 1), in the distance range 48 to 110 km, show several important features. The first arrival curve reveals significant traveltime variations largely due, presumably, to near-surface delays, which are 0.5 s or more in the area of Yucca Mountain. The data show clear secondary arrivals that reveal details of the crustal structure virtually directly beneath Yucca Mountain. The data recorded along the profile from Yucca Mountain to Amargosa Desert (fig. 1), in the distance range 52 to 86 km, also reveals traveltime delays in the vicinity of Yucca Mountain of 0.5 s relative to the region south of Crater Flat. In addition, the recordings near Yucca Mountain show a lower dominant frequency than those further south.

Reports

Healy, J. H., Mooney, W. D., Blank, H. R., Gettings, M. E., Kohler, W. M., Lamson, R. J., and Leone, L., 1981, Saudi Arabian seismic deep-refraction profile, final report, U.S. Geological Survey Saudi Arabian Technical Project Report, in prep.

Hoffman, L. and Mooney, W. D., Data report on the seismic study of the tectonic environment of Yucca Mountain, Nevada, in prep.

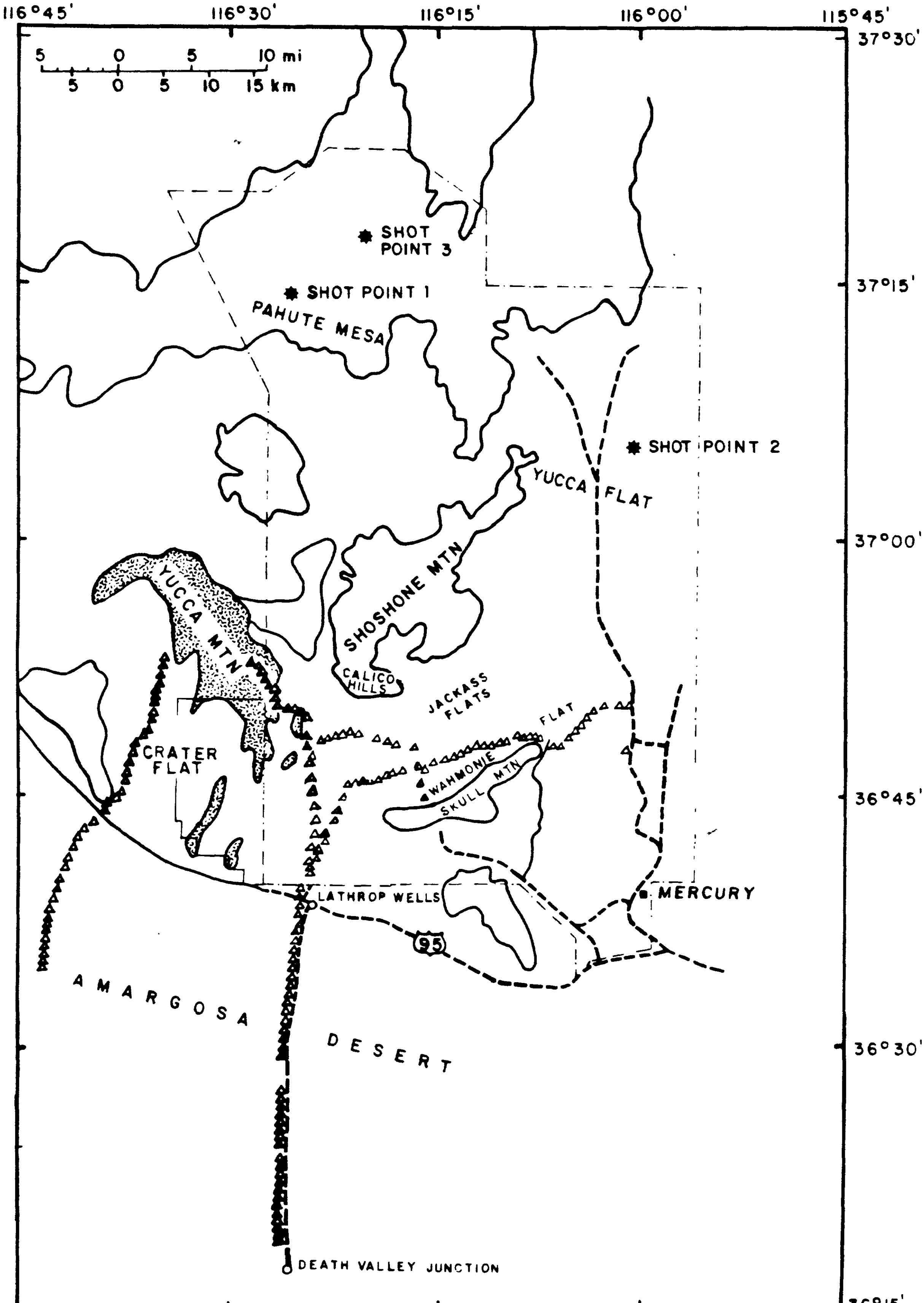

Figure 1 : Shot point and recorder locations

Active Seismology in Fault Zones

9930-02102

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Investigations

1. Collection and analysis of seismic refraction data in central California: Livermore Valley, Great Valley, Diablo Range, Santa Clara Valley, Gabilan Range, and Santa Cruz Mtns. (with A. Walter).

2. Analysis of seismic refraction data from the Mojave Desert, southern California (with G. S. Fuis).

3. Analysis of refraction data from the Mississippi embayment (with W. Kohler, A. Walter, W. Lutter and A. Ginzberg).

4. Continued development of hardware and software systems for analysis of seismic refraction data (with W. Kohler and A. Walter).

Results

1. The analysis of seismic refraction profiles in central California have revealed considerable lateral variations in velocity which reflect its geologic evolution as a sequence of terranes. Previously reported work from this project revealed that there is a resolvable difference in the crustal velocity structure on either side of the San Andreas fault. Below the sediments and weathered zone, the upper crust (3-8 km) of the Diablo Range has an average velocity of 5.5 km/s while in the Gabilan Range the average velocity is 6.1 km/s. In the middle crust (8-17 km) the Diablo Range has an average velocity of 6.1 km/s, while it is 6.3 km/s in the Gabilan Range. In the lower crust (17-29 km) the average velocity in the Diablo Range is 6.9 km/s while it is 6.5 km/s in the Gabilan Range. These contrasts in velocity with depth are indicative of compositional differences between the two ranges. We concluded that the Diablo Range most likely consists of metagraywacke to a depth of 17 km, and of gabboic material below this depth. The Gabilan Range consists of granitic material to a depth of 17 km and of metagranite (gneiss) in the lower crust, but it is possible that some gabbroic rocks are also present.

Newly recorded profiles are currently undergoing analysis. Profiles 1 and 2 run across and along the Great Valley, respectively, and were designed to provide information concerning the basement structure there and its relationship to the flanking Diablo and Sierra blocks. Profile 3 crosses the San Andreas, Sargent and Calaveras Faults. Analysis of data along this profile reveals: 1) there is a scarp with 1.5 km relief along the postulated connection between the Zayante and Vergales and 2) average 'basement' velocity is 5.45 km/s with a higher velocity beneath the Santa Clara Valley (6.0 km/s). Profile 4 in the central Santa Cruz Mts. is undergoing preliminary processing.

2. In June 1980, the U.S. Geological Survey recorded a 38-km-long reversed seismic-refraction profile between Rogers Dry Lake in the western Mojave Desert, California, and the San Andreas fault zone to the south. In April 1981, this profile was extended northward to China Lake, north of the Mojave Desert, with shots at Boron, and at China Lake.

We modeled the Rogers Lake-San Andreas segment of the profile using a two-dimensional ray-tracing program to match first-arrival traveltimes. Three units are recognized: 1) a unit of low velocity (1.6-1.8 km/s), 0 to 0.4 km thick, corresponding to sedimentary deposits, 2) a unit 0.5 to 2.0 km thick in which velocity increases relatively rapidly from 4.7 to 5.4-5.7 km/s, corresponding to the upper part of the granitic basement, and 3) a unit in which velocity increases relatively slowly from 5.7 to about 6.2 km/s at 10 km depth, the bottom of the model. The thickness of sedimentary basins determined from refraction agrees within 0.1-0.2 km with that determined from wells. The relatively high velocity gradient in the upper part of the granitic basement reflects primarily the rapid closing of cracks with depth. This unit thickens southward toward the San Andreas fault and is thickest beneath the deepest sedimentary basin on this profile.

