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GEOLOGICAL SURVEY

Office of Earthquake Studies

SUMMARIES OF TECHNICAL REPORTS, VOLUME X

Prepared by participants in

NATIONAL EARTHQUAKE HAZARDS REDUCTION PROGRAM

June 1980

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This report is preliminary and has not been edited or reviewed for conformity with Geological Survey standards and nomenclature

Menlo Park, California

1980

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Pennsylvania Seismic Monitoring Network
(Northeastern United States Seismic Network)

14-08-0001-17634

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Investigations

The principal objectives of this project are: (1) to establish a regional seismic network centered in Pennsylvania capable of monitoring local seismic activity and that in surrounding areas, (2) to collect baseline data on the spatial and temporal distribution of seismic events, (3) to identify and distinguish local earthquakes from quarry blasts, (4) to calibrate the region with regard to travel-time curves, (5) to construct seismicity maps for Pennsylvania and surrounding areas and relate the patterns to structural features and tectonic stresses, and (6) to work co-operatively with operators of adjacent networks in the Northeast to establish overall patterns of seismicity. The long-term aim is to develop an understanding, now largely lacking, of the state of tectonic stress in the earth's crust and its relation to the location, magnitude, and source mechanism of earthquakes likely to occur in the future in this densely populated part of the eastern United States.

Results

The first eleven stations of the network as shown in Figure 1 have been installed and are operating with data transmission via telephone telemetry to the central recording site at Penn State's main campus. All eleven are at or near a college or university campus and visible recorders are (or will be) operated at each location by local faculty who have agreed to cooperate. Table 1 gives the locations of these stations and the local faculty contact. In addition the stations indicated by asterisks in Table 1 have 3-component capability, including long period. This strategy of monitoring provides back-up analog recording and stimulates local public interest in the network operation. However, because of local high frequency noise levels at several of the campuses, some of the seismometers are being relocated to more remote, quieter sites. In order to continue to operate visual recorders at these campuses, additional single discriminator modules have been added with routing of the FM signal through the campus recording location as it is telemetered to the central recording location at University Park. Stations 12 and 13 in Maryland and West Virginia, respectively, with visible recorders operated by NASA, have been added to the network as telemetered stations.

Event information is regularly exchanged with operators of adjacent networks comprising the Northeast U.S. Seismic Network and provided to others upon request. Four portable systems are kept available for aftershock studies and special recording of quarry explosions in the region.

We have developed a method for combining regional and teleseismic observations and for including multiple reference events (quarry explosions) to improve hypocenter determinations (Baumgardt and Alexander, 1979). It is especially useful when an event to be located lies outside but near a regional network.

Figure 2 illustrates the application of this approach as applied to two small ($m_b \sim 3.0$) events that occurred near Lancaster, PA in 1978. This figure compares the epicenters from NEIS and NEUSSN network observations and the epicenters from intensity observations as reported by Scharnberger, the local operator of the Millersville (MVL) station. The relative location method was applied alternatively using event 1, then event 2 (intensity locations) as the reference event location. The open circles show the results and suggest a relative location accuracy approaching 1 km using NEUSSN stations. It should also be noted that only 15 common stations were used, nearly all situated north of the earthquake epicenters and heavily concentrated in the NE azimuths.

Reports

Baumgardt, D. B. and S. S. Alexander, 1979, Use of Multiple Reference Events to Locate Regional Events with Combined Regional and Teleseismic Data, Earthquake Notes, v. 50, No. 3, p. 13.

Table 1

Pennsylvania Seismic Monitoring Network Stations Located At or Near College or University Campuses

		Station Location			
No.	Campus Site	Lat (deg N)	Long (deg W)	Elev (m)	Local Faculty Contact
3	Beaver, PSU	40.70	80.33	305	Prof. John Ciciarelli
2	Behrend, PSU	42.13	79.98	229	Prof. Eva Tucker
6	DuBois, PSU	41.13	78.75	427	Prof. John Vargas
4	Fayette, PSU	39.93	79.67	335	Prof. Peter Ostrander
5	*Indiana State College	40.62	79.06	396	Prof. Fred Park
8	*Kutztown State College	40.52	75.78	152	Prof. Madin Varma
9	Lehigh University	40.60	75.37	116	Prof. Ken Kodama
7	Millersville State College	39.98	76.37	104	Prof. Chas. Scharnberger
11	Scranton, PSU	41.43	75.62	287	---
1	*University Park PSU	40.80	77.87	352	Prof. Shelton Alexander
10	West Chester State College	39.95	75.58	128	Prof. Allen Johnson

* Three-component stations

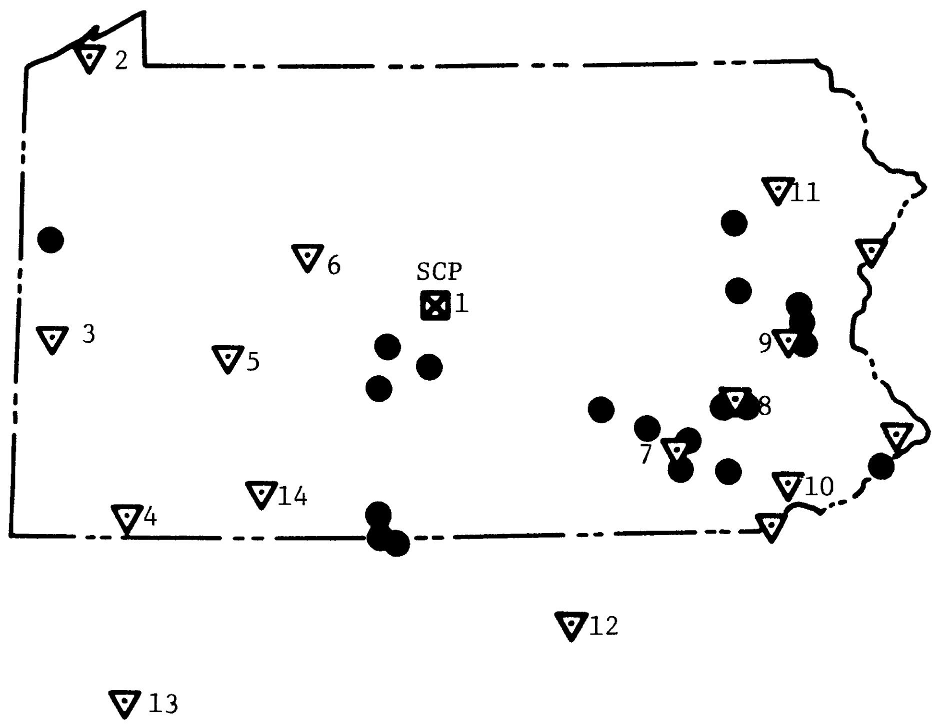

Figure 1. Map showing locations in the Pennsylvania Seismic Monitoring Network (triangles) and the epicenters of previous earthquakes in the region (solid dots). Data from each network station is transmitted via telephone line to a central recording site at Penn State's main campus at State College, Pennsylvania (boxed X in the center). Numbered stations have been installed (see Table 1). Un-numbered stations are candidates for future installations.

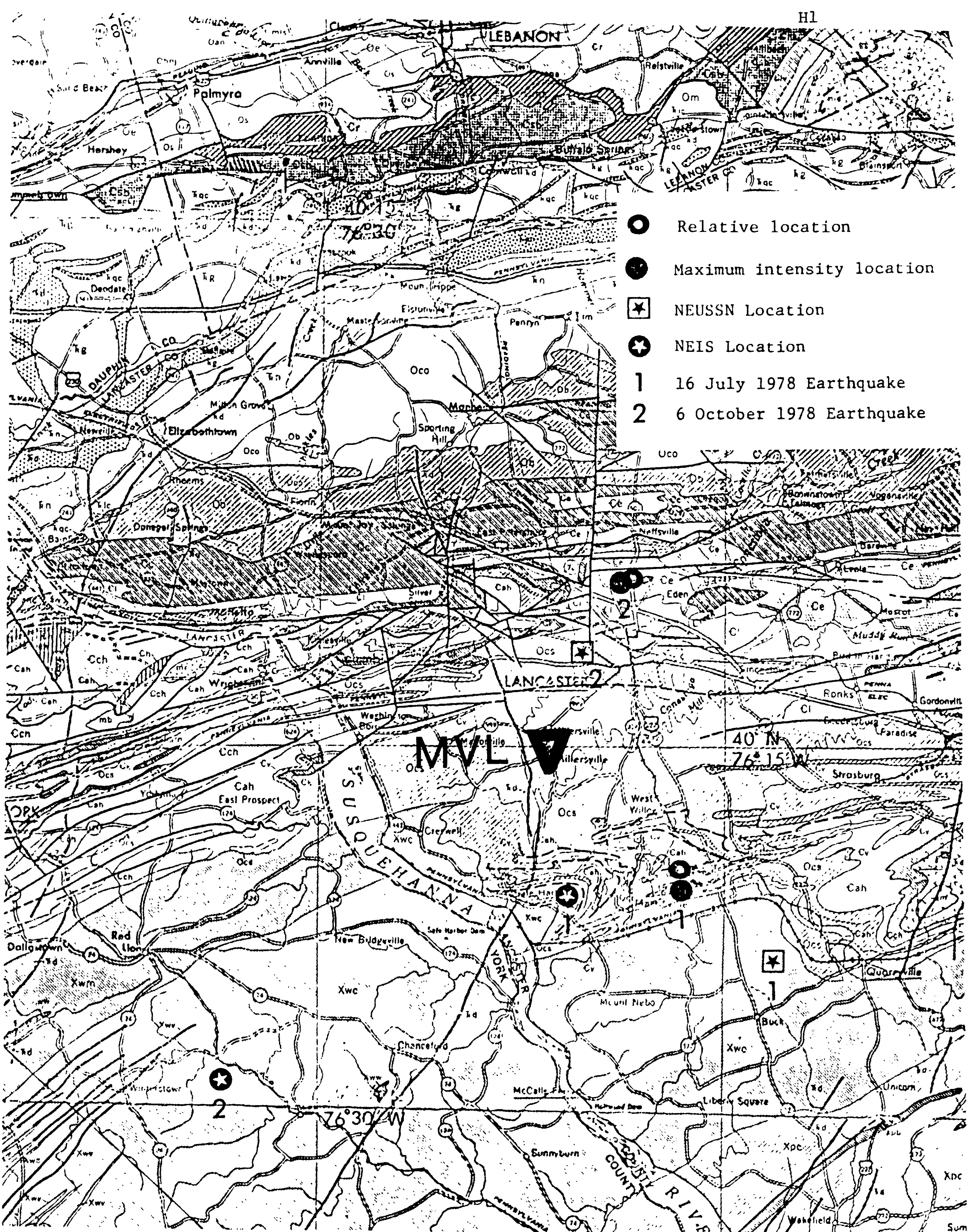

Figure 2. Comparison of maximum intensity locations with relative and absolute locations from NEIS and NEUSSN network observations.

Portable Broadband Seismic System
(Northeastern United States Seismic Network)

14-08-0001-18262

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Investigations

The objective of this project is to assemble two 12-element portable broad-band digital seismic systems that can be used in a variety of modes to supplement fixed networks, particularly those comprising the Northeastern U.S. Seismic Network.

Several types of investigations can be carried out using these systems to provide important data for interpreting regional earthquake events. These include: improved crustal velocity models established by refraction profiles with timed quarry blasts as sources and a conventional source-receiver linear geometry; identification of crustal phases at different distances from quarry explosions by deploying the portable stations configured as one or more local arrays and measuring apparent velocities of each distinct arrival in the wavetrain (this approach could be applied for refractions, wide angle reflections, and surface waves); measurement of lateral variations in average crustal properties by measuring P and S wave delay times through the crust from teleseismic events (because the broad-band seismometers can operate as either vertical or horizontal instruments, S-wave arrivals could be enhanced and their delay times more accurately determined); correlation of crustal refraction arrivals with available crustal reflection data from petroleum exploration or COCORP profiles; average crustal structure from observed fundamental and higher mode surface wave dispersion using tripartite (or multipartite) arrays that may profitably include one or more 3-component stations; determination of attenuation rates for various crustal phases; and spectral variations among crustal arrivals as observed at different distances. These types of applications are relevant to understanding regional seismic activity because they can significantly improve our ability to locate local earthquakes and determine their source mechanisms.

Another important application is to monitor for aftershocks near the epicenters of regional earthquakes. Such a local monitoring capability should improve the location, depth and fault-plane estimates made from the fixed network data alone and provide much-needed data on the magnitude vs frequency of occurrence for aftershocks of crustal earthquakes in the eastern United States.

Another useful application is to test the effects of various possible modifications in the fixed network configuration by deploying stations to alternate desired locations.

The field systems being developed are versatile enough to be used for all of the applications cited earlier. The key characteristics are: portability; broad-band (.05-100 Hz) stable seismometers that can operate interchangeably in the vertical or horizontal mode; field digital recording capability and accurate timing adequate for both short time (expanded scale) recording and continuous operation for the order of days; FM radio telemetry from individual sensors to local central field recorders or to interfaces with telephone telemetry to a distant central recording location.

Results

The first 12-element system is nearing completion, and after laboratory and field tests will be ready for use by mid-1980. The second system will be completed approximately two months later. The central field recording facility consists of: a PDP-1103 minicomputer with 32K of core, a dual floppy disk system, 12 A-D channels, a 800/1600 bpi magnetic tape unit, and scope and hard-copy display. The supporting software (mainly FORTRAN) being developed will provide the user a variety of modes for digital data acquisition ranging from continuous sampling of all or any of the 12 channels to event detection on any desired set of the 12 channels. Data analysis can also be carried out when data acquisition activities permit. Input (analog) data can be from user-supplied seismometers and telemetry or from the broad-band seismometers that will be available with the system.

Revision and Studies of Modified Mercalli Intensity Scale

9950-02145

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Investigations

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

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

3. A field investigation of the effects of the Imperial Valley, California earthquake of October 15, 1979 was undertaken.

Results

1. In cooperation with Project 9920-01222 in the Branch of Global Seismology, two additional State seismicity maps have been issued as MF maps (Kentucky and Arkansas). A computer program has been developed that makes it possible to develop a maximum intensity map or the intensity history (distribution of intensity) of any region of the country (or the entire country). The program distributes the intensities associated with any earthquake into a square grid 10 km on a side. If any area has experienced repeated earthquake activity, the entire intensity history of each 100 km^2 area can be recovered. Thus, maximum observed intensity maps, maps of the frequency of occurrence of any particular level of intensity and similar maps are relatively easy to prepare. The data preparation required is the digitization of available isoseismal maps (or maps developed in this project). For earthquakes for which insufficient data are available to prepare a map, synthetic isoseismal maps can be prepared using other well documented earthquakes in the area. The following table gives the status of intensity map review and development in this project.

Status of Intensity Maps

	Reviewed and contoured*	Nearing Completion (2-3 months)	Need Additional work (3-12 months)	Totals
Eastern U.S.	25	16	8	49
Midwest	53	9	17	79
Western Mountain Region	38	8	3	49
Pacific Northwest	8	2	4	14
California	24	many available -review not complete-		24+

*42 of these maps have been digitized

Technical review of a U.S.G.S. Open-File Report "An Evaluation of the Effects of the October 31, 1895, Charleston, Missouri Earthquake" by Margaret Hopper and S. T. Algermissen is complete and awaits Director's approval. Another Open-File Report "Potential for Liquefaction, Slumping and Landsliding in the Puget Sound, Washington Area" by Margaret Hopper is in technical review.

2. As previously reported, intensity attenuation relations have been developed for the midwest. Eastern isoseismal maps are now being investigated with regard to the best manner of representing the attenuation. Isoseismal maps, particularly for Saint Lawrence Valley earthquakes are very irregular in shape. The larger eastern earthquakes, however, do confirm the regional attenuation anomalies found from studies of the large Mississippi Valley earthquake.

3. A comprehensive investigation of the distribution of damage resulting from the Imperial Valley, California earthquake of October 15, 1979 was completed. Special attention was given to the evaluation of Modified Mercalli intensity in the vicinity of 22 strong motion accelerograph sites in the macroseismic area. It was found that the felt area of the earthquake was almost identical with the felt area of the 1940 earthquake of about the same magnitude on the same fault but the area severely shaken (MM≥VII) was much larger in 1940 than in 1979. There are a number of other important results from the intensity investigation, several of which are believed to be related to the difference in duration of strong shaking in the 1940 and 1979 earthquakes. Preliminary results are being published in a forthcoming U.S.G.S. Professional Paper. A study of the MM intensities at accelerograph sites is being prepared for submission to the Bulletin of the Seismological Society of America.

Reports

Algermissen, S. T., Steinbrugge, K. V., Reagor, B. G., Stover, C. W., Hopper, M. G., and Barnhard, L. M., 1980, The Imperial Valley, California Earthquake of October 15, 1979: Distribution of Intensity and Damage, Earthquake Notes, vol. 50, no. 4, p. 35 (abstract).

Stover, C., Reagor, G., and Algermissen, S. T., 1979, Seismicity maps of the State of Kentucky, U.S. Geological Survey, MF-1144.

______1979, Seismicity maps of the State of Arkansas, U.S. Geological Survey, MF-1154.

Reagor, B. G., Stover, C. W., Algermissen, S. T., Steinbrugge, K. V., Hubrak, P., Hopper, M. G., and Barnhard, L. M., 1980, Preliminary evaluation of the distribution of intensity, in The Imperial Valley Earthquake of October 15, 1979, U.S.G.S. Professional Paper (in press).

Southern California Seismic Arrays

Contract No. 14-08-0001-16719

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This semi-annual report summary covers the six-month period from 1 October 1979 to 31 March 1980. The contract's purpose is the partial support of the seismological arrays of the joint USGS-Caltech SCARLET (Southern California Array for Research on Local Earthquakes and Teleseisms), which is also supported by other groups, as well as by direct USGS funding through its own employees at Caltech. According to the contract, the primary visible product will be a joint USGS-Caltech catalog of earthquakes in the Southern California region, to be issued on a yearly basis, although quarterly epicenter maps and preliminary catalogs are also required. Figure 1 shows preliminary epicenters of all events exceeding magnitude 2.9 that were detected and located by SCARLET during the six-month period. Because of the unusual load of the Imperial Valley earthquakes of October 1979, smaller events during the latter part of the six-month period have not as yet been timed and located, nor is this required at this time by the contract.

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

Number of located events through 1-12-80: 3,118
Estimated number of events to be located for 6-month period: 4,900
Number of earthquakes of M = 3.0 and above: 487
Number of earthquakes of M = 4.0 and above: 51, data for which were immediately transmitted by telephone to interested agencies, according to pre-arranged procedures.
Number of earthquakes of M = 5.0 and above: 6
Number of earthquakes of M = 6.0 and above: 1
Largest earthquake: M = 6.6 (10-15-79, near Calexico)

Certainly the most important seismic event during the reporting period was the M = 6.6 Imperial Valley earthquake of 15 October 1979, which was the largest earthquake in southern California since the Kern County earthquake of 1952. Almost all seismic stations worked well throughout the sequence, and the area was densely instrumented. A wealth of information has been obtained. Preliminary seismic data have been summarized by Johnson and Hutton (in press), and Figure 2 shows preliminary epicenters for the first 15 days. An unusual aspect of the sequence is that the main shock (star in Fig. 2) lies in an area almost devoid of aftershocks, most of which occurred north of the area of faulting during the main shock. A number of scientific and engineering publications have already resulted from this earthquake, which will assuredly be the subject of intensive study for years to come.

Seismic activity remained high in the Mammoth Lakes area during the reporting period, with 9 shocks of magnitude 4.0 and greater, and at least 14 reported as felt. Also significant was a magnitude 5.3 earthquake on 25 February 1980 near the trifurcation of the San Jacinto fault south of Palm Springs. Reconnaissance field investigations by Caltech and CDMG members failed to find evidence of surficial fault displacement. Subsequent to the 15 October 1979 Imperial Valley earthquake, a number of small and moderate shocks (to M = 3.3) have been occurring along the southward projection of the San Andreas fault southeast of Niland. These are intriguing not only because they represent the first known aligned activity along this trend, but also because they lie at the southeastern end of the continuing pronounced seismic gap along this segment of the San Andreas fault -- a gap that extends 100 km northwest to San Gorgonio Pass. As part of another project, two continuously recording creepmeters are now being installed along this fault segment.

The joint seismic network now comprises 139 individual stations, 134 of which telemeter signals to Caltech. The actual number of telemetered signals is 154, inasmuch as several stations have more than one instrument sending data. No new stations were added during the reporting period.

No final yearly catalogs were published during the reporting period, but the 1978 catalog is almost ready for printing. Data for the 1975 and 1976 catalogs were received from the USGS shortly after the end of the reporting period, and these catalogs will be published as soon as data from Caltech and the USGS can be collated.

PUBLICATIONS

Hill, R. L., Pechmann, J. C., Treiman, J. A., McMillan, J. R., Given, J. W., and Ebel, J. E., 1980, Geologic study of the Homestead Valley earthquake swarm of March 15, 1979: California Geology, v. 33, p. 60-67.

Hutton, L. K., Allen, C. R., Blanchard, A. C., Fisher, S. A., German, P. T., Given, D. D., Johnson, C. E., Lamanuzzi, V. D., Reed, B. A., and Richter, K. J., 1980, Southern California Array for Research on Local Earthquakes and Teleseisms (SCARLET), Caltech-USGS monthly preliminary epicenters for July 1979 through September 1979: Pasadena, California Institute of Technology, 19 p.

Hutton, L. K., Johnson, C. E., Pechmann, J. C., Ebel, J. E., Given, J. W., Cole, D. M., and German, P. T., 1980, Epicentral locations for the Homestead Valley earthquake sequence, March 15, 1979: California Geology, v. 33, p. 110-114.

Johnson, C. E., and Hutton, L. K., in press, The 15 October 1979 Imperial Valley earthquake: a study of aftershocks and prior seismicity: U. S. Geol. Survey Prof. Paper.

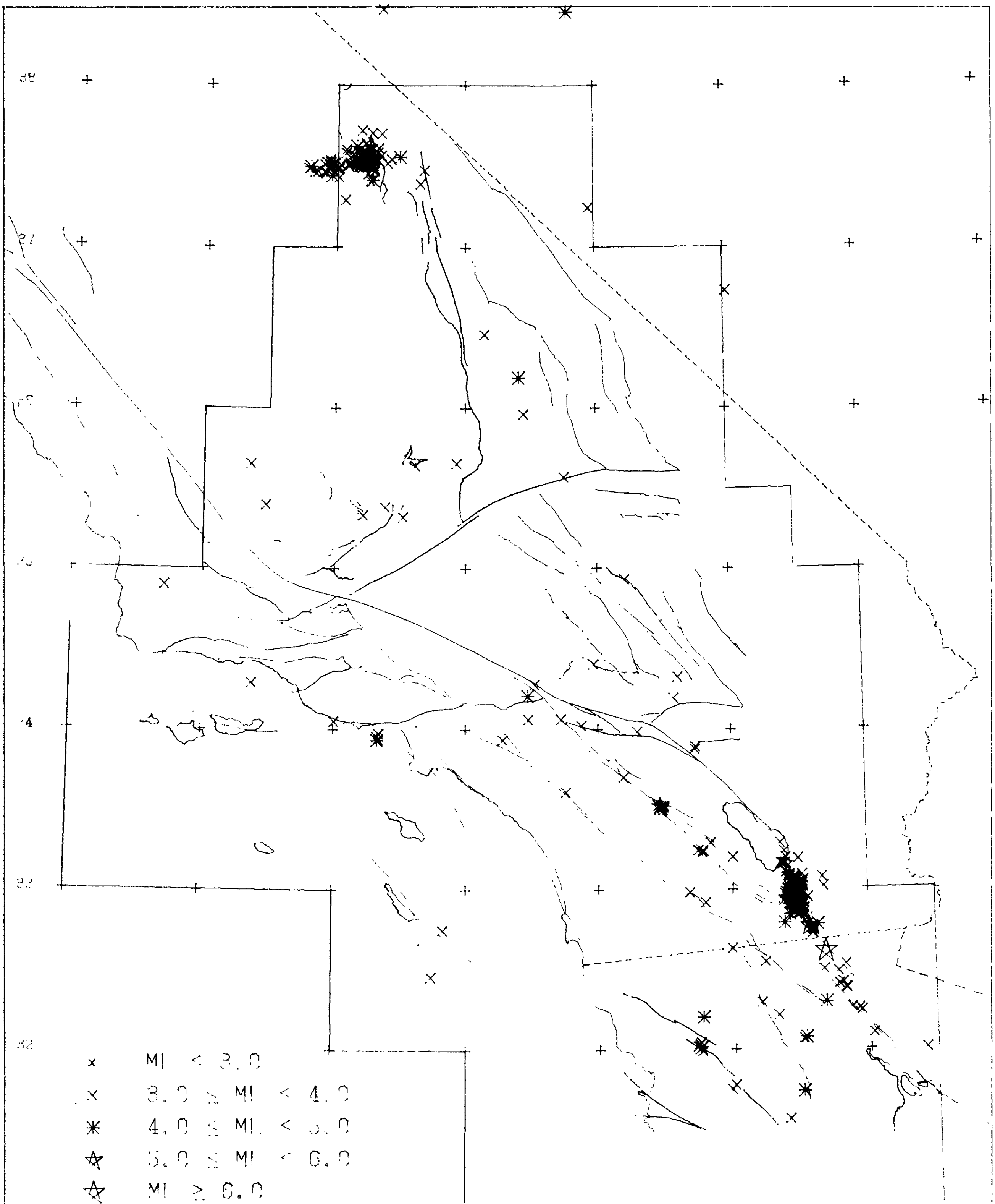

Fig. 1.--Epicenters of 487 earthquakes of M = 3.0 and greater that occurred between 1 October 1979 and 31 March 1980 in the southern California region. The great majority of these occurred as aftershocks of the M = 6.6 Imperial Valley earthquake of 15 October 1979.

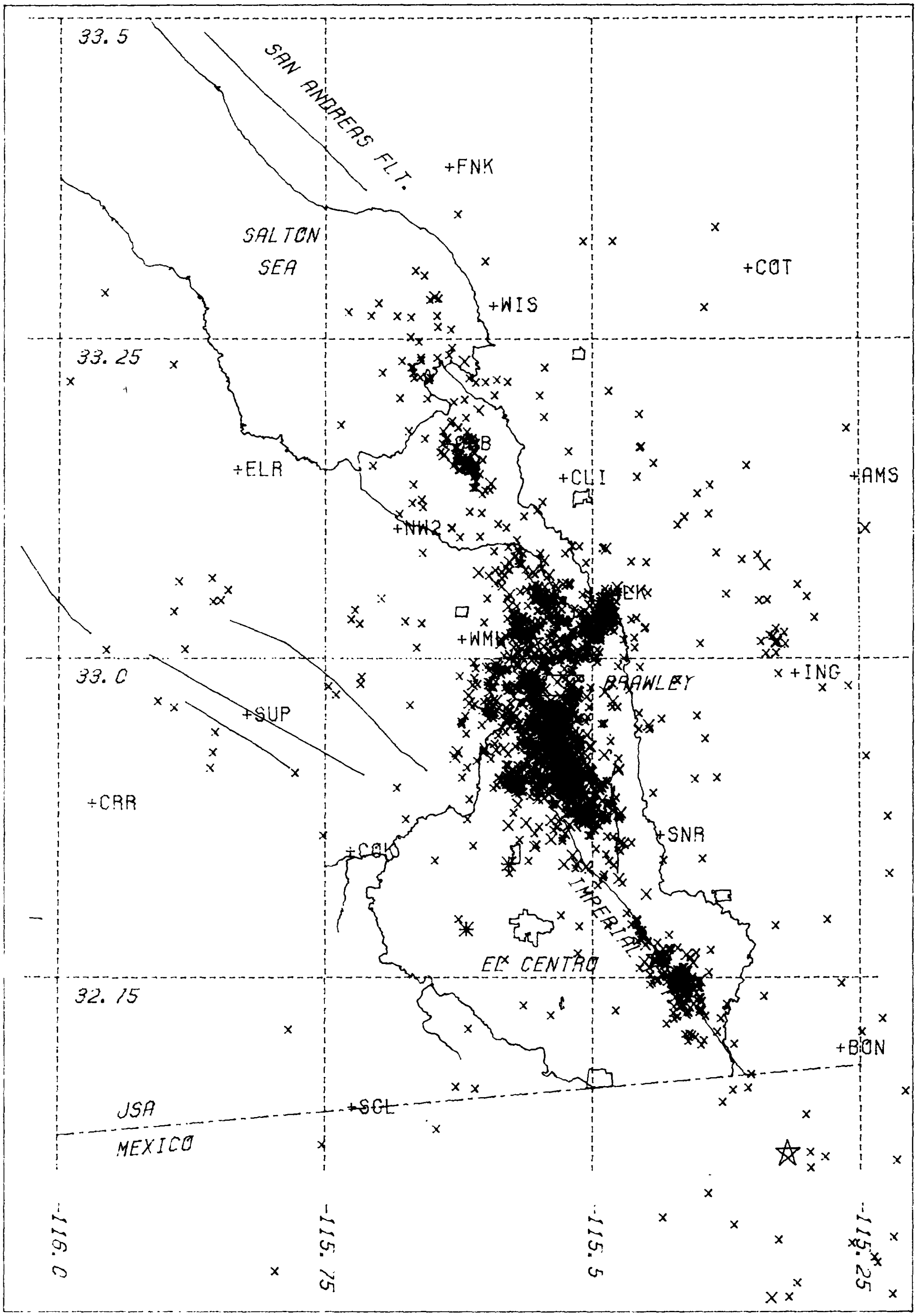

Fig. 2.--Shocks of the Imperial Valley sequence from 15 October 1979 to 31 October 1979. Star (lower right) shows location of main shock (M = 6.6). Note that most aftershocks occurred north of the area of faulting along the Imperial fault, which extended north from near the international border to about the latitude of SNR. Map prepared with the help of C. E. Johnson.

Very Long Period Seismic Studies In The U.S.S.R.

USDI 14-08-0001-18328

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Under the US/USSR "Agreement on Cooperation in the Field of Environmental Protection" we operate two very long period seismic stations which we installed in the Soviet Union. The stations are located in the very seismic region of central Asia and near the Kamchatka-Kermadec seismic zone. The data from these stations are being used to study: variations in the long period spectral content of local earthquakes, possibly premonitory to large events; temporal changes in tidal admittances associated with changes in local elastic properties; and properties of tsunamigenic earthquakes.

NATIONAL DIGITAL SEISMOGRAPH NETWORK (NDSN)

9920-02497

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Investigations

1. The purpose of this project is to establish wideband digital seismograph stations across the United States to demonstrate the capability of such stations and the quality and value of the data.

2. Due to the extended target date of having the telemetry software available for the Jamestown location, it has been decided to install a local DWWSSN system and telemeter the data to Berkeley and Menlo Park at a later date. The system has been fabricated and is now in final stage of testing. Installation is scheduled for the first week of June.

3. Installation of the Longmire DWWSSN system is planned to begin April 10. It is most important that at least two systems be installed as soon as possible for field testing, but because of the resignation of the contract personnel who had been trained for the DWWSSN program, it is planned that Bob Hutt will install Longmire and Jamestown. The remaining three stations listed under this agreement will be installed next fiscal year after technicians have been trained on a new maintenance contract which will become effective October 1, 1980.

Goals

1. Install digital recording seismographs at NAS/NRC committee selected stations in the United States.

2. Modify equipment to telemeter data from remote areas to a central recording location at other than committee selected stations.

Reanalysis of Instrumentally-Recorded U.S. Earthquakes

9920-01901

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Investigations

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

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

Results

1. J. Dewey has relocated the aftershock sequence of the Dulce, New Mexico, earthquake of January 23, 1966, as part of a study of that earthquake being conducted with R. B. Herrmann and S. K. Park of Saint Louis University. The focal mechanism of the earthquake determined by Herrmann and Park and the relocated epicenters point to the main shock having occurred as additional movement on one of a family of NNW striking normal faults that had their maximum activity in Miocene time. The distribution of aftershock epicenters suggests that the main shock triggered aftershock activity on adjacent faults.

2. D. Gordon has read WWSSN seismograms and entered travel-time data into the computer for 150 instrumentally-recorded earthquakes occurring in the central U.S. between 85°W and 105°W.

3. J. Dewey and D. Gordon are completing "mopping up" operations on the catalog of instrumentally recorded earthquakes in the U.S. and adjacent Canada east of 85°W. These operations have included relocation of 25 shocks not previously located that occurred before 1964 and were not listed in the Hypocenter Data File of the U.S.G.S. The format of uncertainty estimates on hypocentral parameters was changed to give uncertainty in terms of a three-dimensional confidence ellipsoid rather than two-dimensional confidence ellipses on pairs of hypocentral parameters.

Enhancement of Data Acquisition in the New Madrid Seismic Zone

14-08-0001-16794

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Goals

Improve detection of microearthquakes in the New Madrid Seismic Zone by the addition of sixteen new seismograph stations.

Install three three-component digital accelerographs to obtain strong motion records from small events.

Major Accomplishments

Digital accelerographs were installed at Marston, MO, within 500 meters of the Marston SMA-1, at Gratio, TN, within 1000 meters of the GRT seismograph station. Negotiations with the Corps of ENgineers are underway for the installation of the third digital accelerograph at Lake Woppapello, MO

The seismic array is providing useful data, even though the remaining stations will be installed during spring, 1980.

Investigations

The present effort is only an augmentation of equipment. Research studies utilizing the data acquired is being performed under Contract 14-08-0001-16708, "Earthquake Hazard Studies in Southeast Missouri."

PROJECT TITLE:	A Study of Earthquake Prediction and the Tectonics of the Northeastern Caribbean: a Continuing Experiment in Two Major Seismic Gaps
CONTRACT NUMBER:	USGS-14-08-0001-16748
PRINCIPAL INVESTIGATORS:	A.L. Kafka, W.R. McCann, L.R. Sykes
INSTITUTION:	The Trustees of Columbia University in the City of New York Lamont-Doherty Geological Observatory
TELEPHONE NUMBER:	914-359-2900

Status of the Seismic Network

The network continues in good working order. The Digital Event Recording System is operational and running well. This recording system is presently being operated with analog triggers, however, these analog triggers will be replaced with the digital trigger system as soon as technically possible.

Significant Observations from On-Going Research

An intensive study of microearthquakes occurring in the region 18.7°N to 19.5°N and 64°W to 65.2°W during the period February 1977 through May 1979 indicates that the downgoing seismic zone dips southward and is continuous from a depth of ∿ 10 km to at least 70 km and perhaps as deep as 130 km. These events were relocated using a new velocity model derived from the inversion of P-wave arrival times of 30 well-chosen events.

In mid-May 1976 the network recorded a sudden increase of seismic activity in the region near 19.1°N, 64.9°W. The number of events recorded at SJV jumped from a few events per day to several hundred events per day. This increase in activity was swarm-like in nature, and the swarm events were probably of shallow depth (∿ 15 km or less). Another large swarm occurred in June of 1976 in the region near 19.1°N, 64.5°W. In contrast to the earlier swarm these events occurred at depths of 30 to 45 km. The depths and locations of the June 1976 events indicate that they occurred within the descending oceanic lithosphere, whereas the events in May appear to have occurred on or near the zone of contact between the two plates.

A large earthquake (M_s = 7.2) occurred in the northern Lesser Antilles on October 8, 1974. Aftershocks of this event were recorded by research teams from L-DGO and USGS, and by the permanent local network operated by the University of the West Indies. Most of the more accurately located events lie on a NE striking plane that dips to the SE. The distribution of the aftershocks constrains the fault plane solution of the main shock derived from body-wave first motions. The shallowness of these events (10 to 40 km) and the general fault motion indicate that these events are not associated with underthrusting of the oceanic slab, but rather with intraplate tectonics of the island arc itself.

We are presently conducting a study of the source parameters of microearthquakes using digital seismograms recorded by the network. The major emphasis of this study so far has been the examination of the pulse shapes and amplitude spectra of earthquakes in the region of the network. This investigation has crucial applications to both the earthquake prediction effort and to seismic source theory. In particular we are studying the temporal variability of the P-waveform during swarms. The variations in the waveforms of microearthquakes may be useful as precursors to larger shocks. The Semi-Annual Technical Report describes some preliminary findings to illustrate how we presently utilize the digital data set and our future intentions.

Earthquakes located in the northern Lesser Antilles region indicate a downgoing seismic zone of intermediate depth shocks dipping to the southwest at depths between 50 and 150 km. The transition between this zone and the above mentioned southward dipping zone between 64°W and 66°W occurs over a distance of about 100 km, between the Virgin Islands platform and the platform of the island of St. Martin. We have located events as deep as 66 km in this transition zone, indicating that a subducted slab may exist beneath it, although its configuration is as yet unresolvable.

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

14-08-0001-16716

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Investigations and Results

To search for possible variations in the mechanism of small earthquakes preceding the M_S 6.7 earthquake of November 4, 1977, a method has been developed to objectively composite, by computer, P-wave first motions from events occurring with a small source region. The data are routinely recorded clear first motions (an average of six per earthquake) at stations of the Adak network. About 350 shallow focus earthquakes with m_b greater than about 2.7 which occurred from August 1974 through June 1978 in a region of roughly 4500 km^2 surrounding the main shock were considered. Although the coverage of the focal sphere for these earthquakes by the Adak network is not complete enough to permit the determination of absolute focal mechanism solutions, the method does distinguish between moderately different mechanisms. The most common is a thrust mechanism (characterized by strictly dilatational P-wave first motions at the local network), in which the strike of the nodal planes is roughly northeast; this mechanism is consistent with teleseismically determined mechanisms of larger thrust earthquakes in the central Aleutians. However, in the immediate vicinity of the hypocenter of the main shock and starting about 10 1/2 months before the main shock, the mechanisms of small earthquakes changed. The "precursory" mechanisms can be interpreted as thrust mechanisms (characterized by a mixture of compressional and dilatational first motions at the local stations) in which the strikes of the nodal planes are rotated clockwise by several tens of degress with respect to the typical mechanism. This change in mechanism coincides approximately in space and time with an increase in rate of occurrence of small magnitude earthquakes before the main shock, and also coincides in space (within the resolution of the method) to the eventual rupture area of the main shock.

A teleseismic solution for the focal mechanism of the earthquake of November 4, 1977 has been determined, based on long-period WWNSS recordings of both P- and S-waves. The solution is for a thrust mechanism similar to those determined by Stauder for the 1965 Rat Island earthquakes. This solution also fits many of the smaller events in the same area, as described in the preceding paragraph. The main shock of November 1977 was recorded at many teleseismic stations with two clear P-waves and two clear S-waves. The time separation between the two P-waves and between the two

S-waves is each about 11 - 12 seconds. This indicates that the event was really a doublet. The polarity of the second P-wave often appears to be the reverse of the first polarity.

From 1970 through 1976 a small seismographic network of four stations spaced at about 2 km was in operation near the Adak Observatory. We are using the data from this network to investigate the seismicity near Adak for the four years prior to the installation (in the summer of 1974) of the present network. Software is currently being debugged to fit a plane wave front to the relative P-wave arrival times across the small network to estimate the back azimuths of events. The difference between P- and S-wave arrival times will be used to estimate the distances to events. This approach will obviously not provide the epicentral resolution of the current network, but may allow us to compare the spatial distribution of seismicity between 1970 - 1974 and 1974 - 1980, and to estimate the size of the aftershock zone of the 1971 (M_S 7.1) Adak Canyon earthquake.

A study of the coherence, at tidal and secular frequencies, both between individual shallow-hole bubble-level tiltmeter records of the Adak array and between the tiltmeter records and meteorological disturbances, has been completed by C. Meertens as part of a Master's Thesis. The most interesting comparisons come from two tiltmeters installed a few meters apart at the "west site". Only digital records from these instruments, recorded from August 1979 to Febuary 1980, were analyzed in detail. Of the 4350 hours of data analyzed, there are only six hours of data missing, with no gap in data lasting longer than 1-1/2 hours. The first step in the analysis was the removal of zeroing offsets and glitches using cursor inputs from an interactive graphics terminal. The resulting time series were then lowpass filtered and decimated into hourly values. Comparison of these values with meteorological data shows that rainfall continues to cause the greatest disturbances, though the response of each of the eight tiltmeters in the array is different. To investigate the coherence between the tiltmeters of the "west site" at periods of less than a few days, a cross spectral computation was run over the entire data set and revealed significant coherence only at tidal frequencies. Only at the M_2 (12.42 hr) tidal harmonic was the signal-to-noise ratio great enough to provide amplitude and phase values that agreed between tiltmeters. To model the M_2 tide, the theoretical solid earth tide was calculated and found to account for only half of the observed signal. However, by including the effects of ocean loading, the observed tidal phases and amplitudes are found to match the predicted values, within the error of the measurements. Despite this success and the fact that it may be possible to observe an anomalous tilt lasting from days to weeks during periods of fine weather, tectonic tilts at periods of days to years are still generally buried under large drift rates and meterological effects.

Technical Advances

During the summer of 1979, an FM-carrier tape-recording system was installed at the Adak Observatory to record on analogue magnetic tapes the data from the fourteen two-component seismic stations, the IRIG-H time code, and a tape speed compensation frequency. Since then, only the tapes containing data from relative large earthquakes have been saved, pending the implementation of the planned tape reproduce system at CIRES. The final elements of the reproduce system were installed in the CIRES computer facility on March 17, 1980, and the first events from Adak magnetic tapes were detected that evening. The tape reproduce system runs at 4-times-real-time, and includes a bank of signal discriminators with tape speed frequency compensation system, and an interface so that the tape reproduce decks can be controlled by programmed software in a PDP 11/34 computer. The tape reproduce system was designed and installed by S. T. Morrissey of St. Louis University. Software developed by S. Malone at the University of Washington for digitizing and event picking of seismic data in real time is used on the PDP 11/34 to generate event tapes. These in turn are used as input, via arrival time picking on an interactive graphics terminal by project personnel, to our standard hypocenter location program on a PDP 11/70 computer. The total system is still being tested, but we expect to be relying upon it as our primary means of data acquisition and analysis within the next two months.

Reports

Frohlich, C., G. V. Latham, J. Lawton, S. Billington, C. Kisslinger, E. R. Engdahl, A. Malahoff, and J. G. Caldwell, Ocean bottom seismograph results from the central Aleutian subduction zone (abstr.), EOS, v. 60, p.878, 1979.

Meertens, C., Analysis of tiltmeter results from the central Aleutians (abstr.), EOS, v. 60, p. 936, 1979.

Morrissey, S. T., Promising new developments in installation and operation of shallow borehole tiltmeters (abstr.), EOS, v. 60, p. 935, 1979.

Microearthquake Data Analysis

9930-01173

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Investigations

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

2. The principal effort during the past six months has been devoted to a) revising the review paper "Principles and applications of microearthquake network" by W. H. K. Lee and S. W. Stewart, and b) developing a new earthquake location program.

Results

1. The first four chapters of "Principles and applications of microearthquake network" have been extensively revised.

2. A new earthquake location program called HYPO80 is being developed. A version of HYPO80 has been written for a low-priced ($6K) microcomputer using less than 48K bytes of core storage. A typical earthquake can be located in about 50 sec. We are now building a hardware floating-point board for the microcomputer. If it is successful, we can reduce the computer time to locate an earthquake to a few seconds. Thus it is possible to process and analyze microearthquake data with a low-priced microcomputer.

Reports

The following papers have been published in the last six months:

Lee, W. H. K., and Brillinger, D. R., 1979, On Chinese earthquake history—an attempt to model an incomplete data set by point process analysis: Pure and Applied Geophysics, v. 117, p. 1229-1257.

Lee, W. H. K., and Stewart, S. W., 1979, Microearthquake networks and earthquake prediction: Earthquake Information Bulletin, v. 11, no. 6, p. 192-195.

Pereyra, V., Keller, H. B., and Lee, W. H. K., 1980, Computation methods for inverse problems in geophysics—inversion of travel-time observations: Physics of the Earth and Planatory Interior, v. 21, p. 120-125.

Pereyra, V., Lee, W. H. K., and Keller, H. B., 1980, Solving two-point seismic ray-tracing problems in a heterogeneous medium; Part 1. A general adaptive finite difference method: Seismological Society of America Bulletin, v. 70, p. 79-99.

Seismic Data Library of WWSSN Seismograms

9930-01501

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

Stony Brook Seismic Network on Long Island, New York: Siting and Installation
14-08-0001-17622

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Investigations

This final summary report covers the six-month period from 1 April 1979 to 18 September 1979. The objective of this contract is to conduct a seismic noise survey to identify sites on Long Island with low enough background noise to record local and regional earthquakes and thereby increase the geographical coverage of the Northeastern U.S. Seismic Network (NEUSSN), and to install two permanent seismograph stations on these sites.

Results

In the search for suitable sites for the installation of permanent seismic stations, at least four signals were recorded on portable seismographs that differ from the background noise by exhibiting distinct wave arrivals and having a different frequency content (3-6 Hz). Three of these signals have been correlated with known earthquakes that occurred in the northeastern United States. The signal that was not recorded by other stations may be a low magnitude ($m_b<1.5$), very local earthquake.

Reports

Schlesinger, E., E. Caiati, N. Barstow and A. Kafka, Macroseismic effects on Long Island, New York from earthquake of 30 January 1979 in New Jersey, Earthquake Notes, submitted for publication, 1979.

Schlesinger, E., A seismic noise survey of Long Island, New York, 75 pages, M.S. Thesis, State University of New York at Stony Brook, August, 1979.

Earthquake and Seismicity Research Using SCARLET and CEDAR

14-08-0001-18331

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a) Analysis of the 1932 to 1979 southern California earthquake catalog reveals a remarkable decrease in seismicity rate at or near the time of the 1952 Kern County earthquake (1). This event is by far the largest one (M_s = 7.7) in the population analyzed. In view of the continuous expansion of the seismic network, such a change cannot be due to catalog incompleteness. The early magnitudes would have had to be biased upward by about 0.3 in order to account for the trend. Spot checks of the magnitude measurement and computation, done at five year intervals from 1935 to the present, do not support this explanation. Detailed analysis shows that this regional seismicity drop is in fact spatially inhomogeneous and is not confined to the area close to the Kern County earthquake. We find that contour maps of the cumulative moment release for southern California similar to the strain release map of Allen et al. (2) permit a convenient display of seismicity patterns suitable for illustration of spatial and temporal fluctuations. As an example, Figure 1 shows the cumulative moment release map for the last decade (1970-80) contoured at order of magnitude intervals.

b) Using data recently available, we have revised our previous analysis of seismicity along the Middle America trench (3). We find that seismic slip rates along the Middle America trench do not agree with rates of plate convergence, assuming uniform slip. Along the COCO-NOAM plate boundary this discrepancy can be explained by non-uniformities in slip mechanism at points of aseismic ridge or fracture zone subduction; it is likely that very large, rate earthquakes occur in these regions. However, a large and systematic discrepancy between plate convergence and seismic slip rates along the COCO-CARB boundary cannot be explained in this fashion. We suggest that significant aseismic slip may take place, due perhaps to decoupling and downbending. The limited statistical evidence available is consistent with a possible forthcoming episode of more intense seismicity, characterized by larger events.

The discrepancy between the average rates of plate convergence (6.5 cm/yr) and seismic slip (4.66 cm/yr) since 1898 offshore Mexico can be accounted for with a 370 km long quiet zone; the quiescent areas near the Orozco F.Z. and Tehuantepec Ridge total about 275 km in length. Currently there exists an additional time dependent deficiency of about 140 cm in seismic slip offshore Mexico, relative to the long term average of 4.66 cm/yr. Considering both spatial and temporal deficiencies in seismic slip, we expect a future episode of high seismic activity. Based on a series of comparisons with carefully delineated aftershock zones, we conclude that the zones of anomalous seismic activity can be identified by systematic, automated analysis of the worldwide earthquake catalog ($M > 4.5$) with a resolution of ~100 km.

c) In laterally homogeneous crust-upper mantle structures, the short period Lg phase can be explained in terms of normal mode superposition. Overtones of either Love or Rayleigh type exhibit very close group velocity curves near 3.2-3.5 km/s, generating the impulsive wave-packet Lg; phase velocity curves, on the other hand, are well distinct at periods greater than 2 s for a wide range of realistic crustal models. This suggests the use of wave-number analysis techniques to isolate different overtones from seismograms observed on arrays of stations. We show on a synthetic example that a 500 km long linear array of 12 stations allows us to isolate the different modes at periods of a few seconds, by using the UC diagram technique which Cara (1978) successfully applied to the S_a phase at longer periods. Rayleigh-type Lg propagating in a laterally homogeneous continental crust can be synthesized by adding only a few overtones at periods greater than 2 seconds. It is shown that wave-number analysis of Lg recorded on a several hundred kilometers long linear array of ten stations should allow us to isolate the different overtones, providing a tool to study both crustal structure and excitation of the overtones at the source. Preliminary investigations using synthetic Lg computed for simple crustal models indicate that SCARLET provides a good opportunity to apply such analysis. Current investigations include addition of "true", recorded seismic noise along an actual profile in southern California (4).

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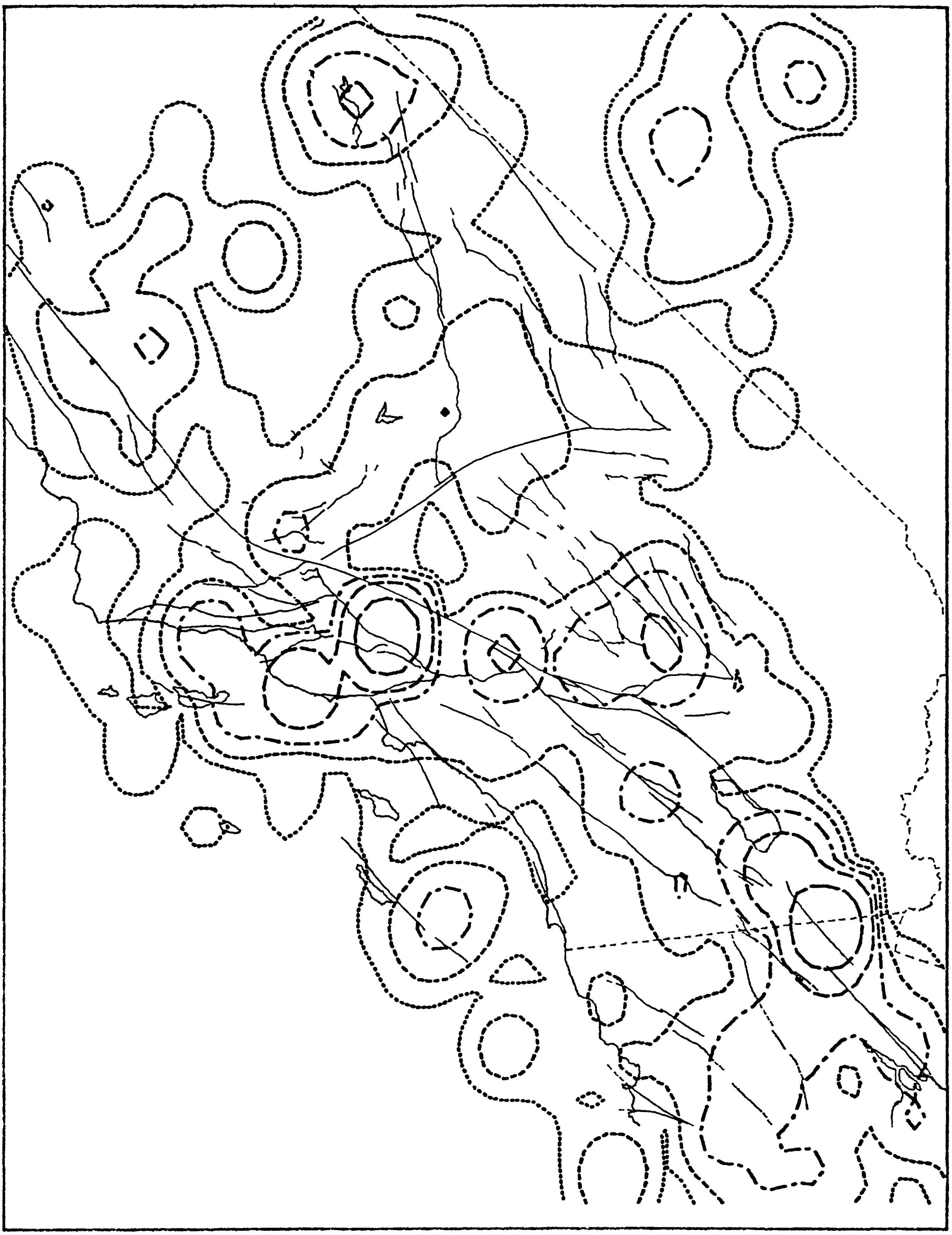
1970/1/1 TO 1980/1/1



NDSN DESIGN STUDIES

9920-02143

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Goals

Develop a concept and design for a wideband, large dynamic range seismograph system that may be used in the proposed National Digital Seismograph Network.

Investigations

Develop a triaxial seismograph system that will produce data in the frequency band from .01 to 10 Hz and operate over an amplitude range from ambient earth noise at a quiet site to an acceleration of 0.1 g; test the concepts in the laboratory; construct and test an engineering model using off-the-shelf hardware if possible to achieve economy.

Results

Preliminary studies indicate that two types of seismometers will be required operating over the same frequency band but in different amplitude ranges. Three separate amplitude levels will be recorded to insure adequate overlap. The most sensitive recording will be split into two bands (short- and long-period) to prevent saturation by microseisms. Mid-gain and low-gain recording will cover the entire frequency band. Modified conventional long-period seismometers and force-balance accelerometers are the two types of instruments considered most appropriate for this study and prospective models have been selected and ordered.

"Analysis of Old Duplex-Pendulum and Weichert Seismograms of Large and Moderate Earthquakes in Western Nevada"

Contract No.:
USDI 14-08-0001-18291

by
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Investigations:

During the period July 1, 1979 to December 31, 1979, we have collected instrumental seismic data available for the Reno-Carson City area prior to the mid-1950's. Ryall (1977) has shown this to be an area of high seisimicity with no historical record of a major earthquake. Adequate seismic coverage in the Reno-Carson City area has only been recently attained. However, current seismic patterns may not be completely representative of the longer term seismic trends. The goal of this research is to study the historic seismic record to better assess the long term seismic trends of the Western Great Basin.

Results:

We have collected seismograms from a number of North American stations to carry out the proposed research. Seismic moments are being calculated for the larger Western Great Basin earthquakes from the observed surface waves by comparing them with synthetic surface waves computed using Harkrider's theoretical surface wave program. Seven moderate earthquakes occurring in the Reno-Carson City area from 1941 to 1953 are being relocated. To relocate these events, we have chosen recent well recorded events whose locations are in close proximity to those of the older events. These are used as master events in relocating the older events using the Joint Hypocenter Routine of Jim Dewey.

EARTHQUAKE HAZARD AND PREDICTION IN NORTHWEST MEXICO AND CALIFORNIA/MEXICO BORDER

Contract No.: 14-08-0001-18216

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I. Northern Baja California Digital Telemetering Seismic Network

Progress in the preparation of equipment for installation of the array has been slow, primarily due to late delivery of some key components. A test telemetry line is operating between the observatory at San Pedro Martir and Ensenada. If this proves successful and when the wideband UHF components are delivered in December, we will start installation of the array. (A rough, snowy winter at San Pedro Martir could delay final operation until early spring. This is a critical receiving site for most stations.) Three temporary stations are in operation along the Northern Baja California coast ranges. One drum and two digital cassette recorders are providing information on background seismicity levels and locations of larger ($m \gtrsim 3$) events. Data from these temporary stations and from the telemetering array, when installed, is incorporated into the CICESE (Centro de Investigación Científica y Educacion Superior de Ensenada) monthly bulletin.

II. Special Studies

An important part of the study of Northern Baja California seismicity, and its relation with that of Southern California is the examination of the historical seismicity -- especially in terms of seismicity patterns and any seismic gaps. Several special studies have been undertaken to expand our understanding of the Northern Baja California seismicity. A relocation of large historical events by Alena Leeds (M.S. Thesis) is being extended and completed by R. Simons of IGPP. A lengthy earthquake swarm (December 1975 - June 1976, several m ~ 5) which occurred near Laguna Salada is being studied with CIT and the then existing Northern Baja California station data. Since this swarm did not occur along the most active brancnes of the Plate boundary (the Imperial - Cerro Prieto faults), it may provide insight into the transfer of seismicity from the Gulf of California system to the various Southern California faults.

Following the Mexicali earthquake of 15 October 1979, portable seismic recorders were deployed south of the border, to insure control in the location of the southernmost aftershocks. The data covers approximately one month following the mainshock. It is being analyzed at CICESE and will be included in their bulletins.

EARTHQUAKE PREDICTION STUDIES IN PAKISTAN

USGS 14-08-0001-16749

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INVESTIGATIONS

The continental convergence zone of the Himalaya and the Chaman transform zone are studied primarily from local seismic network data and from teleseismic and historic intensity data.

RESULTS

In a model of the active tectonics of the Himalayan convergence zone, we subdivide the Himalayan thrust into a shallow dipping Detachment, the portion of the thrust between the subducting Indian shield and the sedimentary wedge, and a Basement Thrust, the portion of the thrust between subducting shield and the overriding Tethyan slab. The great Himalayan earthquakes occur on the Detachment which appears aseismic otherwise, whereas the intermediate and smaller magnitude thrust earthquakes occur along a narrow belt just down-dip of the Basement Thrust Front (BTF), the boundary between the Detachment and the Basement Thrust. Local network data and modeling of teleseismic P and S waves show that these basement thrust earthquakes range in depth between 12 and 20 km and delineate a thrust fault dipping from 20 to 30°. Downdip of this narrow seismic belt the Basement Thrust appears to be aseismic. In these characteristics, continental subduction in the Himalaya resembles closely oceanic subduction zones with wide accretionary wedges as the zone that ruptured in the great 1964 Alaska earthquake.

The BTF corresponds closely with the very pronounced topographic "step" between the High and the Lesser Himalaya and with a small circle of 1700 km radius, along the central 1600 km of the Himalayan arc. Along the extremity of the arc, the BTF and topographic step deviate from the small circle but remain closely associated. At the western syntaxis the BTF and the topographic step is traced straight through the hairpin bend of the surface structures and extends beyond into the Hazara arc for at least 100 km. The Hazara arc is then part of the Himalayan front. The very extensive Detachment under the Hazara thrust-fold belt coincides with a thick Infracambrian evaporite layer and the unusual features of this belt, including the Salt range and the syntaxis, are ascribed to weak detachment coupling. Weak vs. strong detachment coupling (e.g. salt vs. no salt) are found to be important factors in shaping other thrust-fold belts such as the Appalachians.

Seismic hazard is highest in the sedimentary zone above the Himalayan Detachment, especially in the highly populated flood plains. This hazard is easily underestimated during the aseismic interseismic periods. In Hazara the Detachment may slip aseismically.

A good understanding of the tectonics and seismic potential along the Himalayan Detachment can serve as a guide to estimate the hazard along similar active structures. Moreover, long range forecasting of the great detachment earthquakes may be possible if the configuration of the great ruptures can be deduced from the data in light of our tectonic model.

Local network data and teleseismic data from the Chaman continental transform zone indicates:

1. Recent intermediate and low magnitude earthquakes occur mostly on the faults which were probably associated with the four known major earthquakes in this area (1892, 1931, 1931, 1935) but they are concentrated near the inferred ends of these major ruptures.

2. A composite fault plane solution of activity on the 1935 Quetta earthquake fault shows left-lateral slip.

3. The Chaman fault-zone south of the 1892 break (30.3°N) is a series of subparallel left-lateral strike-slip faults which include the Quetta fault. Seismicity in this section is high, but it does not include any major event ($M \geq 7.5$) and is characterized by low stress drops. A comparison between this section of the Chaman fault system and the San Andreas fault system south of the big bend is suggested.

4. A recent abrupt increase in seismicity along the Chaman fault south of the 1892 break (30.3°N) warrants careful consideration as a premonitory signal.

5. The maximum hypocentral depths from network data range from 15 km west of Quetta to 50 km near the axis of the Sibi reentrant east of Quetta suggesting a similar thickening of the crust from west to east.

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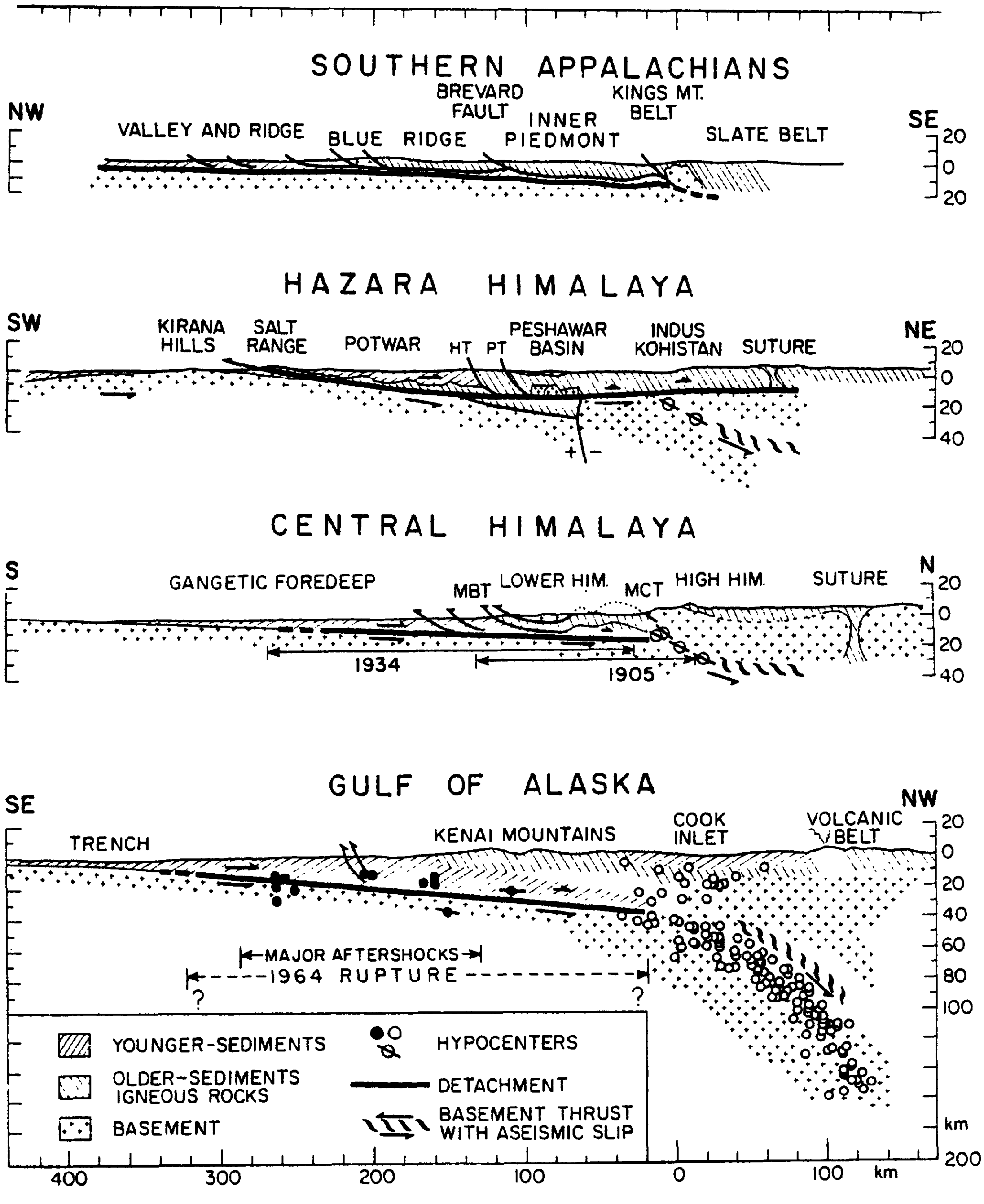

Figure 1. The southern Appalachians, a continental collision structure now inactive, and the active oceanic subduction structure in the Gulf of Alaska are compared to the Himalayan continental subduction structure. The Alaskan section is a superposition of data from the great 1964 earthquake ($M_s = 8.4$); the filled hypocenters are 1964 aftershocks redrawn from Plafker (1965) with slight changes and hypocentral data from a local network obtained in the interseismic period (April-June, 1972; Lahr et al., 1974). The Southern Appalachian section is deduced from recent deep seismic reflection results (COCORP; from Cook et al., 1979). In the Himalayan section the arrows associated with the great earthquakes (1905, $M_s = 8.0$ and 1934, $M_s = 8.3$) indicate the respective extent of intensity $\geq$ VIII which we correlate with the extent of rupture. Note that the great earthquakes are associated with the detachment in both oceanic and continental subduction structures. The four thrust earthquakes in the Himalayan section between the aseismic thrust and the detachment (the bar through the hypocenters indicate the dip of the inferred rupture plane; see Figure 4) indicate the location of the seismically active portion of the thrust. Thrust earthquakes in oceanic subduction structures are similarly located (cf. Isacks and Barazangi, 1977).

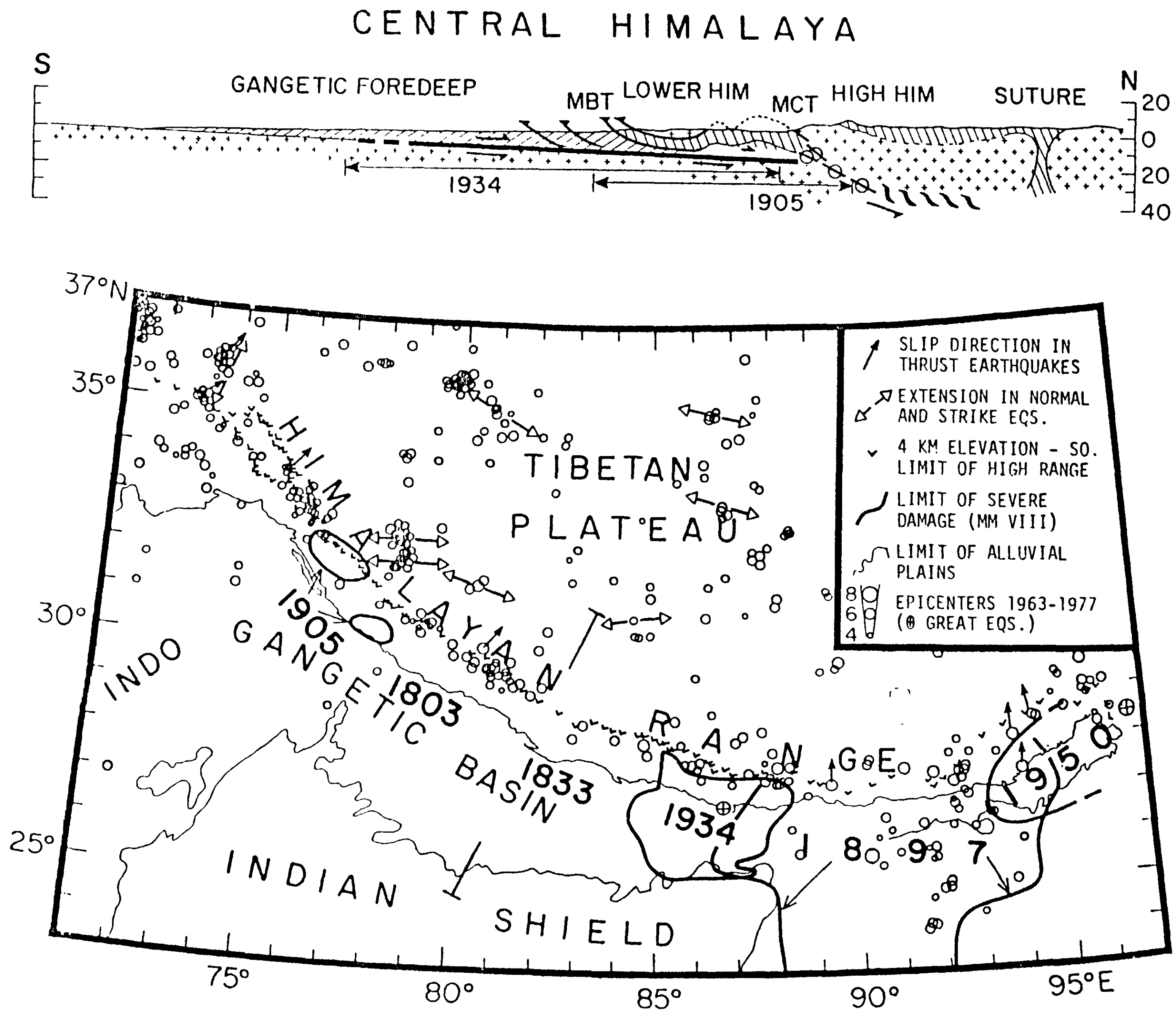

Figure 2. Earthquakes along the Himalayan arc. The distribution of damaga is well known for the 1897 and subsequent great earthquakes. Intermediate and small magnitude thrust earthquakes form a narrow belt at the northern extremity of the zones of severe damage. In our model (sketched in the section: scale 1:1; crosses and hatches indicate basement and sediments, respectively) the great earthquakes (the extent of rupture is approximately indicated by extent of severe damage) and the small earthquakes (circles; the bars indicate the inferred plain of thrust ruptures) rupture distinct portions of the same major fault. Arrows indicate movement with respect to the overriding basement block (High Himalayas).

COOPERATIVE TECTONIC STUDIES FROM A SEISMIC NETWORK IN CENTRAL ITALY

Sponsored by USGS Award No. 14-08-0001-17741

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INVESTIGATIONS

The objectives of this project are to study the tectonics and the seismic hazard in Central Italy primarily using data from the seismic network of the Instituto Nazionale di Geofisica (ING), in a collaborative effort between the ING and the Lamont-Doherty Geological Observatory (L-DGO).

RESULTS

Great detachment earthquakes can occur along the Appennine arc. The African foreland (the Adriatic plate) is overriden by an arc and spreading back-arc (Tyrrhenian basin) system along the Appennines. This interaction is manifested everywhere along the arc by active underthrusting of the foreland below the Appennines. This low-angle thrust presumably extends far down-dip below the Appennines and is similar to the Himalayan detachment. The Himalayan detachment slips by great earthquakes and it appears aseismic during interseismic periods. The historic record indicate that very large detachment ruptures have occurred along the Appennines. These ruptures can be expected to occur again.

On September 19, 1979, an intermediate-magnitude event (M = 5.2) occurred near Norcia, slightly northwest of the Anzio-Ancona (A'A in Figure 10) lineament. The preliminary results about this event from the study of the data from the seismic network in central Italy operated by the ING are:

1. The fault plane solution of the main event has a primary component of normal faulting with a NE strike.

2. The distribution of the aftershocks is consistent with a NE striking rupture.

3. The distribution of seismicity prior to the September 19 earthquake is dependent in space and time with the 9/19/79 event. The seismicity up to June 1979 (up to 2 1/2 months prior to the event) clearly suggest the formation of a "doughnut". The seismicity in the general area of the 9/19/79 event (4 sec $\leq$ S-P at MNS $\leq$ 10 sec) is quite high in August and the first week of September (average of 1 earthquake with M $\geq$ 2 every 2 days). This activity is probably higher than the background seismicity in this area. Two weeks before the event the rate of seismic energy released decreases markedly although the rate of earthquake occurrences changes little.

4. The b-value increases significantly from the foreshocks to the aftershocks. Also a decrease in b-values is detected from the beginning to the later part of the aftershock sequence. A swarm of 13 events characterized by low magnitude ($M < 2.3$) occurs between 4 to 1 days before the main shock. No earthquakes are detected at 18 hours before the main shock (Figure 18).

In a comparison between the Appennine and the Himalayan convergent structures, this earthquake is related to the Tibetan earthquakes which also exhibit T axis perpendicular to the convergence direction.

REPORTS

Seeber, L., Final Technical Report, USGS contract 14-08-0001-17741.

Relazione Conjunta Sol Terremoto di Norcia, September 19, 1979, Al Congresso Geodinamica, Roma, 6-8 Maggio, 1980.

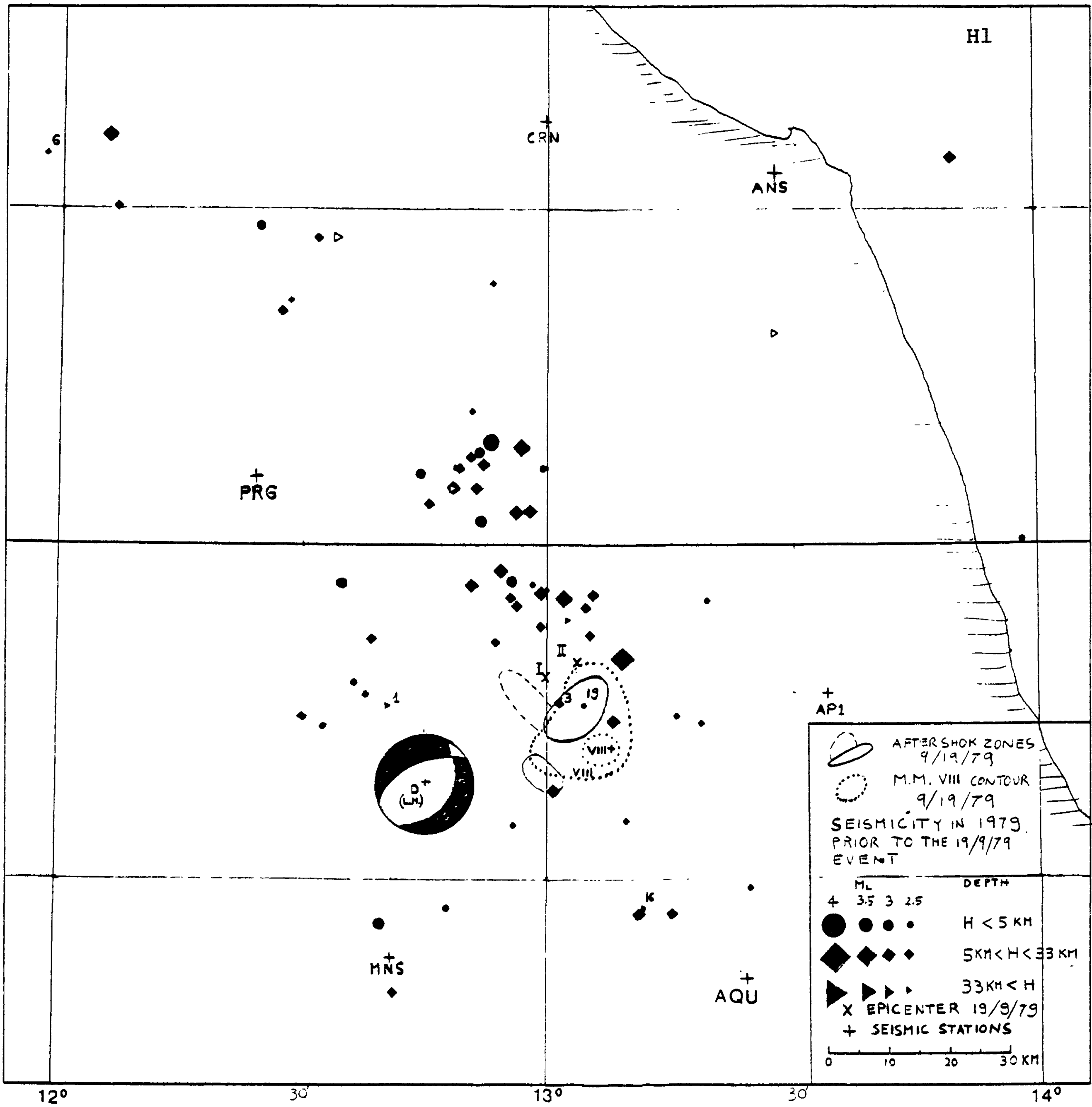

Figure 1. Seismicity during 1979 prior to the 19 September 1979 Norcia earthquake. I and II denote the 19/9/79 epicenters as determined by the U.S.G.S. and the ING, respectively. The fault plane solutions are plotted on the lower hemisphere, black quadrants have compressional first motion. The numbered epicenters occurred during the 19 days of September prior to the Norcia event, the number being the date of occurrence. Note that 2 of the 5 epicenters in this category occur within the main aftershock zone. No other epicenters occur in this zone prior to the Norcia event, during 1979 and 1978.

Earthquake Research and Network Operations in the Intermountain Seismic Belt-- Wasatch Front

14-08-0001-16725

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Investigations

1. Analyses of earthquake data from the 43-station Wasatch Front array, including closely spaced sub-arrays for detailed studies along the Wasatch fault.

2. Estimation of earthquake recurrence intervals from seismic moment rates in Utah.

3. Study of attenuation in the Utah region and implications for the M_L magnitude scale in Utah.

4. Space-time seismicity patterns in the Utah region and the identification of a 300-km-long seismicity gap in the Intermountain Seismic Belt.

5. Study of an upper mantle earthquake (depth = 90 km) beneath the Middle Rocky Mountains in NE Utah.

6. Further study of crustal flexure associated with normal faulting and implications for seismicity along the Wasatch Front.

Results

1. Quarterly bulletins for the Wasatch Front area for the period: July-December, 1979 include 313 earthquakes ($M_L \leq 3.1$). Earthquake sequences ($M_L < 3.0$) occurred near Manti, Utah and Star Point, 40 km east of Manti. Small-magnitude earthquakes ($M_L < 3.1$) continued along the Idaho-Utah border in Pocatello Valley, Hansel Valley, and Blue Creek Valley; and in the Bear River Range 10-20 km east of Logan, Utah.

2. Using available data from fault mapping and dating, moment rates for regions of Utah were calculated in a manner similar to that of Anderson (1979). In order to use this technique properly, a moment vs. M_L relationship was developed for Utah. The analysis resulted in the following relationships: $\log M_O = 1.1\ M_L + 18.56$ (least squares fit to all data) and $\log M_O = .96\ M_L + 19.13$ (excluding 3 poor data points). Return rates for the Wasatch Front determined from the

*Semi-Annual Technical Report also includes contributions from D. Doser, M. Griscom, W. D. Richins, and Dr. G. Zandt.

geologic data using the Utah M_0 vs. M_L relationships agree suprisingly well with return rates calculated from historical seismic data (Fig. 1a). Also, the geologically predicted recurrence rates of 2.3 to 4.0 per 10^3 yrs for a $7 \le M_L \le 7.5$ earthquake on the Wasatch Front agree with those predicted by Cluff and others (1979) based on data from trenching along the Wasatch fault.

3. Based on seismic intensity and Wood-Anderson amplitude data, a case can be made for greater attenuation in Utah than that experienced in coastal California. Of necessity this difference in attenuation must have an effect on local magnitude determination. Application of newly calculated corrections for stations beyond 90 km in conjunction with new estimates for station corrections does not result in a radical change in calculated magnitude; hence, the magnitudes determined in previous work are valid magnitudes and may be used for quantitative analysis. Evernden and Clow (1979) claimed that Utah magnitudes are overestimated by a full magnitude unit. By assuming that Utah earthquakes are much shallower than California earthquakes,as done in this work, any possible overestimation would be emphasized. In fact, no great difference in magnitudes is evident. If one makes the more common and generally accepted assumption that focal depths in Utah and California are the same, the corrections to Richter's -log A_0 table becomes greater, indicating Utah magnitudes may be systematically underestimated.

4. A recent analysis of space-time seismicity in the Utah region (Griscom, 1980; Griscom and Arabasz, 1980) has led to the following, quite unexpected finding. There currently is a <u>300-km-long</u> seismicity gap for earthquakes of M_L3.5 or greater along the main axis of the Intermountain seismic belt (ISB) between 38.9°N and 41.5°N--that is far more extensive than the two 70-km-long microseismic gaps along the Wasatch fault that lie within it. The data are summarized in Figure 1c. A time plot of <u>independent mainshocks</u> within the sample area (Fig. 1b) versus latitude is shown in Figure 1c. Events of maximum Modified Mercalli intensity (I_0) VII or greater, complete since about 1896, are shown as solid circles; hachured circles indicate shocks of I_0 = VI, complete since about 1938; open circles indicate shocks of I_0 = V, complete since 1950; and X's indicate shocks of I_0 = IV or $M_L \ge 3.5$, complete since 1962. The hachured space-time compartment in Figure 1c points out that within a 300 km x 100 km N-S trending zone along the ISB, only one mainshock of M_L3.5 or greater has occurred since 1967 (the M_L4.3 Heber City earthquake of 1972). And along this same zone, no mainshock of $I_0 \ge$VII (~M_L5-1/2) has occurred since 1914. In contrast, the sectors of the ISB immediately north and south of the 300-km-long gap have shown nearly uniform seismic flux since the late 19th century, with moderate-size earthquakes in those sectors occurring roughly every 20-25 years. (Curiously, these shocks appear to occur alternately in the north and south.) The data of Figure 1c suggest to us that the segment of the ISB between 38.9°N and 41.5°N, which includes about 80% of the length of the Wasatch fault, is anomalous with respect to long-term rates of energy release. It is a candidate area for future earthquakes of moderate size --if not for a large earthquake.

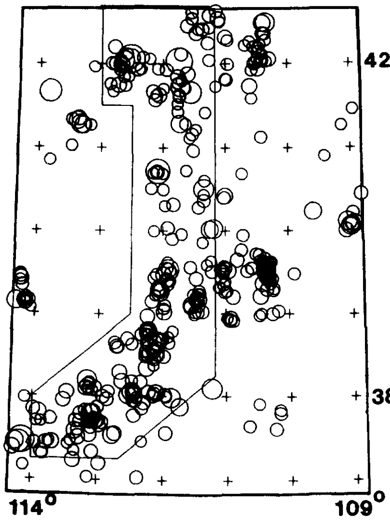
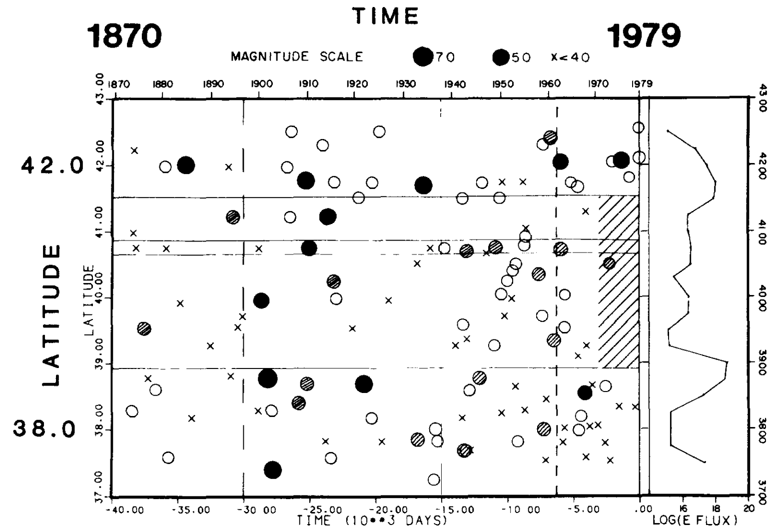


Fig. 1b



LOG(E. FLUX)

Fig. 1c

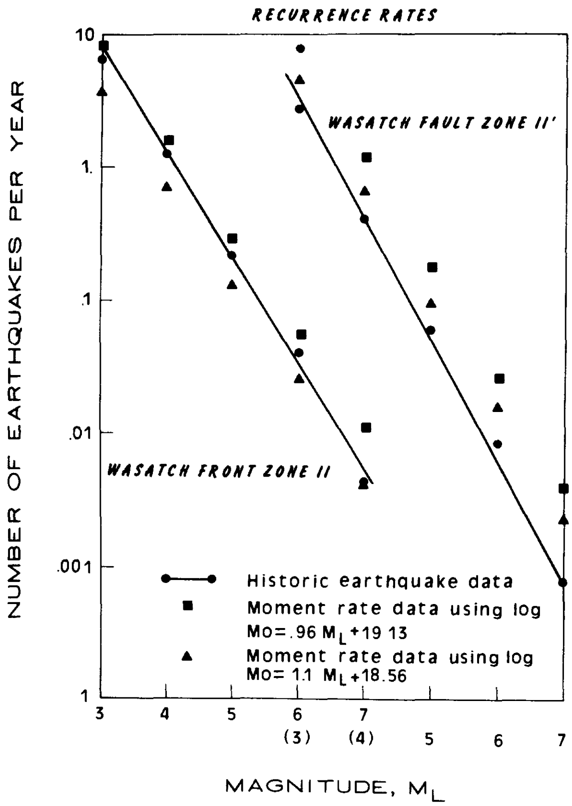


Fig. 1a

5. On February 24, 1979 (12:43 UTC) an earthquake of M_L = 3.8 occurred in NE Utah. The epicenter (41°43'N, 111°90'W) is within 8 km of Randolf, Utah; however, there were no felt reports. No foreshocks or aftershocks were detected. The earthquake is noteworthy because a well-constrained hypocenter solution placed the event at a depth of 90 km. The focal mechanism solution for the earthquake indicates a near-horizontal, west-northwest striking compression axis--consistent with the intraplate stress field postulated for the North American plate by Sykes and Sbar (1973), but inconsistent with surface evidence of roughly east-west extension.

6. Elastic and viscoelastic models of crustal flexure in Utah's Wasatch Front area predict stress fields which are generally consistent with the observed pattern of seismicity. The models consist of an elastic or viscoelastic layer overlying a fluid-like substratum. Normal faulting that penetrates the entire crust induces isostatic forces which produce upward flexure of the footwall side of the Wasatch fault--thus uplifting the Wasatch Mountains. Using a value for the flexural rigidity of 5 x 10^{22}n-m and assuming the end of the layer is constrained at the fault, shallow extensional stresses are induced in a 48 to 80 km wide zone adjacent to the fault. If the end is unconstrained, shallow compressional stresses are induced in a broad area 50 to 100 km wide that peaks about 24 to 40 km from the main fault. Seismicity patterns as well as available focal mechanism are consistent with a model in which the East Cache fault is in a constrained flexure mode; whereas, segments of the Wasatch fault are in unconstrained flexure. The viscoelastic model yields more satisfactory predictions for some of the observed parameters and allows for dissipation of the bending stresses through relaxation without faulting. The time variation of the bending stresses could have a significant influence on the episodicity of faulting on the Wasatch fault.

Reports and Publications

Doser, D. I. and R. B. Smith (1980). Earthquake recurrence intervals from seismic moment rates in Utah (abstract). Earthquake Notes 50, p. 70.

Griscom, M. and W. J. Arabasz (1980). Space-time seismicity patterns in the Utah region: A 300-km-long seismicity gap in the Intermountain Seismic Belt (abstract). Earthquake Notes 50, p. 69.

Zandt, G. and W. D. Richins (1980). An upper mantle earthquake bēneath the Middle Rocky Mountains in NE Utah (abstract). Earthquake Notes 50, p. 69.

Seismic Hazard Evaluation of Large Known and Suspected Active Faults in Western Nevada

Contract 14-08-0001-16741

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Investigations

Investigate the seismic potential and state of activity of large known or suspected faults in western Nevada; search for changes in regional seismicity that may indicate an impending major earthquake; analyse the distribution, magnitude, and mechanisms of earthquakes in the area of interest; continue analysis of earthquakes in Nevada recorded by the statewide network.

Results

1. Seismicity and Tectonics

Anomalous temporal variations of seismicity along the Sierra Nevada-Great Basin boundary zone (SNGBZ) have been documented by UNR network analysis. The burst of moderate-magnitude seismicity that began in September 1978, following a year-long decrease in seismicity in the southern part of the SNGBZ, continued through the current reporting period. An outstanding aspect of the 1977-1979 variations is that their extent is regional, rather than local. Four events of $M_L > 5$, spaced at intervals of approximately 100 km, have occurred since September 1978. The most recent of these events was the M_L 5.2 Bridgeport earthquake of October 7, 1979.

The recent seismicity is not representative of Quaternary tectonic activity along the Sierra front in the sense that most of the events have exhibited predominantly strike-slip rather than oblique dip-slip mechanisms. While strike-slip faulting with an E-W axis of minimum compressive stress is consistant with the regional extension, the maximum compressive stress during the Quaternary has been intermediate between vertical and horizontal (N-S), rather than horizontal or sub-horizontal as in many of the recent events. A striking aspect of the recent seismicity is its concentration near the terminations of the major rangefront faults, which are typically 50 km long, or in zones separating the rangefront faults, which exhibit a left-stepping geometry. Thus, in terms of their mechanism and disposition in relation to the major active faults, the recent earthquakes are not typical of Quaternary tectonic activity. However, the recent seismicity may be preparatory to large-magnitude seismicity on one or more of the major rangefront faults.

In this framework the earthquake swarm near Mammoth Lakes is of particular interest, since mechanisms determined for some of the events exhibit a NNW-striking, east-dipping focal plane consistent with rangefront faulting. The Mammoth Lakes swarm is continuing into its second year. The swarm was initiated in December 1978, by migration of seismicity following the M_L 5.7 event of October 4, 1978, that occurred 25 km NW of Bishop. The migration occurred over a time interval of 6 months, and over a distance of 25 km toward Mammoth Lakes in a WNW direction, oblique to the strike of the NNW-trending, left-stepping normal faults of the Sierra frontal system. The swarm activity has been most intense in a region immediately to the south of Long Valley caldera, where several NNW-striking faults dissect Sierran granites and paleozoics. The activity reached a maximum in November 1979. Twelve swarm events of magnitude between 4.0 and 4.3 occurred in 1979. Several events have been recorded close in on a UNR 3-component wideband digital displacement seismograph and a strong-motion accelerograph.

UNR wideband digital event recorders, developed under separate funding, have been deployed close-in to record hundreds of aftershocks of the recent Sierran front earthquakes as well as numerous events of the Mammoth Lakes swarm. This data will allow a comparative study of strike-slip and dip-slip source characteristics.

2. UNR coda-magnitude scale

The coda-magnitude relation determined for short-period vertical instruments of the University of Nevada network is

$$M_C = -1.2 + 2.65 \log T + 0.0013\Delta \qquad (1)$$

where T is coda duration in seconds, as defined by Lee et al. (1972, USGS Open File Report), and Δ is epicentral distance in kilometers. The relation is based on a set of 12 events of Berkeley magnitude 3.0 - 5.7 which occurred along the Sierra Nevada-Great Basin boundary zone. The standard deviation between BRK and UNR magnitudes for these events is $\pm$ 0.09. Duration data for 9 short-period Benioff stations and 21 L-4 stations were analysed separately. The coefficients of the coda duration and distance terms were found to be the same for the two sets of stations, an unexpected result. Average standard errors of magnitudes determined from the Benioff and L-4 station sets are $\pm$ 0.17 and $\pm$ 0.19, respectively. The constant term in equation (1) is such that the average station adjustment is zero for the L-4 stations. The second moment of the L-4 station adjustments is 0.19. For the Benioff stations the average station adjustment is - 0.40.

Berkeley Wood-Anderson magnitudes can not generally be determined for SNGBZ earthquakes of magnitude less than 3. To extend the coda-magnitude scale to smaller events, magnitudes were determined from synthetic Wood-Anderson seismograms obtained by filtering wideband digital data recorded at station MNA on a 3-component UNR event recorder. Coda durations and magnitudes were determined for 17 local events in the Mono-Mina-Bishop area: 13 of the events occurred in a single source region near Mono Lake, approximately 80 km from MNA. Coda magnitudes calculated from equation (1) differed from synthetic

Richter magnitudes by a constant, 0.19 $\pm$ 0.11, which is attributed to a combination of attenuation and station effects. The standard deviation, $\pm$ 0.11, is not significantly greater than the standard deviation $\pm$ 0.09 between BRK and UNR magnitudes for the larger events on which the coda-magnitude scale was based. Thus equation (1) can be applied in the magnitude range 1.5 - 5.7.

3. Recommended revisions of seismic hazard mapping

Recent seismic hazard maps have been based largely on historic seismicity and consequently show relatively high hazard in the zone of large historic earthquakes in central Nevada and relatively low hazard along the SNGBZ north of Owens Valley. Significant revisions have been recommended (Ryall and VanWormer, 1980) such that hazard mapping conforms with the geologic record of Holocene and late Quaternary faulting (Slemmons, Wallace, Trexler, Bell, Pease), and with Ryall's model of the seismic cycle of Great Basin faults. Recommendations were submitted at USGS EHRP meetings at Alta, Utah and Denver, Colorado during the reporting period, and are being incorporated in the forthcoming revision of the Algermissen-Perkins hazard map of the U.S.

Reports

Greensfelder, R. W., F. C. Kintzer, and M. R. Somerville, Seismotectonic regionalization of the Great Basin, and comparison of moment rates computed from Holocene strain and historic seismicity, submitted to G.S.A. Bull., Part II.

Mohler, A. S., Earthquake/earth tide correlation and other features of the Susanville, California earthquake sequence of June - July, 1976, submitted to B.S.S.A.

Ryall, A., and F. Ryall, Anomalous patterns of earthquake occurrence in the Sierra Nevada - Great Basin boundary zone, submitted to B.S.S.A.

Ryall, A., and J. D. VanWormer, Estimation of maximum magnitude and recommended seismic zone changes in the western Great Basin, submitted to B.S.S.A.

Somerville, M. R., W. A. Peppin, and J. D. VanWormer, An earthquake in the Sierra Nevada - Great Basin boundary zone: Diamond Valley, submitted to B.S.S.A.

VanWormer, J. D., and A. Ryall, Seismicity related to structure and active tectonic processes in the western Great Basin, Nevada and eastern California, submitted to B.S.S.A.

Earthquake Hazard Studies in Southeast Missouri

14-08-0001-16708

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Goals

Monitor seismicity in the New Madrid Seismic Zone, using data from a seventeen station seismic array.

Conduct research on eastern United States seismic sources by using array data and data from other stations.

Investigations

The project consists of the operation of a 17 station micro-earthquake array (to be augmented to 32 stations) in the central Mississippi Valley, near New Madrid, MO. Since the installation of the array on 1 July 1974 a total of 1117 earthquakes have been located through December 31, 1979. The locations of these earthquakes are shown in Figure 1. The operation and analysis of array data is an ongoing effort. Quarterly bulletins of micro-earthquake locations and readings are published.

An investigation of the depth distribution of earthquakes in the central Mississippi Valley is commencing, being made possible by the establishment of a data file of phases read since January 1977. JHD and Master Event Location programs have been implemented on the PDP 11/70 computer to assist this task.

Larger eastern United States earthquakes are being investigated with techniques that study surface wave excitation, body wave forms and Lg spectra.

Results

A major study of the earthquakes near the Rocky Mountain Arsenal, Denver, Colorado is nearing completion. The solutions seem to be well constrained by surface wave, seismicity, seismoscope and strain meter data.

Preliminary depth profiles indicate that the station distribution is sufficient to define the depths as well as to make a JHD relocation of microearthquakes feasible.

A new, simple method for determining crustal shear wave Q is leading to a Q regionalization of the western United States

Publications

Herrmann, R.B. (1979). FASTHYPO - A hypocenter location program, Earthquake Notes 50, 25-38.

Herrmann, R.B. (1980). Q estimates using the coda of local earthquakes, Bull. Seism. Soc. Am. 70, 447-468.

Singh, S. and R.B. Herrmann (1979). Q Regionalization of western United States (Abstract, 75th Annual Meeting, SSA), Earthquake Notes 50, 27.

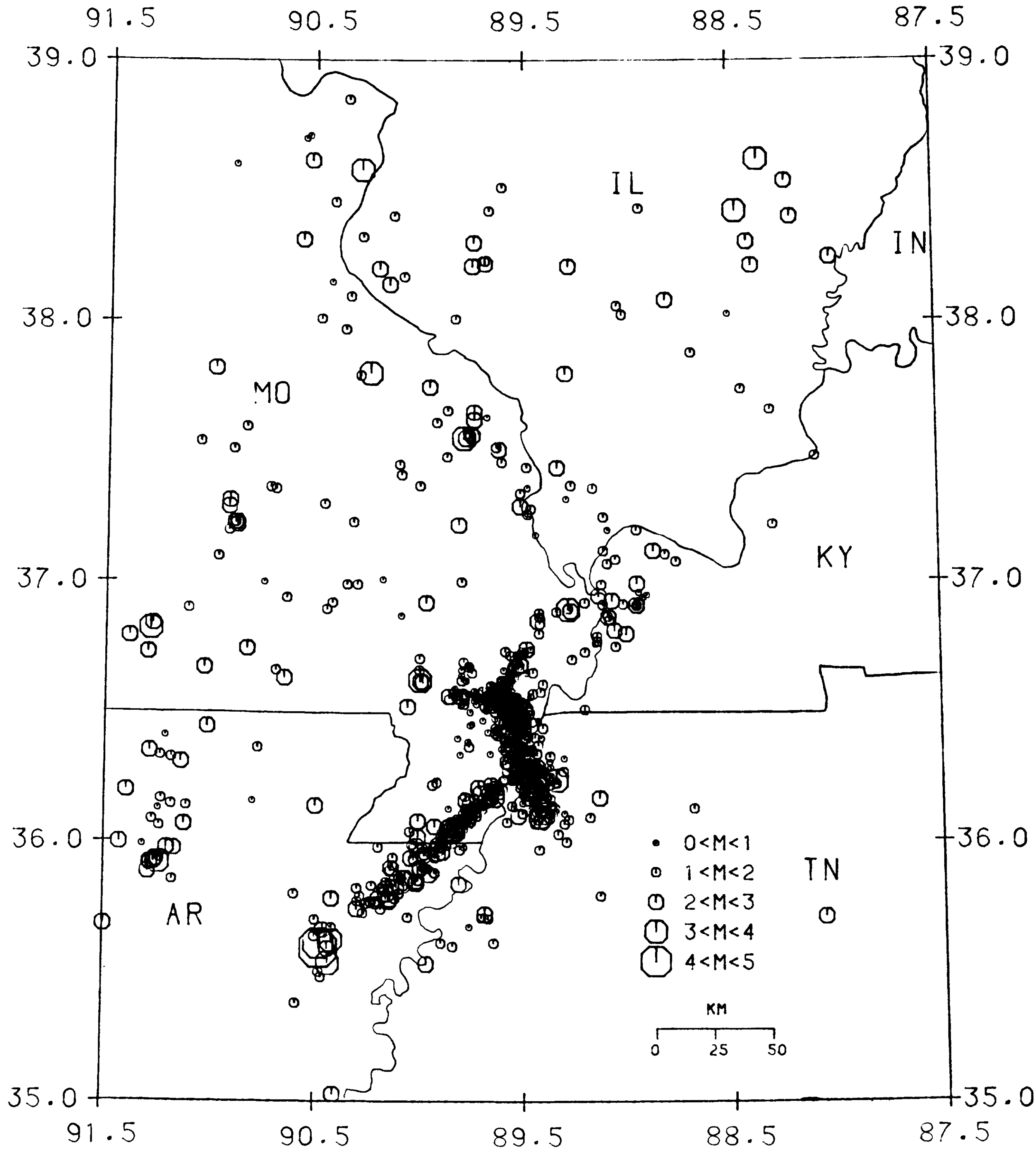

figure 1
REPORTING PERIOD 01 JUL 1974 to 31 DEC 1979
LEGEND ▲ STATION ◦ EPICENTER

National Earthquake Catalog

9920-02648

J. N. Taggart
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Goals

1. Develop a plan for the preparation of a national earthquake catalog within five years.

2. Coordinate the operational and research activities necessary to produce the catalog.

Investigations

1. Discussions with twenty Geological Survey scientists during the first three months of FY 1980 provided background information on problems related to the catalog.