Preliminary results from preparing a true-amplitude record section for this segment of the profile indicate that beyond the crossover to the 5.7 km/s branch (at about 10 km) amplitudes decrease with distance (r) as r^{-2} . At closer ranges, amplitudes decrease more slowly with distance. Velocity-depth functions determined from sonic logs in three wells along or near the profile agree with our model velocity-depth functions.

The reversed segment of the profile between Boron and China Lake is currently being modeled in the same way. Notable features on this profile include an abrupt advance in travel times south of the Cantil Valley fault branch in Garlock fault zone and generally higher apparent velocities northward along the profile than southward. Early arrivals south of the Cantil Valley fault correspond spacially with an area underlain by Rand schist. Apparent velocities suggest southward dips on the blocks north and south of this fault. Conclusions regarding the configuration of the Rand schist will be important, as geologists are currently debating the structural relationship of the Rand schist and its equivalent, the Pelona schist, to other rocks in California. Some geologists would have rocks of southwest California be thrust over the Pelona during subduction or Nevadan-style thrusting, making outcrops of this body, where they are seen, fensters. Other would have a complex of rocks, including the Pelona, accreted or obducted onto rocks of southwest California, making Pelona outcrops klippen.

3. Within the last decade, interest in the Mississippi embayment has been heightened by the seismic activity concentrated there. Research has revealed that a series of the most devastating earthquakes on the continent occurred in the New Madrid region in 1811 and 1812, in an area long thought to be part of the stable craton. Plots from these and other epicenters revealed a roughly linear zone of seismicity extending down the axis of the embayment in the northern portion (Nuttli, 1979; Herrmann, 1980). These patterns led to speculation relating the cause of seismicity to sub-surface structures.

In order to investigate these structures the U.S. Geological Survey recorded in September 1980 34 shots from nine shot points in the northern Mississippi embayment. The velocity layers in the cross-profile support the existence of a late Precambrian to early Paleozoic graben in accordance with Erwin and McGinnis' (1975) interpretation of the embayment. Upwarping of the crust and an anomalous lower crust with a velocity intermediate between mantle and lower crustal velocities suggest an intrusion of mantle into the crust in the late Precambrian, followed by crustal doming and graben formation. The graben is indicated by the 5.6 km/s low velocity zone which lenses out in all directions. Uplift and erosion during the late Precambrian and early Paleozoic in areas peripheral to the graben. account for the 5 km of arkosic sediments deposited in the graben. Erosion and isostatic subsidence created a broad, elongate basin in the early Paleozoic (Reelfoot basin of Schwalb, 1969) that accumulated thick sequences of carbonate sediments. Horizontal tectonic forces began to predominate in the middle to late Paleozoic, culminating in the Ouachita orogeny in Pennsylvanian time in the southern portion of the embayment region. The increasing dominance of plate tectonics during the late Paleozoic and Mesozoic probably succeeded in controlling rifting in the embayment to a greater degree than vertical anorogenic forces. A second stage of major rifting was initiated in the Mesozoic which bears a relationship to global continental rifting in the early part of the era. This rifting was in response to plate forces at the southern margin of the continent and was probably related to transform migration along divergent spreading centers. The Cenozoic era was characterized by constructive delta formation and continued subsidence of the embayment area. The present configuration was established as the Mesozoic rift zone was filled with unconsolidated marine and non-marine deltaic sediments.

4. A major problem in any investigation that requires handling large amounts of data is creating a system that allows rapid and convenient access and display of data. To provide this ease of access we have implimented a number of improvements to our data processing/analysis system. 1) seismic sections with theoretical model times and amplitudes can now be plotted in a variety of formats on the National Strong Ground Motion PDP 11/70 computer. 2) a PDP 11/23 computer with hard and floppy disks has been added to allow for more rapid initial processing.

Reports

Fuis, G. S., Mooney, W. D., Healy, J. H., McMechan, G. A., and Lutter, W. J., A seismic-refraction survey of the Imperial Valley region, California: submitted to JGR.

Fuis, G. S., Mooney, W. D., Kohler, W. M., and Moos, Dan, 1981, A seismic-refraction survey in the western Mojave Desert, California: Earthquake Notes, Seismological Society of America, v. 52, no. 1, p. 50.

Fuis, G. S., 1981, Crustal structure of the Mojave Desert in Howard, K.A., Carr, M. D., and Miller, D. M., eds., Tectonic Framework of the Mojave and Sonoran Deserts, California and Arizona: U.S.G.S. Open-File Report 81-503, p. 36-38.

Fuis, G. S., Mooney, W. D., Healy, J. H., McMechan, G. A. and Lutter, W.J. 1981, Seismic-refraction studies of the Imperial Valley region, California-profile model, a traveltime contour map, and a gravity model: U.S.G.S. Open-File Report 81-270, 73 p.

Ginzburg, A., Mooney, W. D., Peters, D. and Lutter, W., 1981 Crustal structure of the Mississippi Embayment: cross profile (abst.), EOS, (in press).

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Mooney, W. D. and Walter, A., 1981, Seismic refraction studies in the Coast Ranges, central California (abs.): EOS, v. 62, no. 17, p. 328

Mueller, S., Mooney, W. D., Prodehl, C., Smith, R. B., Hill, D. P., Orcutt, J. A. and Ansorge, J., 1981, IASPEI workshop: seismic modeling of laterally varying structures (abst.): IASPEI meeting, London, Ontario, Canada, July 21-30, 1981, (in press).

Walter, A. W. and Mooney, W. D., 1981, Reinterpreting seismic refraction data from central California (abst.), Earthquake notes, v. 52, no. 1, p. 51 (MS. in internal review for submission to BSSA).

Title:	Detailed analysis of deformation associated with the Melones fault: a deeply-eroded former plate boundary, western Sierra Nevada, California
Contract Number:	USGS 14-08-0001-18376
Principal Investigators:	Dr. Richard A. Schweickert Dr. Terry Engelder Mr. Nicholas Bogen
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Field study of the Melones fault zone, involving structural analysis of its wallrocks and nine detailed and eight reconnaissance traverses of the fault zone itself, has clarified the tectonic setting, structural style, and movement history of the fault.

The segment of the Melones fault south of Placerville forms the structural boundary between two related belts of Jurassic rocks, a slate belt to the west and a phyllite-greenschist belt to the east. Lithologic and stratigraphic similarity of the rocks on both sides of the fault indicate that the southern part of the Melones represents a zone of imbrication and is not a major suture. Major strike-slip displacements are ruled out.

The Melones fault zone has had three distinct periods of activity, each characterized by a distinctive style of deformation and displacement.

The Jurassic Melones fault <u>sensu strictu</u> is a narrow (<5m wide) ductile thrust zone which separates Mariposa slate in the FW from more highly metamorphosed phyllite or metaserpentinite in the HW. The fault fabric transposes and overprints penetrative fabrics in Jurassic phyllites in the HW and apparently formed contemporaneously with the slaty cleavage in FW. Faulting was most likely aseismic.

Several ductile Jurassic thrust faults occur in the HW phyllites and greenschists. Unlike the Melones, these do not form metamorphic boundaries. Early Cretaceous brittle reverse faulting generally occurred along the Jurassic faults in the HW of the Melones. Such brittle faults are characterized by complex zones of quartz veining, brecciation, and redeposition of quartz, in gouge zones up to 5m thick. Maximum displacements were typically on the order or tens of meters according to Knopf (1929). The Cretaceous faults experienced seismic slip.

Seismic, Cenozoic brittle normal faulting occurred in many places along zones of Cretaceous reactivation. Nowhere is there evidence that Jurassic faults were reactivated in Cenozoic time without an intervening Cretaceous episode. Cretaceous faulting produced broad, weak zones which have been preferentially reactivated.

U.S. Seismic Network

9920-01899

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Investigations

U.S. Seismicity: Continuously monitor U.S. seismicity using data recorded by the U.S. Seismic Network.

Worldwide Seismicity: Data from the U.S. Seismic Network are used to obtain a preliminary location of significant earthquakes worldwide.

Results

As an operational program, the U.S. Seismic Network operated normally throughout the report period. Data were recorded continuously in real time at the NEIS main office in Golden, Colorado. At the present time, 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."

Development work is continuing on an event detector to monitor the U.S. Seismic Network in real time. Current plans are to use several PDP 11/03 microcomputers to monitor the data and pass events on to a PDP 11/23 for further processing.

The goals of the U.S. Seismic Network are to upgrade the quantity and quality of the data received to make possible more rapid and accurate location of U.S. earthquakes and significant earthquakes worldwide.

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.

Digital Network-Data Processing

9920-02217

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Investigations:

1. Data Processing for the Global Digital Seismograph Network. All of the digital data received from the global network is reviewed and checked for quality.

2. Network-Day Tape Program. All of the digital data received at the ASL is assembled into network-day tapes which are distributed to universities and other organizations.

3. New Event Detection Program Developed for the SRO Installations. A new short-period event detection program has been written and tested for the SRO system and is presently being coded in assembly language for field distribution.

4. Evaluation of the Short-Period Event Detector of the World-Wide Upgrade System. This event detection system was evaluated for effectiveness in sensing small events.

Results:

1. Data Processing for the Global Digital Seismograph Network. During the past 6 months, 296 digital tapes (169 SRO/ASRO and 127 DWWSSN) from the global network were edited, checked for quality, corrected when feasible, copied and archived at the Albuquerque Seismological Laboratory. Station tapes from 6 of the installations are copied and returned to the stations for their own research programs.

2. Network-Day Tape Program. The network-day tape program is a continuing program which assembles all of the data recorded by the Global Digital Seismograph Network for a specific calendar day onto one magnetic tape. This tape includes all the necessary station parameters, calibration data, and time correction information for each station in the network. The production of these day-tapes is normally about 60 days behind the actual recorded date to allow for delays in shipping the data to Albuquerque. As of October 1, 1981, the network-day tapes were completed for August 3, 1981. Six copies of the network-day tapes are forwarded to various research centers in this country. Individual distribution is handled by the Environmental Data and Information Service in Boulder, Colorado.

3. New Event Detection Program Developed for the SRO Installations. A short-period event detecting program previously developed at the ASL for SRO station tapes which had continuous short-period data, has been modified and is in the

process of being coded for use in the SRO field systems. In addition to detecting an event, the algorithm picks the direction of the first break and onset time, evaluates the pick, and estimates the period and amplitude of the signal. In picking onsets, it appears to perform nearly as well as a human who analyzes the helicorder seismograms. Programs for the SRO field systems must be written in machine language for a Data General Nova, Model 1200.

4. Evaluation of the Short-Period Event Detector of the World-Wide Upgrade System. Installation of the DWWSSN stations began in October 1980, however, it was not until this past summer that a sufficient number of stations were installed to begin an evaluation of the efficiency of the short-period event detector. Helicorder seismograms were available from 5 stations, ABQ, AFI, LON, SCP, and TAU. Ten days of data were analyzed from each of the 5 stations. The digital events were plotted on the helicorder records and the comparison was made. All events greater than 10 millimeters peak-to-peak were picked by the event detector. However, some clear events of smaller amplitude were missed. Special tests are underway using the ALB installation to determine if the event detector can be improved.

Reports:

Murdock, J.N., and Jaksha, L.H., 1981, The P-Wave Velocity of the Uppermost Mantle of the Rio Grande Rift Region of North-Central New Mexico: Jour. Geophys. Res., v. 86, No. B8, pp. 7055-7063.

Albuquerque Observatory

9920-01260

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Investigations and Results:

We have participated in a number of seismic-refraction experiments. The CERF III shot was recorded to estimate the Pg-wave velocity in the Albuquerque Basin and to explore the reflectors in the upper crust. DISTANT RUNNER I and MILL RACE were observed along our San Juan Basin line to estimate parameters in the lower crust. Five explosions were detonated in and around the Valles Caldera in northern New Mexico. We recorded these shots along with field teams from Los Alamos National Laboratories, University of Texas at El Paso, and Purdue University. An NTS shot and several timed quarry blasts were recorded during the caldera experiment as well.

About 75% of the work necessary to eliminating the New Mexico state microwave system as a carrier of our San Juan Basin seismicity data has been completed. A data multiplexing site has been established at Washington Pass and a radio repeater installed on Mt. Taylor.

Dave Evans has compiled one year of seismicity data (1980) for the San Juan Basin.

Jim Murdock has begun processing the refraction data that we took in southern Arizona in 1978.

Reports:

Murdock, J.N., and Jaksha, L.H., 1981, The P-Wave Velocity of the Uppermost Mantle of the Rio Grande Rift Region of North Central New Mexico, Journal of Geophysical Research, Vol. 86, pp. 7055-7064.

WORLD-WIDE STANDARDIZED SEISMOGRAPH NETWORK (WWSSN)

9920-01201

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Investigations

1. The Global Network Operations continued to provide technical and operational support to the WWSSN observatories as funding and staffing permitted.

2. During this period, 265 modules were repaired and 239 separate items were shipped to support the network. Forty stations were supplied with annual shipments of photographic supplies and emergency shipments were made to 7 stations.

3. Training was provided for two Raytheon contract technicians during March 23 thru March 27 and one Raytheon contract technician during May 26 thru May 29. Training was provided for three foreign students during June 6 thru June 23: Mr. Bernd Steigner (GRFO), Mr. Henri Floc'h (BCAO), and Mr. Mohammad Taher (KAAO). During July 29 thru August 3 training was provided for one foreign student, Mr. Jose Nieva (LPB). During August 5 thru August 7 training was provided for one Raytheon contract technician.

Results

A continual flow of high quality seismic data from the network of 115 observatories for use by the seismological community.

USGS and Cooperative Observatories

9920-01261

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Investigations:

Field activities consist of occasional visits to the seismic stations for the purpose of maintenance, calibration, or installation of new instrumentation. Stations are provided with advice on operation, maintenance, and calibration. Also, all stations are provided with spare parts, operational supplies and replacement modules.

Results:

These observatories contribute essential data to the NEIS, both routinely and on a rapid basis when required. The locations were selected to fill gaps in station locations and to provide better coverage for local events. All data are available for other seismologists when required.

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, re-design 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 continued with one team leader and six technicians plus a systems programmer was added to the contract during this period.

There was one formal training class conducted in June on the SRO/ASRO system with one person each from the stations in W. Germany, Central Africa, and Afghanistan.

A major software effort was started during this period with a complete redesign of the SRO short-period event detector. The software had been flow charted, coded, and assembled by the end of this reporting period.

The following station maintenance activity was accomplished:

ANMO - Albuquerque - SRO
The operating software on the ANMO system was modified during this period to record 3 short-period channels on an event detected basis. Experimental clip sensors were added to each long-period channel to indicate seismometer clipping and to be recorded in status byte of each magnetic tape record header.
Two (2) corrective maintenance visits were required during the period.

ANTO - Ankara, Turkey - SRO
Two (2) maintenance visits.

BCAO - Bangui, Central African Republic - SRO
One (1) maintenance visit. Borehole seismometer was replaced during this visit.

BOCO - Bogota, Colombia - SRO
One (1) maintenance visit.

CHTO - Chiang Mai, Thailand - SRO
Two (2) maintenance visits.

CTAO - Charters Towers, Australia - ASRO
No maintenance visit.

GRFO - Grafenberg, W. Germany - SRO
No maintenance visit.

GUMO - Guam - SRO
No maintenance visit.

KONO - Kongsberg, Norway - ASRO
No maintenance visit.

KAAO - Kabul, Afghanistan - ASRO
No maintenance visit.

MAJO - Matsushiro, Japan - ASRO
No maintenance visit.

MAIO - Mashad, Iran - SRO
No maintenance visit - out of operation.

NWAO - Mundaring (Narrogin), W. Australia - SRO
No maintenance visit.

SHIO - Shillong, India - SRO
One (1) maintenance visit.

SNZO - Wellington, New Zealand - SRO
No maintenance visit.

TATO - Taipei, Taiwan - SRO
No maintenance visit.

WWSSN
WES - Weston, Mass.
One (1) calibration and training visit.

DWWSSN

Four DWWSSN systems were installed and two installations were in progress at end of period.

APW - Apia, W. Samoa
TAU - Hobart, Tasmania
KEV - Kevo, Finland
TOL - Toledo, Spain
SLR - Silverton (Pretoria), S. Africa - in progress
COL - College, Alaska
LEM - Lembang, Indonesia - partially completed, not in progress.

Two maintenance visits were made at DWWSSN stations:

TAU
APW

ASL Repair Facility:

Assembly, testing and shipping of five (5) DWWSSN systems was accomplished. In addition, routine repair and testing of replaceable modules for the SRO/DWWSSN systems took place as time permitted.

Results:

Installation of the DWWSSN systems has expanded the digital network to a combined total of 24 SRO/ASRO/DWWSSN stations, not including the two currently being installed. This expansion has resulted in a much broader digital data base through the improved geographical coverage of the digital systems.