2. A preliminary plan was prepared and submitted to the Office of Earthquake Studies (OES) on 01 February 1980.

3. A modified plan, which discussed four levels of budgetary and staffing effort, was submitted to the OES on 15 February 1980.

4. A final version of the plan, which assumes $2.5 M effort over a five-year period from existing OES funds and staff, was submitted on 25 March 1980.

Results

1. The OES has identified the preparation of a national earthquake catalog as a priority item during the next five years. The target date for preparation and technical review of the catalog is September 1984. The plan identifies four principal elements in the development and publication of a national earthquake catalog. These elements (summarized below) are: data preparation, related research, data base development, and catalog preparation.

2. The collection, entry, and correction of event list data from numerous sources is a necessary first step in the preparation of the catalog. The individual lists will be carefully checked, then merged with all data in chronological order. Preferred hypocenters will then be selected for each event. The target date for this

stage of the work is September 1982. The plan recommends that the catalog include earthquakes in all 50 states, Puerto Rico, Guam, American Samoa, and parts of Canada and Mexico where earthquakes might potentially be felt in the United States. Thresholds will be selected to provide a good representation of events in all regions of the United States.

3. The research effort will be directed mainly toward determination of the accuracy of a few common event list attributes such as: latitude longitude, focal depth, origin time, magnitude(s), maximum intensity, and damage data. Observational data from a limited number of important historical events will be reevaluated. The change in regional detection thresholds as a function of time will also be estimated.

4. A computer data base will be developed from which the catalog can be published essentially free of typographic errors. Initially the data base will contain only attributes appropriate to the catalog; however, the design of the data base will be sufficiently flexible that it can be expanded to serve as a general purpose national event list data base after the catalog is published.

5. The greater part of the catalog will consist of regional chronological listings of events in a tabular format. Exhaustive references will be included along with a thorough discussion of methodology. A few maps, special statistical tables, and descriptions of notable earthquakes will also be an integral part of the catalog. The Geological Survey is aiming to produce a first-class catalog that will be an important reference for years to come.

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

14-08-0001-16704

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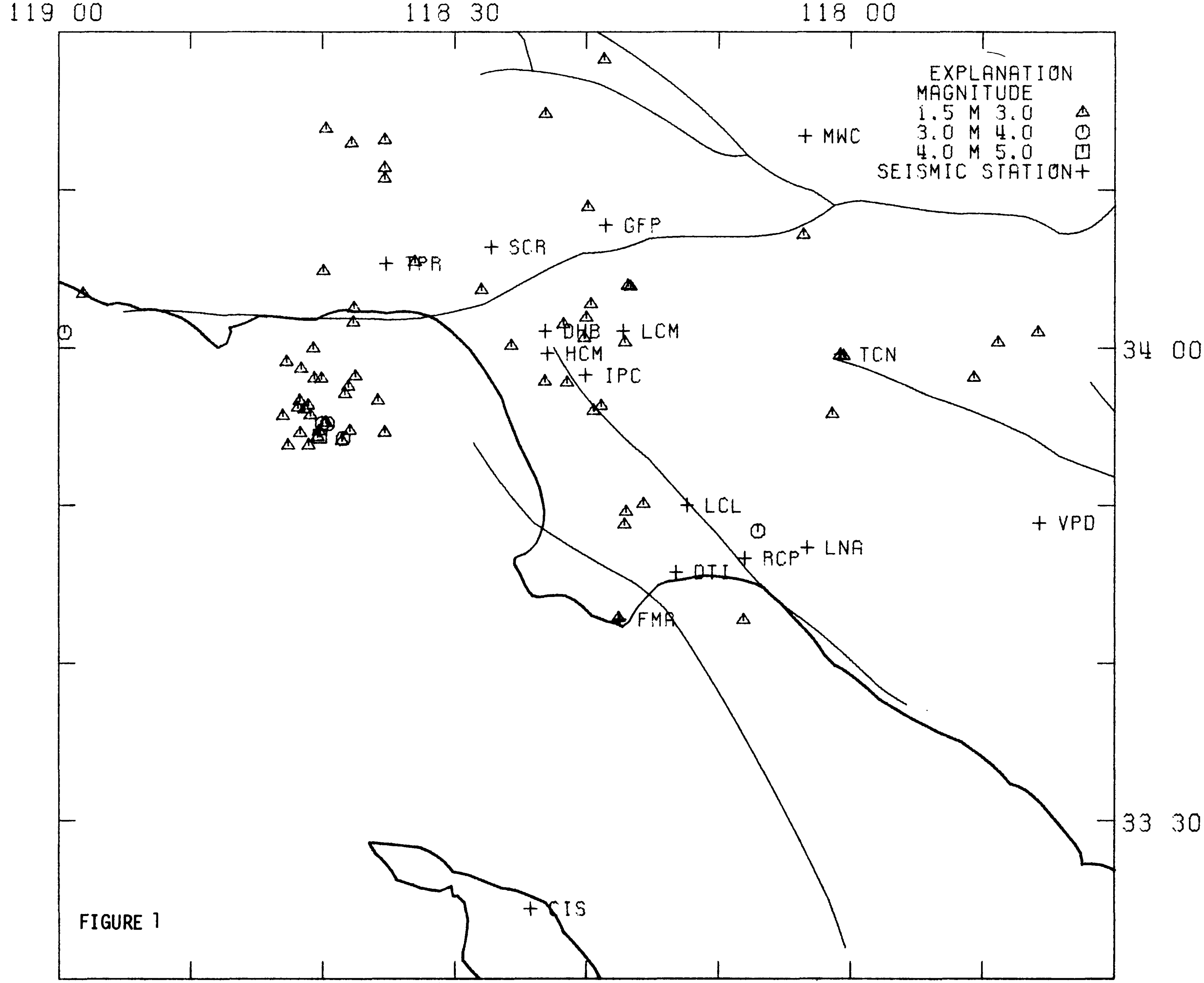
Continued microseismicity monitoring of the greater Los Angeles Basin has two principal objectives:

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.

Epicentral locations of $M > 1.5$ in the greater Los Angeles area between October 1, 1979 and March 31, 1980 are shown in Figure 1. Aftershocks of the January 1, 1979 Malibu earthquake are conspicuous in Santa Monica Bay (this included an M=4.2 event on October 17, 1979). There were several events in the Baldwin Hills area during this period. These events were generally deep (> 10 km) and below producing zones.



SEISMICITY OCT. 79--MAR. 80

Earthquake Data-Base Studies
9950-02092

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Investigations

1. Design master U.S. earthquake data set and catalog, consistent with current data-base management system (DBMS) philosophy

2. Compile earthquake catalogs for the United States for entry into the data-base as a prototype master catalog

3. Compile and evaluate published focal mechanisms and in-situ stress measurements for North America

4. Investigate the effects on the completeness of the earthquake catalog as a result of changing network detection thresholds

Results

The principal accomplishment of this reporting period was the completion of preliminary evaluations of the detection and location capabilities of seismic networks in the southeastern United States. A modified version of NETWORTH, a computer code used in evaluating capabilities for seismic event detection at teleseismic distances, was used to calculate 90 percent detection threshold magnitudes for five or more stations and 90 percent confidence ellipses for magnitudes m_b=2.0, 3.0, and 4.0. A signal-to-noise ratio of 2.0 and nominal noise value of 20 nm were assumed for all southeastern U.S. stations operating on January 1, 1980.

The map of five-station detection threshold magnitude (fig. 1) demonstrate that the current detection capability is good, as expected, in or near places where local and regional seismic networks are established; namely, the Central Mississippi Valley, central Virginia, and Charleston, South Carolina. Figures 2, 3, and 4 demonstrate that the location capability, as shown by the size of the 90 percent confidence ellipses, deteriorates along the Gulf coast and off the Atlantic coast, even at magnitude m_b=4.0. Magnitude m_b=2.0 events are located reliably within local or regional networks only.

These results suggest that the installation of a modest number of single stations could improve both the detection and location capabilities of southeastern U.S. networks dramatically. Possible sites in central Kentucky and Tennessee, central and eastern North Carolina, and northern Mississippi would particularly improve the detection capability for earthquakes in the southern Appalachian seismic zone. Although the seismicity in the Gulf coastal region is low, potentially informative earthquakes probably go undetected below m_b=2.5 with current network configurations.

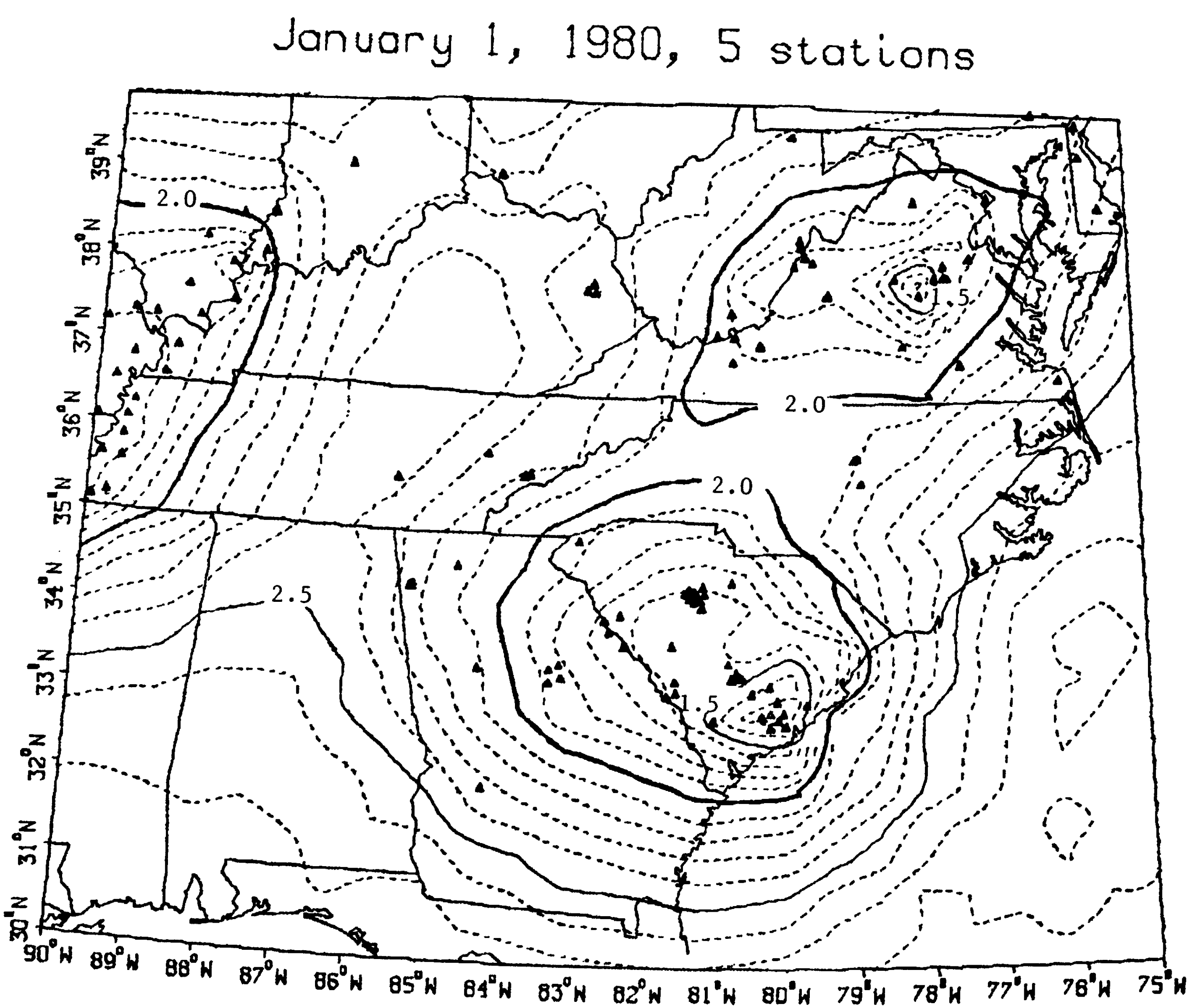

Figure 1.—90-percent detection threshold m_b magnitudes for five or more detections by stations in the southeastern United States (small triangles) operating on January 1, 1980.

January 1, 1980, mb = 2.0

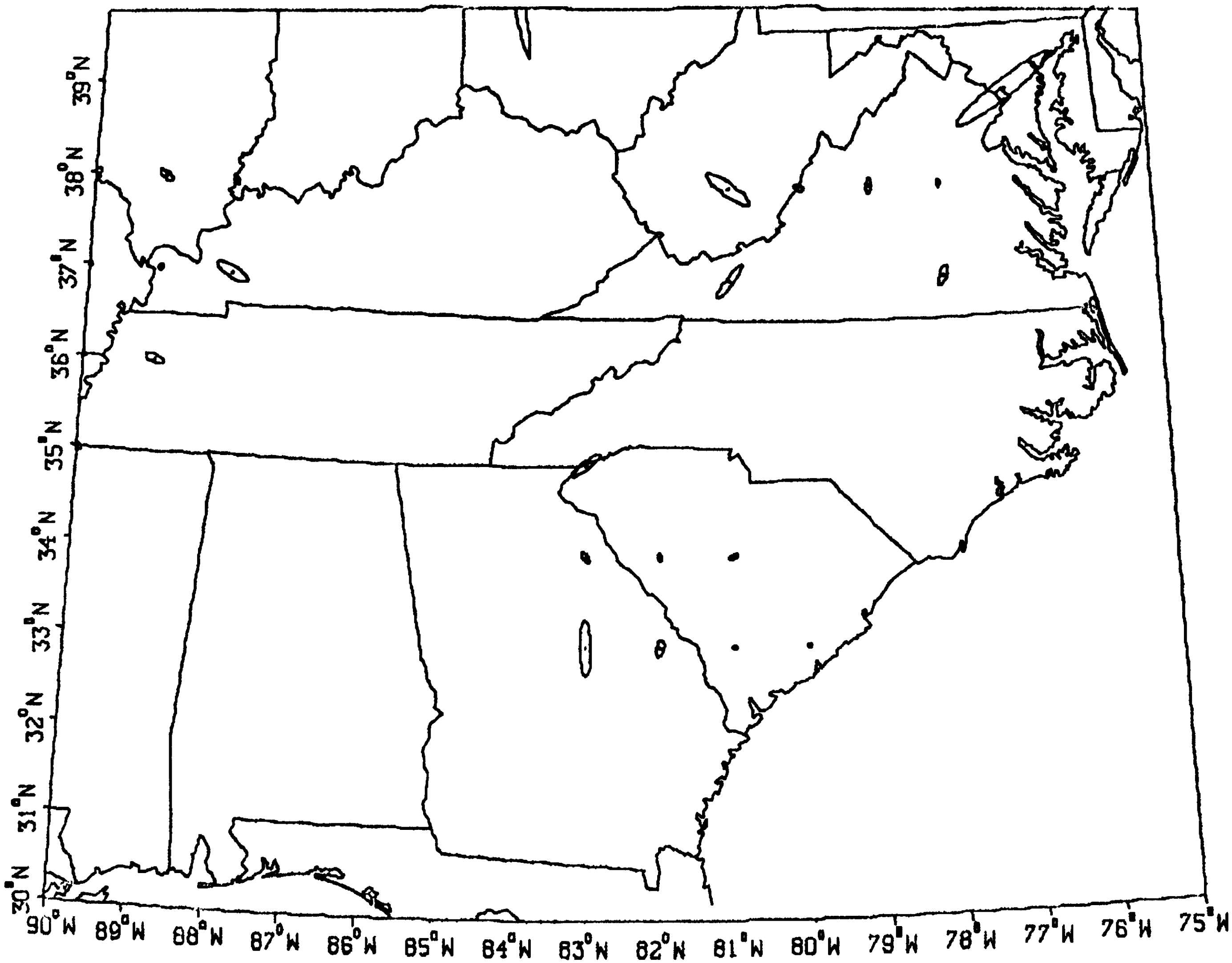

Figure 2.--90-percent confidence ellipses for m_b=2.0 events detected by five or more stations on January 1, 1980. No ellipse is plotted when the semi-major axis is greater than 100 km, when the 95-percent confidence interval on depth is greater than 100 km, or fewer than five stations detect at a probability level of 0.90.

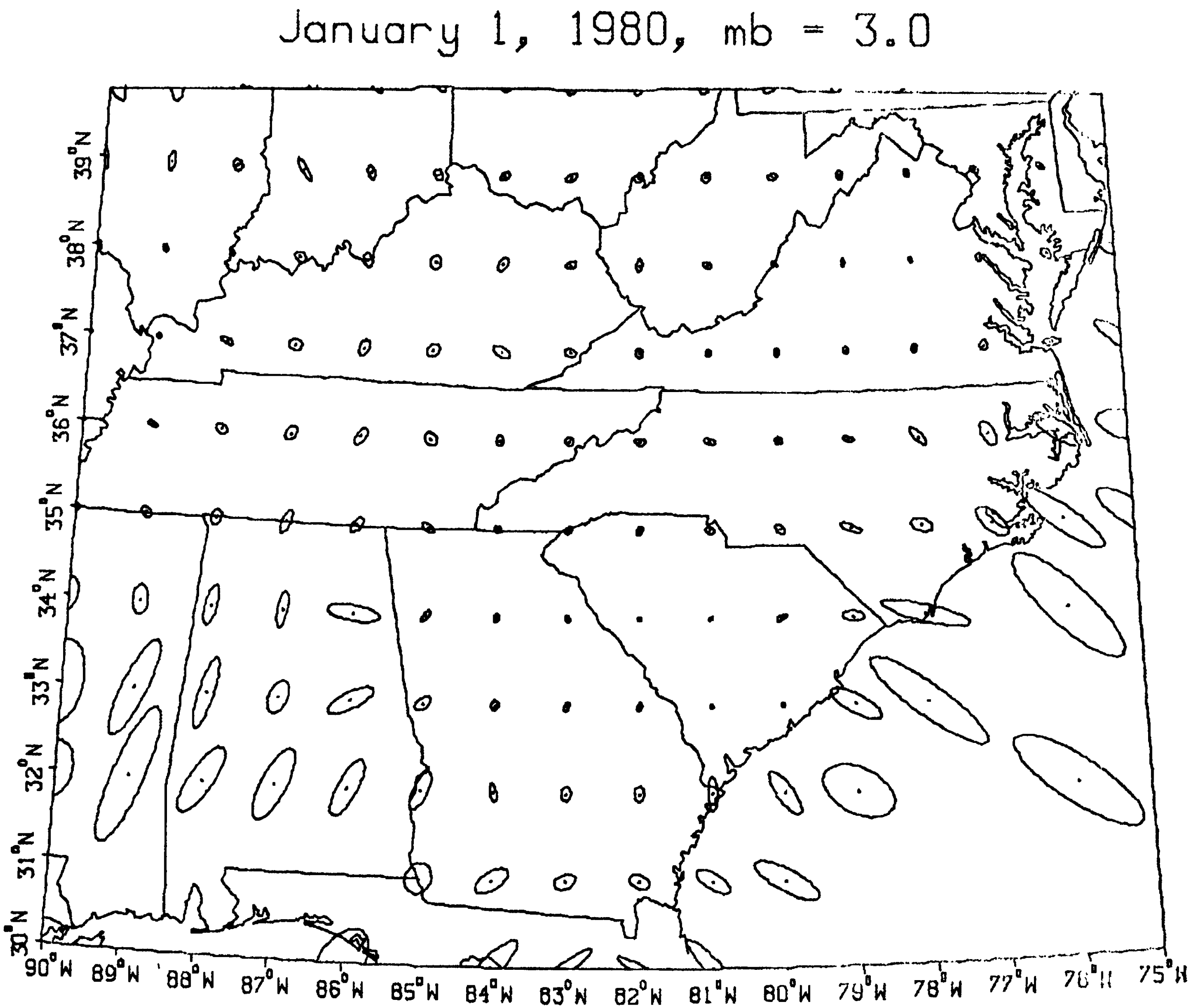

Figure 3.--90-percent confidence ellipses for m_b=3.0 events detected by five or more stations on January 1, 1980. No ellipse is plotted when the semi-major axis is greater than 100 km, when the 95-percent confidence interval on depth is greater than 100 km, or fewer than five stations detect at a probability level of 0.90.

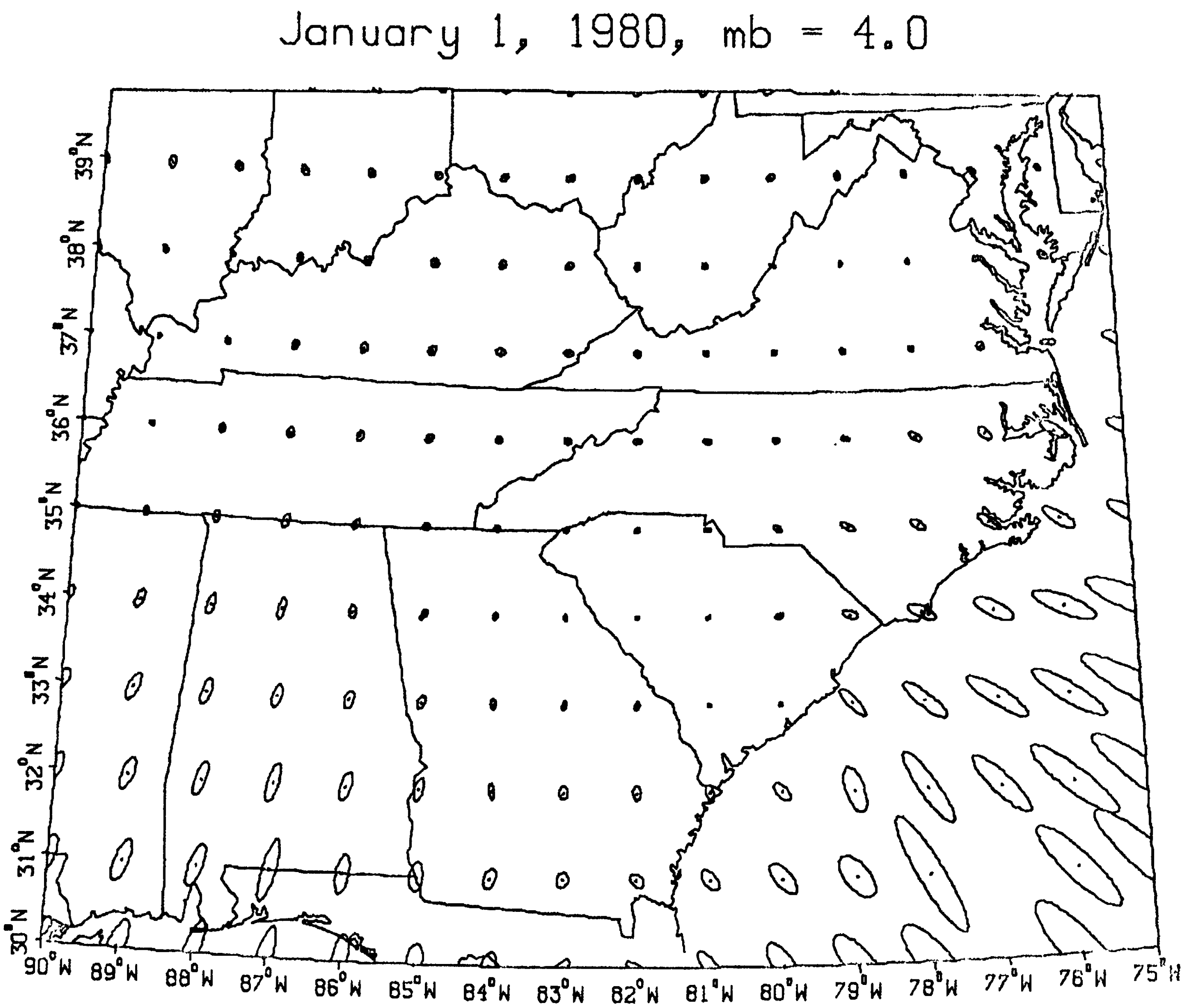

Figure 4.--90-percent confidence ellipses for m_b=4.0 events detected by five or more stations on January 1, 1980. No ellipse is plotted when the semi-major axis is greater than 100 km, when the 95-percent confidence interval on depth is greater than 100 km, or fewer than five stations detect at a probability level of 0.90.

Preparation of Isoseismal Maps and Summaries of Reported Effects for Pre-1900 California Earthquakes
Contract No. 14-08-0001-18243

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(916-322-9309)

Information was obtained for the 13 earthquakes added in the current grant and for 19 significant earthquakes not included in the proposal. Additional information was also obtained for the earthquakes studied in the previous grant year. More than four thousand additional newspaper issues were searched for earthquake reports, bringing the total number of issues examined to more than eleven thousand. About one quarter of the issues searched provided earthquake reports. Summaries of these reports, emphasizing the information used to assign earthquake intensities, are being prepared.

The reported earthquake effects were converted into values of earthquake intensity, and isoseismal maps were sketched for the earthquakes. Epicenters and magnitudes were estimated from the distribution and extent of the isoseismal areas. A table and an epicenter map of the earthquakes added this year are provided. Epicenters were plotted using a symbol of size proportional to magnitude. When it was not possible to estimate a magnitude, the numerical value of maximum reported intensity was plotted at the assumed epicenter. Earthquakes of magnitude 6 or greater were added on the San Andreas system, on the eastern flank of the Sierra Nevada, and near Cape Mendocino. The table includes epicentral coordinates and maximum reported intensity and the areas shaken at various intensity levels. A separate estimate of magnitude was derived from each of the isoseismal areas (Toppozada, 1975) as well as from the maximum reported intensity (Gutenberg and Richter, 1956), and the mean of these magnitudes was assigned to the earthquake. The parameters of all the earthquakes will be reviewed in light of the available data before the annual report.

In the closing decade of the nineteenth century 4 earthquakes $M>6$ occurred on or near the San Andreas fault system north of San Francisco, 2 in 1892 and 2 in 1898. Other earthquakes of this size have not occurred north of San Francisco and south of Cape Mendocino since 1850. This might be premonitory to great earthquakes on the northern San Andreas fault. This observation was reported at the Seismological Society of America meeting in a paper summarizing the salient features of pre-1900 California seismicity (Toppozada et al., 1979).

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Toppozada, T.R. (1975). Earthquake magnitude as a function of intensity data in California and western Nevada. Bull. Seism. Soc. Am. 65, 1223-1238.

Toppozada, T.R., Real, C.R., Bezore, S.P., and Parke, D.L. The seismicity of California before 1900 (Abstract) Earthquake Notes 49, No.4, 86-87.

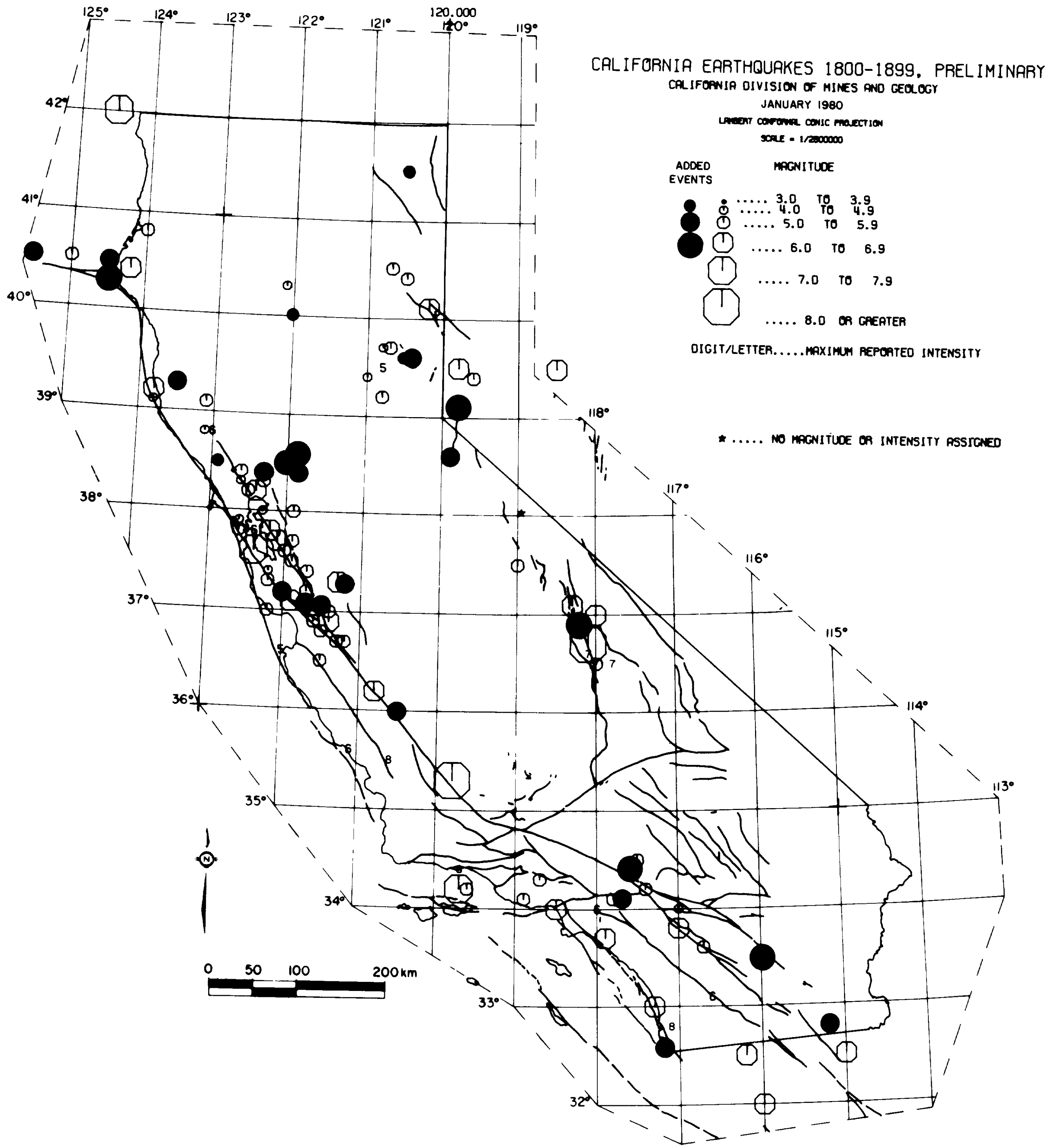
CALIFORNIA EARTHQUAKES 1800-1899, PRELIMINARY
CALIFORNIA DIVISION OF MINES AND GEOLOGY
JANUARY 1980
LAMBERT CONFORMAL CONIC PROJECTION
SCALE = 1/2800000
ADDED EVENTS
MAGNITUDE
..... 3.0 TO 3.9
..... 4.0 TO 4.9
..... 5.0 TO 5.9
..... 6.0 TO 6.9
..... 7.0 TO 7.9
..... 8.0 OR GREATER
DIGIT/LETTER.....MAXIMUM REPORTED INTENSITY
* ..... NO MAGNITUDE OR INTENSITY ASSIGNED
0 50 100 200 km
120.000
125°
124°
123°
122°
121°
120°
119°
118°
117°
116°
115°
114°
113°
42°
41°
40°
39°
38°
37°
36°
35°
34°
33°
32°

TABLE 1. PARAMETERS OF EARTHQUAKES ADDED IN 1979-80

Date			Time (GMT)	Lat. °N	Long. °W	I_{max}	M_I	A_{II}^{**}	M_{II}^{**}	A_V	M_V	A_{VI}	M_{VI}	A_{VII}	M_{VII}	A_{VIII}	M_{VIII}	Mean Mag.
26?	Oct.	1852	-----	-----	-----													±
*16	Dec.	1858	10:00	34.4	117.6	8	6.3			22	5.6							6.0
27	May	1862	20:00	32.6	117.2	7	5.7	75	5.6	20	5.6							5.6
*21	May	1864	2:01	38.4	122.3	6	5.0	50	5.3	14	5.4							5.2
24	May	1865	11:21	37.1	121.7	6	5.0			7.5	5.0							5.0
26	Mar.	1866	20:12	37.1	121.5	7	5.7	110	5.8	43	5.9							5.8
*15	July	1866	6:30	37.3	121.2	5	4.3†	130	5.9	15	5.4							5.7
	May	1868	-----	-----	-----													±
4-17	Sep.	1868	-----	-----	-----													±
*17	Sep.	1868	16:55	38.6	119.8	6	5.0	40	5.1									5.1
21	Dec.	1869	4:00	39.6	120.5	6	5.0	27	4.9	4.5	4.8							4.9
*17	Feb.	1870	20:12	37.2	122.0	7	5.7	82	5.6	13	5.3	1.6	5.3					5.5
		1871	-----	-----	-----													±
*26	Mar.	1872	14:06	36.9	118.2	5	4.3†	400	6.7									6.7
*28	Mar.	1872	13:00	39.6	120.4	6	5.0	48	5.3									5.2
3	Apr.	1872	-----	-----	-----													±
* 3	Apr.	1872	12:15	36.9	118.2	5	4.3†	270	6.4									6.4
* 3	May	1872	1:00	32.8	115.2	6	5.0†	150	6.0			6.6	5.8					5.9
*30	Sep.	1875	12:30	40.5	125.5	7	5.7			27	5.7			0.86	6.0			5.8
3	Jan.	1876	-----	-----	-----													±
29	May	1876	18:55	38.5	122.9	6	5.0	6.6	4.0	1.1	4.2							4.4
* 9	May	1878	4:25	40.3	124.5	8	6.3	150	6.0	33	5.8	6.9	5.8					6.0
* 7	Jan.	1881	2:25	40.0	122.0	5	4.3	16	4.6	3.0	4.7							4.5
* 2	Feb.	1881	0:11	36.0	120.5	7	5.7	68	5.5									5.6
* 3	June	1887	10:48	39.1	119.8	8	6.3			87	6.2	25	6.3	2.6	6.5			6.3
* 3	Dec.	1887	18:55	39.3	123.5	7	5.7			6.5	5.0	0.8	5.0					5.2
*14	Apr.	1888	3:30	41.5	120.5	6	5.0			2.3	4.5							4.8
19	Apr.	1892	10:50	38.5	122.0	9	7.0			150	6.5	29	6.4	8.5	6.9	1.4	7.0	6.8
21	Apr.	1892	17:43	38.6	121.9	8-9	6.7	160	6.1	60	6.1	13	6.1	3.8	6.6			6.3
30	Apr.	1892	0:09	38.4	121.9	6	5.0	42	5.0	5.0	4.9							5.0
*28	May	1892	13:30	33.5	116.0	5-6	4.7†			65	6.1							6.1
*14	June	1892	11:15	34.1	117.7	5-6	4.7†	82	5.6	17	5.5							5.6
*30	Sep.	1894	17:36	40.5	124.5	7	5.7	87	5.7	9.2	5.2							5.5

** Area in 1000 km^2 shaken at the intensity indicated or at higher intensities, followed by magnitude estimated from this area.
± No parameters available.
* Additional earthquakes, not included in the proposal.
† Estimate was not used in computing the mean magnitude.

H1

SEISMIC RISK IN THE ASSAM GAP

Contract No. 14-08-0001-16841

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The Himalaya form a clearly defined arcuate zone of plate consumption along which the Indian and Asian Plates collide at a rate of about 5 cm/year. In the eastern part of this plate boundary a 500 km segment, lying between the epicenters of the great 1897 and 1950 earthquakes, is considered to be a seismic gap. A three station seismograph network with a diameter of about 100 km was operated in the western part of the Assam gap for 5 months during 1979. The main purpose of this pilot program was to determine whether high quality seismograms for earthquake prediction research could be obtained in this area.

It was found that the general area is seismically fairly active. On the average, 20 local earthquakes per day were recorded. Their coda duration times varied between 5 and 200 seconds, with most events having a signal duration length of around 80 seconds. Approximately 25% of these events could be located within the three-station network. The seismograph data from Shillong turned out to be of limited use, because few of these events are recorded there, due to the relatively low frequency (1 cps) response of the WWSSN seismographs.

Out of 425 station-days recording time 87 station-days were lost due to various reasons. This shows that seismic networks can be operated in the Assam area with a down-time of about 20%. With a ten station network, one would thus expect 8 stations to run coincidentally. To date, 124 earthquakes have been located. Several hundred events are in the process of being analysed.

At present a six station network is being installed in the Assam area under a contract funded by the U.S. Geological Survey to continue the work reported here. Several other Indian institutions carry out geophysical research in the area as an integral part of a national effort to evaluate the seismic risk in the region. It is concluded that the U.S.G.S. funded study of the seismicity and physics of the earthquake source properties and other factors, which would make a fundamental contribution to the assessment of the earthquake risk in the Assam gap, can be carried out successfully and that this will constitute an important part of the larger overall project.

Regional and National Seismic Hazard and Risk Assessment

9950-01207

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Investigations

1. Sought to improve speed and accuracy in the map production version of the hazard program and increase the long-return period capability of a research version and investigated the problem of long term hazard assessment.

2. Improved methods of B-value determination, including ways of correcting for bias in grouped data (when using Page or Aki maximum likelihood formulations).

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

4. Investigated relationship between average return periods obtained from analysis of historical seismicity data and return periods developed from field investigations of fault slip.

5. Investigated methods of presenting seismicity data that would be more useful than epicenter maps in delineating seismic sources zones.

6. Investigated means of producing and analyzing Weibull earthquake sequences and the statistics of regions composed of several independent or contagious subzones.

7. Investigated various techniques for allocating future seismicity to various subzones which have historically experienced only a very few earthquakes.

8. Began improvement in speed and accuracy of liquefaction opportunity hazard mapping programs.

Results

1. Developed a production version of the risk mapping program which runs four times faster than the program used to produce the 1976 U.S. map. The research version of the program produces accurate assessment of long return period ground motion than previously possible. Both programs no longer depend upon grid size for accuracy. A report to be published as a U.S.G.S. Circular "Some Aspects of the Seismic Hazard Associated with Radioactive Waste Disposal" by S. T. Algermissen has been completed, received technical reviews and awaits Director's approval.

2. Developed a new maximum likelihood technique for B-values of grouped data. This technique more accurately reproduces the B-value of the underlying continuous process. (This formulation appears identical to one previously proposed by Karnik.) Perkins' minimum chi-squared B-value formulation was improved by placing it in a self-converging process.

3. Geological and geophysical data pertinent to the delineation of seismic source zones and earthquake distributions were discussed at meetings in Golden with Survey and other geologists and geophysicists. Meetings were held to discuss the northern Rocky Mountains (December 6-7, 1979), and the Southern Rocky Mountains (January 23-24, 1980). Summary reports are available for all of these meetings which include suggestions for the delineation of seismic source zones based on seismotectonics data and relative rates of earthquake activity for each of the suggested source zones.

4. Earthquake recurrence rates derived from geologic investigations of fault scarps in Nevada (Wallace, project no. 9900-01270) and Utah (Bucknam, project no. 9950-01738; Anderson, project no. 9950-01538) were found to agree remarkably well with recurrence rates obtained from historical seismicity data, except along the Wasatch fault where geological data indicate an average recurrence interval for magnitude 7-7.5 earthquakes of the order of 350-400 years. A recurrence interval extrapolated from a rather poor historical seismicity sample indicates much longer recurrence intervals of the order of 1400 years. Combining the historical seismicity and geologic data to obtain a composite magnitude distribution for hazard calculations results in an increase of acceleration of about three times over that computed for the 1976 U.S. acceleration map. It has also been found, with the exception of the Wasatch fault, that areas in Utah where respectively, no late Quaternary or younger faulting is found, late Quaternary faulting but no Holocene faulting is present and areas of Holocene faulting correspond approximately to different levels of historical seismicity. Areas with no late Quaternary or younger faulting have the lowest historical seismicity, etc. A paper "Late Quaternary Faulting in Western Utah and its Implications in Hazard Evaluation" by R. C. Bucknam, S. T. Algermissen and R. E. Anderson has been completed and will be submitted to the Bulletin of the Seismological Society of America after technical review.

5. A number of maps have been prepared for the Basin and Range province to show total strain energy release (as equivalent numbers of magnitude 4 earthquakes) for various time intervals of historical seismicity. These maps have been very useful as an aid in delineating seismic source zones and may lead to an improved method of estimating seismic activity.

6. Mixed independent or contagious Weibull processes produce nearly Poisson statistics for relatively small numbers of constituent Weibull subzones.

7. A maximum likelihood allocation scheme for earthquakes into seismic source zones produces a delightfully simple result. Like a number of other procedures we have used, this allocation is consistent when extrapolated to an infinitely large amount of historical data. However, for small samples, the allocation scheme is simply proportional to the total number of earthquakes observed in each subzone--regardless of size.

8. A simple correction makes the old Perkins-Bender liquefaction opportunity computer program give answers within 10 percent of a new, experimental program based upon the procedures of the new production ground motion hazard (risk) program.

Reports

Perkins, D. M., Thenhaus, P. C., Houson, S. L., Ziony, J., and Algermissen, S. T., 1980, Probabilistic estimates of maximum seismic horizontal ground motion on rock in the Pacific northwest and the adjacent outer continental shelf, U.S. Geological Survey Open-File Report 80-471, 39 p. with maps.

Steinbrugge, K. V., Lagorio, H. J., and Algermissen, S. T., 1980, Earthquake insurance and microzoned geologic hazards: United States practice, Proceedings 7th World Conference on Earthquake Engineering (in press).

Steinbrugge, K. V., Shader, E. E., and Algermissen, S. T., 1980, Mobile homes and earthquake damage in California: Report of the California Seismic Safety Commission (in press).

Seismic Wave Attenuation in Conterminous United States

9950-01205

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Investigations

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

2. Continuation of regional compilation of seismograms for selected events in the United States, to be used in the regional seismic-wave attenuation, is in progress.

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

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

5. Data analysis of the strong-motion recordings of the Imperial Valley earthquake of October 15, 1979, at 30 U.S. Geological Survey accelerograph stations and 7 Mexican accelerograph stations is in progress.

Results

1. An empirical seismic moment, M_0, scaling law has been derived, using the strong-motion accelerograms of the 67 most significant Western United States earthquakes. M_0 determined at regional distances, from strong-motion records, is in fairly good agreement with those M_0 determinations from P, S, or Surface-wave spectra estimates, and/or from seismic moment field determinations.

2. An empirical magnitude scaling law (M_L) using the maximum horizontal accelerations as a function of distance has been derived and tested, and is being published. The derivation of this empirical magnitude scaling law for the Western United States partly fulfills the objectives of determining regional attenuation curves for conterminous United States.

3. The anelastic Q distribution for L_g-waves in conterminous United States have been mapped. The overall Q contour lines for L_g-waves are in fair agreement with the variations of crustal thickness and mean crustal velocities compiled by Pakiser and Steinhart. Low Q-values have been found in areas where high-heat flow has been reported (Smith; Zoback and other investigators). Also, low Q-values for regions where low-Q have been reported for P_g-waves (Hill) have been verified by our results.

4. On a regional basis, the absorption coefficient for L_g-waves correlates fairly well with the general tectonic of the region.

5. The absorption coeffcient determined for the New England region is 0.001/km. Fifty events recorded at distances of about 20 km to 400 km were used in this study, in the magnitude range of 1.8 to 3.2.

Reports

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

Research Applications

9900-90027

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Investigations

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

Results

1. The Office of Earthquake Studies is continuing to contribute to the activities of the Interagency Committee on Seismic Safety in Construction, formed in December 1978. One draft report dealing with tsunamis and flood waves has been prepared. Another draft report dealing with procedures for evaluating site hazards is in progress.

2. The Office of Earthquake Studies will co-sponsor the 1980 Summer Institute on Multiprotection Design along with FEMA, NSF, and DOE. This year, the institute will address flood mitigation and environmental engineering (July 28-August 1), wind engineering and energy conservation/management (August 4-8), and building firesafety and earthquake hazards (August 11-15). The institute is held at the FEMA Staff College, Battle Creek, Michigan.

3. USGS and five co-sponsors: California Division of Mines and Geology, California Office of Emergency Services, California Seismic Safety Commission, City of Los Angeles, and Federal Emergency Management Agency convened a conference on "Earthquake Prediction Information" in Los Angeles on January 28-30, 1980. The conference was attended by more than 100 participants who discussed constructive responses that might be taken through broad-cooperative community participation before and after an actual prediction of an earthquake.

4. Fifteen hundred copies of USGS Circular 816, "Program and Plans of the U.S. Geological Survey for Producing Information Needed in National Seismic Hazards and Risk Assessment, FY 80-84" were distributed to Federal, State, academic and private sector representatives.

5. A conference on, "Evaluation of Regional Seismic Hazards and Risk" is planned for Santa Fe, New Mexico, August 25-27, 1980. One objective is to introduce an improved ground-shaking hazard map.

6. USGS participated in a special conference on "Earthquake Hazards, Risks, and Losses" at the March, 1980, meeting of the Property Loss Research Bureau, San Francisco, California.

Results

1. Hays, W. W., 1980, Evaluation of earthquake hazards and risk, Proceedings of Conference on Earthquake Hazards, Risks, and Losses, San Francisco, California, Property Loss Research Bureau (in press).

2. Hays, W. W. (editor), 1980, Earthquake prediction information, Proceedings of Conference XIII, Los Angeles, California, U.S. Geological Survey Open-File Report (in press).

Seismogenic Zones of the United States

9950-01849

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Investigations

Conducted seismic zoning meetings for the Great Basin, Northern Rocky Mountain area, and Southern Rocky Mountain area.

Results

Three meetings were held lasting about one and a half days each to prepare maps of western United States showing zones that represent relative homogenity with respect to young faulting. Rates of the occurrence of earthquakes of magnitude 7 or greater and maximum magnitudes were assigned to each zone. The maps, which are based on geologic, geophysical, as well as seismological information, are now being integrated with historic seismic information to produce the zone maps upon which a new National probabilistic ground motion map will be based. A satisfying result of the integration of data is that the rates of earthquake activity determined independently from geologic data and seismologic data agree. This agreement lends credence to the seismic zoning method being used.

A total of 11 non-Survey and 21 Survey geologists, geophysicists, and seismologists with expert knowledge of the various regions participated in the meetings. Their information, thoughtful opinions, and cooperative spirit contributed immensely to the final results. In addition to the preparation of state-of-the-art seismic zone maps, the meetings made everyone aware of some of the very large gaps in our knowledge of the relationship of earthquakes to tectonics and even young faults. Some of the gaps can be filled fairly quickly; others will take considerable time.

Neotectonic Synthesis of U.S.

9540-02191

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(Work carried out in cooperation with 9950-01849, Seismogenic Zones of the United States)

Investigations

1. A manuscript is well underway that argues the existence of a reverse-fault domain along the Atlantic margin of the continent that is characterized by northwest-southeast compression and is responsible for the MMX Charleston earthquake of 1886. Writing has led to further consideration of Charleston and North Anna seismicity in the context of the Atlantic Coast domain, the frequency of damaging earthquakes, and the consistency of this frequency with fault histories.

2. Digital terrain maps of the eastern third of the country (at 1:2,500,000, CI = 50 m, 3 minute file) and northern California (1:1,000,000, CI = 150 m, 1/2 minute file) were defined and obtained from R. Godson and M. Kane. Preliminary study suggests promising lines of inquiry relative to Cenozoic tectonics and modern seismicity.

3. The Atlantic-coast structure-contour maps were largely completed, although problems remain in extracting the most appropriate information from the available offshore data. Piedmont topography is being generalized to extend the basement surface westward from beneath the Coastal Plain. Suggestions of increased Eocene tectonism led to examination of the subsidence history of the shelf edge from COST well data.

4. Work was begun on a statistical evaluation of the usefulness of certain geomorphic parameters in determining the presence and rates of differential vertical movements. This involves the measuring of such parameters as slope, relief, shape, and trunk-stream length for 50-100 drainage basins adjacent to mountain fronts where independent evidence of recent uplift history is available. The relationship between the variables will then be examined statistically.

5. Work on the 8 neotectonic contracts and the companion work by S. Colman and M. Machette in Colorado and New Mexico is progressing well.

Results

1. Available data require the hypothesis that a broad domain of northeast-striking reverse faults extend along the Atlantic continental margin from Georgia to Canada. For the most part these faults probably follow older discontinuities, particularly early Mesozoic extensional faults. Their full spatial distribution is unknown: they probably have spacings of 20 to perhaps 50 km, are known to be present along the fall line in the southeast, and probably extend at least throughout most of the Piedmont and Coastal Plain (and northeastward equivalents). For the past 100 MY they have undergone sporadic reverse movements, but with cumulation offsets across individual faults on the order of only 100 m. The better studied modern earthquakes are consistent with this geometry (Trenton, South Carolina 1976; North Anna, Virginia microearthquakes, 1974-76; Delaware, New Jersey, 1973; Ramapo, New Jersey-New York microearthquakes, 1962-77).

Available evidence permits Charleston, South Carolina seismicity at least to be consistent with northwest-southeast compression in the Atlantic Coast domain. Recent discovery of the northeast-striking Cooke fault in the 1886 meizoseismal area (Behrendt, Hamilton, and Ackermann, 1980) makes the case much stronger. This fault system shows progressive offset in the Cretaceous and early Tertiary, has a cumulative offset of only 50 m, and is geometrically consistent with the spatial distribution of many of the recent microearthquakes.

If the Charleston and 1755 Cape Ann, Massachusetts, earthquakes are taken as the major historic events in the Atlantic Coast domain in the U.S. since 1700, the frequency of such earthquakes is about 10^{-5} per year per 10^3 km^2. The consistency of this frequency with the geologic evidence of only 100 m of offset in 100 million years on individual faults can be crudely tested if an appropriate size and distribution for individual source areas can be determined, assuming that all offset results from Charleston-type events. As a limit, a fault length of 30 km from western U.S. data can be combined with an estimated average spacing of faults throughout the domain of 35 km. The result is an average fault offset per event 0.1 m. This is about an order of magnitude too small for magnitude 7 events, based on western U.S. data, suggesting that for a given size of fault events eastern earthquakes may be more energetic than western ones. One implication of this argument is that Charleston-type events could occur anywhere in the Atlantic Coast domain, with a frequency not substantially lower than that for damaging earthquakes in many parts of the west.

2. Preparation of absolute subsidence curves for the COST wells GE-1 off Georgia and B-2 and 3 off New Jersey indicate episodic shelf subsidence even after removal of an extreme correction for sediment loading. Periods of more rapid subsidence in the late Cenozoic, Eocene, and possibly Santonian-Coniacian are separated by periods of slower subsidence, or even slight positive movements. The great distance between the two areas of control implies that the histories represent a general behavior of the continental margin. Causal implications are uncertain, but seem to exclude simple crustal cooling.

3. A digital terrain map of the eastern U.S. at 1:2,500,000 shows several very large features of possible neotectonic significance, as well as much

finer structure. The Appalachian highland, for example, extends from Alabama to Maine with a nearly constant width of about 225 ± 25 km. Neither the southeast nor northwest borders appear to follow known geologic features for any significant distance. A strong north-south grain in New England interferes with the northeast Appalachian grain there, and extends westward through the Catskills to at least Indiana. An extension of the St. Lawrence lineament carries at least as far southwest as Indiana as well. Tantalizing relations of these and other features to some Triassic faults and Cenozoic structures and to historic seismicity suggest merit in further inquiry.

Reports

Wentworth, C. M., 1980, The tectonic and geologic setting of the June 12, 1978 Miyagi-Ken-oki earthquake, Japan, _in_ Ellingwood, Bruce, ed., An investigation of the Miyagi-Ken-oki, Japan earthquake of June 12, 1978; United States-Japan Cooperative Program in Natural Resources (UJNR), Panel for Wind and Seismic Effects, Special Report, 22 p. ms in press.

Southwestern Utah Seismotectonic Studies

9950-01738

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Investigations

1. An exposure was excavated near Cove Fort, Utah, allowing for detailed study and mapping of faulted tephra-bearing Pleistocene strata.

2. Detailed field study of the distributions, trends, and relative ages of late Cenozoic mafic dikes along the west margin of the Markagunt Plateau northeast of Cedar City, Utah.

3. Systematic collection and compilation of data pertaining to slip directions on faults and fractures in southwestern Utah.

4. Field measurement of profiles on fault scarps formed on Quaternary alluvium in Dry Lake Valley and Kane Spring Wash, Lincoln County, Nevada.

5. Organized, chaired, and summarized the results of a two-day workshop conducted for the purpose of developing a seismogenic zone map for New Mexico and adjacent parts of Colorado, Texas, and Arizona.

6. Coorganized, cochaired, and contributed two oral presentations to a 3-day Division-sponsored workshop on the tectonics of the Central Region.

Results

1. Strata in the upthrown block of the eastern boundary fault of the Cove Fort graben include highly deformed clastic rocks of probable Oligocene age overlain unconformably by about 15 m of subhorizontal mid-Pleistocene clastic strata that contain two beds of tephra (Bishop and Ranch Canyon tephra). Excavations in the downthrown block exposed approximately 18 m of subhorizontal clastic strata that lack tephra and do not appear to correlate with any strata in the upthrown block. The strata of the downthrown block were probably deposited contemporaneous with faulting, are of late Pleistocene age, and are younger than those in the upthrown block. A minimum of 18-20 m of late Pleistocene normal stratigraphic separation is indicated.

2. Subhorizontal to gently dipping early Tertiary strata at the west edge of the Colorado Plateaus (Markagunt Plateau) 40 km northeast of Cedar City are intruded by two previously unmapped systems of steep late Cenozoic mafic dikes--an early system of at least 25 north-trending dikes and a late system of at least 4 northeast-trending dikes. The dike rocks were sampled and submitted for K-Ar analysis. If reliable ages are obtained, they will constrain the age of clockwise rotation of least principal stress in this area. The data can then be compared with other widespread evidence for late Cenozoic clockwise rotation of the late Cenozoic stress field.

3. Surprising and unexplainable results have been obtained from a systematic collection and compilation of data pertaining to slip directions on faults and fractures in southwestern Utah. Careful study of four localities and reconnaissance study of several others indicate that a widespread predominant mode of strike-slip displacement has occurred on most steep faults and fractures that trend north and north-northeast. Studies of structures with variable attitudes indicate gently plunging kinematic vectors oriented NE-SW, consistent with the slip data from the steep northerly trending structures. Together the data suggest a major widespread episode of predominantly lateral tectonic transport of late Cenozoic age. The data probably represent the youngest displacement event on the structures. The data are very inconsistent with the inferred neotectonic stress regime which is supposed to be extensional in nature and oriented WNW-ESE. A high priority is given to future studies that will attempt to resolve the inconsistency.

4. Twenty-five profiles across the 45 km-long north-trending fault scarp in Dry Lake Valley, Lincoln County, Nev., yield a regression equation of scarp height on maximum scarp slope angle of $\gamma = 5.99 + 15.2x$ with a standard deviation of γ about the line of 1.94. These data, when compared with regression lines from other scarps, indicate a latest Pleistocene age for the Dry Lake fault scarp--possibly 15-20 thousand years old.

Reports

Anderson, R. E., 1980, Notes on the Cenozoic structural history of the Tunnel Spring Mountains area, western Millard County, Utah: U.S. Geological Survey Open-File Report 80-237, 24 p.

Anderson, R. E., and Mehnert, H. H., 1979, The Hurricane fault in Utah as a predominantly Quaternary structure [abs.]: Geological Society of America, Abstracts with Programs, v. 11, no. 3, p. 66.

______ 1979, Reinterpretation of the history of the Hurricane fault in Utah, in Newman, G. W., and Goode, H. D., eds., 1979 Basin and Range Symposium and Great Basin Field Conference: 1979 Basin and Range Symposium, Rocky Mountain Association of Geologists - Utah Geological Association, p. 145-165.

Bucknam, R. C., Algermissen, S. T., and Anderson, R. E., 1979, Late Quaternary faulting in western Utah and its implications in earthquake hazard evaluation [abs.]: Geological Society of America, Abstracts with Programs, v. 11, no. 3, p. 71-72.

Bucknam, R. C., and Anderson, R. E., 1979, Estimation of fault-scarp ages from a scarp-height-slope-angle relationship: Geology, v. 7, no. 1, p. 11-14.

Seismic Hazards of the Hilo 7 1/2' Quadrangle

9550-02430

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Investigations

Investigations consist of geologic mapping and studies of saprolite and ash deposits leading to an analysis of seismic hazards in the Hilo 7 1/2' quadrangle.

Results

The ash deposits in the Hilo area are generally believed to be an eruptive product of Mauna Kea volcano while the saprolite is developed on ancient flows from the same volcano. Locally along the Wailuku River, two separate saprolites can be recognized. The older (lower) saprolite has no capping ash. Where the younger saprolite has been mapped within the Wailuku River drainage and north of it, it is everywhere overlain by ash deposits of varying thicknesses. No saprolite has yet been mapped south of the Wailuku River drainage in the Hilo quadrangle.

South of the Wailuku River the ash deposits within the quadrangle are underlain by slightly weathered flows, probably from Mauna Loa. Between the Wailuku River and the Waipahoehoe-Alenaio stream drainages, the ash deposits are overlain in many areas by younger Mauna Loa flows.

Samples of ash, the youngest saprolite, and a locally thick (up to 0.5 m) clay bed that is often found between the ash and saprolite have been collected from several localities within the quadrangle and adjacent quadrangles. Seismic properties of the materials will be examined in the Engineering Geology Laboratory in Menlo Park.

Reports

None to date; this project is staffed at 1/2 man-year per year. An isopach map of ash thickness is being compiled and construction of a slope map is in the preliminary stage.

Tectonic Framework San Francisco Bay Region

9540-01618

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Investigations

1. Reviewed, edited, and prepared final copy of geologic and liquefaction potential map for northern Monterey County by W. R. Dupré and J. C. Tinsley.

2. Reviewed, edited, and prepared preliminary copy of map showing recently active breaks along the San Gregorio fault zone by G. E. Weber and K. R. Lajoie.

3. Reviewed, edited, and prepared preliminary copy of geologic maps of 16 quadrangles in Contra Costa and Alameda Counties by T. W. Dibblee.

4. Prepared summary report on seismic zonation in the San Francisco Bay Region for American Society of Civil Engineers conference on social and economic impact of earthquakes on utility lifelines.

5. Provided geologic information to Professor Ben Page, Stanford University, who is preparing cross-sections showing crustal structure in the central San Francisco Bay region. The cross-sections will be used by W. H. K. Lee and others to calibrate travel-time curves for seismic events.

6. Prepared, with D. G. Herd, second phase report on geologic hazards associated with the General Electric Test Reactor, Pleasanton, California.

7. Briefed three representatives of Mexico's Department of Planning and Public Works about different methods of coping with seismic hazards.

8. Conferred with geologists and planners from the California Coastal Commission, Monterey, Santa Clara, Santa Cruz, San Mateo, and Contra Costa Counties and the City of Pleasant Hill about seismic and landslide problems in their areas.

9. Received help from Evelyn Newman and Robert Mark in reprogramming the digital tape with information about the distribution of geologic units in San Mateo County. The tape was originally prepared by the Association of Bay Area Governments. After reprogramming, the tape was used to prepare a color proof of the geologic map of San Mateo County.

Results

1. The geologic and liquefaction potential maps of northern Monterey County are already in great demand because of the impact of development on a fragile estuarine system. The maps will be used, for example, by the Coastal Commission to evaluate a proposed sewer line between Seaside and Moss Landing, and by the Water Resources Division of the U.S. Geological Survey, which has a cooperative project with Monterey County to study salt water intrusion of aquifers around southern Monterey Bay.

2. The map showing recently active breaks along the San Gregorio fault zone should be ready for release in open files by June or July.

3. Maps by T. W. Dibblee showing faults and bedrock geology of parts of Alameda and Contra Costa Counties are in demand because of the paucity of recent geologic information in that area. The maps are particularly wanted by the City of Pleasant Hill, which is preparing a seismic safety element for their general plan, and by the Contra Costa County geologists, who must make decisions about land use daily. The following quadrangles will be released in open-files in June or July: Altamont, Antioch South, Briones Valley, Byron Hot Springs, Cedar Mountain, Clayton, Diablo, Dublin, Hayward, La Costa Valley, Las Trampas Ridge, Livermore, Midway, Niles, Tassajara, and Walnut Creek.

Reports

Brabb, E. E., in press, Seismic zonation in the San Francisco Bay region: American Society of Civil Engineers.

Brabb, E. E., and Pampeyan, E. H., in press, Geologic map of San Mateo County, California: U.S. Geological Survey Miscellaneous Investigations Map I-1257A.

Brabb, E. E., 1980, New techniques for seismic zonation in the San Francisco Bay region, California (Abs.): American Association for the Advancement of Science, Abstract of Papers of the 146th National Meeting, p. 12.

Brabb, E. E., 1980, Preliminary geologic map of the La Honda and San Gregorio quadrangles, San Mateo County, California: U.S. Geological Survey Open-file Report 80-245, map scale 1:24,000.

Dupré, W. R., and Tinsley, J. C., in press, Maps showing geology and liquefaction potential of northern Monterey and southern Santa Cruz Counties, California: U.S. Geological Survey Miscellaneous Field Studies Map MF-1199.

Herd, D. G., and Brabb, E. E., 1979, Evidence for tectonic movement on the Las Positas fault, Alameda County, California: U.S. Geological Survey Open-file Report 79-1658.

Passero, R. N., and Brabb, E. E., 1980, Annual report on environmental geology: Geotimes, v. 25, no. 2, p. 19-21.

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

9940-02090

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Investigations

Continued mapping of the Late-Quaternary geology of northern Los Angeles County and vicinity, including the Antelope Valley, the adjacent valleys of the San Andreas rift zone, and the canyons of the northern San Gabriel and southern Tehachapi Mountains; determination of the stratigraphy, physical properties, subsurface distribution, and deformational history of the unconsolidated deposits in the region.

Results

1. Mapping of the Quaternary deposits and active structures at 1:62500 scale is complete for most of the study area. One map is now in review and a second will be sent in for review shortly.

2. The Late-Quaternary (approximately 0.5 million years ago to present day) deposits in the study area apparently record climatically controlled episodes of alluviation. Evidence of an overriding climatic origin for these deposits lies in the recognition of a consistent sequence of alluvial deposition in a variety of tectonic settings in the study area, from the high passes of the San Gabriel Mountains to the low desert basins. The sequence of alluvial deposition was determined by delineating map units on the basis of soil development, topographic position, topographic expression and superposition. An apparent one-to-one correspondence between the sequence of units in the Antelope Valley and a similarly determined sequence of alluvial units in the eastern San Joaquin Valley also exists and further supports the hypothesis that these pulses of alluviation are climatically controlled. Deposition as a result of climatic shifts implies that other sequences of alluvial deposits in the southwestern United States can be correlated in time with the deposits in the Antelope and San Joaquin Valleys.

3. Collection and compilation of the various physical and engineering properties of the alluvial units is nearing completion. The engineer-

ing information is presently being compiled into a computerized data base. A system of computer programs, the MAT_DISPLAY system, has been developed to examine this engineering and geologic data. Some of MAT_DISPLAY's functions are to display various engineering and geologic data in several tabular formats, plot selected portions of the data (such as dry density or lithology) on maps or in cross-section, draw contour maps, and perform statistical analyses on any selected part of the data base. The computer system facilitates the organization of large amounts of data and allows for the rapid interpretation and correlation of the geology and associated physical properties in the subsurface. The MAT_DISPLAY system is available for use by other projects.

Erratum: A slide rule malfunction resulted in erroneous report of late Cenozoic strain rates in the previous volume of this series. North-south crustal shortening between the San Andreas and Garlock faults has probably averaged .5 to 1 microstrain per year during the past 13 million years or so.

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 its relation to the late Cenozoic tectonics in selected parts of California.

2. Continued analysis of the results of the 1978 southern California releveling and comparisons of these results against earlier datums.

3. Examined the general charge that the geodetic measurements that define the southern California uplift are seriously contaminated by height- or slope-dependent systematic errors.

Results

1. Accumulating evidence indicates that episodic, essentially aseismic vertical displacements recognized in southern California probably have occurred on time scales of months or even weeks. Moreover, it is becoming increasingly difficult to escape the conclusion that these displacements tend to be oscillatory, even though they commonly are characterized by long-period trends.

2. Detailed comparisons of the results of the 1978 general releveling of southern California against earlier datums has revealed a series of second-order warps superimposed on a regionally defined down-to-the-north tilt. Areas of sharply defined tilting and warping generally correspond to areas of intensely developed minor earthquake activity. This is particularly evident in the region of maximum tectonic downwarping in the eastern Transverse Ranges.

The 1974-78 height changes measured with respect to the San Pedro tide station reveal a partial collapse of the 1959-74 uplift that does not substantially alter its shape. A ridge of residual uplift (10-15 cm) trending about N60°W roughly parallels the San Andreas through the Palmdale region, turning more westward through the Transverse Ranges west of Palmdale. In addition to the marked decrease in the amplitude of the uplift, the most dramatic changes shown by the residual uplift pattern include: (1) the development of an east-trending downwarp along the south flank of the uplift; (2) a sizable deepening (36-38 cm) of the tectonic depression in the vicinity of the Salton Sea; and (3) the enhancement of an east-trending upwarp extending along the crest of the Eagle Mountains from a point about 20 km north of Mecca.

3. Examination and analysis of a massive volume of vertical control data obtained from within the central part of the southern California uplift indicate that the vertical displacements that define the uplift cannot be dismissed as the products of explicitly height-dependent or less explicitly slope-dependent systematic errors. Our review of rod errors associated with rod manufacture, calibration, field procedures and so forth indicates that these errors are generally trivial and would tend to cancel during the critical interval 1955-65. Comparisons between the results of various measurements in which the correlation between topography and signal is generally poor, reveal large aseismic tilts in a number of places within and around the margins of the uplift. Moreover, pre- and post-uplift levelings over routes characterized by diverse length, topography and atmospheric conditions produce closely matching, temporally equivalent heights for a representative bench mark well within the uplift. Statistical analyses of short-wavelength components of the uplift signal and elevation along a frequently repeated survey line indicate variable correlations between the two. However, the spatial and temporal patterns of these correlations are inconsistent with their attribution to height-dependent systematic errors. Short-wavelength correlations along this line are reasonably explained in part as real movement associated with differentially subsiding bench marks, and there is a strong likelihood that this movement tends to dominate many of these correlations.

Reports

Castle, R. O., Clark, M. M., Grantz, Arthur, and Savage, J. C., 1980, Tectonic state: its significance and characterization in the assessment of seismic effects associated with reservoir impounding: Engineering Geology, v. 15, p. 53-103.

Anchorage-Susitna Lowlands Earthquake Hazards Mapping

9310-02078

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Investigations

1. Continued surficial/engineering geologic mapping and Quaternary stratigraphic studies.

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

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

Results

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

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

3. Completed synthesis of subsurface engineering soils data from the Government Hill area of Anchorage, and prepared report presenting systematic geologic descriptions of the Bootlegger Cove Clay unit, facies changes, and engineering characteristics.

Compilation of Regional Geological and Seismic Site Characteristics

9940-02087

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Investigations

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

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

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

Results

1. Measurements of shear-wave velocities in the San Francisco Bay region were used to differentiate geologic units into groups with similar seismic velocities. This is a preliminary step to producing a map with zones depicting similar near surface earthquake response characteristics. The preliminary work is being done using a new combined geologic map of San Mateo County, California (Brabb, et al., in press).

2. An additional 19 locations have been logged for seismic velocities in the Los Angeles region. This brings the total number of locations logged in this region to 46.

3. Five holes (located in Santa Clara Valley, Calif.) were logged for seismic velocities at locations where strong ground motion was recorded from the August 6, 1979 Coyote Lake earthquake. Average shear-wave velocities of the upper 30 meters range from 1090 m/sec in bedrock near Gavilan College to 220 m/sec in alluvium near San Ysidro School. Average compressional-wave velocities range from 1490 m/sec to 960 m/sec at the same sites.

Report

Gibbs, J. F., Fumal, T. E., and Roth, E. F., 1980, In-situ measurements of seismic velocity at 27 locations in the Los Angeles, California region: U. S. Geological Survey Open-File Report 80-378, 167 p.

Earthquake Hazards Puget Sound Region Washington

9540-02197

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Investigations

1. A 1:250,000 scale seismotectonic map of the Puget Sound Region is nearing completion.

2. Preparation of the bedrock geologic map of the Seattle 1:100,000 scale sheet is nearing completion.

3. A geologic and tectonic map of the Port Townsend area is nearing completion.

4. Bedrock geologic mapping of the Clear Lake Southwest Orthophoto quadrangle is underway as part of the compilation of the bedrock geologic map of the Port Townsend 1:100,00 scale sheet.

5. Compilation and analysis of the subsurface geologic data in the Seattle south and eastern half of the Duwamish Head 7 1/2' quadrangles has been completed, leading to production of a seismic ground response map of those quadrangles, which are in preparation.

6. Near-surface (<50 m) subsurface data is being compiled for purposes of producing a liquefaction susceptibility map of the Seattle south and eastern half of the Duwamish Head 7 1/2' quadrangles.

7. Compilation of subsurface data from the Bremerton east and Bremerton west 7 1/2' quadrangles has begun for purposes of extending seismic ground response techniques developed in the Seattle region to a new area. A limited amount of geologic mapping of Quaternary deposits in the Bremerton area has been done in order to upgrade the available smaller scale (1:48,000 and 1:60,000) published maps of the Bremerton area.

Results

1. Analysis of magnetic and regional gravity anomalies, subsurface well data and marine seismic refraction profiles indicate possible Holocene movement on a large northwest trending inferred fault on southern Widbey Island and the eastern Strait of Juan de Fuca.

2. Numerous faults displacing late Pleistocene to Holocene deposits in the eastern Strait of Juan de Fuca were identified by detailed study of marine seismic reflection profiles. An open-file report describing the results of this study is under preparation.

3. An empirical relationship between ground response during the 1965 Seattle Earthquake (M = 6.5) and the position of the bedrock surface relative to Quaternary units with abnormally low standard penetration values has been established in the Seattle area. Ground response was relatively severe where underlying low resistance artificial fill, Holocene alluvium or preglacial outwash sand occurred less then 100 meters stratigraphically above the Tertiary bedrock surface. This relationship provides a basis for a preliminary seismic ground response zonation of the Seattle region, by preparing maps of the subsurface distribution of low resistance Quaternary units, and super-imposing these distributions on a map of bedrock surface configuration.

Reports

Whetten, J. T., Dethier, D. P., Carroll, P. R., 1980, Preliminary geologic map of the Clear Lake NW quadrangle, Skagit County, Washington: U.S. Geological Survey Open-File Report 80-247.

Dethier, D. P., Whetten, J. T., and Carroll, P. R., 1980, Preliminary geologic map of the Clear Lake SE quadrnagle Skagit County, Washington: U.S. Geological Survey Open-File Report 80-303.

Ground Response, Salt Lake City, Utah Region

9940-01919

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Investigations

1. During the past six months, first priority has been given to completing the processing of the broadband nuclear-explosion ground-motion data recorded in Salt Lake City, Provo, Ogden, Logan, and Cedar City and checking the data for errors. The hybrid computer was unavailable during this period of time so alternate procedures were developed using the Multics. In some cases, data had to be reprocessed in order to correct errors. Data processing is now about 90% complete. The total data sample includes: (1) 66 time histories and spectra for 8 events recorded at 40 sites in the Salt Lake City area, (2) 11 time histories and spectra for 1 event recorded at 11 sites in the Provo area, (3) 15 time histories and spectra for 2 events recorded at 13 sites in the Ogden area, (4) 5 time histories and spectra for 1 event recorded at 5 sites in the Logan area, and (5) 12 time histories and spectra recorded from 2 events at 10 sites in the Cedar City area.

Results

1. Horizontal site transfer functions are being derived from the horizontal component response spectra and used to define the horizontal ground response in each urban area. These data are being correlated with the surficial geology to explain the local variations in ground motion.

Reports

Hays, W. W., 1980, Procedures for estimating earthquake ground motions: U.S. Geological Survey Professional Paper 1114, 77 p.

Hays, W. W., Miller, R. D., and King, K. W., 1980, Ground response in the Salt Lake City-Ogden-Provo Urban Corridor: Proceedings of World Conference on Earthquake Engineering, VII, Ankara, Turkey (in press) 8 p.

King, K. W., Hays, W. W., Miller, R. D., and Hamilton, L. A., 1980, Preliminary evaluation of ground response along the Wasatch front (abs.): Seismological Society of America, Seattle, Washington.

Miller, R. D., Hays, W. W., and King, K. W., 1980, Geology and ground response: Provo, Salt Lake City, and Ogden area, Utah (abs.): Geological Society of America, Ogden, Utah.

Neotectonics of the San Francisco Bay Region, California

9540-01950

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Investigations

1. At the request of Robert Page, Program Coordinator, Earthquake Hazards Reduction Program, a field investigation of the December 12, 1979 magnitude ∿8 earthquake near Tumaco, Colombia, was made. The investigative team included T. Leslie Youd of the Engineering Geology Branch (Project No. 9550-01629, Experimental Mapping of Liquefaction Potential), and members of the Colombian Instituto Nacional de Investigaciones Geológico-Mineras. Coastal southwestern Colombia and northern Ecuador were strongly shaken by the earthquake, largest in that part of South America since 1942. Building damage, ground failure and liquefaction, and tectonic elevational changes accompanying the earthquake were examined.

2. A study of the earthquake ground acceleration hazard in the San Francisco Bay region was continued with R. K. McGuire and K. M. Shedlock of the Branch of Earthquake Tectonics and Risk (Project No. 9950-01733, Methodologies for Seismic Risk Assessment). The size and frequency of earthquakes on the principal recently active faults in the central Coast Ranges of California were evaluated to calculate future ground shaking intensity.

3. A summary review of the geometry, age, and origin of faults at the General Electric Test Reactor site at Vallecitos Nuclear Center, Pleasanton, California, was prepared for the Nuclear Regulatory Commission. The reactor was closed in 1977 by the NRC.

4. A map synthesis (scale 1:250,000) of recently active faults and seismicity (1969-1974) in the greater San Francisco Bay region was begun with W. L. Ellsworth, Branch of Seismology (Project No. 9930-02103, Seismic Studies of Fault Mechanics).

Results

1. At approximately 3 a.m. (local time) on December 12, 1979, Colombia and Ecuador were shaken by a major earthquake located just offshore and southwest of Tumaco, Colombia. Thrust faulting occurred on a roughly rectangular patch (270 km x 130 km) of the subduction zone dipping eastward beneath coastal Colombia. A 240-km stretch of the Colombian Pacific coast tectonically subsided up to 1.6 m; conversely, uplift occurred offshore on the continental slope. Movement of the ocean floor triggered a tsunami which swept inland immediately after

the earthquake, crashing into several coastal villages. Ground shaking (intensity VI-IX) wracked or collapsed many buildings, and generated liquefaction in fills and in late Holocene beach, lagunal, and fluvial deposits, up to 50 km inland.

2. Annual activity rates (number of $M \geq 5$ events per year) were calculated for the principal recently active faults in the central Coast Ranges of California. The rates were derived from geologically determined slip rates for the faults and seismic moment calculations. The rates suggest that $M \geq 5$ earthquakes occur on the San Francisco Peninsula part of the San Andreas fault on an average of every 60 years, but as frequently as every 20 years, for example, on the Calaveras and Hayward faults.

Reports

Published:

Herd, D. G., and Brabb, E. E., 1979, Evidence for tectonic movement on the Las Positas fault, Alameda County, California: U.S. Geological Survey Open-file Report 79-1658, 7 p.

_______________, 1980, Faults at the General Electric Test Reactor site, Vallecitos Nuclear Center, Pleasanton, California: U.S. Geological Survey Administrative Report, 77 p.

Herd, D. G., McLaughlin, R. J., Sarna-Wojcicki, A. M., Clark, M. M., Lee, W. H. K., Sharp, R. V., Sorg, D. H., Stuart, W. D., Harsh, P. W., and Mark, R. K., 1979, Surface faulting accompanying the August 6, 1979 Coyote Lake earthquake (abs.): EOS, v. 60, no. 46, p. 890.

Lee, W. H. K., Herd, D. G., Cagnetti, V., Bakun, W. H., and Rapport, A., 1979, A preliminary study of the Coyote Lake, California earthquake of August 6, 1979 and its major aftershocks (abs.): EOS, v. 60, no. 46, p. 889.

Director's Approval:

Herd, D. G., Youd, T. L., Meyer, Hansjurgen, Arango C., J. L., Person, W. J., and Mendoza, Carlos, 1980, Tumaco, Colombia earthquake ($M \sim 8$) of 12 December 1979: Submitted to Science.

Herd, D. G., Youd, T. L., Person, W. J., Arango, J. L., and Meyer, H., 1980, The Tumaco, Colombia earthquake of December 12, 1979 (abs.): Submitted to the Seismological Society of America, Seattle, Washington, meeting (April 23-25, 1980).

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

9540-02685

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Investigations

1. Stereo aerial photographs (scale 1:50,000) of northern Sonora and Chihuahua (purchased from the Dirección General de Estudios del Territorio Nacional, Mexico City) were examined to prepare a preliminary map of the Sonoran earthquake rupture of 1887. A search was made for older recently active breaks adjacent to the 1887 rupture, and for geologically young faults in neighboring valleys.

2. A preliminary interpretation of the tectonics of the Sonoran earthquake was attempted, comparing the fault's geologic setting to that of Basin-and-Range faults and the neighboring Rio Grande Rift.

3. A reconnaissance field investigation of the 1887 rupture is planned for May-June 1980.

Results

1. The Sonoran earthquake rupture of 1887 bounds part of the east side of San Bernardino Valley, at the foot of the Sierra de San Luis, about 40 km southeast of Douglas, Arizona. The rupture extends southward about 45 km from Arroyo Cajón Bonito (about 15 km south of the U.S. border) to the end of San Bernardino Valley, just east of Colonia Morelos. The rupture consists of a line of en echelon, locally branching, west-facing scarps in late Pleistocene and Holocene alluvium or older Tertiary volcanics. The throw locally varies along the length of the scarp, exceeding several meters in numerous localities. Movement was normal in character, west side down.

   The Sonoran earthquake rupture occurred within a larger zone of recently active faults which extend along the east side of San Bernardino Valley from almost to the border south to the end of the valley. The zone lies generally at the foot of the battered, faceted west face of the Sierra de San Luis, but locally departs from it. The zone is paralleled to the west about 7 km by a second line of en echelon (left-stepping) recently active faults that extends southward approximately 30 km from Arroyo de los Embudos to Arroyo de La Cabellera, where it joins the main fault. The faults differentially displace a number of late Quaternary alluvial fans; several breaks appear more eroded than others. A history of repeated fault movements before 1887 is indicated.

2. A small line (about 4 km in length) of eroded, east-facing scarps in late Quaternary alluvium occurs opposite the 1887 rupture, on the west side of San Bernardino Valley just south of the U.S. border. The existence of the opposing normal faults indicates that San Bernardino Valley is a graben, rather than a typical Basin-and-Range valley, where recent faulting occurs generally on only one side of the valley. Locally the valley is filled by basalt which flowed southward from the Bernardino volcanic field at the north end of San Bernardino Valley. Flows in the field range in age from 0.2 to 3.2 m.y. in age (Luedke and Smith, 1978).

   The graben structure of the valley and its recent basaltic volcanism suggest that San Bernardino Valley is a small rift, perhaps related to the larger Rio Grande Rift, 175 km to the east.

3. In the next valley west of San Bernardino Valley, south of Douglas, Arizona, and Agua Prieta, Sonora, a previously unreported line of recently active faults occurs along the east side of Sulphur Springs Valley. The relationship of this zone of west-facing scarps with other recently active faults in the northern Sulphur Springs Valley (within the United States) is not yet resolved.

   Although Goodfellow (1888) reported that he had been told that there was a duplicate fault to the 1887 rupture on the east side (Chihuahua) of the Sierra de San Luis, no recently active break is evident in the aerial photographs of the area.

Puget Sound Lowland Focused Geophysical Studies

9460-71110

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Investigations

1. The marine field work for the central Puget Sound segment of this project was carried out in February and March aboard the USGS RV DON J. MILLER (Fig. 1). A total of 175 kilometers of gravity profiles and 150 kilometers of single channel (40 cubic inch air gun) seismic reflection tracks were run. Sixteen air gun-sonobuoy refraction lines were shot using a 148 cubic inch air gun. These data were obtained in Lake Washington and from Puget Sound north and south of the Seattle gravity minimum.

Results

1. Several problems were encountered during the field work which affected the geophysical data quality (and quantity). Two of the local television stations operate at frequencies close to those of the sonobuoys; the resulting RF interference prevented reception of data over distances exceeding two kilometers. This problem was eventually solved by modifying normal sonobuoy procedures and employing a second vessel to act as a recording boat. The standard high gain yagi antenna was discarded in favor of a simple wire, and the recording vessel kept station within 75 meters of the moored sonobuoy during shooting in order to minimize the telemetry path link from sonobuoy to receiver. Two other problems about which little could be done were unusually bad weather and the high ambient noise level (in the siesmic band) due to shipping and industrial activity.

2. The seismic data have not yet been analyzed in detail. The refraction records were examined as they were collected in order to determine the approximate depth and velocity of the deepest refractor. In Lake Washington and Puget Sound north of the steep gravity gradient a 3.0-3.1 km/sec refractor can be seen at a subsurface depth of about 1.0-1.5 km. South of the gravity gradient the sonobuoy profiles show a 5.3 km/sec layer at an approximate depth of 1.0 km. Although the interval velocities in the sections above these layers have not yet been calculated, the differences in velocity and apparent depth suggest the existence of a west-trending fault in the vicinity of the steep gravity gradient. The high velocity south of the gradient probably represents Tertiary volcanics (basalt and gabbro) known to exist in the subsurface in southern Puget Sound.

3. Preliminary results from the marine gravity work indicate that the gradient along the southern side of the Seattle gravity minimum is steeper than a simple extrapolation of the land data would suggest; the western "nose" of the gravity minimum itself is also steepened. Preliminary calculations indicate a basement offset (down to the north) of about 6 km across the gravity gradient. This is only half of the displacement proposed by previous investigators. Subsurface density approximations based on results from the refraction survey will be used in conjunction with the revised gravity anomaly map and seismicity data to model the structure beneath the gravity gradient and the Seattle gravity minimum.

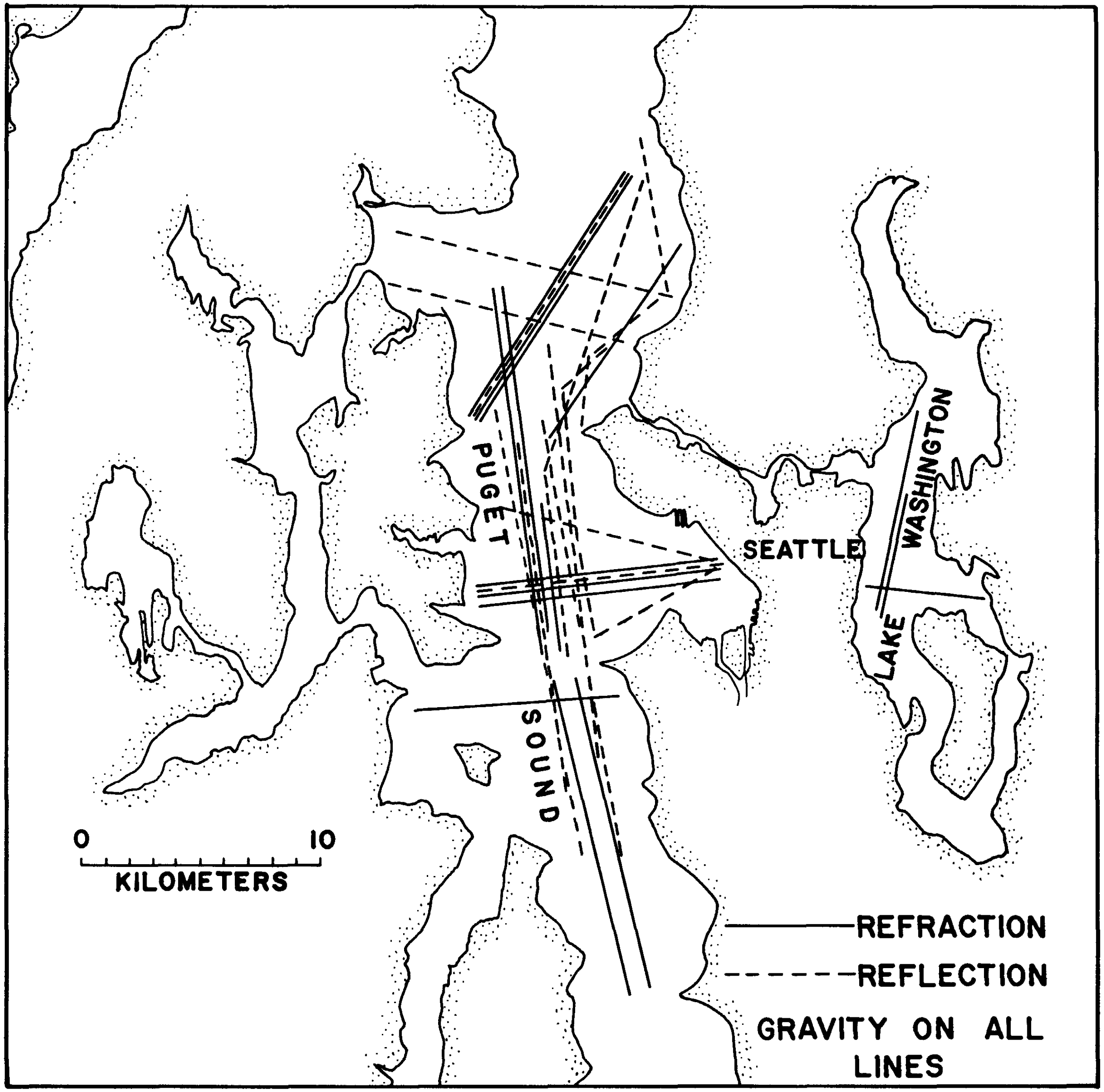

FIGURE 1. Geophysical tracklines, central Puget Sound Lowland.

Tectonics of Central and Northern California

9950-01290

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Investigations

Most of the work conducted under this project in this report period was the study of the tectonic setting of carbon dioxide discharges and their relation to zones of seismicity.

Results

The distribution of CO_2-rich natural springs is generally along major zones of seismicity, both worldwide and on a regional scale, based on earlier studies in collaboration with Ivan Barnes of Water Resources Division. These studies have continued by examining the tectonic setting in more detail, not only for the CO_2-rich springs, but also for CO_2-rich wells that were drilled for hydrocarbon gas or petroleum. As part of this work, a map showing the tectonic setting of CO_2-rich springs and gas wells in the conterminous United States has been prepared at a scale of 1:2,500,000.

Worldwide, the CO_2-rich springs are mainly along young orogenic belts such as those of the alpine belt of the Mediterranean and Middle East regions and of the circum-Pacific belt. CO_2-rich springs are rare in older orogenic belts such as the Caledonides and Urals. They also are uncommon in the tectonically stable cratonal regions of continents, except where the cratons are being actively rifted.

In the conterminous United States, the CO_2-rich springs follow the same pattern as on the global scale. They are abundant in the Cordilleran orogenic region of the western United States, particularly along the tectonically active and highly seismic Pacific coastal region (fig. 1). In the relatively old Appalachian orogenic belt of the eastern United States, CO_2-rich springs are extremely rare, being known only at Saratoga Springs, New York. In the broad cratonal region, the CO_2-rich springs are restricted to the western part where they are associated with a system of extensional faults that include the Rio Grande rift.

Of more than 10,000 published analyses of gas from oil and gas wells in the conterminous United States, approximately 100 are of gas consisting of 50 percent or more CO_2. Nearly all of these extraordinarily CO_2-rich gas wells are in platform deposits that lie on the cratonal Precambrian basement. Their distribution is similar to that of the few CO_2-rich springs found in the cratonal region, by virtue of their restriction to the actively fragmenting western part.

In some instances the source of the CO_2 in the spring or well can be identified by isotopic analysis of the carbon, but these data are available for only a few locations. Three different sources have been identified for CO_2-rich springs of the Pacific Coast region. For example, carbon from the mantle issues from some of the springs of the Sierra Nevada and along the San Andreas fault. CO_2 issuing from Franciscan terrane of the California Coast Ranges is a product of metamorphism of marine carbonate material at some localities, and of the breakdown of organic material at others. The presence of abundant CO_2 in gas wells of the western part of the craton is commonly attributed to thermal metamorphism of platform carbonate strata by young intrusive and volcanic rocks. However, published isotopic analyses of the CO_2 from two of these wells in northeastern New Mexico and two in southeastern Utah indicate a mantle origin.

Reports

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Irwin, W. P., and Barnes, Ivan, 1980, Tectonic relations of carbon dioxide discharges and earthquakes (abs.): EOS, v. 61, no. 7, p. 87: full paper in press, Journal of Geophysical Research.

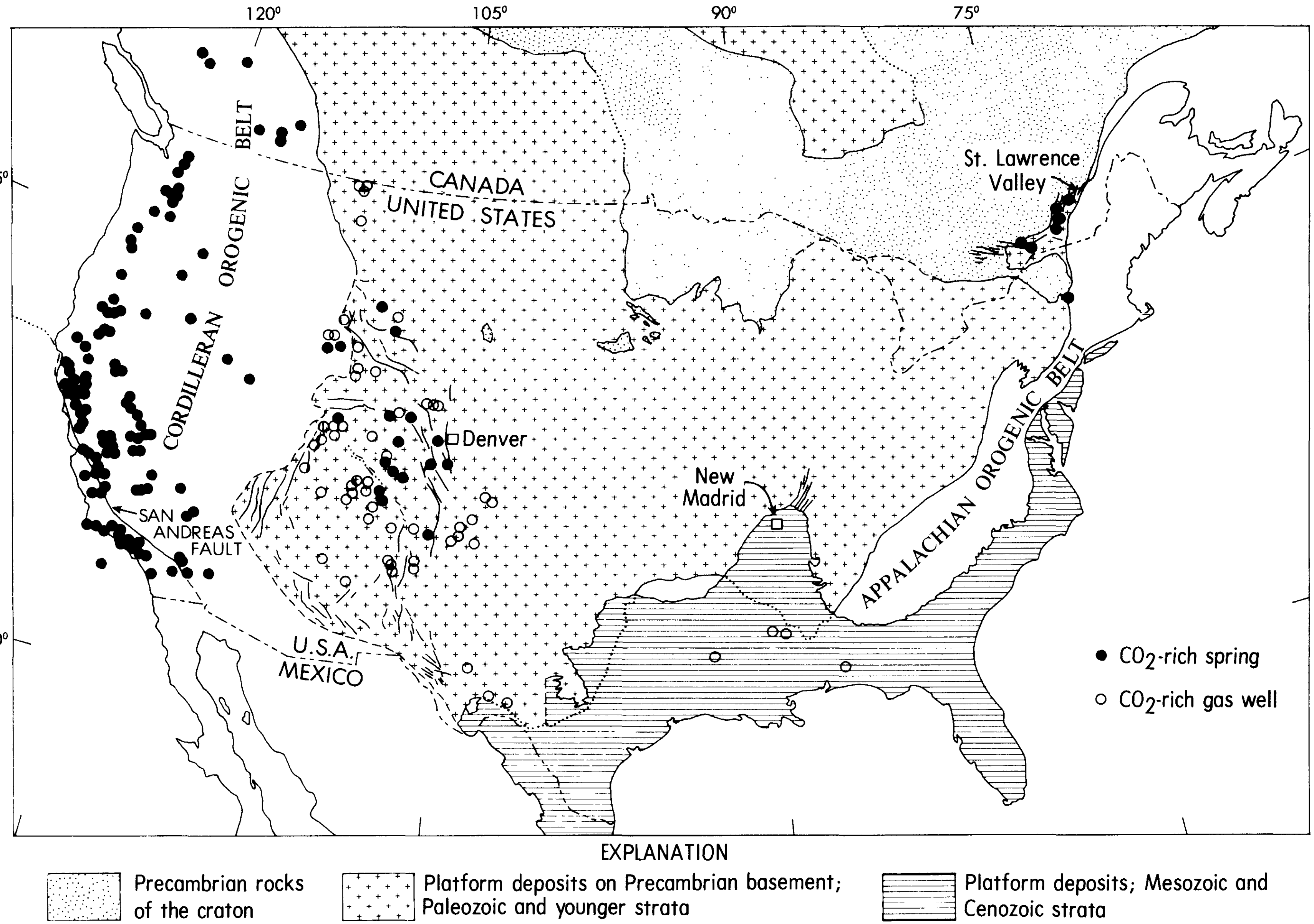

Figure 1. Map showing the distribution and tectonic setting of CO_2-rich springs and gas wells in the conterminous United States and adjacent part of Canada.

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

14-08-0001-17760

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Investigations

1. Continued systematic application of the CSV (clast sound-velocity) method to alluvial deposits along the Sierra Madre fault zone was pursued, with expansion of the area covered.

2. Several sites in the oldest alluvial unit were sampled for paleomagnetic measurements to provide an age constraint on this unit.

3. A detailed CSV examination of several individual clasts was carried out to better understand the effects of clast weathering on the CSV method.

4. A short CSV study of glacial moraines on the east side of the Sierra Nevada was conducted to test the wider applicability of the CSV method to faulted Quaternary deposits in a cliamtically different situation.

Results

1. Using the standardized CSV method as discussed in the semi-annual report, 41 sample groups of Mt.-Lowe-Granodiorite clasts from alluvial deposits representing at least four distinct age groups (Crook and others, 1979) were tested to obtain the mean CSV values for each group. Table 1 shows the group means and estimated standard deviations of the means. All four age-group means are distinguishable from each other at the 95% confidence level or higher, based one a one-tailed $\underline{t}$-test.

Although the Qal_1 and Qal_2 groups are statistically distinguishable, they are thought to be no more than 11,000 years apart in age. Consequently it is not unexpected that some of the individual Qal_2 groups (C_{2a} and E_2) yield mean velocities that are nearly the same as those of the Qal_1 group. Of greater concern is the fact that two sample groups from presumed Qal_3 age deposits (C_{3f} and C_{3h}) in Eaton Canyon yield mean velocities comparable to Qal_1 groups. This apparent reversal is as yet unexplained but may involve faulting. Three sample groups from Qal_4 age deposits (D_{4a}, D_{4b}, and F_{4a}) give anomalously low CSV values. This result suggests that the alluvial deposits from which these samples were obtained are distinctly older than Qal_4; if valid, this would indicate the existence of an alluvial unit that in our terminology should be designated Qal_5. W. Bull has in fact found evidence in San Gabriel Canyon for the existence of such an older alluvial unit. Near Eaton Canyon we have found an older alluvial unit underlying Qal_4 beneath an erosion surface (Crook and others, 1979, p. 18), but have been unable to apply the CSV method to it because it contains no coarse clasts.

The 43 localities sampled to date lie in several different drainages, spread across a distance of 40 kilometers. The general consistency among CSV results from this large area is impressive and suggests that the method is a useful tool for age-correlation and eventually for dating of Quaternary deposits.

2. In an effort to obtain absolute-age information with which to calibrate the relative ages obtained with the CSV method, we undertook to test the possibility that portions of the Qal_4 unit may be old enough to contain the Brunhes-Matuyama polarity reversal. We obtained oriented samples for paleomagnetic polarity determination from five outcrop localities of this unit. Four localities showed normal magnetization. The sample from the fifth locality, in Monrovia, below one of the strongest developed soils, showed a trend toward reversed magnetization when taken through thermal demagnetization up to 400°C. Technical problems with temperature control prevented a final thermal demagnetization step at 500°C. This will be corrected with a new thermocouple and several more samples will be collected and run to establish whether or not a magnetic reversal is in fact present.

3. Analysis of all CSV results obtained to date indicates that there is a correlation between clast size and CSV, larger clasts tending to yield higher sound velocities. In an effort to determine the cause of this effect, several clasts of different sizes and from deposits of different ages were tested. P-wave velocities were determined for the outer surface and through each clast and compared. The results are shown in Table 2. This data suggests that when a clast is from a young enough deposit to have a weathering rind, the difference in velocity for surface layer and center influences the overall CSV velocity obtained if the clast is large enough to allow the refracted P-wave to arrive before the surface P-wave. This difference seems to disappear with older clasts. Care must therefore be taken to standardize the clast sizes used in applying the CSV method.

4. A test of the CSV method was carried out on Pleistocene glacial moraines on the east side of the Sierra Nevada, in the thesis area of graduate student Alan Gillespie. The moraines tested are located in the Independence Creek and South Fork Oak Creek drainages. For each geomorphologically distinct moraine, CSV measurements were made on clasts from one to three localities, 20 clasts being sampled at each locality. Preliminary results show that in both drainages three distinctly different age deposits can be distinguished at the 90% or greater confidence level based on a one-tailed *t*-test. The data collected in Independence Creek suggested an error in previous mapping which in fact was later substantiated. This study suggests that the CSV method is a versatile and powerful tool that may have many applications for relative age dating of clast-bearing Quaternary sediments.

Reports

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Table 1

CSV DATA FOR MT. LOWE GRANODIORITE CLASTS FROM ALLUVIAL DEPOSITS IN ARROYO SECO, BIG TUJUNGA CANYON, EATON CANYON, MILLARD CANYON, MONROVIA CANYON, SAN GABRIEL CANYON, AND SANTA ANITA CANYON, LOS ANGELES COUNTY, CALIFORNIA

A: sample groups from Arroyo Seco drainage
B: sample groups from Big Tujunga Canyon drainage
C: sample groups from Eaton Canyon drainage
D: sample groups from Millard Canyon drainage
E: sample groups from Monrovia Canyon drainage
F: sample groups from San Gabriel Canyon drainage
G: sample groups from Santa Anita Canyon drainage

Age group	Sample group	Mean CSV (km/sec)	s.d. of mean (km/sec)	No. of clasts
Qal_1 (youngest)	A_{1a}	2.13	.11	22
	A_{1b}	2.03	.10	20
	B_1	2.03	.08	20
	C_1	2.10	.07	25
	D_1	2.01	.08	20
	F_1	2.05	.08	20
	G_1	2.12	.12	21
Combined: $A_{1a}+A_{1b}+B_1+C_1+D_1+F_1+G_1$		2.07	.03	148
Qal_2	A_{2a}	1.90	.08	17
	A_{2b}	1.84	.09	20
	A_{2c}	1.84	.08	20
	C_{2a}	2.01	.12	11
	C_{2b}	1.97	.07	35
	E_2	2.04	.11	20
	F_2	1.89	.10	21
Combined: $A_{2a}+A_{2b}+A_{2c}+C_{2a}+C_{2b}+E_2+F_2$		1.93	.03	144
Qal_3	A_{3a}	1.68	.09	20
	A_{3b}	1.65	.08	20
	A_{3c}	1.62	.07	22
	B_3	1.81	.08	20
	C_{3a}	1.60	.11	20
	C_{3b}	1.70	.09	24

Age group	Sample group	Mean CSV (km/sec)	s.d. of mean (km/sec)	No. of clasts
Qal_3 (cont.)	C_{3c}	1.66	.09	24
	C_{3d}	1.74	.08	20
	C_{3e}	1.72	.13	20
	C_{3f}	2.09	.10	20
	C_{3g}	1.83	.12	20
	C_{3h}	2.03	.09	20
	C_{3i}	1.88	.04	20
	E_3	1.79	.09	20
	F_3	1.68	.08	21
	G_3	1.68	.13	22
Combined:				
$A_{3a}+A_{3b}+A_{3c}+B_3+C_{3a}+C_{3b}+C_{3c}+C_{3d}+C_{3e}+C_{3f}+C_{3g}+C_{3h}+C_{3i}+E_3+F_3+G_3$		1.76	.03	329
Qal_4 (oldest)	A_{4a}	1.30	.07	20
	A_{4b}	1.26	.06	23
	A_{4c}	1.35	.08	24
	A_{4d}	1.25	.13	18
	A_{4e}	1.50	.06	18
	A_{4f}	1.46	.15	20
	A_{4g}	1.24	.11	20
	C_4	1.44	.10	20
	D_{4a}	1.13	.08	20
	D_{4b}	1.12	.07	17
	E_4	1.34	.13	20
	F_{4a}	1.07	.08	20
	F_{4b}	1.42	.10	17
Combined:				
$A_{4a}+A_{4b}+A_{4c}+A_{4d}+A_{4e}+A_{4f}+A_{4g}+C_4+D_{4a}+D_{4b}+E_4+F_{4a}+F_{4b}$		1.30	.03	257

Table 2

CSV DATA ON INDIVIDUAL CLASTS OF DIFFERENT SIZES
AND FROM DEPOSITS OF DIFFERENT AGES

clast size >30 cm	body velocity (km/sec)	surface velocity (km/sec)	difference (km/sec)
Qal_2 (youngest)	2.72	2.22	.50
Qal_3	2.11	1.75	.36
Qal_4 (oldest)	2.32	2.31	.01
clast size <20 cm			
Qal_2	2.73	1.95	.78
Qal_3	2.09	2.00	.09

Alaska Seismic Studies

9940-01162

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Investigations

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

2. With funding from NOAA's Outer Continental Shelf Environmental Assessment Program (OCSEAP) seismic stations are operated from the Cordova-Hinchenbrook-Montague area on the west to Yakutat Bay-Harlequin Lake on the east. The northern limit of these stations is approximately 100 km from the Gulf of Alaska. Data obtained from this network are particularly important for establishing criterion for safe oil development on the shelf.

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

Results

1. Preliminary locations have been completed for 1303 earthquakes that occurred during October-December 1979, and about 450 events that occurred during January 1980. These numbers represent an increase by a factor of at least 4 in the number of events that are processed for a particular time period. Most of the events are aftershocks from the St. Elias earthquake of 28 February 1979. Recent changes implemented in the procedures for earthquake processing have increased the efficiency of individual data processors by a factor of 2, and the overall rate of data processing is now commensurate with the rate that data is accumulating.

2. The spatial and temporal properties and magnitude distribution of the aftershock sequence of the 28 February 1979 St. Elias, Alaska earthquake (M_S 7.1) have been reviewed in detail for the period through March 1979. A nearly complete seismic record exists for events with magnitudes above 3.5 starting 20 minutes after the main shock. The largest aftershock, which was previously unreported and has a poorly determined magnitude slightly above 5, occurred about five minutes after the main shock. The frequency distribution of magnitudes above 3.3 has a b-value of 0.96, and the decay with time in the frequency of large aftershocks can be adequately described by a t^{-1} inverse power law.

Epicenters of the aftershocks are non-uniformly distributed in a 70 x 90 km^2 zone extending southeast from the epicenter of the mainshock. Most of the activity occurred in a cluster centered about 50 km southeast of the epicenter of mainshock. Only a few aftershocks were located near the epicenter of the mainshock, and there is a near absence of activity between these events and the main cluster to the southeast. Within the accuracy of the locations, all of the aftershocks have depths less than 20 km. Where good depth control is available, the aftershocks are found not to extend to the earth's surface, and in some areas may be confined to a zone less than 6 km in thickness.

The rupture area of the main shock is estimated to be 3.2 x 10^3 km^2 based on the distribution of aftershocks that occurred during the first 24-hour period following the main shock. The areal extent of the aftershock zone increases significantly after that time. An estimate of the seismic moment, M_0, of the St. Elias earthquake is 2.5 x 10^{27} dyne-cm. Using these values for the rupture area and the seismic moment, the computed average displacement, $\bar{D}$, for the St. Elias earthquake is about 2 meters, and the stress drop, $\Delta\sigma$, is about 36 bars. This value of stress drop is characteristic of values of interplate earthquakes and is consistent with an interpretation of low-angle thrusting between the Pacific and North American plates for the St. Elias earthquake.

Focal parameters for the St. Elias, Alaska earthquake have been determined from regional and teleseismic data. The preferred P-wave nodal solution is consistent with low-angle thrusting to the north-northwest, although the strike of the preferred fault plane is poorly controlled. Estimates of focal depth from both body-wave and surface wave analysis range from about 10 to 20 km. The average rupture velocity is about 2.5 to 3.0 km/sec, probably to the east or southeast. The apparent stress, $\eta\bar{\sigma}$, is 5 bars.

3. A kinematic model for neotectonic deformation in southern Alaska has been formulated from available geologic and seismic data. The purpose for developing this model is to aid in evaluating the potential for and likely site of a future large earthquake in the seismic gap that has been identified between Prince William Sound and the rupture zone of the 28 February 1979 earthquake. In the model, the portion of the North American plate bordering the Gulf of Alaska is divided into two sub-blocks which are partially coupled to the Pacific Plate. Based on the model, the gap-filling rupture, or ruptures, would most likely be along the north-dipping thrust faults of the Pamplona zone between Icy Bay and the Aleutian megathrust. A single event that filled the remainder of the gap could have a magnitude as large as 8.

4. Available data on earthquake occurrences in the region of the aftershock zone of the 28 February 1979 St. Elias earthquake were reviewed to study the spatial and temporal patterns prior to the main shock. Despite limitations in completeness and uniformity of the data set, some interesting variations have been observed. From 1974 to February 1979 this was one of the most seismically active regions along the eastern Gulf of Alaska. One of two prominent earthquake sequences known to have occurred along the eastern Gulf of Alaska during this time period was located at the southeast margin of the

St. Elias earthquake aftershock zone. This sequence was activated by a series of swarms that occurred within three to five months of the main shock.

The magnitude distribution and rate of activity were reviewed for two six-month periods that are uniformly complete above magnitude 1.8. The first interval ended 11 months before and the second immediately before the St. Elias earthquake. During the six months immediately prior to the mainshock the number of events above magnitude 1.8 was 39% greater than in the earlier six-month period. The b-value prior to the mainshock, calculated for four three-month intervals, decreases continuously with time from 1.36 to 0.78, while the b-value for the aftershocks is 0.96. However, none of the pre-earthquake b-values differ from the aftershock b-value at the 95% confidence level. These results, which suggest that prior to the St. Elias earthquake the level of seismicity increased while the b-value decreased need to be reviewed further to insure that there is no bias in the data that might have produced a spurious trend. We are currently monitoring the region between the aftershock zones of the St. Elias earthquake and the 1964 Alaska earthquake for any changes in seismicity that might be precursors of another large earthquake. Of particular interest are patterns similar to those described above for the St. Elias earthquake.

5. During the past two years the voltage-controlled-oscillator electronics at the seismic stations in Alaska have been replaced with newly designed A1-VCO's (Rogers and others, 1980). The new units have worked very well and have had a low failure rate. Their crystal-controlled circuitry has completely eliminated our frequency drift problems and the automatic gain-range feature has increased the effective dynamic range by 20 dB. In addition, daily automatic calibration signals include information on system response, geophone sensitivity and impedance, battery voltage, temperature and station gain setting. With the aid of the detailed report by Rogers and others (1980) other groups could fabricate instruments with the same design.

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Magnetostratigraphy of Sediments in the Atlantic Coastal Plain and Pacific Coast of the United States as an Aid for Dating Tectonic Deformation

14-08-0001-18377

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Investigation

1. Using the paleomagnetic polarity time scale, improve the geochronology of Pleistocene sediments in the Delmarva Peninsula (Delaware, Maryland, Virginia).

Results

1. To help improve the geochronology of Pleistocene sediments in the Delmarva Peninsula, we used samples from outcrop and fully oriented Shelby tube cores for paleomagnetic analysis. The samples were from the informal Accomack Fm and were either a.f. demagnetized (core samples) or thermally demagnetized (outcrop samples). The samples record normal paleomagnetic polarity and are interpreted to be Brunhes age (<0.73 m.y.).

Report

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Wasatch Front Surficial Geology

9550-01622

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Investigations

1. The purpose of the Wasatch Front Surficial Geology Project is to compile basic information about the surficial geology of the area so that it can be used by others to compile a microzonation map of earthquake hazards. Toward this end, surficial geologic and physical property maps of the area are being prepared. The project area has been separated into two segments: a northern segment that contains the urbanized portion of the Great Salt Lake and vicinity and a southern segment that contains the urbanized part of Provo and vicinity covered by a recently available map.

Results

The project was active for only 6 months in fiscal year 1980, during which time the following was accomplished:

1. The surficial geologic map of the northern segment was approved as an MF map by the Director April 1, 1980, and has been sent to the printer. The geology is shown at 1:100,000 in order to be compatible in scale with proposed publications and to be utilized by the Utah Geological and Mineral Survey in preparing maps of surficial geology of a larger area.

2. An open-file report of the results of laboratory analyses and engineering soil tests of samples from five test holes in the Lake Bonneville deposits is nearing completion. Results also will be used to evaluate susceptibility to liquefaction and in preparing the physical properties map.

3. The surficial geology of the urbanized portion of the Provo and vicinity map, also at a scale of 1:100,000, has been compiled from the mapping of others and adjusted to conform to the stratigraphic concepts used on the map of the northern portion of the Wasatch Front. After field checking, the map will be transmitted for review in preparation as an MF map.

4. The surficial map format includes a correlation chart that displays the differences of stratigraphic usage between earlier concepts based on several fluctuating lakes and this study based on field evidence of one major lake filling (Lake Bonneville) and a lowering with pauses at conspicuous shorelines, both major and minor. This study supplements stratigraphic studies underway by W. E. Scott (9530-02174).

5. Support of the project of W. W. Hays (9940-01919) included participation in preparing several papers and geologic support regarding seismograph data obtained from stations on different surficial materials along the Wasatch Front.

Reports

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Hays, W. W., Miller, R. D., and King, K. W., 1980, Ground response in the Salt Lake City-Ogden-Provo, Utah, urban corridor: World Conference on Earthquake Engineering, 7th, Ankara, Turkey, 1980, Proceedings, 6 p., with figures (in press).

Scott, W. E., McCoy, W. D., Shroba, R. R., and Miller, R. D., 1980, New interpretations of the late Quaternary history of Lake Bonneville, Western United States abs.: AMQUA, Biennial Meeting, 6th, Orono, Maine, August 18-20, 1980 (in press).

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

9540-01616

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Investigations

1. Continued investigation of the Quaternary geology of the upper Santa Ana Valley. Emphasis is now on the three dimensional distribution of the valley fill for ground response studies.

2. Continued paleomagnetic and K-Ar dating of young basalts in southern Mojave Desert, San Bernardino Mountains, San Gorgonio Pass, and northern Peninsular Ranges.

3. Continued fault studies in the San Gorgonio Pass and northern upper Santa Ana Valley.

4. Continued mapping of surficial materials of the Perris Block area.

Results

1. An age of approximately 2000 yrs B.P. was obtained from carbonaceous material collectd from an unfaulted horizon exposed in a trench across a fault scarp on Day Canyon. The unfaulted horizon extended about 1 m or halfway across the main zone of faulting; it was erosionally removed across the remaining part of the zone. This scarp is the geomorphically youngest appearing scarp of the Cucamonga fault zone and the date suggests the last ground rupture was prior to about 2000 yrs B.P. Based on fault scarp morphology, this scarp was previously considered to have been formed prior to about 800 yrs B.P.

2. A conglomerate unit mapped in the San Tuneteo Badlands contains a distinctive basement rock assemblage thought to be derived from the central San Bernardino Mountains across all recognized strands of the San Andreas fault zone. This conglomerate appears to be offset not over 25 km right laterally from its probable source terrain. An age of 700,000 to 1 m.y. B.P. was determined by C. A. Repenning from a fossil fauna from this conglomerate which places some constraint on the San Andreas in this area for this time interval.

Geologic Earthquake Hazards in Alaska

9310-01026

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Investigations

1. A study was made of uplifted shorelines in the Lynn Canal, Chatham Strait, and Glacier Bay areas of southeastern Alaska to determine the amount and rate of uplift since tidal bench marks were last surveyed in 1959.

2. Uplifted shorelines in Yakutat Bay were examined to determine the amount and nature of displacements resulting from the 1899 earthquakes as well as movement possibly resulting from pre-1899 earthquakes.

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

4. The meizoseismal area of the 28 February 1979 earthquake was investigated to evaluate geologic events related to that event.

Results

1. Reconnaissance study of the broad area of regional uplift in southeastern Alaska described by Hicks and Shofnos (1965) continues with average rates varying from 0.50 cm/yr at Salt Lake Bay, Chichagof Island, to 7.59 cm/yr at Composite Island, Glacier Bay. Since 1959 the locus of maximum uplift has apparently shifted from near Bartlett Cove in Glacier Bay 65 km northwestward to the vicinity of Composite Island--a shift which may reflect the rapid deglaciation of this area. Another broad zone of uplift that may be tectonic in origin is centered roughly on the Chilkat Range and has maximum uplift rates of about 3 cm/yr since 1959. Further more detailed studies are planned for 1980 to better define the uplift pattern in southeastern Alaska.

2. No definite pre-1899 uplifted shorelines were found that might be related to paleoearthquakes in the Yakutat Bay area. An extensive surface reported to be pre-1899 by Tarr and Martin (1911) along the east side of Yakutat Bay in the Logan Beach area has an even stand forest on it whose age is compatible with uplift in 1899. Elevation measurements suggest broad upwarp of that surface, rather than the highly irregular fault-bounded blocks, including local areas of submergence, as mapped by Tarr and Martin.

3. In the Icy Cape area there are three well-defined continuous Holocene marine terraces with beach angles at roughly 50-70', 100-120' and 200-240' that are cut into Pleistocene(?) fluvioglacial and beach ridge/lagoonal deposits.

The highest terrace is locally covered by wood-bearing Holocene glacial deposits. The lowest terrace locally is mantled with younger beach deposits to 7' above present mean higher high water (MHHW) and marine glacial deposits containing abundant driftwood and mollusk remains that are as much as 26.5' above present MHHW. Radiocarbon dating of wood, peat, and shells collected from the uplifted deposits should provide data on the emergence time-history of the terrace sequence in the Icy Cape area.

4. Major effects of the 28 February 1979 earthquake were snow avalanching and landslides in the foothills and central high core of the Saint Elias Mountains and local ground cracks in unconsolidated deposits along the margin of Malaspina Glacier. No surface faults were found.

Reports

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Plafker, George, and Campbell, R. C., 1979, The Border Ranges fault in the Saint Elias Mountains, in Johnson, K. M., and Williams, J. R., eds., The United States Geological Survey in Alaska: Accomplishments during 1978: U.S. Geological Survey Circular 804-B, p. B102-B104.

Plafker, George, and Bruns, T. R., Late Cenozoic subduction--rather than accretion--at the eastern end of the Aleutian Arc [abs., For Conference on Fore-arc Sedimentation and Tectonics in Modern and Ancient Subduction Zones to be held in London, England, June 23-25, 1980].

Seismic Zonation Studies in Los Angeles Basin

9940-01730

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Investigations

1. Statistical analysis of site transfer functions derived for locations in Los Angeles.

2. Statistical analysis of the comparison between earthquake and nuclear site transfer functions.

3. Preparation of a data report presenting all of the nuclear recordings and computed site transfer function for Los Angeles.

Results

1. For those recording sites where multiple recordings of nuclear explosions were made, the geometric mean site transfer function (STF) and its standard deviation were computed as a function period. The standard deviation ranges between 1.3 and 1.7 for all stations indicating good repeatability of the STF.

2. In order to compare the nuclear and earthquake derived STF we computed the ratio $R = (STF_{EQ}/STF_{NUC})$, as well as the cross correlation (ρ_{12}) of these two functions. These computations were carried out over four period bands: 0.2-10.0 s, D; 0.2-0.5 s, A; 0.5-1.0 s, B; 1.0-3.3 s, C. A total of 74 components from 26 stations were used to find R = 1.06 and $\rho_{12} = 0.29$ across the entire period band (D). If the STF_{NUC} perfectly reproduced the STF_{EQ}, R and ρ_{12} would each have a value of 1.0. The hypothesis that R = 1 cannot be rejected at the 1 percent level, and the hypothesis that $\rho_{12} = 0$ can be rejected at the 1 percent level. These results indicate that while the shape of the transfer functions exhibits a moderately good match, the mean levels of the STF from both sources are nearly equal.

3. Over the partial period bands A, B, and C, the mean value of R are 1.18, 1.02, and 1.20, respectively, and the correlation coefficients are equal to -0.14, -0.10, and 0.56. This result shows that there is no shape correlation at short-periods where the STF is highly oscillatory, but there is good correlation at long-periods. Regardless of the shape correlation, the nuclear STF tends to reproduce the mean level of the earthquake STF.

4. The rock site used as the base station in these comparisons was Griffith Park Observatory. When the computations described above were performed using CIT as the base site, it was found that the nuclear STF was consistently higher than the earthquake STF at short-periods, and the correlation coefficient was lower.

Reports

Rogers, A. M., Covington, P. A., and Borcherdt, R. D., 1980, A comparison of ground response in the Los Angeles region from nuclear explosions and the 1971 San Fernando earthquake: Seventh World Conference on Earthquake Engineering, Istanbul, Turkey, 8 p.

Basement Tectonic Framework Studies
San Andreas Fault System

9950-01291

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Investigations

1. Preparation of an Open-File geologic map and accompanying report on basement rocks of the southernmost Sierra Nevada including new thoughts on the Sierran "tail" and on offset problems at the west end of the Garlock fault.

2. Continued preparation of a somewhat comprehensive report on the tectonic framework of the metamorphic and plutonic rocks of the southernmost Sierra Nevada.

3. Slabbing, staining, determination of specific gravity, and modal analysis of more than 100 granitic samples collected along the Kern Canyon and Breckenridge fault zones for correlation purposes (laboratory work by Deborah Goaldman, San Jose State University).

Results

Geologic investigations in the southernmost Sierra Nevada suggest left-lateral offsets on the order of 50 km near the west end of the Garlock fault based on; 1) the correlation along the fault zone of a distinctive amphibolitic gneiss with coarse red haloed garnets; 2) the setting of fault horses of Rand Schist, relative to their parent terrane; and 3) the presence of similar biotite granodiorite on opposite sides of the fault (see fig.). These offset estimates, only somewhat less than previous estimates of about 60 km of left-lateral offset of basement units and structures in the central and eastern parts of the fault zone, seem to pose a dilemma!

The dilemma of major movement near the end of the fault zone can be resolved rather simply (perhaps too simply!) by having the Garlock fault merge onto the San Andreas "Freeway"--after all this is California!

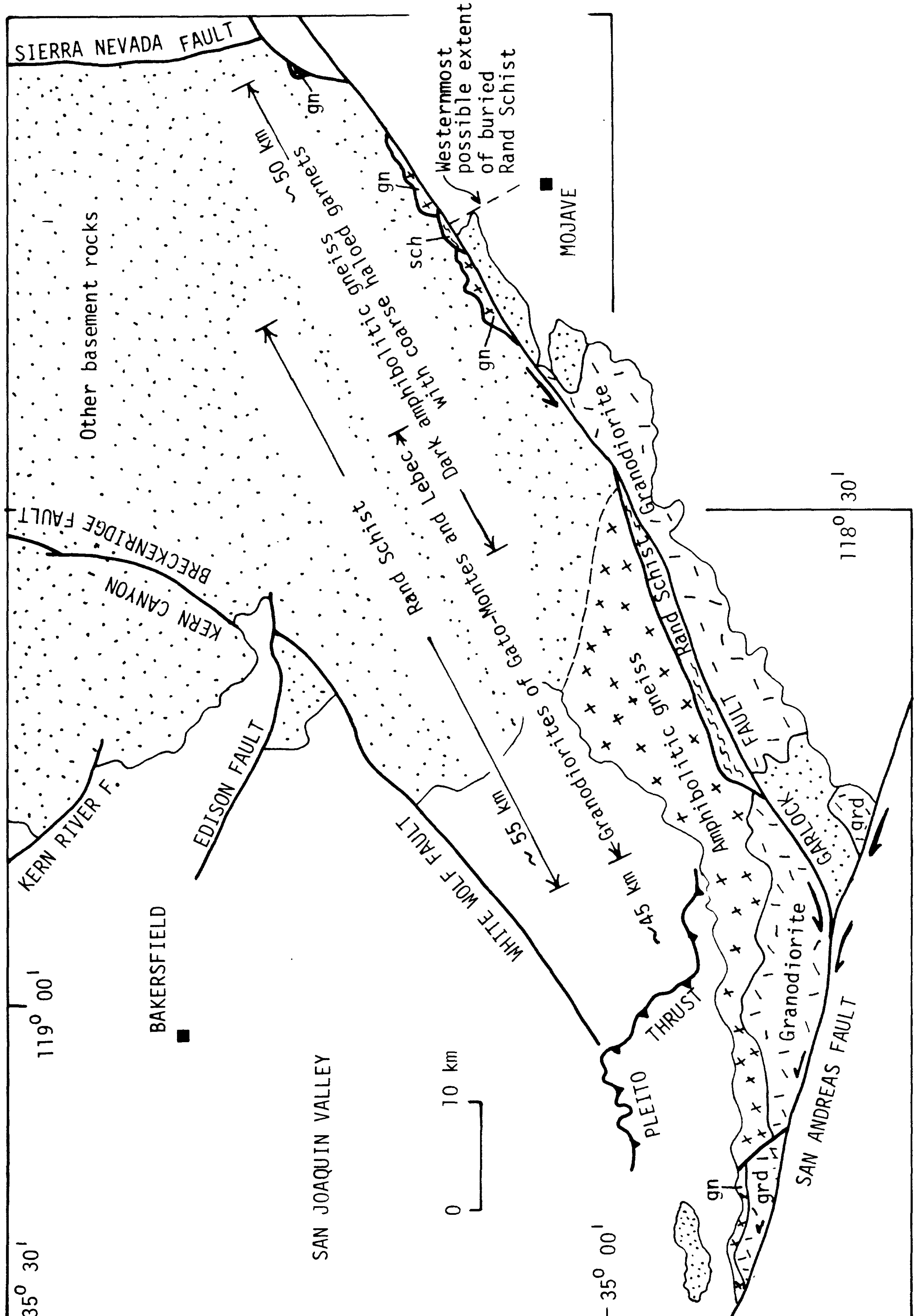
The north side of the Garlock fault (the Sierran block) has been much distended and displaced relative to the more stable south side (Mojave block) by expansion of the Basin and Range Province according to the gospel of Davis and Burchfiel (1973). The Garlock fault does appear to merge into the San Andreas fault; which allows the Sierran block to ride out a short distance onto the northeast side of the San Andreas fault. Movement on the more active plate southwest of the San Andreas fault would aid the distension of the Sierran block as a drag effect and might also be responsible for some bending of the Sierran "tail".

The Big Pine fault, in the past (Hill and Dibblee, 1953; Davis and Burchfiel, 1973) has been considered to be a slightly offset western continuation of the Garlock fault. If the basement relations I have proposed are valid, the Big Pine fault is unrelated to the Garlock fault and the Garlock fault ends as it dies out along the San Andreas fault zone. The two faults are in "competition" for some distance until the westward dying out of Basin and Range distension returns full dominance to the right-lateral San Andreas fault system.

Reports

Ross, D. C., and McCulloch, D. S., 1979, Cross section of the southern Coast Ranges and San Joaquin Valley from offshore of Point Sur to Madera, California: Geological Society of America Map and Chart Series, MC-28H, scale 1:250,000, 4 p. text.

Ross, D. C., 1980, Reconnaissance geologic map of basement rocks of the southernmost Sierra Nevada (north to 35° 30' N.): U.S. Geological Survey Open-File Report 80-307, scale 1:125,000, 22 p. text.



Suggested offsets of basement rock units across the western part of the Garlock fault

Quaternary Stratigraphy of the Wasatch Front

9530-02174

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Investigations

1. W. D. McCoy, Institute of Arctic and Alpine Research, University of Colorado, has completed amino-acid analyses of 21 samples of gastropod shells from deposits of Lake Bonneville at localities in the eastern Bonneville basin.

2. New radiocarbon dates, amino-acid determinations, soils data, and stratigraphic information are providing better control on the age and magnitude of Lake Bonneville fluctuations.

Results

1. Deposits of the last three cycles of Lake Bonneville can be reliably differentiated and correlated by measuring the extent of isoleucine epimerization in both the free fraction and the total acid hydrolysate of amino acids in freshwater gastropod shells (*Lymnaea* and *Amnicola*). Because the rate of isoleucine epimerization varies between genera, each genus within a unit has a characteristic range of alloisoleucine to isoleucine ratios. In deposits at Little Valley, near Promontory Point, and at several localities along the Wasatch Front where two or three exposed units are separated by unconformities, shells exhibit the following ratios:

	Lymnaea		*Amnicola*	
Lake cycle	Free	Hydrolysate	Free	Hydrolysate
last	0.15-0.24(25)	0.08-0.17(28)	0.18-0.29(16)	0.08-0.22(16)
penultimate	0.51(1)	0.26-0.27(2)	0.49-0.56(9)	0.26-0.32(8)
pre-penultimate	- -(0)	- -(0)	0.60-0.66(8)	0.38-0.41(8)

(n) = number of determinations

The range of ratios for either genus from a single horizon at a site is generally less than 10 percent. The larger range of values from deposits of the last cycle is due to the greater range in age of sampled horizons in relation to the age of the deposits and to greater resolution with younger deposits. In fact, significantly different ratios are obtained from transgressive deposits of the last cycle at various altitudes and from overlying, deeper water deposits.

As this method has provided valuable and consistent relative-age information, laboratory studies of reaction kinetics are underway to explore the possibility of obtaining numerical ages.

2. Recent investigations of the stratigraphy and age of Lake Bonneville deposits have led to the following modifications of previously published interpretations of lake-level history during the last two lake cycles (fig. 1). After 11,000 ya (years ago), lake fluctuations were restricted

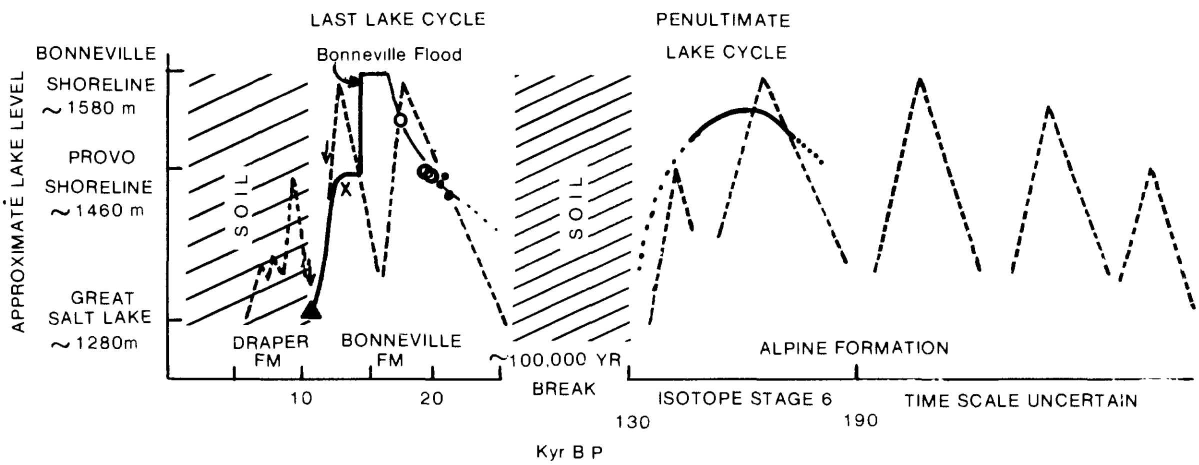

Figure 1. Time-lake level diagrams for last two major cycles of Lake Bonneville. Dashed line represents R. B. Morrison's interpretation of 1965 and as revised in 1975. Solid and dotted (speculative) lines are from this study and are defined by the following key ^{14}C dates (many others on shell, tufa, and bone are ignored): ○ new dates from this study provided by Meyer Rubin (U.S. Geological Survey) on wood and charcoal from transgressive deposits: ● dates on wood from transgressive deposits in Little Valley published by W. S. Broecker and Aaron Kaufman and by Morrison in 1965; × shell date of R. C. Bright published in 1963 and ▲ shell date of R. D. Miller and others published in 1980, both of which relate closely to lake level; ↓ dates on organic matter of Bright and J. D. Jennings published in 1963 and 1957, respectively, from sediments deposited above the level of Lake Bonneville. Altitudes are shown in relation to local altitudes of Provo and Bonneville shorelines and the present altitude of Great Salt Lake.

to within about 15 m of the level of present Great Salt Lake. Deposits of R. B. Morrison's type lower member of the Draper Formation, which were thought to record a rise close to the Provo level at about 9,500 ya, are not of lacustrine origin but are fine-grained alluvium and colluvium of Holocene age. Lake recession from the Provo shoreline to the level of 11,000 ya occurrred in less than 3,000 yr (years). The time of occupation of the Bonneville shoreline and subsequent fall to the Provo shoreline is not precisely known. A new date of 17,580±170 yr. B.P. (W-4451) on charcoal in transgressive deposits from about

65 m below the level of the Bonneville shoreline and several dates of 12,000 to 14,000 yr on deposits associated with and post-dating the Provo shoreline indicate there was only 2,500-5,500 yr for 1) the remaining transgression to and formation of the Bonneville shoreline, 2) the Bonneville Flood, and 3) the stand at the Provo shoreline. Other new dates on wood of 19,580±280 yr B.P. (W-4445) and 19,700±200 yr B.P. (W-4421) from transgressive deposits that lie 50 m and 20 m below the level of the Provo shoreline at Little Valley and North Salt Lake, respectively, combined with previous dates, provide knowledge of the lake level about 20,000 ya. The known shore record does not yet provide much information on lake levels for the preceding part of the Wisconsin other than suggesting that no lake exceeded the relatively low level of 20,000 ya.

The penultimate cycle appears to be broadly correlative with isotope stage 6 of the marine record (130,000 to 190,000 ya), as was suggested by Morrison in 1975, rather than being of middle or early Wisconsin age. Buried soils or soil complexes preserved between deposits of the last and penultimate lake cycles are better developed than soils formed in post-Lake Bonneville time. The older soils have calcic horizons that contain about 10 times more calcium carbonate than the post-Bonneville soils and have better developed argillic B horizons as well. Comparison with other sequences suggests that the buried soils represent about 100,000 yr of development. In addition, gastropods from deposits of the penultimate cycle have ratios of alloisoleucine to isoleucine (allo-iso) about twice as great as ratios from gastropods from deposits of the last lake cycle. Because of the nonlinear increase in allo-iso with time and because of the probable cooler average diagenetic temperature during the last 140,000 yr as compared to the last 15,000 yr, the doubling of allo/iso is indicative of as much as a tenfold greater age.

Deposits of the penultimate cycle, which are identified by their stratigraphic position below buried soils and/or by amino-acid analysis of enclosed fossils, have been found only at altitudes below about midway between local altitudes of Provo and Bonneville shorelines, although isostatic and tectonic effects may introduce complications. As exposures are few and widely separated, little detail is known about this cycle. Many of the deposits in Little Valley from which major fluctuations of Alpine time were inferred by Morrison in 1965 are thought by us to have been deposited during the transgression of the last lake cycle, based on stratigraphic, ^{14}C, and amino-acid evidence. The lack of evidence of penultimate cycle rises close to the level of the Bonneville shoreline suggests that overflow occurred only during the last lake cycle. The cause of the 65-m higher level of the last lake cycle is uncertain, however, the suggestion by R. C. Bright in 1963 that Bear River, Idaho, was diverted into the Bonneville basin during the time interval between the last two lake cycles seems plausible.

Reports

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Scott, W. E., and Shroba, R. R., 1980, Stratigraphic significance and variability of soils buried by deposits of the last cycle of Lake Bonneville: Geological Society America Abstracts with Programs, v. 12, no. 6, p. 304.

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

Salton Trough Tectonics and Quaternary Faulting

9940-01292

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Investigations

1. Field investigations and surface faulting associated with the Imperial Valley earthquake of October 15, 1979. Investigations included: (1) comprehensive mapping of surface ruptures along the Imperial fault and Brawley fault zone in central Imperial Valley; (2) documentation of variation of displacement along the length of the faults and the growth of cumulative slip for several months after the earthquake; (3) repeated surveys of near field leveling arrays across the two faults.

2. Map recently active traces of Elsinore fault south of Lake Henshaw and San Andreas fault south of Transverse Ranges.

3. Analyze cores taken from opposite sides of Garlock fault at Koehn Lake, California.

Results

1. A 30-km-long segment of the Imperial fault shifted right laterally at the surface by a maximum of at least 0.8 m, including afterslip. Although the location of the fault trace coincides with that of the 1940 break, the 1979 lateral displacements are smaller than those of 1940 at the same places except in a 2.5-km interval near U.S. Interstate Highway 8. The southeast limit of new faulting lies near the midpoint of the 1940 break, which extended into Mexico, but the north terminus of the 1979 Imperial fault rupture lies 3 km beyond the northernmost documented 1940 rupture. Early aerial photographs of the Imperial fault indicate that northernmost 1979 faulting follows older Holocene traces, and probably these traces moved in 1940 as well. Maximum lateral slip measured 55-60 cm the first day after the earthquake about 1.4 km from the south end of the rupture, and afterslip shifted the point of maximum cumulative offset northward about 3.5 km within two days. By December 4, coseismic slip plus >34 cm of afterslip near that locality totaled 0.8 m. Three weeks after the earthquake, average dextral slip was about 0.3 m for the length of the Imperial fault surface break.

The Brawley fault zone east of the northern Imperial fault ruptured discontinuously and along multiple strands over a length of 13.1 km. The faulting extended about 1 km northward and 1.5 km southward beyond the traces first known from an earthquake swarm in 1975. Displacement was dominantly vertical, similar to that on the northern Imperial fault. The Mesquite basin block dropped relatively between the two faults. Maximum vertical- and dextral-displacement components on the Brawley fault zone were 9 to 10 cm and 8 cm, respectively.

Three short (<250 m) leveling arrays were installed across the Brawley fault zone at Keystone, Harris and Worthington Roads following the January-February 1975 Imperial Valley earthquake swarm. In 1976 an array was also installed at Harris Road crossing the Imperial fault. Releveling was performed approximately annually or more often when deformation was observed.

Postearthquake releveling began 43 hours after the earthquake of October 15, 1979, (M_L = 6.6) and was repeated at 5-day intervals until November 1. Because of the diminishing rate of afterslip, surveying frequency was reduced thereafter.

Preearthquake movement on the Imperial fault array between January 1976 to April 1979 generally took the form of tilting toward Mesquite Basin; however, apparent discrete slip (3 cm) may have been a delayed effect of the nearby October 1977 earthquake swarm (∿5 km distant; maximum M_L = 4.3). The largest tilt, 54 microradians, was observed between January and April, 1979. No significant tectonic deformation was detected from April to July 1979. Although the duration of the tilting period is not tightly constrained, it may agree approximately with the expected time interval for precursory ground deformation for an earthquake of the magnitude of the October 15, 1979 event.

The Brawley fault arrays appeared relatively quiescent between January 1976 to April 1979; except that a small displacement (0.8 cm) occurred at Harris Road between 25 October 1977 to January 1979, the same time interval when the displacement on the Imperial fault also appeared.

Releveling on 17 October 1979 showed 16 cm vertical displacement at the Imperial fault trace. An asymmetric profile of vertical deformation suggests an obliquely dipping fault. Releveling after an M_L = 4.4 (∿5 km distant) aftershock showed no immediate vertical slip (7 minutes between event and resurvey). The total vertical displacement (coseismic slip plus afterslip) increased logarithmically with time. By 29 December 1979, cumulative afterslip was 14 cm, or about the same as coseismic slip.

From north to south, the Brawley fault showed coseismic displacements 9-10 cm at Keystone Road, 6.3 and ∿7 cm on the west and east breaks at Harris Road and 9.5 cm at Worthington Road. No large-scale (>1 cm) afterslip occurred on the Brawley fault.

2. Elsinor fault map (I-map series) submitted to branch.

3. Careful inspection of Koehn Lake cores shows severe local disturbance from the coring operation. Only one ash horizon could be positively identified from one of the cores; A. M. Sarna will attempt to identify it,

although the sample is very small. Sarna will also attempt a trace element analysis of carbonate-rich horizons to see if inter-core correlations are possible.

Reports

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Quaternary Framework for Earthquake Studies
Los Angeles, California

9540-01611

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Investigations

1. Assigned to separate investigations 7/1/79-2/29/80, 5 months of this reporting period.

2. Initiated and completed an assessment of differential subsidence induced by withdrawal of groundwater between 1945 and 1970 in the upper Santa Clara river drainage basin.

3. Assisted R. P. Sharp and M. G. Bonilla by mapping surface faulting and ground failures associated with the October 1979, earthquakes on the Imperial fault, Imperial Valley, California.

4. Continued 1/24000 geomorphic/photogeologic/soil stratigraphic mapping of the surficial geology of the Los Angeles basin.

5. Completed mapping of surface faulting and of ground failure effects associated with the January 1980, earthquakes near Livermore, California.

6. Continued describing, sampling, and laboratory analyses of pedogenic soils in the Los Angeles basin, the Vidal area, and the San Gorgonio pass area, southern California (McFadden and Tinsley).

7. Completed compilation of 1/24000 maps showing patterns of historical flooding in the San Fernando Valley, California.

Results

1. See below, under Reports.

2. Collected subsurface geologic data and hydrologic data indicating timing and magnitude of observed drawdowns near Saugus.

3. Field notes and photographs were transmitted to R. P. Sharp for compilation and inclusion in forthcoming report of investigations.

4. Surficial geologic mapping is 65 percent completed.

5. Conjugate movement occurred on the Greenville and Las Positas faults during and after the earthquake of January 1980. Left-lateral displacements and left lateral separation were detected using alinement arrays (P. Hansh) on right-stepping en echelon fractures. Propagation of fractures persisting for several weeks following the earthquake. Right-lateral displacement of about 20-30 mm was observed on the Greenville fault. Non-tectonic ground failure complicated the picture of surface faulting in many areas on the Greenville fault.

6. Laboratory analyses are approximately 50 percent completed.

7. Areas of the San Fernando Valley have flooded up to 5 times in nine major flood years between 1934 and 1956.

Reports

Yerkes, R. F., Greene, H. G., Tinsley, J. C., and Lajoie, K. R., 1980, Seismotectonic setting of Santa Barbara Channel area, southern California: U.S. Geological Survey Open-file Report 80-299 (for quick release on 20 Feb. 1980), 22 p., 2 pls; approved for publication as MF 1169.

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

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, including the Municipality of Anchorage, 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 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 related to ground failure in the region. The present study involves {1} detailed determination of present-day susceptability for sensitive clay failure and liquefaction of Quaternary soils in response to a seismic event, {2} characterization and mapping of soil units exhibiting failure potential modes, and {3} establishing an engineering soils data bank of geotechnical borehole logs and associated testing results for the Upper Cook Inlet region.

Results

{1} I have initiated a data bank system for subsurface engineering and geologic information obtained from trenches and boreholes by municipal, state and federal agencies, and by industry. Presently the information is being stored in its original report format with a Kardex catalogue file for data scope and acquisition reference. Several thousand sites are now on file for the areas of Anchorage, Eagle River, Eklutna, Peters Creek, Palmer, Wasilla, Willow and Goose Bay. The acquisition of data continues although a method of public access has not yet been developed.

{2} I have advanced an hypothesis which suggests that discrete geologic facies exist in the Bootlegger Cove formation, that these facies vary in their engineering characteristics based upon differing geologic histories and modern ambient conditions, and that these resultant engineering geologic facies may be characterized in terms of static and dynamic behaviour for earthquake hazard assessment. The Government Hill area of Anchorage {where lies the Port of Anchorage, major fuel depots, and Elmendorf Air Force Base} was used as a model area to test this concept and has resulted in the identification of seven engineering geologic facies, among them one being moderately to highly sensitive, and another often susceptible to liquefaction. These facies have distinct parametric characterizations and are mappable in three dimensions, which has been made possible by use of my newly established data bank. Multiple publications are in preparation as a result of this study. I have targeted Southern Anchorage as a second, expanded study area which will include the International Airport and the now-infamous Turnagain Heights slide area.

{3} Twenty-five slope indicator casings were installed in the major 1964 Anchorage landslides within two months after the event with three additional casings being installed in the past four years. Of these I have found 13 to still exist which I have subsequently been able to monitor with a Digitilt Inclinometer. In addition I have been able to obtain the initial 1964/1965 data on the casings and have found that nearly all had not been measured since that time. I am presently working through the strain history of the slide zones for the 15-year time interval as represented by these casings. Publication of results is projected within six months.

{4} I have completed a first phase field reconnaissance of exposures on the perimeter of Upper Cook Inlet utilizing fixed wing aircraft and helicopter support to document the interrelationship of geologic facies, engineering soil characteristics, existent hydrologic conditions, and ground failure. This work has produced more questions than answers and a second phase of field work is projected for the summer/fall of 1980.

Geothermal Tectonic Seismic Studies - Olympic Peninsula

9930-02097

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Investigations

1. A seismicity study of the Olympic Peninsula was begun using a partly installed seismic network (6 of 12 planned stations operating). The study is oriented toward determining whether the Calawah Fault, a major mapped deformational zone striking WNW across the northern Olympic Peninsula, is seismically active. The new seismic stations will help constrain both locations and focal mechanisms of earthquakes throughout the Olympic Mountains and in western Puget Sound.

2. Regional blasts from a strip mine operation southeast of the Olympic Peninsula are being used to determine gross crustal structure of the region. Several large, shallow earthquakes near Vancouver Island, Mt. Hood, and in eastern Washington are being studied in an effort to reverse travel paths beneath the Olympic Mountains in order to more tightly constrain the crustal structure.

Results

1. The new seismic network stations have not been operating long enough to provide a significant sample of the seismic activity on the western Olympic Peninsula. A few earthquakes have been recorded on the early records, but station coverage is not sufficient to locate the events. The S-P times are on the order of a few seconds, indicating that the events are occurring locally.

2. Apparent velocity studies for upper crustal travel paths across the Olympic Peninsula are slower (6.2 km/sec) than the apparent velocities for similar distance ranges in the Puget Sound region to the west (6.6 km/sec). The transition zone between these two velocities appears to be very sharp, occurring over a distance of 10-20 km.

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

Contract No. 14-08-0001-16822

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INVESTIGATIONS

1. Analysis of the Año Nuevo thrust fault to determine the recency of movement, number of episodes of movement, recurrence interval, displacement rates and expected magnitude of earthquake events on this secondary trace within the San Gregorio fault zone.

2. Analysis of the sedimentary deposits and associated fossils on the first marine terrace at Point Año Nuevo to determine the history of the formation of this broad marine terrace.

3. Analysis of the faults within the Frijoles fault complex to determine the history of late Pleistocene and Holocene behavior (displacement rates, recurrence interval, recency of movement, etc.). The Frijoles fault complex is one of two primary traces that comprises the San Gregorio fault zone and consists of numerous en echelon Reidel shears and P-shears that exhibit both reverse and strike slip displacement. Part of the study is to attempt to determine the relationship of movement along the reverse faults with the movement patterns occurring along the strike slip traces.

RESULTS

1. Detailed mapping of the terrace stratigraphy and the Año Nuevo thrust fault in sea cliff exposures located along the south shore of Point Año Nuevo indicates that since the formation of the erosional platform of the first marine terrace (105,000 years B.P.) a minimum of six and possibly eight faulting events have occurred along this fault. Detailed mapping of exposures in an exploratory trench located 300 feet northwest of the sea cliff indicates repeated fault movement with the most recent faulting event offsetting deposits of an interdune pond. Organic material in the matrix of the pond deposits has yielded a C^{14} date of 6060 ± 105 yrs. B.P. (Beta, 1083), hence there is strong evidence of Holocene activity along this fault.

   Comparison of and correlation of events indicated on the logs of the exploratory trench and sea cliff indicate a total of seven to nine faulting events having occurred between 105,000 years B.P. and 6000 years B.P. Each faulting event was the result of between 1 1/2-4 feet of vertical displacement accompanied by surface rupture. Faulting events that resulted in less than 1 1/2 feet of vertical displacement and that did not produce surface rupture and/or a scarp cannot be recognized as they are not preserved in the stratigraphic record. The Año Nuevo thrust fault has consequently been the site of seven to nine faulting events over a period of 99-100,000 years.

Recurrence intervals would range from 25,000 years (for a vertical displacement of 4 feet) in the seven event model to a minimum of 9,000 years (for a vertical displacement of 1 1/2 feet) in the nine event model. The average recurrence interval for an earthquake producing surface rupture is 12,500-16,500 years.

Because of a lack of understanding of the relationship of the thrust fault to the principal displacement shears it is difficult to assign a magnitude to the earthquake producing such faulting events, but using the fault parameter relationships of Bonilla we would suggest earthquakes between magnitude 5.5 and 7.0 occurring on the principal fault breaks as being the smallest capable of creating the displacements of the size indicated on this secondary trace.

2. We have collected fossil material from several locations near the base of the first marine terrace at Point Año Nuevo and have completed detailed stratigraphic sections within the marine terrace deposits. Amino-acid age dates on the fossil materials indicate that to the southwest of the Frijoles fault at Point Año Nuevo the wave cut platform is 105,000 years old. A step present in the old wave cut platform near the Point is merely an irregularity in the platform and not the shoreline of the 70-80,000 year B.P. high stand of sea level.

3. Detailed geologic mapping and logging of the geology associated with a reverse fault exposed in an abandoned quarry, the spillway for a dam, and three exploratory trenches indicates, the Frijoles fault is a complex zone of faulting that exhibits both right lateral strike slip and reverse components of movement. Most of the movement taking place along Reidel shears and P-shears and is comparable to the post-peak structure of a shear zone as indicated by Tchalenko (1970, p. 1637, 1638). The majority of the fault movement occurring in this fault zone occurs along the Frijoles fault, and the relationship of the movement on the reverse fault (a secondary fault) to the movement on the primary trace (based on our work) appears to be at a ratio lying between 1:7 and 1:20. Our best estimate is that the ratio is about 1:10 for the amount of horizontal slip occurring along the Cascade Quarry reverse fault and the principal displacement zone of the Frijoles fault.

In our study of the Cascade Quarry reverse fault, we noted that the stratigraphy on the foot wall block indicates a minimum of eight episodes of colluvial deposition, probably off of a fault scarp, which exhibit very weakly developed soils. Each of these deposits is interpreted to indicate a faulting event that resulted in 3 to 4.5 feet of vertical displacement accompanied by surface rupture and scarp formation. Since only less than half of the marine terrace deposits on the down thrown block are exposed, it is not unreasonable to assume that probably another seven or eight similar deposits lie buried, and that the reverse fault has moved a minimum of 14 to 16 times in the past 105,000 years. If the ratio of faulting events on the reverse fault to the number of faulting events on the principal displacement shear is the same as the ratio of the total horizontal offset and slip rate, namely 1:10, then approximately 140-160 faulting events must have occurred along the Frijoles fault during the past 105,000 years. The recurrence interval for faulting events would therefore between 650-760 years. Using the average maximum surface displacement for events as determined from a study of the reverse fault the expected Richter magnitude for these events is 7.0-7.5.

REPORTS

Weber, G. E., and Cotton, W. R., 1979, Recurrence Intervals for Surface Faulting Along the Frijoles Fault and Año Nuevo Thrust Fault of the San Gregorio Fault Zone, San Mateo County, California. Abstract, Geological Society of America Abstracts with Programs, vol. 11, no. 3, February 1979.

Weber, G. E., Cotton, W. R., and Oshiro, L. K., 1979, Recurrence Intervals for Major Earthquakes and Surface Rupture Along the San Gregorio Fault Zone. in Field Trip Guide, Coastal Tectonics and Coastal Geologic Hazards in Santa Cruz and San Mateo Counties, California. 75th Annual Mtg. of Cordilleran Section of Geol. Soc. America., p. 112-119.

REFERENCES CITED

Tchalenko, J. S., 1970, Similarities between shear zones of different magnitudes, Geol. Soc. America Bull. v. 81, no. 6, p. 1625-1640.

Tectonic Tilt Measurements Using Lake Levels

9950-02396
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Investigations

Continuous water level measurements since 1976 from two points on the Great Salt Lake, Utah, have been analyzed. Measurements made in southern Alaska are being compared to measurements made in 1964 and 1966. Early in the summer of 1980, lake levels established in the summer of 1979 in southeastern Alaska will be remeasured to detect tilt over the previous year. Efforts will be made in the Salt Lake, Utah area to better define and interpret apparent tilting over the Great Salt Lake.

Results

1. Preliminary 1979 data from the Great Salt Lake, Utah, shows a significant change in differenced water levels measured at the Promintory Point Gauge and at the Boat Harbor Gauge, 50 km south. The difference change amounts to 30 mm ± 15 mm. Interpreted as apparent bedrock tilt in a north-south direction, the change amounts to 0.6 ± 0.3 microradians down to the south.

2. Comparison of 1979 Alaskan-lake measurements with 1966 water-levels has established a lack of tilt over eastern Iliamna Lake (tilt less than 0.1 microradian), but indicates possible tilt on Klutina Lake, which will be verified in the summer of 1980. Other Alaskan lake measurements are being evaluated.

Reports

Wilson, M. E. and Wood, W. H., 1980, Tectonic Tilt Rates Derived from Lake-Level Measurements, Salton Sea, California: Science, 207, p183-186.

Earthquake Hazards Studies, Ventura basin and Metropolitan Los Angeles basin areas, southern California

9540-01615

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Investigations (Yerkes)[1]

1. Continued to completion collection and interpretation of subsurface (exploratory well) data on attitude and displacement history of the Ventura fault.

2. Continued to completion collection and interpretation of marine geophysical and well data to evaluate structure and deformational history of western Santa Barbara Channel area.

3. Began evaluation of newly-acquired deep-well data in central and eastern Santa Barbara Channel, plus well and geophysical data bearing on structural history of Santa Barbara Channel-Ventura basin area.

4. Began evaluation of geophysical maps of offshore Los Ageles basin--Orange County areas.

(Sarna-Wojcicki)

5. Continued to completion a summary report on chemical analyses, correlations, and ages of late Cenozoic tephra units of east-central and southern California. This work documents the identification and correlation of several well dated Quaternary tephra horizons, including six ashes within the deformed Ventura basin, making it possible to estimate rates of deposition and deformation within this area of the western Transverse Ranges.

6. Sampled a stratigraphic section on the north limb of the Ventura Avenue anticline, west of the Ventura River, for paleomagnetic stratigraphy (in cooperation with J. C. Liddicoat, Lamont-Doherty Observatory and K. R. Lajoie BGM & F (9940-01623). This section contains four lower to mid-Quaternary ashes which have been correlated to tephra units of known radiometric age. Paleomagnetic stratigraphy will help refine further the chronology worked out on the basis of the ashes, and the deformational history.

Results (Yerkes)[1]

Previously reported (Vol. IX, p. 48-49)

[1]Assigned to separate investigations 7/1/79-2/29/80, 5 months of reporting period

Reports

Yerkes, R. F. Greene, H. G., Tinsley, J. C., and Lajoie, K. R., 1980, Seismotectonic setting of Santa Barbara Channel area, southern California: U.S. Geological Survey Open-File Report 80-299 (for quick release on 20 Feb. 1980), 22 p., 2 pls.; approved for publication as MF 1169.

Sarna-Wojcicki, A. M., Bowman, H. R., Meyer, C. E., Russell, P. C., Asaro, Frank, Michael, Helen, Rowe, J. J., Jr., and Baedecker, P. A., 1980, Chemcial analyses, correlations, and ages of late Cenozoic tephra units of east-central and southern California: U.S. Geol. Survey Open-File Report 80-231, 51 p. approved.

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.

Results

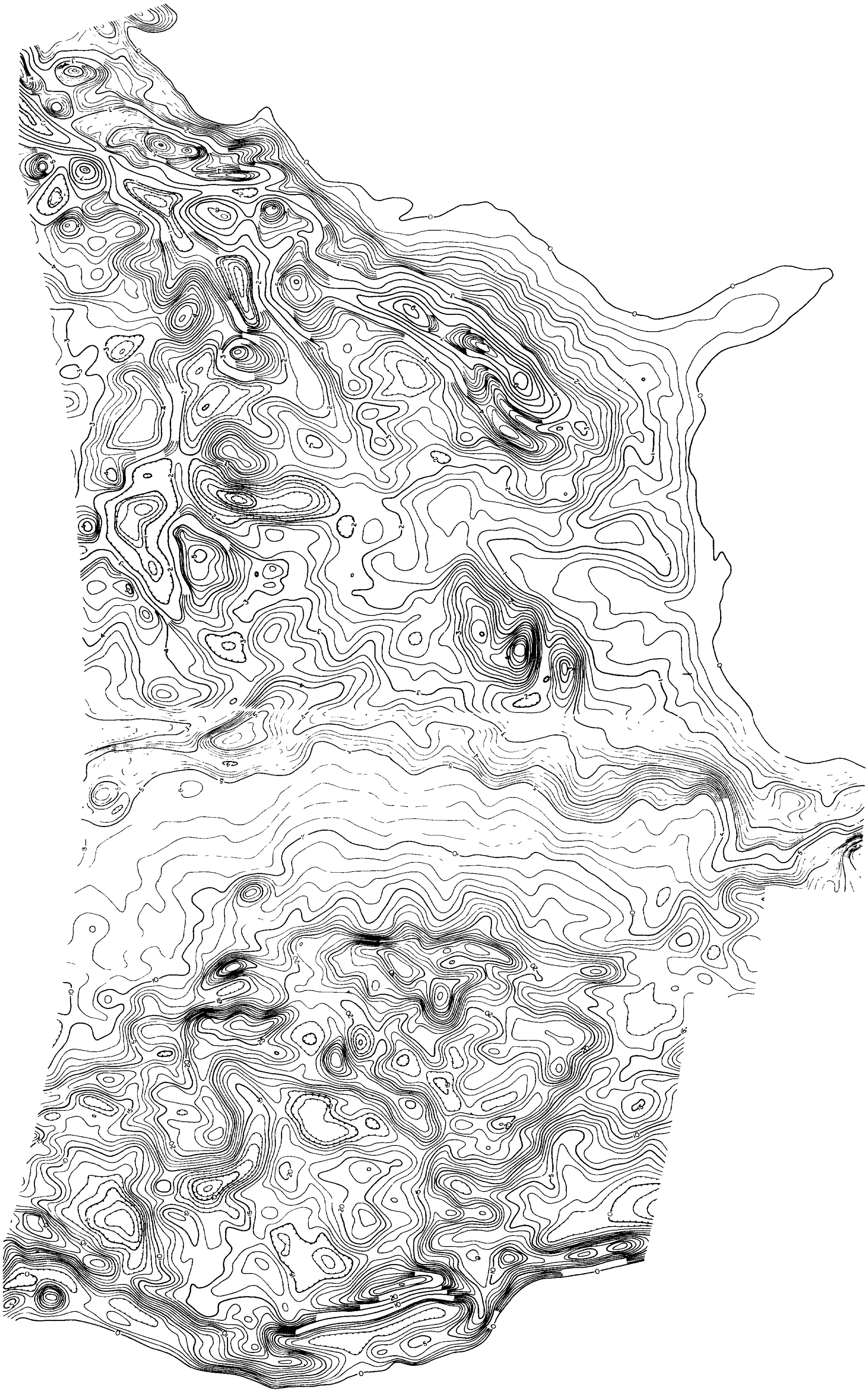
1. A preliminary version of the gravity map of Pennsylvania was exhibited. A final version at a scale of 1:250,000 with a contour interval of two milligals is being prepared.

2. An average elevation map of the conterminous United States was produced at a scale of 1:2,500,000; 20 m contours in the east, 100 m in the west. This map will appear as GP-933. A reduced version appears on the following page. The average elevations were computed from the average elevations of a 3x3 array of 15 minute quadrangles, counting the center quadrangle twice.

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

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

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



Reports

Diment, W. H., 1980, Geology and geophysics of geothermal areas, in Kestin, J., ed., A sourcebook on the production of electricity from geothermal energy: Washington, D.C., U.S. Government Printing Office, (in press).

Diment, W. H., Muller, O. H., and Lavin, P. M., 1979, Basement tectonics of New York and Pennsylvania as revealed by gravity and magnetic studies: in Wones, D. R., ed., The Caledonides in the U.S.A., Proceedings of the 1979 Project 27 Meeting: Blacksburg, Virginia, Department of Geological Sciences, Virginia Polytechnic Institute and State University, p. 221-227.

Diment, W. H., and Urban, T. C., 1980, An average elevation map of the conterminous United States (Gilluly averaging method): U.S. Geological Survey Map, GP-933 (in press).

Muller, O. H., Ackerman, H. D., Diment, W. H., Lavin, P. M., LeClair, L. D., Revetta, F. A., Sumner, J. R., Trembley, J. A., and Urban, T. C., 1979, A preliminary gravity map of Pennsylvania: Geological Society of America, Abstracts with Programs, v. 11, p. 46.

Muller, O. H., Lavin, P. M., and Diment, W. H., 1979, Basement tectonics of New York and Pennsylvania as revealed by gravity and magnetic studies: Abstracts, the Caledonides in the U.S.A., I.G.C.P. Project: Caledonide Orogen, Blacksburg, Virginia, Department of Geological Sciences, Virginia Polytechnic Institute and State University, p. A12.

Diment, W. H., 1980, Significance of the aseismic regions of the eastern United States: Geological Society of America, Abstracts with Programs, v. 8, p. 30-31.

Muller, O. H., Diment, W. H., and Lavin, P. M., 1980, Transverse gravity features and seismicity in New York and Pennsylvania: Geological Society of America, Abstracts with Programs, v. 8, p. 74.

Muller, O. H., Lavin, P. M., Diment, W. H., 1980, A major northwest trending Precambrian strike slip fault in Pennsylvania: EOS, American Geophysical Union Transactions (Accepted).

Tectonic History of Eastern Ozark Uplift

9530-01930

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Investigations

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

2. Began compilation of maps of the western part of the upper Mississippi embayment (scale 1:250,000) showing structure contours drawn on the top of rocks of Paleozoic age, the geographic limits of plutons in the area, and the limits of the Mississippi valley graben.

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

Results

Structure contours drawn on the contact between the top of undifferentiated Paleozoic rocks and the base of younger deposits of the Mississippi embayment (the base of the Upper Cretaceous sequence except in a few localities) depict a generally smooth horizon that dips less than 1° toward the axis of the embayment. The regional dip is well substantiated by data from drill holes. On the other hand, the wide spacing of control points in much of the area does allow local anomalies to go undetected.

The horizon under analysis is the pre-Late Cretaceous erosion surface that was flexed downward more than one kilometer as the Mississippi embayment formed. A few pre-Late Cretaceous topographic irregularities of the surface and a few local Late Cretaceous and later structural anomalies are known and are large enough to be contoured on regional maps. A graben that formed during Paleozoic time and that may be about 3 miles wide is poorly outlined by subsurface data in the central embayment area 20 miles northwest of Memphis, Tennessee, but is clearly shown to have been topographically high (reverse topography relative to structure) prior to the advance of the Late Cretaceous sea. On the western side of the embayment a few low ridges underlain by resistant Paleozoic units were overlapped by Upper Cretaceous deposits. Local structural anomalies that developed around the deeply buried Newport pluton during Late Cretaceous and Tertiary time also are well shown by surface and subsurface data from the western edge of the embayment. Too few holes have been drilled across the areas underlain by the Jonesboro and Paragould plutons to show whether local structural anomalies are present there.

Geophysical investigations, especially seismic, suggest that several faults displace the Paleozoic-Cretaceous contact in the vicinity of the axis of the upper embayment. Even though that deformation is minor compared to the pre-Late Cretaceous deformation of the underlying rocks of Paleozoic age, likely it is related to the present seismicity of the area. Eventually those structural anomalies will be outlined sufficiently for contouring. At present, only regional trends and a few local anomalies show how the Mississippi embayment has been shaped during the past 70 million years.

Reports

None.

Eastern U. S. Seismicity and Tectonic Studies

9950-02303

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Investigations

1. Continuing analysis of seismic reflection profiles in the New Madrid region. S. R. Brockman, A. J. Crone, F. A. McKeown, D. P. Russ and M. D. Zoback are co-investigators.

2. Continuing analysis of land seismic reflection profiles and beginning analysis of marine seismic reflection profiles in the Charleston, South Carolina, area. H. D. Ackermann and J. C. Behrendt are co-investigators.

3. Planning a seismic refraction survey in the New Madrid region with J. H. Healy.

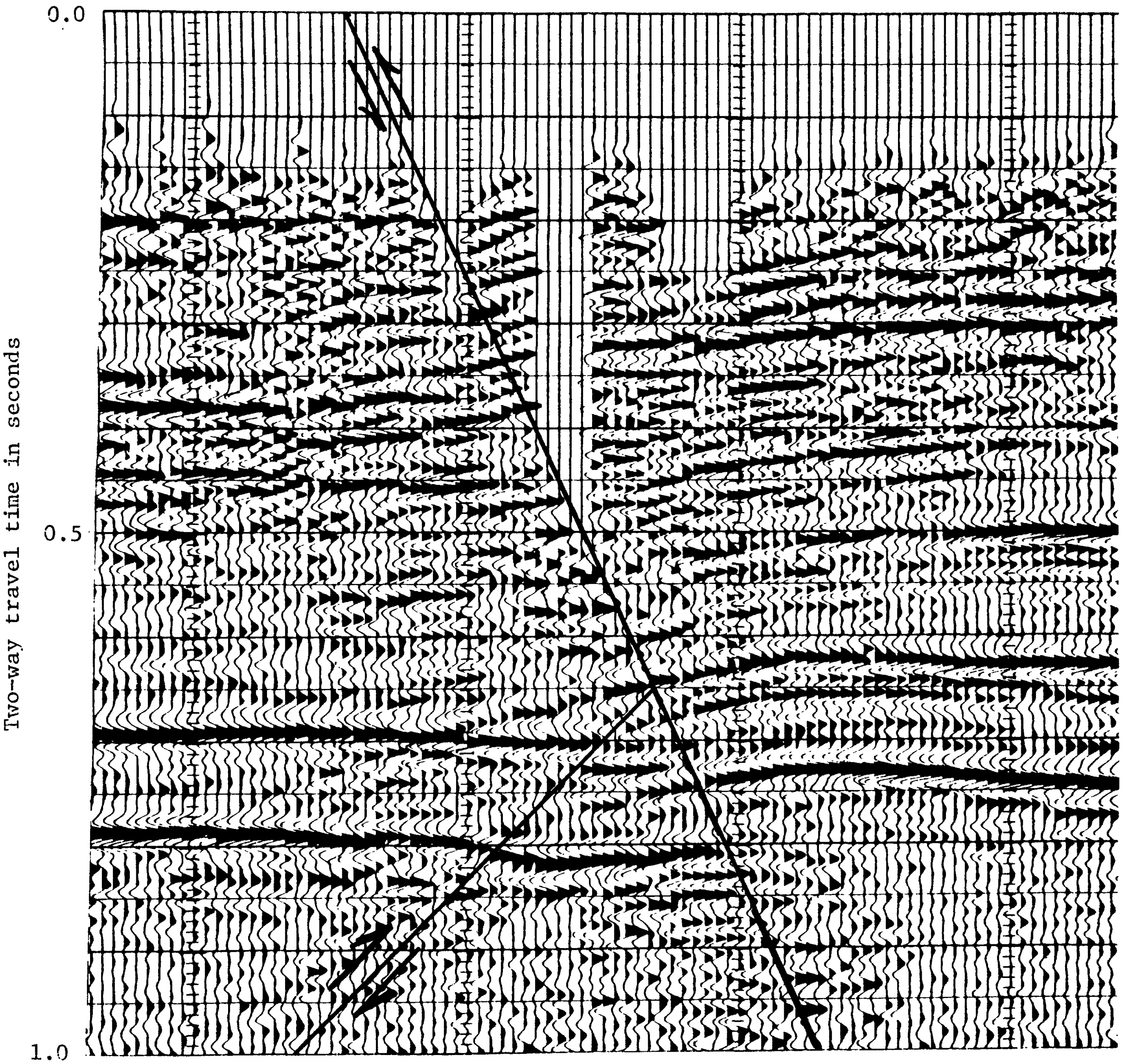
4. Planning additional seismic reflection profiling in the Charleston area with J. C. Behrendt.

Results

1. In the New Madrid region, synthesis of seismic reflection data with other data establishes the relation between modern seismicity and ancient geologic structure. (Details were described in the last report.) Important tectonic features were formed by continental rifting in an ancient extensional stress regime. A northeasterly-striking, high-angle reverse fault of post-middle Eocene age interpreted from the reflection profiles (see attached figure) suggests that the current stress field in the area is compressional, a result that is consistent with fault-plane solutions and with our present knowledge of the modern stress regime in the central U.S.

2. In the Charleston, S. C., area, the seismic reflection profiles show evidence of Cenozoic faulting in four places. Two of these places are correlated between lines to define a northeast-striking fault, named the Cooke fault, which passes through a cluster of epicenters. A basalt flow of Triassic-Jurassic age and overlying late Cretaceous and Cenozoic strata are offset about 50 m, northeast side up. A layer below the basalt flow is offset about 200 m in the same sense. This is evidence for fault reactivation. Zones of layered reflections to almost 3.0 sec on the profiles are interpreted as red-bed deposits, and a boundary fault is seen southeast of these layers.

3. The marine seismic profiles, which extend to 12 sec two-way travel time, show many deep reflections. A change in the character of reflections appears on all the records at about 9 sec, with numerous horizontal reflections of a generally longer period. Interpretation of these records is just beginning.



Portion of a seismic reflection profile from the New Madrid region. The line is located southwest of Ridgely, Tennessee. The record section shows approximately the top kilometer of the crust, and is about 1 km across. At the left edge of the profile the reflection at 0.69 sec represents the contact between Tertiary and late Cretaceous sediments, and the reflection at 0.79 sec represents the contact between late Cretaceous and Paleozoic rocks. The reflection offsets near the center are interpreted as a reverse fault of post-middle Eocene age.

Reports

Hamilton, R. M., and Zoback, M. D., 1979, Seismic reflection profiles in the northern Mississippi embayment: U. S. Geological Survey Open File Report 79-1688.

Zoback, M. D., Hamilton, R. M., Crone, A. J., Russ, D. P., McKeown, F. A., and Brockman, S. R., in press, Recurrent intraplate tectonism in the New Madrid seismic zone: Science.

Behrendt, J. C., Hamilton, R. M., and Ackermann, H. D., in preparation, Cenozoic reactivation of faulting in the vicinity of the Charleston, South Carolina, earthquake zone: Submitted to Science (Director's approval April 7, 1980).

Hamilton R. M., in press, The New Madrid earthquakes: Natural History (Director's approval January 1980).

Tectonic Framework of the New Madrid Seismic Zone from Geophysical Studies

9730-01035

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Investigations

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

2. Commenced studies of magnetic data obtained from a truck-mounted magnetometer.

3. Helped compile a Bouguer gravity map of Arkansas.

Results

1. Magnetic and gravity data reveal probable mafic intrusions within the Mississippi Embayment seismic zone. Of particular interest is a circular anomaly indicating as many as eight dike-like bodies, which is suggestive of a ring-dike complex. This geophysical feature is located near an area where seismicity trends change abruptly from northeast to slightly west of north. In addition, seismicity trends geographically coincide with magnetic and gravity gradients. Observed lateral offsets in gravity and magneic anomalies suggest right-lateral movement along an active fault. As these observations indicate, geophysical structures are spatially related to seismicity in the Mississippi Embayment. Further investigations may reveal those structures that are tectonic stress guides and that determine the occurrence of release of seismic energy.

2. Magnetic data from a truck-mounted magnetometer were gathered along 1500 miles of road within the Mississippi Embayment seismic zone. The purpose of this survey was to delineate small magnetic bodies (dikes, sills, and plugs) and to investigate their possible relationship to seismicity. Igneous intrusions indicated in the data are large in horizontal extent and have been previously observed in the aeromagnetic data. Through future analyses of the truck magnetic data, we anticipate, however, more detailed information concerning the depth and shape of these large intrusions and their possible role as tectonic stress guides.

3. A Bouguer gravity anomaly map of the state of Arkansas will be open-filed in the near future. This map reveals several prominent anomalies and will greatly aid our research in the embayment.

Reports

Kane, M. F., Hildenbrand, T. G., and Hendricks, J. D., 1979, The Mississippi Valley graben, a hidden rift (abs.): American Geophysical Union Transactions, v. 60, no. 46, p. 954.

Central and Eastern U.S. Earthquake Study

9730-02176A

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Investigations

1. The tectonic history of the Mississippi embayment includes development of a graben-rift system in latest Precambrian or earliest Paleozoic time, basinal downwarping in Ordovician and Carboniferous time, igneous activity in mid-Mesozoic time, basinal downwarping in late Cretaceous-early Tertiary time (which formed the present embayment), and contemporary seismic activity that is the most intense of the eastern United States. A model was developed to explain post-Paleozoic tectonic activity.

2. Digital terrain data available for the entire United States, can be utilized using modern computer and plotting techniques, to construct terrain maps at many different scales and in many different forms. Automatic methods of map construction were tested, a series of maps were constructed, selected maps were distributed to a few earthquake research projects for experiments, and analysis was done of several terrain maps of major earthquake areas of the eastern United States.

Results

1. Paleomagnetic directions derived by Hildenbrand by means of the Poisson relation show that the major mafic/ultramafic plutons mapped along the boundaries of the graben underlying the Mississippi embayment are mid-Mesozoic in age. The stratigraphy shows that the major downwarping that formed the present-day embayment took place in late Mesozoic-early Tertiary time. When the regional gravity field is corrected for the low-density sediments laid down in the present day embayment, a major gravity high is defined which coincides closely with the axis of downwarp; the correlation implies a causal relationship.

It is suggested that the mid-Mesozoic intrusive event was tensional in nature and accompanied by crustal stretching and mantle upwarp. This implies that the maximum horizontal compression was oriented parallel to the axis of the graben. Following a time-varying stress model developed for the Tertiary history of the Rhine graben it is further suggested that the tension-induced magmatic event was brought to close by a rotation in the horizontal stress field. Densification and contraction of the mantle welt initiated basin downwarp; the process was augmented by the additional load of the incoming sedimentary rocks. As cooling was completed the downwarping and sedimentation ceased; the changing horizontal stress whose axis of maximum compression was now oriented more normal to the axis of the embayment may have aided the cessation.

In this model the present-day seismicity is explained as the result of contemporary stress acting on the zone of crustal weakness which was the origin of the original graben. If the model is extrapolated back in time it can be used to relate the downwarping of Ordovician age to a mantle upwelling associated with the tensional event that produced the original graben. An implication of this extrapolation is that the graben would be at least partly Cambrian in age.

2. Digital terrain maps of the eastern United States were constructed at several different scales and in different forms (contour, shaded relief, color). A series of regional terrain features were discovered which may have implications for seismicity patterns. The first and most notable is an arcuate zone extending from the St. Lawrence Valley to western Indiana. It connects the earthquake centers of Baie St. Paul, Quebec, Massena, New York, Attica, New York, and Anna, Ohio. It corresponds approximately to a predicted zone of brittle failure caused by the Pleistocene ice load. This hypothesis is buttressed somewhat by a recent Canadian report which attributes three clusters of earthquakes along the eastern margin of Canada, including the 1933 Baffin Bay event (Ms 7.3) and the 1929 Grand Banks (Ms 7.2), to deglaciation. The arcuate zone falls along major geologic boundaries; the earthquake centers are located where major structures are transverse to the boundaries.

A second distinctive feature is a topographic boundary which forms the southwest margin of a zone of distinctive morphology that overlies the Ozark uplift; the boundary can be traced into the Mississippi embayment where it forms the southwest limit of embayment seismicity. Most of the New Madrid seismicity (exclusive of the Wabash Valley trend) is confined to the Ozark block, particularly to its northeast side and its southeast side (as formed by the axial zone of the graben). A third zone, composed of linear highlands, strikes at an oblique angle across the southern Appalachian trend and includes the central portion of the Virginia-Alabama seismic belt. The linear highlands are clearly caused by erosion but their discordant trend and correlation with seismicity and a similarly discordant gravity trend suggest that the three trends are related in cause.

Samples of maps were distributed to several investigators including John Hack at Reston and Carl Wentworth in Menlo Park. Both of the latter have indicated that the maps provide a new data source in support of their studies. Both Hack and Kane have noted that the two broad areas of high terrain in the southern Appalachians coincide with the two main areas of regional gravity lows. The correlation suggests that isostasy may play a role in the uplift of these highlands.

<u>Reports</u>

Kane, M. F., and Godson, R. H., 1979, Topography, structure and seismicity in the eastern United States (abs.): Earthquake Notes, v. 50, n. 3, p. 26-27.

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Puerto Rico Seismic Program

9950-01502

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Investigations

Data from the continued operation of the 15-station Puerto Rico seismographic network are being used to: (1) define local and near regional seismogenic zones on and in the vicinity of Puerto Rico, (2) determine how these seismogenic zones relate to known or suspected geologic structures, and (3) increase the understanding of the tectonic processes operative within this section of the Caribbean plate. The results of these studies are fundamental to the assessment of the earthquake potential, seismic risk, and associated earthquake hazards of Puerto Rico.

Results

The distribution of 268 small earthquakes recorded during a 1-year period (1976) in the western part of Puerto Rico indicates that:

1. The combination of shallow events in the Puerto Rico trench and intermediate to deep focus events (maximum depth of 155 km) under the island defines a seismic zone dipping under Puerto Rico. Shallow crustal seismicity range in depth from near surface to about 30 km.

2. Active deformation is occurring along a well defined surface, based on the spatial distribution of earthquakes, and also on near surface geologic structures.

3. A composite focal mechanism solution for earthquakes along the Mayaguez fault (this fault may represent the western extension of the Great Southern fault) suggests that deformation is occurring in response to active ENE-WSW (N 75° E) horizontal compressional stresses.

4. An apparent rotation of the stress field occurs in the Guayanilla Canyon. A composite focal mechanism solution suggests that deformation is occurring in response to active NNE-SSW horizontal compressional stresses.

5. Most of the earthquake activity north of the Great Southern Puerto Rico fault zone is intermediate to deep focus, probably associated with the south-dipping Benioff zone.

6. The island of Puerto Rico seems to behave like a microplate caught in a wide transform margin between the North American and Caribbean plates. The margins involve strike-slip faulting along the Muertos Trough and Puerto Rico trench.

Report

Asencio, E., 1980, Western Puerto Rico seismicity, U.S. Geological Survey Open-File Report 80-192, 135 p.

Paleomagnetic Dating of Late Neogene Deposits In the Atlantic Coastal Plain with Application to Dating Tectonic Deformation in the Southeastern United States

14-08-0001-17721

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Investigations

1. Establish the magnetostratigraphy of late Neogene formations and units throughout the Atlantic Coastal Plain.

2. Using the paleomagnetic polarity time scale, improve the geochronology of Pliocene and Pleistocene sediments in the Charleston, South Carolina, area, and in the Delmarva Peninsula (Delaware, Maryland, Virginia).

3. Initiate paleomagnetic study of deep-sea cores of the Atlantic Margin Coring Project (1976).

4. Refine the geochronology of Upper Cretaceous deposits in the continuously cored test hole (Clubhouse Crossroads #1) near Charleston, South Carolina.

Results

1. For the entire Atlantic Coastal Plain, the paleomagnetic data place the Brunhes/Matuyama polarity boundary (about 0.73 myBP) in the interval between the deposition of the upper Pleistocene Canepatch (Normal [N] polarity) and the lower Pleistocene Waccamaw (Reversed [R] polarity) Formations in the Cape Fear Arch region, and between the upper Pleistocene Flanner Beach (N) and lower Pleistocene Croatan (R?) Formations in their type area on the Neuse River, North Carolina. This marker horizon is important for interpreting Quaternary tectonism in the Coastal Plain, as well as dating sea-level fluctuations and allowing correlation of the onshore biostratigraphic record with the deep-sea record and a global time scale.

2. In the Charleston, South Carolina, area, paleomagnetic samples from outcrops and fully-oriented, split-spoon or Shelby tube cores drilled by the USGS, identify Waccamaw-age deposits (reversed polarity) that formed in a fluvial to marine deltaic environment. Additionally, preliminary paleomagnetic data from an upper Pliocene calcarenite exposed along Goose Creek in North Charleston, South Carolina, suggest the unit is time-equivalent to the so-called Bear Bluff Formation near the North Carolina-South

Carolina State line, as both have normal polarity (Gauss Normal Epoch [?]: 3.40-2.48 myBP). Younger, post-Waccamaw Pleistocene sediments also have normal polarity and were deposited during the Brunhes Epoch (0.73 my to present). This threefold division of the Pliocene and Pleistocene sedimentary record can now be made independently of geomorphic and topographic evidence, and the magnetostratigraphy, in conjunction with litho- and biostratigraphic data, can be used in the Charleston area to test conflicting morphostratigraphic correlations made by previous workers. Another important application is more precise dating of surficial stratigraphic units in the area most directly affected by the 1886 Charleston earthquake.

To help improve the geochronology of Quaternary sediments in the Delmarva Peninsula of the Central Atlantic Coastal Plain, we sampled key formations and stratigraphic sections either in outcrop or using fully-oriented Shelby tube cores. The "Accomack Fm" near the Virginia-Maryland State line records normal paleomagnetic polarity, and this information, combined with other geochronologic data (faunal analysis, radiometric dates, amino acid enantiomeric ratios), indicates the deposits formed during the Brunhes Epoch.

3. Besides paleomagnetically dating sediments in the southeastern United States, we have extended the work to the Atlantic Continental Shelf and Slope using cores from the Atlantic Margin Coring Project. These cores penetrated as much as 310 meters of the sea floor and recovered Miocene and younger sediments. Four cores (two each from the shelf and slope) off the New Jersey and New York coast appear particularly suited to our purposes, and we will work primarily on them; overall, there might be as many as seven cores that we can use at least in part.

Improved dating of the cores will be valuable for interpreting the late Neogene onshore and marine record along the East Coast. These data then have application in studies of Quaternary datum planes and eustatic changes in sea level, both of which provide information about tectonic deformation in the southeastern United States.

4. Related, but not directly involving deposits of late Neogene age in the southeastern Atlantic Coastal Plain, is our attempt to paleomagnetically date Cretaceous sediments recovered from the continuously cored test hole, Clubhouse Crossroads Core #1 (CCC-1), of the Charleston Project. The Project is a multidisciplinary investigation of the U.S. Geological Survey to determine the cause of seismicity near Charleston, South Carolina. Paleontology has been used to date the sediments in the core, placing the Cretaceous/Tertiary boundary at 244 meters (Hazel, et al., 1977).

We attempted to refine the geochronology of the Upper Cretaceous deposits in CCC-1 by comparing the magnetostratigraphy in the core with the paleomagnetic polarity sequence at Gubbio, Italy (Alvarez, et al., 1977). Our data suggest that if the sedimentation rate was roughly constant for the Upper Cretaceous of CCC-1, then at least some of the *Abathomplalus mayaroensis* Subzone of foraminifera (late Maastrichtian) should be present in the core. Failure to find *A. mayaroensis* was noted in the preliminary report of the biostratigraphy of CCC-1 (Hazel, et al., 1977), so a reexamination of the microfauna in that portion of the core might reveal that more of the Cretaceous is recorded on the East Coast than was previously thought. This notion is supported by the paleomagnetic polarity in Upper Cretaceous sediments recovered at site 6004B of the Atlantic Margin Coring Project (Hathaway, et al., 1976). In that core, we document normal polarity exclusively below the unconformity that marks the Cretaceous/Tertiary boundary. On that basis, and the occurrence of *Globotruncana gansseri* and *G. contusa* foraminifera (but not *A. mayaroensis*) in the core, we correlate the sediments with Gubbio Normal Polarity Subzone F1+.

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Reports

Liddicoat, J.C., Blackwelder, B.W., Cronin, T.M., Ward, L.W., 1979, Magnetostratigraphy of Upper Tertiary and Quaternary Sediments in the Central and Southeastern Atlantic Coastal Plain: Abstracts with Programs, 1979 Southeastern Section Meeting, Geol. Soc. Am., V. 11, No. 4, p. 187.

Quaternary Stratigraphy and Bedrock Structural Framework of Giles County, Virginia

9510-02463

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Investigations

1. Quaternary deposits are being mapped and studied by Hugh Mills to determine details of origin and to discover effects, if any, of local seismicity.

2. Data on Paleozoic bedrock is being compiled to determine the structural setting of the area and its relationship to historic earthquakes.

Results

1. Size analysis of coarse to fine samples from colluvial deposits has resulted in differentiation of colluvium into several types on the basis of stoniness or percent clay.

2. Size analysis of samples from New River terraces shows that the clay/silt ratio increases linearly as a function of vertical distance above modern river level.

3. Analysis of fabric data from deposits of talus and colluvium demonstrates that fabric patterns and strength differ significantly for different types of these deposits.

4. Analysis of topographic profiles across New River terraces indicates that there are no consistent terrace levels in the study area.

5. Detailed and reconnaissance mapping of the Paleozoic bedrock have shown greater complexity than previously reported, but no indication of post-Paleozoic movement has been found in any of the known faults in the area. A geologic map of the area is being compiled.

6. Preliminary analysis of data on the Hurricane Ridge syncline, previously shown to cross the juncture between the southern and central Appalachians, indicates that: (a) it is actually three separate synclines, and (b) there is no evidence of a greater accumulation of sediments in the trough than in adjacent areas, as has been stated in support of a "thick-skinned" style of deformation for Appalachian structures.

Reports

Mills, H.H., 1980, Observations on boulder streams in the Valley and Ridge Province, Giles County, Virginia [abs.]: Geological Society of America Abstracts with Programs, v. 12, no. 4, p. 201-202.

The Determination of the Magnitude and Date of Dip-Slip Faulting by Discordance in Sets of Sea Level Curves.

H4

14-08-0001-17729

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Investigations

We have now dated 88 basal peat samples from ten tidal marshes along a 135 kilometer transect striking north from Cheesequake State Park on the New Jersey Coast of Raritan Bay up the Hudson Estuary to Marboro, New York. The transect crosses the Ramapo Fault Zone between kilometers 32 through 38 south of Marboro. Our purpose is to determine the practicality of discerning Holocene movement of the fault zone by comparing marine transgression curves across and within the fault zone. We still have 21 additional radiocarbon dates in various stages of preparation.

Results

1. All but one of our dated samples yielded marine and or brackish water diatoms confirming that all but one of these samples are indeed associated with saline water. The one exception gave a depth-time data point well above the remaining data confirming its unsuitability for our purposes.

2. Much to our surprise, the plot of all 88 points (Figure 1) yields a relative decreasing rate of marine transgression upon which are superimposed fluctuations in the sense of Fairbridge (1976). Although we have documented similar fluctuations along the South Atlantic Coast (Brooks and others, 1979) where the marine transgression rate is less than one meter/millennium, the Hudson Estuary transgression rate of nearly two meters/millennium was expected to mask any fluctuations. However, the density of our data now reveals fluctuations having amplitudes of as much as two meters. Fairbridge's (1976) Roman, Crane Key and Bahama Emergences are clearly revealed centering upon 2100, 3200 and 4000 Radiocarbon Years B.P. These fluctuations obviously complicate our analyses.

3. In spite of the complications introduced by these sea level fluctuations, several of our basal peat samples from the marshes at Iona Island and Roa Hook, on the Timp and Camp Smith faults respectively and within the Ramapo Fault Zone, yield anomalous depths for their age. Although we initially believed these particular peats were allochthonous and had been eroded from their point of origin, the consistency and apparent repeatability of these points indicate they may well be the result of down-faulting. So far, we discern a one meter throw of the Camp Smith Fault (down towards the

southeast) which occurred subsequent to 4000 YBP (radiocarbon years Before Present) and an up to 4 meter throw (down towards the southeast) along the Timp Fault subsequent to 2000 YBP. However, we caution these results are provisional. We do believe we have located the Camp Smith fault scarp buried under the Roa Hook tidal marsh.

4. Our data continues to show that the entire transect is also subsiding differentially down towards the south.

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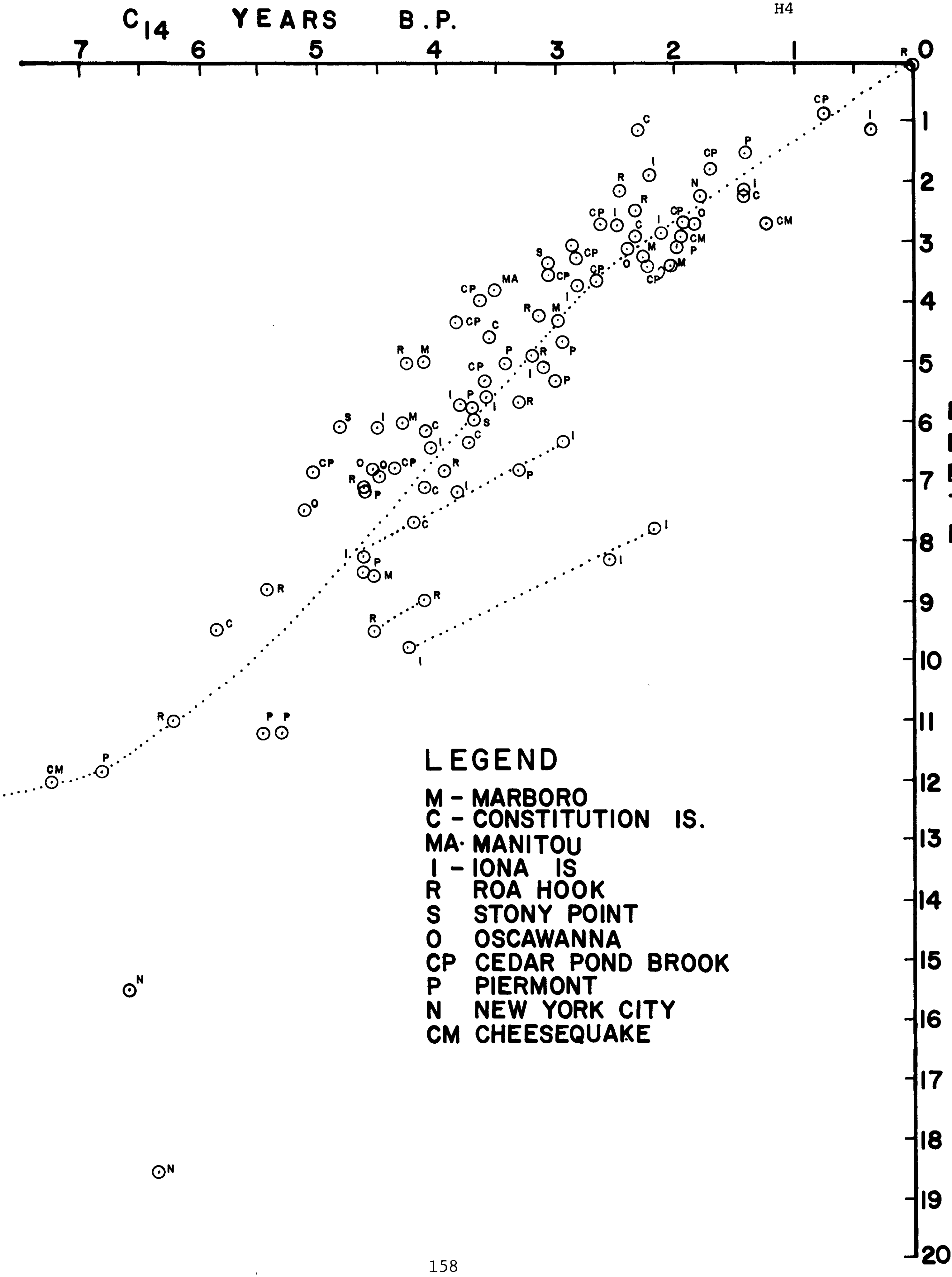
Fairbridge, R.W., 1976, Shellfish-Eating Preceramic Indians in Coastal Brazil: Science, v. 191, p. 353-359.

Figure 1 Time-Elevation plot of 88 radiocarbon-dated points from ten stations along 135 kilometer transect. The scatter of these points are due to fluctuating sea level, crustal warping, fault throw and operator-error.


C14 YEARS B.P.
7 6 5 4 3 2 1 0
DEPTH
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
LEGEND
M - MARBORO
C - CONSTITUTION IS.
MA· MANITOU
I - IONA IS
R ROA HOOK
S STONY POINT
O OSCAWANNA
CP CEDAR POND BROOK
P PIERMONT
N NEW YORK CITY
CM CHEESEQUAKE

Ground Failure Related to the New Madrid Earthquake

9550-02160

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Investigations

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

2. Completed summarization of field engineering test data (500 Standard Penetration Tests), and summarization of laboratory gradation data on substratum sands which underlie the alluvial valley.

Results

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

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

Reports

None.

Northeastern U.S. Seismicity and Tectonics

9510-02388
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Investigations

1. Relationship of ductile and brittle fault zones in basement rocks adjacent to and north of the Newark Basin in the Ramapo seismic zone of New York and New Jersey.

2. Core drilling of bedrock and trenching of Pleistocene and younger sediments at the Ramapo fault, New York and New Jersey.

Results

1. Regional fault maps based on detailed study of selected fault zones reveals that ductile faults of Precambrian and Paleozoic age are virtually colinear in the Ramapo seismic zone to the west of the Newark Basin. North of the Basin the Mesozoic brittle faults diverge from the more northeasterly-trending ductile faults. In the West Point area of New York, Mesozoic and younger(?) fault zones define the course of the Hudson River whereas ductile faults extend to the northeast in a broad zone through Carmel, New York.

2. Analysis of epicentral data for a cross section across the Hudson Highlands suggests that semi-ductile thrust faults of Paleozoic age may be localizing seismicity rather than reactivated Mesozic brittle fractures as commonly assumed.

3. Core drilling of the Ramapo fault was completed at our fifth and final site at Riverdale, New Jersey. Excellent recovery of fault gouge in two holes normal to strike show that the fault dips 50^{o} SE. A zone of soft gouge 4-5 cm thick defines the actual fault in both cores. Analysis of movement sense show that the last movement was normal and no evidence for recent reverse movement as required by the current NW-SE compressive stress field.

4. Reconnaissance study of bedrock geology of the Mendam, New Jersey, area suggests that a broad zone of Mesozoic brittle faulting that was previously unrecognized joins the Ramapo fault with the Flemington fault in the Chester, New Jersey, area. A belt of shallow seismicity in the Dover-Bloomingdale area, New Jersey, appears to be spatially associated with this zone.

Reports

Ratcliffe, N.M., 1979, Cataclastic rocks from the Ramapo fault and evaluation of evidence for reactivation on the basis of new core data: Geological Society of America, Abstracts with Programs, v. 11, no. 1, p. 50.

Mississippi Valley Seismotectonics

9950-01504

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Investigations

1. Structural and stratigraphic interpretations of 250 km of seismic reflection profiles that were run in various parts of the upper Mississippi embayment continued. The latest studies were concerned with details of fault movement, location and shape of intrusive masses, tectonic history, and the relationships of the structures seen on the seismic profiles to rifting and intra-plate earthquakes. R. M. Hamilton, M. D. Zoback, F. A. McKeown, and S. R. Brockman are co-investigators.

2. Geological and statistical studies to characterize the structural configuration of the buried Paleozoic surface between Ridgely, Tennessee and New Madrid, Missouri continued.

3. A detailed description of the cores and samples collected from the New Madrid Test Well (NMTW-1-X) was made using a binocular microscope. This data will be open-filed.

4. Offsets exposed in Tertiary sediments along the northwest flank of Crowleys Ridge, 20 km northwest of Paragould, Arkansas, were mapped and analyzed.

5. A generalized informal analysis was made of potential seismic hazards present in Obion County, Tennessee near the sites of 16 proposed Soil Conservation Service dams.

6. With S. Obermeier of the Engineering Geology Branch, continued field investigations of the factors that control the occurrence and characteristics of earthquake-induced liquefaction phenomena in the upper Mississippi embayment.

7. With J. R. Healy, planning a seismic refraction survey in the upper Mississippi embayment.

Results

1. Interpretation of final stacked seismic reflection profiles and of migrated seismic sections (also reported by R. M. Hamilton in this volume) indicates that the Cottonwood Grove fault in northwestern Tennessee is a reverse fault. Faults adjacent to the Cottonwood Grove fault that offset the Paleozoic-Cretaceous contact are primarily dip-slip. Though many of these faults deform strata as young as middle Eocene age, it is uncertain whether the faults continue as mappable offsets into the younger strata, or whether

deformation in the younger strata is best represented as structural draping. The interpretation of reverse movement on the Cottonwood Grove fault is consistent with a model where an area of compression exists between two en echelon northeast-trending strike-slip faults (the major seismicity trends from Marked Tree, Arkansas to Caruthersville, Missouri and from Lilbourn, Missouri to Charleston, Missouri) and with the pattern of deformation at the ground surface.

2. Trend surface and gridding analyses of two-way travel times from seismic reflection profiles establish that the buried Paleozoic surface between about Ridgely, Tennessee and New Madrid, Missouri has been uplifted in a manner similar to the ground surface upwarping of the Lake County uplift. The subsurface uplift comprises about 367 km^2 and can be subdivided into the Tiptonville dome (uplift as much as 42 m) and Ridgely ridge (uplifted as much as 50 m). Reelfoot Lake, which was much enlarged during the New Madrid earthquakes of 1811-12, is underlain by a structural depression that may have been downwarped during the large 1811-12 earthquakes. The close spatial relationship between the subsurface and surface uplifts and the modern seismicity suggests that the forces producing the earthquakes also caused the uplift and are, in fact, still active today.

3. Several faults located along the northwest edge of Crowleys Ridge, about 25 km northwest of Paragould, Arkansas, have been studied in detail. Previous investigations have suggested that these faults and others nearby may be evidence that Crowleys Ridge is a structural block or that its evolution has been structurally controlled. Results of the present investigation reveal, however, that these faults are landslide slippage planes, produced when Lafayette gravels and sands of the Eocene Wilcox (?) Formation slid down a steep slope on the ridge's edge. The age of movement is uncertain, but the presence of loess, possibly involved in the sliding, suggests a movement age as recent as late Pleistocene or early Holocene. The significance of other faults in the area is yet to be determined.

Reports

Zoback, M. D., Hamilton, R. M., Crone, A. J., Russ, D. P., and Brockman, S. R., 1979, Major fault zone associated with the main New Madrid seismic trend shown by seismic-reflection profiling: Earthquake Notes, Eastern Section, Seismological Society of America, v. 50, p. 45-46.

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

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

Contract No. 14-08-001-18200

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Investigations

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

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

Results

1) A succession of four discrete episodes of fault displacement, ending with the 1857 event, was recognized. A further succession of four separate faulting events was also recognized in an adjoining part of the trench wall, but it was not possible to combine the two successions stratigraphically. Twenty charcoal samples were collected and sent to the University of Washington radiocarbon laboratory. When these dates are available the dated sequence of faulting events will range from a minimum of four to a possible maximum of eight.

Charcoal fragments were collected from within differentiated alluvial units and fissure fillings above faults.

Recognition of the faulting events was based on the following evidence: -

a) Fissures occurring at the paleo-ground surface and leading down into fault traces.

b) Deformation and overturning of lacustrine clays.

c) Progressive growth of a pressure ridge resulting in:

(1) Systematic angular discordances within the stratigraphic sequence.

(2) Systematic changes in the depocentre of the lacustrine clays, i.e., advancing progressively towards the pressure ridge with successive alluvial episodes, and moving abruptly away from the pressure ridge following a faulting event.

d) Thin sheets of gravels reworked from the pressure ridge and immediately overlying deformed lacustrine clays adjacent to the active fault trace. These gravel sheets thinned away from the fault trace and appeared to be derived from a fresh scarp produced by movement on the fault.

e) Fault breaks within the section juxtaposing contrasting sediments and weathered bedrock.

2) Two samples of fragmental charcoal were collected from within the landslide deposit. When dates are received from the samples it will be possible to propose a minimum average displacement rate for this part of the fault.

Northeast Tectonics and Geophysics

9730-00364

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Investigations

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

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

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

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

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

Results

1. A 1:250,000 Bouguer gravity map of Eastern Maine, soon to be on open file, comletes the gravity coverage of New England at this scale. A 1:1,000,000 Bouguer gravity map of the Northeastern U.S. has been contoured and will soon be put on open file.

2. Available aeromagnetic coverage for the Boston 1^{o} x 2^{o} sheet has finally been digitized and edited.

3. Several hundred kilometers of truck magnetometer data were collected in the vicinity of the Ramapo Fault in northern New Jersey and the Flint Hill Fault in southern New Hampshire in conjunction with geologists studying these faults.