GLOBAL SEISMOGRAPH NETWORK EVALUATION AND DEVELOPMENT

9920-02384

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Investigations

Peterson and C.R. Hutt continued to work on a design study for a national digital seismograph network and also continued testing and evaluation of the DWWSSN system. Peterson investigated the causes of transients that occasionally appear in the SRO and ASRO long-period data. L.G. Holcomb continued an analysis of SRO and ASRO calibration, continued his study of earth noise, and performed a design study for upgrading seismic instrumentation in Antarctica.

Results

A preliminary design study for a national digital seismograph network was completed during the reporting period and the results have been published in an open-file report. The types of data that might be acquired from the new stations are described and data system and data management concepts are presented.

Transfer functions for the DWWSSN system have been derived from a parametric system analysis and fitted to measured calibration data by adjusting key parameters. The derivation of the short-period transfer function is complicated by the fact that there are two current sources in the circuit, but the results reveal that the galvanometer generator can be ignored.

An investigation of transient pulses in the SRO and ASRO long-period data associated with impulsive body wave arrivals revealed that some are caused by a nonlinear process (clipping) and some are due to a linear process (filter impulse response). The short-period waveform should always be checked for possible clipping when large-amplitude long-period signals are being analyzed. A short report on the results of this study has been submitted for publication.

Calibration data from all SRO and ASRO stations for the calender year 1980 were analyzed to test and evaluate the algorithm being used to compute the calibration data for the GDSN network-day tape operation and to compile statistics on the performance of the overall calibration scheme. This study indicates that the station calibration amplitudes can be evaluated with a precision of better than $\pm$ 1% and that the phase angle can be determined to within $\pm$ 0.5 degrees. The sensitivities of individual channels were essentially constant over the year indicating that the station calibrations are very stable. The results of the study have been submitted for publication in an open-file report.

A study of background earth noise levels was conducted to provide estimates of simultaneous noise levels at stations distributed around the world. Power spectral estimates from 0.1 to 600 seconds were calculated for 15 stations during the first two weeks of October, 1981. These data are useful to designers of systems intended to isolate sensitive instruments from background earth motion interference. The results of the study were presented to a conference of the American Institute of Aeronautics and Astronautics. Maximum entropy spectral analysis of the 26-second spectral line in long-period earth background reveals that this line is much narrower than originally believed, thereby indicating that a very high Q source must be generating this energy.

Several methods were investigated for improving seismic stations at the South Pole and the McMurdo-Dry Valleys region of Antarctica. Feasible alternatives ranged from a short-period vertical-component seismometer installed in a shallow borehole at the Pole to a three-component short- and long-period seismometer installed in a deep borehole in the Dry Valleys with the data acquired by telemetry. The results of the study have been submitted for publication as an open-file report.

Reports

Holcomb, L.G., 1981, The lower limits of seismic background noise levels: Proceedings of the AIAA Guidance and Control Conference, August 19-21, p. 249-252.

Holcomb, L.G., 1981, High resolution spectral analysis of long-period microseisms: (abs.) IASPEI General Assembly, London, Ontario.

Holcomb, L.G. and Peterson, J., 1981, A technique for compressing seismic digital data: (abs.) IASPEI General Assembly, London, Ontario.

Peterson, J. and Hutt, C.R., 1981, Preliminary design study for a national digital seismograph network: U.S. Geological Survey Open-File Report No. 81-1046, 55p.

Peterson, J., 1981, A note on transients in the SRO and ASRO long-period data: submitted to BSSA.

Peterson, J. and Engdahl, E.R., 1981, Recent developments in the GDSN: (abs.) IASPEI General Assembly, London, Ontario.

Seismic Observatories

9920-01193

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Investigations

Recorded and provisionally interpreted seismological and geomagnetic data at observatories operated at Newport, Washington; Cayey, Puerto Rico; Adak, Alaska; and Guam. At Guam, 24-hour standby duty was maintained to provide input to the Tsunami Warning Service operated at Honolulu Observatory by NOAA and to support the Early Earthquake Reporting function of the NEIS.

Results

Continued to provide data on an immediate basis to the National Earthquake Information Service and the Tsunami Warning Service. Supported the Puerto Rico Project of the Branch of Earthquake Tectonics and Risk. Provided geomagnetic data to the Branch of Electromagnetism and Geomagnetism. Responded to requests from the public, interested scientists, state and federal agencies regarding geophysical data and phenomena.

During this report period the government geophysicist was transferred from Adak Observatory and this observatory is now operated under contract with CIRES of the University of Colorado. Also, the personnel complement at Guam Observatory was reduced by one, leaving this station with two employees for its operation.

Seismic Review and Data Services

9920-01204

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Investigations and Results

The quality control and technical review were carried out on 124,100 seismograms (678 station-months) generated by the World-Wide Standardized Network (WWSSN).

Fifty-two (52) station performance reports were sent out during this period. These reports which cover instrumental and station operational detail show continued high standards in recording quality, timing precision, instrumental accuracies and program cooperation.

The monthly project report which covers the WWSSN analog seismogram receipts, the Seismic Research Observatory (SRO) and Abbreviated Seismic Research Observatory (ASRO) analog seismogram receipts has been expanded to include the digital tapes received at the Albuquerque center covering the expanded WWSSN (DWWSSN), along with the SRO and ASRO tapes. Operational status, quality of the data and any pertinent notes are included.

The overall operational status of the WWSSN remained about the same. With the 70-mm filming being phased out at the filming service, those stations with backlogs to be filmed in the 70-mm format (pre-July 1978) were notified to send seismograms as soon as possible. The cooperation received from these stations was excellent. No special problems were encountered with the system during this period.

Film filing of the fiche formated WWSSN, SRO and ASRO, along with the historical films (35 mm rolls) is on schedule. The files are located in a room set aside for this function. Two Itek 18-24 Reader-Printers, converted to dry reproductions, plus a table top viewer which will handle 70-mm and 35-mm films, are also located in the library room.

National Earthquake Information Service

9920-01194

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Investigations and Results

The weekly publication, Preliminary Determination of Epicenters (PDE), continues to be published on a weekly basis, averaging about 50 earthquakes. The PDE, Monthly Listings, and Earthquake Data Reports (EDR) were removed from the 11/70 in June 1981 and are now being computed on the VAX. We continue to publish all earthquakes which have data available within 30 days of the earthquake. We are still having some improvements on rapid data flow from our foreign contributors, but in order to reach our goal of a faster PDE, we will need much faster reporting of seismic data from our contributors, both foreign and domestic.

These problems are still being worked on and slow but steady improvement is taking place. We continue to receive telegraphic data from the USSR on magnitude 6.5 or greater earthquakes and some damaging earthquakes with magnitudes less than 6.5; the latest was the 6.1 damaging quake in northwestern Kashmir. Data from the PR China via the American Embassy in Beijing is still being received, a total of four stations in time for the PDE and a total of 17 stations in time for the Monthly Listings.

The Monthly Listings of earthquakes and Earthquake Data Reports (EDR) are up to date. To date the Monthly Listings have been completed through May 1981, and are being printed and mailed. The EDRs are computed through May 1981 and printed and mailed through October 1980. Printing of the EDRs resumed October 1, 1981 and should be up to date in a few months. We began publication of fault plane solutions in the January 1981 Monthly Listing. Fault plane solutions are being determined when possible for any earthquake having a magnitude $\geq$ 6.5.

The program for entering seismic data on the BGS 11/70 has been modified, is presently being tested, and should be operational in a few weeks. Programs for producing the NEIS publications have been operational on the Golden VAX since June 1981 with the exception of the EDR. That program should be operational in a couple of months.

We continue to provide services on recent earthquakes in response to the ever increasing demands from scientists and the general public.

Reports

Preliminary Determination of Epicenters (29 weekly publications--April 1981 to September 29, 1981--Numbers 09-81 through 36-81).
Compilers: W. Leroy Irby, Reino Kangas, John Minsch, Waverly J. Person, William Schmieder.

Monthly Listings of Earthquakes and Earthquake Data Reports (EDR) (6 publications--December 1980 through May 1981). Earthquake Data Reports (EDR)) for November 1980--May 1981 have not been printed but are in the process of being printed.
Compilers: W. Leroy Irby, Reino Kangas, John Minsch, Russell Needham, Waverly J. Person, Bruce Presgrave, William Schmieder.

Goals

Provide more rapid and comprehensive hypocenter locations to the government and the scientific community using our in-house computers.

Provide more rapid notification of significant or damaging earthquakes to relief agencies, the press, the scientific community, and the general public.

To receive more foreign data telegraphically on a weekly basis, including the USSR.

Keep the Monthly Listings and Earthquake Data Reports up to date.

United States Earthquakes

9920-01222

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Investigations

1. Sixty-seven earthquakes in 17 states were canvassed by a mail questionnaire for felt and damage data. Thirty-two of these occurred in California. The most significant earthquake for the period was in the Imperial Valley of California on April 26, 1981, at 33.13N, 115.65W, depth 6 km, magnitude 5.5 mb, 6.0 MS, and 5.6 ML (PAS).

2. The United States earthquakes for the period April 1 to September 30, 1981 have been located and the hypocenters, magnitudes, and maximum intensities have been published in the Preliminary Determination of Epicenters.

3. The seismicity maps for Minnesota, North Dakota, and South Dakota have been printed at a scale of 1:1.000.000. The ones for Kansas, Iowa, Nebraska, Oklahoma, and South Dakota have been completed and are being printed. The data for Colorado and New Mexico have been compiled.

Results

The maximum Modified Mercalli intensity of VII was assigned to Westmorland for the April 26, 1981, earthquake. The most significant damage was to some old adobe buildings on Main Street which sustained cracked and bowed walls, with some walls collapsing. Other major effects were the movement of support columns under the porticos which rendered some buildings unsafe.

United States earthquake data for July - September 1980 have been compiled and is being printed as a circular.

Reports

Stover, C. W., Minsch, J. H., Reagor, B. G., and Smith, P. K., 1981, Earthquakes in the United States, October-December 1979: U.S. Geological Survey Circular 836-D, 43 p.

Stover, C. W., Minsch, J. H., Reagor, B. G., and Smith, P. K., 1981, Earthquakes in the United States, January-March 1980: U.S. Geological Survey Circular 853-A, 41 p.

Stover, C. W., Reagor, B. G., and Algermissen, S. T., 1981, Seismicity map of the states of Delaware and Maryland, U.S. Geological Survey Miscellaneous Field Studies Map MF-1281.

Stover, C. W., Barnhard, L. M.,Reagor, B. G., and Algermissen, S. T., 1981, Seismicity map of the state of Maine, U.S. Geological Survey Miscellaneous Field Studies Map MF-1284.

Stover, C. W., Reagor, B. G., and Algermissen, S. T., 1981, Seismicity map of the state of Minnesota, U.S. Geological Survey Miscellaneous Field Studies Map MF-1323.

Stover, C. W., Barnhard, L. M., Reagor, B. G., and Algermissen, S. T., 1981, Seismicity map of the state of New York, U.S. Geological Survey Miscellaneous Field Studies Map MF-1282.

Reagor, B. G., Stover, C. W., and Algermissen, S. T., 1981, Seismicity map of the state of North Dakota, U.S. Geological Survey Miscellaneous Field Studies Map MF-1326.

Stover, C. W., Reagor, B. G., and Algermissen, S. T., 1981, Seismicity map of the state of Pennsylvania, U.S. Geological Survey Miscellaneous Field Studies Map MF-1280.

Reagor, B. G., Stover, C. W., and Algermissen, S. T., 1981, Seismicity map of the state of South Dakota, U.S. Geological Survey Miscellaneous Field Studies Map MF-1325.

Stover, C. W., Reagor, B. G., and Algermissen, S. T., 1981, Seismicity map of the state of Wisconsin, U.S. Geological Survey Miscellaneous Field Studies Map MF-1229.

Digital Data Analysis

9920-01788

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Investigations

1. Mantle Wave Magnitude. Develop methods for routine estimation of moment magnitude M_w from long-period surface (mantle) waves.

2. Moment Tensor Inversion. Develop methods for inverting body phase wave forms for the best point source description.

3. Computation of Free Oscillations. Develop practical methods for computing free oscillations of the Earth and combining them to construct synthetic seismograms.

4. Computation of Travel Times. Develop practical methods for computing body phase travel times directly from arbitrary, realistic Earth models.

5. Swedish Experiment. Analyze both analog and digital data acquired during the DARPA "Swedish experiment" for the U.S. Delegation to the U.N. Committee on Disarmament.

6. Network-Day Tape. Develop 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 a new NEIS publication containing detailed investigations of selected events.

Results

1. Mantle Wave Magnitude. An existing method is being redeveloped on a branch minicomputer for the special event reports. This software also serves as the nucleus for a general purpose time series analysis package to be used in conjunction with the Network Day Tape software.

2. Moment Tensor Inversion. Methods already developed have been successfully compared with a number of event studies reported in the literature. A scientific article is being prepared detailing the methods and their application.

3. Computation of Free Oscillations. A paper on a Rayleigh-Ritz method has been prepared for publication in the Journal of Computational Physics. A computationally advantageous hybrid (Rayleigh-Ritz and finite difference) method is being investigated.

4. Computation of Travel Times. Numerical experiments comparing several methods is ongoing. A paper is in preparation describing the most promising method.

5. Swedish Experiment. Processing is completed. The work is published in the U.S. Delegation report listed below. A related communcations experiment for the DARPA Seismic Data Center is being planned.

6. Network-Day Tape. Revised software is currently being documented for a new public distribution. The new version provides access to an older data format and automatic detection and correction of known errors in the data set. A new effort to develop methods for automatically testing data consistency has been initiated.

7. Special Events Reports. Focal mechanisms are now being produced for events of magnitude 6.5 or larger and published in the Monthly Listing of the NEIS. Miscellaneous graphics software has been developed to support more extensive reporting, planned for even larger events.

Reports

U.S. Delegation, 1981, Experience with the International Data Collection Experiment: Report to the U.N. Committee on Disarmament.

Buland, Ray, and Gilbert, Freeman, 1981, Computation of Free Oscillations of the Earth: Journal of Computational Physics (in preparation).

Buland, Ray, 1981, Free Oscillations of the Earth: Annual Reviews of Earth and Planetary Science, v. 9, p. 385-413.

Earth Structure and its Effects upon Seismic Wave Propagation

9920-01736

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Investigations

1. Use of short-period waveforms to infer earth structure. Develop methods of generating synthetic waveforms that correctly incorporate the frequency dependent effects that arise from source directivity and the effects of propagation through the earth. Apply these methods to infer the fine structure of velocity and attenuation at specific regions in the earth.

2. Source parameters from GDSN data. Extract source parameters from digitally recorded data of the GDSN by developing techniques of processing and by determining corrections to waveforms to distinguish source effects from propagation effects.

3. Experiments with the GRF array. The GRF array digitally records broadband data from both vertical and horizontal components using a Wielandt seismometer. Array data are ideal for examining the effect of lateral inhomogeneities on the coherence of a waveform across closely spaced stations and anisotropy. The data produced by the Wielandt instrument can be compared to the SRO.

4. Normal mode interactions with earth structure. Develop theory and implement computer programs that compute normal modes of earth models and to construct synthetic seismograms from them.

Results

1. Use of short-period waveforms to infer earth structure. Programs to synthesize seismograms that combine full wave theory and a casual rupture model to describe propagation and source effects have been converted to run on a local computer. The comparison of 8 digitally recorded PKP body waves from a deep earthquake with synthetic seismograms has permitted the resolution of the C and D cusps to better than +2°. Strong gradients in P-velocity, S-velocity, and attenuation exist in the top 100-300 km of the inner core.

2. Source parameters from GDSN data. Programs to perform the simultaneous deconvolution of GDSN long- and short-period data have been converted to a local computer. Frequency dependent attenuation operators for some earth models have been catalogued. We are examining the rupture characteristics of a suite of 4 large earthquakes (m_b>5.5) that encircled and preceded over a period of 2 years the eventual rupture zone of the Miyagi-Oki earthquake of June 12, 1978.

3. Experiments with the GRF array. Data from this array have been examined and selected events stored on magnetic tape. Preliminary processing shows that the coherence of body waves under the array is frequency dependent. Anisotropy in S-waves was observed.

4. Normal mode interactions with earth structure. A hybrid method of computing normal modes using Rayleigh-Ritz and finite difference methods is being investigated.

Reports

Boatwright, J., Choy, G., and Cormier, V. F., 1981, Inner core structure inferred from short-period waveforms (abstract): IASPEI General Assembly London, Canada.

Choy, G. L., and Cormier V. F., 1981, The structure of the inner core inferred from short-period and broadband waveforms: Submitted to Geophysical Journal Royal Astronomical Society.

Harvey, D., and Choy, G. L., 1981, Broadband deconvolution of GDSN data: Geophysical Journal Royal Astronomical Society, in press.

Systems Engineering

9920-01262

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Investigations:

1. Design, develop, and test microprocessor based seismic instrumentation.
2. Design, develop, procure, and test special electronic systems required by seismic facilities.
3. Design, develop, and test microprocessor/computer software programs for seismic instrumentation and seismic data recording systems.