Reports

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

14-08-0001-16827

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Investigations

Detailed geologic studies that include mapping of the late Quaternary deposits, topographic profiling of displaced geomorphic surfaces, and trenching have been completed at three locations along the Wasatch fault zone. Data on the cumulative displacement of late Quaternary deposits, the number of surface faulting events, and the amount of displacement per event have been collected at these sites to estimate the magnitude and frequency of past surface faulting on the Wasatch fault zone.

The results of the investigations at the Kaysville and Hobble Creek sites, 32 km north and 46 km south of Salt Lake City respectively, are described in our earlier reports (see list of selected reports). The results of our investigations at the Little Cottonwood Canyon site are summarized below. Two additional sites, one north of Ogden and one near Nephi, will be investigated during fiscal year 1980.

Results

The Little Cottonwood Canyon site is 20 km south-southeast of downtown Salt Lake City. At this location, the Wasatch fault is a zone up to 0.5 km wide that lies a few hundred meters west of the range and generally trends parallel to the mountain front. Seismicity data compiled by the University of Utah (16 years of record) suggest that the Little Cottonwood site is located near the northern end of a 70-km-long seismic gap (Arabasz and others, 1979). The Hobble Creek site is located near the southern end of this seismic gap.

Late Pleistocene lateral moraines at the mouths of Little Cottonwood and Bells canyons are displaced by numerous east- and west-facing scarps that form a series of graben. Individual scarps within these graben are up to 35 to 40 m high. The cumulative net tectonic displacement across the zone is estimated to be 14.5 (+10.0; -3.0) m on the basis of topographic profiles of the displaced moraines, which are 16,000 ± 3000 years old. The late Pleistocene (post-Bells Canyon till) slip rate is 1.0 (+0.9; -0.4) mm per year.

The cumulative displacement was produced by multiple surface faulting events. Data from trenches excavated across a graben north of Little Cottonwood Canyon that displaces Holocene alluvial fan deposits indicate that the graben was produced by a minimum of two or three surface faulting events. Recurrent displacement is also suggested by three or four terraces on the upthrown side of the fault in glacial outwash deposits in Little Cottonwood Creek. Due to the complexity of the fault zone and to suburban development of the area, it was not possible to determine if the graben and the terraces were produced by different faulting events. Although a unique sequence of faulting events cannot be reconstructed for the Little Cottonwood Canyon site, the available data suggest that the history of faulting at the site is probably similar to the history of faulting 50 km to the south at the Hobble Creek site.

Selected Reports

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Cluff, L. S., Patwardhan, A. S., and Coppersmith, K. J., 1979, Estimating the probability of occurrence of surface faulting earthquakes on the Wasatch fault zone, Utah: to be published in the Proceedings of Conference on Earthquake Hazards Along the Wasatch Front and in the Reno-Carson City Area (U.S. Geological Survey Open-File Report).

Cluff, L. S., Patwardhan, A. S., and Coppersmith, K. J., in press, Estimating the probability of occurrence of surface faulting earthquakes on the Wasatch fault zone, Utah: Bulletin of the Seismological Society of America, v. 70, no. 5, October, 1980.

Schwartz, D. P., Swan, F. H., III, Knuepfer, P. L., Hanson, K. L., and Cluff, L. S., 1979, Surface deformation along the Wasatch fault, Utah: Geological Society of America Abstracts with Programs, v. 11, no. 3, p. 127.

Schwartz, D. P., Swan, F. H., III, Hanson, K. L., Knuepfer, P. L., and Cluff, L. S., 1979, Recurrence of surface faulting and large magnitude earthquakes along the Wasatch fault zone near Provo, Utah: Geological Society of America Abstracts with Programs, v. 11, no. 6, p. 301.

Swan, F. H., III, Schwartz, D. P., Hanson, K. L., Knuepfer, P. L., and Cluff, L. S., 1978, Recurrence of surface faulting and large magnitude earthquakes along the Wasatch fault, Utah: American Geophysical Union Transactions (EOS), v. 59, no. 12, p. 1126.

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Swan, F. H., Schwartz, D. P., Cluff, L. S., Hanson, K. L., and Knuepfer, P. L., in press, Study of earthquake recurrence intervals on the Wasatch fault at the Hobble Creek site, Utah: U.S. Geological Survey Open-File Report, 40 p.

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Structural Framework of Eastern U.S. Seismic Zones

9950-02653

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Investigations

1. Characterize, locate, and interpret cross-strike structural discontinuities (CSD's), which are transverse alignments of structural disruptions (many are anticlinal noses) in the Appalachian and other thrust belts. CSD's may reflect basement structure otherwise masked by overlying thrust complexes.

2. Develop efficient methods to map intensity of systematic joints: joint surface area per unit volume of rock. CSD's are characterized by high joint intensity.

3. Improve a pattern recognition program developed in the U.S.S.R. and at M.I.T., in order to use it to seek patterns in the geological, geophysical, and topographic characteristics of selected Eastern seismic areas.

4. Compile and synthesize extant geologic, geophysical, and other data in selected areas of Eastern seismicity, and coordinate this new project with planned or continuing work elsewhere. Work will concentrate on the Giles Co. area, in southwestern Virginia and adjacent West Virginia, the second most seismically active area in Southeastern United States.

Results

1. CSD's each contain about 1,000 cubic km of rock, with high joint intensity both at ground level and in the subsurface. Anomalous faulting in CSD's is minor to unrecognized: CSD's are not faults or fault zones. Many or most appear to have been developing through large parts of Paleozoic and later time, and may overlie or once have overlain basement faults now otherwise masked by thrust complexes. Recognition and mapping of CSD's may provide a way to locate such faults by looking through the overlying thrust complexes. Such basement faults may be seismogenic now; so far CSD's have not been sought in seismically active areas (the project chief joined the USGS in June, 1979).

2. A fast, robust estimator of joint intensity, calculated as the sum of the inverse mean spacings for the various joint sets in an exposure, has been developed and tested, and is being extended.

3. The pattern recognition program has been modified to produce more objective and reproducible results. Statistical tests aid in evaluation of the patterns found. The method is being tested on a data set from the

Southeastern United States, and results are being compared to those of an NRC-funded project based on multivariate statistics. Preliminary results show low topographic gradients to be a ubiquitous contributor to combinations of features characterizing most seismically active areas in the Southeast. The areas of Charleston, South Carolina, and Giles Co. are not characterized by these same combinations of features.

Reports

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Wheeler, R. L., Winslow, M., Horne, R. R., Dean, S., Kulander, B., Drahovzal, J. A., Gold, D. P., Gilbert, O. E., Jr., Werner, E., Sites, R., and Perry, W. J., Jr., 1979, Cross-strike structural discontinuities in thrust belts, mostly Appalachian: Southeastern Geology, v. 20, p. 193-203.

Earthquake Hazards Geologic Mapping of the San Andreas Fault Zone, Los Angeles County, California near Three Points and Pine Canyon

14-08-0001-18244

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Investigations

Annotated fault maps of the Pine Canyon and east-half Three Points segments of the San Andreas fault zone in Los Angeles County are being prepared upon orthophoto bases at a scale of 1:12,000. The primary activity on this project consists of field mapping upon aerial photos as well as interpretation of several sets of aerial photos that cover this 15 km stretch of the fault zone.

Results

Mapping of the fault traces and fault-related features within the San Andreas fault zone is proceeding well. The main trace of the San Andreas fault in the western part of the area is not a single, continuous trace but consists of multiple traces some up to 200 meters apart. In the eastern part of the area (Pine Canyon), on the other hand, the San Andreas fault is simpler and more continuous. Few branch or subsidiary faults of note have been identified to date.

Reconnaissance geologic mapping, also in progress, has revealed previously unmapped small slivers of Tertiary sediments (Hungry Valley Formation) scattered along the north side of the San Andreas fault at least as far east as Bushnell Summit. These rocks are inferred to have been offset from the Quail Lake-Gorman area although estimates of the amount of offset are not yet being made because mapping is incomplete at this time. Marble bodies along the northern slope of Sawmill Mountain are also being mapped in an attempt to evaluate the extent of faulting within the basement terrane south of the main trace of the San Andreas fault.

Quaternary Fault Map of the Reno 1x2° Quadrangle

Contract No. 14-08-0001-18375

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Goals

1. To compile all existing published and unpublished maps showing young faulting within the Reno 1x2° quadrangle.

2. To cross-check existing data and map young faults in unstudied portions of the quadrangle.

3. To assess recency and recurrence of movement on all major fault zones in the quadrangle.

Approach

Low sun-angle, black and white aerial photography (1:40,000-scale) is being flown for the entire 1x2° area and will provide complete, uniform coverage for the study area. It is being supplemented with existing 1:60,000-scale AMS photography and large-scale (1:12,000) low sun-angle photography in certain portions of the quadrangle. Fault scarps, suspected fault scarps, and fresh-appearing bedrock lineaments are being mapped on the new photography. The mapped features are cross-checked against existing literature, and all major fault scarps are investigated by field reconnaissance. Interpretations of recency of movement are made based upon an evaluation of the alluvial-, fluvio-lacustrine-, and soil-stratigraphic record at each site. Selected faults and suspected faults will be trenched.

With the completion of photographic and field interpretations, fault scarps are delineated on a 1:250,000-scale base map by age of most recent movement: 1) historic surface ruptures, 2) post-high Lahontan shoreline (less than 12,000-18,000 years old), and 3) pre-high Lahontan shoreline (greater than 12,000-18,000 years old).

Preliminary Results

The study to date has compiled and identified numerous areas of Holocene-age (historic and prehistoric) fault scarps. Much of the Holocene-age fault activity is concentrated along the major structural features in the quadrangle: the Sierra Nevada Frontal Fault Zone, the Walker Lane, the Carson Lineament, and the Olinghouse Fault Zone. In particular, the junctures of these structural features show evidence of repeated Holocene activity, some of which may have been only slightly prehistoric.

Six areas of historic surface rupture are known to have occurred within the quadrangle:

1869 Olinghouse Fault Zone
1903 Gold King Fault
1954 Rainbow Mountain Fault
1954 Rainbow Mountain Fault
1954 Dixie Valley Fault Zone
1954 Fairview Peak Fault Zone

A seventh area of surface rupturing may have occurred in the Carson Desert area around 1850, and the Holocene-age scarps in this region are presently under investigation.

Analysis of faulting along the right-lateral Walker Lane suggests that Quaternary-age movement in the quadrangle changes style of deformation from northwest to southeast. In the Pyramid Lake segment of the zone, prominent northwest-trending scarps, pressure-ridges, and sag ponds characterize the movement. To the southeast, however, the northwest-trending structures appear to be replaced by broad, arcuate faults concave to the northwest and north.

Surface Faulting Studies

9940-02677

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Investigations

The project chief participated in mapping of the surface faulting that occurred in the Imperial Valley on October 15, 1979. He also became involved in studies of the method of using geologic slip rate to estimate earthquake magnitude, which has been proposed by the applicant in connection with the San Onofre Nuclear Generating Station. A field investigation was made of the surface faulting near Livermore, California, that accompanied the earthquakes of January 24 and 26, 1980.

Results

A first draft of a report on trenching across the 1915 faulting in Pleasant Valley, Nevada, was prepared, and is being readied for open-file release. Although dating of the faulted sediments is uncertain, evidence in the trench suggests that the interval between fault-events on that fault is substantially less than has been inferred from geomorphic studies.

Estimates of errors in reported rupture length were completed for the better-documented historic fault ruptures (about 30). A review and partial revision of magnitudes of earthquakes associated with these ruptures was completed and the errors in magnitudes estimated. These data are now ready for statistical analyses of magnitudes versus surface rupture length with consideration of errors in both variables.

The surface faulting that accompanied the earthquakes of January 24 and 26 occurred along various strands of the Greenville fault as mapped by Herd (1977 and unpublished data), and tectonic displacements also occurred along parts of the Las Positas fault as mapped by Herd (1977).

On the Greenville fault the principal surface break extended discontinuously for at least 4 km, and perhaps 6 km. Maximum right-lateral displacement was about 25 mm, including afterslip through January 28; vertical components as large as 50 mm were seen locally, but these included an indeterminate (probably large) component of non-tectonic gravity effects.

On the Las Positas fault the fractures had, in places, a right-stepping pattern indicative of left-lateral displacement and locally displayed small (< 2 mm) left-lateral displacements. An alinement array surveyed by P. W. Harsh showed about 6 mm of left-lateral displacement between February 21 and March 26, 1980. These observations coupled with progressive growth of some of the fractures indicate tectonic surface displacement along at least 1 km of the Las Positas fault. Concurrent displacement on two faults having a conjugate relation to one another, such as between the Greenville and Las Positas faults, has occurred before. Examples are the faulting associated with the Tango, Japan earthquake of 1927 and the North Izu, Japan earthquake of 1930. A draft report describing the faulting near Livermore has been prepared and is being revised following technical review.

Reports

Bonilla, M. G., 1980, Comment on "Estimating maximum expectable magnitudes of earthquakes from fault dimensions": Geology, v. 8, no. 4, p. 162-163.

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

USGS Contract No. 14-08-0001-18255

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Goals

The goals of this study are to evaluate the historical earthquake effects of the 1902 and 1915 earthquakes in the Los Alamos area and to evaluate potential sources of those earthquakes. The study emphasizes delineation of surface faulting, its linear extent and age in the central Santa Maria Basin area.

Investigations

The evaluation of surface faulting near Los Alamos included interpretation of 1:24,000 scale, low-sun angle aerial photographs covering approximately 325 square miles. Major and minor lineaments were compiled on 1:24,000 scale maps. Based on the aerial photographic interpretations, geomorphic features indicative of fault activity along the lineaments were identified.

Evaluation of the historical effects of the 1902 and 1915 earthquakes included collecting newspaper accounts of damage, research in archives of local libraries, local historical societies and long term residents of the area.

The investigations for early 1980 will include field reconnaissance in areas of lineaments and reported earthquake effects, selection of trench sites and trenching across probable fault traces.

Results

Two strong lineament trends were identified north of Lake Cachuma and extending to the northwest as far as central Santa Ynez Valley. Both trends coincide with prominent scarps in Pliocene and Quaternary sediments. Westward the scarps diminish in height and prominence. Together, the two lineaments bound an apparent structural graben. The southern lineament coincides with the Baseline fault and is accompanied by deflected and antecedent streams. The northern lineament is geomorphically expressed as a south facing scarp accompanied by numerous faceted ridges. No fault is yet mapped along this northern trend.

West of the Santa Ynez Valley, the most prominent lineament coincides with a fault trending along the north edge of Los Alamos Valley. The lineament is marked by a hillside scarp, linear trenches and a few sag degressions aligned along the fault trace. East of Los Alamos Valley, the same lineament trend extends weakly toward Los Olivos and may tie with the Baseline fault. Westward from the lineament trend in Los Alamos Valley, other lineament trends are weak and generally coincide with the valley alluvium-bedrock contacts.

Physical and Mathematical Descriptions of Active Faults

9950-01538

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Investigations

1. Data on the distribution and ages of late-Quaternary surface faulting in the Great Basin were used to define seismic source zones and to estimate long-term average rates of occurrence of high magnitude earthquakes for the region.

2. Kaye Shedlock, in cooperation with Dave Perkins, has been investigating the sensitivity of probabilistic ground motion to changes in input seismicity parameters and developing methods of presenting measures of site safety as a function of seismic parameters.

Results

Several regions within the Great Basin on the order of 10,000 km^2 or more in area appear to be characterized by distinctive ages (and, thus, rates) of late Quaternary surface faulting. Regions recognized thus far are:

1. regions within which there are no fault scarps in unconsolidated deposits;
2. regions containing fault scarps of late Pleistocene age but which lack fault scarps of Holocene age, and
3. regions which contain fault scarps of Holocene age.

Data reported by Slemmons (1977) for the relationship between earthquake magnitude and surface displacement for normal faulting show that earthquakes above magnitude 7 typically result in a maximum displacement of at least several meters. Because all scarps mapped by us are the result of at least 1 meter of vertical displacement, we infer that they were produced by earthquakes of about magnitude 7 or larger. In addition, our studies show that such scarps are well-preserved for at least Holocene time and, thus, probably represent a virtually complete record of magnitude 7 and greater events in the region during the past 10,000 years.

The fault scarp data from the various seismic source regions that we have defined permit calculation of the rates of occurrence of magnitude 7 and greater earthquakes (events). Values range from 0.7 events/10^4yrs/$10^4$$km^2$ to 3.4 events/10^4yrs/$10^4$$km^2$. The highest value was determined by R. E. Wallace (1978) in an area studied by him in north-central Nevada. Combining rates and areas for each of the source regions gives an average recurrence interval of 240 years/event for the entire Great Basin. This value does not reflect the contribution of fault systems of possibly higher than average rates of activity such as the Wasatch fault in Utah.

Reference Cited

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Report

Bucknam, R. C., Algermissen, S. T., and Anderson, R. E., 1979, Late Quaternary faulting in western Utah and its implications in earthquake hazard evaluation: Geological Society of America Abstracts with Programs, v. 11, p. 71-72.

Earthquake Hazards Associated with the Verdugo-Eagle Rock and Benedict Canyon Fault Zones, Los Angeles County, California

14-08-0001-18245

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Geophysical Phase of the Study

Investigations

The principal product for this reporting period is a report by R.H. Chapman and G.W. Chase entitled "Geophysical investigation of the Verdugo-Eagle Rock and associated faults, Los Angeles County." The geophysical investigation conducted by the authors consisted principally of making a series of detailed gravity lines across the trace of the Verdugo-Eagle Rock fault zone, supplemented by compilation of other available gravity data plus a brief study of available aeromagnetic maps that include the study area. The report consists of an illustrated text and a gravity map of the study region. Profiles along gravity lines and principal facts for the data from which the map was compiled are included in the text. The report is the second of a two part series; the first, on the Santa Monica-Raymond fault zone, was submitted in the Final Technical Report submitted for last year's study (Hill and others, 1979).

Results

Evidence for the location of the mostly concealed Verdugo fault consists of steep gradients that are defined on the gravity profiles; similar evidence on some profiles suggests the locations of the Eagle Rock and San Rafael faults. Additionally, the gravity data indicate that if the Eagle Rock fault is a southeastern continuation of the Verdugo fault, there is either a bend or offset in the fault zone near Verdugo Canyon. The aeromagnetic data show a magnetic high over the Verdugo Mountains and San Rafael Hills, and a steep magnetic gradient in the vicinity of the zone comprising the Verdugo, Eagle Rock, and San Rafael faults. The fault zone, therefore, may be the boundary between relatively magnetic igneous and metamorphic rocks exposed to the northeast and non-magnetic sedimentary rocks and sediments to the southwest.

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Geological Phases of the Study

Investigations

The geologic aspect of the study is divided into two parts: surface and subsurface. The surface part of the study consists of a continuation of work by F.H. Weber, Jr. on a map that was submitted preliminarily as part of a report in Hill and others (1979). This study entails field mapping, study of aerial photographs and relating soils maps to alluvial units. The subsurface part of the study was initiated in mid-late 1979 by R.B. Saul and emphasizes relationships of younger and older alluvium to recency of faulting by interpretation of ground water and other subsurface data, principally in the central and eastern San Fernando Valley region.

Results

The subsurface data compiled and plotted by Saul so far indicate possible Holocene deformation in the Pacoima-Mission Hills area in the vicinity of the trace of the Verdugo fault.

HOLOCENE BEHAVIOR OF THE SAN ANDREAS FAULT SAN JUAN BAUTISTA TO POINT ARENA, CALIFORNIA

Contract No. 14-08-0001-18229

by

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SUMMARY

During the first year of our two-year study of the Holocene behavior of the San Andreas fault in Northern California we located six sites between Point Arena and San Juan Bautista (Figure 1) that met our requirements for recurrence interval studies. Exploratory trenches were excavated at three of these locations. 1) the Olsen Ranch on the Garcia river near Pt. Arena (pt. 1), 2) Dogtown near Bolinas and Pt. Reyes (pt. 4), and 3) Anzar Road, a few miles northwest of San Juan Bautista (pt. 6).

The Dogtown - Point Reyes site proved to be the only scientifically instructive location of the three.

Initially four trenches (totalling approximately 120 meters) were excavated to a depth of about 3 1/2 meters. They were geologically logged and sampled for carbonaceous material. These trenches revealed evidence of not only the 1906 rupture on the San Andreas fault, but also evidence for at least three seismic events that occurred prior to 1906. Drafting of the trench logs has not been completed at this time, but figure 2 is a schematic composite of all the trench logs, and the locations of the four dated C^{14} samples are shown. Samples were selected to bracket the three pre-1906 seismic events. The reported ages are:

1906 Event
▲1. 380 + 85 years
Pre-1906 Event (1)
▲2. 1245 + 105 years
Pre-1906 Event (2)
▲3. 2230 + 105 year
Pre-1906 Event (3)
▲4. 1410 + 100 years

Later, three new trenches were located parallel to the original four at the Dogtown - Pt. Reyes site. They had a total length of 45 meters and were about 3 1/2 meters deep. One important exposure in the southeast wall of trench 5 revealed an unconformity in the fault zone that establish a fourth pre-1906 seismic event. This relationship is shown diagrammatically on figure 2 as the stratigraphic horizon separating Red Gravel and Unit X. Charcoal was sampled from the rock units shown by a star on figure 3 for C^{14} dating. We now believe that four pre-1906 seismic events can be demonstrated at this locality. The youngest two are shown by rupture surfaces truncated by unconformities. At least two ruptures preceding them are recognized by increasingly dissimilar stratigraphic juxtapositions across the fault surface, which could have been caused only by continued lateral displacements (see figure 2). Indeed, there may be several events recorded by each of these stratigraphic offsets.

At the present time we are in the process of obtaining C^{14} ages from the six stratigraphic horizons shown on figure 3. We hope they will accomplish two things:

1) Resolve the ambiguity of ages of our initial four C^{14} dates. It is possible that one, or all, of the previously determined values shown on figure 3 are too high.

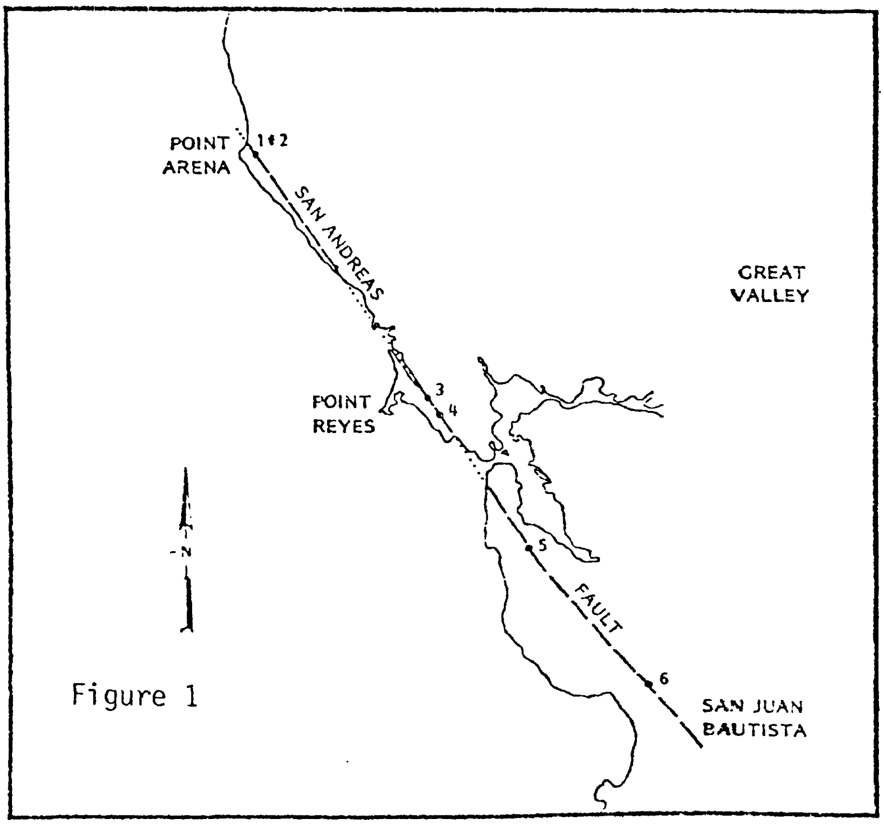
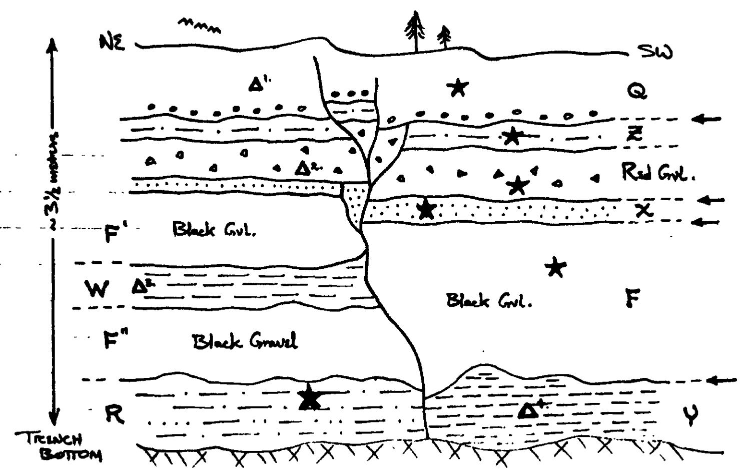


Figure 1

2. Establish recurrence intervals for the last two pre-1906 earthquakes on the San Andreas fault, and perhaps for the two events that preceded them.

It seems likely that the first two pre-1906 ruptures seen in the trenches were caused by two earthquakes that occurred sequentially prior to 1906. The older stratigraphic offsets, however, might well have resulted from multiple offsets, the accumulated effects of which are what we currently see. We must await the C^{14} dates in order to evaluate this possibility.

FIGURE 2. Dogtown-Point Reyes Trench Site.



SCHEMATIC COMPOSITE TRENCH LOG
(Seven Trenches)

C^{14} ages at locations shown by Δ above:

1. 380 ± 85 yrs.
2. 1245 ± 105 yrs.
3. 2230 ± 105 yrs.
4. 1410 ± 100 yrs.

★ Sites at which C^{14} ages are currently being determined.

← Horizons formed following a seismic event.

Late Tertiary and Quaternary Shoreline Datum Planes and Tectonic Deformation in the Southeastern U.S.

9490-02744

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Investigations

1. Middle and late Pleistocene marine terrace and sea level chronologies from the Virginia-North Carolina border, the Cape Fear Arch, and the Charleston, S.C., regions were compared with one another and with terrace and eustatic sea level chronologies from Barbados, New Guinea and Bermuda.

2. Net uplift rates for the last 200,000 years were estimated on the basis of discrepancies between various Pleistocene Atlantic Coastal Plain sea level positions and correlative eustatic sea level positions.

3. Samples from sediment cores and outcrops from an across-strike transect in the Cape Fear Arch region (running from the downdip marine facies to the paleoshoreline or Orangeburg Scarp) were examined to establish the age, origin, and history of the Orangeburg Scarp.

Results

1. Faunal and floral assemblages from marine deposits in the Virginia-North Carolina border area indicate two Pleistocene interglacial intervals during which paleo-sea level ranged from 2 to 12 m (meters) and from 4 to 10 m. Uranium-series dates on fossil corals from these deposits yielded ages of 188,000 and 72,000 yr B.P. (years before present), respectively. Near Charleston, S.C., late Pleistocene sea level high stands from 6 to 9 m and from 3 to 10 m and their associated interglacial faunas and floras were dated at 120,000 and 94,000 yr B.P. On the south flank of the Cape Fear Arch in northeastern S.C., a 440,000 yr B.P. high stand characterized by interstadial floras and faunas, and perhaps a distinct, slightly younger transgression are in evidence. These paleontologic, morphostratigraphic and radiometric data indicate that a simple "layer-cake" model for Atlantic Coastal Plain marine Pleistocene deposition is incorrect. Although there is a major glacio-eustatic component to the local sea level record, a tectono-eustatic component is also in evidence from the similar elevation along the coast of non-correlative deposits and inferred paleo-sea levels which, if tectonically undisturbed since formation, should be at different elevations according to independent eustatic sea level data. Further, some correlative deposits and paleo-sea level positions are found at different elevations in different regions, implying crustal displacement.

2. The composite sea level chronology for the Coastal Plain does not correspond to eustatic sea level chronologies derived from Barbados, New Guinea, and Bermuda (Figure 1). If these independent eustatic models are correct, net uplift rates of roughly 0.20 to 0.45 mm yr^{-1} for the Charleston, S.C. and Virginia-North Carolina border areas are in evidence for about the last 100,000 yr B.P. Rates of about 0.10 to 0.20 mm yr^{-1} are indicated for northeastern North Carolina since 200,000 yr B.P. Hydroisostatic

adjustment from glacial/interglacial sea level fluctuations causing ocean basin depression and Atlantic continental margin uplift provides, at least in theory, a possible mechanism to account for these discrepancies.

3. The Orangeburg Scarp of South Carolina was last occupied by a marine transgression which ended about 3.0 ± 0.2 m y a. Faunal and floral evidence indicates that regression from the scarp coincided with the final closing of the Isthmus of Panama and documents major Pliocene cooling corresponding to the initial Tertiary Northern Hemispheric glaciation which is in evidence from deep sea cores. The scarp may have been uplifted as much as 50 m in this region since the glacio-eustatic sea level drop caused the regression.

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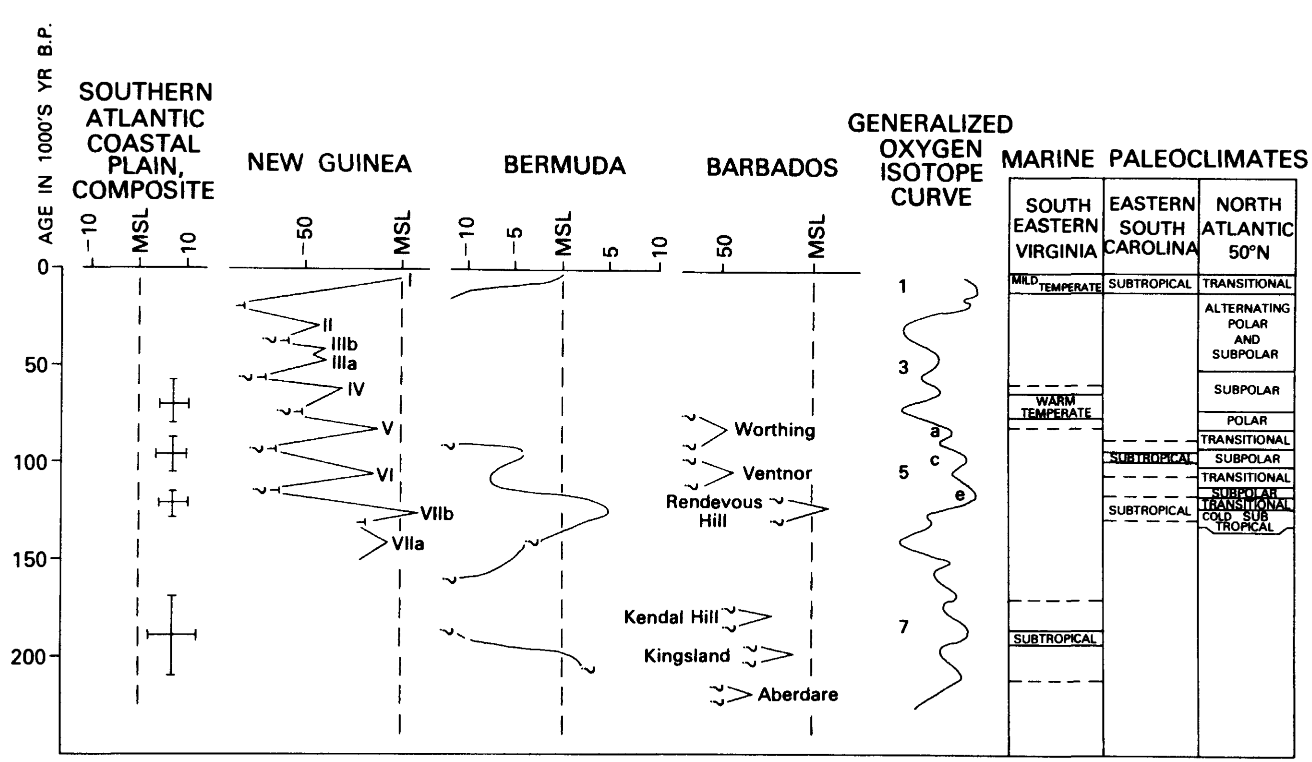

Figure 1. Comparison of southern Atlantic Coastal Plain Quaternary sea level record to models of eustatic sea level estimated from studies of New Guinea, Bermuda and Barbados emerged coral terraces and speleothems. Marine paleoclimatic conditions are shown for periods of relative high stands of sea level along the Atlantic Coastal Plain.

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

Study of late Quaternary land forms along the San Andreas fault in the "Big Bend" area from near Elizabeth Lake to California Highway 33 has been in progress and is illuminating the late Quaternary record of past earthquake activity and neotectonic movements in the area.

Results

The zones of surface rupture produced by the 1857 earthquake and earlier events have been mapped across the entire area except near Gorman where the mapping is now nearing completion. In the "Big Bend" area the fault zone is generally rather narrow and the rupture produced in 1857 is seldom more than a few tens of meters wide. It follows along a fault zone of variable width characterized by subdued older fault land forms.

The Holocene shear pattern is dominated by left-stepping right shears which often bound linear pressure ridges of similar orientation. Sag depressions of several types, shutter ridges, and other geomorphic features are the result of right simple shear.

Where deep canyons cut the fault zone in the western part of the area, Tertiary and older crystalline rocks have been squeezed up along the fault zone and thrust over both late Quaternary surfaces and deposits. These fault slices blend into landslides at their distal ends.

Although our studies show evidence of continuing late Quaternary right slip, no compelling evidence of significant regional vertical slip was found across the fault zone. The region as a whole, however, has been elevated significantly, including both fault walls.

The north flank of the San Emigdio Range, lying between the Plieto thrust system on the San Joaquin Valley side and the San Andreas system to the south, gives abundant evidence of rapid and substantial deformation during the late Quaternary. The flexure also shows expansion to the north during this period.

The junctions of the Big Pine and Garlock faults with the San Andreas are buried beneath young alluvium and the lack of fault-related topography on the alluvial surface suggests either little late Quaternary activity, or long recurrence intervals between major seismic events.

Three map sheets are completed but not yet published. These are believed to be the most detailed maps so far prepared of land forms and fault features in the Big Bend area of the San Andreas fault.

A discontinuously exposed north-dipping thrust fault, the Caballo Canyon fault, has been mapped for a distance of about 16 km, 1 km north of and generally parallel to the San Andreas fault. This thrust was active from late Oligocene to early Miocene time and places Paleozoic metasedimentary and Mesozoic granitic rocks over Miocene Temblor Formation. It is interpreted as a fault older than the San Andreas and transected by it.

Using morphometric techniques and multi-stage steroscopic imagery, erosional surfaces and stream courses in an area of about 6000 km^2 on either side of the San Andreas fault have been analyzed to detect any changes which may be attributable to recurrent movements on the fault.

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The San Miguel Fault Zone, Baja California, Mexico

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Investigations

During 1979 the San Miguel fault zone was mapped in detail at a scale of 1:25,000 from Real De Castillo to Jamu, Baja California, a distance of 84 kilometers. To date only one trench across the fault trace has been completed.

Results

The fault zone consists of several major right-stepping strands, each consisting of left-stepping segments. The faults cut Cretaceous tonalite, granodiorite, and gabbro, and pre-Cretaceous andalusite schist and other metamorphic rocks. A swarm of near-vertical dacite dikes are believed to also be of Cretaceous age. The fault zone forms the boundary between Valle San Rafael and the Alamo plane to the southwest, and the Sierra Juarez to the northeast. The vertical separation between the pre-Miocene erosion surface on the Sierra Juarez and that of the Alamo Plane ranges from 320 meters in the north to 200 meters in the south. Bedded strata consist of pre-Miocene fluvial strata, volcanic rocks of 18 to 8 million years, and post-eight million year fanglomerates and fluvial deposits. Four generations of these latter deposits were mapped, the younger ones presumably being of Pleistocene age. The youngest of these deposits are cut by some, but not all, segments of the fault system. Typical vertical separation of post Miocene deposits are only a few meters. South of San Miguel a post-Miocene erosion surface appears to be downdropped as much as 46 meters to the southwest and tilted as much as 21 degrees to the southwest. Fault plane striations indicate that the most recent motion of some strata is purely dip-slip.

The maximum strike separation of near-vertical Cretaceous dikes is 254 meters. A small body of gabbro may be offset as much as 600 meters. The composite strike offset of Cretaceous rocks on all strands does not exceed this magnitude.

Due to the careful mapping of Shor and Roberts (1958) it has been possible to exactly relocate the 19 kilometer rupture line of the 6.8, February 1956 event. Air photographs taken in October 1956 show the rupture line discontinuously along much of the length observed by Shor and Roberts. Today the surface evidence of the rupture can only be detected along a distance of 2.5 kilometers south of San Miguel. Along this segment the trace can be followed by a line of dead juniper trees, a vertical separation of up to 114 cm, down to the southwest, and fresh tension cracks parallel to the trace. Shor and Roberts did not record vertical separations in excess of 60 cm along this segment of the fault, leading us to the conclusion that either the additional separation has resulted from continued settling of the downdropped side, or additional creep motion on the fault. It is no longer possible to measure the strike component of separation caused by the 1976 event.

Prominent northeast trending lineaments up to 15 km in length cross the fault zone, and show some evidence for left lateral separation. A study of joint lineaments throughout the fault zone suggests that the basement rocks are fractured on a pervasive set of microfaults, right lateral to the northwest, left lateral to the northeast, similar to those described by Lockwood and Moore (1979) in the southern Sierra Nevada. East of San Miguel the mesas capped by 10 my old ignimbrite display a pattern of joints very similar to those displayed by the crystalline basement rock, suggesting that the deformation pattern is post 10 m.y.

Our tentative conclusion is that the cumulative composite strike separation across the San Miguel fault zone is less than one kilometer and of the same order of magnitude as the composite vertical separation. The lack of offset streams, sag ponds, recent scarps or other evidences of Holocene fault motion indicates that there have probably not been frequent events of major separation during the past few thousand years.

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Correlating and Dating Quaternary Sediments by Amino Acids

9460-01996

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Investigations

1. Completed preliminary time-temperature kinetic studies in the laboratory in order to develop parameters by which to evaluate results of field studies.

2. Completed preliminary investigations of the geochemistry of amino acids in sediments from Clear Lake, California, as a prelude to a more complete study on the Clear Lake core to be obtained in July, 1980.

Results

1. Fragments of modern specimens of the venerid bivalve *Saxidomus giganteus* from the Palix River, Willapa Bay, Washington, were heated with water in sealed tubes in a constant temperature oven. Temperature settings ranged from 121° to 165°C with multiple analyses conducted at 141°C. Time of heating ranged from 1.5 h at 141°C to 326 h at 121°C. After heating, the shells were analyzed for the content of amino acids and for the D/L ratios of the amino acid enantiomers. The results show that protein diagenesis in *Saxidomus* can be modeled by these kinds of experiments. Absolute concentrations of amino acids decrease at rapid rates during initial diagenesis and then most amino acids approach a constant decomposition rate that is two orders of magnitude slower than the initial rates of decomposition. Laboratory-derived kinetics of racemization follow different pathways for each amino acid. Activation energies of racemization range from 28.0 kcal/mole for proline to 31.1 kcal/mole for isoleucine and average 29.4 kcal/mole, the value we have assumed previously in our geochronologic calculations. Curves of rates of decomposition versus rates of racemization of amino acids in high temperature experiments provide a control for comparison of amino acids in fossil specimens. The relationships between results from the laboratory and from fossils are similar in the region of high concentrations and low D/L values. Results diverge as concentrations decrease and D/L ratios increase. Excess leaching of the amino acids with respect to racemization accounts for some of the divergence.

2. Amino acid geochemical studies of lacustrine sediment in Core 4 from Clear Lake, California, show that the total absolute concentration of fourteen amino acids systematically decreases with depth from 8700 nanomoles/g at 4.57 m to 330 nanomoles/g at 79.6 m. The extent of racemization (D/L ratios) of seven amino acids increases with core depth; however, only aspartic acid and alanine have undergone sufficient racemization to provide D/L ratios useful for geochronologic applications. Kinetics of racemization of aspartic acid are non-linear below a depth of 30 m where the D/L ratio is 0.24. On the other

hand, the kinetic curve for alanine racemization is linear to the lowest sampled depth at 79.6 m. Therefore, alanine was used for preliminary age dating. The average rate constant for the racemization of alanine was determined to be $2.78 \pm 0.54 \times 10^{-6} yr^{-1}$, and the age at 79.6 m was estimated to be about 55,000 ± 13,000 yr. The estimated age falls between ages determined previously by radiocarbon and by oak pollen-oxygen isotope chronologies. But the upper limit amino acid age of 68,000 yr approaches closely the oak pollen-oxygen isotope age of ∿ 70,000 yr.

This preliminary study of amino acids in Clear Lake sediments has shown that (1) measureable amounts of amino acids are present, (2) concentrations and D/L ratios systematically change with depth, and (3) age estimates are reasonable. This work demonstrates that amino acid geochemistry will be potentially useful in geochronologic studies on the Clear Lake core to be recovered in July, 1980.

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Coastal Tectonics Western United States

9940-01623

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Investigations

1. Emergent marine terraces and deposits were mapped and dated by radiocarbon, amino-acid and trace-element techniques to establish tectonic uplift rates and date faults. Lacustrine deposits east of the Sierra Nevada were correlated and dated by radiocarbon, trace-element and paleomagnetic techniques to develop new Quaternary dating tools and refine stratigraphic ages of correlative marine deposits in coastal areas.

Results

1. Trace-elements correlate a volcanic ash in tectonically deformed marine strata in the Humboldt Basin of northern California with the Maidu ash dated at 450,000 years. This correlation establishes a precise age calibration for the biostratigraphy of the Humboldt Basin and provides a means of dating faults and folds in the area. This work is in cooperation with Sam Morrison and Andrei Sarna-Wojcicki.

2. Amino-acid age estimates of ~250 kA and 85 kA on fossil mollusks from two marine terraces near Gaviota indicate tectonic uplift rates have accelerated slightly in late Quaternary time. A discontinuous, but prominent, 2 m bench at the base of the modern sea cliff in the area is bored locally by pholads (littoral to sublittoral rock-boring bivalves). Because of these borings this bench was tentatively interpreted to be a wave-cut platform uplifted in late Holocene time.. However, living pholads were found in splash pools on the bench. Therefore, the presence of these borings above the tidal zone cannot be used to definitely indicate very recent rapid uplift.

Fifteen km to the west near Point Conception a 40-85 kA marine terrace is warped into the Government Point syncline and the Point Conception anticline. The terrace platform rises from about 2 m above sea level in the axis of the syncline to 20 m on the north limb of the anticline.

This work is in cooperation with George Kennedy, John Wehmiller and Scott Mathieson.

3. Fossil mollusks from a 37 m marine terrace on the south limb of the Ventura Avenue anticline yield a ^{14}C date of about 6.5 kA. The 6 m/kA uplift rate derived from these data is consistent with rates derived from a higher terrace dated at about 40 kA by amino-acid techniques. Also, this rate

and the late Pleistocene sea level curve indicated there should be a 28-30 kA marine terrace at about 170 m in this area. Fossil mollusks from a terrace remnant at this elevation yield a ^{14}C date of about 27 kA. This work is in cooperation with Andrei Sarna-Wojcicki, George Kennedy and John Wehmiller.

4. Trace-elements and paleomagnetic data (reversed) correlate tephra units in lacustrine deposits from Mono Basin and Long Valley, California. This short reversal may be the Blake paleomagnetic event. Stratigraphic refinement and dating of intercollated lacustrine and volcanic (tephra) deposits in this area provides a means of dating tectonically deformed strata in local basins and in coastal basins where the same tephra units are found. This work is in cooperation with Andrei Sarna-Wojcicki, Joseph Liddicoat and Roy Bailey.

5. Radiocarbon dates on calcareous tufa nodules from lacustrine sediments in Mono Basin revise the age of the Mono Lake paleomagnetic excursion from 25 kA to 27-29 kA. This work is in cooperation with Joseph Liddicoat and Steve Robinson.

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Seismological Field Investigations

9950-01539

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Investigations

1. Peru aftershock study--continued analysis and interpretation of aftershock data obtained from the magnitude -7.8 (M_S) earthquake of October 3, 1974.

2. Argentina aftershock study--regional investigation of the magnitude 7.1 (M_S) western Argentina (Caucete) earthquake of November 23, 1977.

Results

1. Nearly all aftershocks of the October 3, 1974 Peru thrust-faulting earthquake (M_S = 7.8), which were located from regional network data, lie south of the main shock epicenter (12.39° S., 77.66° W.). The 113 located epicenters, October 7-24, occurred within an irregularly shaped region between about 11.9° S. and 13.8° S. latitude, measuring approximately 220 km long by 150 km wide. These aftershocks range in magnitude from 2.5 to 5.3. There are two pronounced clusters of activity, one which is between the location of mainshock and the M_S = 7.1 aftershock (12.638 S., 77.563 W.) of November 9, and consists of ten events. The other cluster occurs in the vicinity of the Chilca station, approximately 70 km SSE of Lima, and is at the eastern end of the northeast-trending segment of the aftershock zone. The 66 events in this cluster reflect, in part, the lower magnitude for which good locations were determinable here relative to elsewhere within the aftershock zone. Hypocentral solution control by data from nearby seismographs to the northwest (Ñaña and Lima) and to the southeast (Cañate and Paracas), as well as Chilca, implies that the continental or near-continental hypocenters are well determined. Other continental (and, coincidentally, near-station) events include two earthquakes located close to Lima and one at the southern extreme of the aftershock zone, near Paracas. Additionally, one teleseismically located aftershock (m_b - 4.7) occurred near Paracas on October 5, prior to installation of the temporary seismic net. The Lima and Paracas aftershocks may actually be separated from the primary aftershock trends. There are apparent gaps of aftershock activity landward of the main shock location, landward of the southern limb of the offshore aftershocks, and immediately to the south of the November 9 aftershock location.

The vertical distribution of aftershock hypocenters show focal depths that range from less than 10 km for the more oceanward events to about 65 km for the deepest Chilca aftershock and the northern most aftershock near Lima. The most oceanward events, including the mainshock and November 9 aftershock, appear to be confined within a 50 km wide section (SW-NE) of the subducting Nazca plate and dip landward at about 10°. The indicated dip is consistent with the mainshock focal mechanism solution and the results of Hussong and others (1976) near 12° S. latitude. Focal depths of the landward events show an apparent increase in dip, to between 20° and 30°, of the Nazca plate as it extends to the northeast beneath coastal Peru.

The Chilca epicenter cluster and the epicenters that trend oceanward from Chilca, present what is perhaps the most interesting geometrical aspect of the aftershock series. P-wave first-motion data (158 points) from 25 aftershocks of magnitude $\geq$ 3.6 within the Chilca cluster and the southwest trend of epicenters away from the Chilca group, were used to construct a composite focal mechanism solution. A statistical evaluation of the distribution of first-motion data, determined by the focal mechanism solution program, indicate that the strike and dip of both nodal planes are well constrained. The strike of the "A" plane (N. 35° W.) is roughly parallel to the coastline and to the preferred nodal plane of the main shock; the dip of the "A" plane is 40° NE. The slip vector in this plane would require the displacement to be approximately 63% left-lateral strike-slip and 37% moderate angle thrust. Considering the long (~ 125 km) and narrow (~ 25 km) northeast alignment of aftershocks used in the composite focal mechanism solution, the motion required by the "A" plane seems tectonically implausible. The "B" nodal plane strikes N. 31° E. and dips 71° NW. This strike is essentially perpendicular to the coastline, and is roughly subparallel to the alignment of epicenters of the aftershocks used in the solution. The slip vector in the "B" plane implies that the component of strike-slip displacement (right-lateral) is approximately 42%, accompanied by a reverse faulting component of 58%. Because the strike of the "B" plane is roughly parallel to the epicenter alignment of the Chilca cluster and the offshore Chilca trend (those aftershocks used to determine the composite focal mechanism solution), the "B" plane of the focal mechanism is preferred. Displacement along the "B" plane suggests that there was differential, oblique motion within the subducting Nazca plate and that it was coseismic with the main shock.

2. Most of the 100 previously located aftershocks of the M_S = 7.1 western Argentina (Caucete) earthquake have been relocated. Data for determining approximately 150 additional aftershock hypocenters have also been read and are currently being processed. At least seven earthquakes, recorded during the two-week field study, have been located at depths between 100 and 120 km, the largest of which is approximately magnitude 3.5. It is not clear at this time what the relationship is, if any, between these deep events and the seismicity associated with the main shock.

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Soil Correlation and Dating, Western Region

9540-02192

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(415) 323-8111 x 2009

Investigations

1. About seventy-eight soil profiles (including about 250 samples) have been described, sampled and submitted for laboratory analysis to study changes of properties in six well dated time sequences (chronosequences) of soils in the western United States. Partial or complete laboratory data is now available for five of these chronosequences. The chronosequence samples are developed in alluvium, colluvium, till, and marine terrace deposits derived from granitic, volcanic, and sedimentary terrains in Colorado, western Washington, and central California. Chronosequence selection, sampling, description, data analysis and interpretation are being carried out cooperatively with Michael J. Singer, Alan Busacca, and Richard Meixner (University of California, Davis); Peter W. Birkeland and Marith Reheis (University of Colorado); and John Bethel (University of Washington), Bill Bull and Les McFadden (University of Arizona); Ed Keller, and Tom Rockwell (UC, Santa Barbara) and David Dethier (USGS, Seattle). Laboratory analyses are being conducted by UC Davis, Univ. of Washington, and the U.S.G.S. (Menlo Park and Denver).

2. R. M. Burke, J. W. Harden, and D. E. Marchand have reconnoitered more than 15 potential soil chronosequences in California, Arizona, Colorado, Wyoming, Idaho, and West Texas. Three more chronosequences will be sampled this year--near Santa Cruz and two in the eastern Sierra Nevada of California and two chronosequence studies have been started (Sacramento Valley, CA and Bighorn Basin, Wyo.-Mont.).

3. Our soil studies are coordinated with other projects involved in Quaternary dating, especially uranium series and uranium-trend dating (J. N. Rosholt), amino acid dating (K. R. Lajoie, John Wehmiller, Keith Kvenvolden, and Etta Peterson), tephrochronology (A. M. Sarna-Wojcicki), magnetostratigraphy (Ken Verosub, UC, Davis), thermoluminescence (Rodd May), and other studies involving soils (K. L. Pierce, Ralph Shroba, M. N. Machette).

4. A terminal-operated program, MINITAB, is being used for storage, plotting, and statistical interpretation of soil information. Soil data stored for each profile and sample include 25 field properties; soil thin section information; quantitative mineralogy of very fine-sand fractions; semiquantitative mineralogy of clay fractions; bulk density; complete particle size information; 25 chemical properties of the less-than 2 mm soil fraction; and bulk chemistry of the less-than 2 mm and silt-plus-clay fractions (13 elements by X-ray spectroscopy, 26 elements by neutron activation). We are also storing and plotting published soil chronosequence data by previous workers.

Results

1. Time plots of nearly all properties studied show clear but nonlinear changes with time. Many properties show rapid increases up to 10,000 to 100,000 years, followed by a slower rate of increase. Rates of change are controlled by both climate and parent material: soil properties change more rapidly in western Washington than in the drier San Joaquin Valley; rates are more rapid for volcanics than for granitic parent materials and more rapid for fine-grained than coarse-grained deposits.

2. Results from x-ray fluorescence and neutron activation analyses of 44 soil samples from the Merced, Tuolumne, and Stanislaus River areas of the northeastern San Joaquin Valley indicate striking and systematic changes in bulk soil chemistry with age. Aluminum, silicon, iron, calcium, magnesium, hathium, and scandium show the best trends, but manganese, sodium, potassium, barium, nickel, zirconium, tantalium, and thorium also yield good plots against absolute time. Calcium, magnesium, strontium, and sodium are quite strongly intercorrelated, whereas titanium varies independently of all other elements and shows no trend with soil age. Titanium therefore appears to be a useful index element.

3. Morphological properties observable in the field are usually a reliable index of soil age. We have found the following properties to be most useful: 1) presence, nature, and thickness of B horizons or horizons in the B position, 2) depth to unweathered parent material, 3) B horizon structure, 4) location, thickness, and abundance of oriented clay films in B horizons, 5) B horizon texture and consistency relative to A and fresh C horizons, 6) nature, abundance, and size of interstitial and tabular pores in B horizons, 7) color of B horizon relative to A and C horizons, and 8) number and distinctness of soil horizons. In old desert soils where B horizons have been eroded, the character of subsoil horizons of calcium carbonate accumulation becomes more diagnostic of soil age than the overlying B horizons.

4. Thin sections of soil B horizons reveal progressive textural development. Stages of development can be recognized for correlation purposes. Thin sections and grain counts of A horizons show progressive etching, alteration, and depletion of weatherable minerals with time.

5. A horizon thicknesses tend to increase for several tens of thousands of years, then decrease. Evaluation of A horizon properties may be useful means of dating soils less than about 70,000-100,000 years old.

6. Particle size analyses provide valuable information for correlation and dating. Content of less-than-2 and less-than-1 micron clay constitute two of the most reliable age indices for soils in all chronosequences studied. Silt and sand fraction data permit categorization of parent materials and adjustment of clay contents for profile stratification or textural differences between profiles.

7. Bulk density analyses show very small standard deviations between replicate samples. Bulk density increases rapidly during the first 10,000 to 20,000 years of soil development, then increases at a slower but steady rate to a limiting value of about 2.0 g/cc. The product of bulk density and clay content, summed through a soil profile above fresh parent material correlates very well with soil age.

8. Semiquantitative clay mineralogy appears to be a promising technique, although our present data are limited. Arkosic chronosequences tend to show progressive depletion of illite and concomitant increase in kaolinite/halloysite, whereas volcanic and metavolcanic parent materials show a gradual buildup in smectite with time.

9. Soil properties related to leaching (pH, extractable cations, base saturation) become more useful as age indices in regions where precipitation is moderate to high. pH decreases and total profile hydrogen ion content increases with age in the Merced, Dry Creek and Cowlitz chronosequences. In the Sierra Nevada foothills, however, older soils are invariably buried beneath younger deposits and the pH and extractable cations change rapidly following burial.

10. Cation exchange capacity increases with clay content and therefore with the age of a soil. Because CEC is also affected by organic matter and clay mineral composition of the soil, it tends to be less useful as an age index than other soil properties. Determination of CEC and extractable cations, however, permit calculation of base saturation percentage, which may be a useful parameter for soils in humid regions.

11. Well drained and oxidized soil profiles display increases in dithionite-extractable free iron (Fe_d) and aluminum (Al_d) oxides with time. Free iron appears to be lost in soils subject to reduction during their development. The rate of Fe_d and Al_d increase is clearly dependent upon climatic and vegetational environment.

12. Organic carbon values, like bulk density determinations, are readily reproducible. Organic carbon shows a smooth exponential decrease with depth, but the rate of decrease is greater in older soils. It may be possible to determine approximate soil age back to about 100,000 years, independent of parent material, from organic carbon profiles. Carbon is also a valuable aid in recognition of buried soils.

13. In general, profile summations (e.g., total clay in profiles), horizon ratios (e.g., free iron in B/free iron in A), and differentials (B-A, B-Cn) tend to correlate better with time than do absolute values of individual variables.

14. Studies of replicate samples and analyses indicate that laboratory error is generally small compared to the variability between soil sampling sites on the same deposit.

15. Under ideal circumstances (a soil adhering closely to a well studied chronosequence), a careful profile description and full laboratory analysis will permit accurate age estimation of relict soils within about 25 percent of the stated value. Further work will attempt to reduce this margin of uncertainty. Extreme care in soil profile site location, description, and sampling are essential to obtain reliable and reproducible results.

Reports

Burke, R. M., and Birkeland, P. W., 1979, Reevaluation of multiparameter relative dating techniques and their application to the glacial sequence along the eastern escarpment of the Sierra Nevada, California: Quaternary Research, v. 11, no. 1, p. 21-51.

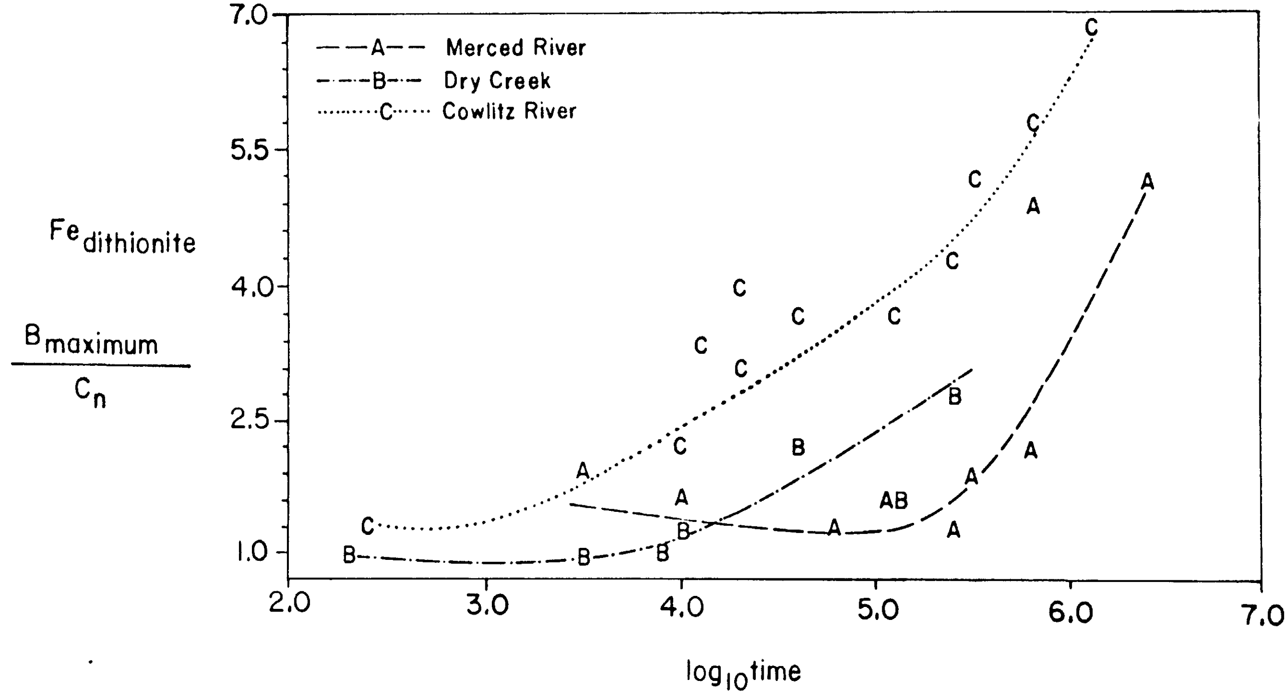
Busacca, A. J., Meixner, R., and Singer, M. J., 1979, Rates and processes of clay mineral transformation in a soil chronosequence from the Merced River, California (abs.): Agronomy Abstracts and Programs for 71st Soil Science Society of America Annual Meeting, Fort Collins, Colorado, p. 188.

Harden, J. W., and Marchand, D. E., 1980, Quaternary stratigraphy and interpretation of soil data from the Auburn, Oroville, and Sonora areas along the Foothills fault system, western Sierra Nevada, California: U.S. Geological Survey Open-file Report 80-305, 57 p.

Marchand, D. E., and Harden, J. W., 1979, A stratigraphic sequence of Quaternary colluvial and alluvial deposits and soils, western Sierra Nevada foothills, California (abstract): Geological Society of America, Cordilleran Section, Abstracts with Programs, v. 11, no. 3, p. 90.

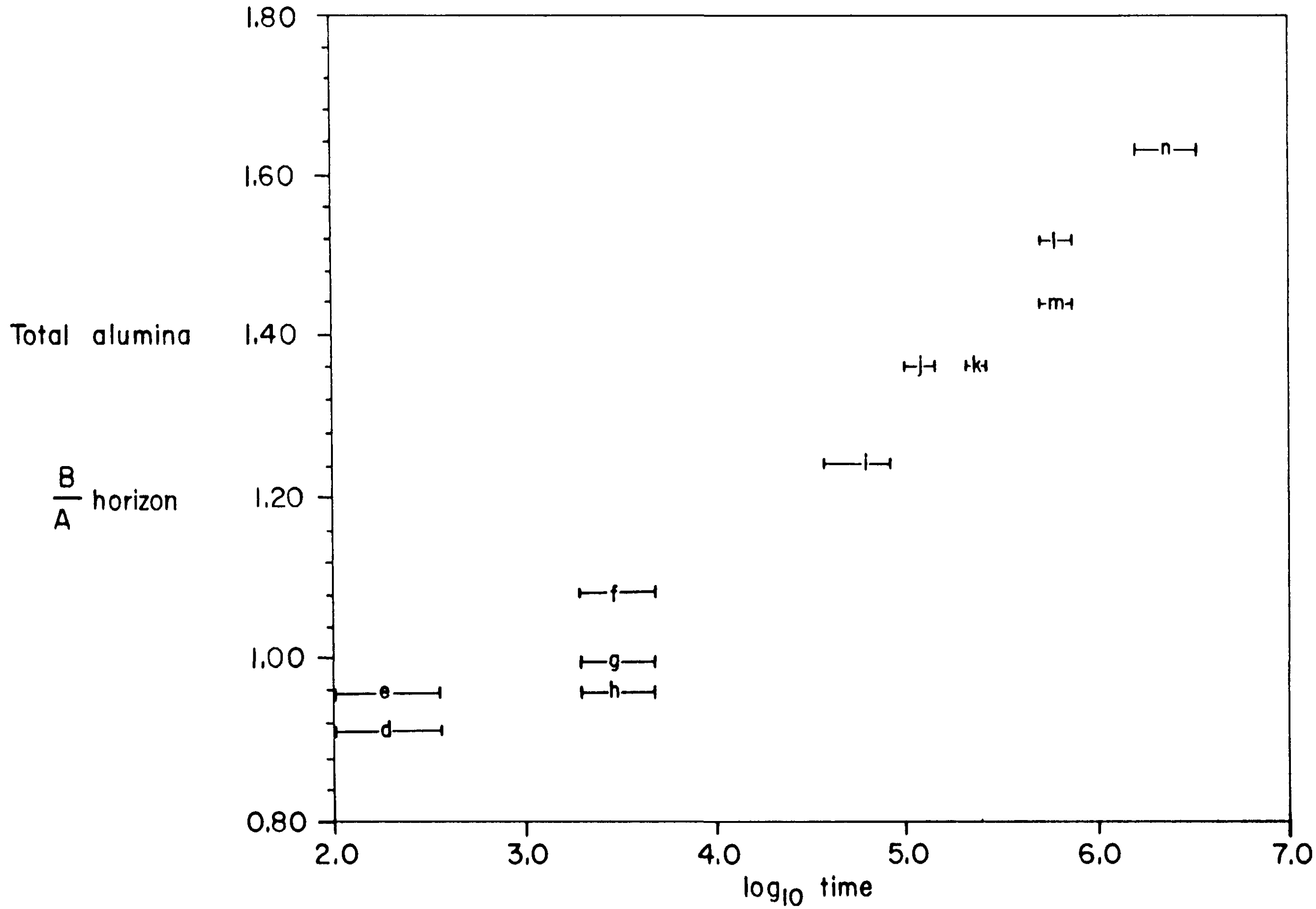
Marchand, D. E., Harden, J. W., Burke, R. M., Singer, M. J., Busacca, A. J., Meixner, R. E., and Bethel, John, 1979, Soils as a dating technique: Preliminary results from five chronosequences in the western United States (abs.): Geological Society of America, Abstracts with Programs, 1979 Annual Meeting, San Diego, California.

Meixner, R., Busacca, A. J., and Singer, M. J., 1979, Phosphorus fractions as age indicators in a chronosequence of alluvial soils (abs.): Agronomy Abstracts and Programs for Soil Science Society of America Annual Meeting, Fort Collins, Colorado, p. 229.



Dithionite iron of < 2mm fraction soil, Merced River, Dry Creek, and Cowlitz River

$\frac{\text{Maximum iron of B position horizon}}{\text{freshest C horizon}}$ versus $\log_{10}$ time



Total alumina of <44 micron fraction, Merced River Sequence

$\frac{\text{B horizon}}{\text{A horizon}}$ versus $\log_{10}$ time

Quaternary Dating and Neotectonics

9530-01559

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Investigations

1. Completed preparation of map, text, and cross sections for map covering about six 7.5' quadrangles in the northern Raft River valley, Idaho (K. L. Pierce with H. R. Covington and P. L. Williams).

2. Preliminary investigation to determine if relative abundances if K, U, and Th change with age of soil (K. L. Pierce).

3. Investigate age and position relative to sea level of "Salmon Springs" outwash and associated deposits along the Chehalis River near Aberdeen, Washington (K. L. Pierce and S. M. Colman).

4. Compiled the surficial geology of the Crested Butte 7 1/2' quadrangle based on 1979 fieldwork (S. M. Colman).

5. Began compilation and continued literature search of the neotectonic history of Colorado (S. M. Colman).

6. Completed manuscript on the chemistry and mineralogy of weathering-rind formation on andesite and basalt cobbles (S. M. Colman).

7. Continued study of buried and surface soils along the Wasatch Front to determine which soil properties are the most useful for correlating deposits of the Lake Bonneville sequence and younger subaerial deposits, especially those that are offset by range-front faults (R. R. Shroba).

8. Prepared draft manuscript on the "Quaternary tectonic history of the La Jencia fault, central New Mexico" (initial release as USGS open-file report) and prepared thematic I-map of the La Jencia fault, scarp morphology data and logs of four exploratory trenches (M. N. Machette).

9. Began literature search and compilation of Quaternary fault scarps within the Rio Grande rift, New Mexico and western Texas (M. N. Machette).

10. Compiled geology of the Beaver 15' quadrangle, Utah (1:50,000 scale) for release as USGS open-file report (M. N. Machette, with T. A. Steven, C. G. Cunningham, and J. J. Anderson). Processed soil profile samples as initial phase of soil chronosequence for the Beaver, Utah, area.

Results

1. The Raft River valley, in the Basin-Range of southern Idaho, is about 70 km long and 20 km wide. On the west side of the valley, but 2-5 km east of the mountain front, Quaternary faults locally cut alluvial fans with multiple scarps distributed across a 3-km-wide zone. No range-front fault has been demonstrated along the east side of the valley. Geologic cross sections drawn by Covington and Pierce with a subhorizontal listric fault at 1-3 km depth inclined gently to the east with curved splays coming to the surface are consistent with 1) the surface geology of the ranges on both sides of the valley, 2) Covington's observation of horizontal fault movement in deep geothermal cores from the base of the valley fill, and 3) the patterns shown by reflection seismic profiles across the valley (K. L. Pierce, investigation No. 1).

2. Samples from the upper part of B-horizons of soils in deposits of Pinedale, Bull Lake, and pre-Bull Lake age were submitted to Joel Leventhal for U, Th, and K analysis by delayed neutron and gamma spectrometer methods. It was expected that the abundance of the more soluble elements such as K relative to the less soluble elements such as Th would diminish in increasingly older deposits. The results from the three samples show essentially the same concentrations and ratios between elements for deposits considered to be about 20,000, 150,000, and more than 300,000 years old (K. L. Pierce, investigation No. 2).

3. Salmon Springs outwash forms terraces along the Chehalis River near Aberdeen, Washington. Dating studies reported in the last semiannual report suggest that the lower Salmon Springs terrace, previously considered to be of early Wisconsin age, predates the last interglacial, is probably about 140,000 years old and probably is correlative with oxygen-isotope stage 6. A clayey bed 8 m below the top of this terrace contains estuarine diatoms (J. P. Bradbury, written commun., 1980) indicating this area has been uplifted at least 20 m since deposition (K. L. Pierce and S. M. Colman, investigation No. 3).

4. Compilation of the neotectonic history of Colorado indicates that the present tectonic regime dates back to early Miocene, when large-scale regional uplift and block faulting was initiated after a period of regional tectonic quiescence. The Rio Grande rift forms the dominant tectonic feature since the Miocene, but substantial related deformation extends to the north and to the east of the rift proper. Holocene fault movements document the continuation of this tectonic activity to the present. Other young deformation is associated with the movement of salt in the Paradox and Eagle Basins (S. M. Colman, investigation No. 5).

5. Buried soils and soil complexes preserved between deposits of the last and penultimate cycles of Lake Bonneville, near Salt Lake City, Utah, differ in horizon morphology and degree of development. Despite major differences in the mineralogy and texture of the parent materials and variation in carbonate morphology, the secondary carbonate content is a useful criterion for identifying and correlating soils. At four localities, buried soils that formed between the last and penultimate high stands (an interval of about 100,000 years) have 55-60 g of secondary $CaCO_3$. These values suggest an average secondary $CaCO_3$ accumulation rate of about 0.6 $g/cm^2/1,000$ years. This rate is about four times greater than that of nearby but younger post-Bonneville soils and about 1 to 2 times greater than the average rate reported for 0.5-m.y.-old soils in southern New Mexico. In addition, the findings also suggest that: 1) the type Promontory and Dimple Dell

Soils of Morrison are now considered to be stratigraphically equivalent (Scott and Shroba, 1980) and contain similar amounts of secondary $CaCO_3$ (58 vs. 56 g/cm^2, respectively), and (2) the rapid rate of carbonate accumulation between high stands of the last two lake cycles may be due to greater airborne carbonate influx from sediment deflation and more effective carbonate translocation due to soil moisture conditions (R. R. Shroba, investigation No. 7).

6. The La Jencia fault in central New Mexico is a major range bounding fault along the western margin of the Rio Grande rift. The fault was tectonically inactive for much of the Quaternary but experienced renewed activity at the close of the Quaternary. This last phase of tectonism produced a nearly continuous scarp some 35 km in length and up to 7.5 m in height. Both scarp morphology and trench exposures reveal a history of areal and temporal segmentation of fault activity. At least four (and as many as seven) discrete episodes of surface rupturing occurred during the period from about 40,000 years B.P. to 5,000 years B.P., a duration of 35,000 years. The average recurrence interval for this renewed phase of tectonism is 5,000 to 9,000 years. Corresponding earthquake magnitudes computed from surface offset and length of scarp segments range from 6.8-7.1 using the relationships of Slemmons (1977) and Weiss (1979) (M. N. Machette, investigation No. 9).

7. Existing tectonic maps of the Rio Grande rift show abundant faults which cut middle Pleistocene and younger deposits, but only two of these faults, the Cox Ranch and La Jencia, are currently documented as having Holocene activity. Equally anomalous is the existence of numerous mountain fronts which do not have surficial evidence of fault control. Some of these fronts were seemingly very active prior to middle (?) Quaternary time and now are experiencing an extraordinarily long period of stability. The La Jencia fault previously experienced such a period of quiescence (M. N. Machette, investigation No. 9).

Reports

Pierce, K. L., 1979, History and dynamics of glaciation in the northern Yellowstone National Park area, U.S. Geological Survey Professional Paper 729-F, 90 p. (Fieldwork and first draft done under now terminated Yellowstone Glacial Project.)

Colman, S. M., 1980, Rock-weathering rates as function of time: Quaternary Research, in press.

Shroba, R. R., 1980, Influence of parent material, climate, and time on soils formed in Bonneville shoreline and younger deposits near Salt Lake City and Ogden, Utah: Geological Society of America Abstracts with Programs, v. 12, no. 6, p. 304.

Scott, W. E., and Shroba, R. R., 1980, Stratigraphic significance and variability of soils buried by deposits of the last cycle of Lake Bonneville: Geological Society of America Abstracts with Programs, v. 12, no. 6, p. 304.

Uranium Series Dating

9740-00378

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Investigations

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

2. Isotopic fractionation between ^{234}U and ^{238}U in altered volcanic tuff of various ages is being investigated for information regarding the mechanisms of uranium isotope fractionation. A better understanding of these mechanisms is necessary to further evaluate the empirical model that is the basis of uranium-trend dating. Ash fall and water-laid tuffs that have been altered to zeolites provide excellent material with large surface areas demonstrate an enhancement of isotopic fractionation.

Results

1. Horst Sterr, Institute of Arctic and Alpine Research, Univ. of Colo., working with Ernest Anderson, Earthquake and Tectonics and Risk Branch, collected and helped analyze four alluvium terraces in the Beaver Basin of southwest Utah for uranium trend dating. Soils are developed on the four different alluvial deposits, each distinct in age and stratigraphic position in the vicinity of Beaver, Utah (sec. 5 and 6, R.8W., T.29S., Richfield, UT 1°x2° map). The purpose of this investigation is to determine age estimates for the faulted deposits from which seismotectonic trends may be established for the Beaver Basin since mid-Pleistocene time.

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

North Creek at a position 8-15 meters above stream level. Profile MT is developed on a middle terrace remnant in the South Creek drainage which lies 5-8 meters above stream level. Profile LNCT was collected from a natural stream bank exposure of North Creek, from the lowest and youngest pre-Holocene terrace in the basin which lies 2-5 meters above modern stream channels. An insufficient number of samples were analyzed from the LNCT profile and its age was not determined until two additional samples, collected recently and now being analyzed, are completed. Additional samples from the MT profile are required for collection and analyses to reduce the uncertainty in the age of this terrace. The results on the older three terraces are listed in the following table.

Terrace	U-trend slope	X-intercept ^{232}Th Index	Half period of F(o) KA	Age KA
LCB	-15.0	+0.118	580	390± 60
HNCT	+ 1.01	- .194	350	240± 50
MT	+ .761	- .203	330	220±160

Reports

Zielinski, R. A., Lindsey, D. A., and Rosholt, J. N., 1980, The distribution and mobility of uranium in glassy and zeolitized tuff, Keg Mountain Area, Utah, U.S.A.: Chemical Geology, v. 29, p. 139-162.

Tephrochronology of the Western Region

9540-01947

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Summary

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

Investigations

Continued specific regional and topical tephrochronologic studies reported in Summaries of Technical Reports, Volume VIII, June 1979 (p. 150), and Volume IX, December, 1979 (p. 117). Additional studies include:

1. Initiated a study of ash and other volcanic ejecta erupted from Mount St. Helens during the current eruptive episode which began on March 27, 1980. Studies include wind dispersal patterns, areal distribution, thickness, volume, grain size, texture, petrography, and chemistry of the ash. Studies are in cooperation with scientists from the U.S. Geological Survey, U.S. Forest Service, and a number of individuals from other governmental, research, and educational institutions.

2. Continued to completion summary report on chemical analyses, correlations, and ages of late Cenozoic tephra units of east-central and southern California.

3. Sampled a stratigraphic section on the north limb of the Ventura Avenue anticline for paleomagnetic stratigraphy (in cooperation with J.C. Liddicoat, Lamont-Doherty Geological Observatory, and K.R. Lajoie, BGM & F, 9940-01623). This section contains four lower- to mid-Pleistocene ashes which have been correlated to isotopically dated tephra units at other localities in California.

Results

1. The Mount St. Helens eruption of 1980-- The current eruption of Mt. St. Helens in southwestern Washington provides an opportunity to observe first-hand the eruption, dispersal, and depositon of tephra. These observations in turn provide some new insights into the recognition and correlation of prehistoric tephra units and interpretation of features associated with tephra layers.

Composition of the volcanic ash and coarser ejecta

The material produced by phreatic (steam) eruptions from the volcano was a rock "flour" presumably produced by the grinding and jostling action of rock within the vent. The ash consists of very poorly sorted, euhedral to anhedral crystals and crystal fragments, and lithic grains. Scanning electron microscope photos show some rounding, presumably due to abrasion in the vent, as well as conchoidal fractures and impact pits. Dominant phyric minerals are calcic plagioclase and hypersthene, with subordinate amounts of clinopyroxene and hornblende, as well as some minor iron-titanium oxides. No phyric quartz was detected. Petrographic examination of thin sections made from lithic ejecta collected at the summit of the volcano (which included some blocks up to 30 cm. in diameter) indicate that lithic mineralogy is identical to that of the ash. Energy-dispersive X-ray fluorescence analysis of ash and lithic fragments indicate that bulk composition of the ejecta has not changed significantly since the beginning of the eruption. No new, "pyrogenic" material such as volcanic glass has been detected in the ejecta to date.

The type of tephra erupted from Mount St. Helens could easily be overlooked or misidentified as a clastic sedimentary deposit in sections where such ashes are bedded with clastic sedimentary layers. Where properly identified by textural, mineralogic, and chemical criteria, such tephra layers can be used for stratigraphic correlation. Furthermore, such layers are indicators of past volcanic activity. Their significance as possible precursors to pyrogenic eruptions has not been evaluated and is presently being studied.

Dispersal patterns of the volcanic ash

Since the beginning of eruptions on March 27, 1980, and through the first two weeks of activity, ash erupted from the volcano has been carried to every direction of the compass within a radius of about 20 km, and at least as far as about 100 km to the SSE, and 50 km to the east. Reports of the ash 100 km to the NNW of the volcano are as yet unconfirmed.

Although the eruption is small in volume compared to other historic and prehistoric eruptions, and probably cannot be used as a scale model for wind dispersal patterns for larger prehistoric eruptions because higher wind levels are not involved in the dispersal, the multi-directional distribution pattern is somewhat surprising and may explain in part the seemingly anomalous distribution patterns of such prehistoric ashes as the Bishop and "Maidu".

Reports

Sarna-Wojcicki, A.M., Bowman, H.R., Meyer, C.E., Russell, P.C., Asaro, Frank, Michael, Helen, Rowe, J.J., Jr., and Baedecker, P.A., Chemical analyses, correlations, and ages of late Cenozoic tephra units of east-central and southern California. U.S. Geological Survey Open-File Report 80-231, 51 p.

Title:	Movement and Deformation on the Southern Foothills Fault System, California
Contract Number:	USGS 14-08-0001-17724
Principal Investigators:	Drs. Richard A. Schweickert, Terry Engelder, and Dennis V. Kent
Institution Name and Address:	Lamont-Doherty Geological Observatory of Columbia University Palisades, New York 10964
Telephone Number of Principal Investigators:	914-359-2900

Fault zone studies

Figure 1 and Table 1 summarize the field studies that were conducted in June and July of 1979. In brief, our preliminary analysis of the data indicates the following: 1) fault-related deformation of the hangingwall schists of the Calaveras Complex is minor and is characterized by sporadic, weak crenulation cleavages that can be recognized up to a km east of the fault; 2) the fault zone is characteristically very narrow (only a few m wide) in most cases, but where serpentinite forms the footwall, the zone broadens to 1-200 m; 3) the broader parts of the fault zone containing serpentinite show evidence of later (Cretaceous? and possibly Cenozoic?) reactivation; the narrower parts of the fault zone do not show evidence of reactivation. The following sections include brief capsule summaries of results of structural traverses on the Melones fault zone.

1. Old Priest Grade traverse

Strongly flattened pillow lava (now greenschist) of the Calaveras Complex forms the hangingwall, and serpentinized peridotite forms the footwall. Within the peridotite, 4 styles of structure occur: 1) massive, serpentinized peridotite, probably the protolith for the whole complex, containing abundant, irregular fractures; 2) a "broken formation" with large blocks of massive serpentinized peridotite in a sheared matrix lacking a strong preferred orientation of shear planes; 2) schistose serpentinite with a pronounced shear foliation that is locally highly folded; 4) clay and magnesite-rich serpentinite gouge zones. All of these structures are cut by numerous dikes of diabase and albitite which lack foliation and which in turn are cut by quartz veins striking 114° and dipping 18°S.

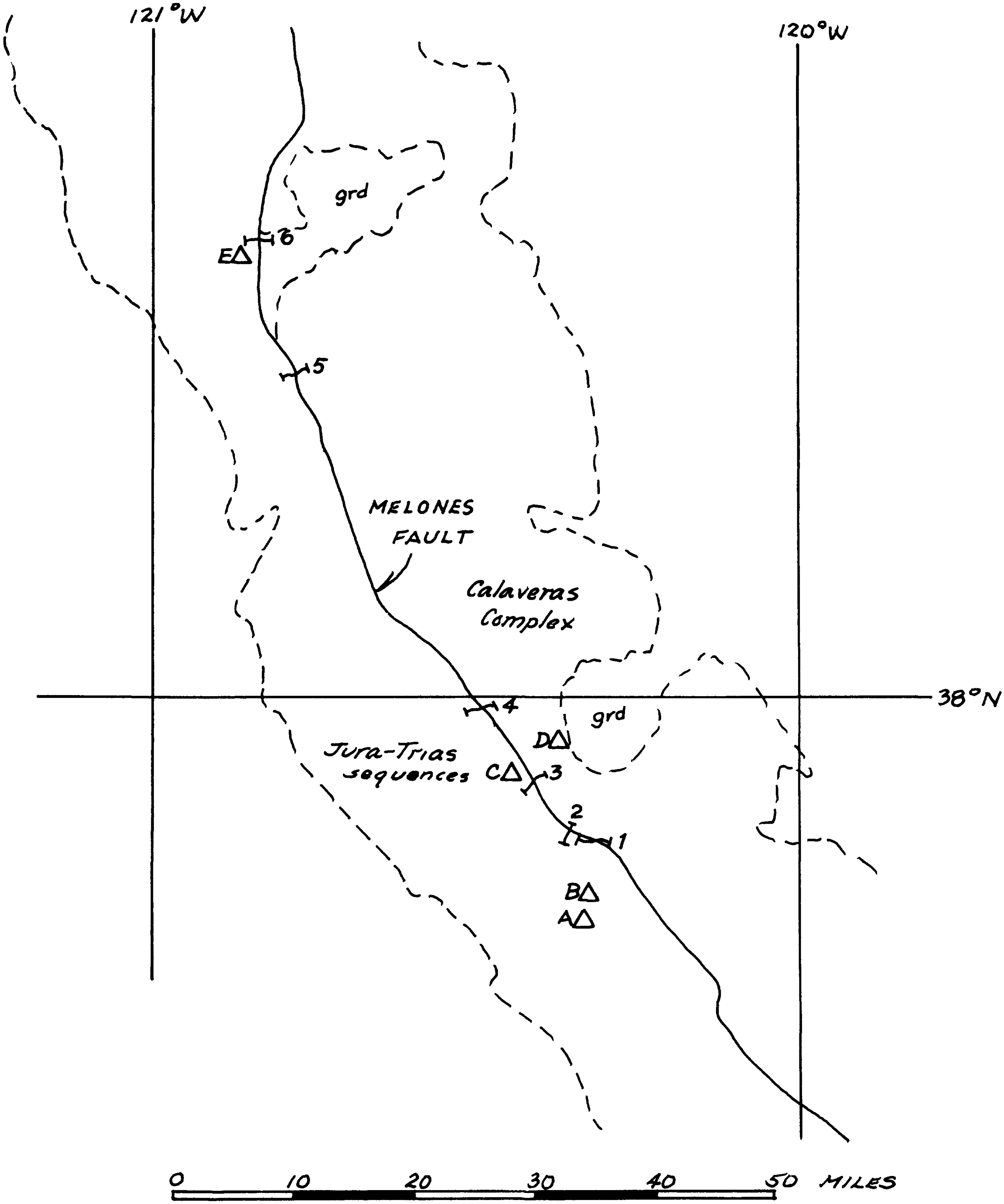

Figure 1. Sketchmap of the southern part of the Melones fault in the western Sierra Nevada, California. Numbers 1-6 designate fault traverses; letters A-E designate paleomagnetic sampling localities.

Table 1. Detailed traverses of Melones fault zone (see Fig. 1)

	Location	Hangingwall	Footwall	Narrow (N) Broad (B)	Evidence for Reactivation
1.	Old Priest Grade	greenschist	serpentinite	B	x
2.	Stent-Jacksonville bridge	schist and marble	serpentinite	B	x
3.	Sullivan Creek	greenschist	slate	N	
4.	Mormon Creek	phyllite	slate	N	
5.	Sutter Creek	greenschist	slate	N	
6.	Cosumnes River	granodiorite	slate and greenstone	B	?

2. Stent-Jacksonville Bridge

This traverse is characterized by a 200 m wide zone of sheared serpentinite with augite porphyry near its eastern edge. The augite porphyry closely resembles the Penon Blanco Volcanics 1 km to the west, suggesting a considerable degree of imbrication along the fault zone. Deformation becomes progressively more intense from the western edge toward the center of the fault zone. The protolith is a foliated peridotite which is gradually sliced up and overprinted by a shear fabric of duplexing fractures. As the intensity of the duplexing increases the outcrop takes the appearance of a schistose serpentinite. The schistose serpentinite is locally cut by narrow shear zones and both are cut by systems of late quartz veins and joints. The narrow shear zones may indicate a later (Cretaceous?) phase of reactivation of the fault zone.

3. Sullivan Creek

A narrow fault zone (20 m) separates the Mariposa slates from conspicuous, flattened pillow lavas of the Calaveras complex. Approaching the fault zone from the hangingwall (Calaveras rocks), quartz veins normally cutting foliation at 30° became progressively sheared. Within the fault zone, a second foliation parallel to the fault develops with the progressive shearing of the greenstones. Progressive shearing of pillows deforms them from axial ratios of 5:1 to 100:1. The Mariposa also contains a foliation parallel to the Melones fault. Local shear zones within the Calaveras are also indicated by the transposition of quartz veins.

4. Mormon Creek traverse

Phyllite with lenses of marble and chert forms the hangingwall and tuffaceous slate forms the footwall. The phyllite contains a strong transposition foliation (S_1) that is axial planar to isoclines (F_1), cut locally by a spaced cleavage (S_2) axial planar to open folds (F_2). F_1 and F_2 have parallel hingelines. These structures predate the fault fabric. Within a narrow zone (ca 10-20 m wide) the Melones fault is characterized by phyllonite containing a strong, domainal slip cleavage which separates microlithons with vestiges of the earlier fabrics. In addition, the fault-related slip cleavage is locally crenulated. Slates in the footwall contain only a slaty cleavage parallel to the slip cleavage on the fault and a weak crenulation cleavage similar to that observed in the fault zone.

5. Sutter Creek

A narrow fault zone separates the Mariposa slates from greenschists of the Calaveras complex. 200 m from the fault contact metagreenstones with an early crenulation cleavage may be mapped. Approaching the fault the primary structures of the metagreenstones are transposed by foliation which is in turn isoclinally folded. The contact is not visible. Mariposa on the west side of the fault appears to have tops of beds facing west.

6. Cosumnes River

The Melones fault zone along the Cosumnes River has several slices of various lithologies between the Mariposa on the west and a granodiorite pluton with a down-dip lineation on the east side. Progressing westward thru the fault zone, a foliated augite porphyry occurs next to the granodiorite. This rock may be a sliver of the Logtown Ridge Fm. 1 km west. The augite porphyry is bordered to the west by a highly cleaved tuffaceous or siliceous slate resembling the Mariposa Fm. The next lithology to the west is a very highly deformed greenschist with no visible pillow structures, and with steeply plunging isoclinal folds. The intensity of deformation decreases towards the contact between the greenschist and the Mariposa slate, as indentifiable relict augite phenocrysts occur in clasts near the contact. The Mariposa contains a penetrative slaty cleavage parallel to the fault zone. Small shear zones containing quartz veins are visible in the Mariposa within 200 m of the fault contact.

Paleomagnetic studies

Figure 1 and Table 2 summarize the progress of the sampling program conducted during June and July, 1979. West of the Melones fault zone, stratigraphic units of Triassic, Lower Jurassic, and Upper Jurassic age were intensively sampled. East of the Melones fault zone a swarm of Upper Jurassic dikes was samples in an attempt to provide a North American pole position.

A. Marsh's Flat Road

Three sites (18 oriented cores) were sampled from the diorite of Don Pedro, dated by U-Pb at 182 m.y. The bedding attitudes of layered rocks on Hatch Creek will be used to establish the original orientation of the pluton when it cooled. It was expected that results from this pluton would provide data on a Lower Jurassic paleomagnetic pole for the Jurassic terrane west of the Melones fault zone.

B. Hatch Creek

Three sites (19 oriented cores) were placed in a section of basaltic pillow lava which underlies the Upper Triassic(?) Hunter Valley chert, and which probably represents layer 2 of oceanic crust beneath the Penon Blanco Volcanics. These are distinctly older than the volcanic rocks sampled on the Cosumnes River and on Woods Creek.

C. Woods Creek

Three sites involving 22 cores were collected in the Penon Blanco Volcanics spanning an interval approximately 100 m thick beneath the Mariposa Fm. Two sites are in a pillow lava unit, one is in a pillow breccia. These sites lie on the east limb of a major synclinal fold cored by the Mariposa Fm.; these sites, together with those on the Cosumnes River, which are on the west limb of a major synclinal fold, should constitute a fold-test.

Table 2. Locations of paleomagnetic sites (see Fig. 1)

	Location	Formation	Age	Sites	Cores
A.	Marshes Flat Road	diorite of Don Pedro	Lower Jurassic	3	18
B.	Hatch Creek	pillow lava	Triassic	3	19
C.	Woods Creek	Penon Blanco Volcanics	Callovian	3	22
D.	Sonora area	dikes in Calaveras complex	Upper Jurassic	6	33
E.	Cosumnes River	Logtown Ridge Fm.	Callovian-Oxfordian	13	74

D. Dikes of Calaveras Complex

Six dikes (33 oriented cores) within the Calaveras Complex near Sonora were sampled. These dikes are part of an extensive E-trending dike swarm between 170 and 150 m.y. old (e.g. Callovian to Kimmeridgian). Locally this dike swarm is overprinted by Late Jurassic cleavage. Compositions range from olivine basalt to plagioclase andesite. These sites were chosen in an attempt to determine a reference pole for North America against which the poles for Jurassic rocks west of the Melones fault zone can be compared.

E. Cosumnes River

Thirteen sites, involving 74 oriented cores were collected in the type area of the Logtown Ridge Formation. The sites span 3,000 feet of stratigraphic section, and were placed in 6 distinct pillow lava horizons, two isolated pillow breccias, and two shallow intrusive bodies that are feeders for pillow lavas. The lower three sites are bracketed between Callovian fossil localities, while the upper ten sites are in Callovian or Oxfordian rocks. This section offers the best opportunity to determine the inclination and magnetic polarity of Jurassic rocks west of the Melones fault zone.

Preliminary paleomagnetic analysis

As of this writing, eight sites have been analyzed paleomagnetically: 6 sites on the Cosumnes River, one site on Woods Creek, and 1 site from the diorite of Don Pedro. Thus far only a very strong secondary component has been isolated with certainty. Statistical analysis of the data is not complete, but the orientation of this component appears to bear no relation to bedding or other structural attitudes, but is consistent over the entire region sampled. This indicates that this secondary component postdates or is contemporary with the formation of the steep attitudes of bedding throughout the belt. The pole position for this secondary component plots on the late Kimmeridgian segment of the North American polar wandering curve, and thus it can be tentatively suggested that the secondary overprint occurred during the Nevadan orogeny. This further implies that the steep dips and dominant structural grain of the Jurassic rocks, in addition to the steep dip of the Melones fault zone, formed during the Nevadan orogeny.

Study of the remaining sites and analysis of the data are still in progress, so these conclusions are tentative. In particular, work is currently underway to isolate the primary remanence in these samples.

LATE HOLOCENE BEHAVIOR OF THE SAN ANDREAS FAULT

U.S.G.S. Contract No. 14-08-0001-16774

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This contract supports continuing investigations of the behavior of the faults of the San Andreas fault system during the past several thousand years. The purpose of these studies is to determine the long-term fault slip rates and the frequencies and spatial relationships of large earthquakes along the faults.

During 1979 we accomplished the following: (1) Completed excavations at Wallace Creek which confirm a slip rate along the San Andreas fault of ⩾33 mm/yr and an average recurrence of 10-m slip events of ⩽300 years there. (2) I continued field studies at Van Matre Ranch in the Carrizo Plain, where the past three events were associated with 8 to 10 m of slip each, and a fascinating story of late Pleistocene and Holocene tectonic activity is unfolding. (3) Elizabeth Thomas began a study of the young and severely deformed Elkhorn Hills at the northwestern end of the "Big Bend". (4) Kristian Meisling and I finished a manuscript which describes our study of trees along the fault that were affected by the 1857 earthquake. (5) New evidence from extensive excavations at Pallett Creek indicates a) perhaps 4 earthquakes occurred between 500 A.D. and 0 A.D., b) all nine earthquakes since 500 A.D. were large events, c) a possible event previously unrecognized at about the 1600 A.D. level may reduce the average recurrence interval from about 160 to about 145 years, and d) the range of recurrence intervals may be reduced from about 55-275 years to about 100-230 years. Plan-view maps of the ground surface at the time of each earthquake at Pallett Creek show how each event has been associated with slightly different faulting, folding, and liquefaction phenomena, even though the principal trace has not changed greatly from event to event. Maps of offset facies in 200 to 2000 year old strata are not yet completed, but may yield slip rates and the amount of slip per event at Pallett Creek. (6) Ray Weldon's study of the offset late Pleistocene and Holocene Lone Pine Canyon terraces near Cajon Pass suggests a slip rate along the San Andreas fault at that locality of 20 to 25 mm/yr. (7) I completed field work along the dormant southern segment of the San Andreas fault aimed at determining the amount of fault slip associated with the latest (prehistoric) event(s). Along the freshest part of that segment, I have found a site at the intersection of the San Andreas fault and the northern shoreline of ancient Lake Cahuilla where the dating of prehistoric earthquakes may be possible.

Paleoseismic Indicators in Sediments

9950-01294

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Investigations

1. Detailed gologic mapping of a 2-km-wide strip of the San Andreas fault zone from Cholame to San Juan Bautista to determine the geometry and history of movement of the fault zone.

2. Examination of seismic data (1969-1979) in the Mustang Ridge area to determine the activity of the main trace and subsidiary faults. This work is in cooperation with R. L. Nowack and W. L. Ellsworth.

3. Laboratory analysis and interpretation of cores from Ancient Lake Cahuilla, Imperial Valley, California.

4. J. D. Sims is cooperating with Joe Smoot (SUNY-Stonybrook) in the examination of exposures of Ancient Lake Cahuilla sediments to determine the mode of formation of deformational structures preserved therein.

5. M. J. Rymer assisted R. V. Sharp and M. G. Bonilla in post-earthquake investigations of breakage due to the Imperial Valley (10-15-79) and Livermore area (1-24-80) earthquakes respectively.

Results

1. Detailed geologic mapping along the San Andreas fault zone is proceeding in three areas. Along Mustang Ridge, in the Monarch Peak 7 1/2-minute quadrangle, mapping by M. J. Rymer is now complete and the task of transferring data to a topographic base has begun. Mapping by J. A. Perkins, J. D. Sims, and Andrei Sarna-Wojcicki in the Bickmore Canyon 7 1/2-minute quadrangle is nearing completion. R. S. Makdisi has completed an areal photograph survey of fault traces and possible fault traces in the Cholame-Parkfield area. In all of these areas the main trace of the fault zone is characterized by local splays, offsets, and en echelon features. Also, there are abundant subsidiary faults, many of which have evidence of Holocene activity, and which hitherto have not been mapped.

2. M. J. Rymer is cooperating with R. L. Nowack and W. L. Ellsworth to study in detail the distribution of seismicity in the Mustang Ridge

area. This study was initiated to determine the seismic activity of subsidiary faults, but now includes the study of seismicity and seismic gaps in relation to the detailed geologic mapping done in 1 above. To date, the seismic data have been relocated using a revised velocity model for the region, and plotting of the data is in progress.

3. Detailed size analysis of all 11 cores from Ancient Lake Cahuilla is now half completed. A preliminary description and interpretation of the cores and inferred depositional environments is in progress as an open-file report.

4. Detailed follow-up investigations on Ancient Lake Cahuilla sediments were begun in cooperation with Joe Smoot (SUNY-Stonybrook). These investigations revealed additional zones of liquefaction-induced deformation. The exact origin and timing of the structure zones is unknown because travel restrictions have prevented further field work.

Quaternary Reference Core, Clear Lake, California

9940-02394

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Investigations

1. Procurement of supplies, logging equipment, and barge for coring operations in Clear Lake.

2. Completion of amino acid dating of Clear Lake core 4 sediments from previous coring operations.

3. Analysis of sediments from Searles Lake core KM-3 in cooperation with G. I. Smith (U.S.G.S.).

4. Analysis of correlation of varve thickness versus temperature in cores from Skilak Lake, Alaska by James Perkins.

Results

1. All supplies and equipment for the deep coring operations in Clear Lake in summer 1980 have been procured or are on order. Coring will begin on or about 15 June 1980 and continue for 60 days consecutively.

2. Amino acid racemization dating on samples from core 4 collected in prior coring operations was completed in cooperation with Kieth Kvenvolden and David Blune (U.S.G.S.). These results show that the sediments in Clear Lake are datable by the amino acid racemization technique and that the dates are in agreement with dates estimated from Oak pollen curve correlation with ^{18}O-curves from deep Pacific Ocean cores (Sims, Adam, and Rymer; in press). A report has been prepared by Blunt, Kvenvolden and Sims and is ready for review.

3. A new set of grain-size analyses of samples from the Kerr-McGee core KM-3 from Searles Lake, California, were begun. These new analyses will fill in critical spots in the original set of samples completed in the last report period. The bimodal population in the grain-size analysis probably reflect varying wind regimes and thus paleoclimate in the Searles Lake basin.

4. J. A. Perkins and J. D. Sims have conducted a study (manuscript in prep.) on the degree to which annual temperature influences the total thickness of varve formed in Skilak Lake, Alaska. Regression

analysis of vavre thickness on annual temperature for southern Alaska for the years 1909-1932 indicates up to 88 percent of the variations in thickness may be explained by variations in annual temperature. A paleotemperature curve was constructed for southern Alaska based on varve thickness for the years 1700-1909, using a regression equation. The curve indicates two relatively cool periods; 1700 to 1761 and 1791 to 1868 and two relatively warm periods; 1761 to 1791 and 1868 to 1932.

Reports

Ager, T. A., and Sims, J. D., in press, Holocene pollen and sediment record from Tangle Lakes area, central Alaska: Palynology.

Rymer, M. J., in press, Stratigraphic revision of the Cache Formation (Pliocene and Pleistocene), Lake County, California: U. S. Geological Survey Bulletin 1502-C.

Classification and Mapping of Quaternary Sedimentary Deposits for Purposes of Seismic Zonation South Coastal Los Angeles Basin Orange County, California

14-08-0001-18241

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Objectives of this continuing investigation are to define the spatial distribution and physical characteristics of young near-surface sediments within the study area and to provide an estimation of the probable response of these discriminated sediments to seismic impact. Geologic and seismic data from other types of project investigations have been located and collected for use in this investigation. These collected data are now being augmented by refraction seismic surveys, shallow drilling to obtain sediment samples for physical properties analysis and downhole measurement of seismic velocities in these boreholes. An electronic data processing management program is being developed which will store, selectively retrieve and graphically display specified geotechnical parameters colleted during this investigation.

Downhole measurement of seismic P wave and SH wave velocities have been conducted in five water observation wells. Well depths ranged from 40 m to 65 m and the total Holocene section was measured in each well. Additionally, refraction surveys, measuring both P wave and SH wave velocities, were tied to two of the measured wells. The area of investigation is urbanized and two of the measured wells are located beneath asphalt paving. Preliminary evaluation of recorded measurements indicates the shear wave propagation through the asphalt paving to the well bore was achieved.

Seismic Hazard Study of the Western Portion of the Garlock Fault

14-08-0001-17791

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Investigations

Investigations of the western segment of the Garlock fault were conducted at Castac Lake, Twin Lakes and Oak Creek Canyon with studies concentrated on the youngest fault trace. Seismic refraction surveys, topographic surveys and geologic mapping provided positive evidence for fault offsets in Quaternary deposits at Twin Lakes and Oak Creek Canyon. Specific investigations performed at these locations were:

1. Photogeologic analysis at all locations.
2. Seismic refraction and topographic surveys at Castac Lake and Twin Lakes.
3. Trenching, trench logging, and radiocarbon dating of sag pond deposits at Twin Lakes.
4. Geomorphic analysis, mapping and description of stream channel cuts in Oak Creek Canyon.
5. Compilation of detailed topographic maps from aerial photographs at all locations.

Results of a previous investigation at Castac Lake (LaViolette and others, 1979) were incorporated into the report to provide additional data to evaluate the seismic hazards associated with this segment of the Garlock fault zone.

Results

1. Trenching of sag pond deposits at Twin Lakes revealed fault traces representing at least 2 episodes of movement; the traces were confined to a zone 3 meters wide. The

stratigraphy at Twin Lakes consists of alternating units of clay and sand which allow measurements of vertical offsets. Based on radiocarbon dates of detrital charcoal, the most recent movement occurred less than 800 ±195 years B.P. and the preceding event occurred more than 2,800 ±165 years B.P. Total vertical slip was 80 to 100 cm for the most recent movement and 55 to 60 cm for the preceding event.

2. Geomorphic analysis of offset alluvial stream channels at Oak Creek Canyon provided an estimate of 1.6 to 3.3 mm per year of left-lateral movement during the last 140,000 ±50,000 years. This estimate is based on correlation of soil profile development with dated soil stratigraphy in the San Joaquin Valley. Scarp heights and lack of definitive evidence for recent left-lateral offset in Oak Creek Canyon indicates a significant and perhaps predominant vertical component of movement with: (1) a comparatively long recurrence interval; and/or (2) a small component of left-lateral movement. Arching of late Pleistocene deposits in Oak Creek Canyon is consistent with right-lateral rather than left-lateral wrench faulting, suggesting a fluctuation in stresses along this part of the fault since late Pleistocene time.

3. Investigations at Castac Lake were concentrated on the fault segment north of the lake. No evidence of offset of young deposits was found from surface investigations or seismic refraction data. Previous investigations south of the lake and across the dry lake bottom exposed unbroken strata dating back 8050 ±300 years B.P.

Based on the results of geomorphic analyses and trenching from this and the previous investigations the western postion of the Garlock fault is characterized by: (1) relatively long recurrence intervals; and (2) a predominance of vertical over lateral movement. The fault should be considered active and capable of generating large-magnitude earthquakes.

Reports

LaViolette, J. W., Guacci, G., Payne, C.M., and Grannell, R. B., 1979, Seismic hazard study of the Garlock fault at Castac Lake, Lebec, California: Geological Society of America, Abstracts with Programs, V. 11, no. 7, p. 463.

STRATIGRAPHY OF PRE-VASHON QUATERNARY SEDIMENTS APPLIED TO THE EVALUATION OF A PROPOSED MAJOR TECTONIC STRUCTURE IN ISLAND COUNTY, WASHINGTON

14-08-0001-17753

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The main objective of this project was to conduct a careful stratigraphic study of Quaternary nonglacial sediments on southern Whidbey Island, Washington, in an attempt to "fingerprint" the Whidbey Formation. Once it was defined by sedimentary petrologic criteria, we hoped to be able to correlate outcrops of the Whidbey Formation on Whidbey Island. The ultimate goal was then to correlate stratigraphically equivalent units within the Whidbey Formation across a proposed major tectonic structure, and determine the amount of vertical tectonic movement (if any) along the structure.

Five representative outcrops on southern Whidbey Island, which contain thick sections of nonglacial sediments previously assigned to the Whidbey Formation, were described, measured, and sampled. Descriptions of lithology, texture and sedimentary structures were made. Representative samples of peat and wood fragments were collected and radiocarbon dated. Lab tests performed on the samples include grain-size analyses by sieving and hydrometer methods, clay mineralogy by X-ray diffractometry, and heavy mineral analyses by heavy liquids and magnetic separation. The following conclusions were drawn:

1. Correlation of sedimentary units within the Whidbey Formation on southern Whidbey Island cannot be made using field criteria, for the following reasons:

    a. Numerous erosional unconformities are present which eliminate layer-cake stratigraphy and produce complex stratigraphic relationships.

    b. Horizontal facies changes are common, which increase the difficulty of characterizing and tracing Whidbey Formation sedimentary units, especially across covered areas.

    c. There are few distinctive horizons in the Whidbey Formation sediments, and those which are present are only found in single outcrops.

    d. All radiocarbon age dates from the Whidbey Formation are infinite (greater than 40,000 years B.P.), prohibiting correlation of sedimentary units by their age.

Since identification of sedimentary units or sequences of units in the Whidbey Formation is not possible, correlation across the proposed tectonic structures of previous workers cannot be made.

2. Sedimentary units within the Whidbey Formation on southern Whidbey Island cannot be identified by grain-size properties, clay minerology, or heavy mineral composition. The sediments are characterized by homogeneous textural and mineralogic compositions, with variations within Whidbey Formation units just as great as between units, and variations within the Whidbey Formation nonglacial sediments just as great as between Whidbey Formation, younger(?) nonglacial, and glacial sediments. The similarity of the properties of nonglacial and glacial sediments on southern Whidbey Island even prohibits characterization of these depositional environments by sedimentary petrologic criteria. Apparently, the homogenization of Pleistocene sediments is the result of continual erosion and reworking of sediments prior to deposition. Since no distinctive units or beds have been identified by laboratory analyses, the horizontal tracing of sedimentary units within the Whidbey Formation over long distances is not possible, and correlation of Whidbey Formation sedimentary units across proposed tectonic structures cannot be made.

3. Three independent lines of evidence suggest that the nonglacial sediments in the Double Bluff East section are significantly younger than the nonglacial sediments at the type locality of the Whidbey Formation (Double Bluff West), and may record deposition during the Olympia Interglaciation:

   a. Double Bluff East nonglacial sediments are separated from Double Bluff West sediments by an erosional unconformity.

   b. If peat clasts found in the Double Bluff East nonglacial sediments are reworked from Double Bluff West sediments, the Double Bluff East sediments should be substantially younger, since the peats would have to have been compacted and tough to survive reworking without disintegrating. Whether the sediments represent a younger Whidbey Interglaciation age or an Olympia Interglaciation age cannot be determined.

   c. The Double Bluff East section apparently records an uninterrupted transition from nonglacial to glacial (Fraser glaciation) sedimentation, which suggests a finite age for the Double Bluff East nonglacial sediments. The lack of datable organic material in the nonglacial sediments prohibits verification.

4. Radiocarbon age dates from the base of the Esperance Sand suggest that outwash marking the beginning of the Fraser glaciation in the northern Puget Lowland had reached as far south as southern Whidbey Island by 22,000 to 23,000 years B.P., significantly earlier than previously reported.

Geologic Mapping of the Vista and Steamboat 7 1/2-minute Quadrangles, Nevada

14-08-0001-17774

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Investigations

1. Standard geologic mapping at a scale of 1:24,000 was performed in the Vista and Steamboat 7 1/2-minute quadrangles. This scale has been found suitable for the presentation of information on the distribution of Quaternary units in the detail necessary for the production of earthquake hazards maps.

2. Fifty line miles of low sun-angle photography were flown over the northern portion of the Vista quadrangle at a scale of 1:12,000. Interpretation of this photography, as well as, other low sun-angle photography, which had been obtained for previous investigations, provided information on the subtle expression of faults which cut alluvial material and are often not apparent on conventional aerial photography.

3. Three trenches were excavated across two faults which cut alluvial material and are subparallel to the range bounding fault of the Virginia Range.

4. Relationships between glacial outwash deposits and sediments of Lake Lahontan in the Truckee River Canyon presented by previous workers has been modified based on the results study.

Results

1. Results of the study have provided information on the distribution and physical properties of the geologic units within the Vista and Steamboat 7 1/2-minute quadrangles. The location of the various unconsolidated deposits in the Truckee Meadows is important because it is the site of the Reno-Sparks urban area. The unconsolidated Quaternary deposits of the Truckee Meadows and the Spanish Springs Valley area in the northern portion of the Vista quadrangle pose the most immediate concern for seismically induced ground failure. Both of these areas contain groundwater depths less than 10 meters and in many areas the depth to groundwater is less than 2 meters. Potentially liquefiable deposits include floodplain and lacustrine deposits consisting of interbedded silt, fine sand and minor peat which underlie approximately 20 square kilometers (8 square miles) in the two quadrangles. These materials are highly compressible and have low shear strength and when coupled with conditions of saturation they are susceptible to liquefaction and differential ground failure.

Unconsolidated Quaternary deposits are not the only units susceptible to ground failure during seismic loading. Tertiary age volcanic rocks of intermediate composition have been hydrothermally altered. These altered bedrock areas, which have been delineated as a result of this investigation, pose an additional seismic related problem. Because of their lack of resistance to erosion they form steep clay mantled slopes in bedrock areas in the Steamboat quadrangle. These altered volcanic rocks range from weakly altered, containing small amounts of chlorite and calcite to thoroughly altered rocks containing quartz and clay. Areas of intense alteration are marked by the presence of kaolinite, montmorillonite, illite and mixed layered clays and may pose slope stability problems during seismic loading.

Other unconsolidated Quaternary deposits that are potentially hazardous because of the combination of physical properties and occurrences in low lying areas of the Spanish Springs Valley and the Truckee Meadows are the youngest valley fill alluvial deposits. These deposits are unconsolidated sands and sandy mud which are covered by cambic soils suggestive of mid-Holocene age. Their location in recently alluviated areas in the lowest parts of Spanish Springs Valley and peripheral to the Truckee River suggest that their condition may well be one of saturation due to agricultural irrigation practices which are common in the area.

2. Tectonic regimes impacting the Vista and Steamboat quadrangles are the Sierra Nevada frontal fault system, Basin and Range normal faulting and left-offset strike-slip faulting. These major regimes and the combinations of stress resulting from their interaction provide a complex structural setting. In the southern portion of the study area (Steamboat quadrangle) faulting appears to have components of two of the major styles of deformation identifiable, the Sierra Nevada and the Basin and Range. The combined effects of the interaction of two orthogonal sets of structural activity are apparent along the western front of the Virginia Range where northeast trends associated with larger regional orientations interact with typical Basin and Range faulting and produce a saw-tooth appearance in the range front. Similar effects in the range front configuration have been noted at larger scales where east-west and northeast trending structural grains intersect regional structures, such as the Sierra Nevada front (Trexler, 1979). The saw-tooth appearance produced by the intersection of lineaments of regional scale produce small scale effects which are discernable at scales of 1:24,000.

Faulting in the Vista quadrangle has components of the northeast trending left-offset Olinghouse fault zone and north-northeast Basin and Range fault trends. Northeast trending faults are the predominant trend. The morphology of the scarps suggests a relative young age, although deposits of similar age are not present. Northeast trending faults to the west and east of the Vista quadrangle have had historic seismic activity with associated ground rupture (Olinghouse, M6.7, 1869 and Truckee, M6, 1966). Mapping under the present program has not indicated any faulting in the Vista quadrangle to be younger than mid-Pleistocene in age.

3. Trenching techniques used in this investigation deviated from previous investigations so that hydraulic shoring was not needed. This entailed using larger excavating equipment than has been employed in the past and laying the face opposite the working face back to a 1:1 slope and keeping depths of excavation to 2 m (6 ft) nominally, and 3 m (10 ft) maximum. Trenching of the faults provided information on the spatial relation of the fault scarp to the fault trace, the subsurface expression of the shear and stratigraphic relationships which relate to the age of last movement. The subsurface expression of the zone of movement was considerably larger than the area of surface disturbance. Examination of soil development in materials exposed in the trenches provided information on the age of last movement. Movement along both faults that were excavated did not offset durargid soils which indicates a pre-Sangamon age.

4. Glacial outwash deposits associated with Tahoe glaciation are exposed throughout the Truckee Meadows and at Mustang in the Truckee River Canyon. The deposits form an extensive low-gradient terrace in the Truckee Meadows, but only remain as a dissected terrace remnant at Mustang. These deposits are overlain by argillic soils, which indicate a Wisconsinan age. They have been referred to as being the same age as Eetza sediments of the Lahontan Group by Birkland (1968) but the soil development negates this assumption.

Reports

Trexler, D. T. (1979) Earthquake hazards mapping in the Reno-Carson City area, Nevada: U.S. Geol. Survey open-file rept. (in press).

References

Birkland, P. W. (1968) Correlation of Quaternary stratigraphy of the Sierra Nevada with that of Lake Lahontan area, in Morrison, R. B., and Wright, H. E., eds., Means of correlation of Quaternary successions: Proc. VII INQUA Congress, v. 8, p. 469-500.

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 of Basin and Range.

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

Results

Possible interpretation of the fault and tectonic data are expressed in two steps of increasing speculation in figures 1 and 2. The diagrammatic cross section of the study area shown in figure 2 is constructed to show: (1) eastward tilting of ranges, (2) first and second order relationship of ranges, some blocks representing blocks rotated and slumped off of other blocks, (3) Moho at 30+ km, (4) maximum depth of seismicity, thus of brittle zone, about 15-18 km, (5) narrow zones of extension at depth, (6) listric form of faults, similar to those bounding rotated blocks elsewhere (McDonald, 1976, Davis and others, 1979), and (7) zone of decoupling to accommodate listric-style of faulting. The diagrammatic cross section in figure 2 carries speculation a step further and includes ideas such as: (1) zones of extension possibly invaded by intrusive rocks (see A, figure 2) (as proposed by Thompson and Burke, 1974), (2) vertical propagation of tension cracks through listric faults (see B, figure 2) to account for narrowness of band of reactivation of surface faulting; (3) complexity of glide blocks (see C, figure 2) of many sizes, some unrotated glide blocks (as on Heart Mt. thrust, see Pierce, 1941, 1979) as well as rotated glide blocks; some glide blocks of Mesozoic and Paleozoic age overriding Tertiary beds, (4) sequence of events, including earlier westward tilting of Humboldt Range (see D, figure 2) cross cutting of older by younger faults, (5) zone of decoupling that is complex rather than simple, including glide planes providing bias toward westward sliding and toward local zones of extension (see E, figure 2).

Scarps that developed in Holocene time (last 12,000 + years) appear to be distributed in narrow, elongate belts trending N.10°-25°E (see figure 3). The belts cross range blocks, for example, the belt produced in 1915 (see 1915, figure 3) crosses four range blocks, and the Western Cortez belt (see WC, figure 3) trends at a high angle across the Cortez Range front fault trend. Within other belts such as the Shoshone Range (see SR, figure 3) belt and the Humboldt Range belt (see HR, figure 3), faults of diverse trends appear reactivated. This independence of the belts from obvious surficial structures suggests that the elongate belts of reactivation relate to deep structures, and that the effects are propogated upwards and become superimposed across upper crustal blocks. Regional extension appears to be normal to the long axes of these belts.

Reports

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3. _____1980, Gilbert's studies of faults, scarps and earthquakes: Geological Society of America Special Paper (in press).
4. _____1980, Active faults, paleoseismology and earthquake hazards: Proceedings of the Seventh World Conference on Earthquake Engineering, Istanbul, Turkey, September, 1980 (in press).
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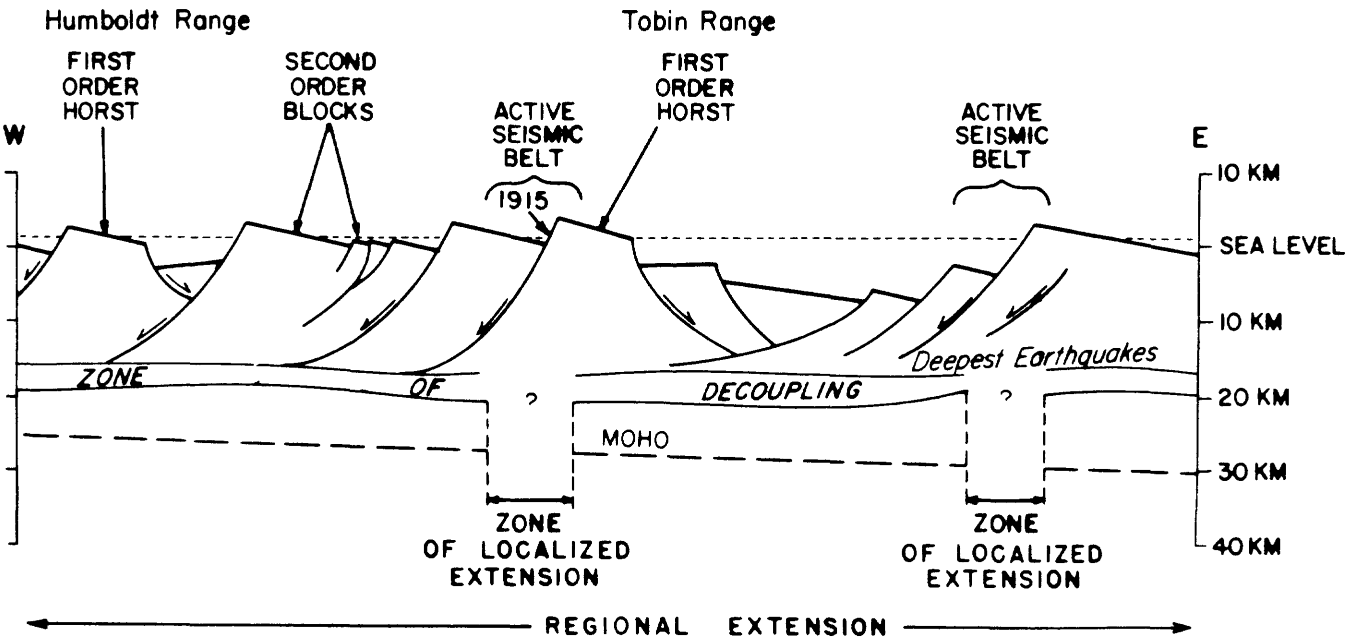

FIGURE 1

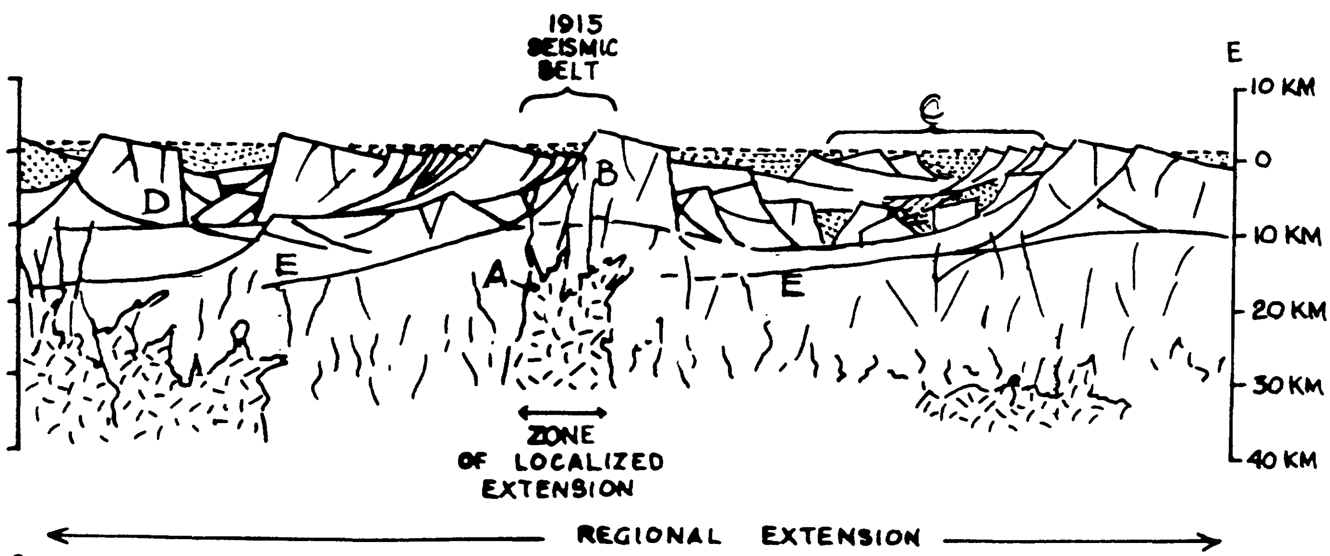

FIGURE 2

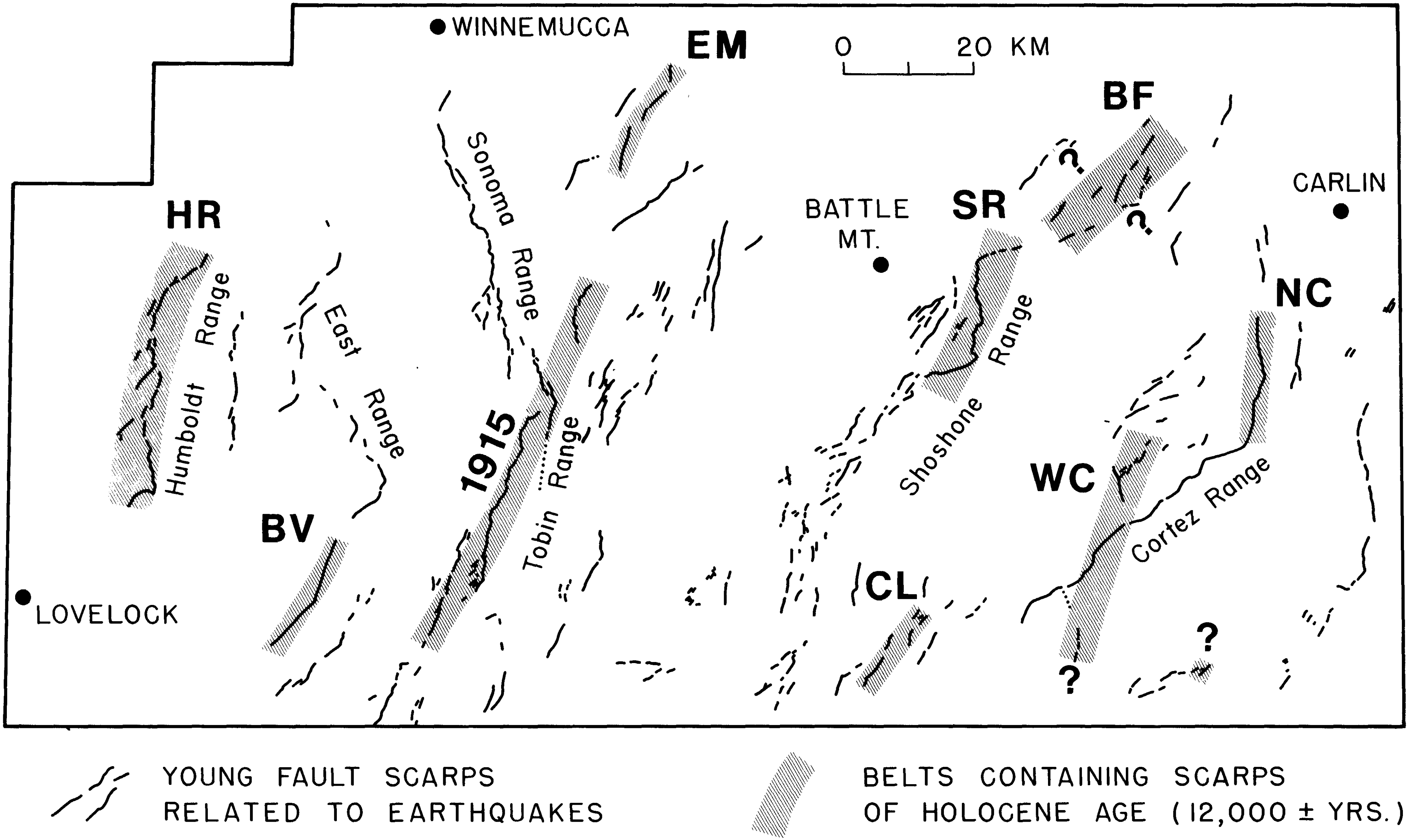
WINNEMUCCA
EM
0
20 KM
BF
CARLIN
HR
BATTLE MT.
SR
Sonoma Range
Humboldt Range
East Range
NC
1915
Tobin Range
Shoshone Range
WC
Cortez Range
BV
CL
LOVELOCK
?
YOUNG FAULT SCARPS RELATED TO EARTHQUAKES
BELTS CONTAINING SCARPS OF HOLOCENE AGE (12,000 ± YRS.)

Figure 3

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GEOLOGIC INVESTIGATION OF THE MARINE TERRACES OF THE SAN SIMEON REGION AND PLEISTOCENE ACTIVITY ON THE SAN SIMEON FAULT ZONE, SAN LUIS OBISPO COUNTY, CALIFORNIA

14-08-0001-18230

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INVESTIGATIONS:

The object of this study is to determine a late Pleistocene history of movement along the San Simeon fault zone. This will include determination of the probable rates of movement, the style of deformation, probable recurrence intervals, and the most recent episodes of movement on both the fault zone as a whole and the individual faults within the zone.

We are attempting to achieve these goals through detailed field mapping of the marine terraces and the faults from the Cape San Martin area south to Cayucos. If the terraces in the terrace sequence can be correlated between fault blocks and on opposite sides of the fault zone we can estimate the vertical component of motion on the fault and estimate the rates of motion. Similarly horizontal components of movement and the rates of motion can be determined from the offset of shoreline angles of marine terraces.

RESULTS:

Our preliminary results, after completion of the field work but prior to the completion of the project, are as follows:

1) The marine terrace sequences on opposite sides of the fault zone and within fault blocks show considerable variation. A 250 foot high, erosionally modified fault scarp along the San Simeon and Arroyo Laguna faults also suggests considerable vertical movement in mid-late Pleistocene time.

2) The absence of marine terraces northeast of the fault zone north of Arroyo de la Cruz suggests as much as 5000-10,000 feet of right lateral displacement since the mid-Pleistocene. Shorline angles of several high terraces are obviously displaced in a right lateral sense.

3) In San Simeon Cove the Arroyo Laguna and/or San Simeon faults offset weakly cemented aeolian deposits of probable Holocene age. Other faults in the fault zone appear to have smaller amounts of total offset and have not moved as recently as the Arroyo Laguna and San Simeon faults.

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

14-08-0001-16747

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Investigations

1. Complete subsurface mapping of the Castaic Hills area of the San Gabriel fault (SGF) for a semi-annual technical report. This includes a compiled surface map to facilitate correlation between exposures of Miocene-Pleistocene sedimentary rocks of the East Ventura basin and exposures of Ridge basin strata with the subsurface geology in the Castaic Hills and Tapia oil field areas.

2. Construct cross sections across the Simi fault in the Simi Valley and Tierra Rejada area.

3. Collect well data for a study of the Holser fault.

Results

1. The Saugus Formation can be correlated by electric logs across the SGF, suggesting little if any right slip across the SGF since Saugus deposition. In contrast, the Towsley Formation bears no resemblance to the coeval Castaic Formation directly across the fault. Based upon electric-log correlation, the Pico Formation probably has not undergone much lateral displacement, but this observation lacks precision until stratigraphic sections extending parallel to the fault on both sides can be compared.

2. The western portion of the Simi fault in the Las Posas and Camarillo Hills originated after the deposition of the upper Miocene Modelo Formation but prior to the deposition of the Saugus Formation (earlier than 1.2 Ma). The fault may have been controlled by the structural anisotropy produced by the abrupt southward thickening of the Conejo Volcanics where Conejo isopachs trend east-west. At Oxnard, Conejo isopachs turn southwest toward Port Hueneme, but the fault dies out and does not follow the anisotropy to the southwest. The Modelo and older rocks were folded and faulted prior to Saugus deposition, then the Saugus was itself folded and faulted. The Las Posas and Camarillo Hills are tectonic uplifts which involve Quaternary older alluvium, but no post-Saugus sediments are observed to be faulted. Possibly the Simi fault continued to be active at depth, but it was expressed at the surface by sediments which were warped but not faulted. If this can be documented geodetically, or if the young deformed sediments can be dated, the Simi fault may be shown to constitute more of a seismic shaking hazard than a ground-rupture hazard.

Reports

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

14-08-0001-17730

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Investigations

1. Completed subsurface mapping of the south flank of the Ventura Avenue anticline, including two regional cross sections from the Ventura Avenue anticline across the Santa Clara trough to the Oak Ridge fault. Completed a cross section of the Ventura Avenue anticline which included a 21,500 foot deep-test well drilled by Shell (R. S. Yeats).

2. Continued subsurface mapping of Carpinteria basin from Summerland to Rincon Point, including Summerland offshore oil field. This will include a compiled surface geologic map of the onshore and offshore area and regional cross section from Summerland offshore oil field to the Carpinteria and Rincon Creek faults (P. A. Jackson).

Results

1. The Ventura Avenue anticline did not begin to form until after the end of Saugus (San Pedro) deposition about 200 ka ago; end of Saugus deposition may have been triggered by the horizontal compression producing the fold. The fold is a flexural-slip buckle whose limbs tilted at an average rate of 3.4×10^{-6} radians/year and whose crest rose at a rate of about 10 mm/y. North-south shortening between the Santa Clara trough and the south edge of the Sulphur Mountain anticlinorium took place at a rate of 6.5 cm/y or 2.86 ppm/y in the last 200 ka.

The recency and rapidity of folding may explain the unusual behavior of fluids in the oil field. The entire oil field is geopressured; the fluid pressure approaches lithostatic pressure in the 6th through 8th zones as the radius of fold curvature decreases downward from 800 feet to 100 feet, nearly a chevron fold. Nonplanar oil-water contacts throughout the field and distribution of residual water saturations in the 8th zone indicate that fluids have not reached hydrostatic or capillary equilibrium. Fluid migration within sealed structural blocks is apparently still in progress.

Reverse faults of the Barnard group dip south and are folded over the crest of the anticline; these faults apparently formed as the anticline was formed. The faults may pass into bedding downstructure and be decollement structures. The 21,500 foot Shell-Taylor 653 well bottomed in marine Miocene above the Vaqueros and penetrated rocks of low but variable dip below the chevron-folded 8th zone, suggesting that the Ventura Avenue anticline itself may be rootless, not involving basement. This may mean that all faults related to the fold may be rootless as well, not penetrating downsection into rocks of high enough strength to store enough elastic strain energy to generate a large earthquake when released.

2. The Ventura fault of Sarna-Wojcicki and others (1976) was not found in south-flank wells on a subsurface projection from where it was mapped at the surface. This includes the Getty VL & W5 well in which a fault cut had earlier been indicated by Ogle and Hacker (1969). The fault seems to mark the boundary between the steeply-dipping south flank of the Ventura Avenue anticline and the gently dipping Santa Clara trough. As such, it may simply represent shear along the leading edge of the Ventura Avenue buckle fold and, like the fold itself, not involve high-strength rocks below the marine Miocene. Alternatively, it may be a fault which began forming so recently that it has not accumulated enough displacement to be recognized in the subsurface. If the fault extends eastward across the Santa Clara Valley, as suggested by photo linears (Sarna-Wojcicki and others, 1976) and a groundwater cascade (Geotechnical Consultants, 1972), and does not follow the base of the hills to the east-northeast, this latter explanation is preferred, and the fault would still constitute a seismic-shaking hazard.

3. The north-dipping Taylor and Taylor 73 faults are not the subsurface expression of the Ventura and Pitas Point faults, as suggested in a previous semi-annual technical report. As based upon thickness differences between the hanging wall and the footwall of this fault set, the vertical component of displacement on these growth faults accumulated between 2 and about 0.4 Ma at rates of 0.56-0.63 mm/y, ending near the base of the Saugus Formation. Net slip is northwest-southeast, parallel to the strike of the Grubb fault, a tear fault which terminates the Taylor fault set on the southwest. The faults are folded across the axis of the anticline and pass into bedding on the north flank of the fold. They are interpreted as detachment faults, the upper plates of which moved during deposition in a southeast direction, possibly caused by gravity sliding along incompetent beds within the turbidite sequence as the Red Mountain area to the northwest was uplifted.

4. The Carpinteria area contains folded and faulted Pleistocene strata north of the Red Mountain fault, described as the Santa Barbara and Casitas Formations. The angular unconformity between this sequence and underlying Sisquoc and older strata is in great contrast to the conformable sequence in the Dos Cuadras-Carpinteria offshore anticline. In the Summerland offshore field, the Monterey Shale and Rincon Formation have folded disharmonically above a low-relief fold in the competent Vaqueros and Sespe Formation. South-side-up reverse faulting in the Carpinteria graben may be related to this disharmonic structure.

Reports

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Yeats, R. S., 1980, Neotectonics of the Ventura Avenue anticline: Semi-annual technical report to U.S. Geol. Survey, Contract No. 14-08-0001-17730.

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Geophysical and Tectonic Investigations of the Intermountain Seismic Belt

9950-02669

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Investigations

1. Investigations of the modern state of stress and tectonic style throughout the conterminous United States. This study included determination of principal stress orientations from geologic information (alinement of volcanic feeders and fault offset data) and compilation and critical evaluation of existing earthquake focal mechanisms and *in situ* stress data.

2. Analysis of the late Cenozoic evolution of the state of stress responsible for the tectonic deformation in the Basin and Range province. Both a change in stress orientation and the timing of this change were evaluated through a critical analysis of existing geologic mapping and data.

3. Analysis of lower crust and Moho structure in northern Nevada using long-wavelength gravity and seismic refraction results. This study was aimed specifically at understanding lower crustal structure of a 250-km long mid-Miocene "rift" feature in northern Nevada which is marked at the surface by graben-filling basalt flows and a 3.5-km wide diabase dike swarm.

4. Investigation of the pattern and style of faulting in Yucca Flat (NTS), Nevada through preliminary interpretation of seismic reflection profiling (obtained from ARPA) and gravity data.

Results

1. A map of principal horizontal stress orientations of the conterminous United States has been produced (figure 1). On the basis of orientations and relative magnitudes of principal stress, the country can be subdivided into stress provinces within which the stress orientation appears quite uniform, ($\sim\pm 15^{o}$). In the western United States the pattern of stresses appears controlled primarily by plate interactions along the Pacific coast and also, possibly, by regional changes in upper mantle structure. A broad area of the Mid-continent is characterized by roughly northeast-southwest compression approximately the direction of "absolute" velocity of the North American plate and suggestive of "asthenospheric drag" as a possible source of stress. The Eastern Seaboard appears to be in a relatively uniform state of compression directed approximately perpendicular to the continental margin. The source of this compression is ambiguous. Both "ridge-push" and "asthenospheric drag" forces seem unlikely as possible sources of this stress field as the predicted directions are 30-50^{o} oblique to the observed directions.

2. Using dike trends and slip directions of older faulting exposed in ranges, a relatively uniform "Miocene" (∿20-10 m.y.B.P.) WSW-ENE least principal stress orientation was inferred for the entire western United States, west of the Front Range and east of the Sierras. Modern deformation in the Basin and Range is occurring in response to a WNW-ESE least principal stress, requiring a ∿45° clockwise change in stress orientation. Local geologic evidence in the northern Basin and Range, the southern Basin and Range and the Rio Grande rift constrain this change to have occurred between about 13 and 7 m.y.B.P. Much of basin-range deformation in the southern Basin and Range probably occurred under the "Miocene" stress field while the NNE-trending structural grain in the northern Basin and Range suggests development under a stress field similar to the modern one. The "Miocene" stress field probably is related to "back-arc extension". The clockwise change in stress orientation is consistent with superposition of right lateral shear along the western plate boundary related to the development of the San Andreas transform.

3. Gravity anomalies were computed from a map of crustal thickness (determined from published seismic refraction data) and fit to a smoothed version of the Bouguer gravity map of northern Nevada. A prominent (∿10-14 mgal) gravity high was not explained by the crustal thickness model. This high coincided with the mid-Miocene rift described above. Modelling of this residual gravity high suggest a lower crustal body with a density contrast +0.20-0.275 g/cm^3. Physically, this deep structure which is probably related to formation of the rift may represent: 1) thinning of the crust resulting in a small scale bump on the Moho, or 2) massive intrusion of mafic material into a relatively low density, possibly granulitic lower crust.

4. As revealed by seismic reflection profiling, the subsurface structure of Yucca Flat is that of a graben whose eastern margin if formed by a broad zone of step faulting while the western margin is formed primarily by two previously identified major normal faults. Lack of coherent reflectors in the Paleozoic bedrock underlying the basin (possibly due to poor coupling resulting from an extremely deep water table, ∿1500', in the valley) obscured deep structure and made it impossible to trace the normal faults into the bedrock and determine their attitude with depth. The seismically determined subsurface structure is consistent with gravity data; however, a uniform density can not be used to represent the anomaly. Don Healey (Special Projects, Denver) suggests the non-uniform density required to fit the gravity and seismic data may result from shallow density contrasts in the bedrock underlying the basin.

Reports

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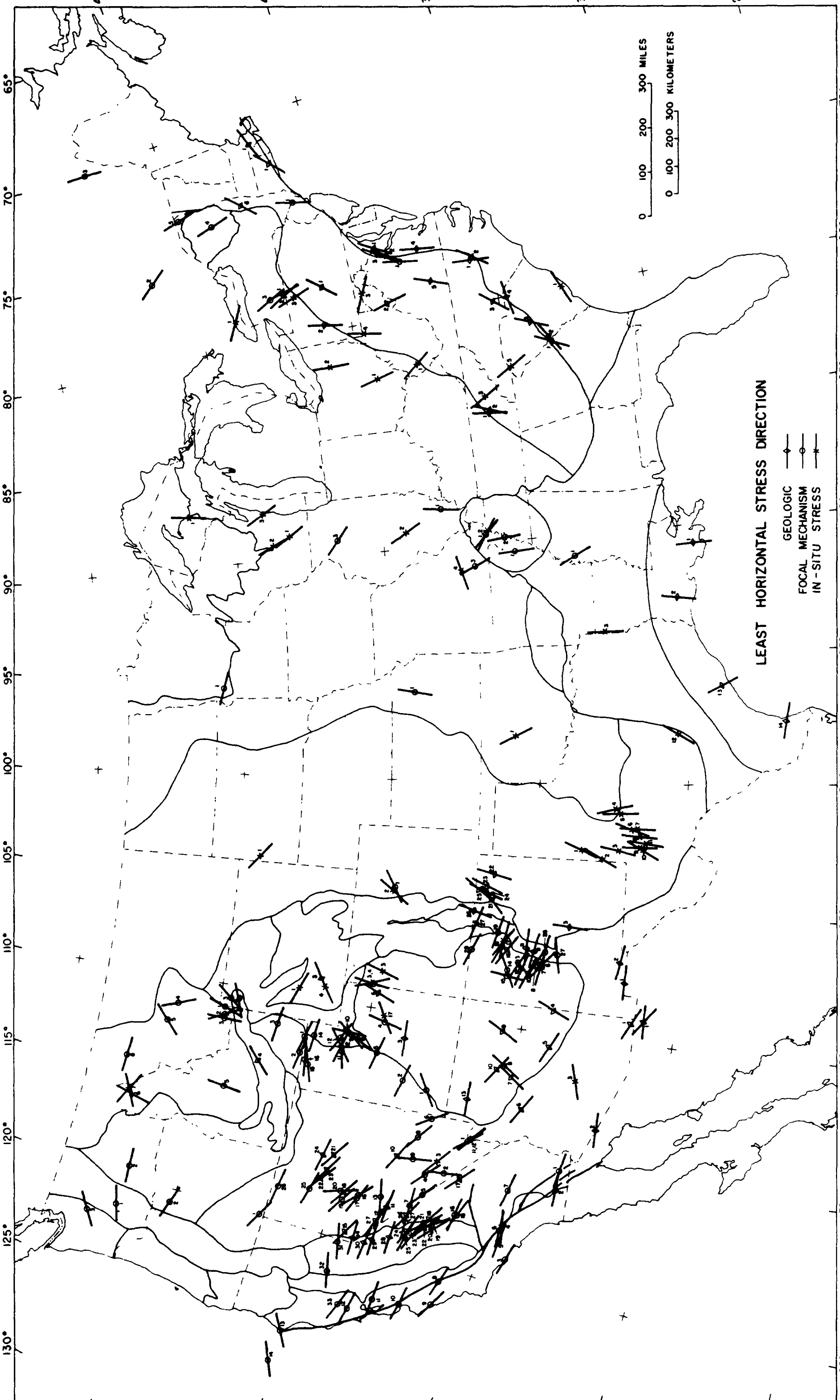
LEAST HORIZONTAL STRESS DIRECTION
GEOLOGIC
FOCAL MECHANISM
IN-SITU STRESS
0 100 200 300 MILES
0 100 200 300 KILOMETERS

Figure 1

A New Attempt at Seismic Zoning Maps for Southern California

Contract No. 14-08-0001-17745

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This semi-annual report summary covers the nine-month period from 22 June 1979 to 23 February 1980, inasmuch as a three-month, no-cost extension was awarded to the original one-year contract. The amount of the contract is $23,823.

During the reporting period, the Principal Investigator continued to accumulate data relevant to the understanding of the degrees of activity of the many seismogenic faults in southern California -- one of the principal bases on which the eventual zoning maps will be constructed. A number of these concepts have been formalized during the reporting period in the Principal Investigator's contributions to Hall et al. (in press), and relationships between seismicity and geologic structure have been re-examined in Allen (in press).

Much of the work of this project remains to be completed, although the formal contract has terminated. The Principal Investigator expects to finish the study during the coming summer, at no additional cost to the Government.

References:

Allen, C. R., in press, The modern San Andreas fault: ch. 15 in Ernst, G., ed., The geotectonic development of California, Rubey Volume No. 1, Prentice-Hall, Inc., New York.

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Physical Constraints on Source of Ground Motion

9940-01915

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Investigations

1. Stochastic fault modeling.

2. Fault mechanics in Fourier-transform domain described by an impedance function.

3. Analysis of ground motion records.

4. San Onofre site review.

Results

1. Work is continuing on modeling high-frequency ground motion radiated by a rough fault surface with self-similar irregularity.

2. The response of the elastic medium in which a fault is contained determines one relation between the slip function and the stress function on the fault. In the space-time domain the slip and stress functions are related by a singular integral equation. If a Fourier transformation is performed over the two space dimensions on the fault and over time, the stress transform equals the slip rate transform times an impedance function. Using this impedance function, we may determine the energy radiated or stored in the elastic medium from either the slip or stress transform.

3. Mike Raugh, in collaboration with April Converse, has adapted the standard LBL strong ground motion analysis programs for use on the Branch's DEC 11/70. He is designing a thorough revision of the system in regard to both file manipulation and numerical techniques.

4. Joe Andrews attended a meeting with the Nuclear Regulatory Commision to hear Southern California Edison and their consultants reply to questions on the seismic design of San Onofre Nuclear Generating Station Units 2 and 3, and critically reviewed their presentation.

Reports

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

9940-02674

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Investigations

1. An analysis of the nearfield records of the Aug. 6, 1979, Coyote Lake earthquake has been started.

2. An analysis of the nearfield records of the Oct. 15, 1979, Imperial Valley earthquake has been started.

Results

1. For the Coyote Lake earthquake we determined several important features: first the main shock had a rupture velocity of about .75 times the shear wave speed and had a rupture length of at least 8 km; second the sediment structure of the Santa Clara valley gives rise to an important S-P converted phase which produced the largest peak acceleration in the nearfield.

2. We have concentrated our efforts on the Oct. 15, 1979, Imperial Valley earthquake (M_s = 6.9) and one of its aftershocks. We have acquired the strong motion data and stored it on our local PDP 11/70 computer. From preliminary analysis of the main shock records we estimate a rupture velocity of 2.25 km/sec. and an effective stress of 25 bars. It is clear that the main shock ruptured unilaterally from south to north on the Imperial fault. This unilateral rupture caused a pronounced difference in the peak particle velocity measured at different stations. The Bonds Corner accelerometer (8 km north of the epicenter) shows the peak particle velocity for SH motion of 44 cm/sec. Whereas El Centro stations 6 and 7 (29 km north of the epicenter) both within .8 km of the fault trace record peak particle velocities of 108 cm/sec. The ratio of station 6 (or 7) to Bonds Corner is 2.47. Using a rupture velocity of 2.25 km/sec. we derive from directivity a ratio of 2.51. From the research of others at the USGS the average slip as of Nov. 7, 1979, (creep has continued to increase the slip since the main shock) is 40 cm. Based on this average we have computed a nearfield moment M_o for the earthquake of 2.2×10^{25} dyne-cm and a static stress drop of 6.4 bars.

In addition to the main shock records, we have been analysing records of an aftershock: Origin time Oct. 31, 1979, 11:43:46.45, $32^o 44.25'$ N, $115^o 24.75'$ W, $M_L \simeq 3.5$, $M_o = 7.9 \times 10^{20}$ dyne-cm. We obtained these records from digital velocity transducers that were placed by us at the same sites of key strong motion accelerometers. This aftershock locates north of Bonds Corner but south of the El Centro array stations. Because of its location, it is extremely valuable for our future synthesis of the main shock. It gives us important constraints on the local structure. By modelling this aftershock we can ascertain the quality of our assumed velocity structure of the Imperial Valley.

Reports

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Spudich, P. A., and Angstman, B. G., 1980, Lateral variations in velocity and Q structure in the region of the 1979 Coyote Lake, California earthquake, Earthquake Notes, v. 50, p. 64.

Archuleta, R. J., Spudich, P. A., and Olson, A., 1980, Synthetic seismogram studies of an aftershock of the 1979 Imperial Valley, California earthquakes, Earthquake Notes, v. 50, p. 50.

Interactive Data Processing Center for Ground Motion Studies

9940-02085

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Investigations

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

Results

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

(1) Hardware

With the addition of one more Tektronix graphics terminal and several editing terminals, the center is now able to support up to seven simultaneous users: 2 at graphics terminals, 3 at editing terminals, and 2 on dial-up lines. Additional capability for handling more users is planned for the second half of this year.

(2) Software

Conversion to the next release of the operating system, RSX-11M V3.2, and the FORTRAN compiler, FORTRAN IV-PLUS V3.0, has been successfully completed. The additional capabilities of these products, especially the support of large core (VIRTUAL) arrays in the new FORTRAN, have enabled the development of programs that would otherwise have been impossible on a minicomputer. Additional software utilities were written to ease user interaction and provide new capabilities (see below). Work was also done to consolidate multiple data file formats into a common file format.

The following programs were developed or modified to run on the PDP-11/70 during this period:

(a) Application programs:

BUTTER - Reassembles digitized film records for standard CalTech Volume I processing
DL11E - General reader for instruments played back over serial lines (for use with GEOS system)
EPIMAP - Plots epicenters or hypocenters and station locations with Mercator or Lambert Conformal projection.
GEOS - Decodes GEOS files produced by DL11E.
DRCONVERT - Converts GEOS format files into DR100-type files for analysis.
INVERTO3 - Computes the moment and formal mechanism for a point-source, double-couple using amplitude and first motion data. (Interfaces with the output of the HYPO location program.)
LNRSYS - Computes the approximate response of a stack of layers.
PH2RSX - CalTech Volume II processing extended to longer records using VIRTUAL arrays.
RAYTRC - Plots ray paths and travel times for laterally homogeneous layers.
ROSE - Writes DR100 format files to tape in ROSE format for export.
TINKER - Filters (high and low pass), integrates, rotates and computes spectra of digital data in DR100 format.
WHERE - Produces a cross reference of events vs. stations for a given earthquake and aftershock sequence.
WKBJ - Traces rays through a layered structure using the WKBJ method.

(b) System commands:

CDOS - Reads CDOS/CP-M format floppy disks from digitizing system.
CRASH - Forces a machine crash.
CWD/PWD - Change/print current working directory.
IDX - FORTRAN IV/FORTRAN IV-PLUS cross reference generator.
MTDUP - Generalized magnetic tape duplicator.
SNAP - Takes a snapshot dump of a running task.
UNDELETE - Recovers accidentally deleted disk files.
WHO - Displays currently logged on users and their active tasks.

(3) Data

A substantial amount of strong-motion data was collected from the October 15, 1979 El Centro earthquake (M_S = 6.8) and aftershock sequence and the earthquakes in late January 1980 near Mt. Diablo/Livermore, California.

Reports

None

Ground Motion Prediction at Selected Strong Motion Sites

9940-01168

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Investigations

1. A study of the scattering of body waves to surface waves by abrupt changes in surface topography using finite difference models.

2. Attenuation of peak ground motion with distance for Imperial Valley earthquake.

3. Aftershocks of the Imperial Valley earthquake.

4. Preparation of paper on:

   (a) interpretation of geodetic data from 1952 Kern County earthquake.

   (b) interpretation of strong motion data from 1966 Parkfield earthquake.

   (c) attenuation of peak velocity.

Abstracts of these papers are included in the next section.

5. Shallow refraction profiles and P and S velocity surveys in the Chalome, Gilroy, Taft and Imperial Valley areas to provide data for modeling strong motion records.

Results

1. For P and S pulses impinging on both vertical and inclined steps, the scattered Rayleigh waves have amplitudes as large as 0.5 times that of the surface displacement of the incident wave. At wave lengths ranging in size from the cliff height to several times the cliff height, the amplitude spectra indicate scattering coefficients in the range of 0.2 to 0.6 (S. Harmsen, S. Harding: coinvestigators).

2. The peak horizontal ground motions from the 1979 Imperial Valley earthquake at distances greater than about 15 km from the fault surface are in excellent agreement with values from previous earthquakes of similar magnitude; 71 percent of the new peak acceleration data fall within the 70-percent prediction intervals defined by the previous data. The peak

velocity and displacements are predicted almost as well. The primary significance of the new data is that they include records at distances less than 10 km, where few data are available from previous earthquakes. An understanding of the full implications of the new data for general attenuation relations between peak ground motions and distance to the fault surface awaits further study of the effects on the recorded motions of fault propagation, radiation pattern, and geologic structure. (R. Porcella: coinvestigator).

3. Starting 28 hours after the mainshock, ten Sprengnether DR100 seismograph systems were deployed in an array about 18 km across, centered on the northern terminus of the Imperial fault. About 30 aftershocks were recorded on three or more stations. Both P and S arrival times were used to calculate hypocentral solutions: depths ranged from 3.5 km to 9.0 km, with most events around 5.0 km (corresponding to the bottom of the sediment filled basin), and epicentral locations were similar to those given in the preliminary analysis of the telemetered, high gain data (C. Johnson, written commun., 1979). Most of the events clustered near the northern terminus of the surface traces of the Imperial fault, although no distinct lineaments were detected. Some events occurred several km to the west of the mapped traces, and others occurred in the region between the Imperial and Brawley faults. Focal mechanism showed that most events were essentially vertical strike-slip faults striking northwest even though the earthquakes occurred in a region where the fault turns to the north and has a significant amount of dipslip motion at the surface. The shallowest event, a north-trending normal fault, agreed with expectations from surface faulting, suggesting that the mode of faulting is depth dependent.

After about ten days, five of the instruments were deployed to sites near the strong-motion instruments which recorded the mainshock and were closest to the Imperial fault (sites 5, 6, 7, 8, and Bonds Corner). One aftershock was recorded at all of these sites and showed that significant differences in travel times, wave forms, and spectral amplitude occur at sites on either side of the Imperial fault. Relative to site 7 at Imperial Valley College on the west side of the fault, the S waves near site 6 in the region between the Imperial and Brawley faults are delayed by about 0.5 s and the spectral amplitudes are increased in the 2 to 5 Hz range by up to a factor of 10. Records from a swarm of earthquakes in 1977 had larger peak accelerations at station 6 than station 7, consistent with our finding. Most importantly, the mainshock accelerograms at station 6 have obvious 3-5 Hz oscillations that are not present on the record from station 7, suggesting that digital velocity of recordings of aftershocks can provide important information on the characteristics of strong-motion accelerograph sites. (J. Fletcher, R. Archuleta, E. Sembera: coinvestigators).

4a. Triangulation surveys carried out in the vicinity of the White Wolf fault in 1932, 1952, 1953, and 1963 are used to delineate the strain changes preceding, accompanying and following the 1952 earthquake. The strain rate (engineering shear) during the preseismic interval (1932-52) was 0.36 ± 0.10 strain/yr and was nearly uniform across the 70 km long triangulation arc, with the plane of maximum left-lateral shear oriented N $44^{\circ} \pm 7^{\circ}$E, nearly parallel to the White Wolf fault. The coseismic observations (1952-53), supplemented by leveling data, are matched using a dislocation model with the following characteristics:

Dip = 60° SE

Strike = N50° E

Length = 70 km

Left-Lateral Strike-Slip - 2.4 $\pm$ 0.1 m

Reverse Dip-Slip = 1.9 to 0.6 m (decreasing to the NE)

Seismic moment $\geq$ 0.9 x 10^{27} dyne-cm

The data also require most of the slip to have occurred below ~5 km in our model), on roughly the southwest half of the fault, with the slip occurring at shallow depths to the northeast. The postseismic triangulation data (1953-63) indicate that the average shear strain rate in the 10 years following the earthquake (0.80 $\pm$ 0.20 μstrain/yr) was about twice that during the 20 years preceding it. The postseismic strain changes were concentrated closer to the fault than those determined for the preseismic time interval, and the 1953-63 data are explained well by episodic postseismic slip of about 2 m (left-lateral strike-slip) occurring on the downdip extension of the coseismic fault plane. (S. Dunbar, W. Thatcher: coinvestigators).

4b. A reanalysis of many of the available data for the 1966 Parkfield, California earthquake (M_L 5½) shows that although the ground breakage and aftershocks extended about 40 km along the San Andreas fault, the initial dynamic rupture was only 20-25 km in length. The foreshocks and the point of initiation of the main event locate at a small bend in the mapped trace of the San Andreas. Detailed analysis of the P-wave first motions from these events at the Gold Hill station, 20 km to the SE, indicates that the bend in the fault extends to depth, and apparently represents a physical discontinuity on the fault plane. A variety of circumstantial evidence suggests that this discontinuity plays an important part in the recurrence of remarkably similar magnitude 5-6 earthquakes at Parkfield.

The rupture stopped at another discontinuity in the fault plane; an en echelon offset near Gold Hill. The en echelon offset at which the 1966 rupture stopped lies at the boundary on the San Andreas fault between the zone of seismic slip and the locked zone on which the great 1857 earthquake occurred. The 1857 foreshocks occurred in the area (Sieh, 1978), and we speculate that the epicenter of the mainshock may have coincided with the offset zone. If so, a detailed study of the geological and geophysical characteristics of the region might be rewarding in terms of understanding how and why great earthquakes occur where they do. (A. Lindh: coinvestigator).

4c. A set of curves giving peak horizontal particle velocity as a function of distance for various magnitude earthquakes has been constructed by combining the definition of Richter local magnitude (M_L) and a correlation between peak velocity (V) and the computed Wood-Anderson seismograph response (WA) from a set of strong-motion data (V = .77WA, with V in cm/s and WA in m). The attenuation function given by Richter in his definition of M_L needs modification at distances close to the fault surface, for existing data show that at these distances there is less than the expected factor of ten increase in amplitudes for each unit increase in magnitude. Existing data have been used to constrain the curves at close distances. The modified attenuation curves are, by definition, consistent with the local magnitude of moderate distances from the fault (several tens of kilometers) and are consistent with the sparse data at close distances to the fault. The problem of accounting for the saturation in peak motions at a given distance as the size of the earthquake increases is transferred to the estimate of M_L given some measure of the physical size of the earthquake rupture, such as seismic moment. Observations suggest that M_L saturates as the moment increases.

5. Recordings of the Coyote Lake earthquake at the Gilroy strong motion array provide a uniquely valuable data set for examining the effect of local geology on strong ground motion. At station number two of the array of Quaternary alluvium the ground motion was amplified to a peak horizontal acceleration of 0.26 g and a peak horizontal velocity of 33 cm/sec., compared to 0.13 g and 10 cm/sec. at station number one only 2 km away on Franciscan bedrock. Downhole P and S velocity surveys were made to bedrock at a depth of 595 feet at station number two and to depths of 65-200 feet at the other four sites of the array. Analysis of the strong motion data in conjunction with the downhole velocity data indicates that the ground response at site number two was linear. Demonstration of linear soil response to earthquake motion at this high a level is unprecedented and contradicts views widely held among soil engineers. (R. E. Warrick, J. F. Gibbs, T. E. Fumal, and R. M. Hazlewood: coinvestigators).

Reports

Boore, D. M., 1980, On the attenuation of peak velocity: World Conference Earthquake Engineering, 7th, Instanbul, Turkey, Proceedings, in press.

Dynamic Soil Behavior

9550-01630

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Investigations

1. Analyzed free-vibrational behavior of nonlinear soil samples in torsion.

2. Studied the methods of estimating in situ nonlinear soil behavior and their effects on site response during earthquakes.

Results

1. Based on results from theoretical calculations, possible errors associated with the use of the existing interpretation procedure of the torsional pendulum test on nonlinear soil specimens were identified. Improvements proposed to minimize these errors include the concept of effective displacement, a new definition of vibration period, and the use of acceleration amplitudes for the logarithmic decrement in damping computation.

2. Among the five currently available methods for estimating in situ loading curves of soil that were studied and compared, the reference strain method proved to be the most logical one for application. It was also demonstrated that, if the laboratory curve is directly used as the in situ loading curve with no adjustment, a difference of 50 percent in surface acceleration prediction can be expected. In addition, for shallow sites with low-intensity excitation and for deep sites with high-intensity excitation, a substantial shift in the frequency content of the surface response is noted.

Reports

Berends, B. E., and Ko, H. Y., 1980, Cubical multiaxial cell for testing cohesive soils: Journal of Geotechnical Division, ASCE, v.106, no. GT1, pp.106-111.

Stokoe, K. H., II, and Chen, A. T. F., Effects on site response of methods of estimating in situ nonlinear soil behavior: paper submitted to the 7th World Conference on Earthquake Engineering, Turkey, 1980.

Strong Ground Motion Data Analysis

9940-02676

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Investigations

1. Source parameters such as strike, dip, rake, moment, source dimension and stress drop have been calculated for 3 events (out of 7 to be analyzed) for which three-component digital recordings were obtained in the spring of 1977 at Monticello, South Carolina, a site of induced seismicity.

2. Ground motion parameters of mine tremors and earthquakes measured from accelerograms recorded at small hypocentral distances are analyzed in terms of several models of faulting to determine the effects of such factors as seismic moment, stress drop and instrument bandwidth on peak velocity and acceleration. This investigation continues work begun in terminated project no. 9940-02408.

3. Prediction of high frequency strong ground motion as measured by the rms acceleration using a model that describes the dominant accelerations as random white noise with a Gaussian distribution that is bandlimited at the low end by the corner frequency and the high end by anelastic attenuation.

4. Quasi-dynamic rupture models are derived from theoretical and finite difference solutions to the mixed boundary value problem of a 3-D frictional rupture and the results are then used in the analysis of strong ground motion data.

Results

1. The three earthquakes that have been analyzed have moments of a few tenths of 10^{18} dyne-cm, source radii of about 100 m, and stress drops of .3 to .7 bars. These estimates are averaged for 4 to 5 stations for both P and S waves. Fault plane solutions are obtained by inverting the P-wave and S-wave displacements using a computer program written by Vince Caterina. Solutions considered to be reliable are thrust with the nodal planes striking mostly north-south. Work is now proceeding in locating the events with a program that uses a linear gradient velocity model derived from well logs. Static and dynamic stress drops will be compared to the effective stress determined from an in-situ stress measurement.

2. Peak velocity v and peak acceleration a were found to be consistent with the following relationships derived from Brune's earthquake fault model.

$$R\underline{v} = 0.57\beta\ \Delta\tau\ r_0/\mu$$

and $$\rho R\underline{a} = 1.14\ \Delta\tau\ r_0\ f_s/\beta \qquad (1)$$

where R is the hypocentral distance, β is the shear wave velocity, $\Delta\tau$ is the stress drop, r_0 is the source radius, μ is the modulus of rigidity, ρ is the density and f_s is the band-limited maximum frequency. Although equations (1) are broadly in agreement with observations over a range in seismic moments from 5×10^{16} to 1.4×10^{26} dyne-cm there are some important limitations to the usefulness of analyzing ground motion parameters using Brune's model which involves a homogeneous stress drop over the fault. To overcome some of the limitations, work has begun on developing a fault model involving the failure of an asperity within an annular fault zone.

3. RMS accelerations have been analyzed with respect to a model of the earthquake source that describes earthquake generated ground acceleration as random white noise with a Gaussian distribution that is bandlimited. Data from San Fernando are predicted using this model if 100 bars stress drop is assumed. A correction for the radiation pattern also appears to be necessary to obtain a fit that is roughly within a factor of two of the data. RMS accelerations from the Oroville aftershock sequence also demand an assumed stress drop of 100 bars for adequate agreement between the model results and the data in spite of the well determined stress drops of several hundred bars. This curious discrepancy may be the result of assuming that the high-frequency portions of the displacement spectra diminish according to w^{-2} whereas the actual spectra often show a roll-off proportional to W^{-3}.

4. The quasi-dynamic rupture model yields an analytic form for the slip velocity, which can be divided into phases of self-similar growth and healing, which decreases linearly to zero. The results of the model were applied to the analysis of velocity and velocity-squared pulse shapes of the aftershock of 0103 hours August 3, 1975, two days after the Oroville, California earthquake. Besides the usual source parameters, the rupture velocity and dynamic stress drop (effective stress) were determined using the model results.

Reports

Boatwright, J. L., 1980, Quasi-dynamic models of simple earthquakes: application of an aftershock of the 1975 Oroville, California earthquake, submitted to Bulletin of the Seismological Society of America.

McGarr, A., 1980, Relationship of peak ground velocity and acceleration to seismic source processes [abs.]: Earthquakes Notes (Eastern Section, Seismological Society of America), v. 50, p. 19.

Boatwright, J. L., 1980, The Radon transform and the inversion of body wave pulse shapes [abs.]: Earthquake Notes (Eastern Section, Seismological Society of America), v. 50, p. 31-32.

Analysis of Natural Seismicity at Anza, California

9940-02731

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Investigations

This is a cooperative project with James N. Brune and Jonathan Berger of the UCSD. A digital-telemetered seismic array will be installed in the Anza-Coyote Canyon seismic gap with the intent to: (1) determine if there are any premonitory changes in seismically observable quantities preceding small and moderate events; (2) increase understanding of mechanisms and spectra of small and moderate earthquakes to improve capability of predicting strong ground motion; (3) study relationship between earthquake activity and crustal deformation as measured geodetically and with instruments at the Piñon Flat Observatory.

Results

This year has been spent in procuring a Digital Equipment Corporation PDP 11/34 as the minicomputer for collating the incoming digital words and detecting events, and deciding on the specifications of the electronics at each field site. If all goes well the first field site at Piñon Flat and the minicomputer should be installed in July-August 1980.

Numerical Methods

9950-01896

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Investigations

1. The frequency and time histories have been computed for a steep and slanting cliff in conjunction with Dave Boore, and a basin with flanks dipping of 26°-45°-90° with basin materials of various geotechnical properties, including a consideration of both isotropic and transverse isotropic materials.

Results

1. Conversion of body-waves to surface-waves is a means for converting energy with essentially infinite horizontal wavelength to motion with short wavelengths. This process is of interest to engineers designing structures with large horizontal dimensions, such as pipelines, tunnels, and bridges, but it has received little attention from seismologists. Finite-difference calculations for the simple case of vertically incident SV and P waves impinging on a step change in surface elevation predict scattered Rayleigh waves with amplitudes as large as 0.4 times that of the surface motion of the incident waves in the absence of any topographic relief, even for incident wavelengths several times the height of the step.

2. Steve Harmsen has developed a method of modeling waves propagating through transversely isotropic materials. This permits the modeling of thinly layered and jointed materials where there is a different P-wave velocity in one direction than in the direction normal to it.

3. A number of different shaped basins were studied. Figure 1 shows six different frozen time steps of one of the basin. This gives an unusual picture of the complex scattering from a simple compressional wave. Figure 2 is a three-dimensional plot showing changes in spectra across a basin as a function of distance from corner of basin, frequency, and the ratios of energy in converted waves to energy in the incident waves.

Results

Dewey, J. W., McCann, W. R., Murphy, H. J., and Harding, S. T., 1980, A large normal fault earthquake in the overriding wedge of the Antilles subduction zone: The Antigua earthquake of October 8, 1974, AGU Spring Meeting.

Boore, D. M., Harmsen, S. C., and Harding, S. T., 1980, Body to surface wave scattering from step changes in surface topography: Earthquake Notes, v. 50, no. 4, p. 24.

Harding, S. T., and Harmsen, S., 1980, Modeled response of an alluvial basin to vertically incident body waves--both isotropic and transverse isotropic models: Earthquake Notes, v. 50, no. 4, p. 25.

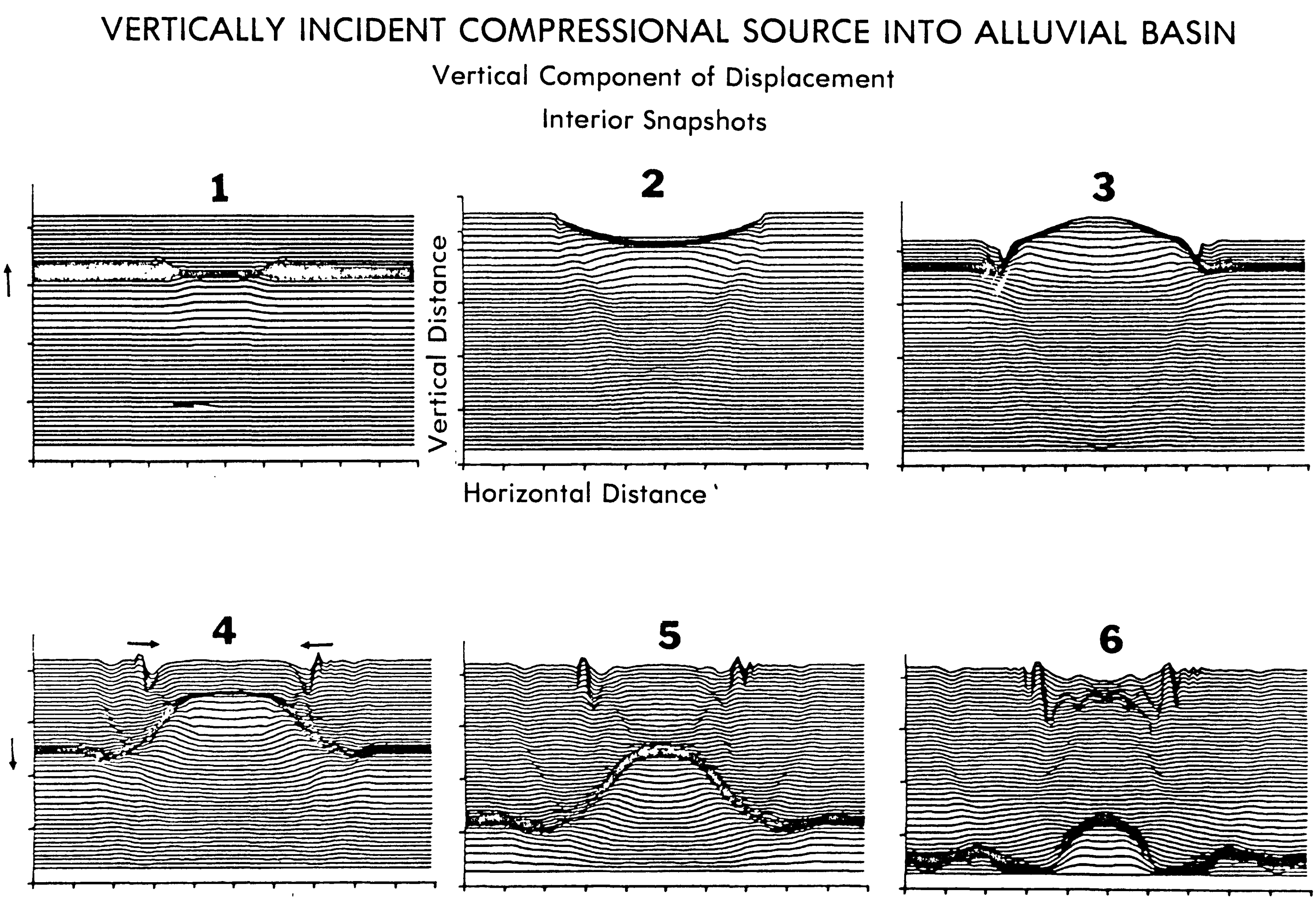
VERTICALLY INCIDENT COMPRESSIONAL SOURCE INTO ALLUVIAL BASIN
Vertical Component of Displacement
Interior Snapshots
1
2
3
4
5
6
Vertical Distance
Horizontal Distance

Figure 1.

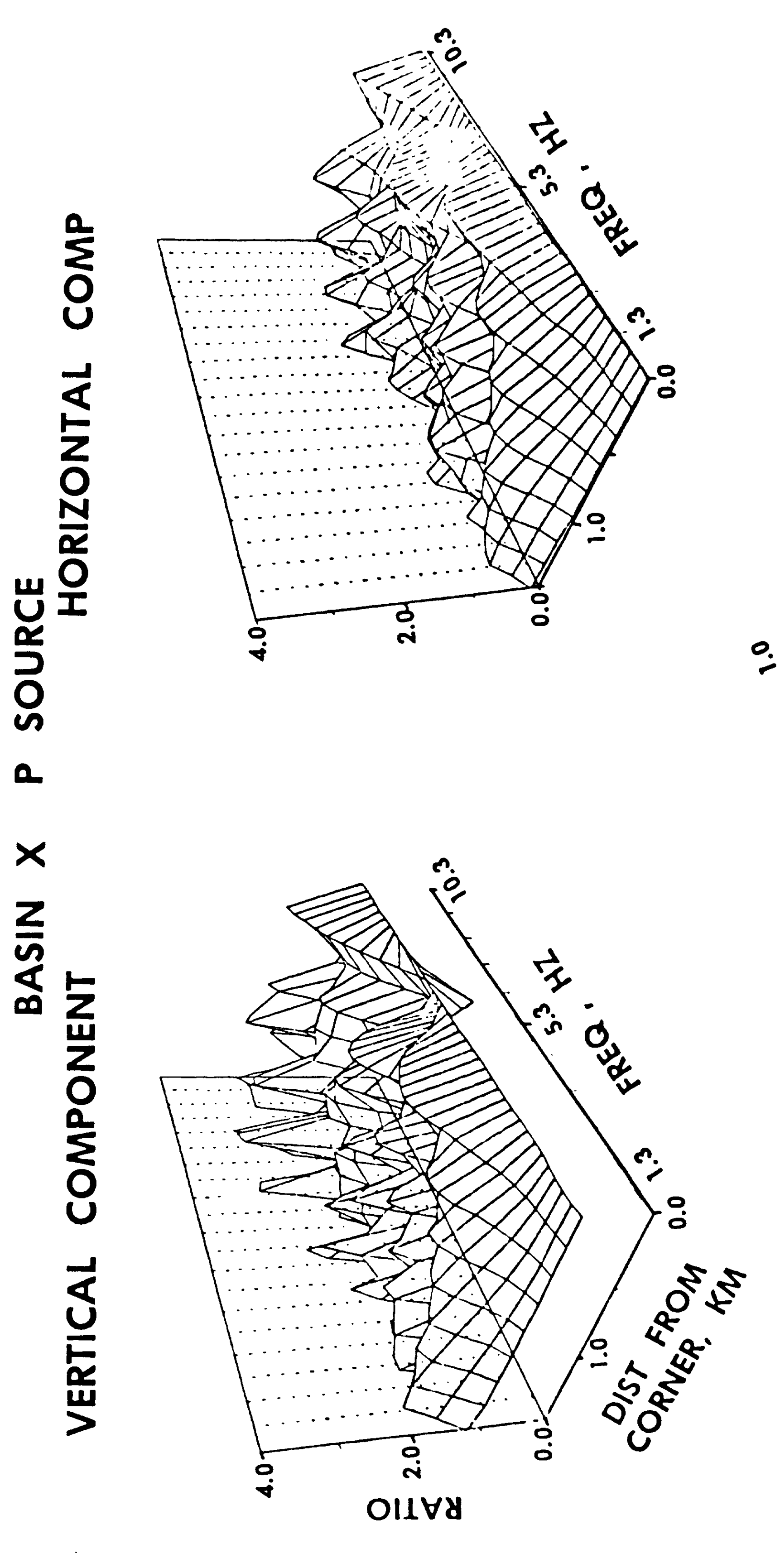
BASIN X P SOURCE
VERTICAL COMPONENT
HORIZONTAL COMP
RATIO
4.0
2.0
0.0
1.0
DIST FROM CORNER, KM
0.0
1.3
5.3
10.3
FREQ ' HZ

Figure 2.

Stochastic Source Models for Synthetic Strong Motion Seismograms

9940-01913

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Investigations

1. Development of methods utilizing stochastic source models for the generation of seismologically realistic time histories of earthquake ground motion and mean Fourier spectra.

Results

Methods have been developed for computing synthetic seismograms and mean spectra for a fault extended in one dimension (i.e. a point source moving along a line) and imbedded in a modified half-space. The methods have been applied to the Temblor strong-motion record in the 1966 Parkfield earthquake and the Taft strong-motion record in the 1952 Kern County earthquake.

Reports

Joyner, W. B., and Boore, D. M., 1980, A stochastic source model for synthetic strong motion seismograms: World Conference on Earthquake Engineering, 7th, Istanbul, Turkey, Proceedings, in press.

Joyner, W. B., and Boore, D. M., 1980, The mean spectrum for a stochastic source model [abs.]: Seismological Society of America, Annual Meeting, April 1980.

Application of Earthquake Mechanism Studies to Prediction of Long-Period Ground Motion and Related Problems

Contract No. 14-0001-18321

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This report summary covers the six-month period from October 1, 1979 to March 31, 1980.

Investigations

In order to obtain fundamental data for the synthesis of long-period ground motions from large earthquakes, we determined the local magnitude M_L for several important intra-continental events with various fault geometries. The M_L values are compared with those for California earthquakes and subduction-zone events.

Results

We used strong-motion records and seismoscope records of several recent intra-continental events by using the method by Kanamori and Jennings (1978) and Jennings and Kanamori (1979).

Table 1 summarizes the data and the results. Since the local magnitude, M_L, was originally defined for California earthquakes (Richter, 1935), it is not directly applicable to earthquakes in other regions. In partiular, the amplitude attenuation function used for the M_L determination depends upon the crustal structure and the focal depth, both of which differ substantially from place to place. However, when M_L is determined from strong-motion records obtained at short distances, the effect of the different crustal structure is relatively small. The effect of the depth is difficult to determine at present. In the present paper we used an estimated distance (Δ_h in Table 1) between the station and the nearest point on the rupture zone for the calculation of the magnitude.

Figure 1 compares the results with those for California earthquakes and the 1976 Guatemala earthquake. Except for the Romanian earthquake, the difference between the intra-continental and the California earthquakes is relatively small. The data point for the Gazli earthquake falls on the trend for California events, while those for the Friuli, the Monte Negro and the Tangshan earthquakes lie near the upper edge of, or slightly above, the trend for California events. The average value of M_L for the Romanian earthquake is 7.9 and is substantially larger than any other events. Although this value may not be directly comparable with those for other events because of the large depth of this event, it is important to note that M_L can become as large as 8 under certain circumstances.

Because of the relatively small number of records used in this analysis, the results presented here should be considered preliminary. However, they do seem to substantiate the conclusion obtained from teleseismic observations that intra-continental events involve slightly higher stress drops than the events on plate boundaries, and may generate stronger ground shaking than inter-plate events with a comparable surface-wave magnitude.

It is interesting to note that a recent study by Heaton and Tajima (1979, personal communication) indicates that the values of M_L for Japanese events (mainly subduction zone events) are systematically smaller than those for California events with the same M_s (or M_w).

Table 1. Local Magnitude M_L

Event	Depth (km)	m_b	M_s	M_w	Station	Component	Δ_h (km)	M_L
Gazli, 5/17/76	19	6.3	7	6.8[2]		NS	10	6.4
						EW	10	6.3[1]
Friuli, 5/6/76	9	6.0	6.5	6.4[3]	Tolmezzo	EW	25	6.6
Romania, 3/4/77	100	6.8	7.1	7.5[4]	Bucharest	EW	190	8.0
						NS	190	8.2
					Galati	NS	140	7.6
						EW	140	7.7
Monte Negro, 4/15/79[7]	40			7.0[5]	Petrovac	NS	24	6.7
					Ulcinj	NS	34	6.9
					Bar	NS	21	6.7
Tangshan, 7/28/76	16	6.3	7.4	7.4[5]		EW	157	7.4
						NS	157	7.4
						EW	153	7.3

1) Cagnetti and Pasquale (1979) gave $M_L = 6.3$. For comparison with other data, the value determined from strong-motion records is used here.

2) Hartzell (1979b)

3) Cipar (1980)

4) Hartzell (1979a)

5) This study

6) Butler, Stewart and Kanamori (1979)

7) Digitized strong-motion records compiled by Naumovski et al. (1979) are used.

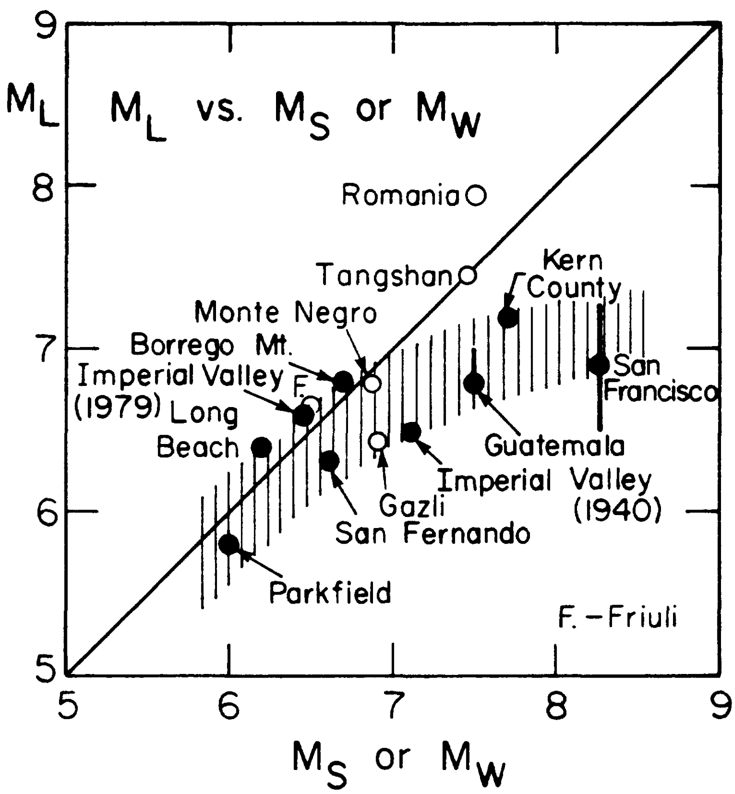

Fig. 1. The relation between M_L and M_s (or M_w). The values of M_L computed from strong-motion records are used in this figure.

Microzonation of the Memphis, TN Area

14 - 08 - 001 - 17552

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The purpose of this research is two-fold: to microzone the city of Memphis, TN with respect to ground surface shaking, liquefaction potential and landslides during earthquakes and, to document the ease and/or difficulty of the microzonation approach using existing information on seismology and geotechnical parameters. No field or laboratory tests were performed as part of this research study.

Investigations

1. The seismicity of the central United States is reviewed to obtain data on source mechanisms for earthquakes that would be felt in Memphis, TN.

2. Artificially generate accelerograms representative of the source locations found in item 1 above in terms of frequency content (predominant frequency), peak acceleration, and duration.

3. Determine geologic profiles of the study area from existing information sources. The soils and rocks in the upper 60 meters are of most concern. Once representative profiles are established, assign dynamic properties (shear modulus, damping factors) for response analysis.

4. Perform response analysis assuming horizontal motion input (SH waves) at a depth of 45 meters below the ground surface.

Results

1. Five zones or source areas were found capable of generating earthquakes that could be felt in the Memphis area. The maximum credible earthquakes which are likely to affect Memphis are evaluated as the one in a thousand year occurrence. However, earthquakes of a lower intensity (and lower recurrence rates) are selected as design earthquakes to permit a more realistic microzonation to be performed.

2. Three artificially generated earthquakes are prepared so as to display the following features:

   (i) Peak acceleration which corresponds to the intensity at site, after having been attenuated from the source,

   (ii) Strong motion (bracketed) duration,

(iii) Predominant frequency, reflecting the effects of greater attenuation of the higher frequencies contained in the accelerogram plus effects of magnitude.

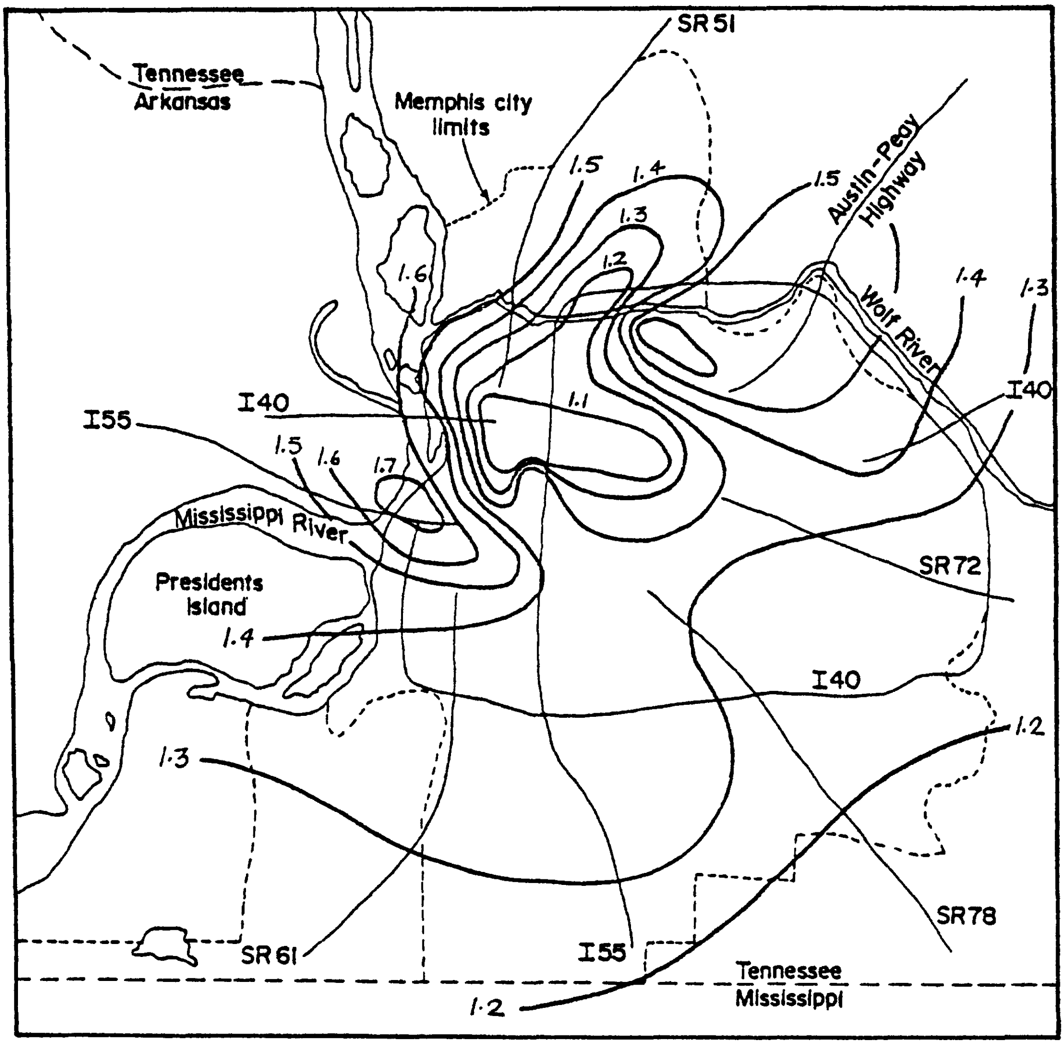
3. The geologic soil profiles were obtained from published and unpublished reports, and knowledgeable individuals. None of these sources provided information on the dynamic soil properties directly; it was necessary to assign dynamic properties based on soil type, Standard Penetration Test blow count, existing vertical effective overburden stress and soil shear strength. The assumptions made in assigning soil properties is discussed in detail.

4. Once the design earthquakes, soil properties and layering were established in representative areas throughout the city of Memphis, the ground response was evaluated by means of the program SHAKE developed at the University of California, Berkeley. The response calculations were carried out for peak "bedrock" accelerations of 18, 14, and 11 percent g representing three epicentral distances of 50, 100, and 200 km. Figure 1 shows the ground amplification factors based on a peak bedrock acceleration of 18 percent g for a bracketed duration of 19 seconds. Microzonation maps were also drawn for amplification factors for peak-spectral acceleration assuming 2 percent structural damping, as well as contours indicating the natural periods of the soil profiles for the pertinent design earthquakes. Zones where liquefaction is expected to occur were also delineated.

This study is essentially a first-attempt to evaluate the seismic-microzonation of Memphis, Tennessee, and thus should be viewed only as a preliminary analysis. As microzonation is a very complex analysis, a future multidisciplinary approach is recommended to enable a more design oriented outlook.

Reports

Sharma, S. and Kovacs, W. D. (1980) "The Microzonation of The Memphis, TN Area," Final Report - Phase 1, Geotechnical Engineering, School of Civil Engineering, Purdue University, May, 129 pp.



Contours indicate amplification factors for the assigned "bedrock" motion of 18% g.

FIG 1, Ground Acceleration amplification factors

Calculation of Strong Ground Motion and Local Field-Far Field Relationships for the April 29, 1965, Puget Sound, Washington, Earthquake

14-08-0001-18235

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Investigations

Work related to this contract has concentrated in producing viable source models for the April 1965 Puget Sound earthquake and viable earth structure models for Puget Sound and nearby areas to study the effects of strong ground motion wave propagation. Several different yet related topics have been addressed in this study and are in various stages of completion. These are:

1. Construction of both deterministic and empirical source models for the 1965 Puget Sound earthquake based on teleseismic body wave data;

2. Investigation of crustal and upper mantle structure under specific sites in the Pacific Northwest;

3. Calculation of strong ground motions using these source and structure models with comparison to existing strong motion data recorded from the 1965 event.

Results

1. Software for the systematic testing of finite fault and rupture parameters has been developed to model the teleseismic short- and long-period P and S wave form data from the 1965 earthquake. Synthetic seismograms calculated from these deterministic fault models will be compared to the observations to deduce acceptable fault models to serve as constraints in strong ground motion modeling. An empirical approach to deducing source time functions for the 1965 event has also been developed which uses a time domain deconvolution technique.

2. Structure under station TUM (Tumwater, Washington) is being investigated using teleseismic data obtained from the University of Washington. This station is within 4 km of a major strong motion recording site (Olympia Highway Test Laboratory) so structure deduced from this study will offer constraints to structure incorporated in strong ground motion calculations. Preliminary modeling of PS conversions show the existence of strong velocity contrasts within the upper few kilometers of the surface.

3. Structure under VIC (Victoria, British Columbia) is being investigated using teleseismic sources. Observed P-to-S conversions and reverberations from interfaces under VIC are similar to observations made at COR (Corvallis, Oregon) from a previous study. This indicates structure at VIC is similar to structure under COR. A high contrast interface at 45 to 50 km depth is inferred.

4. Digital and analogue strong motion recordings for the 1965 Puget Sound earthquake have been obtained and are being prepared for numerical processing.

Strong-motion interpretations for structural engineering

9910-02759

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Investigations

1. Evaluate current seismic design zones relative to recorded building response and propose appropriate criteria for seismic zonation for building design.

2. Develop models and procedures for including nonlinear structural reponse and nonlinear soil-structure interaction into routine response calculations with a view to evaluating current use of response spectra in building design and to including such nonlinear effects in routine strong-motion data processing

Results

1. A preliminary evaluation of current seismic design zones has been performed based on a review of current performance criteria, current design practice, the measured response of buildings during earthquakes, and current methods of estimating peak ground motions. This preliminary evaluation indicates that the present design zonation is such that buildings in Zone 3, which are designed in accordance with current practice, are unlikely to be subjected to damaging levels of ground motion, whereas those in Zone 4 will be subject to damaging levels of ground motion eventually. No evaluation could be made of the likelihood of building collapse based on current design practice and recorded building response. The preliminary evaluation will be refined.

2. A simple model that includes both nonlinear structural response and nonlinear soil-structure interaction has been formulated and has the capability of representing the principal characteristics that have been observed in the measured response of buildings. This model is being incorporated into Joyner's procedures for analysing nonlinear response histories (ref.: Joyner and Matthiesen, 1977, Response spectra for hysterical systems, abstract for SSA annual meeting, Reno). When the programing is completed, parametric studies may begin.

The Role of Anelasticity in Earthquake Ground Motion

Contract No. 14-08-0001-G493

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A vertical seismic array at the Richmond Field Station has provided some excellent experimental data showing the effects of unconsolidated sediments on ground motion during local earthquakes. The experiments are well controlled in that good estimates of the material properties of the sediments are available, with the largest uncertainty being in the attenuation. Three components of acceleration have been recorded in bedrock below the sediments, within the sediments, and at the surface of the sediments from two local earthquakes. The maximum accelerations at the surface are between 1.5 and 4.3 times those in the bedrock.

Analytical calculations which assume vertically propagating waves and which are suitable for highly attenuating materials do a reasonably good job of predicting the differences between the bedrock records and the surface records for both vertical and horizontal components. Maximum accelerations, duration, frequency content, general character of the records, and response spectra are all in agreement. Some of the energy arriving late in the records can best be explained by surface waves propagating horizontally in the sediments.

Earthquake intensity and fault creep

9940-02675

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Investigations

1. An improved technique for mapping seismic intensity and ground motion was developed using the disturbance of materials in grocery stores and furniture stores. The technique was field-tested with the October 1979 Imperial Valley earthquake and the January 1980 Livermore earthquakes.

2. The re-examination of the damage and seismic intensity ratings of the great California earthquake of 1906 has continued.

3. A portable creepmeter instrument was designed and installed on an earthquake-caused fracture on Sao Jorge island in the Azores Islands (Atlantic Ocean), at the request of the Portuguese Geological Survey (funded by the U.S. Agency for International Development).

Results

1. The seismic intensity technique of store disturbance was successful in the accurate mapping of seismic intensity of the 1979 Imperial Valley earthquake. The seismic intensity at all towns in the central region was MM VII, which correlates well with horizontal peak acceleration values of 0.25g on the strong motion instruments in the same towns. Intensity MM VI correlates well with horizontal peak accelerations of 0.12g. The store disturbance technique also allows separate determination of aftershock ratings.

2. Use of the store disturbance technique at towns around the two Livermore earthquakes of January 1980 showed that the shaking of the first earthquake was stronger than the second earthquake to the south and southeast, while the second earthquake was much stronger than the first to the west, even though the two earthquake epicenters are close to each other. This clearly shows a difference of the seismic ground motion in different directions for the two events.

3. The intensity rating of the 1906 earthquake damage in San Mateo and other counties shows that the seismic intensity pattern was very different than is shown on the 1908 maps of Lawson and others. In particular, the shaking intensity in many parts of the hills was one or two levels of intensity greater (Rossi-Forel or Modified Mercalli scales) than is shown on the Lawson maps.

3. The detailed seismic intensity map of San Mateo county shows very little difference in intensity between the hills west of the earthquake fault and the alluvial valley east of the hills. This similarity of strong seismic intensity is different from what has been observed with weak shaking, which suggests that weak shaking and strong shaking act differently with regard to geologic conditions.

Reports

Nason, Robert, 1980, Damage in San Mateo county, California in the earthquake of 18 April 1906: U.S. Geological Survey, Open-file Report 80-176, 52 p.

Global Accelerograph Project

9940-02689

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Investigations

The Global Accelerograph Project had an excellent beginning. Prior to the beginning of the fiscal year, a detailed plan was drafted within the Branches of Ground Motion and Faulting and Seismic Engineering and coordinated within the Office of Earthquake Studies. The plan was introduced to State Department representatives of the Office of Cooperative Science and Technology Programs at a special meeting in July 1979. The plan was favorably received and suggested changes incorporated into a final revision.

Results

The objective of the Global Accelerograph Project is to obtain critical near-source ground motion data from large earthquakes and aftershocks. Data would be obtained from permanent and temporary arrays in foreign countries. The plan includes a comprehensive list of countries around the world likely to experience earthquakes and aftershocks of the magnitude we need for our research.

Following the State Department meeting in July work began on the selection of the first countries to be approached for introduction of the project. Ten countries were selected with consideration given to both technical and political factors. A suggested airgram was forwarded to the Office of International Geology (OIG) for internal USGS coordination and forwarding through the State Department to the 10 selected embassies around the world. The airgram contained the project plan, introduced the project to the addressee countries and requested their expression of interest in participation in the project. The airgram also included the names of physical scientists and engineers who have served as USGS contacts in strong motion research through the years. We suggested that the embassy use those names as appropriate for a starting point to introduce the project into the in-country political/scientific structure. Unfortunately, 6 months later, the plan still rests in OIG. The OES Deputy for Research is working with OIG to get the airgram released in a timely manner.

In efforts related to but separate from this project, the principal investigators, in cooperation with colleagues at CalTech and USC, prepared a proposal for the installation of strong motion instrumentation in the Peoples Republic of China. This proposal has been submitted through CalTech to the National Science Foundation.

D. M. Boore, A. Lindh, and W. Joyner submitted a propsal to the strong motion program of the California Division of Mines and Geology for the installation of a dense network of accelerographs along the San Andreas fault near Parkfield, California. This proposal was accepted and the above named investigators are advising the state in the deployment of the array.

Future Plans

Future plans call for following through with the release of the airgram, initiating agreements with those countries who respond favorably and initiating the procurement of instrumentation.

Data Processing, Golden

9940-02088

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Investigations

1. Develop a system for switching terminals, peripherals, and CPU ports to allow efficient use of Golden Computer Center equipment and easier user access to all major systems.

2. Develop and implement charging algorithms and automatic accounting on all major systems.

3. Process ground-motion data as requested.

4. Further automate digitizing system.

5. Continue to develop data-acquisition systems for the US Net.

6. Run day-to-day operations of the Golden Computer Center.

Results

1. Commercially available systems have been investigated and because of cost a "hybrid" patch-panel/micro-processor-based system looks like the best approach.

2. Usage statistics are being gathered at this time.

3. Data digitization has resumed with an automated system on the 11/40 eliminating the hybrid computer.

4. A time-code-reader based program is implemented.

5. The data acquisition system for the Snyder, Texas, is up and running.

Computer-Based Earthquake Mapping
San Francisco Bay Area

Contract No. 14-08-0001-17751

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PROJECT COMPONENTS

1. Several data files that have not been available in ABAG's computer-based geographic data system have been developed, either by digitizing maps or by obtaining existing machine-readable data sets.

2. A series of earthquake hazard map files have been produced for the San Francisco Bay Area by combining the data files developed in the first task in various ways.

3. Various applications for these files have been explored.

4. Much effort is being made to ensure that this information is effectively communicated to city and county staff.

DISCUSSION OF RESEARCH

1. File Development

Several basic data map files that have not been available in BASIS* have been developed, either by digitizing maps or by obtaining existing machine-readable data sets. In those cases where regional coverage is either too general or too costly, subregional data sets have been developed for San Mateo County for experimental and demonstration purposes. San Mateo County was chosen because both ABAG and USGS have more information on that County than any other one in the Bay Area. Basic data map files developed include:

- a detailed geologic map of San Mateo County with hectare resolution**
- a revision of an existing map file of generalized geology to provide hectare resolution for the other eight counties**
- a flatland materials map of the Bay Area, with hectare resolution**
- the expansion of an existing fault file to include recent work for the entire region with hectare resolution
- a digital elevation model file of San Mateo County with hectare resolution
- a landslide map for San Mateo County with hectare resolution
- dam inundation maps with hectare resolution and regional coverage
- a tsunami inundation map with hectare resolution and regional coverage
- a land use file for San Mateo County with hectare resolution

*BASIS - Bay Area Spatial Information System

2. Reworking of Data File

A series of earthquake hazard map files have been produced for the San Francisco Bay Area by combining the data files developed in the first task in various ways. Derivative files produced include:

- o a map of maximum intensity of earthquake ground shaking for the Bay Area
- o a series of four regional maps showing the risk of damage for three types of building and two sets of recurrence intervals for earthquakes
- o liquefaction susceptibility and potential maps for the region
- o maps of landslide susceptibility for San Mateo County from rainfall and earthquake-induced failures
- o two sample composite maximum earthquake damage maps for San Mateo County (combining maps of maximum ground shaking intensity, faults, landslide and liquefaction susceptibility, and dam failure and tsunami inundation)
- o a sample composite map showing risk of damage within San Mateo County from those earthquake hazards listed above.

The assumptions and data used in developing these maps have been documented in a series of working papers.

3. File Applications

These maps have been used:

- o to begin development of an automated regional environmental assessment document to serve as a background report for local Environmental Impact Reports (EIRS)
- o to compile sample composite maps of earthquake hazards
- o to compare the land affected by various earthquake hazards and to relate these hazards to their potential effects on both people and property

4. Communication of the Information

Much effort has been made to ensure that this information is effectively disseminated.