Results:

1. The checkout and field testing of the portable DRS Verify-Playback System has been completed and the system meets all performance specifications. These systems will allow the installing and maintenance teams of the DWWSSN program to completely checkout the quality of recorded DWWSSN Upgrade DRS Systems in the field by plotting all recorded channels and by record-to-record time check programs. In the past these teams had to make a test tape which was sent to the Albuquerque Seismological Laboratory for verification and the results given to the team. This process took many days to complete and the teams had to wait for the results to determine if further maintenance was required or the system was working properly. Now a simple, few-minute test will give these teams the playback and verification of the system. Plans are for more of these DRS Verify-Playback Systems to be built in the next few months. Five DRS Verify-Playback Systems have been built. The original DRS Verify-Playback System had to be rebuilt because of damage in air shipment.
2. A telemetered version of the DWWSSN Upgrade DRS System is being designed and built for the Jamestown-Berkeley installation. This telemetered DRS System will allow the DWWSSN seismometers with the associated analog to digital conversion unit to be remotely connected to the central recording system by a hardwire circuit. The data rate of this link is 2400 baud and will operate over voice grade telephone lines. In addition, a remote calibrator unit is being designed to allow the central facility to activate 29 different calibration sequences. These 29 calibration sequences will allow SP, IP, LP, and LP-Photo calibration functions of daily step cals, daily sinewave cals, and full frequency response calibrations. It is also possible to get different current levels for each of the function type calibrations. This calibrator unit will be located at the remote site, but will be controlled by the central facility operator. A special digital to analog MUX system is being designed and built which will allow all of

the received seismic channels to be available in an analog form for helicorder recording or further analog telemetry transmission. This will provide three LP channels, three IP channels, and one to three SP channels of realtime analog seismic data. The calibrator is in final design checkout and all tests are positive. Installation should be in early FY-82.

3. An earlier analog/digital test unit for the DWWSSN Upgrade DRS is being considered as a test item for each of the DWWSSN maintenance teams. This unit was initially designed for the Upgrade DRS four years ago and is used by the Albuquerque Seismological Laboratory for initial test and system checkout. It has been extremely helpful in checking the ADC unit and will aid the teams in the field during their installation and maintenance visits.

4. Ed Medina completed a special trip to calibrate the WWSSN station in Mexico.

5. A special three channel short-period frequency division multiplated (FDM) radio telemetry seismic system has been designed and is in final system checkout for La Paz, Bolivia. Special training was conducted at Albuquerque for personnel from La Paz who will be installing and maintaining this system.

Tsunami Network Support

9920-01263

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Investigations:

1. Design, develop, and test microprocessor based TSUNAMI related seismic and tide systems.
2. Design, develop, and test GOES satellite related TSUNAMI data transmission techniques and instrumentation.
3. Design, develop, and test microprocessor/computer software programs for TSUNAMI instrumentation and TSUNAMI data retrieval systems.

Results:

1. A standard short-period TS-4 Seismic System was modified for an audio alarm and was installed at the NASA facility in Chile. This system will operate as a stand-alone unit without a GOES radio set for satellite communication. In the event of selected seismic events, the NASA personnel will start monitoring the NOAA/NWS Tsunami Warning channel 111 from the GOES satellite for the Tsunami tide system data.
2. Five TT-4 Tsunami Tide Systems were designed and assembled at the Albuquerque Seismological Laboratory. Four of these systems were installed by NOAA personnel along the western South American cost. The four installation sites are: Easter Island; Galapagos Islands (Baltra Island); La Punta, Peru; and Antofagasta, Chile. These TT-4 systems will operate with the older float and pulley-type tide meters (Bristol) or new pressure-type sensors. The fifth system is operating at Albuquerque with constant pressure readings. This system will record 20 minutes of tide data with a tide-word being recorded every 30 seconds. This time rate, as well as the total storage capacity, is software programmed. The present 40 tide-word capacity can be expanded to 250, if required. These TT-4 systems will respond to interrogation requests from the GOES Satellite System. Data from these TT-4 systems transmit through the GOES Satellite Network channel 111.
3. Checkout and evaluation of the four installed TT-4 Tsunami Tide Systems is continuing.

Seismicity and Tectonics

9920-01206

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Investigations

1. Peru Seismicity and Tectonics. Determine the space-time patterns of aftershocks of the October 3, 1974, Peru earthquake.

2. Mantle Structure Beneath the Rio Grande Rift. Use a 3-D, seismic ray tracing algorithm to invert a set of teleseismic P-wave delay data, with the objective of determining the maximum depth and degree of velocity anomaly in the upper mantle beneath the Rio Grande Rift.

Results

1. Peru Seismicity and Tectonics. The aftershocks to the great (M_S = 7.8, M_W = 8.1) Peru earthquake of October 3, 1974, occur in two separate spatial zones which are alternatingly active, for durations of about 2 1/2 days or longer, and to the general exclusion of seismicity in the other zone. There are five primary temporal phases. Aftershocks tend to occur at locations not previously an aftershock site and there is a sequential cessation of aftershock activity in several aftershock subzones. When the zone containing the main shock is active, any two consecutive aftershocks tend to be separated by distances that are many times greater than the rupture length of an individual aftershock, creating the appearance of aftershock oscillation. Within this zone is a large, central patch that is lacking in aftershocks. This patch extends updip and then southward from the main shock and may reflect an area that was destressed during the main shock rupture. This inactive patch surrounds a 30-km-diameter cluster of aftershocks which is bounded by the main shock on the north and the M_S = 7.1 aftershock of November 9, 1974, on the south. This cluster includes aftershocks from all but one of the phases of aftershock activity may define the location of a barrier (Aki, 1979) that did not rupture during the main shock, leading to the occurrence of the 'twin' earthquake. The second active zone trends northeast and downdip from the southern part of the inactive patch of the first zone. This zone contains an aftershock cluster at its northeast end which was active for a total time of about 5 1/2 days, the activity occurring in two very distinct phases separated by an offshore phase lasting for somewhat over 2 days. The dramatic alternation of aftershock activity between these two zones suggests that there existed an interplay between these zones that governed the mechanism of stress release of the entire system. The alternation of periods of aftershock activity, the long jump lengths and the systematic cessation of aftershocks in certain subzones between many aftershocks may indicate that the specific distribution of strength and stress heterogeneity in this source zone is an informational property of the entire source zone and that the destressing process associated with this earthquake series follows a well-ordered determinism that culminates with the two largest aftershocks of the entire series.

2. Mantle Structure Beneath the Rio Grande Rift. We have determined the resolution matrix for the 3-D seismic-ray-tracing inversion of a large set of teleseismic P-wave data taken at the Rio Grande Rift. We are now evaluating the degree of reliability of the inversion results, with particular attention to the low velocity zone at a depth interval of 90-130 km beneath a 150-km length of the Jemez shear zone.

Report

Spence, W., 1981, Review of the Denver Water Department Induced Seismicity Program at Strontia Springs, Colorado, 17 p. with 4 figures (in press).

Permeability of Fault Zones

9960-02733

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Investigations

Laboratory studies of the permeability of fault gouge were carried out to provide information that will assist us in evaluating whether, in a given region, fluids can migrate to a sufficient depth during the lifetime of a reservoir to trigger a large destructive earthquake.

Results

1. Permeability of the fault gouges ranged over many orders of magnitude. The lowest values (~1 nda), were characteristic of the montmorillonite-rich gouges, and the highest values of a few hundred nanodarcies were typical of the serpentine-type gouges.

2. The rate of change of permeability with confining pressure was similar for all the samples studied.

3. Grain size was an important factor in the permeability values.

4. Permeability decreased with shear for the coarse-grained high permeability gouges, but not for the fine-grained low permeability gouges. This decrease in permeability may be caused by the continued compaction of the sample that was observed during shearing. This compaction during shear was elastic and recoverable.

5. The gouges and pure clays under drained conditions exhibited a wide variety of shear strengths. Montmorillonite had anomalously low strength in relation to the other gouges and pure clay samples. Strength did not correlate with permeability, nor were these properties related in a systematic way with the location of the samples from either creeping or locked regions along the San Andreas fault.

Reports

Morrow, C., L. Q. Shi, and J. D. Byerlee, 1981, Permeability and strength of San Andreas fault gouge under high pressure, Geophysical Research Letters, vol. 8, no. 4, p. 325-328.

Project Title: Self-Potential Measurements Near Dams

Project Number: 9780-02917

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Investigations

Work was carried out on the development of software for the processing and display of self-potential (SP) field data. Some field measurements were made to determine the effect of normal ground water flow, which is related to elevation changes, on SP data.