- o Key local staff have been involved in reviewing the working papers.
- o Potential users suggested that all map files should have hectare resolution. This suggestion has been implemented.
- o Targeted local staff and other users have been helpful in designing the three map applications described.
- o A user's manual, A Guide to ABAG's Earthquake Hazard Mapping Capability, has been developed and is being distributed.

**These three files were combined to create a new geology file.

RESEARCH CONCLUSIONS

This ABAG research has demonstrated that a computer-based geographic data system is a useful tool in examining earthquake-related hazards. The computer system enabled ABAG staff to use to the entire Bay Area as a study area for developing most test products. It ensured that the information was consistent from one part of the region to another and enabled staff to easily expand projects developed in part of the region to the entire nine county area. In addition, the map files are more adaptable to different uses than the more traditional map product. Maps can easily be produced at any scale for any area of interest. In addition, files can be manipulated to provide a listing of information for a given location and to produce an unlimited number of composite maps. Cross tabulations and statistical procedures can also be performed to compare files.

The methods used in developing the hazard maps were developed or modified as part of this project. The techniques and procedures, especially those related to mapping of risk of ground shaking damage and of liquefaction susceptibility and potential, make use of some valuable economic techniques. These techniques served to point out areas where more data and research is needed. The working papers, especially Paper #9 on composite maps, point out many of these needs.

This project focused on developing an operational earthquake hazard mapping capability and demonstrating some sample uses for researchers and local geologists and planners. ABAG has begun a project (USGS Contract No. 14-08-0001-19108) that will expand the area for which highly detailed topographic and geologic data is available as well as the types of applications. The study will focus on special products suited to the rapidly developing areas adjacent to Petaluma and the ridgelands of Santa Clara, Alameda and Contra Costa Counties.

Computer-Based Earthquake Mapping

San Francisco Bay Area

Contract No. 14-08-0001-17751

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Project Components

1. Several data files to be used that have not been available in ABAG's computer-based geographic data system have been developed, either by digitizing maps or by obtaining existing machine-readable data sets.

2. A series of earthquake hazard map files are being produced for the San Francisco Bay Area by combining the data files developed in the first task in various ways. The possible effects of earthquakes in the region as predicted by these files is being assessed.

3. Much effort is being made to ensure that this information is effectively communicated to city and county staff.

Research Progress

1. File Development

   - A geologic map of San Mateo County has been digitized.

   - The existing computer file of faults zoned by the State Geologist as part of the Alquist-Priolo Special Studies Zones Act has been expanded to include recent work on other active faults in the Bay Area and its vicinity.

   - A map of the flatland materials for the region has been digitized and combined with ABAG's existing map of generalized geology.

- o A digital elevation model file of San Mateo County (including elevation and slope) has been obtained from the U.S. Geological Survey Topographic Division and a file of percent slope derived from that data.

- o Dam inundation maps have been collected and digitized and a computer file completed. The maps have all been redrafted on 7-1/2' quadrangle sheets because of the need to keep track of the dams which would inundate each area, as well as the areas which would be inundated.

- o A tsunami inundation map has been digitized and a computer file completed.

- o Land-use information is being digitized for San Mateo County for use in assessing the impact of earthquake hazards. Half of the 7 1/2-minute quadrangles in the county have been digitized to date.

2. Reworking of Data Files

It is the intent of ABAG staff to develop a series of working papers to serve as documentation of the data and assumptions used to recombine the files into maps showing various earthquake hazards and risk. Seven of the ten working papers to be written are now completed. They discuss:

- o faults and ground shaking intensity
- o geologic materials and ground shaking
- o damage and ground shaking intensity
- o liquefaction potential mapping
- o slope stability mapping
- o tsunami inundation areas
- o dam inundation areas

The maps that will be produced by combining the files developed in the first task will show:

- o maximum intensity of earthquake ground shaking for the Bay Area

- o risk of damage from earthquake ground shaking for at least two types of buildings for the Bay Area

- o liquefaction potential for the Bay Area

- o relative slope stability for San Mateo County only

- o composite maximum earthquake intensity for San Mateo County

- o composite risk of damage from earthquakes for San Mateo County

The composite maps will be produced by combining the earlier maps of ground shaking, faults, slope stability, liquefaction, and dam and tsunami inundation.

3. Communication of the Information

Much effort is being made to ensure that this information is effectively disseminated. Key local staff are being involved in suggesting special projects and in designing the form of the final maps. For example, the City of Pacifica is most interested in having this information in a format suitable for an Environmental Impact Report. ABAG staff therefore are working on integrating this information into an automated environmental assessment system. The San Mateo Area Disaster Office is interested in an atlas of earthquake hazard maps for several cities at a scale of 1:24,000. The series of working papers being developed also will aid in receiving comments from local staff on the type of earthquake maps to be produced.

Microseismic Zoning of St. Louis County (Pilot Study) 14-08-0001-G-518

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INVESTIGATIONS

As a part of the pilot study, a review of the regional geology and seismicity, as well as an estimation of bedrock motions from the maximum expected earthquakes in the surrounding region, was conducted. The design earthquakes chosen consits of a near field, high frequency Ozark Uplift earthquake and a far field, low frequency New Madrid Region earthquake. The design earthquakes were selected to represent the maximum bedrock motion expected at the study site in terms of peak horizontal acceleration, peak horizontal velocity, predominant period, and bracketed duration. Existing acceleration time-histories were modified to match these ground motion parameters to produce the design earthquake accelerograms. A field exploration program also was undertaken to establish the soil stratigraphy, depth to bedrock, depth to ground water, and to collect quality soil samples for laboratory analyses of engineering properties.

A computer program, PACTT, was developed for cyclic triaxial test data acquisition. The program was designed to provide control over testing methodology and the recording of data. In addition, it generates immediate feedback to aid in adjusting the testing program to obtain all the necessary information desired for an analysis. The SHAKE computer program, which was used in the ground response analysis, was modified to accept more materials of the same type. This modification allows the use of a less generalized soil column model and yields a truer account of dynamic behavior for similar material types.

For this study, the appraisal of the relative levels of individual seismic hazards was accomplished by inputting the selected design earthquakes and the static and dynamic properties of the soil deposits into the SHAKE computer analysis to determine the modification of the ground response from the various soil deposits at the study site. The resulting ground response data, combined with the static and dynamic material properties and data on thickness, topography, and ground-water levels were used to determine the susceptibility of the unconsolidated units to seismic-induced geologic hazards. The relative potential for failure of these units was evaluated on the basis of computed factors of safety for the different levels of ground motion.

RESULTS

The result of this study was the development of a set of maps which shows the response of the various soil deposits to the design base motion, and the potential for slope failure, liquefaction, and damage to structures in the event the maximum expected earthquake were to occur. Since the maps are based on state-of-the-art analytical methods and engineering hazard evaluations, they should be useful in the planning, development, and design of new structures in the rapidly growing Creve Coeur area. In addition, the research has led to the development of systematic techniques for appraisal of individual seismic hazards based on the dynamic response of the local soil deposits. These procedures of seismic hazard analysis and mapping are believed to be an improvement over existing procedures since they incorporate both quantitative engineering data and qualitative geologic data. Also, these procedures have a wide range of applicability for seismic zoning studies other than in the St. Louis area.

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Analysis of Strong Motion Data and the Effects of Earthquake Source Parameters on Ground Motion in California

Contract No. 14-08-0001-16756

Principal Investigator: M. Nafi Toksöz

The effects of the source, medium and site on recorded strong motion have been studied through the analysis of observations and through theoretical modeling. The analysis of the strong motion data from the San Fernando and other earthquakes indicates the importance of both the source radiation and the geologic conditions local to the site on the recorded ground motion.

The effects of a sedimentary site are modeled using a propagator matrix solution which includes attenuation. This solution is used in the analysis and interpretation of the site effects in strong motion data. The observed effects of a sedimentary site depend on the frequency band being considered and the variation of the medium parameters with depth. For a deep sedimentary site the amplifying effects of decreased seismic velocities and internal reflections may be offset, sometimes severly, by the amplitude reduction effects of attenuation. A striking example of this is shown in the data from the Puget Sound earthquakes of 1949 and 1965. Sites with sedimentary structures of intermediate depth may show amplification at low frequencies and attenuation at higher frequencies.

The strong motion from the San Fernando earthquake shows significant source radiation effects. Records from stations to the north and east of the fault, on the up-thrust block, are of shortened duration and less complexity than those to the south and west, on the down-thrust block. This is a modellable effect of rupture on a dipping thrust fault, and may be expected to occur for future earthquakes of this geometry. The modeling also shows that the parameters of the initial rupture event determined teleseismically are consistent with those required to model the initial part of the local records.

The early, body wave portions of the velocity records at SL and GPK, bedrock stations in Pasadena and Los Angeles respectively, are successfully modeled. The modeling of these velocity records requires the presence of localized areas of high slip or high strength on the fault. These areas are important in their implications for the generation of high frequencies in strong motion. The predictive modeling of strong motion may be best approached through the deterministic modeling of rupture on a postulated fault, with an overlying stochastic specification of the sub-areas of high slip or pre-stress. Deterministic post-earthquake modeling studies remain to be important for the determination of the dimensions and the magnitude of slip or pre-stress on these localized rupture areas for input to the stochastic modeling.

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Analysis of Strong Motion Data and the Effects of Earthquake Source Parameters on Ground Motion in California

Contract No. 14-08-0001-16756

Principal Investigator: M. Nafi Toksöz

The effects of the geologic structure at a site on the recorded ground motion are investigated through the analysis of data and through the theoretical modelling of the site response. The solution for the response of a plane layered structure is discussed for the case of attenuating layers. This solution is applied to the modelling and interpretation of site effects in the strong motion observations. Particular applications include the San Fernando strong motion recorded in the Pasadena and Lake Hughes areas. The Puget Sound data from the 1949 and 1965 earthquakes are also analyzed. The low amplitudes and frequencies in the Seattle records are shown to be due to the strong attenuation effects of the deep sediments underlying Seattle.

Instrument Development and Geotechnical Studies

9940-02089

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Investigations

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

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

Results

1. Three major instrument deployments were made for recording the aftershocks of the El Centro 79, Coyote Lake, and Mt. Diablo earthquakes. This experience has assisted in the process of development of improved instrumentation and in field techniques necessary in this program.

2. A 186 m drill hole near the site of the Gilroy #2 strong motion station was logged for P and S velocity to get preliminary data on the vertical velocity structure in that portion of the Santa Clara Valley.

PROJECT TITLE: "Development of techniques for evaluating seismic hazards associated with existing creeping landslides and old dams"

RESEARCH GRANT NUMBER: 14-08-0001-17761

PRINCIPAL INVESTIGATOR: Richard E. Goodman

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The investigation includes monitoring of creeping and stable slopes in natural hillsides with sensitive creep meters to find a technique for distinguishing between them on an instrumental basis. Additionally, recognizing that the failure of a major dam in an earthquake would have great damage potential, instruments are being developed towards evaluating fractures intersected by boreholes used in exploring foundations of existing dams. The Final Report of this project will be issued in May 1980, after the termination of a no-cost extension period. This is an interim report of progress.

Creep Studies:

No activity on creep monitoring took place in the previous six months. We are now gearing up for studies in the Congress Springs Landslide near San Jose. The improvements in instrumentation and technique brought about by previous efforts on this contract have enabled the manufacturer of our creep meter--Serata Geomechanics--to prepare a proposal for funding under next year's Earthquake Program.

Fracture Studies:

We have completed assembly of an impression packer with pressurizing and positioning mechanisms. Procedures for operation in the field were developed, together with forms and techniques for data analysis. In several field tests, both the instruments and the procedures proved feasible, but wanting in some details. The data obtained were analyzed and interpreted using methods suggested by Rosengren (1970) and Goodman (1976). Areas of needed improvement being addressed concern procedures for installing the impression material (parafilm), orienting the instrument in the hole, guarding against blowout in the case of cavities in the borehole wall, and handling and storing impression records.

A higher pressure impression packer has been constructed for us at Imperial College, and we have inquired about purchasing a much higher pressure, small diameter duct-tube from France that could significantly improve the dilatometer capability. In the final phase of this project, the pressurizing and measuring systems for the dilatometer will be finished and experiments will be conducted in our drill holes in Marin County.

Experiments with the new impression packer are described on the attachment--a report of investigation. Difficulties with getting our own drill rig and trailer finished are described on the fourth Management Report, for the period ending February 15. The drill is now available for research with the dilatometer-impression packer and we are planning experiments in Marin County beginning in March.

Earthquake-Induced Landslides

9550-01452

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Investigations

1. Reconnaissance of ground failure from the October 15, 1979 Imperial Valley earthquake was undertaken to determine the types and distribution of failures and their relation to geological and geotechnical parameters.

2. A geotechnical study of an incipient slump in artificial fill and a slump in river banks near Brawley, California, from the Imperial Valley earthquake was conducted to determine subsurface conditions and materials involved in the failures. Static cone penetration soundings and sampling were employed to investigate subsurface conditions and failure mechanism.

3. A ground failure reconnaissance and monitoring of aftershock strong motion was undertaken to determine the distribution and types of landslides occurring in response to the January 24, 1980, Mt. Diablo earthquake. Portable strong motion seismometers were deployed at sites of failure from the main shock to measure actual ground motion in aftershocks causing additional failure thus indicating thresholds of motion necessary to cause failure at various susceptible sites.

4. Refinement of mapping of regional seismic slope stability for San Mateo Co., California, was accomplished as a result of additional data pertaining to average shear strengths of certain lithologic units.

Results

1. The most numerous types of ground failures occurring during the Imperial Valley earthquake were soil falls from river bluffs, slumping of river and canal banks, and lateral spreading failures. Recent stream deposits appear to have played a major role in affecting the failure distribution. Indeed prominent liquefaction-induced failures south of Holtville, California, appear to be influenced by the deltaic deposits of ancient "Lake Cohuilla".

2. Static cone penetration soundings and samples of an earthquake-induced incipient slump in artificial fill near Brawley, California, have helped to indicate the subsurface conditions of the soils involved and failure surface geometry. Shear strength results from samples will allow a seismic analysis of slope behavior and a comparison between calculated and measured displacements of the slide mass.

3. Cone penetration data and coring of a large seismic-induced slump within the Rotary Park near Brawley, California, has established the soil units involved in failure and has indicated a mechanism of failure triggered by liquefaction with a fine to medium grained sand to about 3 m depth. Extremely low cone penetration resistances and poor sample recovery within the sand suggest that the sand was in a semi-liquefied or metastable state at the time of sampling.

4. Ground failure reconnaissance after the January, 1980, Mt. Diablo earthquake established that most failures were rock and soil falls from roadcuts from extremely steep natural slopes. Most were small (less than 5 m^3) failures involving extensively fractured sandstones. More massive sandstones however did produce some rather large dislodged boulders which fell, rolled, and bounced several hundred meters from steep slopes above the Morgan Territory Road in the vicinity of the epicenter. Other common failures were the settling of roadway fills, especially the least compacted portions at the road edge.

5. The deployment of portable strong motion seismometers following the initial 5.6 m Mt. Diablo earthquake allowed the recording of several strong aftershocks (M = 4.4, 4.6) at sites where additional rock fall and fill settlement occurred. Two closely juxtaposed seismometers at one site also provided a situation whereby amplification of ground motion by topography could be recorded. A preliminary examination of the data gathered from these instruments suggests that differences in shaking levels are related to the topography of the site locations.

6. Continued testing of rock units in San Mateo Co., California, led to the upgrading of the Butano sandstone from a seismic susceptibility rating of "marginally stable" to relatively stable". This resulted in a change of seismic slope stability rank of approximately 10% of the map area.

Reports

Published

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Harp, E.L., Bennett, M.J., Wieczorek, G.F., and Youd, T.L., Rotational slump along the New River near Brawley, California, caused by the October 15, 1979, Imperial Valley earthquake (abs): Earthquake Notes, v. 50, no. 4, p. 36.

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Wieczorek, G.F., and Youd, T.L., Landslides, liquefaction, and other ground effects induced by the 1979 Imperial Valley earthquake (abs): Earthquake Notes, v. 50, no. 4, p. 35.

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Ground Failures Caused by Historic Earthquakes

9550-02161

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Investigations

1. Data on ground failures was collected and compiled from 15 historic earthquakes (see below). Data have now been compiled for 41 earthquakes since the beginning of the project.

Earthquakes studied 1 October 1979 through 1 March 1980

Earthquake	Date	Magnitude
Calabria, Italy	5 February 1783	
Long Beach, California	10 March 1933	6.3
Imperial Valley, California	19 May 1940	6.4
Khait, USSR	10 July 1949	7.5
Puget Sound, Washington	13 April 1949	7.1
Assam, India	15 August 1950	8.6
Kern County, California	21 July 1952	7.7
Gobi-Altai, Mongolia	4 December 1957	8.6
Daly City, California	22 March 1957	5.3
Southeast Alaska	9 July 1958	8.0
Puget Sound, Washington	29 April 1965	6.5
Parkfield, California	28 June 1966	5.5
Honomu, Hawaii	26 April 1973	6.3
Hawaii	29 November 1975	7.1
Kulm, Afghanistan	19 March 1976	5.5

2. A tentative system was developed to rate the severity of various types of ground failures in individual earthquakes (Table 1). The system allows comparisons between earthquakes with precise quantitative data on numbers and types of ground failures and between earthquakes in which only the locations of ground failures are described. The system is based on determinations of the number of ground failures/square kilometer or

percentage of area affected by failure for regions affected by five recent earthquakes (San Fernando, California, 1971; Friuli, Italy, 1976; Guatemala, 1976; San Juan, Argentina, 1977; Coyote Lake, California, 1979).

3. Studies were begun to define quantitative relationships between occurrence of ground failures, shaking intensity, and energy release.

4. Post-earthquake investigations were carried out in the Livermore, California, area following the earthquakes of 24 and 26 January, 1980.

Results

1. The tentative rating system for ground failure severity is shown in Table 1.

2. As noted in previous semi-annual technical reports, the types and abundance of ground failures in an earthquake are strongly dependent on the local geological environment and on the energy release and ground motion characteristics of the earthquake. Results from the earthquakes studied during the past six months generally conform to preliminary results reported in Keefer and others (1978).

3. In the Livermore earthquakes of January 24 and 26, 1980, ground failures occurred within an area of approximately 500 km^2. Most of the failures were caused by the January 24 event; re-examination of the area after January 26 indicated that the second shock cause relatively few failures. The most common failures were falls of soil and poorly consolidated rocks from steep road cuts. Cracking and slumping of roadway fills was also common in the epicentral region, especially along Morgan Territory Road. A large approach fill on Interstate 580 at the Greenville Road overpass experienced about 20 cm of settlement. This settlement caused the eastbound lanes of I-580 to be closed for several hours while repairs were made.

4. Evidence of surface fault rupture on Vasco Road was discovered while conducting reconnaissance on the afternoon of January 24 (fig. 1).

Reference

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Reports

Keefer, D. K., Wilson, R. C., and Tannaci, N. E., 1980, Reconnaissance report on ground failures and ground cracks resulting from the Coyote Lake, California, earthquake of August 6, 1979: U.S. Geological Survey Open-File Report 80-139, 14 p.

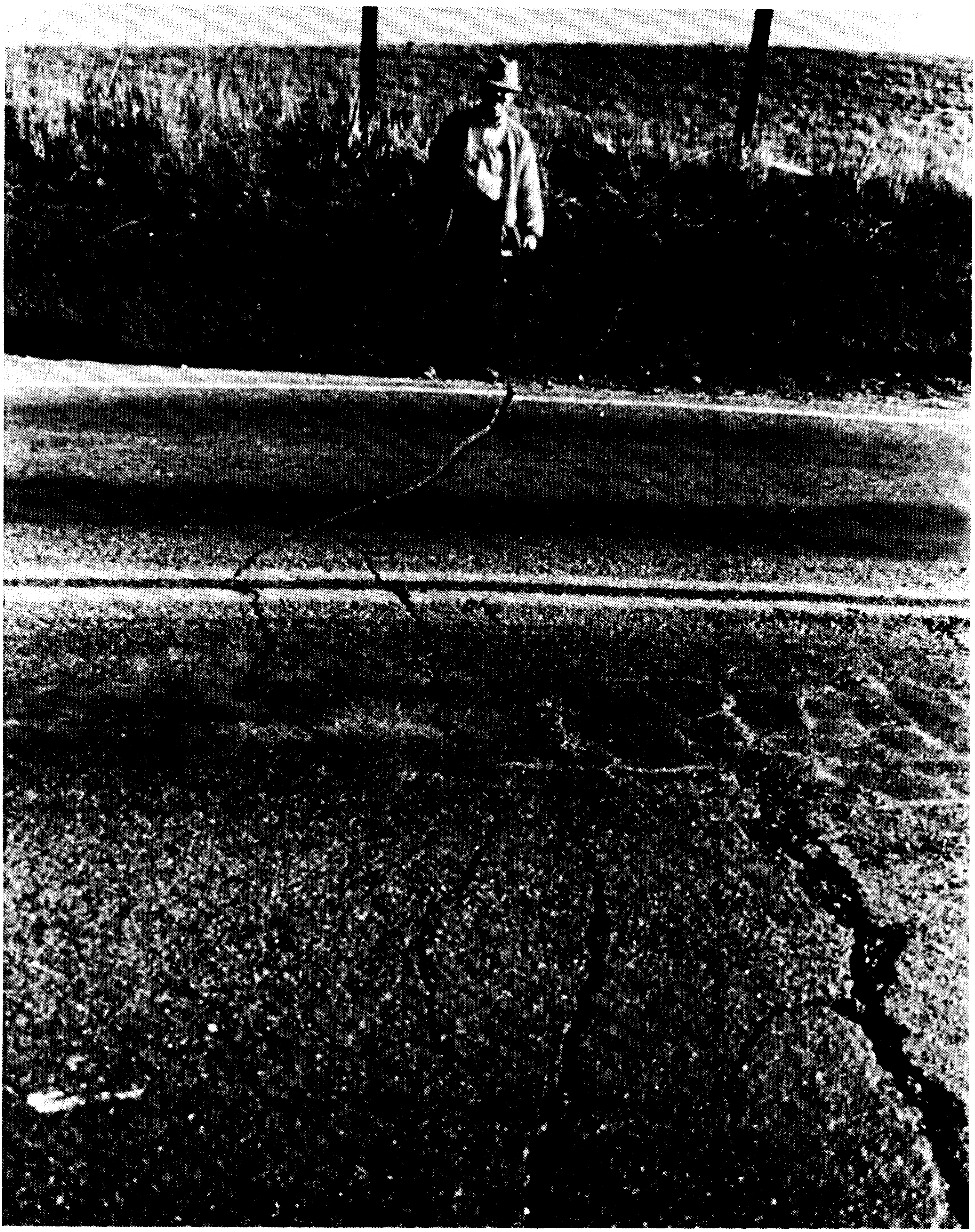
Wilson, R. C., and Keefer, D. K., Dynamic analysis of a slope failure from the Coyote Lake, California, earthquake using strong-motion records (abs.). Earthquake Notes (Seismological Society of America Meeting, April 1980), v. 50, no. 4, p. 64.

TABLE 1:
SEVERITY SCALE FOR EARTHQUAKE-INDUCED GROUND FAILURES
(Numerical rating shown as roman numeral)

	Number of small failures ($<100,000\ m^3$)	Area where failures are common (1-10%)	Area with scattered failures ($<1\%$)	Area with very abun- failures ($>10\%$)	Number of large failures ($>100,000 m^3$)
I	I	I	I	I	I
	10	5 km^2 (1.93 mi^2)	20 km^2 (7.7 mi^2)	1 km^2 (0.39 mi^2)	1
II	II	II	II	II	II
	100	50 km^2 (19.3 mi^2)	200 km^2 (77 mi^2)	10 km^2 (3.9 mi^2)	10
III	III	III	III	III	III
	1000	500 km^2 (193 mi^2)	2000 km^2 (772 mi^2)	100 km^2 (38.6 mi^2)	100
IV	IV	IV	IV	IV	IV
	10,000	5,000 km^2 (1,930 mi^2)	20,000 km^2 (7,720 mi^2)	1000 km^2 (386 mi^2)	1000
V	V	V	V	V	V

Figure caption

Surface fault break in Vasco Road near Livermore, California, caused by 24 January 1980 earthquake (M=5.6). Fault break in road showed offsets of 2 cm right lateral, 3 cm vertical (up on northeast), and 4 cm separation. View is southeast. Photo taken at 3:30 p.m. on January 24, 15 minutes before road was repaved.



Evaluation of the Cone Penetrometer for Liquefaction Hazard Assessment

14-08-0001-17790

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Scope

The program is directed at evaluating the potential of the Cone Penetrometer for use in assessment of liquefaction hazard on a regional or site specific basis. Current capabilities for quantitative assessment of liquefaction hazard are limited to simplified methods based upon Standard Penetration Tests or more elaborate methods involving sampling, laboratory cyclic testing and dynamic analyses. Because of high cost, the more elaborate methods are not suitable for regional microzonaton efforts. Likewise, the simplified methods require a field boring which results in unaccetably high costs when planned for use on a regional basis.

In contrast the Cone Penetrometer Test is rapid (2 cm/sec), easily standardized, and does not require a boring. However, simplified methods of liquefaction hazard assessment are based upon observations of liquefaction at sites where Standard Penetration Tests had previously been performed. As data of this type does not exist for Cone Penetrometer Test measurements, it is first necessary to relate CPT data to SPT data and hence to liquefaction hazards.

Investigations

The investigations underway in this program (to be completed in 1980) are of the influence of geologic origin, age, and physical properties of cohesionless soils upon the CPT-SPT correlation. The California sites that have been investigated include a hydraulic fill in San Diego, and predominantly fluvial sites near Moss Landing, Salinas, and San Jose. In addition, a river deposit in central Oklahoma has been investigated. The use of such diverse sites has resulted in obtaining data upon virtually all liquefiable materials, including clean sands, silty sands, clayey sands, silts, and gravels at depths ranging from zero to 80 feet. In addition, material densities have ranged from loose to very dense, and particle sizes and shapes and mineralology have shown significant differences from site to site. Analysis of the effects of these physical variables and the effects of in situ confining pressures upon the CPT-SPT correlation is in progress.

Earthquake-Induced Liquefaction and Subsidence of Granular Media

14-08-0001-17770

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Investigations

The behavior of dry or saturated granular materials under monotone loading and cyclic shearing has been investigated theoretically and experimentally, in an effort to identify the major factors which are essential for the description of the consequent deformation and flow of drained and undrained soils. The theoretical effort during the second six-month research has been focused on the following three complementary aspects: (1) densification and liquefaction of sand in cyclic shearing (strain- or stress-controlled cases); (2) application of plasticity theory (with plastic volumetric changes and including internal friction) for the description of the sand behavior in monotone loading regimes; and (3) development of the basic rate constitutive relations by a statistical averaging which is based on the behavior of individual grains at microscale. The experimental effort, on the other hand, has been devoted to the study of liquefaction of cohesionless sand in cyclic shearing.

Results

Theoretical work consisted of three complementary aspects summarized below.

(1) Densification and Liquefaction: First, by means of a simple dimensional analysis, the essential features of these phenomena are brought into focus. Then several physically motivated assumptions are used in line with the work completed during the first six-month research, in order to obtain explicit expressions for the changes of the void ratio and the pore water pressure as functions of the number of cycles and other relevant parameters.

(2) A Plasticity Theory: This includes the effects of plastic volumetric change and internal friction which are of major importance in flows of granular materials. The theory provides a systematic and consistent basis for critical state soil mechanics. For example, it is shown that the concepts of normality and associative flow rules used in the theory do not accord with the notion of internal friction and plastic compressibility. The introduction of the non-associative flow rule removes this inconsistency and at the same time provides a theory which contains parameters with clear physical definitions.

(3) A Statistical Approach: The final aspect concerns the methodology for a fundamental statistical approach to the description of the macroscopic response of granular masses on the basis of an examination of microstructural changes.

In addition to the theoretical work summarized above, systematic experiments are being performed on cylindrical samples of undrained cohesionless sands, obtaining at this writing reliable and good results.

Reports

A. During first six-month research:

Nemat-Nasser, S., and Shokooh, A., 1979, A framework for prediction of densification and liquefaction of sand in cyclic shearing: Ingenieur-Archiv, in press.

Nemat-Nasser, S., 1979, On behavior of granular materials in simple shear: Earthquake Research and Engineering Laboratory, Technical Report No. 79-6-19, Dept. of Civil Engineering, Northwestern University, June 1979; Soils and Foundations, in press.

Nemat-Nasser, S., 1979, Finite deformation plasticity and plastic instability: (Invited General Lecture) Transactions of Twenty-fifth Conference of Army Mathematicians, ARO Report 80-1, U.S. Army Research Office, pp. 715-731.

B. During second six-month research:

Nemat-Nasser, S., 1980, On dynamic and static behavior of granular materials: Abstract appeared in Soils under Cyclic and Transient Loading, Proc. Int'l Symp., Swansea, G. N. Pande and O. C. Zienkiewicz (eds.), Vol. 1, A. A. Balkema, Rotterdam, pp. 435-436.
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BEHAVIOR OF SLOPES IN WEAKLY CEMENTED SOILS UNDER STATIC AND DYNAMIC LOADING

Contract No. 14-08-0001-18380

by

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Large surface and near surface deposits of weakly cemented soils occur in various geologic environments. These materials are typically composed of sand or silt size particles and can have unconfined compressive strengths from slightly greater than zero up to 690 kN/m^2. After failure in an unconfined test, a weakly cemented soil exhibits brittle response and loses most, if not, all of its strength. In spite of their relatively low strength, however, vertical to near vertical slopes of heights in excess of 100 m are found in these materials. Examples may be found in the marine terrace sands along the Pacific Coast of California and Oregon, the windlaid ash deposits in central America, and the loess soils in the central United States and along the Yellow River in China.

Failure of a steep slope in cemented soil during a seismic event is usually spectacular because, if the strength of the soil is exceeded near the face of the slope, it collapses and cascades downward. Observations of such failures have been made in numerous cases, and loss of life and property is substantial where populated areas are involved. Interestingly, however, little is known about the cemented soils. This report represents the results of the first phase of an investigation of slope behavior in cemented soils, and it is directed toward: (1) documenting of the behavior of natural slopes in weakly cemented soils, (2) defining the engineering response of weakly cemented soils under static and dynamic loading, (3) establishing the stress conditions in steep slopes during static and dynamic loading, and (4) developing guidelines for evaluation of seismic stability of slopes in cemented soils.

To achieve these objectives, field observations of slope behavior in the weakly cemented soils have been conducted in Guatemala and in California, along the Pacific Coast, between San Francisco and Santa Cruz. A laboratory testing program of over 200 static and dynamic tests on artificially and naturally cemented sands was carried out, and static and dynamic finite element analyses of idealized vertical slopes in linear elastic material were performed.

The results of the field studies show that failure in a cemented soil slope initiates by tensile splitting in the upper part of the slope. The failure then progresses either by toppling of blocks in the upper part of the slope or by shear failure in the lower part of the slope. The likelihood of the tensile fracturing phenomenon is supported by the fact that the dynamic tensile strength of cemented soil decreases as a result of cyclic loading.

The finite element analyses indicate that the magnitude of the dynamic stresses in a slope is a function of both the size of the earthquake as well as the degree of matching between the natural period of the slope and the dominant period of the earthquake. The analyses are also used to develop non-dimensionalized charts for evaluation of slope stability of vertical slopes in cemented soil.

Interactions Between Ground Motion and Ground Failure

9550-01628

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Investigations

1. Performed a dynamic analysis of a slope failure caused by the Coyote Lake earthquake to test the validity of the Newmark seismic slope stability analysis.

2. Contributed to preparation of a seismic slope stability map of San Mateo County, California.

3. Conducted reconnaissance survey of ground failures from the Livermore/Mt. Diablo earthquake (1/24/80, M 5.6).

Results

1. The Coyote Lake, California earthquake (8/6/79, M 5.9) provided a rare opportunity to perform a dynamic numerical analysis of a seismically induced slope failure using actual strong-motion records. On the northeast shore of Lake Anderson, an earthquake-induced slope failure formed a 20 m long fissure across a paved road. Offsets of 7 mm vertical and 18 mm horizontal were measured across the fissure. Two strong-motion recordings were made in the vicinity of the failure—Coyote Creek, 5 km to the southeast, and Gilroy 6, 15 km to the southeast. A topographic profile and estimates of the strength of the shale were used with a dynamic numerical model, based on Newmark's analysis of seismic slope stability, to calculate a predicted displacement of the landslide of 10-25 mm, which is in excellent agreement with the measured displacements. Because strong-motion records and slope failures rarely coincide, this landslide provides an important "test case" for the analysis of seismic slope stability developed by this project.

2. Using criteria for mapping seismic slope stability on a regional scale previously developed by this project, G. Wieczorek of the Earthquake-Induced Landslides project (E. Harp, chief) has prepared an experimental seismic slope stability map of San Mateo County, California, at a scale of 1:62,500. In addition to the design earthquakes and lithology/slope categories for the map, this project also prepared estimates of the probability of ground failure for each mapping zone. The seismic slope stability map of San Mateo County is to be published in the coming year as part of the San Mateo County geologic hazards folio edited by E. Brabb.

3. This project participated in the investigation of ground failures from the Livermore/Mt. Diablo, California, earthquake of January 24, 1980, (M 5.6). On the afternoon of the earthquake, R. Wilson and D. Keefer observed a fissure across Vasco Road, near the mapped trace of the Greenville fault, and measured 2 cm. of right-lateral offset. This measurement was made under the impatient gaze of a road crew who immediately re-paved the break in the road. The most numerous (>100) seismic ground failures were small (<1 cu. meter) rock and soil falls which occurred across an area of approxi-

mately 100 square miles. The largest rock falls were noted along the Western Pacific Railroad west of Altamont Pass (20 cu. m.), on Vasco Road (10 cu. m), and on Tesla Road (5 - 10 cu. m). An especially interesting type of rock fall was the displacement of large boulders (up to 2 m diameter) from ridge tops, rolling down the steep slopes and impacting on Morgan Territory Road, removing trees and anything else in their path. A number of road-fill failures were also noted along Morgan Territory, Vasco, Tesla, and Collier Canyon Roads. The eastbound lanes of Interstate 580 were closed for several hours to repair the Greenville Road overpass where the ramp fills subsided some 20 cm. A M 5.4 seismic event occured on the Greenville fault on Jan. 26, causing re-newed movement of many of the ground failures of the Jan. 24 event, triggered a new rock fall of 10 cu. m on Vasco Road, and caused additional ground cracking in road-fills along Morgan Territory Road.

Reports

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Keefer, D. K., Wilson, R. C., and Tannaci, N., 1980, Reconnaissance report on ground failures and ground cracks resulting from the Coyote Lake, California, earthquake of August 6, 1979: U. S. Geological Survey Open File Report 80-139, 14 p.

Experimental Mapping of Liquefaction Potential

9550-01629

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Investigations

1. Continued research on seismically induced liquefaction potential.

2. With Gerald Wieczorek, conducted reconnaissance investigations of liquefaction effects generated by the October 15, 1979, Imperial Valley, California earthquake.

3. Conducted detailed subsurface investigations at two sites of liquefaction in the Imperial Valley, California.

3. With Darrell Herd, conducted post-earthquake investigations following the December 12, 1979, Tumaco, Colombia earthquake.

Results

1. A map was compiled and a report drafted on secondary ground effects caused by the October 15, 1979 Imperial Valley, California earthquake (M = 6.4). Distribution of effects caused by liquefaction was controlled by both geologic environment and proximity to the fault. Liquefaction occurred in two geologic settings--along active rivers, and on a remnant delta into prehistoric Lake Coahilla. Most instances of liquefaction were within 4 km of the tectonic surface rupture, but a few sand boils were found as far as 35 km from the rupture. The farthest ground failure capable of causing damange was 16 km from the fault. Effects of liquefaction included sand boils, lateral spreads, fissures, and ground settlement. The distribution and types of liquefaction effects are consistent with effects of past earthquakes. (See Earthquake-Induced Landlsides , 9550-01452, for results on secondary ground effects not associated with liquefaction.)

2. Subsurface investigations were made at two sites where liquefaction occurred during the 1979 Imperial Valley, California, earthquake--a 160-m wide lateral spread and an area where hundreds of sand boils erupted. The investigations included static cone (CPT) and standard penetration (SPT) soundings, continuous sampling of sediments, and laboratory classification tests. The lateral spread formed in a 5-m deep layer of very loose silty sand fill (CPT cone reisitance less than 20 kg/cm^2. and SPT blow count less than 4). The water table was 2 m deep. The second site where many sand boils erupted

consisted of 2 to 3 m of silt and sand underlain by a 1-m thick layer of silt and clay, in turn underlain by a thick bed of sand. Water table was near surface. Textures of the sand boil deposits indicate that liquefaction occurred in both the upper layer of silt and sand and in the lower bed of sand.

3. Investigations of the Tumaco, Colombia, earthquake revealed that crustal subsidence occurred along a 200-km long coastal zone extending northward from the Equadorian border. Changes in sea level indicated subsidence as great as 1.5 m. The earthquake produced a tsunami that swept inland following the shock killing about 200 people and causing severe damage to some coastal communities. Liquefaction developed in poorly compacted sand fills, in beach deposits, and in channel and floodplain deposits. Lateral spreads and slumps caused by liquefaction severed roads and pipe lines in and near Tumaco leaving that community isolated and without water. The spreads and slumps pulled apart, shifted, or otherwise damaged several buildings. Strong ground shaking collapsed tens of reinforced-concrete and hundreds of wood-frame buildings. Particularly hard hit was the small community of El Charco where about 90% of the buildings collapsed, and Tumaco, the largest city in the region, where many buildings near the shoreline of the island-community suffered.

Reports

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Wieczorek, G.F. and Youd, T.L., 1980, Landslides, liquefaction and other ground effects induced by the 1979 Imperial Valley earthquake (abs): Earthquake Notes, v. 50, no. 4, p. 35-36.

Youd, T.L., and Bennett, M.J., 1980, Liquefaction during the 1979 Imperial Valley earthquake: subsurface investigations (abs): Earthquake Notes, v. 50, no. 4, p. 37.

TITLE: Seismic Damage Assessment for High-Rise Buildings

CONTRACT NO.: 14-08-0001-16814

PRINCIPAL INVESTIGATOR: Roger E. Scholl

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URS/John A. Blume & Associates, Engineers, is conducting a three-year research program, now in its second year, to consider how procedures for predicting dollar losses for high-rise structures damaged by earthquakes can be improved. The problem is addressed by the identification, evaluation, and correlation of ground motion data and structural parameters. Ground motion data bases, analytical techniques, and known motion-damage relationships which have already been developed for high-rise buildings and for other classes of structures were identified early in the investigation; they are to be refined and extended so that reliable quantitative seismic risk evaluations can be made.

The research effort consists of three one-year phases composed of five major tasks, as follows:

Task I	Data collection
Task II	Building categorization and calculation of theoretical motion-damage relationships
Task III	Estimation of engineering intensity from seismological intensity data
Task IV	Evaluation of empirical motion-damage relationships
Task V	Correlation of theoretical and empirical motion-damage relationships

Task I was completed during the first year (1978-1979). Tasks II and III were initiated during the first year and are scheduled to be completed during the third year. Task IV was initiated during the current year and will be completed along with Task V in the third year.

Task I

The objective of the investigation was to collect information to establish a data base of world-wide seismic response and damage information for high-rise buildings. Only earthquakes that had affected high-rise structures were selected for study.

Five different forms were developed to systematically record pertinent data from the following regions: North America; Latin America; Europe and the Mediterranean; and the western Pacific, which includes Japan and New Zealand. Form 1 provides general earthquake data; Form 2, motion and damage data; Form 3, site information; Form 4, building categorization; and Form 5, detailed site and building information, such as soil-test boring logs or design calculations, Data that were collected for the continuation of the study include strong-ground-motion parameters, soil characteristics, estimated damage, design parameters, building categorization, and geographical location. For selected areas, seismological data, information on constuction codes and practices, and other general data were also collected. The computerized data base system HIRISE was established using the information collected on the forms. The data base facilitates access and retrieval of data in any order or arrangement desired, thus simplifying the correlation procedure.

Initially, the study focused on collecting data for specific buildings, primarily those damaged during each earthquake. Information on the characteristics of each building and on the damage it had sustained was stored in the data base HIRISE. When the data base was established, space was left to accommodate additional information that is necessary for reconstruction of a realistic damage scenario -- such as statistical data on the undamaged buildings in each area -- and data on overall seismicity, distribution of soil types, density of high-rise buildings, and intensity distribution for each earthquakes, all needed to construct a profile for each area.

During the second year of study, the data base was reviewed and updated. Subsequent efforts focused on the completion of a profile for each urban area under investigation. For this task, soil maps, street maps, aerial photographs, and intensity maps of the various areas were used to establish grids dividing each city into sections with similar soil and motion intensity characteristics.

Task II

The task of building categorization has been completed. The following categories were established on the basis of structural systems: foundation systems, vertical-load-support systems, lateral-load resisting systems, and floor systems. Lateral-load-resisting systems are the most important for seismic resistance. Structural and architectural materials were also considered, since architectural materials, although not specifically designed to do so, contribute in varying degrees to lateral-load resistance and therefore are important for damage evaluation. Architectural materials' contribution to seismic resistance depends not only on the types of materials used, but also on the framing characteristics of building systems. Building configuration was analyzed because irregularity in plan and elevation may result in torsional response or have other secondary effects. Torsional response may also occur because of eccentric location of either the building masses or the lateral-load-resisting elements. Each of these items was recorded on Form 4.

Damage factors for both structural and nonstructural building components are calculated on the basis of theoretical studies. Starting with detailed three-dimensional mathematical structural models of selected buildings for which motion was recorded and damage is known, an exhaustive procedure of structural analysis is carried out. The onset of nonlinear behavior that can be realted to damage is identified with instantaneous transfer functions obtained from accelerograms. The instantaneous transfer functions are also valuable in identifying the variability in structural parameters during the earthquake. From information about the transient nonlinear behavior of the structure inferred from these instantaneous transfer functions, mathematical models are calibrated and adjusted. Taking into account the reported damage, simple global damage indicators in the theoretical damage-motion relationships being developed are then tested. The global response that better represents the onset of damage has been identified as being the interstory displacement. Studies are currently under way to establish correlation between responses such as interstory-displacement, drift, and strain, base shear, ductility, and other structural deformations, with high levels of damage.

Task III

A breakthrough has been made toward relating seismological intensity and magnitudes to engineering intensity. The methodology employed is an application of the random vibration theory with the data needed for the solution based on empirical work and engineering judgement. An anchor point of the response spectrum at period T=1sec is obtained where a spectral shape corresponding to the soil characteristics at the site is attached. The spectral moment (M_{bLg}) or other magnitude representations (M_s, M_b, I_o), the epicentral distance, and the strong motion duration are needed to obtain the response spectrum. An interactive computer program that implements this methodology has been developed.

Task IV

Various empirically derived motion-damage relationships are being tested with the data base HIRISE. Damage factor and damage ratio (the latter is defined as the ratio of the number of buildings damaged to the total number of buildings in an area shaken by an earthquake) are functions of the global parameters mentioned above and of indicators of seismic motion such as Modified Mercalli Intensity, (MMI) and Engineering Intensity, (EI).

These empirical motion-damage relationships also take into account building categorization, soil types, and local construction practices.

Up to this point of the research no clear indication has been found of the worthiness of any of the existing damage functions. The tests have proven the need to create or modify existing damage functions so that, based in probabilistic concepts, they can use the data in the form that is available. The creation and evaluation of new motion-damage functions relating Engineering Intensity values and damage ratios will be continued into the third year of the research project.

Reports

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_____, *Seismic Damage Assessment for High-Rise Buildings; Annual Technical Report: April 1979*, San Francisco, 1979.

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NATIONAL EARTHQUAKE LOSS ASSESSMENT: SENSITIVITY TO ALTERNATIVE RISK MAPPING PROCEDURES

14-08-0001-18204

by

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Earthquakes have caused substantial losses to human lives and structures. Many investigators have sought to quantify the degree of hazard posed by earthquakes. In recent years, various techniques for mapping the maximum ground shaking expected from earthquakes have been developed. Early seismic hazard maps showed the maximum earthquake intensity expected for a region. These estimates were based primarily on the historical record of earthquake shaking in the area and generally did not provide recurrence relations so that the frequency of occurrence of shaking could be determined. More recently, probability theory has been used to estimate both the intensity of shaking (in some form such as peak acceleration, velocity, displacement or Modified Mercalli Intensity) and its frequency of occurrence at specific levels. These maps allow comparisons of the relative level of earthquake hazard for different regions. It is also possible to estimate the actual earthquake risk, in terms of potential losses, using these maps.

*Principal Investigator

Three seismic hazard maps showing expected levels of peak horizontal acceleration for the contiguous United States have been developed recently. These maps are being used to design and analyze important construction throughout the United States. Algermissen and Perkins (1976) developed a national earthquake hazard map under the auspices of the U.S. Geological Survey. They utilized historical earthquake data to define the seismicity of the earthquake source regions, also incorporating geological data into their model. The J.H. Wiggins Company, in 1975, prepared a similar national seismic hazard map for the National Bureau of Standards and later provided a revised version to the Massachusetts Institute of Technology. In 1978, the Applied Technology Council (ATC-3) of the Structural Engineers Association of California also prepared a probabilistic seismic hazard map, using as a base the Algermissen and Perkins (1976) map. All three of these recent hazard maps display expected peak horizontal accelerations for the contiguous United States for a 10% probability of exceedance in a 50-year exposure period (or equivalently, a 475-year return period), yet each is distinctly different. Specific differences in these hazard maps result from various sources, such as how local soil conditions are incorporated, and what seismicity data are used.

The purpose of this investigation was to examine the specific differences between each of these seismic hazard maps by evaluating the actual risk predicted by each map. The measure of risk used in this study was expected annual loss to buildings. More specifically, loss was defined by the total cash value required to fully repair buildings damaged by earthquake shaking. A technique for computing annualized losses due to natural hazards was developed by the J.H. Wiggins Company, in 1975. The method consists of integrating the product of the hazard-intensity probability function and the damageability distribution over all probable levels of intensity. The resulting loss rate is then multiplied by the value of the items at risk.

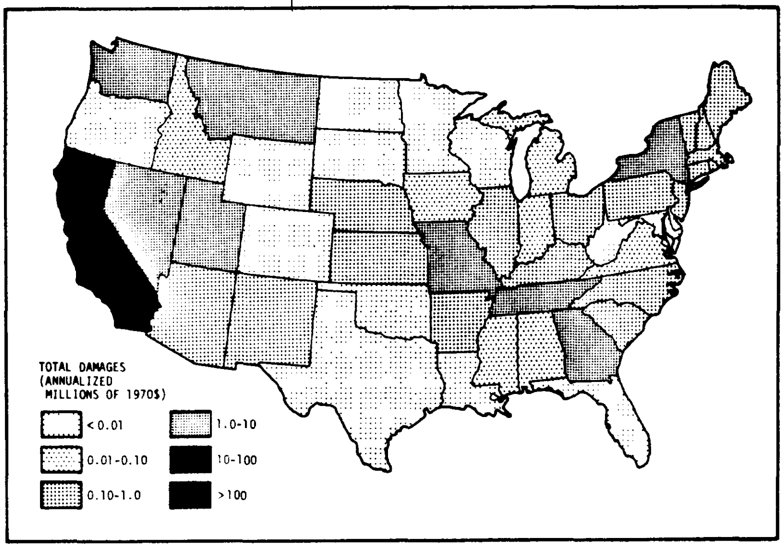
The annualized losses computed in this study based on the three hazard maps, are tabulated in Table 1 and displayed graphically in Figure 1. The annualized losses computed show that, depending upon which risk mapping procedure is adopted, estimated losses can vary by as much as a factor of 4.5. Using the three seismic maps, we found that the national annualized loss total for the year 1980 ranged from $339 million to as much as $743 million--depending upon the hazard map, damage algorithm, or Modified Mercally Intensity-versus-peak ground acceleration relation used. Using relations we believe most consistent with proper interpretation of the various risk maps, we found the variability in loss estimates between maps reduced by one-half.

Depending on what lower limit of expected peak ground motion is presented by the map, the regional distribution of damages by state and county shows that losses can vary from zero, (representing no risk) to over

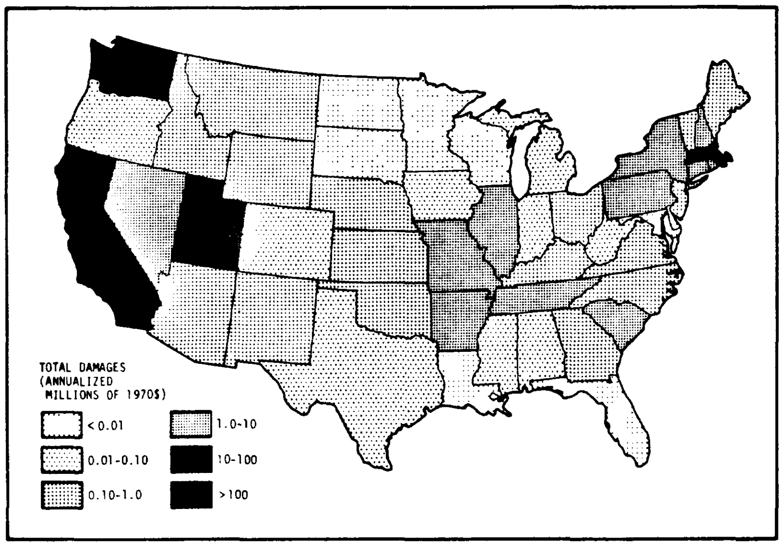
$6 million per annum. These regional comparisons among maps also show that particular areas often represent different percentages of the national total. For example, the ratio of California-to-U.S.-loss total varies from 45% to 95%, depending on which map is used. Factors which significantly affect earthquake losses include: soil factors, return period of the maximum credible earthquake, damage algorithms, intensity-versus-peak ground acceleration relations, and the map level of the peak ground motion. Because of the great sensitivity of the annualized loss estimates to the risk-map-specified ground motion, it is very important to exercise great care and use all available data, in preparing seismic hazard maps. Strict rules of contour mapping should also be observed.

Table 1. 1980 Annualized State Losses in Percent of National Total

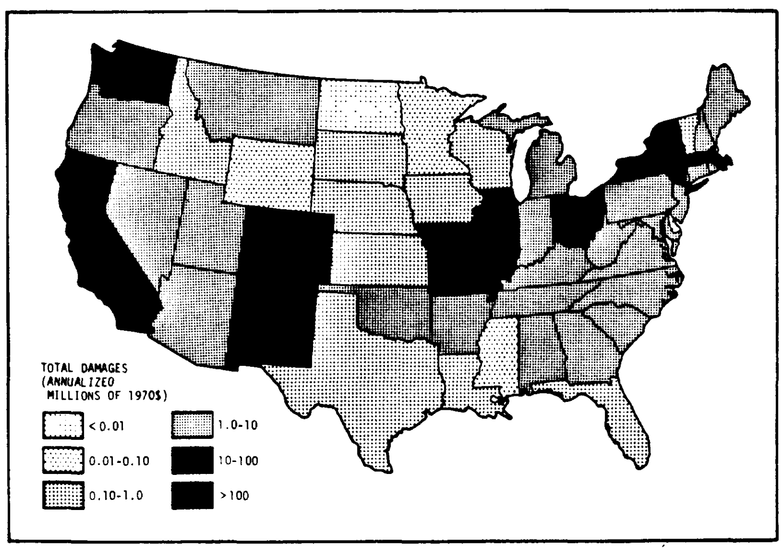
STATE	ALGERMISSEN - PERKINS	ATC - 3	WIGGINS
ALABAMA	.0073	.0087	.1597
ARIZONA	.0819	.0857	.0988
ARKANSAS	.0910	.4324	.2565
CALIFORNIA	95.1874	72.4048	49.0352
COLORADO	.00002	.0083	5.6556
CONNECTICUT	.1259	.7936	.7008
DELAWARE	0	0	.6452
DISTRICT OF COLUMBIA	0	0	.2862
FLORIDA	0	0	.0602
GEORGIA	.2541	.2066	.1999
IDAHO	.0161	.1748	.1254
ILLINOIS	.0620	.5166	2.7000
INDIANA	.0109	.0156	1.1753
IOWA	.0039	.0194	.0664
KANSAS	.0830	.2686	.0789
KENTUCKY	.0315	.0643	.9673
LOUISIANA	0	0	.0121
MAINE	.0265	.1267	.2949
MARYLAND	0	0	.4901
MASSACHUSETTS	.1077	5.4423	3.3101
MICHIGAN	.0052	.0092	.9051
MINNESOTA	0	0	.0118
MISSISSIPPI	.0029	.0190	.0916
MISSOURI	.2903	1.9918	3.5324
MONTANA	.3187	.1281	.4030
NEBRASKA	.0786	.1470	.0736
NEVADA	.2593	.7584	.5593
NEW HAMPSHIRE	.0560	.7274	.4947
NEW JERSEY	.1006	.1739	1.3030
NEW MEXICO	.0301	.1114	1.7037
NEW YORK	.4894	1.1435	3.0843
NORTH CAROLINA	.0936	.1678	.2793
NORTH DAKOTA	0	0	.00002
OHIO	.0342	.2242	2.7710
OKLAHOMA	0	.1791	.5220
OREGON	.0005	.0157	.5217
PENNSYLVANIA	.0829	.7018	.9360
RHODE ISLAND	.0271	.3221	.1914
SOUTH CAROLINA	.1653	1.2275	.5215
SOUTH DAKOTA	0	.0016	.0176
TENNESSEE	.404	1.0552	.9556
TEXAS	0	.0061	.0779
UTAH	.9562	4.2904	.8576
VERMONT	.0319	.2193	.0907
VIRGINIA	.0043	.0582	.3471
WASHINGTON	.4796	5.6817	13.6877
WISCONSIN	.00006	.0062	.0865
WYOMING	.0005	.0670	.0125
TOTALS (PEPCENT)	100.00	100.00	100.00
TOTAL DAMAGES (MILLIONS 1970 $)	450.10	339.00	742.80



ALGERMISSEN-PERKINS



ATC-3



WIGGINS

Figure 1. Damage Totals Annualized for 1980 - 475 Year Maps

Teleseismic Search for Earthquake Precursors

9920-02142

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Problem to be addressed

Consider that a moderate or large earthquake, X, has just occurred and its hypocenter has been determined by the NEIS to be in a subduction zone. The problem is to determine, (1) if X is part of a pattern (ominous) precursory to a larger earthquake within three years or (2) on the contrary, X is a part of a pattern (non-ominous) indicating that a larger earthquake will not occur within several years, or (3) contrary to both of the above, the occurrence of X tells us nothing about the likelihood of a large earthquake in several years. In order that the method eventually be useful, it must be possible to determine within a relatively short time (say, a month) whether or not X is likely to be precursory to a larger earthquake. For this reason, we attempt to find patterns of seismicity involving X, shocks occurring prior to X, and aftershocks of X occurring within one week.

Investigations

(1) Apply the Bongard pattern recognition algorithm (use of the algorithm for a problem different than ours is described by Briggs, Press and Guberman, GSA Bull., 88, p. 151-173, 1977) to the search for characteristics of seismicity and tectonics, or combinations of characteristics, that distinguish the class of ominous events from the class of non-ominous events.

(2) Conduct special studies of individual strong subduction zone earthquakes in order to identify, using high quality data, characteristics of seismicity or tectonics that may be searched for in the less precise data associated with most large subduction zone shocks.

Results

(1) B. G. Reagor modified the hypocenter data file search program and has it running on the PDP 11/70. This will enable many of the operations of the pattern recognition study to be conducted on the branch computer.

(2) J. W. Dewey, W. R. McCann, A. J. Murphy (both at Lamont-Doherty Geological Observatory) and S. T. Harding (USGS) have found that the large (magnitude 7.1-7.6) Antigua earthquake of October 8, 1974, occurred in the overriding wedge of the Caribbean plate. Hypocenters of locally recorded aftershocks suggest that the main shock rupture extended from a depth of 40 kilometers, immediately above the inferred thrust interface between the Caribbean and American plates, to shallow crustal depths of about 10 km. The focal-mechanism solution and aftershock hypocenter locations imply that the earthquake occurred on a southeast-dipping normal fault that strikes north-northeast to northeast, transverse to the regional strike of the northern Lesser Antilles arc. The location and focal mechanism of the 1974 shock are similar to those of small earthquakes occurring in the Adak Canyon region of the Central Aleutians and studied by R. LaForge and E. R. Engdahl (Bull.Seism. Soc. Am., 69, p. 1515-1532, 1979).

The position of the 1974 earthquake above the Benioff Zone and its normal fault focal mechanism indicate that the shock has not released a significant amount of the elastic strain thought to have been accumulating along the thrust boundary of this segment of the Lesser Antilles arc since the great earthquake of 1843.

Reports

Dewey, J. W., McCann, W. R., Murphy, A. J., and Harding, S. T., 1980, A large normal fault earthquake in the overriding wedge of the Antilles subduction zone: The Antigua earthquake of October 8, 1974, (Abstract), to be presented at the AGU 1980 Spring Meeting, May 22-27.

Garm Source Mechanism Studies
9930-02100

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Investigations

Several questions of current interest to U.S. and Soviet investigators involved in joint studies for earthquake prediction concern properties related to the source mechanisms of local earthquakes. We will collect sufficient data and perform analysis necessary to determine the utility of seismic source spectrum measurements for earthquake prediction. Specific preliminary questions involve corrections for station locations, propagation paths, and source orientation.

Results

A least squares procedure was used to simultaneously estimate hypocenter and velocity model parameters for earthquakes near Garm beneath the Peter the First range. Input data involved P and S arrival times for 26 earthquakes with preliminary locations in the 0 to 27 km depth range (241 total observations). The final velocity model has satisfactory resolution and indicates increasing P and S velocity with depth: 0-8 km, P = 5.3 km/sec, S = 2.9 km/sec; 8-16 km, P = 6.1 km/sec, S = 3.5 km/sec, greater than 16 km, P = 7.7 km/sec, S = 3.9 km/sec. These results are inconsistent with the results of Nersesov and Chepkunas (1971), who suggested a low-velocity zone between 12 km and 25 km in depth in the Garm area.

A report by Robert Kovach, Alan Levander, and Mary Monfort (USGS contract 14-08-0001-16855) noted critical deficiencies with the data recording and processing system in Garm. Changes to the USGS/Garm system are well underway. However, due to a cancellation of travel funds for this fiscal year, equipment is now being prepared for a return to the field site next October. Specifically, additional J600 VCO/preamps are being constructed to operate from a 12 volt solar panel assembly.

Reports

None for this period.

Central American Seismic Studies

9930-01163

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Investigations

Cooperative programs are continuing between the USGS and Government agencies in Guatemala and Nicaragua to establish and operate earthquake research institutes in Central America. One goal of this project is to provide data for earthquake hazard reduction efforts in Central America. Another goal is to search for precursory phenomena in seismicity patterns preceding earthquakes of magnitude 5.0 and larger. Installation of a 22-station seismograph network in Guatemala was completed in December 1979. Ten additional stations will be purchased and installed during 1980. The operation of the 16-station seismograph network in Nicaragua has resumed following an interruption caused by the the recent revolution. All the Nicaraguan seismograph stations and equipment have been repaired and were fully operational by January 1980. The close monitoring of seismic activity in the vicinity of a seismic gap near the Pacific Coast of Nicaragua is continuing.

Results

During a recent field trip to Guatemala a study was undertaken to better understand a long-term earthquake swarm. The largest earthquake is a magnitude 5.0 event that destroyed 140 adobe dwellings and damaged several hundred more. This seismic swarm is occurring near Cerro Cruz Quemada that is located in line with the chain of active volcanoes that lies along the Pacific Coast of Central America. More than 40,000 events have been recorded since mid-August 1979 and as of April 1980 the seismic activity is continuing. This activity is typical of earhquake swarms in the vicinity of active volcanoes and therefore may be the result of near-surface magma movement. Cerro Cruz Quemada, however, has not erupted in more than 2 million years and the long history of similar episodes of seismic activity every 20 to 40 years argue against the present seismic activity being a precursor to a volcanic eruption.

Reports

White, R. A., Sanchez, E., Cifuentes, I. L., and Harlow, D. H., 1979, Preliminary report to the Government of Guatemala on the ongoing earthquake swarm in the Department of Santa Rosa, Guatemala. (This report is now being prepared as an Open-File Report.)

Tilt Measurements in the New Hebrides Island Arc: Search for Aseismic Deformation Related to Earthquake Generation in a Major Zone of Lithosphere Subduction

14-08-0001-18350

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Investigation and Results

Analysis is continuing on the two moderate (Ms = 6) earthquakes that occurred in the New Hebrides Island Arc in August 1979. The first large event (Ms = 6.1) occurred on August 17 about 44 km from Efate Island where we have a seismograph network, three bubble - level tiltmeters, a long - baseline (100 m) water - tube tiltmeter, a one km levelling array, and a tide gauge. The earthquake occurred at a shallow depth in the arc - trench gap and has a focal mechanism solution showing underthrusting on a shallow dipping fault plane. The slip vector for this event is consistent with others obtained for the region.

Prior to the mainshock the region where the earthquake occurred had been seismically quiet during the previous eleven months that the network had been operating except for clusters of events in March 1979 and June 1979. The seismograph network recorded a foreshock sequence of small magnitude earthquakes starting eight days before the mainshock. In the following days the foreshocks migrated toward the epicenter of the mainshock. The foreshock sequence ended with a very intense concentration of seismicity seven hours before the mainshock and then the region became seismically quiet. Abundant aftershocks were well-recorded by the seismograph network including nine with magnitudes (Mb) greater than 4.2 and located in the P.D.E. bulletin. The aftershocks migrated away from the mainshock toward the trench with time.

The second moderate (Ms = 6.0) earthquake occurred on August 26 just north of the August 17 aftershocks. The focal mechanism solution for the event was also an underthrusting solution. There was a small cluster of earthquake activity in the region of the August 26 event six days before the event and then the region became seismically quiet. The August 26 earthquake was followed by numerous aftershocks including five with magnitudes greater than 4.2 and located in the P.D.E. bulletin. The aftershocks migrated away from the August 26 mainshock toward the trench with time and abut the aftershocks of the August 17 event with little overlap.

An analysis of the space - time distribution of P.D.E. locations in the New Hebrides since 1961 reveals three different patterns of seismic activity along the part of the arc monitored by the seismograph network. The August 1965 sequence of thrust events dominates the evolution of the seismicity in the South Santo - North Malekula area. It is preceded by a quiet period of at least 4.5 years. It is followed by a long sequence of aftershocks and by a remarkable increase in the rate of activity at intermediate depth beneath Santo. Both phenomena last almost to the time of the major adjacent thrust sequence of December 1973 - January 1974 in North Santo and may result from the diffusion of a stress pulse away from the August 1965 sequence.

The north Efate area is the most active part of the arc. Its rate of activity has been remarkably uniform for the last 19 years. The August 1979 sequence does not modify this trend. It appears to be very similar to other sequences in 1962, 1973 and 1974 in the same region. The mode of strain release in this part of the central New Hebrides seismic gap may thus differ from the cycle of major earthquakes and involve a continuous creep at the plate boundary.

The area covered by the southern network has been very quiet since 1962. The January 1979 event with Ms = 5.9 between Efate and Erromango coincides with an increase of activity in this region and may correspond to the beginning of a new phase of earthquake cycle.

During the period covered by this report an unusual storm occurred near Mt. Bernier on Efate Island and lightning struck the main telemetry link connecting the outlying seismograph stations to the recording station in Port Vila. Lightning damaged the electronics for all transmitters and receivers on Mt. Bernier and temporarily disabled most of the network. Fortunately, spares were available for most of the critical frequencies and the network was operating again within about one month of the lightning strike. We are currently in the process of repairing the damaged equipment and devising better protection against future lightning strikes.

The network of biaxial tiltmeters continues to operate with near 100% temporal coverage. Since these instruments are subject to drift over periods of a week or several weeks, we have designed high pass filters to peak the frequency response at periods of hours, where the signal to noise is optimum. These filters have yet to be constructed. We have built an auto-calibration circuit to be introduced into the recording system. The positive and negative calibration marks will serve also as 24 hour marks.

The long baseline water tube tiltmeter has been subject to another generation of modifications both in mechanical parts and in the associated electronics. In particular a new system of seals has been devised to make the measurement pots completely airtight. It is suspected that two sets of electronics were destroyed by lightning at the long baseline site, and we have incorporated protection circuits to reduce the chance of a recurrence. Both the long baseline tiltmeter elctronics and the Rustrak units have been modified so that the signals recorded at each vault have an identical time base.

There has been another levelling at Devils Point and Ratard bringing the total number of levellings to 21. Both sites are being levelled about the time of this writing. A detailed examination of misclosures and signals in the levelling data has been finished, and a manuscript will shortly be submitted for publication.

Reports

Isacks, B.L., Bevis, M., Chatelain, G., Cardwell, R., and Louat, R., 1979, Search for precursors in the New Hebrides Island Arc: the August 17, 1979 Earthquake (Ms = 6.2), EOS, Trans. Am. Geophys. Union, v. 60, no. 46, p. 884.

Isacks, B.L., Bevis, M., Cardwell, R., Chatelain, J.-L., Louat, R., and Marthelot, J.-M., 1980, Monitoring Seismicity and Surface Deformation in the New Hebrides Island Arc, Ewing Symposium on Earthquake Prediction, May 12 - 16.

Cardwell, R.K., Isacks, B.L., and Chatelain, J.-L., 1980, A Detailed Study of a Sequence of Magnitude 6 Earthquakes in the central New Hebrides Islands, EOS, Trans. Am. Geophys. Union, v. 61, no. 17, p. 370.

Marthelot, J.-M., Isacks, B.L., 1980, Space - time distribution of shallow and intermediate earthquakes in the New Hebrides Island Arc, EOS, Trans. Am. Geophys. Union, v. 61, no. 17, p. 288.

Coudert, E., Isacks, B.L., Cardwell, R., Chen, A., Latham, G., Dubois, J., Louat, R., 1980, Search for velocity anomalies in the New Hebrides Island Arc from residuals observed with combined land - OBS stations of a temporary network, EOS, Trans. Am. Geophys. Union, v. 61, no. 17, p. 301.

Worldwide Earthquake Research Database

9930-02104

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Investigations

The main goal of this project is to provide up-to-date information which will facilitate research on earthquakes. Two major topics are now under investigation:

1. Establish a seismograph library of significant earthquakes (especially those before 1963).

2. Organize and maintain a bibliographic data base and retrieval system on current earthquake literature.

Results

Seismogram Library. Under contract from this project, the National Geophysical and Solar-Terrestrial Data Center, NOAA, has built a portable photocopying system for filming historical seismograms. Seismograms from key U.S. stations are now being filmed. Please see Meyers and Lee (1979) for details.

Bibliographic Database and Retrieval System. The Current Earthquake Literature (CEL) database has been maintained and kept up to date. Annual and bimonthly indexes are being distributed on schedule.

Reports

Meyers, H., and Lee, W. H. K., 1979, Filming historical seismogram project: First progress report: U.S. National Oceanic and Atmospheric Administration, Environmental Data and Information Service, World Data Center A for Solid Earth Geophysics, Report SE-22, 66 p.

Gunn, M., and others. Index to Current Earthquake Literature (bimonthly issues).

Gunn, M., Hayashida, B. S., and Lee, W. H. K., 1980, 1979 annual index of current earthquake literature: U.S. Geological Survey Open-File Report 80-238, 320 p.

Goodstein, J. R., Kanamori, H., and Lee, W. H. K. (eds.), 1980, Seismology microfiche publications from the Caltech archives: Seismological Society of America Bulletin, v. 70, p. 657-658.

MEKOMETER MEASUREMENTS IN THE IMPERIAL VALLEY

Contract No. 14-08-0001-17698

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The objectives of this project, which was started more than eight years ago, are specifically to make a detailed study of movements on, and strain adjustments round, the Imperial Fault in the vicinity of El Centro, California, and more generally to look for evidence for active faults elsewhere in the neighborhood. This is being done by repeated measurement of a network of geodetic stations about 800 m apart, which now numbers about 290 stations, the most important part of which comprises a block of about 140 stations spanning the Imperial Fault.

The first few weeks of the period reported on, from May 1 through October 31, 1979, were spent in completing a six-week measuring program started in April. Because less than four months had elapsed since completion of the previous re-measurement, the time was mostly spent in adding stations and measuring the new lines, although a small number of the lines measured in 1978 were re-measured in 1979 in order to provide a link between the two sets of measurements. Considerable strength was thereby added to the Imperial Fault sector of the network, which proved fortunate in the light of the magnitude 6.6 Imperial Valley earthquake, which occurred six months later, on October 15, 1979.

Specifically, (1) nine stations were added to the Imperial Fault sector, and 152 new lines in it were measured, involving the new stations and stations constructed but not used in 1978, and (2) three small-scale networks, involving 17 new stations, were constructed around the USGS/Caltech creepmeters spanning the fault at Ross Road, Heber Road and Tuttle Ranch, and a total of 45 lines within them were measured. The purpose of these networks is to provide a long-term check on the validity of the creepmeter results, which we hope to be able to use in processing and interpreting our own results.

As the primary objective of the fieldwork was to extend the network rather than to re-measure it, no new results were expected. However, the re-measurement of lines crossing the Imperial Fault about 2 km north of Highway S80 revealed movements that imply about 15 mm of right-lateral slip in the ten months between July 1978 and May 1979. It might not be without significance that this represents a creep rate of more than twice the average rate of about 8 mm/yr between 1971 and 1978.

Mekometer measurements in the Imperial Valley

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Investigation

During the six weeks following the October 15, 1979 Imperial Valley earthquake, parts of an 8 km x 10 km block of geodetic stations about 800 m apart spanning the Imperial fault in the vicinity of El Centro, together with two small networks outside the main block, were resurveyed to assess coseismic and postearthquake slip on the fault, and horizontal strain adjustment around it. Repeated measurements were made of five figures along the fault and two on each side, each comprising 5-11 lines, and a single measurement of three chains of triangles, one along the fault and two normal to it, for comparison with measurements made in 1978 and the Spring of 1979, as part of a long-term investigation started nine years ago.

Results

1. The Imperial fault was found to be slipping throughout the six weeks, at an exponentially decreasing rate with time, such that half the predicted postearthquake slip of 9-15 cm would have occurred within about twelve days of the earthquake.

2. Extrapolating back to the time of the earthquake, the coseismic slip was estimated to have been about 37 cm right-lateral at a point 2 km north of Highway 80, increasing steadily southeastward to about 62 cm at Heber Road, 13 km to the southeast and only 1 km from the southern end of the surface break. Six weeks after the event, when the postearthquake slip had reached 94% of its predicted final value, these figures had increased to about 48 cm and 70 cm respectively. From the survey of the chain of triangles along the fault, the increase in displacement from northwest to southeast was seen to have come about through a shortening of the southwest side of the fault relative to the northeast, which had also shortened, but by a smaller amount.

3. Coseismic changes of linear strain were found to be dominantly normal to the fault, and asymmetric about it, with values in excess of 200 μstrain, extensional on the southwest side of the fault and compressional on the northeast. These values imply relative displacements normal to the fault of the same order as slip on it. Thus points about 2 1/2 km from the fault on its southwest side have moved away from it by more than 25 cm, while points at a similar distance from the fault on its northeast side have moved towards it by as much as 50 cm.

4. On both sides of the fault, but particularly on the southwest, there are zones in which the coseismic changes of shear strain were dominantly right-lateral parallel to the fault. This is contrary to what would have been expected if the earthquake had led to a relaxation of shear strain on either side. It might be interpreted as indicating additional right-lateral slip parallel to the fault, unrecognized on the ground. This could amount to more than 50 cm within the 2 1/2 km adjacent to the fault on its southwest side.

Publication

Crook, C.N., R.G. Mason and P.R. Wood, 1980. Geodetic measurements of horizontal deformation on the Imperial fault. In C.E. Johnson, C. Rojahn and R.V. Sharp (eds), The October 15, 1979 Imperial Valley earthquake, U.S.G.S. Professional paper (in press).

Tilt and Strain Instrumentation
9960-01801

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Investigations

1. The project investigators continued to search for tilt and strain precursors to earthquakes in California and Alaska, specifically by operating and monitoring tiltmeter and strainmeter arrays in central and southern California, totaling 46 sites, and an array in Alaska consisting of three doubly instrumented sites.

2. A systematic program has been implemented to evaluate the thermal stability of the tiltmeter electronics and to retrofit, retune and test all instruments on hand for maximum electronic stability.

3. A circuit has been designed and built that permits interfacing a long cable ($\sim$ 30 m) between the tiltmeter sensor and the electronics. The purpose of this design is to test the potential advantages of improved thermal isolation and immunity from surface noise sources of a deep borehole tilt installation. Tests on the new circuit are proceeding.

4. Construction has been completed on a long base-length tiltmeter installation. This design is intended to improve immunity from surface noise sources by averaging over a longer base. The installation awaits the availability of the revamped sensor packages.

5. A deep borehole tiltmeter package is being designed that will include high-angle remote leveling capability. This design will be mated to the modified electronic design that provides for the long cable interface.

6. The thermal response of the strainmeter electronics has been evaluated and analysis of data to determine the response of the complete system is being conducted.

Results

1. A circuit that monitors supply voltage and shuts off power in the event of low batteries or other power supply degradation has been designed, built and tested in the field. The circuit is being manufactured inhouse and will be deployed at all instrument sites.

2. During the period of this report the loss of availability of the LBL computing facility, the exorbitant cost of computing on Multics as well as the lack of a microfiche plotter, and the slow pace of graphics capability on the inhouse 1170 have resulted in negating the ability to monitor the low-frequency network data in near real-time for other than basic system operating status.

Reports

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RECENT VERTICAL MOVEMENTS OF THE CRUST IN THE WESTERN UNITED STATES: REDUCTION AND ANALYSIS OF LEVELING DATA AND ITS INTERPRETATION IN LIGHT OF RELATED SEISMOLOGICAL AND GEOLOGICAL INFORMATION

14-08-0001-17625

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Background

Vertical crustal movement information has been derived from releveling data collected by the National Geodetic Survey (NGS) in the western U.S. Our objective is to determine to what extent this data base can contribute to our understanding of geodynamic phenomena with emphasis on earthquake prediction and seismic hazard evaluation. After critically examining the crustal movement information from a geodetic perspective, the leveling results are interpreted in view of other relevant geophysical and geological data.

Recent Accomplishments

I. Topography and Vertical Motion

Examination of National Geodetic Survey (NGS) releveling suggests that topography-correlated errors are pervasive and can easily be misidentified as tectonic movement. New field experiments and theoretical calculations by the NGS confirm that refraction errors can be much larger than previously thought. In order to determine the extent of such errors, identify criteria to recognize them, and develop empirical corrections to remove their influence, 73,962 km of NGS releveling have been analyzed for correlations between apparent movement and topography. Significant correlations were visually identified for 23% of these measurements, some with correlation coefficients greater than 95%. Apparent errors greater than 100 mm per 100 m of topographic relief are indicated in some cases—several times larger than previously cited. Such errors are often easy to recognize, but they can also be quite subtle. Topographic correlation alone, however, is insufficient to confirm leveling error: there are examples of strong correlations which appear to involve real crustal motion, e.g. in New Mexico and SW Montana. Examples of questionable "movement" include data used to define the Palmdale bulge and uplift in the Appalachians. Thus topography-dependent errors may explain some, but certainly not all, patterns of apparent elevation change.

II. Non-Tectonic Influences

Estimates of crustal movement provided by leveling observations may reflect tectonic deformation, near-surface non-tectonic motions, or artifacts generated by systematic measurement errors. Surficial movements and systematic errors have been familiar to geodesists, but the extent to which they distort or mask estimates of deep-seated movement has only recently been fully appreciated. Near-surface movements may result from sediment compaction due to fluid withdrawal (water, oil, gas), imposition of man-made loads (reservoir impoundment, building construction), variations in soil moisture and temperature causing swelling of surficial deposits, surface failure (landslides, mining activity, karst collapse), and frost heave, among other processes. Subsidence due to fluid withdrawal, well-known in the Gulf Coast, southern Arizona, and California, appears to be more pervasive and sometimes more subtle than commonly realized. Surficial movement of this type can often be identified by its close relationship with water level changes monitored in wells. Unlike fluid withdrawal and reservoir loading (relatively easy to identify), which can affect large areas (~100 km^2), other varieties of surficial instability tend to have very local effect. Systematic leveling errors, often more difficult to confirm, are suggested by unrealistically close correlations between elevation change and topography, disagreements between leveling and mareograph measurements along the coasts, and internal inconsistencies in leveling circuits.

III. Tectonic Deformation

Many U.S. releveling observations have been convincingly related to known tectonic phenomena. The clearest examples are coseismic and postseismic movements in the vicinity of dip-slip earthquakes (e.g., 1954 Dixie Valley, Nevada; 1964 Alaska). Such movements are often large (coseismic movements reaching a few meters) and/or closely associated with earthquake faults. Evidence for preseismic deformation is more limited due at least in part to paucity of data, examples being the 1959 Hebgen Lake, Montana and the 1971 San Fernando, California earthquakes. Detection of more subtle earth movements (Δh~few cm; ΔV~few mm/yr) with geodetic leveling is illustrated by deformation in the Rio Grande rift which has been related to crustal magmatic activity. The validity of these movements is supported by independent geologic and geophysical observations and the internal consistency of multiple releveling data. Isostatic processes have been suggested for observed movements near Pleistocene Lake Bonneville and near the Mississippi delta. Active tilting of the Pacific northwest coast has been related to aseismic subduction. In contrast, some apparently significant elevation changes are difficult to relate to plausible driving mechanisms, particularly in the intraplate U.S. Such apparent movements commonly correlate with geologic structure and/or with geomorphic features (e.g., uplift of the Adirondacks and the Southern Appalachians), but the possibility that other than tectonic effects are the sources of the observations is not completely eliminated.

IV. Gravity Reobservation near Anchorage, Alaska

In order to investigate possible gravity changes associated with postseismic deformation following the 1964 Alaska earthquake, the NGS completed (1978) a gravity survey along a line extending east from Anchorage. We have applied drift and tidal corrections to surveys conducted in 1964, 1965, 1975, and 1978. Comparisons indicate large scatter ($\pm$ .3 m gal) in temperal gravity variation which obscures any true tectonic signal.

The large scatter in the temporal gravity variation may be due to unmodeled effects of the ocean tides. The survey route is located along Turnagain Arm where tides often reach 10 m. We are currently investigating a number of procedures to remove ocean tide effects from the observations.

V. Map of Apparent Elevation Change for the Southern and Southwestern U.S.: Possible Evidence for Dynamic Flexure of a Possible Continental Margin

In cooperation with the NGS we have produced a map of apparent elevation change for the Southern and Southwestern U.S. The map is based on all available releveling and tide guage data and covers a region of approximately 8°x20°. Apparent movements with wavelength of less than 50 km were not considered in order to filter out effects due to near surface processes and benchmark instability. The most important feature shown in the map is a uniform doming of the Gulf coastal plain. The overall pattern of movements is elongate and parallel to the coast. The observed uplift is consistent with longer term trends indicated by deformed beach terraces in southern Mississippi. Water, oil, and gas withdrawal mechanisms as well as sources of systematic leveling errors appear to be inadequate to explain the wavelength and magnitude of the observed uplift. The geometry of the relative uplift is similar in nature to the outer bulge which is due to loading and bending of the oceanic plate. We have proposed that the doming of the gulf coast is a consequence of melted ice water and sedimentary loading in the Gulf of Mexico. These observations may represent the first *in situ* measurements of ongoing dynamic flexure at a passive continental margin.

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Earthquake Prediction Research in Taiwan*

#14-08-0001-16895

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Geomagnetic Station Network in Taiwan, China

We have constructed two base stations and 22 roving stations for geomagnetic studies in Taiwan, China.

The base stations operate continuously. The 22 roving station sites (sites were selected with due consideration for geographic distribution and seismic activities) are fairly uniformly distributed throughout the Taiwan island, except in the vicinity of Tseng Weng Reservoir (south-central Taiwan) and Lang-Yang Plain (NE section of Taiwan). These sites were chosen for denser station coverage. Local seismic activities around the reservoir appear to correlate with water level change and we hope to see some magnetic variation associated with these seismic activities. A series of moderate earthquakes occurred in 1978 off the Lang-Yang Plain with some continuing aftershock activity.

Three stations are located along the Longitudinal Valley fault, believed to be a boundary between the Philippine and Asian Plates. One section is located in the southwestern area of Taiwan, which experienced disastrous earthquakes in the past, but is quiet at present.

The magnetic field intensities at the two base stations are visibly correlatable in terms of peaks and troughs. The differences between the magnetic intensities at the two bases show, however, significant time-trend variations. In the daytime, the differences are relatively erratic whereas in the night, the differences are fairly uniform. It appears, at least for the duration of present recording (7 months), the magnetic variations in the daytime can hardly be useful for earthquake prediction purposes because of the erratic daytime differential magnetic intensity.

To minimize the effect of intrinsic magnetic variation which is unrelated to seismic activites, the observations of magnetic field at roving stations have been made in the nighttime. The site construction of roving stations is similar to that at the base station. In case of need, a base-station magnetometer can be installed at a desirable site in a short time. Each roving station is visited twice per month.

Up to this report writing, we have not yet detected any possible correlation between magnetic variation and seismic activities. Since the installation of the magnetic observation network, no major earthquake has occurred either.

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Groundwater Radon Monitoring

The equipment (radon extraction line, α-detector and counter) has gone through thorough testing. Minor problems in the counter and a small leak in the extraction line have been corrected. Field work has started to select sampling sites in northern and eastern Taiwan. As a result of work in the United States, hot springs and geothermal wells are the prime targets.

PRECURSORY SEISMICITY PATTERNS BEFORE LARGE EARTHQUAKES

14-08-0001-17746

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Our search for precursory seismicity patterns has been very successful. For the first time we have demonstrated the occurrence of decreased seismicity rates ,(quiescence), before four large earthquakes at confidence levels exceeding 99%. Further, we have found that before some earthquakes the eventual hypocenter is surrounded by a zone of relatively high seismicity embedded in a volume of quiescence. This observation has lead to a precursory model, termed the asperity model, which requires two types of precursors, (high- and low-stress), for the same earthquake. Finally we have found that a 400 km zone of the Kuriles arc, previously identified as a seismic gap, (Fedotov, 1965), has experienced seismic quiescence since 1967. This observation of quiescence in a seismic gap is interpreted as an indication that this gap has begun the preparation for the event which will fill it. We predict that this event will occur between now and 1994. It may be that three volumes with relatively high seismicity rates within the quiet volume are major asperities where the future mainshock(s) may initiate.

The seismic rate decreases we have found are usually on the order of 50%, and occur in a volume nearly the same as the source volume of the following mainshock. The duration of the quiescence precursors is several years for M=7 earthquakes, and it appears to exceed a decade for earthquakes with M > 8. Before at least four earthquakes quiescence could be defined at the 99% confidence level with reference to background seismicity in the same crustal volume before and after the anomalous period. In two cases the quiescence could also be referenced to seismicity rates in surrounding volumes during the times of the anomalies.

In a detailed study of the Kalapana, Hawaii, M=7.2 event we found that the volume within a five km radius of the foreshock and mainshock hypocenters did not exhibit a precursory quiescence while the surrounding region, corresponding to the source region, did. This, together with several other precursory observations, leads us to propose the asperity model for earthquake precursors. In most of the future rupture zone strain softening or precursory displacement occurs, this leads to strain (stress) relaxation and low stress anomalies, including quiescence. Some number of smaller volumes, within the future aftershock zone, termed major asperities, are characterized by increasing seismicity, velocity decreases, and other high stress anomalies. The major asperities are expected to be sites of rupture nucleation and sources of high energy radiation during multiple rupture type earthquakes.

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Microprocessor-Based Seismic Processing

9970-02119

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Investigations

The earthquake picker algorithm developed earlier has been adapted for use in a multiprocessing environment in which each microprocessor monitors 8 seismic lines. Up to 32 processors (256 seismic lines) report to another microprocessor which acts as a supervisor for the pickers. This supervisor accepts reports of probable seismic events, cross-references them, and sorts out which reports should be grouped together as representing one earthquake. In performing this task the supervisor makes use of station location information and calculates a preliminary location for the event. Output from the supervisor consists of station arrival information in standard phase card format for use by any of the usual USGS locator programs such as HYPOINVERSE or HYPO71. Output is via an RS-232 link which can go to a recording device such as a card punch or line printer; or it may go directly to a computer for on-line location.

Results

The 80-input prototype is in operation with results being reported to the PDP 11/70 for locating through HYPO71. The prototype system is being operated with two subsets of the California net. These subsets are: 16 stations in The Geysers area and 64 stations from Hollister to the Parkfield area.

Early estimates indicate that the system reliably detects events down to about magnitude 0.9. It reports approximately 8 to 12 false events per day. This figure will be reduced by new software criteria now being installed.

The first of the projected two units, each capable of handling 256 seismic stations, will be operating in May, with the follow-on unit to be ready in early autumn.

Digital Signal Processing of Seismic Data

9930-02101

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Investigations

1. Catalogs for earthquakes along the south half of the Calaveras fault in central California are used to search for seismicity patterns precursory to moderate sized earthquakes.

2. M_L 5 earthquakes (1934 to 1975) on the San Andreas fault near Parkfield, California, are used to search for spectral discriminates for foreshocks.

Results

1. Cumulative seismic moment ΣM_o for earthquakes on a 50-km-long creeping section of the Calaveras fault from near Mount Hamilton southeast to San Felipe Lake correlates with mapped fault-trace characteristics. In general ΣM_o is lower at the left stepping offset in the trace at the south end of Anderson Lake and along linear segments of the fault than near right stepping offsets and bends in the trace and intersections of the Calaveras with other faults. The correlations of seismic activity and fault-trace characteristics are similar to that for shocks along the creeping section of the San Andreas fault in central California. The rate of microearthquake earthquake occurrence along the 50-km-long section of the south half of the Calaveras fault zone increased beginning in May-June, 1978. If this increase is viewed as a 15-month-long large scale precursor to the 1979 Coyote Lake sequence, the August 29, 1978 shocks at Halls Valley 30 km northwest of Coyote Lake and the M_L 4.5 shock on May 8, 1979 are foreshocks, in a broad sense, to the Coyote Lake sequence. Details of the space-time pattern of microearthquake activity near Halls Valley and near San Felipe Lake are similar to those associated with moderate sized shocks on the creeping section of the San Andreas fault, and this similarity suggests that they are contemporary, parallel examples of seismicity patterns that precede larger shocks. First, there is a deficit in cumulative seismic moment of several years along the section of the fault where the subsequent larger earthquakes are located. Second, the rate of microearthquake occurrence increases before the larger shocks along the fault near the section deficient in cumulative seismic moment. Third, a cluster of microearthquakes at one end of the zone marks the start of the increased rate of microearthquakes.

2. Epicenters of Parkfield earthquakes #1 to #6, listed below, lie within 4 km of the epicenter of the 1934 and 1966 Parkfield main shocks. Shock #7 occurred 7 km northwest of the 1966 main shock. We compare seismic moment M_o times corner frequency f cubed from P_n spectra obtained from Wood-Anderson

seismograms recorded at Mount Hamilton (MHC, 185 km, 327°), Tinemaha (TIN, 240 km, 56°), and Santa Barbara (SBC, 180 km, 158°). Relative M_0f^3 is controlled by source directivity at azimuths aligned with the fault break (at MHC and SBC). At TIN, broadside to the fault trace, M_0f^3 reflects relative stress drop of the shocks. M_0f^3 at TIN for the immediate (17 minutes) foreshocks is more than that of any other shock considered, and for the early foreshock, which occurred 55 hours before the main shock in 1934, is the lower bound for the set.

			Relative M_0f^3			Conclusions	
#	Date	Type	MHC	SBC	TIN	Directivity	Stress Drop
1	6-5-34	Early foreshock	0.51	1.72	0.22	Southeast	Lower
2	6-8-34	Immediate foreshock	1.58	0.39	1.89	Northwest	Higher
3	12-24-34	Late aftershock	0.17	1.04	0.66	Southeast	Average
4	11-16-56	Isolated shock	0.17	--	0.38	---	Lower
5	6-28-66	Immediate foreshock	2.38	0.44	1.89	Northwest	Higher
6	6-29-66	Aftershock	1.34	1.04	0.81	Bilateral	Average
7	9-13-75	Isolated shock	0.87	1.38	1.13	Bilateral	Average

Reports

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Seismic Studies for Earthquake Prediction

9930-01727

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Investigations

The objectives of this project are to develop, by seismological techniques, an understanding of earthquake mechanics and the physical properties of fault zones leading to the prediction of potentially damaging earthquakes. During the reporting period, project effort was directed toward completion of the Willits aftershock study and analysis of California seismicity since 1850 in collaboration with Tousson Toppozada of the California Division of Mines and Geology.

Results

Willits Aftershocks

Aftershocks of the M 4.9 November 1977 Willits earthquake have been located along an unnamed fault on the eastern side of Little Lake Valley, 5 km east of Willits. The Maacama-Talmadge fault, which shows evidence of recent fault creep, passes through the city of Willits. Little Lake Valley is an apparent pull-apart feature between these northwest-trending right-lateral strike slip faults. Analysis of P and S travel-time residuals for station WSH at Willits indicates significant heterogeneity in the upper crust under Little Lake Valley.

End to Seismic Quiescence in California?

Recent earthquake sequences in the San Francisco Bay area, the Sierra Front, and the Imperial Valley indicate California may be emerging from a period of seismic quiescence which began in the late 1950's. During the 1960's and the 1970's, only 2 earthquakes of magnitude 6 or greater occurred per decade. From the 1850's through the 1950's, earthquakes of this magnitude occurred at an average rate of 7 or 8 per decade, based on data tabulated by the California Division of Mines and Geology. The seismic quiescence since 1960 is unprecedented in the available 130-year record, and is therefore unlikely to continue through the 1980's.

Reports

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Remote Monitoring of Source Parameters for Seismic Precursors

9920-02383

P2

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Investigations

1. We sought to design and implement techniques of processing (SRO) digital data. This processed output (e.g., deconvolved displacement, velocity or velocity squared) would be in a convenient form for extracting source parameters such as pulse duration, stress drop, focal planes, rupture direction, and radiated energy.

2. We consolidated several programs from various aspects of seismology to develop a technique of generating seismograms that incorporates propagation and source effects. Propagation effects include attenuation, diffraction and frequency-dependent reflection-transmission coefficients. The source is described by a class of kinematic rupture models that specify causal rupture, healing and stopping within a fault surface.

3. We used the programs described in (1)and(2) to analyze the rupture characteristics of two deep earthquakes. The parameters extracted from body phases produced by this earthquake provided the insight required to examine shallow earthquakes where one must account for the surface reflected wave forms that are not well separated in time.

4. We are currently examining sequences of earthquakes in various regions. By studying the records of displacement and velocity, we hope to discern a pattern of stress drop or rupture propagation in a sequence of earthquakes which could have been used to predict the main shock.

Results

1. A computer program has been developed that deconvolves the instrument response from SRO digital data by combining long and short period seismograms to yield broad band displacement records. The same program yields in the time domain broad band velocity and velocity-squared seismograms.

2. We studied the rupture characteristics of two deep earthquakes. The azimuthal distribution of the limited number of SRO stations which recorded the events enabled us to obtain a large number of source parameters. By comparing actual and synthetic records of displacement and velocity, we constrained source geometry, stress drop, moment, and the average direction and velocity of rupture. The propagation modelling required that attenuation be frequency dependent in the Earth. Source modelling showed that the deep earthquakes had a complex time history that could be explained by the presence of asperities.

Reports

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INVESTIGATION OF RADON AND HELIUM AS POSSIBLE FLUID-PHASE PRECURSORS TO EARTHQUAKES

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This report includes new measurements made during the period April - December, 1979, on our Southern California network, together with graphs of the accumulated radon, helium, nitrogen, and methane data for the past five years of monitoring these gases.

Two aspects of the accumulated data are discussed in this report. First, it is shown that mean radon concentrations have been essentially constant on the Elsinore, San Jacinto, and San Andreas faults over the five-year monitoring period 1975 - 1979. No significant changes of a systematic nature have been observed during this period, though seasonal effects and fluctuations with irregular periodicity are observed at certain sites.

At Arrowhead Hot Springs near San Bernadino, a very constant radon level was observed from 1975 through 1978 and early 1979. A large radon increase, approximately 72%, occurred in May, 1979, two months prior to the Big Bear Lake earthquake swarm, 19 miles to the east in the San Bernadino mountains (M = 4.8). The radon concentrations observed in May and the following months were the highest ever observed at this San Andreas fault site in 4.5 years of monitoring. They were accompanied by a similar increase in helium and by smaller increases in methane (60%), argon (25%), and nitrogen (17%). All concentrations declined rapidly in the months following, and had returned almost to baseline levels by the end of 1979. The He^3/He^4 ratio in the dissolved helium did not change during the helium peak. This appears to be a definite precursory increase in dissolved gases, correlated with a specific nearby seismic event.

Helium concentrations at our other sites have been generally constant over the network, except at two sites on the San Andreas fault in the Salton Sea area. At "CO_2 Wells" the helium concentration has increased by 50% relative to the 1975-1977 level. At the nearby Frink Springs, helium has increased by approximately 20% over the past four years. It is noteworthy that the only area in which such helium increases are observed is the Salton Sea region, where a large mantle helium component can be identified by the high He^3/He^4 ratios found in this region. In particular, the CO_2 Wells site has the highest ratio (6.5 times the atmospheric ratio) observed in the region.

Nitrogen and argon concentrations have remained essentially constant over the past five years throughout the network, with only two exceptions: the recent increase at Arrowhead mentioned above, and a small increase at Robison Well on the San Jacinto over the past two years. Methane concentrations show no systematic changes at eight of the eleven sites where it is a significant component. At Warner Hot Springs there has been a general increase in methane concentration over the past five years, while at the new Niland hot well near the Salton Sea, there has been a continual decrease in methane concentration since the well was drilled four years ago, probably reflecting depletion of an initial accumulation .

In TR 7 and 8 a two-component model for dissolved gases in hot springs was developed, based on the linear arrays formed by He, Rn, and CH_4 plotted vs. N_2 or Ar. The data for Arrowhead Hot Springs (discussed in detail in TR 7) provided a type example: variations in gas concentrations reflect dilution of rising, partially degassed hot water with surface water saturated with atmospheric gases at the hot spring temperature. The concentration increases in May essentially followed this pattern, with a decrease in the ambient surface component, so that we observed an increase in <u>all</u> gas concentrations, reflecting less dilution by downward convective mixing of surface spring water. If these increases were indeed precursory, the induction period was 60 ± 15 days prior to the June 29 - 30 earthquakes with three events of $M = 4.5$, 4.6, and 4.8. The empirical correlations of precursory period vs. magnitude of Scholz, Sykes, and Aggarwal predicts $t = 46$ to 73 days for $M = 4.5$ to 4.8 events. It should be noted, however, that the epicenter for the Big Bear event lies considerably east of the San Andreas fault on which Arrowhead Hot Springs is located.

New measurements of helium and helium isotope ratios are reported for Icelandic thermal wells, where a radon increase has been observed by LDGO and Icelandic workers prior to an earthquake. The helium isotope ratios, 17 to 19 times the atmospheric helium ratio, are characteristic of "hot spot" type helium observed at Kilauea Volcano.

INVESTIGATION OF RADON AND HELIUM AS POSSIBLE FLUID-PHASE PRECURSORS TO EARTHQUAKES

14-08-0001-18348

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This report includes new measurements made during the period October-March, 1980, on our Southern California network, together with graphs of the accumulated radon and helium data from 1975 to the present.

Two aspects of the accumulated data were discussed in the last report (TR# 11). First, it was shown that mean radon concentrations had been essentially constant on the Elsinore, San Jacinto, and San Andreas faults over the five-year monitoring period 1975 - 1979 with no significant changes of a systematic nature. Second, large radon and helium increases were observed at Arrowhead Hot Springs near San Bernadino in May 1979, two months prior to the Big Bear Lake earthquake swarm. The radon concentrations observed in May and the following six months were the highest ever observed at this San Andreas fault site in five years of monitoring. Continued monitoring has shown that radon dropped to the baseline level of 0.3 dpm/g in November and December, 1979, and since then fluctuated up until the present. Radon variations were closely correlated with those of helium in the same period. The He^3/He^4 ratio in the dissolved helium did not change during the helium peak. This appears to be a definite precursory increase in dissolved gases, correlated with a specific nearby seismic event.

Radon measurements at most of our other sites show that the level has remained essentially constant throughout the monitoring interval. No long-term significant trends can be seen above the natural noise level. Helium also remains constant for most of the other sites, except for CO_2 Wells and Frink Spring in the Salton Sea area. These two sites show a systematic helium increase over the past several years. However, no such trends are observed in radon at these sites.

At Murrieta Hot Springs on the Elsinore fault zone, we resumed monitering radon, helium and other dissolved gases in February after hiatus due to flooding out of well site for about two years. Now we are monitering at a different site, a pool about 200 m away from the previous well-site. Since February, both radon and helium have increased by almost a factor of two. These increases are also associated with a significant temperature increase. Along the same fault at Warner Hot Springs, south of Murrieta Hot Springs, radon and helium have also been increasing since February. However, no such increases have been observed further south along the fault at our Agua Caliente site.

In the Salton Sea region at the Hot Mineral Well Site , radon has increased significantly (over 30%) since February, 1980. A similar but smaller radon increase ($\sim$10%) has occurred at the nearby Bashford Well. These radon increases are not accompanied by helium, which shows a fairly constant level during this period.

Lead-210 data from the Southern Network sites and from the Palmdale area are updated in this report. Significant variations in the Pb-210/Rn-222 ratio are observed among the monitroing sites. In the Palmdale area, the activity ratio is smaller and more uniform at about 10^{-5}, with model "ages" between three hours and one day. In the Southern Network, the activity ratio is higher with model "ages" ranging between one and six days. The "ages" cited represent the time required for growing in all the observed lead-210 by radon decay, with no initial lead-210 content. These times are very short by any estimate of circulation times. Thus lead is probably removed rapidly from the water by scavenging of rock surfaces or suspended particulates, and variations may be expected to correlate with flow rate changes, possibly associated with pre-seismic events.

Recent radium-226 measurements from the Southern Network sites show fairly constant levels slightly lower than our earlier data. All the monitoring sites along the Elsinore and San Jacinto faults have negligible radium concentrations. Higher radium values are observed in the Salton Sea region, especially at Hot Mineral Well and Bashford Well. However they are at most, only a few percent of the corresponding radon contents. At present, correction for radium on observed radon is applied only at four sites, all in the Salton Sea region.