Results

The software for processing SP data is operational. Field measurements from a recent volcanic region with large elevation changes (~2000 m) and much rainfall (~3-6 m/yr) showed large elevation effects ranging from less then -0.5 mV/m to over -10mV/m. No clear cut method for removing this effect from the data has been developed, but this is considered to be an important problem as elevation effects can mask anomalies due to water flow through or around a dam. The next phase of field work will be to conduct measurements near filled dams.

Reports

No reports have been written.

In Situ Stress Measurements

9960-01184

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Investigations

During the last six months the project effort has been directed primarily toward measurement of in situ stress, permeability, natural fracture distribution, and other physical parameters in an approximately 600-m deep well drilled 32 km from the San Andreas fault in the Mojave Desert. The measurements made in this hole, together with those made in an approximately 1-km deep hole drilled last year 4 km from the San Andreas fault, were intended to yield new insight into the vertical variations in stress and the manner in which these variations change with distance from the San Andreas fault. We have also expended considerable effort drilling holes for the emplacement of instruments for the continuous monitoring of volumetric strain changes near the San Andreas fault in central California.

Results

Recent measurements taken in a hole drilled to about 600 m depth near Hi Vista, about 32 km north of the San Andreas fault, are very similar to the stress measurements made in the approximately 1-km deep hole at Crystallaire, about 4 km from the San Andreas fault. In contrast to the increase in the maximum horizontal stresses and maximum shear stress with distance from the San Andreas fault, as suggested by measurements made in a profile of four shallow (about 200 m deep) holes previously drilled in the Mojave Desert, the two deep holes imply that these stresses are approximately invariant with distance from the San Andreas fault. This information places important constraints on models predicting the variation of shear stress with depth on the San Andreas fault. Detailed logging of the Hi Vista hole revealed a zone of fractured granite extending from the surface to about 100 m that are highly fractured and friable. This zone ends abruptly at a transition to a hard granite with a velocity approaching 6 km/s. Major zones of open fractures were identified through borehole televiewer logging and permeability testing at 470 and 567+ m. It seems reasonable to assume that the step-like increase in stress observed with depth in the Crystallaire and Hi Vista wells is controlled by fractures. The similarity between the Crystallaire and Hi Vista data suggests that the distribution of fractures at these depths was not random and that further research on the relationship between stress and fractures may lead to important new insights that will be relevant to earthquake prediction.

Preliminary test measurements of the water level in the Hi Vista hole revealed large tidal signals, and instruments were installed to continuously monitor tidal signals generated by the major fracture zone at the bottom of this hole. The amplitude of the tidal signals observed in the water level is about 10 cm. After filtering this water level data to remove the tidal components, we hope to use this data as an indication of tectonically induced volumetric strain variations near the San Andreas fault.

Reports

Healy, J. H. and Urban, T. C., Drilling holes for earthquake prediction, accepted for presentation at American Geophysical Union Meeting, December 1981.

Hickman, S., Healy, J., Zoback, M., and Svitek, J., Recent in-situ stress measurements at depth in the western Mojave Desert, accepted for presentation at American Geophysical Union Meeting, December 1981.

Hickman, S. and Zoback, M. D., On the interpretation of hydraulic fracturing pressure-time data for in situ stress determination, submitted to Proceedings of Hydraulic Fracturing Conference, Monterey, December 1981.

Kohler, W. M. and Healy, J. H., The mechanism of anisotropic wave velocity in crystalline rocks of the Mojave Desert, accepted for presentation at American Geophysical Union Meeting, December 1981.

Zoback, M. D. and Hickman, S., In-situ study of the physical mechanisms controlling induced seismicity at Monticello Reservoir, South Carolina, submitted to Journal of Geophysical Research.

Induced Seismicity and Earthquake Prediction Studies at the Koyna Reservior, India

9930-02501

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The aim of this project is to set up 13 portable seismic stations in the Koyna Dam region of Maharashtra State, India. Even though the dam is located in the Peninsular Shield of India, traditionally a region of low seismicity, after the impoundment of the reservoir in 1963, seismic activity in the Koyna region started increasing. A destructive earthquake of magnitude 6.3 occurred in 1967 and an unusually long aftershock activity is still in progress. Several medium-sized earthquakes of magnitude greater than 4 occur here every year. Although there is a seismic network in operation at Koyna, due to non-standard equipment, timing problems, and non-precise earthquake location procedures, the seismicity shows a big scatter. Very few fault-plane solutions are available. There is some evidence of migration of seismicity, but because of the scatter in the data, it is difficult to assess the extent of the migration.

During a recent visit to Koyna on a U.N.D.P. mission, I was convinced that by establishing a high-quality seismic network here, valuable information can be gathered on the mechanism of induced seismicity associated with reserviors. In additon there is potential for carrying out earthquake-prediction research. The thick basalt flows, overlain by thin soil cover, are conductive to setting up, tilt, strain, and magnetic observatories, in addition to seismic stations, to look for pre-monitory phenemena associated with the medium-sized earthquakes occurring here.

Unfortunately, though we have enthusiatic support from the Indian scientists, due to some unfathomable causes, the required clearence to go ahead with the project is not yet forthcoming from the Indian Government. As soon as the permission is obtained, work on installation of the network and data analysis will be started in collaboration with the National Geophysical Research Institute, Hyderabad, India.

Seismological Field Investigations

9950-01539

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Investigations

Provide technical support to the Induced Seismicity Program for the operation and maintenance, recording, playback, and digitizing of seismic data obtained from a 10-station seismograph network installed around the Monticello, South Carolina reservoir. Purpose of the investigation is to study reservoir-induced earthquakes that result from water loading and unloading following the reservoir impoundment. Pradeep Talwani, University of South Carolina, Department of Geology, is principal investigator.

Results

Routine operation and maintenance of the Monticello network has continued throughout the report period. Following the July, 1981 retirement of Lyle Benson, USGS Electronic Technician stationed at Columbia, the University of South Carolina has provided personnel (Don Stevenson and Bob Collins) to operate and maintain the network. A solicitation for competitive bid for a formal maintenance contract is currently in preparation. The contract should be awarded by early January, 1982.

Large Scale Laboratory Contained Fracture Experiment

9960-02941

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Investigations

1. Determination of source parameters during unstable sliding on a fault.

2. Producing contained fracture events by altering the stress field along the fault.

3. Measuring heat generated during unstable sliding on a fault and relating this to the total energy released during sliding.

Results

1) Experiments have been conducted at normal stress up to 6.4 MPa on a 200 x 40 cm simulated fault. By injecting water onto the ends of the fault while applying shear stress, the ends of the sample were pre-slipped up to 50 microns while the center of the sample remained locked. Then, by removing water pressure and continuing to raise shear stress, the pre-stressed central portion of the fault failed unstablly. Ruptures produced in this manner were successfully contained by the low-stressed ends of the fault. Results for eight events produced by this method are as follows. Total fault slip measured at the center of the slipped zone ranged from 8.5 to 38.9 microns. Slip velocity increased with increasing dynamic stress drop. Dynamic stress drop increased with increasing normal stress with a ratio of approximately 0.09. Seismic moments for these events ranged from $6x10^7$ to $3x10^8$ dyne-cm. This technique will now provide a powerful tool for studying source parameters related to the stopping phase of ruptures as well as in studying the effect of fault inhomogeneity.

2) Temperature rises have now been measured for slip along the fault while dry, wet and with a layer of simulated gouge. For the dry fault, the frictional heating of the fault during unstable slip is 88 $\pm$ 6% of the total energy released. From this observation, a seismic efficiency between 5 and 10 percent is inferred. When water was injected on the fault, no significant change in the heating of the fault was detected. Wetting of the fault does tend to increase both the yield strength and the relative stress drop for these conditions of low stress and finely ground surface. Sliding of the fault with a 1.5 mm thick layer of Ottowa sand suppressed 'stick-slip' behavior. Heat generated on the fault was found to be approximately proportional to sliding rate and normal

stress. For all these low normal stress events, with energy densities up to 10^5 erg/cm^2, the temperature rise on the fault was less than a few degrees Celsius. Even for relatively small earthquakes having an energy density 1000 times greater than this, heating of water in the fault zone could become important.

Reports

Lockner, D. A., P. G. Okubo and J. H. Dieterich, Observations of confined unstable slip produced by fluid injection on a simulated fault, Trans. Amer. Geophy. Union, Fall meeting, 1981.

Okubo, P. G., J. H. Dieterich and D. A. Lockner, Rupture velocities and fault roughness, Trans. Amer. Geophys. Union, Fall meeting, 1981.

Lockner, D. A., P. G. Okubo and J. H. Dieterich, Containment of stick-slip failures on a simulated fault by pore fluid injection, to be submitted to Geophys. Research Letters.

Lockner, D. A. and P. G. Okubo, Measurements of frictional heating in granite, to be submitted to J. Geophys. Res.

Brittle Tectonics and Reservoir-Induced Seismicity

9510-02389

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Investigations

1. Cores and cuttings from the Monticello Reservoir (South Carolina) drill holes #1 and #2 were studied in detail to determine the characteristics of crystalline rock lithologies and late stage fracturing at both sties. The style of fracturing and the associated neomineralization of the fractures were used in comparison to fractures in fault zones outside of the reservoir area.

2. Brittle fractures at the Richard Russell Reservoir site were compared to those encountered at the Monticello Reservoir for the purpose of establishing some general association.

Results

1. Monticello drill holes #1 and #2 lie within the Winnsboro Igneous Complex near Jenkinsville, S.C. The Winnsboro complex is largely composed of coarse-grained granodiorite and contains amphibolite zenoliths of the local country rock which are more abundant toward the margins. Drill hole #1 lies well within the granodiorite body whereas drill hole #2 is nearer the edge. Consequently, drill hole #2 contains significantly more amphibolite than does drill hole #1 and it has a more diverse mineralogy. Fractures in drill hole #2 generally are steeply oriented and occur in the upper two-thirds of the hole. Biotite has been retrograded to chlorite along the fracture surfaces and later hydrothermal activity has altered the chlorite to a green mixed-layer clay. Hydrothermal activity has also resulted in filling of the fractures by carbonate and pink zeolite which optically show the effects of internal strain. Hence, the fractures are not simply open voids such as joints.

   Monticello drill hole #1 is far more homogeneous and contains only one small chloritized shear. The predominant fracture pattern in the cored sequences of drill hole #1 is that of horizontal to sub-horizontal partings or openings correlative with exfoliation joints in the surface exposures of equigranular rocks in other regions. The fractures in drill hole #2 are generally healed and shown no sign of recent cataclasis, but the horizontal fractures in drill hole #1 may be fairly recent features. The neomineralization in the fractures of drill hole #2 and the one shear in drill hole #1 suggests that the fracturing was associated with late magmatic activity probably in the late Paleozoic or early Mesozoic.

2. Fractures at the Richard Russell Reservoir site are similar to those in the Monticello drill hole #2 in that they show evidence of biotite being retrograded to chlorite. Late stage metamorphic fluids typically have invaded the low pressure areas of the fractured zones crystallizing as feldspar and quartz. The brittle nature of the shearing at the Russell Reservoir is distinctly different from the local ductile deformation associated with regional metamorphism and the shears crosscut the adjacent metamorphic fabric. This suggests that the rocks were far below peak metamorphic grade at the time of latest shearing but the nature of the neomineralization requires higher than normal temperatures in the surrounding rocks. Therefore, shearing probably occurred sometime from the late Paleozoic to the early Mesozoic.

Reports

Bramlett, K. W., Secor, D. T., Jr., and Prowell, D. C., (in press), The Belair fault: A Cenozoic reactivation structure in the eastern Piedmont: Geological Society of America Bulletin.

Geological Investigations in an Area of Induced Seismicity at Monticello Reservoir, S. C.

18-08-0001-19833

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Project Description

Monticello Reservoir, S.C., is an area of well documented induced seismic activity in the Charlotte belt of the Piedmont province. This area is the focus of a geological and geophysical research program aimed at evaluating the potential hazard and understanding the causes for the activity. At the onset of the seismic activity, the geology of the region surrounding the reservoir was poorly understood, and this study was undertaken to provide the geological information necessary for evaluating the activity.

Results

The area immediately south of the reservoir, along the border between the Carolina slate and Charlotte belts, is underlain by a stratified sequence of late Precambrian and Cambrian metavolcanic and metasedimentary rocks, several kilometers in thickness. During the early to middle Paleozoic, this sequence experienced an intense episode of tight passive folding and greenschist to amphibolite facies metamorphism, followed by an episode of more open flexural folding. The northern part of the study area is underlain by the late to post-kinematic Newberry granite of Silurian age, and by a pluton of biotite-hornblende granodiorite of Carboniferous(?) age. The stratified rocks in the southern half of the study area have been cut by two sets of faults. Set I faults of latest Paleozoic or early Mesozoic age are steeply dipping and trend to the east. They have been extensively silicified and have experienced only small displacement. Set I faults are offset by set II which dip steeply and trend to the north. The Wateree Creek fault, a large set II fault in the Chapin quadrangle south of Monticello Reservoir, has a predominately dip slip displacement (down to the east) of 1700 m. The Wateree Creek fault is thought to have formed under conditions of relatively low temperature and pressure such that carbonates were the only mineral component sufficiently mobile to contribute appreciably to vein fillings. The Wateree Creek fault is cut by a large diabase dike of Jurassic age. No evidence has yet been found for post-Jurassic slip on the Wateree Creek fault.

The region of induced seismic activity around Monticello Reservoir is underlain by a pluton of medium to coarse grained biotite-hornblende granodiorite of Carboniferous(?) age. This pluton is relatively inhomogeneous in that the proportions of hornblende and biotite are variable, and it contains several large enclaves of amphibolite as well as numerous xenoliths. Our geologic mapping suggests the induced seismic activity is not controlled by through-going faults or major lithologic boundaries, but instead is due to slip along the innumerable short joint fractures which are present in this pluton.

Induced Seismicity and Earthquake Prediction Studies in South Carolina

Contract No. 14-08-0001-19252

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1. Induced Seismicity at Monticello Reservoir, South Carolina.

One spurt of activity was observed in March-April 1981, with the largest event of M_L 2.4 occurring on April 1, 1981. This event occurred to the west of earlier activity, but was confined to the region between the Broad River and Monticello Reservoir. Some recent activity appears to lie along the Broad River, extending to the northwest.

The seismicity has been monitored on portable digital event recorders for a study of source properties. Stress drops for all events 8-'80 - 8-'81 are less than 10 bars. The results of this study will be presented in Kevin Hutchenson's M.S. thesis.

2. Source Properties and Directivity of Events Recorded on Monticello Network.

We are carrying out a systematic analysis of P and S wave signals of induced earthquakes at the Monticello Reservoir network to study their source properties and possible temporal changes associated with different swarm activities. Presently we have analyzed about 75 events of magnitudes ranging between 0.57 and 1.86 from October 1979 swarm. Preliminary results based on S wave spectral analysis from six single (vertical) component stations indicate that stress drop in this magnitude range varies between 0.4 to about 7.5 bars. On the other hand, corner properties and hence the source radii (determined using Brune's model) of these earthquakes show very little difference. This would suggest that the earthquakes are mostly occurring on the already existing fracture planes and release varying amounts of stress for different magnitude earthquakes.

Analysis of S wave energy contents of different earthquakes in low (below 10 hz) and high frequency (above 10 hz) bands, indicate that their high frequency energy changes significantly along different azimuths. These changes do not show any correlation with the hypocentral distances. This apparently rules out the possibilities of observed differences in high frequency contents to be associated with attenuation effect. It is very likely that the observed azimuthal dependence is associated with directivity effect of the source radiation.

3. Induced Seismicity at Lake Jocassee, South Carolina.

Seismicity at Lake Jocassee has been monitored since October 1975, using portable seismographs and recently three permanent stations. One of these stations, SMT, was connected to the state seismographic network on February 25, 1980. In 1980 there were 8 events, and through September 1981, 2 events with magnitudes greater than 2.0. This compares with 7 and 3 events with magnitudes greater than 2.0 at Monticello Reservoir in 1980 and 1981, respectively.

4. Earthquake Prediction Studies at Lake Jocassee.

We have continued to monitor radon concentration and other geochemical parameters in an observation spring at Lake Jocassee. No notable anomalies have been observed.

5. Earthquake Prediction Studies at Monticello Reservoir.

Here we have continued to monitor water levels in two observation wells and geochemical parameters at three sites. Anomalous changes in radon concentration were noted before the April 1, 1981 earthquake.

Papers

Talwani, Pradeep, Earthquake prediction studies in South Carolina, in Maurice Ewing Series Volume 4: Earthquake Prediction, An International Review, (D. W. Simpson and P. G. Richards, editors), American Geophysical Union, Washington, D.C., 381-393.

Tarr, A., Pradeep Talwani, S. Rhea, D. Carver and D. Amick, Results of Recent South Carolina seismological studies, to appear in the Bulletin of the Seismological Society of America, December 1981.

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