On February 25, 1980, an earthquake of 5.1 magnitude occurred near Hemmet about 65 miles northeast of San Diego, The epicenter was located near the middle of the San Jacinto fault. No precursory effects have been observed at the monitoring sites along this fault. Post-quake sampling was cancelled due to heavy floods which made the site visit impossible.

Installation and collection of film strips for soil radon measurements (monitored at Menlo Park) continued during this period.

Central California Network Processing

9930-01160

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Investigations

Recordings from 270 stations of the multipurpose central California Seismic Network are telemetered continuously to the central laboratory facility in Menlo Park where they are recorded, reduced, and analyzed to determine the origin times, magnitudes, and hypocenters of the earthquakes that occur in or near the network. Data on these events are presented in the form of lists, computer card catalogs, 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 the earthquake mechanics and prediction. A magnetic tape library of "dubbed" unprocessed records of the network for significant local earthquakes and teleseism is prepared to facilitate further detailed studies of crust and upper mantle structure and physical properties and of the mechanics of earthquake sources.

Results

Summary catalogs of earthquakes located by the network from 1969 through 1976 have been published. Preliminary results for the years 1977 through March 1980 are accessible in various forms, and work on completing and publishing the summary catalogs for these years has high priority.

A study of the three-dimensional structure of the upper mantle beneath central California is in progress. Data from 24 teleseisms have been analyzed and these form the basis for construction of a high resolution image of the lateral variations in velocity at depth. Results indicate the presence of a 100 km thick, east-dipping, low-velocity layer, with a 3% decrease in velocity from the surrounding region. This layer extends from approximately the San Andreas fault, at the surface, to a depth of over 200 km beneath the Sierra Nevada.

The Livermore Valley earthquake sequence of January 24 to February 26, 1980 is currently being investigated. For this time period, 575 earthquakes have been located in this region, mostly along a 30 km section of the Greenville fault. The largest earthquake of this sequence occurred on January 24 and had a magnitude of 5.9. Fault plane solutions for most of these earthquakes indicate that movement was predominately right-lateral strike-slip, which is consistent with geologic field data for movement on the Greenville fault system.

Implimentation of standard data processing techniques for locating earthquakes is currently underway on the ECLIPSE computer system. Events from several days have been wholly processed on the system and the results are favorable. Various members of the project are learning the system and are assisting in the further development and refinement of software and processing techniques.

Reports

Cockerham, R. S., and Ellsworth, W. L., 1979, Three-dimensional large-scale mantle structure in central California (abs.), EOS, v. 60, no. 46, p. 875.

Hall, P. C., and Lester, F. W., 1979, Preliminary catalog of earthquakes in central California for January 1979, USGS Open-File Report 79-1571, 6 p.

California Seismic Network Development

9970-90007

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Investigations

Extend the central and southern California seismic networks to provide more uniform moderate density coverage of the San Andreas fault system and contiguous seismically active regions of California. In central California an additional 100 stations are needed, about half to broaden the southern part of the net and extend it to the Transverse Ranges and about half to extend the northern part of the network to the Klamath Mountains. In southern California an additional 75 stations are needed to provide moderate density coverage of the Transverse Ranges and of parts of the San Jacinto and San Andreas faults near Salton Sea and to provide selective augmentation of the network in the northern Mojave Desert and along the eastern flank of the Sierra Nevada.

Results

Tentative sites have been selected for all the new stations in both Central and Southern California. Purchase and fabrication of equipment for all the stations is nearly complete and all recording facilities have been established.

Equipment has been installed in about 10 new stations in Northern California and permitting is underway for an additional 15 stations in this area.

In Southern California about 60 of the tentative 75 sites have been permitted. Radio frequency authorizations have been requested and telephone lines ordered for most of the 60 sites already permitted.

During the next six months about 50 stations will be installed in Southern California and some final permitting and installation will be done in Central California.

Precursory strain/seismic anomaly studies on a strike-slip fault system

9930-02393

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Investigations

Approximately twenty years of seismic data are being analyzed to test seismicity as an earthquake prediction tool. Intense seismicity and the central location of our study area within a dense seismometer network operated by the Hawaiian Volcano Observatory provides ideal conditions for an earthquake prediction study supplemented by strain studies. Our current goals are to obtain improved hypocenter locations (for all events) based on a number of crustal models and to determine focal mechanism parameters for all large magnitude events. Computer programs and data analysis techniques are being developed at the University of Washington to analyze and present this voluminous data set. Early efforts will focus on events associated with a body wave magnitude 5.5 event that occurred on November 30, 1974 on the Kaoiki fault system.

Results

A. Seismic

Approximately 1000 copies of earthquake film records and hard copies of digitized seismic events have been collected for a focal mechanism study of the Kaoiki region and the south flank of Kilauea. These events are part of a group of 5000 events that have been relocated using two different crustal models. First motion plots have been completed for larger magnitude events from 1972-1979. 1979 results indicate more than one type of faulting taking place in the Kaoiki study area. In addition to right lateral strike-slip faulting, low angle normal or thrust faulting appears to be also taking place in the Kaoiki area.

To meet our project goals, the effect of structure models has been studied. A paper, coauthored with Robert Crosson of the University of Washington and pointing out the effect of structure models on focal mechanisms, has been completed and will be submitted for technical review. The report discusses focal mechanisms related to the November 29, 1975 Kalapana earthquake. In a followup study of the Kalapana earthquake, focal mechanisms for 200 Kilauea south flank earthquakes with body wave magnitudes greater than 3.3 have been determined. Consistent with the results of our paper is the invariance of what we consider to be the slip directions for individual events. The slip directions of focal mechanism solutions are also consistent with the results of strain studies on the south flank of Kilauea.

The work on the south flank events gives us some knowledge of station reversals that are important to reliable focal mechanism solutions for the Kaoiki study area. The same computer graphics FORTRAN programs developed for the south flank study are being used to present results of the Kaoiki fault zone study. A focal mechanism catalog for large magnitude events is in the planning stage.

B. Deformation

Level lines and EDM arrays have not been reoccupied since initial measurements during the summer of 1979, hence there are no results to present for this report.

Tests of the Kinemetric's platform type tiltmeters are encouraging. Two tiltmeters, one located in the Mauna Loa seismic vault and the other located in the Uwekahuna seismic vault, tracked water-tube type tiltmeters. In addition, during a March 1980 summit deflation of Kilauea, the platform tiltmeter at Uwekahuna tracked a 1 meter base Ideal-Aerosmith mercury tiltmeter to within a few tenths of a micro-radian during the deflation event. Preliminary results suggest vault installations to be far superior to any borehole installation.

Reports

Endo, E. T., Nakata, J. S., and Crosson, R. S., 1979, Focal mechanisms of crustal and mantle earthquakes beneath the island of Hawaii, (abs.), Symposium on intraplate volcanism and submarine volcanism, p. 160.

Assessment of the $^{234}U/^{238}U$ Activity Ratio as a Possible Earthquake Precursor

14-08-001-17744

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Report Summary

This report describes work done as part of a study to assess the utility of the U-234/U-238 activity ratio as a possible earthquake precursor. Uranium concentrations and isotope ratios have been measured in water from wells and springs at 24 Southern California sites located in six tectonic areas:

1. San Andreas Fault (Palmdale Area)
2. San Andreas Fault (San Bernardino Area)
3. Mission Creek-Banning Fault
4. San Andreas Fault (Imperial Valley Area)
5. San Jacinto Fault
6. Elsinore Fault

A monitoring network has been set up comprising 14 sites along the San Andreas, San Jacinto, and Elsinore fault systems in the region between San Bernardino and the Mexican border (Fig. 1). Along this primary monitoring network activity ratios, U-234/U-238, vary from 0.88 at Agua Caliente Springs (ACAL-1S) on the Elsinore Fault to 5.4 at Niland Slabs (NILA-2W) just east of the Salton Sea. Uranium concentrations vary from 0.002 ppb at Indian Canyon Springs (INCA-1P) on the San Jacinto Fault to 4.6 ppb at Frink Spring (FRNK-1P) on the San Andreas Fault in the Imperal Valley. At these 14 sites uranium concentrations were determined on a monthly or bimonthly basis.

At the Niland Slabs well, located at the southeastern corner of the Salton Sea, two samples taken after the 15 October 1979 Imperial Valley earthquake (m=6.6) showed a significant decrease in the U-234/U-238 activity ratio (from 5.4 to 1.1) and an increase in uranium concentration (from 0.005 ppb to 0.295 ppb). The uranium concentration and isotope ratios for NILA-2W are given in Fig. 2.

At all other sites, within the experimental uncertainty as determined by counting statistics, the U-234/U-238 activity ratios have not shown significant variation from month to month. Although no absolute regional correlations exist, there is a tendency for Imperial Valley sites to have the highest ratio and for sites along the Elsinore fault to have low values. The

absolute uranium concentrations vary much more than do the isotope ratios, but there is as yet no discernable pattern to the observed concentration variations.

Table 1 summarizes the U-234/U-238 activity ratios for the 14 sites which comprise the primary sampling network. Measurements are separated by at least one month. In most cases the relative standard deviation of the set of measurements is not significantly larger than would be expected from the analytical uncertainty. The relative standard deviation gives an indication of the magnitude of the earthquake precursor signal which could be detected.

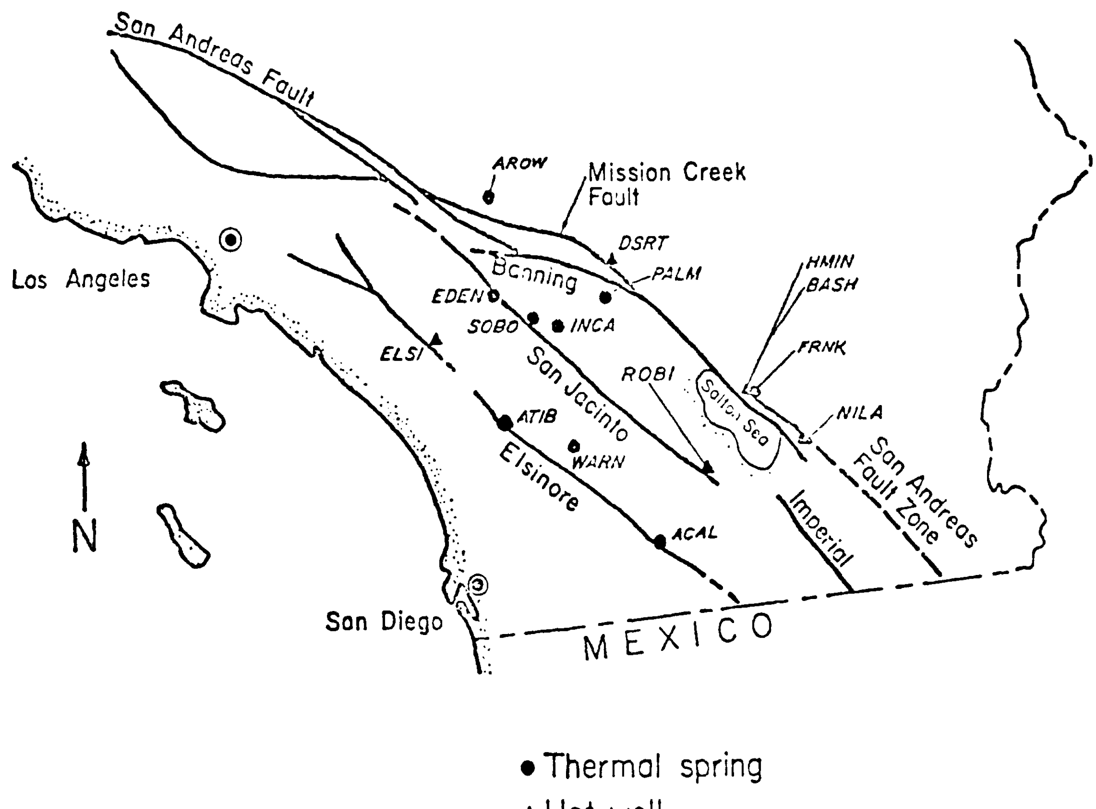

Figure 1. Location map for the Southern Network

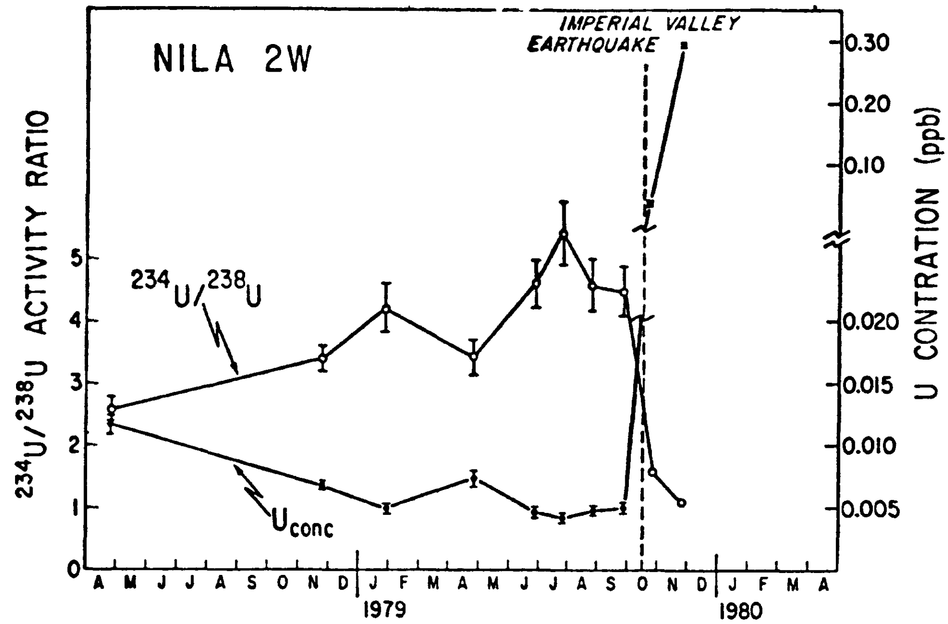

Figure 2. Uranium Isotope Activity Ratio and Uranium Concentration in Niland Slabs Well

TABLE 1: TEMPORAL VARIATION OF $^{234}U/^{238}U$ ACTIVITY RATIOS

Site Code	Number of Measurements	$^{234}U/^{238}U$ Mean	Standard Deviation %	Uncertainty in Individual Measurements %
AROW-1P	7	1.0 ± 0.1	10%	9%
DSRT-1W	11	1.00 ± 0.03	3%	2%
PALM-1P	4	1.16 ± 0.09	8%	3%
HMIN-2W	8	1.60 ± 0.05	3%	3%
BASH-1W	12	1.87 ± 0.06	3%	2%
FRNK-1P	9	1.98 ± 0.02	1%	1%
NILA-2W	11	3.5 ± 1.4	40%	10%
EDEN-1P	7	1.3 ± 0.1	8%	8%
SOBO-1S	7	1.04 ± 0.03	3%	4%
INCA-1P	9	1.4 ± 0.3	24%	13%
ROBI-1W	16	1.17 ± 0.02	2%	2%
ELSI-1W	9	1.14 ± 0.04	4%	3%
WARN-1P	7	1.2 ± 0.3	25%	15%
ACAL-1S	7	0.88 ± 0.02	2%	2%

Geochemical Precursors in Well Waters for Earthquake Prediction: Helium

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Investigations

Helium contents of well waters are being measured at 14 stations in the Yellowstone National Park vicinity of Wyoming and Montana and a number of stations in the Imperial Valley of California. In general, samples are taken daily by volunteer or paid collectors and mailed to the Denver laboratory in sets of 5 samples. In addition, a remote operating helium "sniffer" has been operating for over a year at Yellowstone. Six or eight helium atoms are formed in each radioactive decay of a uranium or thorium atom. Helium is a stable, non-reactive, rapidly diffusing element that may build up indefinitely in perfectly tight rocks. Most rocks are not perfectly tight, however. Increases in helium contents in well waters may reflect rocks opening up as a result of microfracturing, dilatency, increased tension, or other causes whereas decreases in helium content below normal may indicate rocks are sealing up because of phase changes, compression, material transport or other causes.

Results

No response was noted in any of the stations in the Yellowstone Park vicinity to the magnitude 4.7 earthquake near Fawn Pass on February 22, 1980. The closest station to the Fawn Pass earthquake (Miller Station 300) had previously had a very marked decrease in helium content to almost 0 ppm starting 17 days before the time of the magnitude 4.7 earthquake of October 19, 1977 near Hebgen Lake with a large increase in helium content observed afterward. Measurements were begun only in the fall of 1977 and the area has experienced fewer earthquakes than expected of magnitude 4.5 or greater, so we do not yet have sufficient statistics to judge the applicability of this kind of study to earthquake prediction.

Reports

Doering, W. P., and Friedman, I., 1980, Survey of helium in natural water wells and springs in southwest Montana and vicinity: U. S. Geological Survey Open File Report 80-181, 42 p.

University Student Volunteer Program for Earthquake Prediction

by
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Following the purchase and construction of necessary equipment and field studies to locate appropriate fault traces, we began to measure creep rates across various San Francisco Bay region faults in September 1979. Our primary purpose was to determine the rates of creep on these faults and to check for any deviations from the average rates.

We determined the total amount of slip occurring on Bay region faults by noting changes in angles between sets of readings taken across these faults at different times. A model T3 theodolite was used which allows an angle to be read to the nearest 0.1". We believe that we can detect slip occurring in excess of a millimeter or two between successive measurements. Calculated slip less than a millimeter or two may fall within the "noise" level due to the measurement method and possible instability of the reference stations in the ground.

Our sites on the Calaveras fault and the Hayward fault showed no significant movement in the several-month interval in which they were monitored. Both our measurement sites on the Concord fault, however, showed that about a centimeter of right-lateral slip occurred during October and November 1979. Since then, the Concord fault has moved very little or not at all.

The measurement sites on the Concord fault are within 25 kilometers of the epicenter for the 24 January 1980 Mt. Diablo earthquake. The only significant historic earthquake that has occurred on the Concord fault was an M5.4 in October 1955. This earthquake may have been preceded or followed by rapid creep on the Concord fault.

At present any relationship between the accelerated creep and subsequent "locking" of the Concord fault and the Mt. Diablo earthquakes is equivocal. The unusual activity on the Concord fault could be a precursor of a forthcoming earthquake on the Concord fault itself. Alternatively, the unusual activity may be unrelated to any past or future earthquakes.

We would like to continue monitoring the rate of creep on Bay region faults. We have already established measuring sites on the Antioch, Seal Cove, and San Gregorio faults and have field-checked additional sites on the Hayward and San Andreas faults. We believe that collecting additional slip data fairly frequently in many locations in an area where future seismic activity is inevitable will help in establishing any systematic relationship that may exist between creep and earthquakes.

Tectonic Monitoring of the Solomon & New Hebrides Islands Regions

14-08-0001-17771.

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INTRODUCTION

This report covers the first major development and fabrication stage for the project. Efforts have been concentrated exclusively into design, testing and development of the remote field sites for establishment throughout the islands. The actual field deployment has been prevented by late arrival of major items of equipment and the field trip initially intended for late in the funding year will now take place in April and May 1980. No major changes from the initial plans have been necessary.

DETAILS OF PHASES COMPLETED

1. The development of a digital synthesiser and modifications to the Geometrics 826 Magnetometer station have been completed to allow remote automatic operation. All twelve units provided by the contract have been modified and tested. They will be installed in the April field trip.

2. A high reliability power supply system consisting of solar panels, gel cell, and reserve carbonaire supply with control systems, has been developed and tested to provide 3Ah/day uninterrupted capacity for the five year life period of the field stations.

   Routine production of these units is in progress.

3. Instrument huts approximately 1.2m x 1m x 1.4m are also in production. These huts will house power supplies, batteries and all instrumentation for the programme. Magnetometer bottles for permanent stations and antenna for the satellite link will be accommodated separately on masts, and these are also in production.

4. Interface electronics from the magnetometer to the DCP units, and including analogue environmental channels, have been designed, tested and are in production.

5. All major plans for the final station deployment have been completed. The ultimate system comprises a microprocessor based control system which services the digital real time clock, magnetometer, printer, strain and tilt meters and various environmental sensors, operating through a 12 bit bus. Our sensor is provided with field options to allow operation independently of all other devices and where satellite data linkage is not possible an alternative magnetic tape recording system can be used. Stations are designed to operate uninterrupted without local servicing or maintenance for periods of up to one year.

RESULTS

No experimental results outside the test programme of the instrumentation have been taken.

Continuous Gravity Measurements In the Region of the Palmdale Uplift

14-08-0001-18353

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Investigations and Results

One of our superconducting gravimeters has been operating at the Lytle Creek Ranger Station, 34.25° North Latitude, 117.5° West Longitude, since November, 1978. The very heavy rainstorms of that first year caused large apparent variations in gravity which decayed away in about one week. At intervals when rainstorm effects were absent, a steady decrease in gravity was apparent on the data. That decrease continued through 1979 and into 1980 and has resulted in a total change in gravity which is more than an order of magnitude larger than the variations, for comparable time periods, which we are observing at other sites.

Gravity as a function of time for the dry period of 1979 is shown in Figure 1 with tides and the varying gravitational attraction of the atmosphere removed. The short term fluctuations in this residual are due to small rainstorms, uncorrectable (at present) influences of atmospheric pressure, periodic realignment of the gravimeter along the vertical, and technical problems with the time base. The monotonic decrease averages 0.28 μgal/day and is consistent with the variation observed between rainstorms for the earlier part of the record. If the change were caused entirely by vertical uplift it would correspond to 1.0 mm/day.

We have also investigated the connections between rainfall and the gravity variations. We anticipated that it could come either from direction gravitational attraction of groundwater or from tilting of the instrument due to softening of the soil and landslide. For groundwater to cause an increase of 100 μgal in local gravity, a 150 foot rise in the water table in soil with 20% pore space would be necessary. In January 1980 a depth gauge was installed in an existing well located approximately 200 meters from the gravimeter. From January through March a rise in the well level of 20 feet was measured. While this change could have a significant effect on local gravity, it would not approach the 100 μgal increase observed.

If a superconducting gravimeter is tilted slightly away from vertical, the result is an apparent increase in gravity that is proportional to the square of the tilt angle. A tilt of 500 μrad would be sufficient to explain a 100 μgal increase. In October 1979 a tiltmeter was installed on the concrete pier which supports the gravimeter. Sufficiently large tilts were measured during a subsequent storm to completely explain the accompanying increase in gravity. An automatic leveling system was developed and installed to eliminate the tilt. Since its installation in April 1980 the system has successfully maintained its alignment through two small showers.

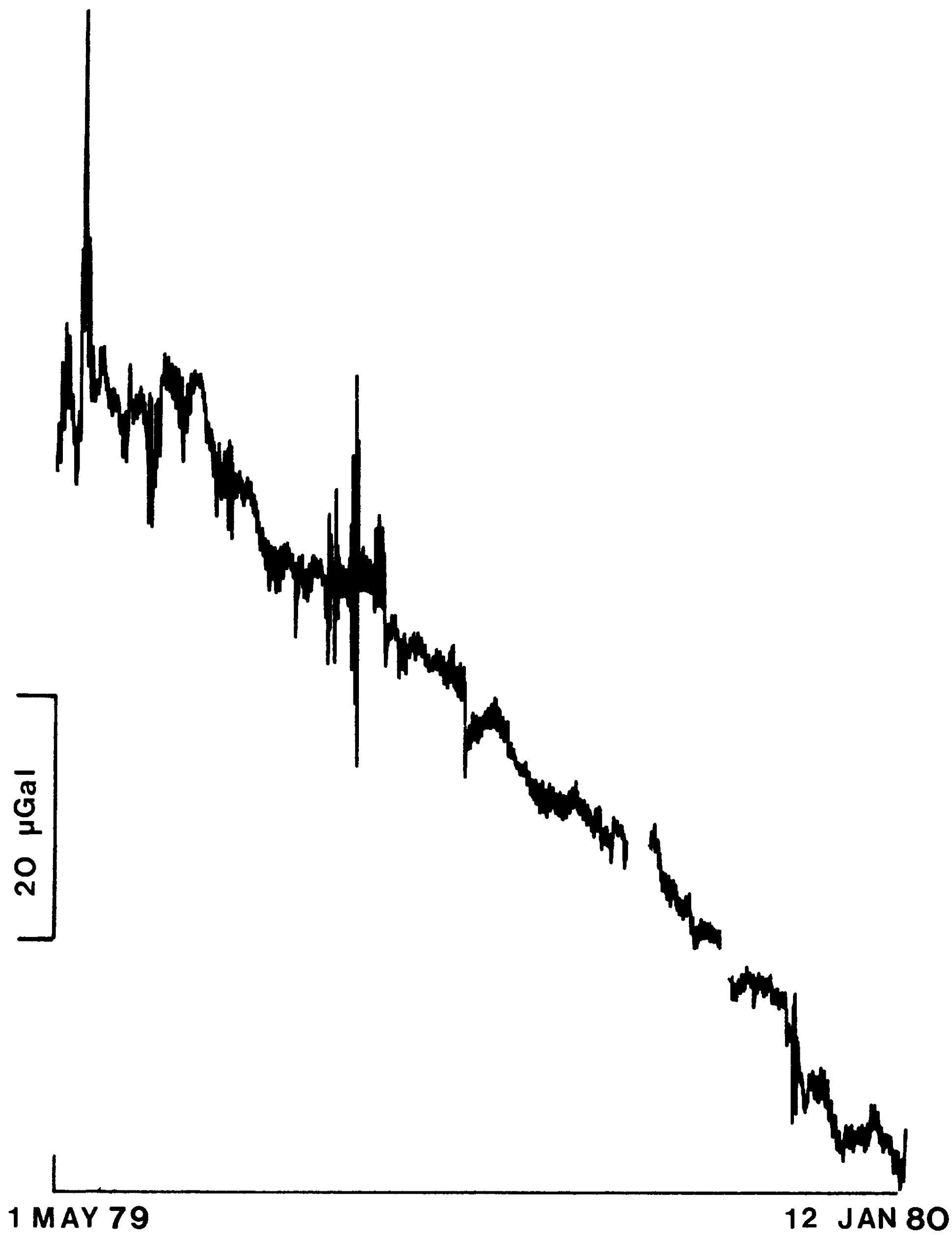

Figure 1. 254 day gravity residual from Lytle Creek, California.

Central California Network Operations

9970-01891

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Investigations

Maintenance and recording of 383 seismic, 34 tiltmeters, 16 magnetometers, 31 creepmeter, 3 strainmeter equipment sites located at 351 separate locations in northern and central California, covering 63,000 square miles.

Results

1. The Stanwick Corporation under contract 14-08-0001-19145 is responsible for the maintenance of seismic, tiltmeter, magnetometer, creepmeter and strainmeter field sites; inside maintenance of low frequency digital equipment; installation of new seismic stations and final testing of J402 VCO/AMP's.

2. The Stanwick team consisting of ten members has far exceeded maintenance goals set by the reference contract (95% operational). Maintenance delays greater than 48 hours were attributable to weather, transportation, or access problems.

3. Replacement of the 5.6 volt mercury cell used as the calibration battery in the J402 VCO/AMP with a 6 volt pack of 1.5 volt alkaline cells. This modification will provide greater battery longevity and will decrease the number of required site visits.

4. New seismic stations
   Installation of:
   - 1 single component station in Mendocino County
   - 19 single component stations in Oregon
   - 2 multicomponent stations in Livermore
   - 1 single component station in Tomales Bay
   - 3 single component stations in Mt. Hamilton-East area
   - 3 single component stations in Walker Pass Area

5. New Phone Lines
   - 3 from Yellowstone National Park. Receive Only.
   - 3 from Oregon. Receive only.
   - 1 from Golden Colorado via University of Nevada. Transmit and receive.
   - 2 from Livermore (LLL). Transmit and receive.
   - 1 to University of Oregon. Transmit only.

6. Fabricated and installed a low frequency digital system calibrator. This unit contains all signal modulated carrier frequencies and is designed to enable a dynamic check of all receiver channels.

7. Installed a signal distribution frame to interface the Automatic Seismic Processor and Telemetry Center. Signal capacity of distribution frame is 630 stations.

Fault Zone Structure
9960-01725

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Investigations

New seismic instruments are used to study a wide range of earth structures to provide data needed for earthquake prediction research, the calculation of strong ground motion, the estimation of seismic hazards, the evaluation of geothermal areas, and the examination of potential nuclear waste disposal sites.

Results

Long seismic refraction profile in Saudi Arabia: Modification of playback equipment for improved digitization of Saudi data. Preparation of new record sections in progress. Interpretation of the section of the profile crossing the transition zone from the Red Sea structure to the continental structure.

Snake River Plain and Yellowstone: Submission of digitized data to Robert Smith at the University of Utah for inclusion in overall data set. A data report is in preparation.

Seismic investigation of Mount Hood: The most important results of this study are an indication of a large oval-shaped structure underlying Mount Hood which may reflect the roof of a large batholith, and a clear indication of seismic anisotropy of a direction and magnitude that suggests a relationship to the current stress field. In other words, we may be seeing the opening and closing of fractures in response to present tectonic stress. A paper describing these results has been finished and will be submitted for publication in May.

Coyote Lake aftershock studies: Demonstrated the feasibility of recording instruments to record a few earthquakes at many stations to calibrate velocity structure in an aftershock zone. Paper in preparation.

Imperial Valley structure studies: Preparation of data and record sections has been completed and four papers describing this work are in the process of publication.

Imperial Valley aftershock studies: Recorded several aftershocks on an 100-station network overlying the epicentral area of the Imerial Valley earthquake. Data should be useful in checking structure determined from surface shots.

Imperial Valley reflection profile: A 25 km long detailed reflection profile was recorded using a variety of sources, including a repeating air gun source. Data from this profile will be used to look for deep reflections and temporal variations, and to test the relative effectiveness of an air gun compared with explosives for temporal monitoring of seismic travel time. Data preparation is in progress.

Seismic studies in the Mojave desert associated with the examination of the Palmdale Bulge: Seismic profiles are planned to study the structure of the Mojave desert north of the San Andreas fault to determine the degree of anisotropy with velocity structures in these rocks and relate this anisotropy to stress. A preliminary attempt will be made to record deep reflections, particularly any relections that might be associated with a shallow thrust fault.

Instruments have been deployed across a proposed waste disposal site at the Nevada Test Site where recordings of nuclear blasts will reveal the deep structures in the vicinity of this site. Successful recordings were achieved at 50 sites.

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Prediction Monitoring and Evaluation

9920-02141

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Investigations

1. This project monitors and evaluates earthquake predictions from any source. Techniques have been established which can determine whether success in predicting earthquakes is due to skill or to chance. An extensive file of predictions now exists. Though predictions are no longer being evaluated, we continue to accumulate them both from non-scientists and scientists in the event the prediction of a particular event or predictions from a particular individual become an issue. Predictions are submitted to this office or extracted from a variety of publications which are monitored.

Results

1. Since this program is a continuing project which monitors published predictions, final results in the usual sense cannot be expected although interim reports have been published in the past. Analysis has shown that non-scientist predictions are of no value.

2. The program created for the purpose of estimating the random probablity of an earthquake in a region could be of some use to other projects. This program gives the probability of an earthquake for various geographic regions or locations, adjusted for size of quake and time span of interest, based on the Hypocentral Data File for the years 1963 through 1977 and assuming earthquakes of the observed sizes occur at the same rates. We have decided that the best way to extend the effective data time span to the length of the catalogues established for the U. S. is to use the data base used in the Seismic Risk Program.

3. The probability program could be expanded to calculate the changing probability of a quake as precursory phenomena are noted. The equations would be based on Bayes Law and require the random probability of an earthquake in a region and estimates of the probabilities that precursors precede earthquakes and non-earthquakes.

4. Because the project budget was not increased to cover the large increase in computer charges, items 2 and 3 above, any prediction scoring or evaluation and all program development has been impossible. Predictions received can only be dated and filed.

Reports

No reports were published during this period.

Magnetometer Array

8-0001-17688

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Investigations

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 instruments deployed are indicated in Table 1.

TABLE 1. Magnetometers in test

Number	Type	Operating Institution
2	fluxgate (vector	UCLA
2	cryogenic (vector)	USC
4	proton precession (scalar)	UCLA
2	proton precession (scalar)	USGS

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 temperature was controlled by active heating for UCLA fluxgate #2.

We have carried out a laboratory program to identify and remove sources of noise in fluxgate and proton precession magnetometers.

Results

For one twelve-day period, all of the instruments in Table 1 recorded successfully, with the exception of one channel of one cryogenic magnetometer. Thus there are 17 channels of data collected with a short distance (30 m). For a 43-day period, we have redundant vector data from at least one fluxgate and at least one cryogenic magnetometer. For a 52-day period, all of the UCLA magnetometers functioned successfully. The data have not yet been fully analyzed, but we have a very valuable data base on which to work. Examples of vector data from the UCLA array are shown in Figure 1, while scalar data from UCLA and USGS are shown in Figure 2. On the basis of preliminary analysis, we may make the following conclusions:

a. The stability at the temperature controlled fluxgate was excellent. Drift with respect to a proton magnetometer was less than 2nT, and possibly much less, over more than a month.

b. The temperature controller maintained both sensor and electronics temperatures to within 0.01°C for UCLA fluxgate #2. Based on lab tests, the temperature sensitivity of these instruments is about 2nT/°C.

c. As shown in Figure 3, there is a significant daily variation in the difference between total fields measured at two nearby sites. This may indicate a temperature sensitivity for the proton magnetometers that is much larger than previously suspected.

d. Many problems arose. We found unacceptable clock drift in UCLA fluxgate #1, that disappeared when the electronics temperature was controlled. Problems in correcting for flux jumps and resets still occur with the cryogenics.

Publications Under This Contract

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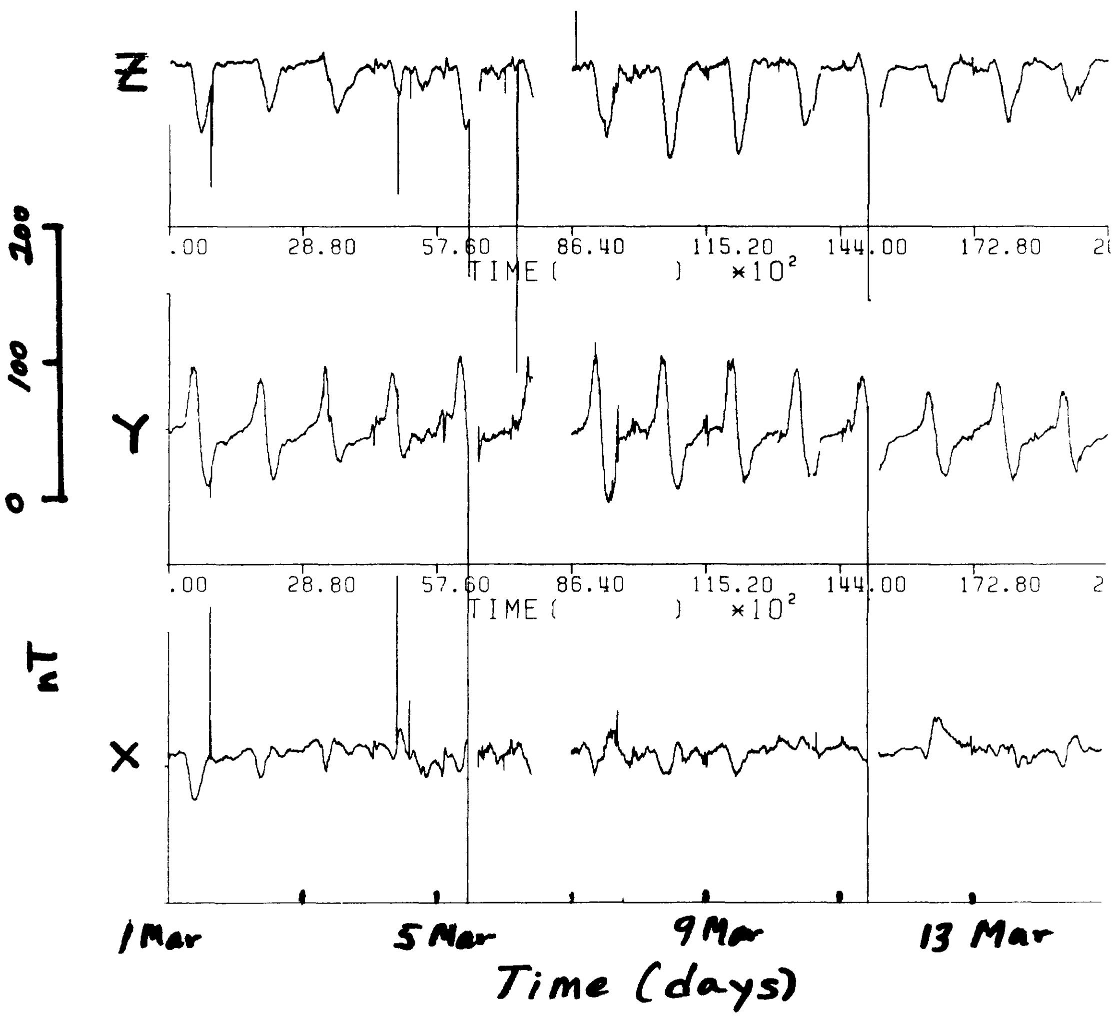

Fig. 1 Magnetic field components vs. time for UCLA fluxgate #1. The top trace is the field-aligned (z) component, the second trace is oriented perpendicular to z in a N-S plane, and the bottom trace is oriented E-W.

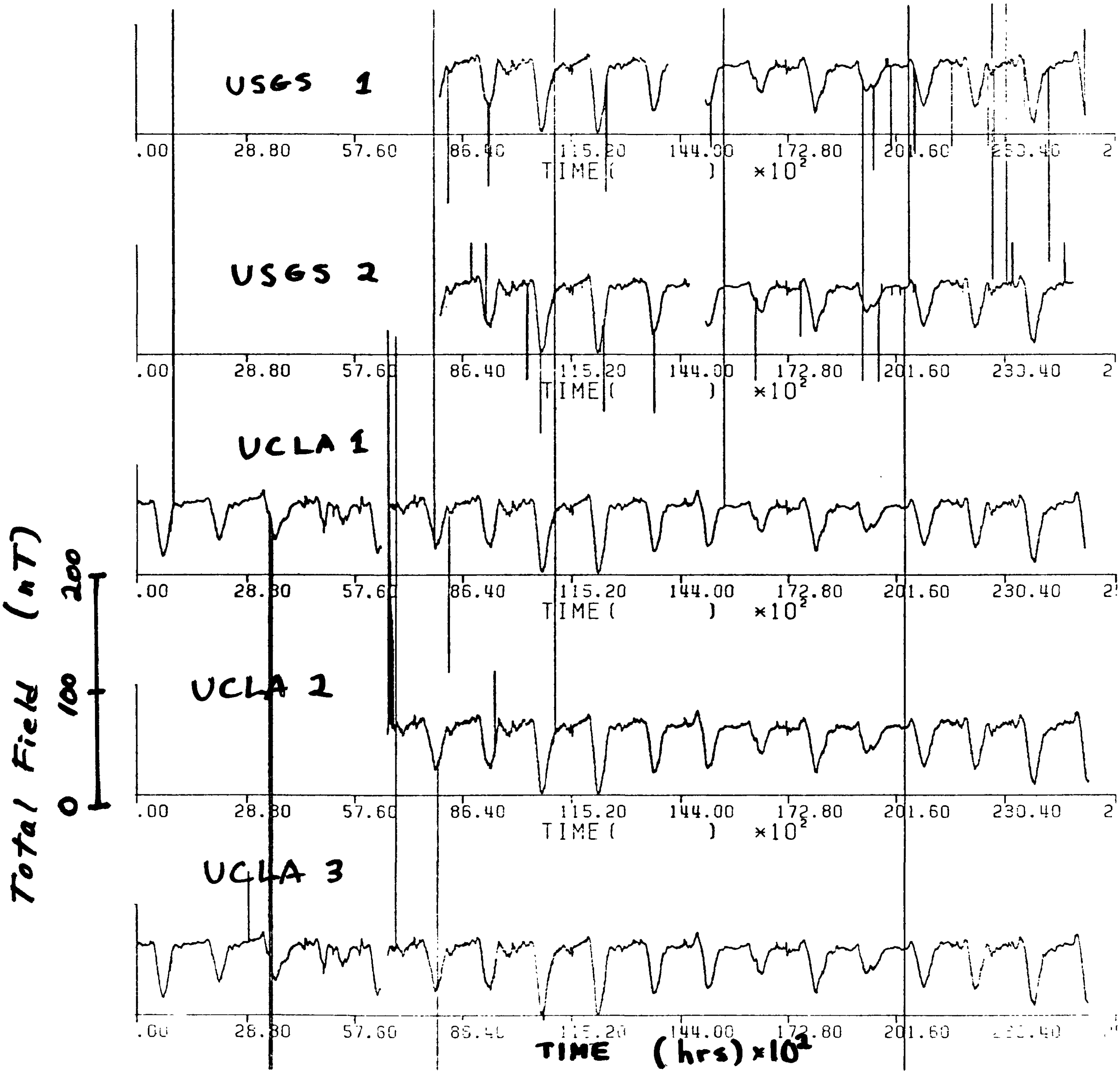

Fig. 2 Total field vs. time for two USGS and three UCLA proton magnetometers.

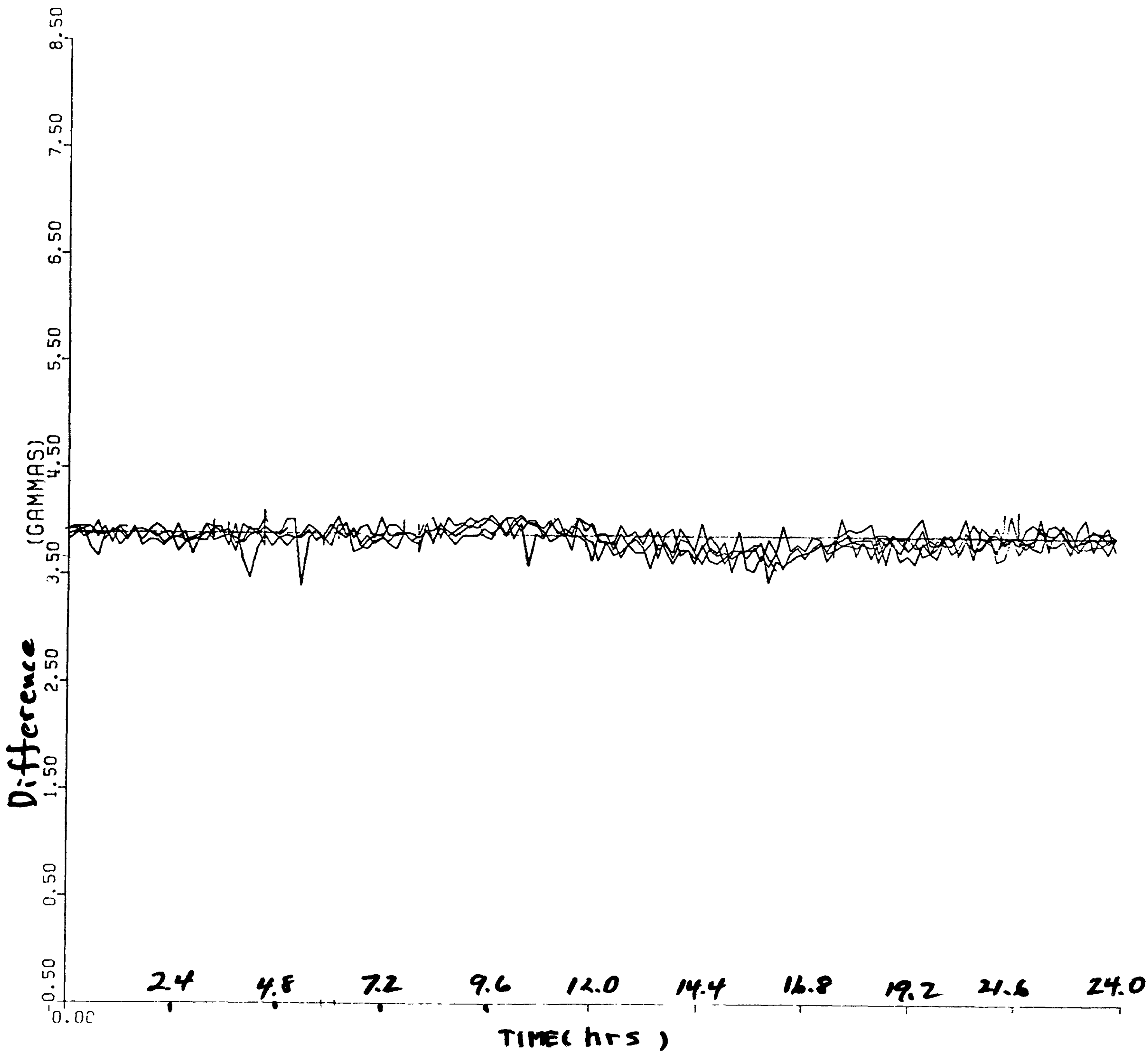

Fig. 3 Differences in total field recorded on two nearby proton magnetometers, vs. time of day. Four days of data are shown overlapped. Data shown are 10-minute averages of one-minute samples. Note the dip of about 0.2 nT in the late afternoon.

Southern California Cooperative Seismic Network

9930-01174

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Investigations

1. Investigations conducted using stations of the southern California cooperative seismic network are reported here for the period October 1979 through March 1980. In excess of 4,000 events have been timed and located in cooperation with Caltech using the Caltech Earthquake Detection and Recording System (CEDAR). For a detailed discussion of the results of this investigation refer to C.R. Allen, Southern California Seismic Arrays, 14-08-0001-16719.

2. *In Situ* timing of blasts at Eagle Mountain mine was continued.

3. Sixty new stations are scheduled for installations during FY80. Of these, none have been installed, 45 have been permitted with installation pending, and site reconnaissance has been completed on an additional 15.

4. An on-line system for the PDP 11/34 systems recently acquired by the U.S.G.S. has been designed and implemented jointly with the University of Washington. The initial version is presently in full-time operation of U.W. and is being installed at CIRES. The University of Washington system was fortuitously placed in operation two weeks prior to the onset of activity at Mt. St. Helens, providing an intriguing base of digital data for future investigations as well as expediting the task of monitoring daily changes in seismicity. The system distributed provides for the real-time detection and digital recording at sampling rates up to 100 hz. Changes currently being made will bring the station capacity to 128 stations at the same sampling rate.

5. We are investigating the problem of tidal triggering of earthquakes for both southern California earthquakes and also large earthquakes around the world. We have searched for tidal periodicities in the foreshock and aftershock sequences of southern California earthquakes by stacking those sequences in a manner such that the mainshock times coincide. Although tidal periods can clearly be seen in the stacked earthquake sequence, it does not appear that the correlation is significant enough

to conclusively state that tidal triggering is an established fact. We are also collecting the focal mechanisms of several hundred earthquakes recorded world-wide. We will then compute the tidal shear stress along the slip vector of these earthquakes to see whether the earthquakes occurred during times of maximum shear stress.

6. Necessary hardware for the recovery of network data from FM analog tape has been assembled and partially interfaced to a PDP 11/70 computer.

7. We responded to the 15 October 1979 earthquakes by deploying several field teams to the epicentral area within the first day. One team deployed a network of high gain smoked paper recorders in the region of most intense aftershocks, monitoring the initial aftershock distribution during the first several days. These instruments were then replaced by 5-day tape recorders which were kept in operation for several weeks. A network of 10 strong motion instruments (Kinemetrics SMA-1's) was installed within the first 24 hours in a cooperative effort involving personnel from the U.S.G.S., U.S.C., Caltech, Kinemetrics, and Sierra Geophysics. A total of 52 accelerometer records were recovered during the critical period after many of the permanent stations had exhausted their film. The most important of these have been processed at U.S.C. by Trifunac and Lee. A field team was dispatched to investigate the possibility of a causal relationship between a linear zone of ground disturbance and the largest aftershock ($M_L = 5.8$) which coincidentally occurred along the same trend. No compelling surficial evidence for this association could be found. A group of investigators was sent to look for surficial effects associated with a linear zone of seismicity activated following the 15 October event which appears to extend along the trend of the San Andreas fault into the Imperial Valley. No surface effects were found. Field investigations were also conducted in the vicinity of the Superstition Hills fault where a zone of sympathetic slip was discovered and subsequently mapped in detail. Several shot points occupied during the Imperial Valley refraction experiment completed last year were reoccupied to provide a data base for looking at small coseismic changes in *in situ* velocity. The analysis of these data is in progress.

8. An annual mailing program has been initiated requesting 500 water companies in southern California to notify us in the event of any ground water conditions they feel are unusual. We hope that this program will enable us to recognize relatively obvious ground water changes that may be associated with seismic activity.

Results

1. Preliminary analysis of more than 2,500 aftershocks of the October 15, 1979 Imperial Valley earthquake (M_L = 6.6). The best-located of these are shown in Figure 1 together with several representative focal mechanisms. Several rather surprising observations can be made directly from this figure. 1) There is a surprising absence of aftershocks near the main shock epicenter. 2) Most aftershocks occurred near the Brawley (the northern limit of mapped surface breakage). 3) The M_L 5.8 "Brawley Aftershock" (focal mechanism near Brawley) appears associated with a northeasterly striking seismicity trend suggesting conjugate faulting at the northern rupture limit. 4) A surprising lineation of small events appears to extend the trend of the San Andreas into the Imperial Valley. Activity has continued as isolated clusters along this trend, which was aseismic prior to the time of the mainshock, through the present.

2. There appears to have been a seismic precursor to the October 15 event in the Imperial Valley in the form of a three month period of depressed seismicity. This is shown in Figure 2 where daily count of events detected in the Imperial Valley is plotted for the past two years. The arrow on the abscissa several weeks after the beginning of quiescence marks a change in anti-aliasing filters that may provide in part an instrumental basis for the observed change. Efforts to date suggest, on the contrary, that the change was real.

3. The data obtained during the Imperial Valley refraction experiment partially supported under this project during FY79 has been analyzed resulting in an extremely detailed three-dimensional structure for the Imperial Valley. A number of rather surprising conclusions emerged. 1) Sediment velocity appears to increase with depth with a notable absence of sharp discontinuities. 2) Saddles in travel-time residual crossing the axis of the Imperial Valley seem to correlate with known geothermal areas. 3) Several faults (eg Imperial fault, Superstition Hills fault) are also revealed in basement topography.

4. Pn residual contour maps have been prepared for southern California for 8 events of sufficient magnitude to be recorded well throughout the southern California network. One such example is shown in Figure 3 for the Santa Barbara earthquake (M_L = 5.1) of 13 August, 1978. The closed region of delayed arrivals near the center appears to be a common feature in such plots. The manner inwhich this zone shifts spatially with source azimuth argues for the existence of a region of slower and/or deeper (partial root) mantle in the vicinity of the San Bernardino Mountains.

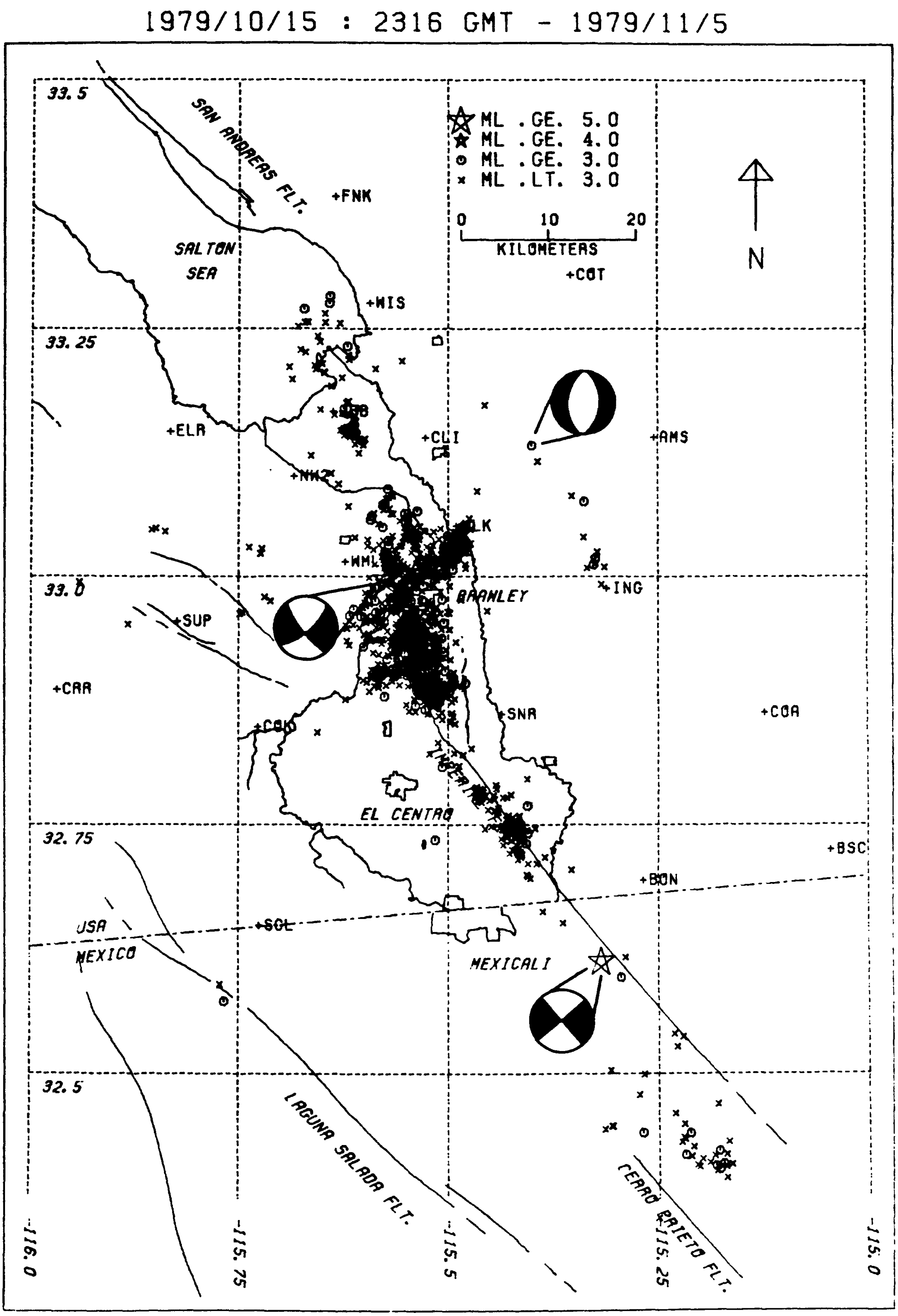

Figure 1 Map of all well-located aftershocks (Quality A, B, or C) from 15 October through November, 1979. Station locations are marked by a '+'. Focal mechanisms are lower hemisphere, equal-area projections with compressional quadrants darkened. The location of the mainshock is indicated by a large star.

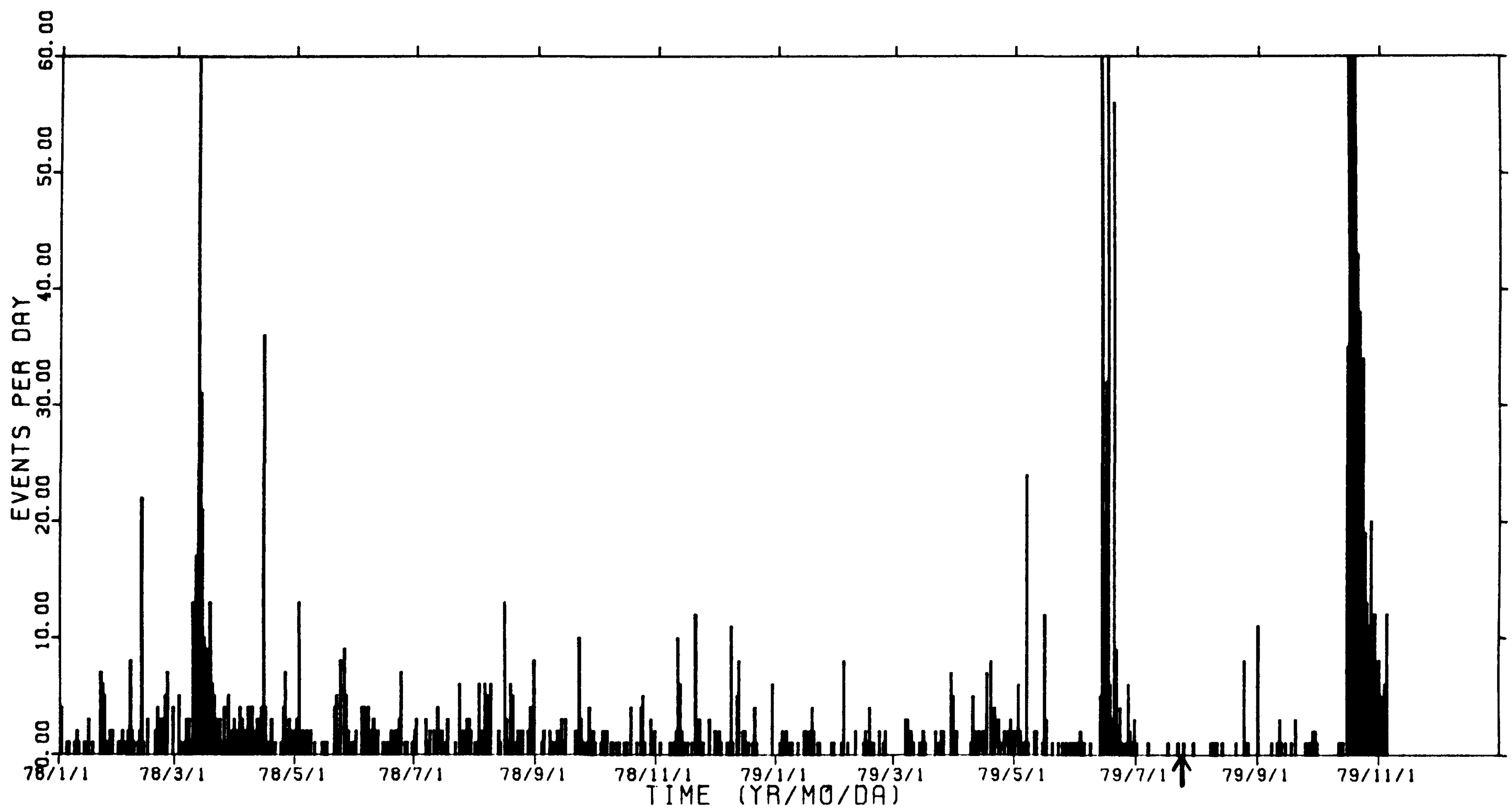

Figure 2 Histogram showing the daily number of events detected by the CEDAR system in the central part of the Imperial Valley from 1 January, 1978 through 5 November, 1979. The arrow marks a change in instrumentation (see text).

AUGUST 13, 1978 VPN = 8.3 KM/SEC

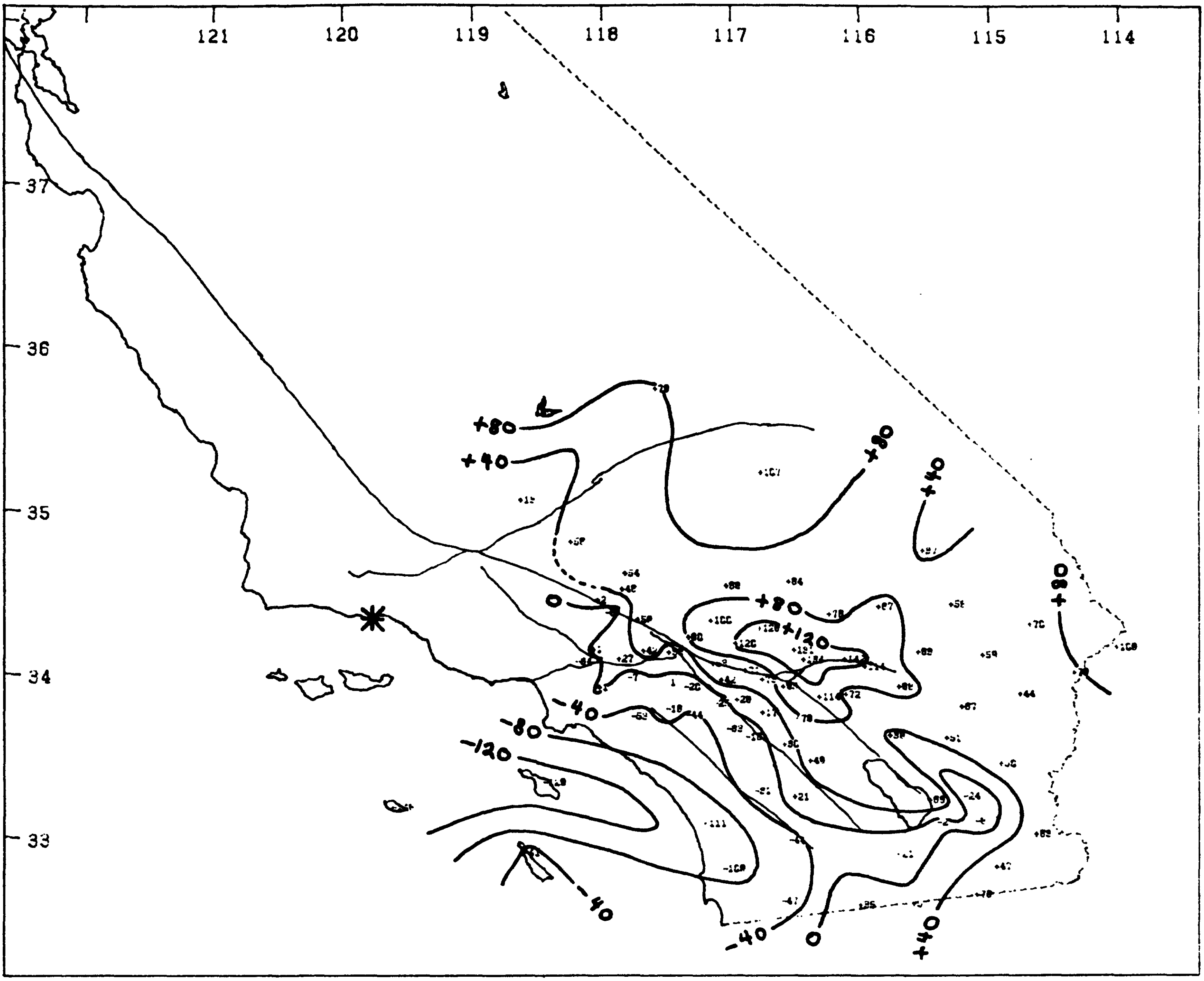

Figure 3 August 13, 1978 Santa Barbara earthquake relative Pn travel time residuals for stations beyond the crossover distance of 125 km from the preliminary epicenter. A mantle velocity of 8.3 km/sec was used with a contour interval of 0.4 seconds.

Reports

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Tilt Strain and Magnetic Measurements
9940-02114

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Investigations

1. Continuous monitoring of various types of crustal deformation parameters now occurs at more than 100 points throughout the San Andreas fault system. Sample rates with digital telemetry are typically 6 per hour. Data are immediately available in an interactive minicomputer for testing, plotting and checking. Precursor algorithms can be routinely run on the data but await demonstration of reliable relationships between earthquakes and the various parameters. The goal is to understand the mechanics of earthquakes by analyzing tilt strain and magnetic field variations which occur as a result of fault activity and by comparing the variations with expectations from the various fault models.

Results

Modeling and analysis of the Coyote Lake earthquake magnetic data is now complete. Analysis in terms of a piezomagnetic source indicates that the only recording instrument in the vicinity of the earthquake was at a point of almost zero signal if uniform magnetization is assumed. This position is not improved if a more complex yet realistic distribution is used. Electrokinetic mechanisms appear to be obviated by these data.

The identification of large scale magnetic field anomalies in California that may result from regional scale stress differences (e.g. southern California versus northern California) is now possible. Secular variation effects have been determined in both space and time and removed from the total field data. Comparison of a group of northern California sites with a group of southern California sites indicates that no significant large scale anomaly has occurred in the past eight years but localized anomalies do occur along particular sections of the San Andreas and adjacent faults.

Drill holes for the Carnegie Institution volume strain meters have now been completed and logged. Installation is planned for April for 3 sites at increasing distance from the fault and 2 sites at about 10 Km from the fault.

Analysis and reduction of magnetic noise has revealed an anomalous signal at a second magnetometer prior to the Thanksgiving Earthquake in 1974.

Post-seismic deformation data obtained by Langbein, Johnston and McGarr after the October 1979 El Centro earthquake show a complex pattern of post-seismic strain readjustment around the northern end of the surface rupture.

Reports

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Seismicity Studies for Earthquake Prediction in Southern California Using a Mobile Seismographic Array

14-08-0001-18322

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Investigations

A 100 km section of the southern San Andreas fault between the Salton Sea and Desert Hot Springs was the focus of an intensive microearthquake field study from February thru September 1979 using a mobile array of eight photographically recorded seismographic trailers. The work was undertaken to examine the nature of quiescence along the San Andreas fault in this region which had not ruptured in historic time. Based on SCARLET array data, this portion of the San Andreas has been in a period of quiescence since 1932 for events of $M_L \geq 4.0$. With two exceptions, events in 1963 and 1977, the quiet has been maintained at the level of $M_L \geq 3.0$ over a 65 km portion of the fault.

Our findings on the nature of seismic activity in the study area are summarized by Figure 1 which shows activity noted during slightly more than half of the study period. Timing and location of events are in progress for the final portion of the field study in which similar observations are expected. The seismicity plot (Figure 1) illustrates the relative quiescence observed along the surface trace of the San Andreas fault even at microearthquake detection thresholds of $M_L = 1.4$.

Having documented characteristic features of microearthquake activity prior to the large event of 15 October 1979 ($M_L = 6.6$) which occurred about 100 km to the south, we considered it essential to reexamine the study area in order to assess any changes which might have been induced as a result of stress redistributions along the San Andreas following the mainshock. Furthermore, Sieh had observed slip along the locked section of the fault in the region of our intensive microearthquake survey (see Figure 2). Aftershock activity was high at the ends of the active zone, particularly north of the mainshock, and extended even beyond the zone of mapped surface rupture, indicative of stress redistribution during the main event. We were able to examine the effects of the stress redistribution by making comparisons between the pre-mainshock and post-mainshock seismicity in the region just north of the primary aftershock zone.

For a one week period beginning 9 days after the mainshock, we occupied five temporary sites (labeled ORF, PAC, BRD, FSH and TRR on Figure 2), on both sides of the San Andreas fault. The stations were operated using MEQ800 continuously recording smoked paper instruments.

Results

Earthquake activity in the Coachella Valley is concentrated on east-west lineations to the east of the main trace of the San Andreas such as the Pinto Mountain fault, the Blue Cut, Porcupine Wash and Salton Creek, and commonly occurs in "clusters" which are very closely related in space and time. Activity associated with these trends has been observed since the installation of the CEDAR system station CTW in 1977. In addition, a particularly quiet area has been observed to the west of the San Andreas in the region of the San Jacinto Mountains. Essentially, no activity is observed between Palm Springs and the Salton Sea throughout the time period which has been analyzed for microearthquake activity. This feature of the seismicity supports the suggestion of a "gap" in this area.

During the one week study using MEQ800 instruments which followed the Imperial Valley 1979 event, earthquake activity was high in the Coachella Valley, but at a rate not unusual for this area (see Figure 2). Specifically, on the third and fourth days of our occupation of these sites, a "cluster" of earthquake activity occurred along an east-west lineation on the eastern side of the San Andreas fault known as Porcupine Wash. The cluster contained about 85 events at the very low $M_L << 1.0$ detection threshold of the nearby temporary station PAC. Similar "clusters" occur commonly along east-west lineations in the study region and were observed in our earlier microearthquake work. Small numbers of events were observed along the San Jacinto fault to the west (Figure 2), along the Banning and Mission Creek branches of the San Andreas to the north, along the east-west trends of the Pinto Mountain fault and the Blue Cut lineation and along the eastern and southern edges of the San Jacinto mountains. Again these events appeared consistent with the pre-mainshock seismicity (see Figures 1 and 2). Magnitudes of the events whose locations were aided by the inclusion of data from the MEQ800 array, range from $1.0 \leq M_L \leq 2.5$. Two events observed during the special study after the Mexicali event of 15 October 1979 do appear related to the slip of Sieh's work (refer to Figure 2). These events, near Sieh's observed surface cracks, occur within 4 km of the mapped surface expression of the San Andreas, thus they are among the closest to the fault of any events observed during the entire microearthquake study.

Reports

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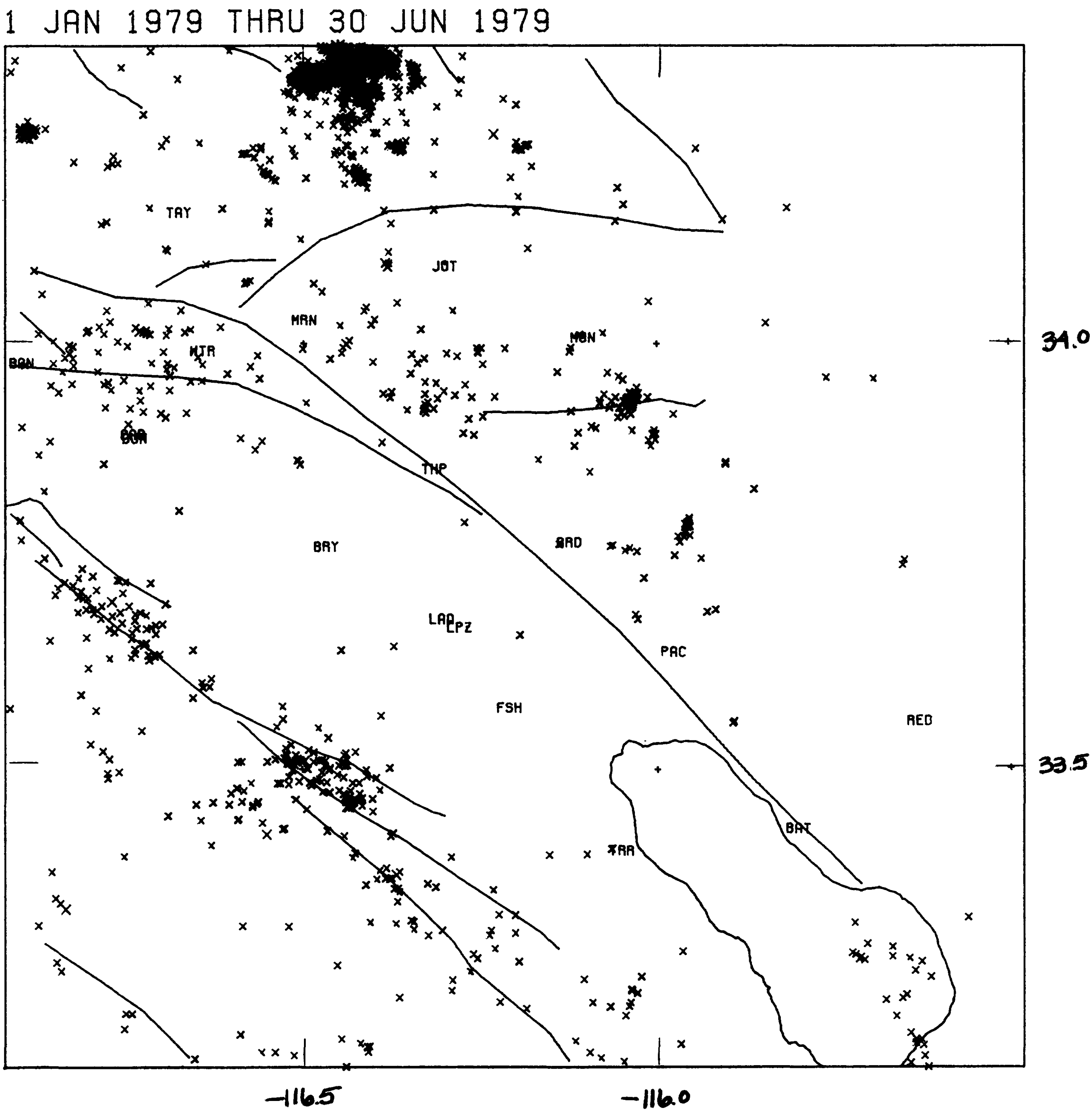
1 JAN 1979 THRU 30 JUN 1979
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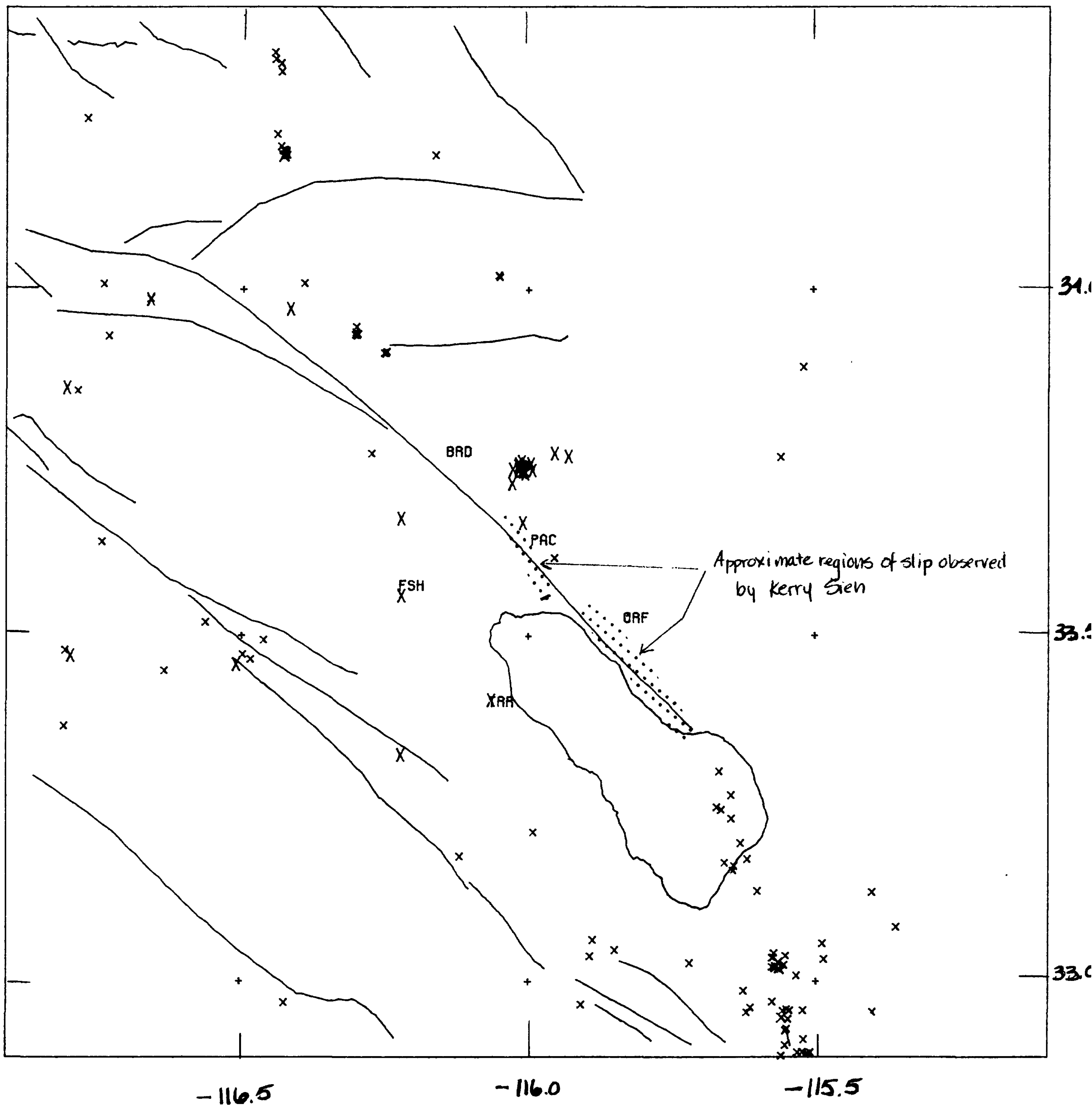
Figure 2

10-24-79 THRU 10-31-79 ALL EVENTS MEQ800 AND CIT



Fault-Zone Water and Gas Monitoring

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Investigations

1. Radon content of subsurface soil gas was continuously monitored by the Track Etch method in capped shallow holes at about 80 sites along several active faults between Santa Rosa and Cholame in central California and 35 sites in southern California (in cooperation with USC, UCSD, and UCSB).

2. Radon content of ground water was continuously monitored at two artesian wells in San Juan Bautista, California (in cooperation with University of Tokyo) and near Banning, California (with USC and University of Tokyo).

3. Water level was continuously recorded and several water quality parameters (temperature, salinity, conductivity, pH) were periodically measured at 8 wells in central California.

4. Water quality and flow rate were periodically measured at two springs near Calaveras fault in San Jose, California.

5. Water samples were collected from the above-mentioned wells and springs and were sent to two USGS groups (I. Barnes and J.R. O'Neill) for chemical and isotopes analyses.

6. A weather station was maintained at Stone Canyon, California. Weather data were collected from a few other local weather stations.

7. Soil-gas samples were periodically collected from eight radon-monitoring sites and were sent to G.M. Reimer of USGS for helium-content measurement.

Results

A moderate earthquake of magnitude 5.5 occurred near Mount Diablo, California on January 24, 1980. Although this quake and its aftershocks are located along a minor fault outside of our monitoring networks, possible premonitory changes were recorded at three soil-gas radon stations along Hayward and Calaveras faults at epicentral distances ranging from 30 to 50 km. Radon concentration at these stations increased episodically with peaks occuring in October or November, 1979. The radon concentration had returned to normal when the earthquake occurred.

Water level recorded at the Chabot well in Oakland (about 30 km from the epicenter) showed several rapid fluctuations of as much as 1.5 meters during the period between December 23, 1979 and January 10, 1980. It is not clear whether these fluctuations are related to the earthquakes or to rainfall.

Electrical Conductivity Sounding Experiments in Seismically Active Areas

Contract No. 14-08-0001-17763

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Controlled source electromagnetic studies of the San Andreas fault south of Hollister indicate that the fault is not vertical but dips westward. At 12 km depth our data indicate that the contact between the poorly conducting Gabilan granite to the west and the conductive material to the east is about 8 km west of the surface manifestation of the San Andreas fault. If the fault is vertical, rather than dipping westward, these data indicate that a wedge of electrically conductive material lies under the Gabilan granite with conductivity similar to that of the Franciscan sediments to the east.

Data analysis thus far has been limited to applying simple, though asymptotically correct methods. The structural complexity of the faulted region coupled with the importance of understanding the fault structure demand doing further analyses and also experiments to conclusively determine the material and geologic structure at the depths where the San Andreas earthquake hypocenters are located. The systematic variation of the data obtained and their coherence with the theory used gives confidence in the qualitative verity of our conclusions.

Water-Level Monitoring Along San Andreas and San Jacinto Faults, Southern California, During First Half of Fiscal Year 1980

14-08-0001-18358

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Investigations

Beginning in October 1976, a program of water-level monitoring of abandoned water wells was initiated in the Palmdale area with the purpose of identifying possible water-level changes premonitory to a major earthquake on the San Andreas fault. In October 1977, the program was extended southeastward along the rift zone to the Valyermo area. In November 1977, the monitoring of water wells along the San Jacinto fault was initiated with the expectation of experiencing a moderate size earthquake while monitoring was in progress. Currently about 35 wells are being monitored. Eight wells are monitored continuously with Stevens Type F recorders. The remaining wells are probed weekly, or in some cases semi-weekly or daily, by volunteers. We are endeavoring to improve the volunteer program by increasing the frequency of measurements and simplifying the procedure to minimize measurement errors.

Weekly water-level data are displayed on computer-generated hydrographs for each well. Rainfall and earthquakes are plotted on the graphs for direct comparison with water levels. The hydrographs are updated and reviewed weekly. Weekly hydrographs are also prepared from recorder charts on two wells maintained by W. R. Moyle, Jr., of the U.S. Geological Survey, Water Resources Division Office, Laguna Niguel, California.

Remote Observatory Support Systems (TIMS) constructed by the Caltech Seismological Laboratory have been installed at wells in Juniper Hills and Anza to telemeter water-level data to Caltech. Because of noisy phone lines, neither system is operational at present.

Results

A M5.3 earthquake occurred on 25 February 1980, between the Buck Ridge and San Jacinto strands of the San Jacinto fault zone, about 8 miles east-southeast of Anza. This is the largest earthquake which has occurred on the faults within our monitoring network. Figure 1 shows the Stevens recorder chart for well number 11S/6E-3N4 located in Borrego Valley about 22 miles southeast of the epicenter. During a period of about four hours on 21 February, the water level rose 1.5 to 1.6 feet and returned to its prior level. This is one of the most remarkable short-term water-level fluctuations observed during our monitoring program; it occurred about 88 hours prior to the earthquake. This well has been monitored since October 1977 and has had a Stevens recorder since October 1978. Long-term water levels have been remarkably steady compared to those in other wells we are monitoring. Since October 1977, the water level has gradually and steadily dropped about two feet and has shown

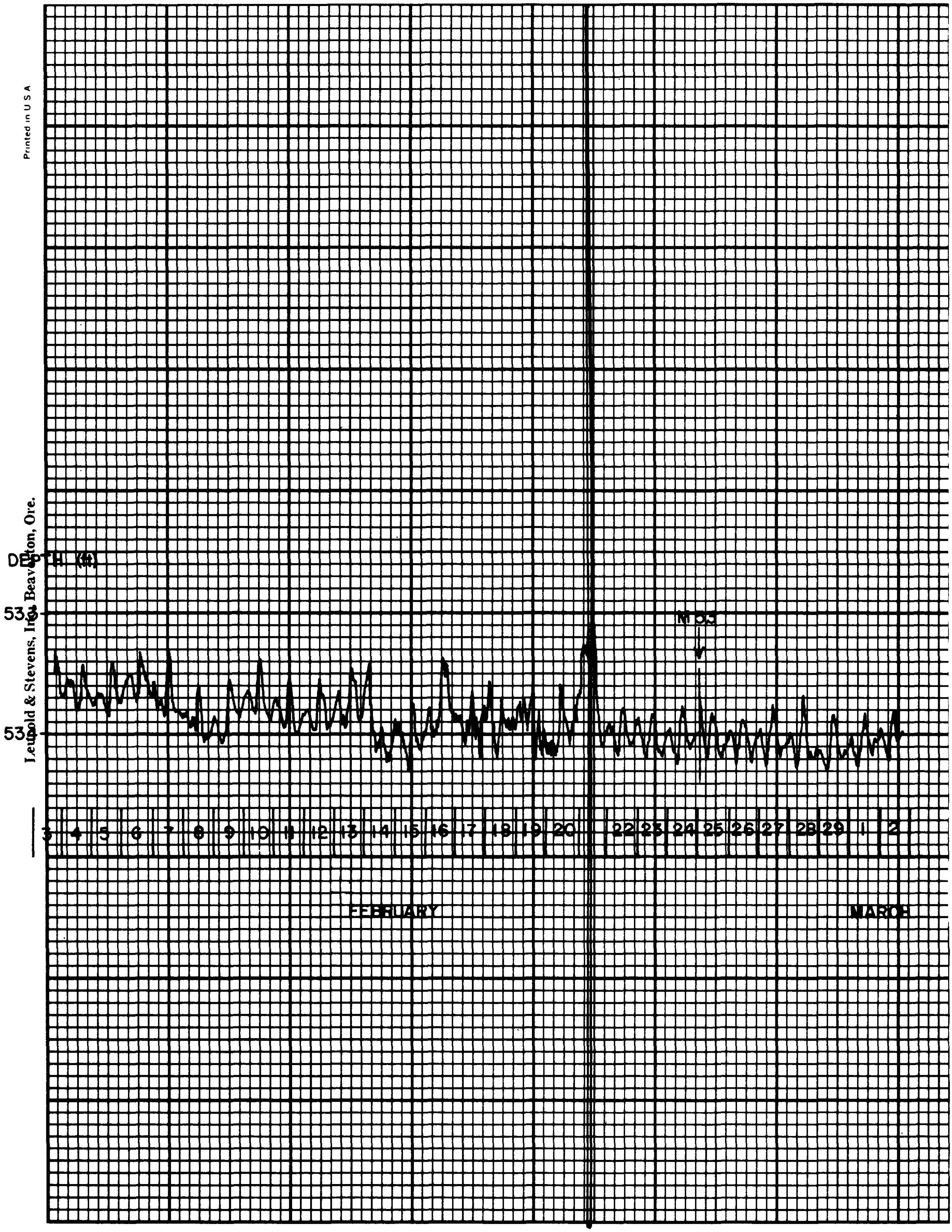

Figure 1 - Stevens water-level recorder chart for well number 11S/6E-3N4, Borrego Valley, for period February 3 - March 2, 1980.

no seasonal variation and no identifiable response to rainfall. This well shows a strong response to earth tides (short-period fluctuations on Fig. 1). The Stevens record on a second well in Borrego Valley showed a much smaller (0.1 foot) spike in water level at the same time as the spike in well number 11S/6E-3N4. Other continuously recording wells in Anza and Ocotillo Wells showed no identifiable water-level anomalies. The two wells in Borrego Valley which showed the possible strain-induced water-level spikes appear to be more sensitive to earth tides than wells in the same area which did not show spikes in water level. We cannot conceive of any nontectonic cause for the spike in Figure 1. A creep event on the Coyote Creek fault about 4 miles from the well is one possibility. Because the spikes in the two wells in Borrego Valley are unique for the long-term record of these wells, they may represent precursors to the 25 February earthquake.

Several wells in the Palmdale-Valyermo area have shown peculiar changes in water level within the past year or so. Figure 2 shows the long-term hydrograph of the well with the most unusual behavior. The well showed no response to the 1977 and very heavy 1978 rainstorms, yet began to rise in early 1979 and continued to rise through the dry season of 1979. By comparison, Figure 3 shows a more normal seasonal response to rainfall. Most wells show a similar pattern, but eight wells in the Palmdale-Valyermo area have shown water-level changes which are different than would have been predicted from the previous history of water-level changes and seasonal rainfall. A longer period of observation is required to determine whether the changes are anomalous. Changes in the strain pattern and other geophysical phenomena have also been observed in southern California during the same period as the water-level changes. If the water-level changes are the result of tectonic strain, the mechanism and significance are unknown. However, it is interesting that five of the eight wells with possibly anomalous water-level changes have been identified as good strain meters based on their response to earth tides. Six wells showing an unexpected rise in water level are located west of the earthquake swarm which occurred in 1976-1977 (McNally et al, 1978), whereas those which show water levels lower than would have been predicted are located east of the earthquake swarm.

Reference

McNally, K. C., H. Kanamori, J. C. Pechman and G. Fuis, 1978, Earthquake swarm along the San Andreas fault near Palmdale, southern California, 1976 to 1977: Science, v. 201, p. 814-817.

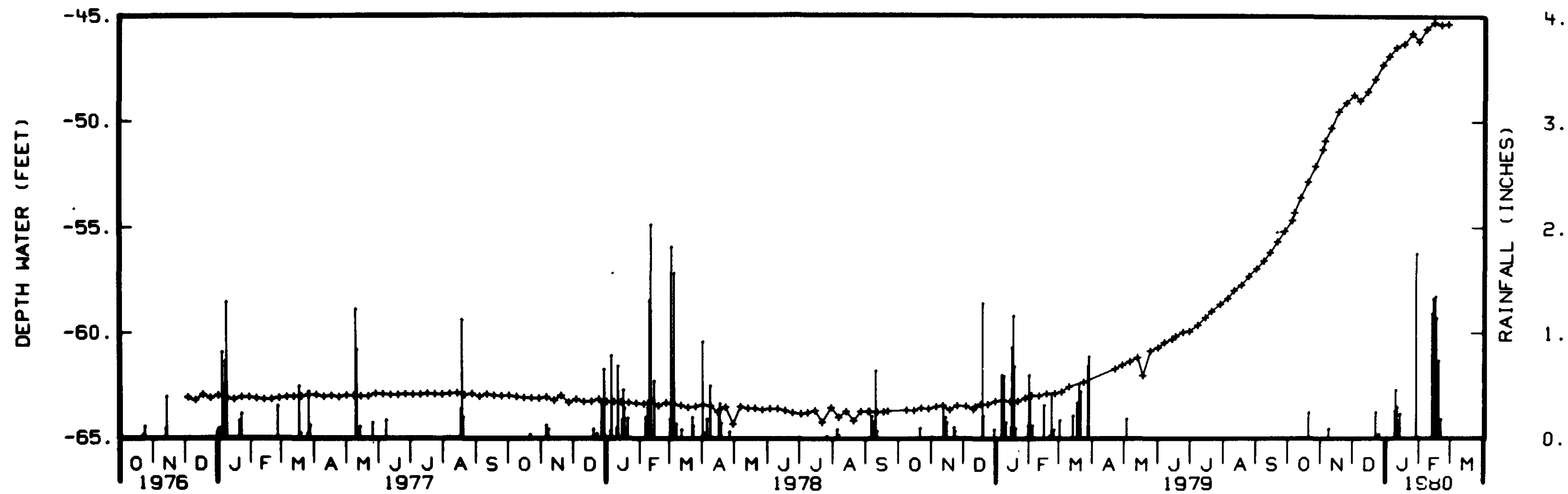

FIGURE 2 -- WEEKLY OBSERVATIONS OF WATER LEVEL (+) AND RAINFALL (.) IN WELL NUMBER 05N/12W-04H01 DURING 1976-1980, PALMDALE AREA

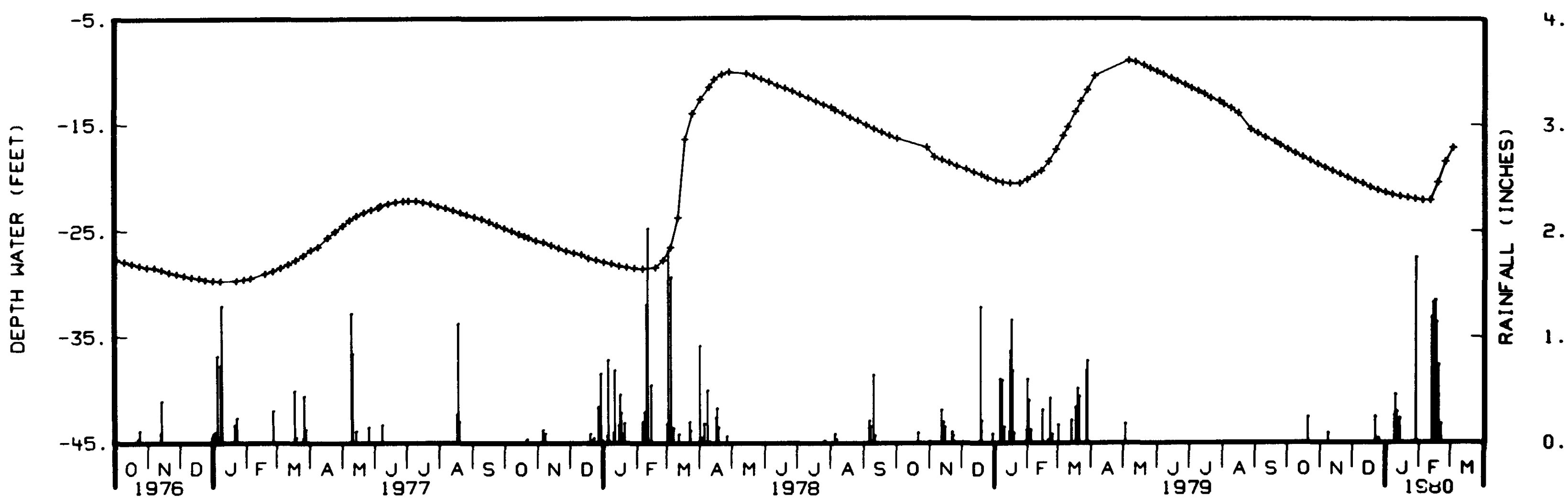

FIGURE 3 -- WEEKLY OBSERVATIONS OF WATER LEVEL (+) AND RAINFALL (.) IN WELL NUMBER 05N/11W-07G02 DURING 1976-1980, PALMDALE AREA

Investigation of Thermal Regime Across the San Jacinto Fault

14-08-0001-17714

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Investigation

Geothermal gradients measured at six sites along a profile increase toward the San Jacinto fault in southern California. Four measurements made at individual sites between June, 1979 to March, 1980 which covered the local dry and wet seasons show the measured gradients vary at most 3% from each other within the depth range from 50 to 100 m. Steady-state topographic effect on the measured gradients amounts to $\sim$1%. There appears no systematic variation in thermal conductivity with distance to the fault trace. On the northeastern side of the San Jacinto fault, the heat fluxes are 39, 49 and 59 $\times 10^{-3} W/m^2$ at a distance of 16, 7, and 0.5 km, respectively, from the fault trace; on the southwestern side, the heat fluxes are 27, 25 and 72 at 20, 5 and 1 km, respectively, from the fault trace. The latter trend confirms previously reported values of 40, 58 and 51 $\times 10^{-3} W/m^2$ at a distance of 13, 4 and 1 km from the fault trace.

Heat-flow anomaly has been speculated to be associated with major active strike-slip faults but the substantiation of the expected anomaly has been hampered by complicated geological and hydrological conditions near a major fault zone. This study demonstrates, perhaps for the first time, a heat-flow anomaly approximately $30 \times 10^{-3} W/m^2$ over an active fault zone. The anomaly provides an interesting constraint toward the understanding of faulting mechanism.

Results

We have made four gradient measurements in each of six wells from June, 1979 to March, 1980. The measured gradients vary at most 3% at individual sites for the depth range of 50 to 100 m. Because the measurements were made both in the wet and dry seasons, the effect of groundwater on the geothermal gradients appears to be negligible in those sites.

The gradients on the northeastern side of the San Jacinto fault are 17, 19 and 27°C/km at distances of 16, 7 and 0.5 km from the fault trace, respectively; the gradients on the southeastern side are 27, 15 and 11°C/km at 1, 5 and 20 km from the fault trace, respectively (Table 1). The gradient measured at site W1 may not be as reliable as those at other sites because the collapse of well has shortened the well depth for measurements. Site N1 is approximately 35 km to the northwest of the profile of other sites.

Topographic effect amounts to about 1% on the assumption of steady-state condition at sites E1, E2 and E3. The effect at other sites is judged to be insignificant too. The gradient values cited here are obtained with the least-squares method.

Thermal conductivity have been measured for core and chip samples with the divided-bar apparatus. Table 1 shows the means of the measured values for core samples. There appears to be no systematic variation with the distance from the fault trace. The rocks measured are tonalites of the southern California batholith, except at site E1 where the rocks are deposits consisting mainly of decomposed granites. The cores from site E1 were too severly distorted to be measured in the divided-bar apparatus.

Our results indicate clearly heat flux increases toward the San Jacinto fault. The trend on the southwestern side of the fault confirms previous study made by Henyey and Wasserburg (1971). They report values of 51, 58 and $40 \times 10^{-3} W/m^2$ at 1, 4 and 13 km, respectively, from the fault trace.

Various investigators have reported absence of heat flow anomaly associated with major strike-slip faults. This study demonstrates, perhaps for the first time, a heat flow anomaly over a major strike-slip fault zone.

References

Henyey, T. L. and Wasserburg, G. J., 1971, Heat flow near major strike-slip faults in California: Journal of Geophysical Research, V. 76, no. 32, p. 7924-7946.

TABLE 1

Heat Fluxes Across the San Jacinto Fault

Site	E3	E2	E1	N1	W1	W2
Latitude 33°N	37' 00"	32' 30"	34' 06"	42' 15"	33' 36"	28' 40"
Longitude 116°W	25' 30"	30' 12"	37' 45"	53' 22"	42' 55"	50' 43"
Distance* km	+16	+7	+0.5	-1	-5	-20
Conductivity** W/ms	2.32 (18)	2.59 (6)	2.17 (8)†	2.67 (7)	1.68 (10)	2.48 (2)
Gradient °C/km	17	19	27	27	15	11
Heat Flux $10^{-3}W/m^2$	39	49	59	72	25	27

*Distance to fault trace "+" for sites to the northeast of the fault and "-" for sites to the southwest of fault

**Numbers in parenthesis indicate number of core samples measured

†Tentative estimate from chip samples

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Contract #14-08-0001-17686

Can Animals Predict Earthquakes?
A Search for Correlations Between Changes in the Activity Patterns of Captive Fossorial Rodents and Subsequent Seismic Events

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Page Hayden, Research Associate

This project is an experimental investigation of the possibility that certain animals may behave in unusual ways immediately prior to nearby earthquakes. To that end, we are continuously monitoring the activity of a small number of individuals of a few species of captive burrowing rodents. At a facility located on the Big Morongo Wildlife Reserve in San Bernardino County, California, we have the capability of monitoring 20 animals housed individually in running wheel cages in an indoor, temperature controlled room, and 11 animals housed individually in fabricated burrow systems located out of doors. We also have installed a second burrow system facility in Stone Canyon, San Benito County, California. The latter facility has the capablilty of monitoring 10 rodents.

At the indoor facility on the Morongo Reserve we have been using kangaroo rats (Dipodomys merriami), and at the outdoor facility we have recently been monitoring six little pocket mice (Perognathus longimembris), four kangaroo rats, and one large pocket mouse (Perognathus sp.). These species are native to the area, and all individuals were trapped on or near the Reserve. At Stone Canyon, we are monitoring six P. longimembris and will begin monitoring four larger animals, probably P. californicus, which is native to the region.

The most significant seismic events of the last six months, relevant to this study, occurred near Lake Hemet, California, and near Hollister, California. The Hollister event was of magnitude 4.9, with its epicenter about 30km from the Stone Canyon Study Site. This is approximately the same distance as the Landers quake of March 1979 for which we reported unusual animal behavior. The quake occurred 13 April 1980, and analysis of animal data is in progress.

The Lake Hemet event was of magnitude 5.3, with its epicenter about 40km from the Morongo Study Site. The quake occurred 25 February 1980 and was experienced by residents at the Study Site. Analysis of wheel running activity from the indoor facility did not support the premise that animals do anticipate seismic events. Results of the analysis were not surprising, and do not invalidate the study. The Lake Hemet quake was a considerable distance from the Morongo Site, and in a geological setting which, in our judgement, would make seismic precursors at Morongo Valley rather unlikely.

Animal data taken from the Morongo Site, prior to the March 1979 earthquake swarm near Landers, California, was compared with foreshocks probably experienced at Morongo. Foreshocks were found to correlate with the animal activity anomalies reported earlier. Thus, foreshocks must be included in the list of coincident environmental changes that might have triggered the behavioral changes observed.

Parkfield Prediction Experiment
9930-02098

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Investigations

Seismic data are being analyzed in conjunction with geodetic observations to develop the ability to predict the next magnitude 5.5 Parkfield earthquake. Our immediate goal is to use this information to build a strong working hypothesis against which slip and stress distribution along this segment of the San Andreas can be predicted and measured.

Results

We have relocated the earthquakes in the Parkfield area ($M \geq 2$) for 1969-78 and are compiling a near real-time (within three weeks) seismic catalog ($M \simeq 1$). We have also reexamined the seismic activity for the six months preceding the 1966 Parkfield earthquake and found that seismicity levels were five-to-ten-times lower than recent levels. We are presently in a relatively quiet period possibly similar to the period in 1974, 1976 and 1977 which preceded a magnitude 4-5 earthquake.

A paper with Dave Boore on the 1966 Parkfield earthquake has been completed in which it is shown that two discontinuities (a bend and an offset) controlled the points of initiation and termination of that rupture. These same two features play a large part in controlling the creep and seismic regime.

Several new alignment arrays and an array of invar wire strainmeters have been installed near the 1966 epicenter where measurement of established alignment arrays indicate a recent change in creep rate. We have assumed responsibility for Caltech's cluster of creep-, strain-, and tiltmeters at Gold Hill and are in the process of acquiring all local data records by telemetry. Creepmeters at Gold Hill and Slack Canyon have operated well and we were able to monitor a 1 mm creep event at Gold Hill in real time. The tiltmeters have not performed well due to thermal instability but field testing of a modified unit is underway.

Results of a gravity survey and geologic reconnaissance were used to resolve local structural complexities and to evaluate several rock units as possible sites for a pair of Sachs-Everson volumetric strainmeters. We intend to emplace the instruments at Gold Hill at a depth of 150-300 meters in hornblende quartz gabbro.

Since 1966 a variety of geophysical measurements have been made in this area by Caltech, the State of California (Division of Mines and Geology) and the USGS. Analysis of this data has led us to the following conclusions: 1) The 1966 earthquake (and by inference the earlier events as well) occurred on a slip patch approximately 5 km wide and 20 km long, centered at a depth of 5 km beneath the town of Parkfield. Displacement during the earthquake averaged about 50 cm. 2) To the north of this 20 km long zone the surface slip rate for 1970-80 is 25 mm/yr but less than 10 mm/yr to the south. 3) Similarly the microseismicity rate is 15 eq/yr ($m > 1\ 3/4$) to the north but only 5 eq/yr to the south. 4) The microseismicity which does occur adjacent to the '66 rupture is clustered on the periphery, much as the aftershocks were. This activity is somewhat deeper and has a lower b-value (0.8) than seismicity in the north which has a b-value of 1.2. 5) Analysis of the geodetic data indicates that between 1970-80 the '66 slip patch slipped on the average between 0 and 15 mm/yr, while the adjacent portions of the fault, to the north and below 10 km, slipped at about 30 mm/yr.

We assume that the next Parkfield earthquake will involve this slip patch "catching up" with the adjacent portions of the fault. We hope that prior to the final failure some accelerated deformation will occur, and our efforts at this time are directed to detecting this deformation.

Reports

Mantis, C., Lindh, A., Savage, W., and Marks, S., 1979, Catalog of Oroville, California earthquakes - June 27, 1975 to July 31, 1976: U.S. Geological Survey Open-File Report 79-932.

Centrifuge Modeling of Earthquakes
Air-Gun Seismic Velocity and Attenuation Measurements
in the San Andreas Fault Zone
9960-02413

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Investigations

1. Range and repeatability test of Bolt Associates PAR DHS-600B borehole air gun in Imperial Valley, California.

2. Laboratory measurement of rock internal friction at seismic amplitude ($\sim 10^{-8}$ strain) and frequencies.

Results

1. A 40 cubic inch borehole air gun (Bolt Associates PAR DHS-600B) range and repeatability test was conducted in conjunction with the Fault Zone Structure Project (9960-01725) in Imperial Valley, California, in November 1979. The firing conditions of the air gun were: (i) air pressure 138 bars (2,000 psi), (ii) depths 1 m (in a surface mudpit 1.5 m x 1.5 m x 1.5 m filled with drilling mud) and 43 m (in a 20 cm diameter steel cased hole). The result of the range test is shown in Figure 1. The first p-arrival of a single shot can be detected 5.5 km away through the unconsolidated sediments. The result of the repeatability test is shown in Figure 2. The wavetrain remained essentially unchanged after one hundred shots both for the shallow mudpit and the downhole emplacement conditions.

2. An apparatus for measurement of rock internal friction by the mechanical hysteresis loop method at seismic amplitude ($\sim 10^{-8}$ strain) and frequencies has been constructed. Some features of this apparatus are: (i) The stress transducer (solenoid) is placed in series with the sample column. The stress applied to the sample is measured by a loadcell also placed in series with the sample column. (ii) An analog function amplifier was constructed to correct for the non-linear force-current characteristics of the solenoid. (iii) A noise isolation table and a low vacuum bell jar were assembled to reduce the background noise and drift during the internal friction measurement. This investigation is performed in conjunction with Rocks under Geothernal Conditions Project (9960-01490).

Reports

Liu, H.-P., 1980, Driving stress waveform and the determination of rock internal friction: Geophys. J. R. Astr. Soc., 60, in press.

Liu, H.-P., 1980, The structure of the Kurile Trench-Hokkaido Rise System computed by an elastic time-dependent plastic plate model incorporating rock deformation data: J. Geophys. Res., 85, 901-912.

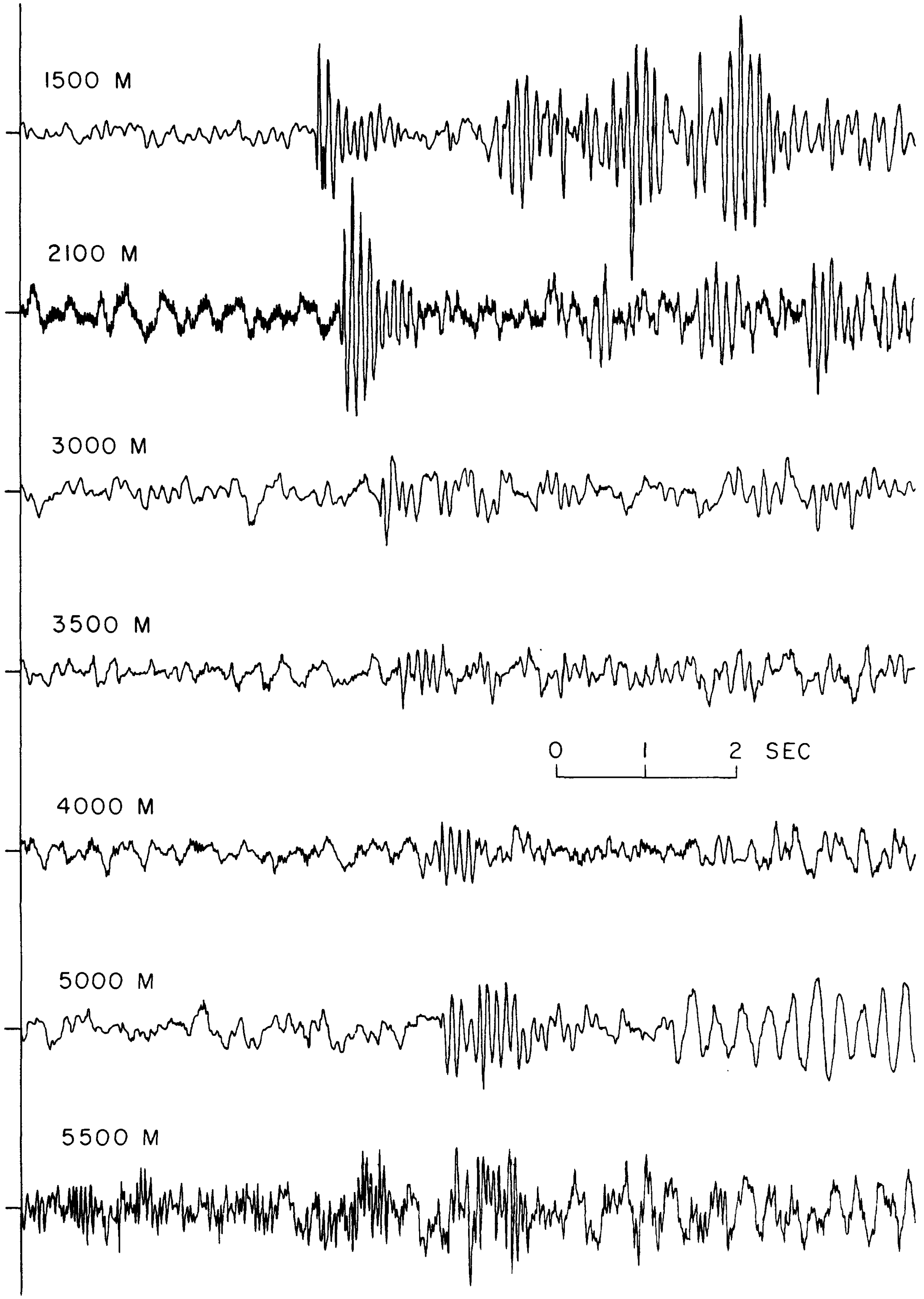

Figure 1. Air gun range test (single shot in shallow mudpit).

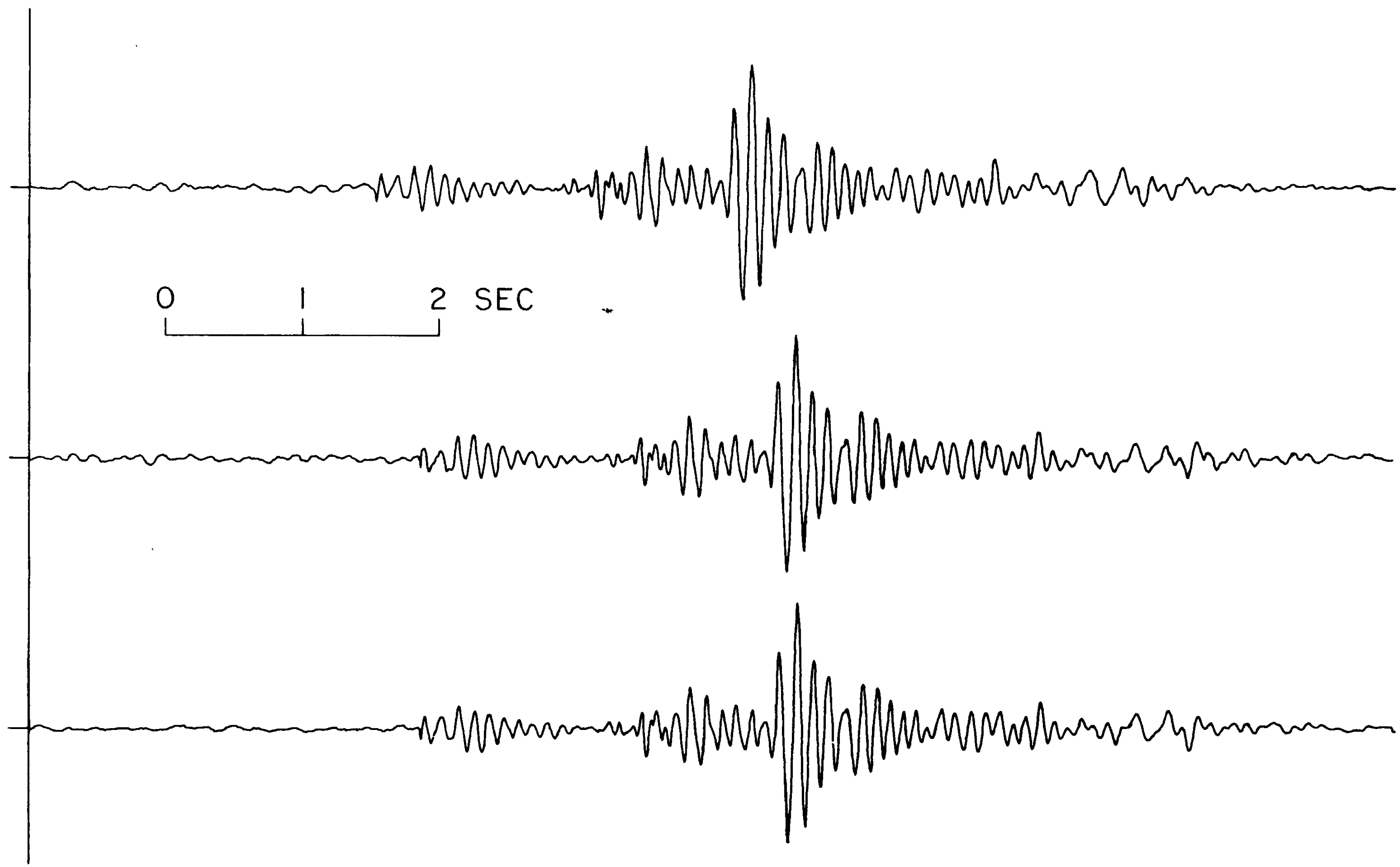

Figure 2. Air gun repeatability test. From top to bottom the first, the twentieth and the fortieth shot (shallow mudpit).

Baseline Studies of the Feasibility and Reliability of Using Animal Behavior as a Component in the Prediction of Earthquakes

14-08-001-G-482

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Investigations:

We are continuing our investigation of the possibility that abnormal animal behavior may result from precursory earthquake stimuli. From May 1979 to the present, we have acquired additional data from seismically active portions of the island of Hawaii, from the Coyote Lake earthquake of August 1979, and from the Mexicali earthquake of October 1979. We have also met with Japanese scientists to discuss their methods of data collection and interpretation in an effort to analyze the relationship between animal activity and earthquake stimuli. Data collection was terminated in October 1979. Our primary activity for the period of November 1979 to June 1980 is to analyze data collected during the entire project and to summarize and publish information on: 1) animal behavior as it relates to different types of earthquakes, varying magnitudes and distance from the epicenter, 2) the relative degree that local custom or culture influences the acquisition of reliable and credible reports of abnormal animal behavior before earthquakes, 3) the characteristics of abnormal animal behavior as it varies from species to species, and 4) the feasibility and reliability of using abnormal animal behavior as a component in the prediction of earthquakes.

Results:

Fifty-two interviews were conducted following the Coyote Lake earthquake. These interviews provided us with information on approx. 1251 domestic animals, including 60 dogs, 41 cats, 54 horses, 924 cattle and 50 chickens among others. We believe, based on our experience with animals and their owners, that the rate of unusual animal behavior at Coyote Lake was not greater than the rate that would be observed on any ordinary day. We also investigated a publicized cluster of reports of unusual animal behavior occurring at a wild animal park about 70 km from the epicenter. In-depth interviews with individuals responsible for the maintenance and handling of these animals indicates that in most cases the behavior attributed to the earthquake by the news media is better explained by other factors not associated with the earthquake. A more complete analysis of these data was presented at the December meeting of the American Geophysical Union.

Baseline Studies of the Feasibility and Reliability of Using Animal Behavior as a Component in The Prediction of Earthquakes.

Purchase No. 91622

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From December 1979 to May 1980 we have devoted all our time to compiling and analysing the data gathered during the whole of our project, and reviewing the literature on this topic preparatory to publication and the writing of our final report. While data analysis is not completely finished the current state of the analysis strongly suggests that the incidence of abnormal animal behavior increased before one of the eight earthquakes we studied but not the other seven.

Studies of folklore have produced a converging line of evidence for our conclusion that some earthquakes are preceded by unusual animal behavior and others are not. For example, Cuzco, Peru has strong folklore traditions of unusual animal behavior as a precursor while the island of Hawaii does not. This raises the possibility that unusual animal behavior may be consistently present as a precursor near some fault systems and consistently absent near others.

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High Sensitivity Monitoring of Resistivity and Self Potential Variations in the Palmdale and Hollister Areas for Earthquake Prediction Studies

Contract No. 14-08-0001-16724

Principal Investigators: T. R. Madden and M. N. Toksöz
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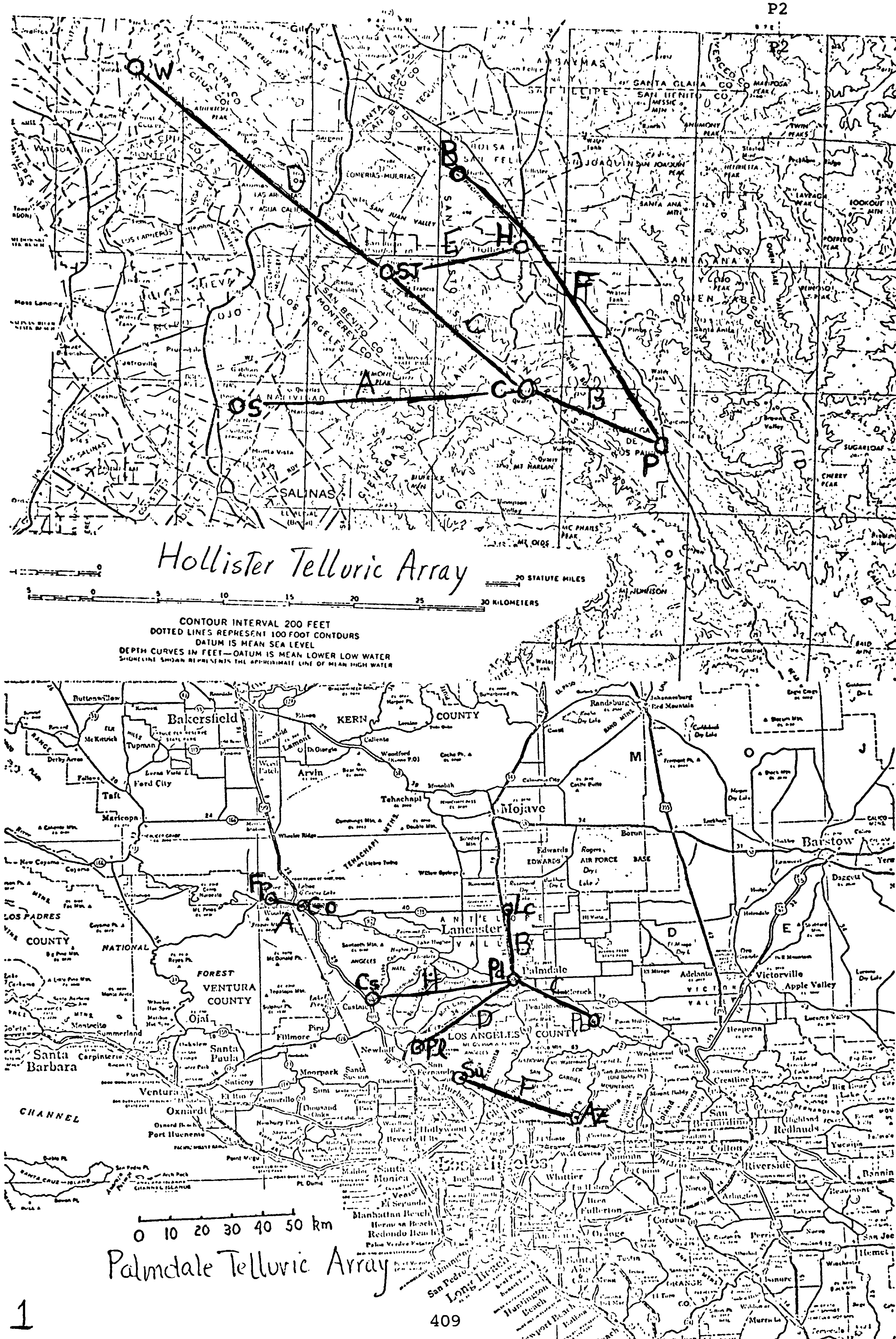
We are still in the midst of changes in our analysis methods to try and deal with gradient effects in the source fields and our data is not yet in its final form. The Palmdale data is effected by self potential noise at Castaic and this will require some special processing as the Palmdale-Castaic dipole is used as a reference signal. The electrodes presently being used are judged to be unsatisfactory and we shall be installing new types in the very near future.

An earthquake occured at San Juan Bautista on day 103, 1980, but we did not observe any coseismic effects. Fig. 2 shows the self potential variations on the Hollister array. Some drift set in at Cienega and San Juan Bautista through February and March, but we have not yet assessed what part of this was electrode potential drift. There was no observable self potential signal relating to the April 12 event at San Juan Bautista. The resistivity variations are shown in Figure 3 as running three day averages. The correlations seen between B and F and D and E are probably due to the slightly damped inversion of the cancellation residuals to obtain dipole variations.

The Palmdale array self potential variations are shown in Fig. 4. Here we are experiencing even more severe electrode problems than in Hollister and we will soon be installing new electrode types. The Castaic potential is cultural and now some 200 mv positive, but showing large fluctions. These are effecting our resistivity variation analysis as the Pd-Cs dipole is one of the reference signals. This shows up as strong correlations in all the dipole apparent resistivity variations. This effect can be accounted for in the data processing but we have not finished this analysis. The variations shown in Fig. 5 are thus not true resistivity variations. F and A also have some bad data due to noise in the telemetering circuits which we hope to eliminate.


Hollister Telluric Array
W
D
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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
SALINAS
Bakersfield
KERN
COUNTY
Mojave
Barstow
Lancaster
Palmdale
Victorville
Apple Valley
VENTURA
COUNTY
LOS ANGELES
COUNTY
Santa Barbara
Fr
Co
A
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0 10 20 30 40 50 km
Palmdale Telluric Array

Fig 1

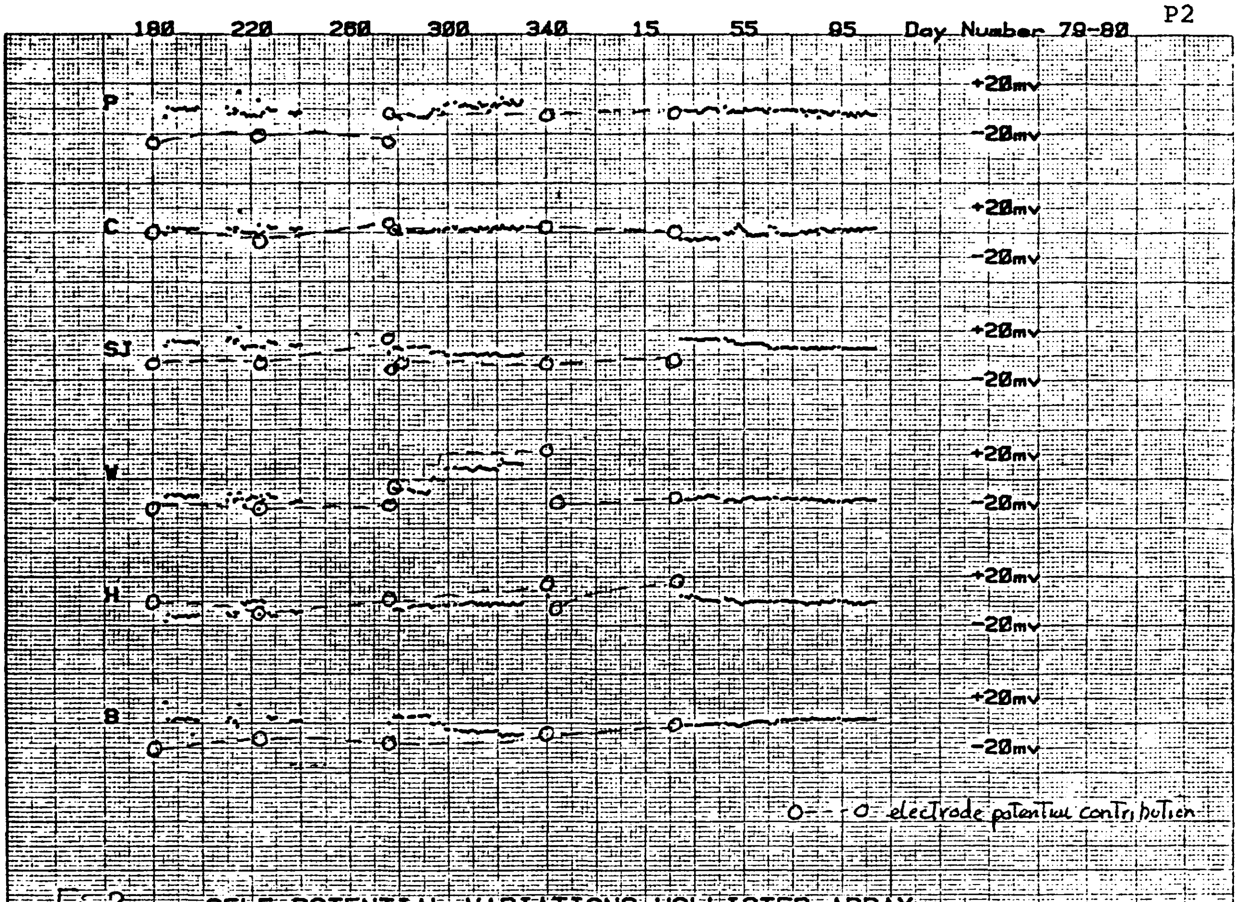

Fig 2 SELF POTENTIAL VARIATIONS HOLLISTER ARRAY

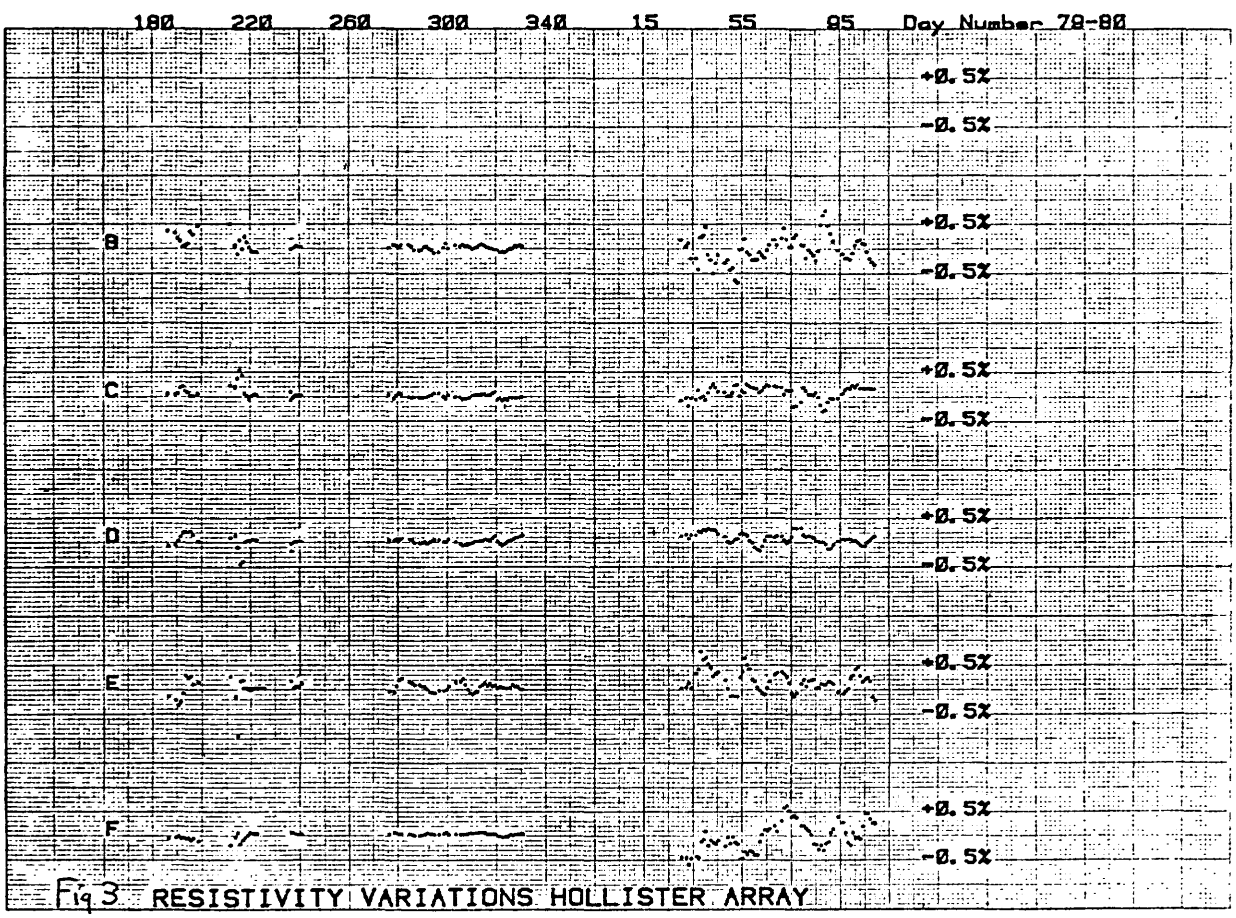

Fig 3 RESISTIVITY VARIATIONS HOLLISTER ARRAY

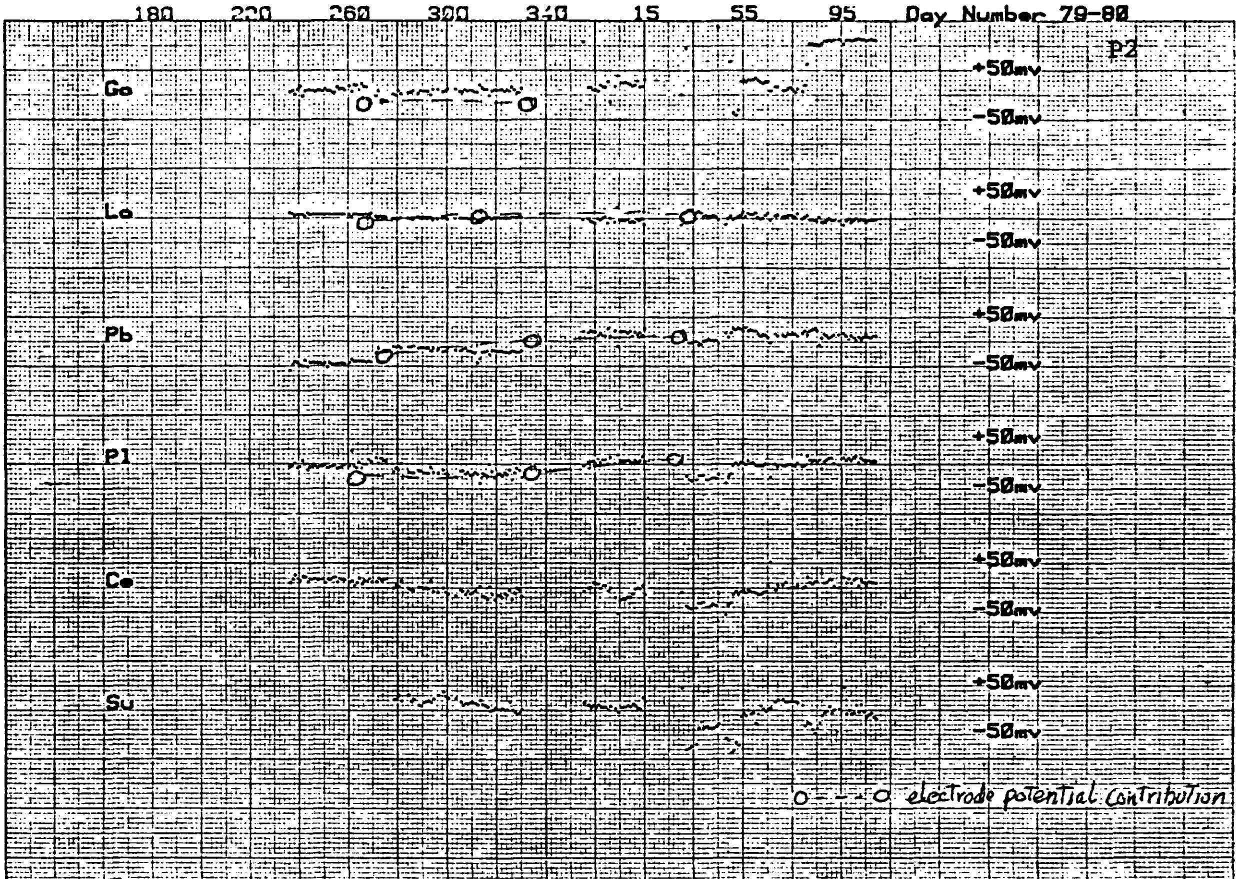

Fig 4 SELF POTENTIAL VARIATIONS PALMDALE ARRAY

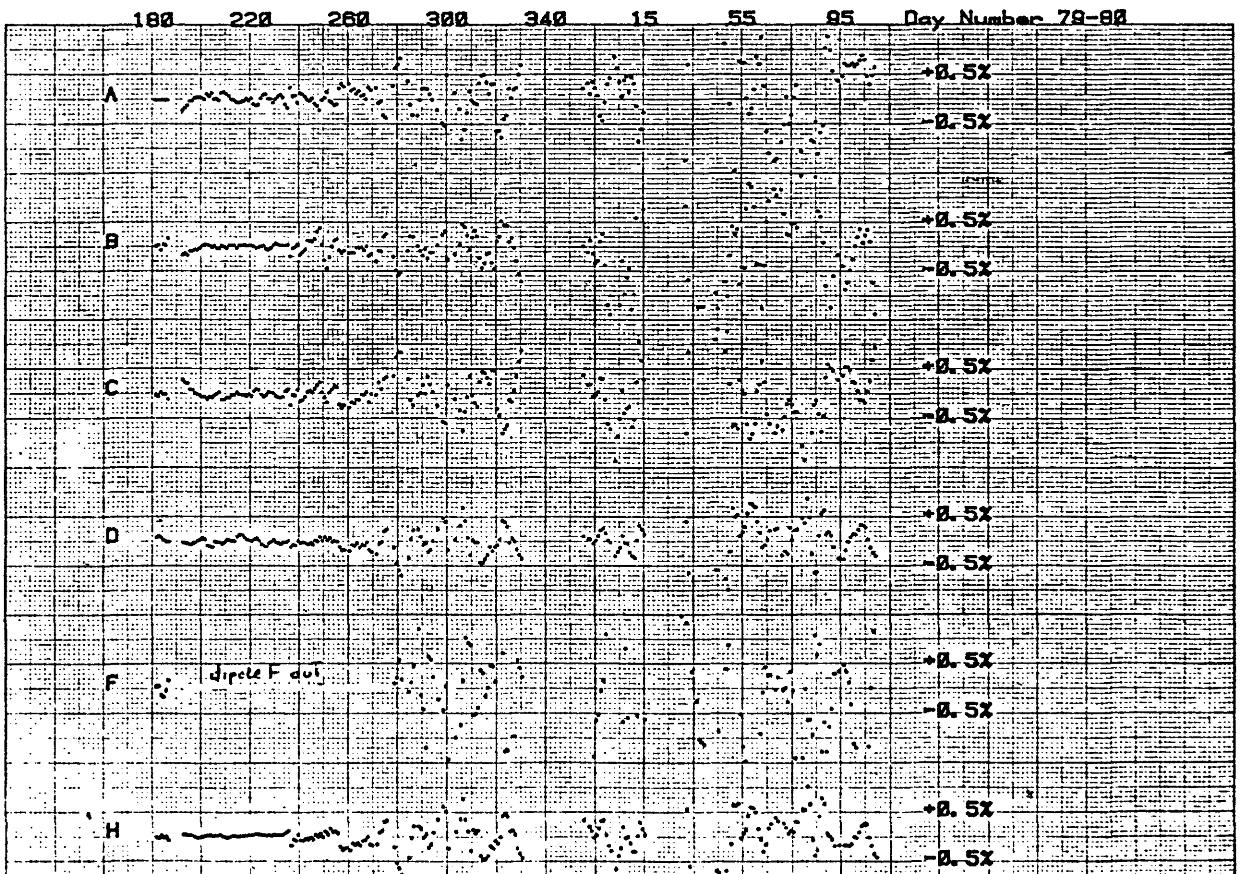

Fig 5 RESISTIVITY VARIATIONS PALMDALE ARRAY

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9960-02156
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Investigations

1. A portable two-color laser geodimeter (Terrameter) was ordered in 1978 for the purpose of high-resolution trilateration surveys in selected areas of the San Andreas fault system.

2. Postseismic deformation was measured using an electronic distance measuring instrument in the region around the morthern third of observed surface rupture of the October 1979 Imperial Valley earthquake.

3. Multi-wavelength geodetic measurements across the Hollister network were analyzed in relation to the August 1979 Coyote Lake earthquake and episodic creep measured in and to the north of Hollister.

Results

1. The measurement program has not yet begun due to delays in the delivery of the Terrameter. The Terrameter was shipped to Menlo Park in the latter part of February 1980 but was found to have some serious problems during the course of the acceptance tests at Hollister during the following several weeks.

2. A geodetic network consisting of 54 baselines, typically 1 km in length, extending northwestward from the Imperial College network, was established starting on 27 October 1979, about 12 days after the Imperial Valley earthquake. The network was surveyed Five times during the period from late October 1979 until mid-February 1980 and the resulting time histories of the baselines were analyzed. From remeasurements of the baselines spanning the trace of the Imperial fault, the fault slip accumulated as a logarithmic function of time with a rate of 3.2 $\pm$ 0.1 mm/day in late October to 0.34 $\pm$ 0.01 mm/day in mid-February. The corresponding strain changes, deduced primarily from measurements over lines on either side of the fault, were largely consistent with a pattern of strain release due to the postseismic fault slip. From October 27 to November 14 the most significant strain change was a northwesterly compression at a rate of 0.3 $\pm$ 0.1 μstrain/day. The data are in quite good agreement with

expectations based on a simple model of uniform slip on the Imperial fault and homogeneous strain accumulation in the surrounding medium; in this model the time histories of both the fault slip and strain accumulation are assumed to be logarithmic functions.

3. If the ground deformation within the MWDM network at Hollister is analyzed in terms of slip on the Calaveras fault plus a homogeneous strain change, it appears that during the year preceding the Coyote Lake event the rate of fault slip was about 8.6 mm/year, which is low compared to the more usual rate of about 15 mm/year. There was a correspondingly large component of strain accumulation during the same period with a large component of shear strain parallel to the Calaveras fault. Following the earthquake considerable aseismic deformation was recorded in the Hollister area both by the MWDM instrument and two creepmeters. During the following 17 days the MWDM line-length changes indicate 5 to 6 mm of fault slip and a substantial reduction in accumulated right-lateral shear strain; this amount of fault slip is consistent with that recorded by the creepmeters.

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Study of the Foreshock-Mainshock-Aftershock Sequence of the 1978 Oaxaca Earthquake

14-08-0001-18371

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Investigations

Four weeks before the Oaxaca, Mexico earthquake of 29 November, 1978, (M_S = 7.8), a portable array of seismometers was emplaced in the epicentral region by the Instituto de Geofísica, Universidad Nacional Autónoma de México (UNAM) and the Seismological Laboratory, Caltech. The array successfully recorded foreshocks, mainshock, and aftershock activity. Preliminary locations have been determined for this sequence and are now being finalized.

Major features of the foreshock activity are:(1) The mainshock location is surrounded by a seismically quiet area of at least 1800 km^2 prior to failure which is broken by only a single cluster of activity 2 weeks before the final foreshock sequence; (2) Thirty-one hours before the mainshock, this foreshock sequence began migrating NE to SW through the quiescent zone toward the eventual rupture point; (3) activity then subsided for 12 hours until failure. A significant result of this study is the documentation of a foreshock sequence at energy levels below standard detection thresholds, but otherwise highly similar to those observed worldwide. This suggests the possibility that many more than the 44% of large earthquakes reported may have foreshock activity which has been undetected and that small earthquakes are at least as sensitive indicators of the level of stress as are larger earthquakes.

Aftershocks of the 1978 Oaxaca earthquake define a rupture area of about 6000 square kilometers along the boundary of the subduction zone. Travel time data from well recorded aftershocks were inverted to estimate a velocity model for both P and S waves so that eventually all events may be relocated and seismicity patterns analyzed in detail. Sixty-eight P travel times were inverted using the Levenberg-Marquardt nonlinear least squares algorithm to obtain a dipping gradient layer over a constant velocity half-space. Once the P velocities and structure had been estimated, nineteen S travel times were inverted to obtain the S velocities. The structure obtained is a crust-mantle interface dipping approximately 7° to the northeast, where:

$v_{po} = 5.432 \pm .029$ $\qquad$ $v_{so} = 2.853 \pm .029$

$v_{p1} = .045Z$ $\qquad$ $v_{s1} = .046Z$

$v_{p2} = 8.186 \pm .048$ $\qquad$ $v_{s2} = 4.965 \pm .414$

At 15° 47.4' N, 96° 43.44' W the interface depth is approximately 26 km.

We have studied the body and surface waves generated by the Oaxaca mainshock in order to constrain the source mechanism and determine rupture characteristics. We conclude that the event represents oblique thrust faulting on a plane which dips 14° to the north ($\phi = 270°$, $\delta = 14°$, $\lambda = +54°$); the earthquake is best modeled as a single simple event, suggesting smooth propagation of the rupture. The seismic moment is $M_o \approx 3 \times 10^{27}$ dyne-cm. These results, when combined with those of ongoing studies of other events along the Middle America Trench, should lead to a better understanding of the regional tectonics and associated earthquake phenomena.

Results

Our 1978 data set allows a detailed evaluation of the precursory nature of the spatio-temporal variations in seismic activity for three sequences in Oaxaca in 1965, 1968, and 1978 through master-event relocations, fault mechanism solutions, and earthquake statistics. At present, using locations from PDE listings, it appears that the seismic "gap" in the Oaxaca region was not filled by the 29 November, 1978, mainshock and aftershocks. Furthermore, the gap appears to exist prior to the precursory period from June, 1973 - May, 1975, identified by Ohtake et al., as can be seen in Figure 1. This figure shows all shallow (depth $\leq$ 60 km) seismic activity located by the U. S. Geological Survey for the Oaxaca region from 1966 to 1978. The 1965 and 1968 aftershock areas are crosshatched; open circles are the 1978 Oaxaca main shock and aftershocks through December 1978. The area of aftershocks located by the field seismograph array is the shaded area (center). The areas that were quiet since 1966 (solid outline) and since 1973 (dashed rectangle) are also shown. Triangles indicate earthquakes in the large quiet area preceding the 1978 main shock. In order to determine the exact nature of the "precursory gap" and to resolve whether or not the "gap" has been filled, we have undertaken the relocation of all Oaxaca seismicity from 1965 to 1978 using JHD methods and the 1978 sequence as calibration events. Preliminary results are shown in Figure 2. All seismicity presently relocated is shown (R); the redetermined aftershock areas of the 1965 and 1968 sequences are outlined as well as the 1978 aftershock zone; the dashed outlines show the same aftershock areas before relocation. The original and relocated mainshock epicenters (1965 and 1968) are shown as open circles and X symbols, respectively. These results suggest that the "Oaxaca gap" has not been entirely filled at present.

In Oaxaca, large earthquakes occurred at the turn of the century in 1903/1917, again in 1928/1931, and most recently in 1965/1968/1978. Comparison of the three failure episodes in the same region shows distinct differences: in 1903 and 1917 two large events, $M_S = 8.1$ and 7.5, occurred within 14 years; in 1928, 4 large events, $M_S = 7.5$, $M_W = 8.0$, $M_S = 7.4$ and $M_S = 7.6$ occurred within only 9 1/2 months and were followed by an earthquake with $M_S = 7.8$ in 1931; in the most recent case the region has broken with only three earthquakes which occurred with a temporal separation of 3 and 10 years and magnitudes of only $M_S = 7.6$, 7.1 and 7.8. From the relation $M_o = 1.5\, M_S + 16.0$, the sums of earthquake moments (ΣM_o) in the three episodes are respectively: 15.9×10^{27}, 20.6×10^{27} and 8.0×10^{27}. If the same area ruptured in all three cases, the seismic slip in the earlier two periods was more than double that observed most recently. If the rate of subduction is uniform on this time scale then either (1) the entire region has not yet broken and additional large earthquakes should be expected in the near future, or (2) the mode of subduction is time dependent with aseismic slip now accommodating the subduction in this region. The third alternative is that the rate of plate subduction has changed on a time scale of less than 50 years.

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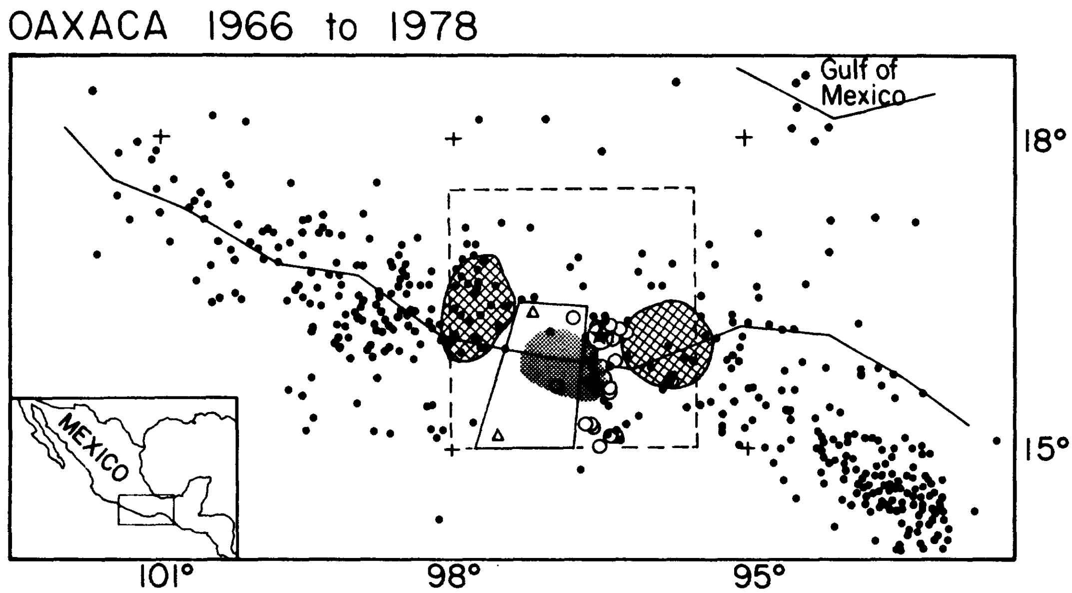

Figure 1

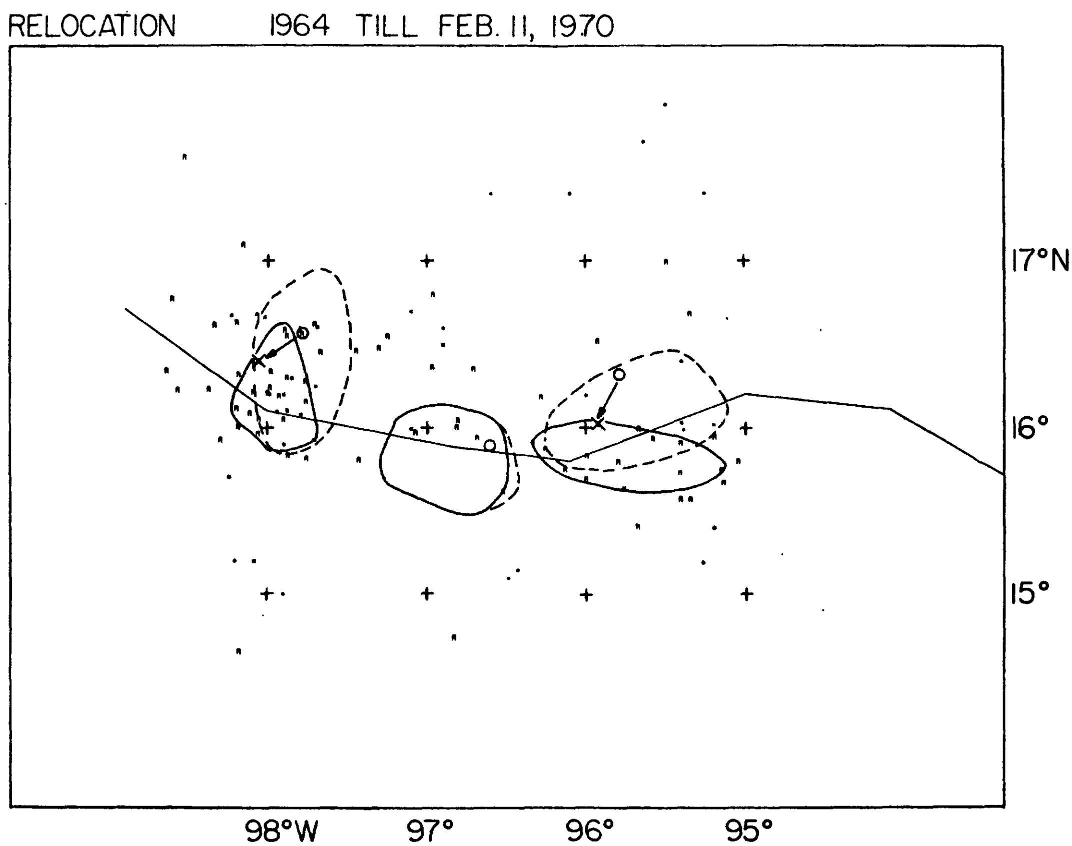

Figure 2

Deviatoric Stresses in the Earth's Crust and Uppermost Mantle

9960-02414

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Investigations

An analysis of the stress regime in the earth's crust was conducted in two parts. The first project involved a regional analysis of North American gravity anomalies, which constrain the long-term (hundred million year) rheology and deviatoric stress level in the continental crust. The second project considered stress on the very much shorter time scale corresponding to the earth tides. The most immediate purpose of this study was to investigate the hypothesis of Mr. James Berkland, the Santa Clara County Geologist, that an eight day "seismic window", commencing with each syzygy (new or full moon) represents an earthquake-prone period for the San Jose area. From a more scientific viewpoint, if one could find a convincing correlation between tides and seismicity, the known stress levels associated with the tides would provide a constraint on the stress regime under which faulting occurs.

Results

Gravity data from the United States and Canada were divided into two grids, one corresponding to the Basin and Range, Rocky Mountain, and Sierra Nevada regions, and the other including the Appalachain Mountains, the Great Lakes area, and the Mississippi Valley. The gravity and topography data in these two grids were reduced to isostatic response functions which summarize the relationship between the topography and its compensation. These response functions were then directly inverted to determine parameters in simple isostatic compensation models. The implied mechanisms and the residual isostatic gravity anomalies suggest that the tectonic processes that formed the topography in the western grid, by some mechanical or perhaps thermal means, left the crust and upper mantle incapable of transmitting stress laterally. In the eastern United States, at least part of the crust is capable of responding elastically and supporting stress differences of the order of 50 MPa or more over time scales of hundreds of millions of years. A very simple model which could explain these results is shown in Figure 1. Perhaps the thin-skinned tectonics responsible for the Appalachian Mountains left the lower part of the elastic lithosphere undisturbed. This type of isostatic compensation

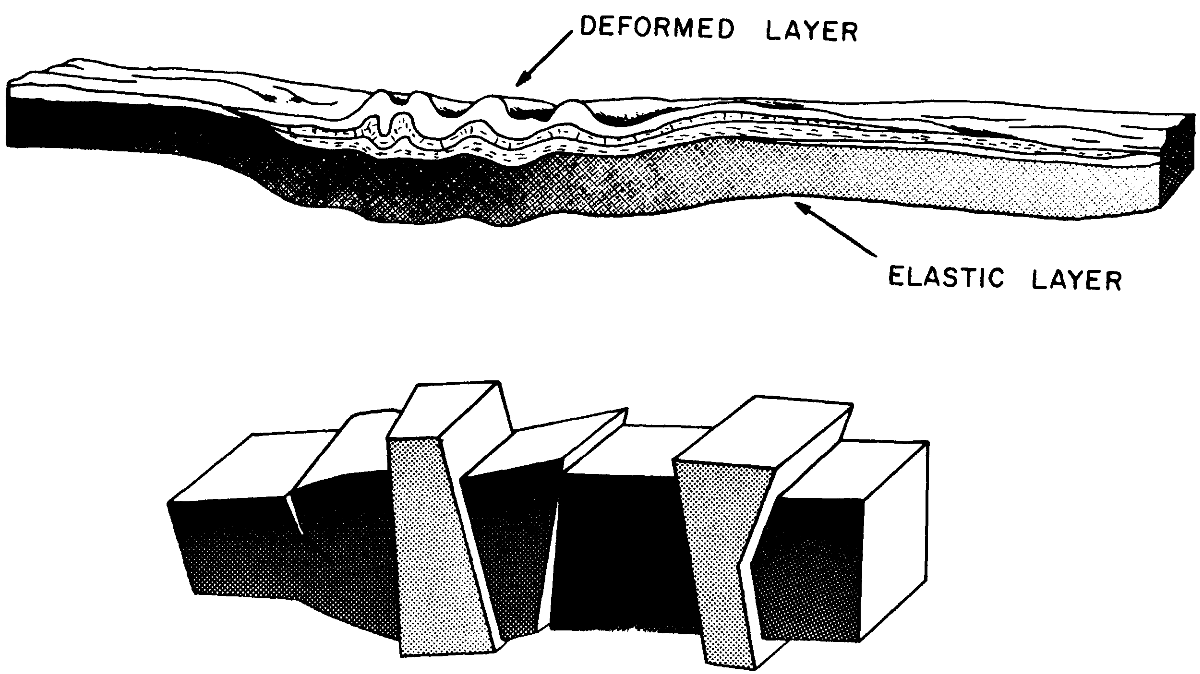

Figure 1. Simplified models of two styles of tectonic deformation. The upper diagram shows "thin-skinned" compressional deformation, while the lower diagram represents vertical or tensional tectonics.

would result from shallow, compressional tectonics. In the western United States the topographic elevation is caused by tensional and/or vertical stresses affecting the entire crust and upper mantle. Whether movement occurred along faults, as shown in the schematic diagram, or high temperatures caused the rocks to behave viscously rather than elastically, is immaterial for the purpose of explaining the gravity and the compensation. The possibility remains that since the time of formation of the topography, the lithosphere in the west has cooled and stiffened to the point that it now can sustain high deviatoric stresses. The gravity anomalies only give clues to the stress regime at the time when the topography is initially compensated. Since, however, there is every reason to believe that the western United States is still very active tectonically, at least in the Basin and Range area, it is likely that only low deviatoric stress levels can be supported.

From the analysis of Berkland's seismic window theory, we conclude that there is no basis for the contention that seismicity within 100 km of San Jose is correlated with a fortnightly tidal fluctuation. As shown in Figure 2, earthquakes in the area are uniformly distributed with respect to the 14 day period, showing no tendency to cluster in the seismic window period, from day 0 to day 7. In addition, for the earthquakes that do occur during seismic windows, the tidal stress vector in the coordinate system defined by the fault plane and the slip vector was as likely to oppose the fault rupture as to aid it. These results do not rule out the possibility that individual swarm sequences could show some correlation with the diurnal tide, but as a method of earthquake prediction, the seismic window theory shows no merit.

Reports

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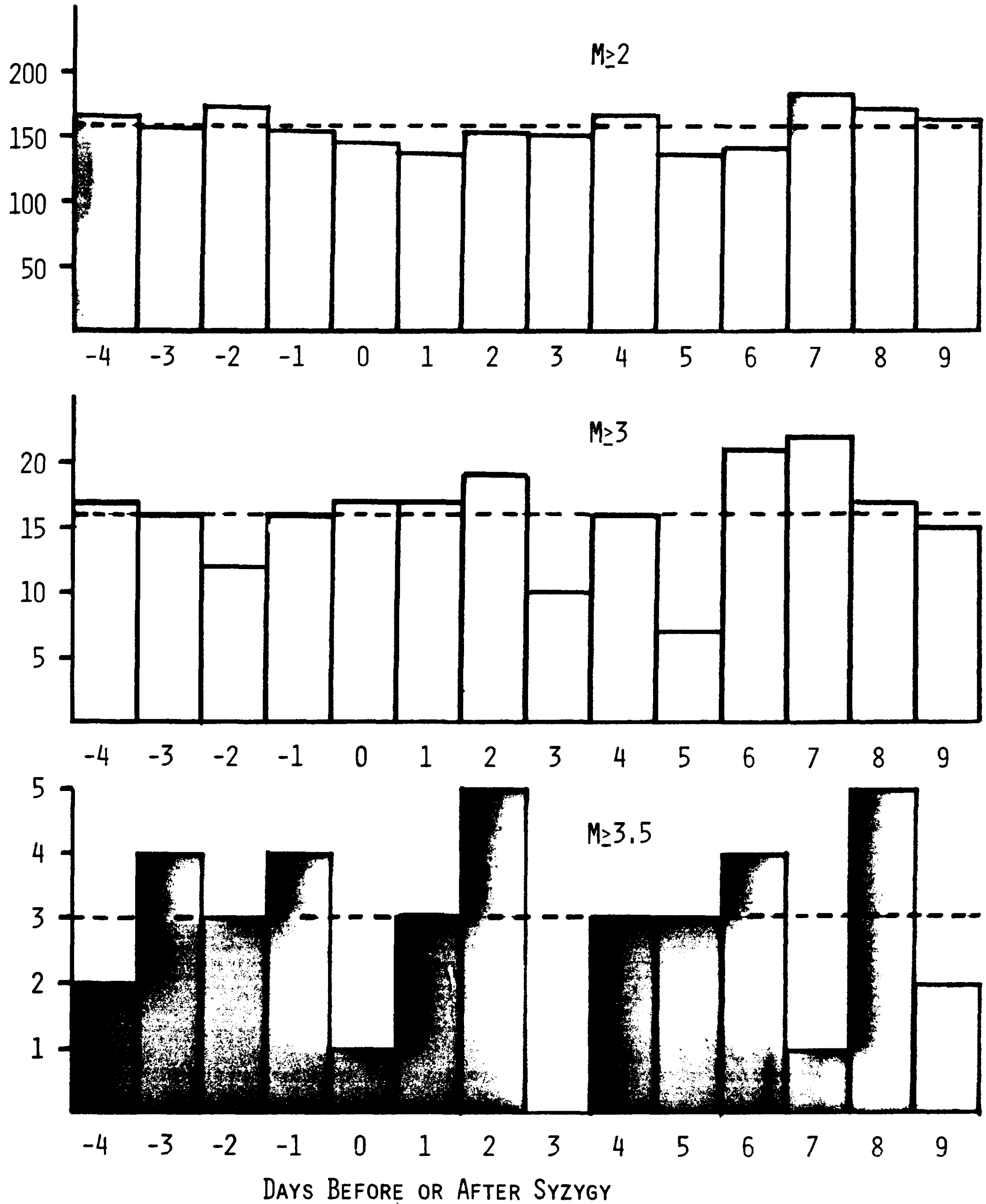

Figure 2. Distribution of earthquakes within 100 km of San Jose as a function of day before or after syzygy. For all earthquakes of magnitude 2 or greater, there is no tendency to cluster at any particular phase in the fortnightly cycle.

STUDY OF ATMOSPHERIC ELECTRIC PROCESSES AND OF THEIR ASSOCIATION WITH EARTHQUAKES

14-08-0001-17711

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Introduction

Various observations suggest that there may be atmospheric electrical activity associated with earthquakes. If these obsevations are verified, the detection of such activity could serve as the basis for an earthquake-warning system.

The purpose of this program is to perform a systematic series of measurements of atmospheric electric parameters in an earthquake zone and to establish a data base for testing physical theories and for assessing the possible response of animals to changes in electrical parameters.

Progress

Four electric-field monitoring systems have been deployed. Two permanent locations have been instrumented near radon sampling wells in California. Two other temporary installations also were made near Livermore, California, after the earthquake sequence that started on January 24, 1980.

On April 12, 1980, at 22:15 there was a magnitude 4.7 earthquake along the San Andreas Fault near San Juan Bautista, California. The instrument located nearby recorded an unusually low daily averaged electric field at the time of the earthquake. The normal diurnal fluctuations in the electric field were also low. Further analysis is being done to determine if this phenomenon may be associated with an increase in radon concentrations in the air-near-ground level. It has been predicted that such an increase would decrease the average electric field.*

Future Plans

It is planned that data will continue to be collected and analyzed to detect and characterize changes in atmospheric electric fields prior to and during period of earthquake activity. One of the four monitoring systems is being fitted with weather instrumentation to allow electric-field variations due to local weather changes to be recognized and correctly interpreted during data analyses.

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*C.T. Pierce, "Atmospheric Electricity and Earthquake Prediction," Geophysics Research Letter 3, p. 1851 (1976).

Biological Premonitors of Earthquakes: A Validation Study

14-08-0001-16784

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Popular reports of anomalous animal behavior before earthquakes are common and extend through most of recorded human history up to the present. Birds, household pets, fish, and farm animals are cited most frequently, with occasional mention of dozens of other animals with which man has contact.

Unfortunately, these reports are of little scientific value because they are anecdotal and subject to the inaccuracies of observations, recall, and assessment of significance that usually accompany laymen's reports of disasters. Moreover, the reports provide scanty data, and the credentials of the observer are rarely provided.

No concerted effort has been made in the United States to gather animal behavior data either before or after earthquakes. However, the recent successful short-term predictions of earthquakes in the People's Republic of China have impressed U.S. seismologists, and a principal element of the Chinese program is reports of unusual behavior of animals by volunteer observers.

The purpose of this research is to determine whether unusual animal behavior may serve as a biological premonitor of earthquakes. Our approach was designed to test this hypothesis and incorporates some features of the Chinese program. Specifically, a network of qualified volunteer observers has been established along seismically active areas of California. These volunteers are collecting daily observational data on the behavior of animals with which they are in daily contact through their employment or hobbies.

A toll-free (WATS) hot line at SRI operates for 24 hours a day, 7 days a week. Each call is automatically recorded on tape; an independent circuit also records the date and time the call is received. Volunteer observers are instructed to call the hot line on a designated day once weekly to check in, and to use it any time they observe an instance of unusual animal behavior. Only hot line reports received prior to earthquakes are treated as valid information for purposes of data analysis.

Observers are given 30-day log sheets on which they rate the behavior of their animals daily on a scale of 0 to 4. Zero denotes typical behavior, 1 slightly atypical behavior, 2 clearly atypical behavior, 3 very atypical behavior, and 4 behavior never previously observed. Logs are mailed to SRI when completed. The reliability of observer reporting is assessed, in part, by comparing log sheet entries with transcripts of hot line calls; observers are instructed to report on the hot line all behaviors that are rated 2 or more on the log sheets.

Observers are categorized 1, 2, 3, or 4 on the basis of their performance in checking-in weekly on the hot line, and returning the monthly log sheets to SRI. Category 1 observers are the most reliable, categories 2 and 3 are progressively less so, and category 4 observers have discontinued voluntarily or have been terminated because of unacceptable performance.

Since January 1978, we have recruited 1200 volunteer observers in selected seismically active areas of California, principally in Humboldt County, the San Francisco Bay area (extending south to Hollister and Santa Cruz, and north to Santa Rosa), and Los Angeles and Ventura Counties. Nine hundred and twenty-nine observers were recruited during 1979. The attrition rate was approximately 25%; most of these were individuals who received all of the materials but never started. The accompanying figure displays the location of the 1167 volunteer observers who were active during all or part of 1979 as well as all 1979 earthquakes having preliminary magnitudes of at least 4.0.

Approximately 250 species of house pets and other domestic and wild animals are being observed, including arthropods, fish, reptiles, amphibians, birds, and mammals. Reports of unusual behavior typically refer to unexplained or prolonged vocalization; restlessness; a change in regularly occurring habits; pacing, running or attempts to escape from enclosures; immobility; refusal to enter normal housing; hiding; and unexplained absence from a usual locale. Five-hundred-seventy observers reported one or more instances of unusual animal behavior during 1979. A total of 2062 calls were received.

In the absence of a major earthquake ($M \geq 5.0$) within the regions being monitored during the period that we have been collecting data, we are tentatively treating the reports received as baseline data--that is, as reports of unusual behavior that probably reflect the generally increased awareness and interest of observers in the behavior of their animals since joining the network. Such behaviors are very probably part of the animals' normal behavior repertoire but occur infrequently. The owners may not have noticed them or considered them particularly significant before they became members of the network. Our working assumption is that the frequency of reports will increase significantly above this baseline level just before a major earthquake that occurs within our network of observers. Other possible causes will be excluded before such an increase in reporting behavior is considered relevant to the animal hypothesis.

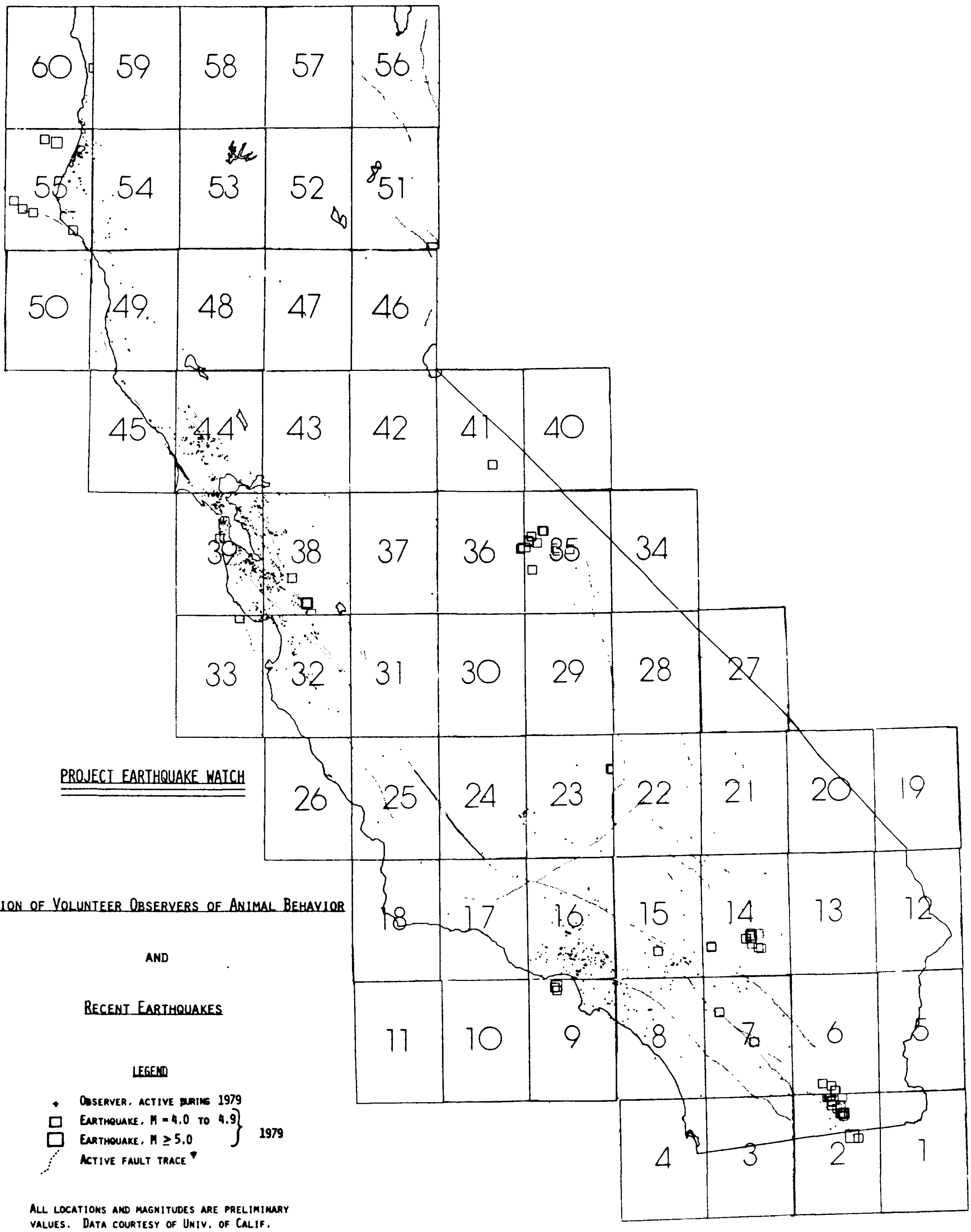
A novel statistical method has been devised for determining whether an increase in the frequency of hot line reports received just before an earthquake from the vicinity of the epicenter is sufficiently higher than the background level of reporting to constitute evidence in support of the animal-behavior hypothesis. The background level is established from a control group of reports from the same region that are not associated with the earthquake in question or any other. All reports occurring within 48 hours after earthquakes are disregarded. This analysis is based on an evolving predictive model in which the sizes of the pre- and post-earthquake vicinities (in both time and space), as well as the minimum earthquake magnitude and minimum observer report rating to be included, are treated as parameters of the hypothesis. That is, they initially are assigned various combinations of values, and those values that lead to the strongest results are retained for testing against future data.

During 1979 the epicenters of 6 of the 9 California earthquakes with $M \geq 5.0$ occurred ≥ 80 km from all but a few (i.e., ≤ 8) observers. The other three (Coyote Lake, 6 August 79; one near Point Mugu on 1 January 79; and one at sea near Eureka, 3 February 79) and two smaller shocks ($M = 4.4$, at sea near Pacifica, 26 April 79; and $M = 4.8$, Mt. Hamilton near San Jose, 7 May 79) occurred on its periphery; 21, 20, 32, 51, and 55 observers, respectively, fell within 30 kilometers of the epicenters. For the first, fourth, and fifth events, the level of local reporting did indeed increase somewhat during the 10 days preceding the event. For the first event 49 post-earthquake reports of pre-earthquake behavior were received, prompting a campaign to encourage observers to report more promptly to render their reports usable. While these indications are encouraging, the data analysis for these earthquakes revealed that the increases noted were insufficient to constitute clear evidence in support of the animal behavior hypothesis.

Simulation of the responsiveness of the observer network (as of 4 January 1980) to all recorded California earthquakes in the 30-year period 1945-74 has shown that, if past seismicity continues during 1980, the probability that at least one $M \geq 5$ shock will occur within 80 kilometers of 30 or more observers exceeds 0.96. This and similar calculations indicate that the observer network is well-placed for capturing at least one moderate-to-large earthquake within the next year or so.

In addition to the 1167 observers active during 1979, 15 nonobserving volunteers have contributed to the project in various ways: editing and mailing of the monthly Newsletter, logging of observer reports and maps for computer entry, computer programming, recruiting additional observers, and other related activities.

Our experience to date indicates that members of the community may participate constructively in data collection for certain kinds of earthquake research, suggesting that this potential resource may be useful for other geophysics research programs.



PROJECT EARTHQUAKE WATCH

LOCATION OF VOLUNTEER OBSERVERS OF ANIMAL BEHAVIOR

AND

RECENT EARTHQUAKES

LEGEND

- Observer, active during 1979
- Earthquake, M = 4.0 to 4.9 } 1979
- Earthquake, M ≥ 5.0 } 1979
- Active fault trace *

All locations and magnitudes are preliminary values. Data courtesy of Univ. of Calif. Seismographic Stations, Berkeley, and Calif. Inst. of Technology Seismological Laboratory, Pasadena. Only those events having preliminary magnitudes at least 4.0 are listed.

* Digitized California boundary and fault contours courtesy of U.S.G.S. (R. Lester)

Mechanics of Geologic Structures
Associated with Faulting
9960-02112

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Investigations

(1) Field mapping and thin section investigation of faults, fractures, and related structures in granitic rocks of the Sierra Nevada, California.

(2) Theoretical analysis of the stability of an array of propagating extensional cracks in an elastic material.

(3) Theoretical analysis of a two-dimensional, elastic fault model which includes the complete mechanical interaction of discrete fault segments.

(4) Experimental analysis of slip initiation and propagation along echelon fault segments.

Results

(1) Several sites within the Mt. Abbot quadrangle (central Sierra Nevada) have been selected for detailed mapping and thin section study. Fractures within a given area typically form a parallel, northeast trending set, with separations between fractures small compared to average fracture lengths. Individual fractures display left-lateral strike-slip offsets of 0-2 meters. It has been possible to demonstrate that the fractures initially formed as extensional cracks. The cracks acted as conduits through which hydrothermal fluids circulated, altering the wall rocks, and precipitating an assemblage of quartz+epidote+chlorite. Subsequent to this, the region was subjected to shear, and the resulting deformation concentrated on the pre-existing fractures. The shearing induced large inelastic deformations, both within the fracture-filling minerals and the host granodiorite. This process eventually led to the formation of narrow mylonite zones. Secondary fracturing also acted to link individual shear cracks together, forming fault zones of $\sim$1 meter in width with offsets of $\sim$10 meters.

(2) In crystalline rocks the presence of extensional fractures can control the bulk permeability and gross mechanical response of the rock. Both these effects are observed in the field study discussed above. The growth of a system of distributed cracks in a two-dimensional medium with

prescribed remote displacements is under investigation. It is assumed that cracks begin growing when the crack extension force (G) reaches some value required for stable (quasi-static) crack growth. The decrease in stored elastic strain provides the energy to drive crack growth. Thus crack growth terminates when a sufficient strain is accommodated by cracking. The analysis predicts that on average the ratio of final crack length to initial crack length depends on the initial spatial density of cracks. The average behavior is modified by the local interaction between neighboring cracks. By determining the final (present day) spatial density of cracks in the field, it is possible to estimate the lengths of initial cracks that grew into the observed fractures.

(3) Fault traces consist of numerous discrete segments, commonly arranged as echelon arrays. In some cases, discontinuities influence the distribution of slip and seismicity along faults. To analyze fault segments we derive a two-dimensional solution for any number of nonintersecting cracks arbitrarily located in a homogeneous elastic material. The solution includes the elastic interaction between cracks. Crack surfaces are assumed to stick or slip according to a linear friction law. For an array of echelon cracks, the ratio of maximum slip to array length significantly underestimates the difference between the driving stress and frictional resistance. The ratio of maximum slip to crack length slightly overestimates this difference. Stress distributions near right- and left-stepping echelon discontinuities differ in two important ways. For right-lateral shear and left-stepping cracks, normal tractions on the overlapped crack ends increase and inhibit frictional sliding, whereas for right-stepping cracks, normal tractions decrease and facilitate sliding. The mean compressive stress between right-stepping cracks also decreases and promotes the formation of secondary fractures, which tend to link the cracks and allow slip to be transferred through the discontinuity. For left-stepping cracks, the mean stress increases; secondary fracturing is more restricted and tends not to link the cracks. Earthquake swarms and aftershocks cluster near right steps along right-lateral faults. Our results suggest that left steps store elastic strain energy and may be sites of large earthquakes. Opposite behavior results if the sense of shear is left-lateral.

(4) The static elastic analysis described above suggests that right- and left-stepping discontinuities between echelon fault segments might respond quite differently to a slip event propagating toward the discontinuity. In laboratory experiments we loaded a slab of gelatin in uniaxial compression and watched slip events propagate along two echelon cracks trending at 30° to the compression such that shear was right-lateral. For a left-step, as a slip event ran toward the discontinuity, rupture would initiate at the near end of the adjacent crack and run away from the discontinuity. For a right-step, as a slip event ran toward the discontinuity, rupture occasionally would initiate at the

far end of the adjacent crack and run toward the discontinuity. Such results are consistent with the static changes in stress state due to slip on the cracks mentioned above. We emphasize that these are preliminary results of a poorly controlled and very simple model. However, they are sufficiently intriguing to motivate further research.

Reports

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Coherent Seismic Wave Analysis

9930-02296

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Investigations

1. The width of the seismic zone associated with the San Andreas fault has not been adequately determined. Epicenters from the USGS central California seismic network cluster over a swath approximately 5 km wide, or more. Yet the pattern of seismicity retains a distinctly linear character. (While outlying events, particularly to the east of the fault, clearly show that not all the action takes place in the fault zone, we are only concerning ourselves here with the dense band of seismicity that tracks the fault.)

While it is fairly certain that much of the epicentral scatter is due to picking errors and inadequacies in the velocity model, we are not sure how much scatter can be explained this way. The actual width of the most active portion of the seismic zone bears directly on our physical/conceptual model of the San Andreas fault. Is the fault a shearing and creeping planar interface containing sticky patches (in which case the width of the seismic zone would approach zero), or is it a zone of substantial width (a few km wide?) consisting of weakened or fractured rock and clay throughout which earthquakes are distributed?

Seismic data are being analyzed in order to better constrain the width of the seismic zone in the region of Bear Valley, California. We are doing this by relocating earthquakes from this region in a new way. Our conventional location algorithm tries to simultaneously minimize errors in epicenter, depth and origin time. If we completely relax the requirements for determining origin time, depth and epicentral location <u>along</u> the fault, and only require determinization of the perpendicular epicentral distance <u>from</u> the fault, we should do much better at determining this one parameter. This is done by <u>reducing</u> the number of stations, taking advantage of a favorable symmetric station geometry (thereby minimizing the reliance on ray paths through the fault zone), and using differential arrival times (which eliminates the origin time from the solution).

2. On the home front, we are upgrading our computer facilities for seismic data processing. When the CDC-1700 computers were retired last winter, we temporarily lost our ability to digitize data from our five-day-recorder portable seismic network. We have developed a suite of programs to replace this facility on the Eclipse mini computer and DEC PDP-11/70 UNIX system.

3. Finally, we are making a systematic and analytical assessment of the performance of a new microprocessor-based on-line earthquake p-picker and off-line location system. (See report by Rex Allen.) We must thoughtfully and objectively compare the locations and picks from this completely automated real-time system with those of our staff of trained scanners and pickers, in order to understand the quirks of both the automated and human endeavors.

Results

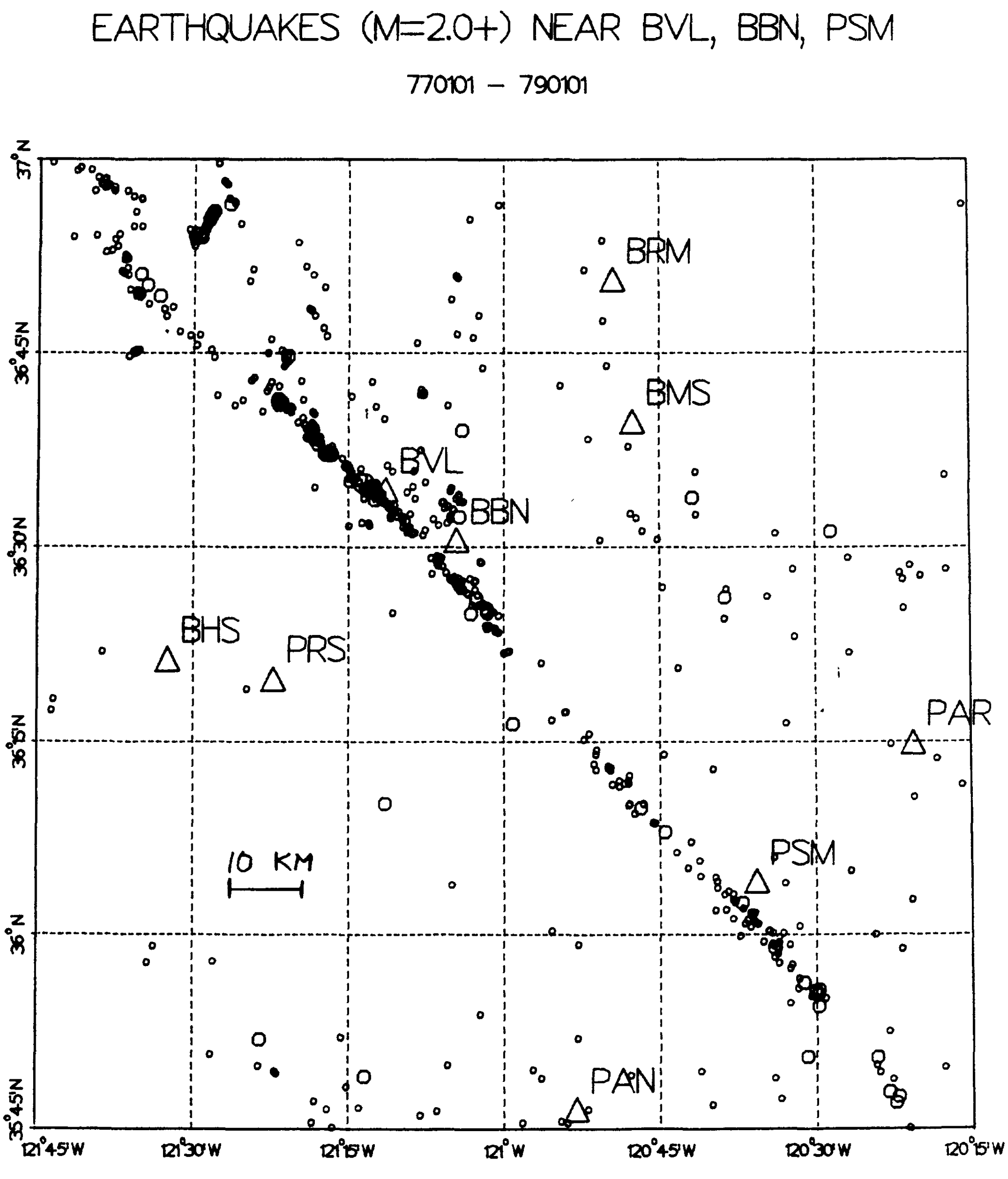
1. We have chosen a data set of earthquakes in the region of Bear Valley, California, for relocation. This portion of the fault zone is fairly linear and its seismicity is well clustered. Without any re-timing of phases, we have constrained the statistical width of the seismic zone in the area of BVL to less than 1 km. We are proceding to re-time all the events and then repeat the differential location method.

2. A facility now exists for digitizing five-day tape data. Digitizing is initiated by an interactive process on the Eclipse. The data are transferred by tape to the DEC PDP-11/70 UNIX system.

3. The comparison of automatic and conventional earthquake locations has just gotten underway. We should be able to say something definite by July, 1980.

Reports

Reasenberg, P., and Hobson, J., 1980, Digitizing five-day-recorder tapes on the Eclipse and PDP-11/70 Unix Systems, U.S. Geological Survey Open-File Report 80-610.



Linear clustering of earthquakes along the San Andreas fault near Bear Valley. How much of the scatter is real and how much is due to location errors?

Helium Monitoring for Earthquake Prediction

9440-01376E

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Investigations

The variation of the soil-gas helium concentration is being monitored at 10 stations south of Hollister, CA along a 20 km traverse on the San Andreas Fault. Samples are collected about once a week and returned to Denver, CO for analyses. This study should reveal the typical seasonal pattern the helium concentrations exhibit; higher levels during the wet season, lower levels during the dry season. It will also exhibit the "noise" levels that must be contended with to make any connection between helium soil-gas variation and earthquake activity.

Results

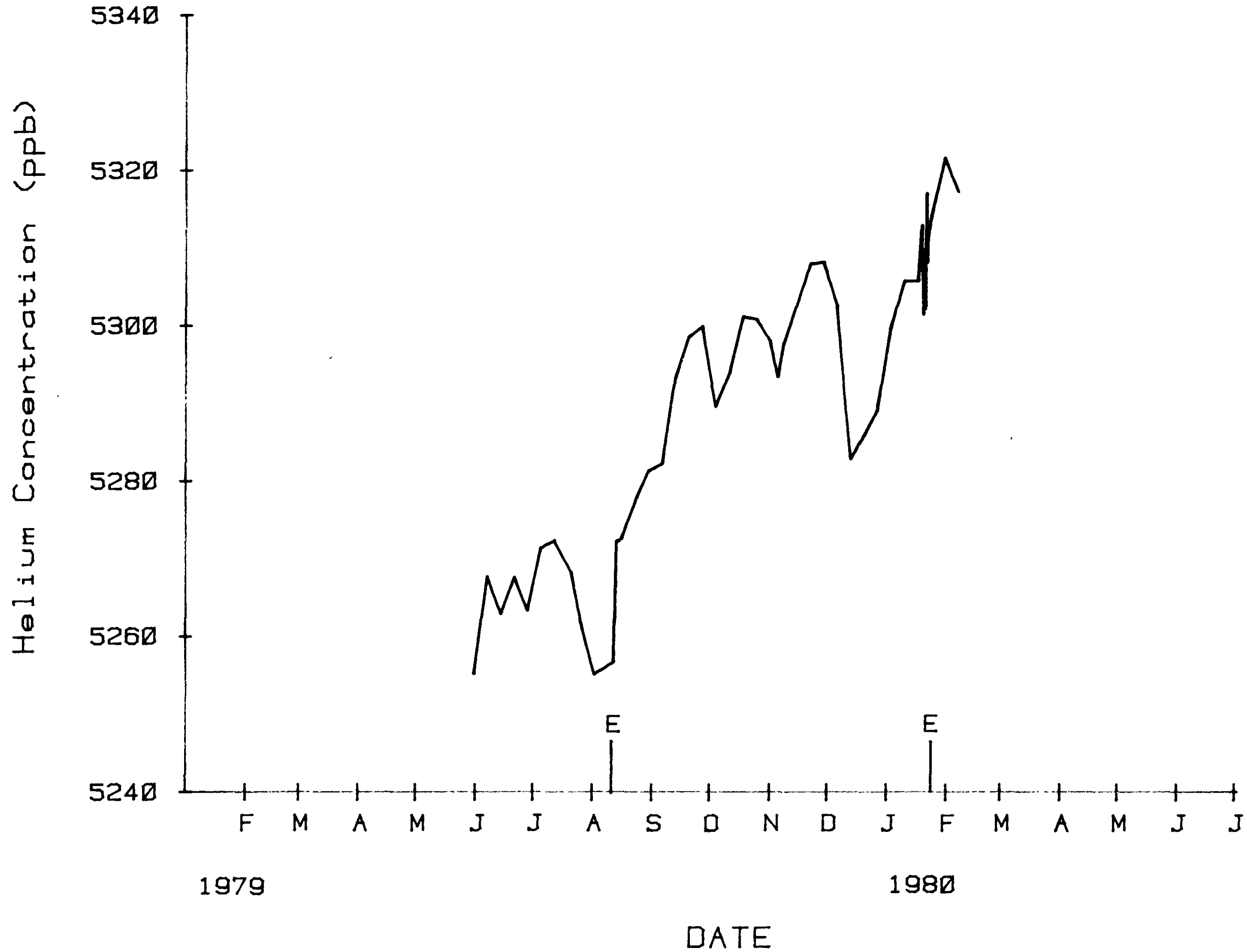
The accompanying figure shows the results to date. Presently, the data is being averaged for all stations for which a sample has been collected (some times less than 10) for each week. Then a 3-point moving average of that weekly value is used on the figure. The overall increase in helium concentration is due to the increasing soil-moisture content. Two marked decreases in the helium soil-gas concentration occur near the time of moderate central California earthquakes. These results are extremely intriguing and the study is continuing.

Reports

Reimer, G.M., 1979, The use of soil-gas helium concentrations for earthquake prediction: Studies of factors causing diurnal variation: U.S. Geol. Survey Open-File Report 79-1623, 68 p.

HELIUM CONCENTRATION IN SOIL-GAS NEAR HOLLISTER, CA

3-POINT MOVING AVERAGE FOR 10 STATIONS



Crustal Strain
9960-01187

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Investigations

1. Analysis of strain accumulation in central and southern California was the principal subject of investigation, although some analysis of networks elsewhere in western United States was undertaken. A detailed search of Geodolite measurements was made to detect possible earthquake precursors with negative results.

Results

Recent surveys of the southern California Geodolite networks seem to indicate a deviation during 1978-79 from the strain accumulation trends established in 1974-78. The deviation is a tendency for the north-south contraction to be somewhat smaller and the east-west extension somewhat greater. For the Palmdale network this change has been striking. The net north-south contraction (about 1 ppm) accumulated in the 1974-1978 interval was completely reversed during 1979. Similar, but smaller reversals in 1978 or 1979 have been noted in the Salton, Anza, Tehachapi, and Los Padres networks.

An analysis of the deformation of the Geodolite networks at Seattle and Hanford, Washington, 1972-79 indicate a compression in the northeast-southwest direction possibly associated with subduction of the Juan de Fuca plate. The principal strains at Seattle were 0.07 ± 0.03 μstrain/a N20°W and -0.13 ± 0.02 μstrain/a N70°E and at Hanford (south central Washington) -0.02 ± 0.01 N36°W and -0.04 ± 0.02 μstrain/a N54° E. Extension is taken as positive and the uncertainties quoted are standard deviations.

The deformation of a Geodolite network across the Rio Grande rift near Socorro, New Mexico, from 1973 to 1979 shows no significant east-west spreading across the rift at a detection threshold of 1 mm/a. The observed strain rates at Socorro were -0.01 ± 0.02 μstrain/a N74°W and -0.04 ± 0.02 μstrain/a N16°E. This is the lowest rate of strain accumulation that we have observed in any Geodolite network.

A releveling of a bench mark array at Middleton Island in the Gulf of Alaska indicates continuing deformation at a high rate. From the 1974 to 1979 the north end of the island moved down relative to the south end at a rate of 3 mm/a. All points at the same distance from the nearby Aleutian Trench have a common motion.

Analysis of Geodolite data in the greater San Francisco Bay area reveals a complex pattern of deformation. Strain appears to be concentrated in the vicinity of the San Andreas and Calaveras faults (tensor strains of 0.30 μstrain/a east-west and -0.30 μstrain/a north-south). Along the Hayward fault the deformation is accommodated by fault creep. East of the Calaveras fault and east of the Rodgers Creek fault the shear strain falls quickly to zero leaving a slight contraction normal to the faults (-0.10 μstrain/a).

Reports

Savage, J.C., 1979, Strain patterns and strain accumulation along plate margins, in An International Symposium on the Applications of Geodesy to Geodynamics, p. 93-97, Dept. of Geodetic Sci., Rept. No. 280, Ohio State University, Columbus, Ohio.

Prescott, W.H., Savage, J.C., and Kinoshita, W.T., 1979, Strain accumulation rates in western United States between 1970 and 1978, J. Geophys. Res., v. 84, p. 5423-5433.

Slawson, W.F., and Savage, J.C., 1979, Geodetic deformation associated with the 1946 Vancouver Island, Canada earthquake, Bull Seismol. Soc. Am., v. 69, p. 1487-1996.

Savage, J.C., Prescott, W.H., Chamberlain, J.F., Lisowski, M., and Mortensen, C.E., 1979, Geodetic tilt measurements along the San Andreas fault in central California, Bull. Seismol. Soc. Am., v. 69, p. 1965-1981.

Lisowski, M., Prescott, W.H., and Savage, J.C., 1979, Geodetic tilt observed near the epicenter of the Saint Elias, Alaska, earthquake of February 28, 1979, Bull. Seismol. Soc. Am., v. 69, p. 2121-2123.

Savage, J.C., Prescott, W.H., Lisowski, M., and King, N., 1979, Geodolite measurements of deformation near Hollister, California, 1971-1978, J. Geophys. Res., v. 84, p. 7599-7615.

King, N., Savage, J.C., Prescott, W.H., and Lisowski, M., 1979, Geodolite measurements near the epicenter of the Coyote Lake earthquake of August 6, 1979 (abstract), EOS Trans. Am. Geophys. Union., v. 60, p. 890.

Lisowski, M., Prescott, W.H., and Savage, J.C., 1979, Geodetic tilt near the epicenter of the Saint Elias, Alaska, earthquake of February 28, 1979 (Abs.), EOS Trans. Am. Geophys. Union, v. 60, p. 936.

Savage, J.C., Prescott, W.H., Lisowski, M., and King, N., 1979, Geodolite measurement of deformation in southern California 1971-1979 (abstract) EOS Trans. Am. Geophys. Union, v. 60, p. 809.

Prescott, W.H., 1979, The accommodation of relative motion at depth on the San Andreas fault system in California (abstract): EOS Trans. American Geophysical Union, v. 60, no. 46, p. 955.

COMPARISON OF RADON MONITORING TECHNIQUES, THE EFFECTS OF THERMOELASTIC STRAINS ON SUBSURFACE RADON, AND THE DEVELOPMENT OF A COMPUTER OPERATED RADON MONITORING NETWORK FOR EARTHQUAKE PREDICTION

14-08-0001-17734

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INVESTIGATIONS

The observation of substantial radon anomalies at Kresge and at Dalton Canyon during the second half of FY79 has necessitated some changes in the schedule for the Caltech radon monitoring program that was described in the semi-annual technical report. Owing to the anomalous data at Kresge, deployment of additional temperature probes for the thermo-elastic strain experiment at that site has been deferred. Greater emphasis has been placed on the expansion of the network and timely analysis of the data. At present radon monitors are operating at San Juan Bautista in central California and at five southern California sites: Stone Canyon Reservoir, Kresge, Santa Anita Canyon, Dalton Canyon, and Lytle Creek. An installation at Pacoima Dam is in progress.

The data collection and analysis part of the project has been divided into two efforts. One effort consists of off-line analysis of data read out from the field monitors using an interim telephone call-up computer program. The off-line data analysis has included (a) determination of background and net Radon and Thoron activities from raw data, (b) creating files and plots of 24-hr and 72-hr running averages and of weekly averages, and (c) determining correlations between radon data and the ambient temperature (which the deployed monitors measure eight or nine times a day). The other effort in the the data collection and analysis part of the project is development of software for our LSI-11 computer system with floppy disc mass storage, to carry out automatically the telephone callup of the field monitors and the data reduction procedures (a), (b), and (c) described above. This effort is essential because the volume of data from the six instruments now operating in the field is reaching the limits of our ability to provide off-line analysis on a timely basis.

RESULTS

A full year's data has been collected from a Caltech instrument at San Juan Bautista, sited along side three other kinds of radon monitoring devices, for the purpose of comparing different radon monitoring techniques. A preliminary comparison of data from the Caltech unit and one of the other instruments at the site--A. Smith's LBL gamma ray radon instrument-- showed that both instruments detect similar radon level variations, the Caltech instrument showing approximately twice the size of variation as the LBL instrument. An interface to the LBL instrument allows the Caltech monitor to read out data from it once every 3 hours and transmit this data over telephone lines along with the usual Caltech radon-thoron monitor data. Summarizing this data along with data from the other two instruments at the site (to be obtained from C. Y. King at the USGS) has been deferred until the fully automatic data collection and anaylsis software is developed, since this software will permit a much more thorough and accurate correlation of the data from the different radon instruments.

The radon anomaly which began about 21 June 1979 at Kresge and about two weeks later at Dalton Canyon soon reached levels which far exceeded those previously observed on our system. Fig.1 shows temperature corrected 24-hr running averages of data from Kresge and Dalton during the period of the anomaly and Fig.2 shows similar data from Lytle Creek and Stone Canyon Reservoir during the same period. Exchange of data with other investigators indicates that other geodetic and geophysical anomalies are being observed in the same general area in which the radon anomalies exist. At this time additional stations are being added to the network in order to determine the spatial extent of the radon anomalies.

REPORTS

M.H. Shapiro, Computer Controlled Collection of Radon Data for Earthquake Prediction Research. Invited Paper-Washington Meeting, American Physical Society, 24 April 1979.

M.H. Shapiro, J.D. Melvin, T.A. Tombrello, and J.H. Whitcomb, Automated Radon Monitoring at a Hard Rock Site in the Southern California Transverse Ranges, J. Geophys. Res., in press.

M.H. Shapiro, J.D. Melvin, T.A. Tombrello, and J.H. Whitcomb, Southern California Radon Anomaly, Contributed Paper-San Francisco Meeting-A.G.U., 4 December 1979.

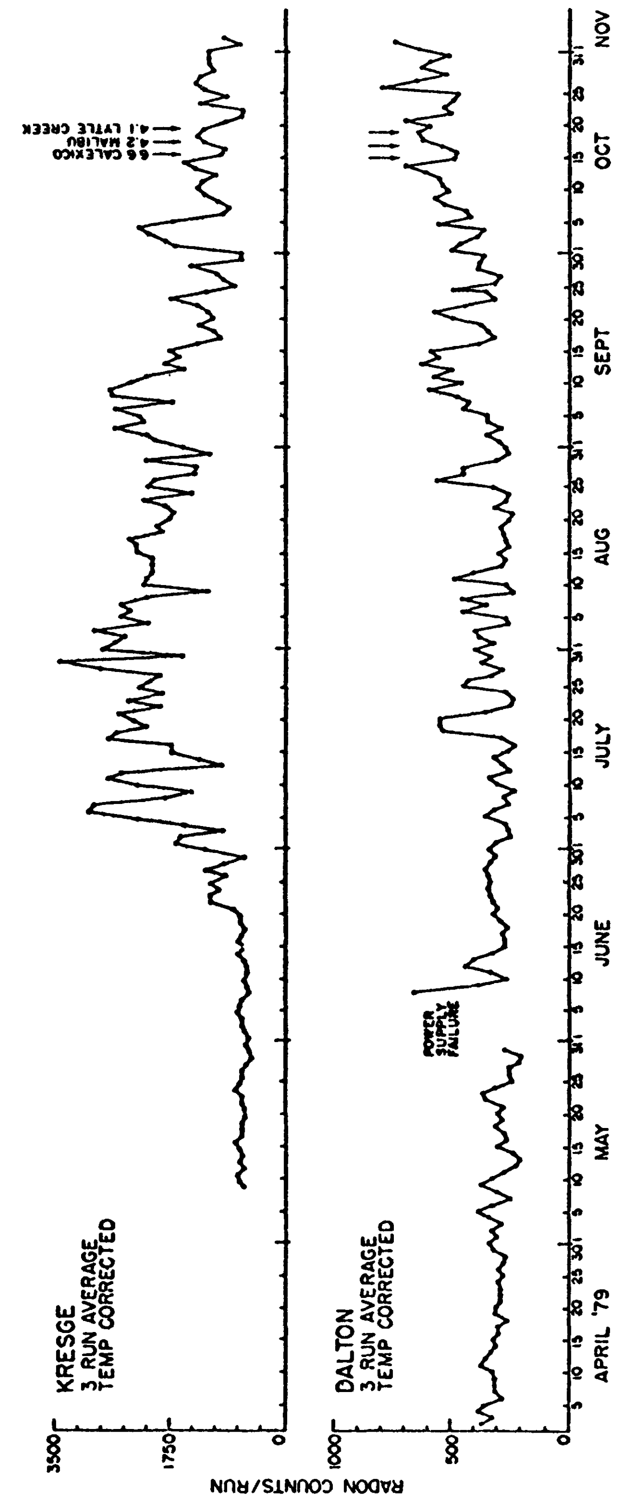
KRESGE
3 RUN AVERAGE
TEMP CORRECTED
DALTON
3 RUN AVERAGE
TEMP CORRECTED
RADON COUNTS/RUN
3500
1750
0
1000
500
0
POWER SUPPLY FAILURE
6.6 CALEXICO
4.2 MALIBU
4.1 LYTLE CREEK
APRIL '79
MAY
JUNE
JULY
AUG
SEPT
OCT
NOV

Figure 1

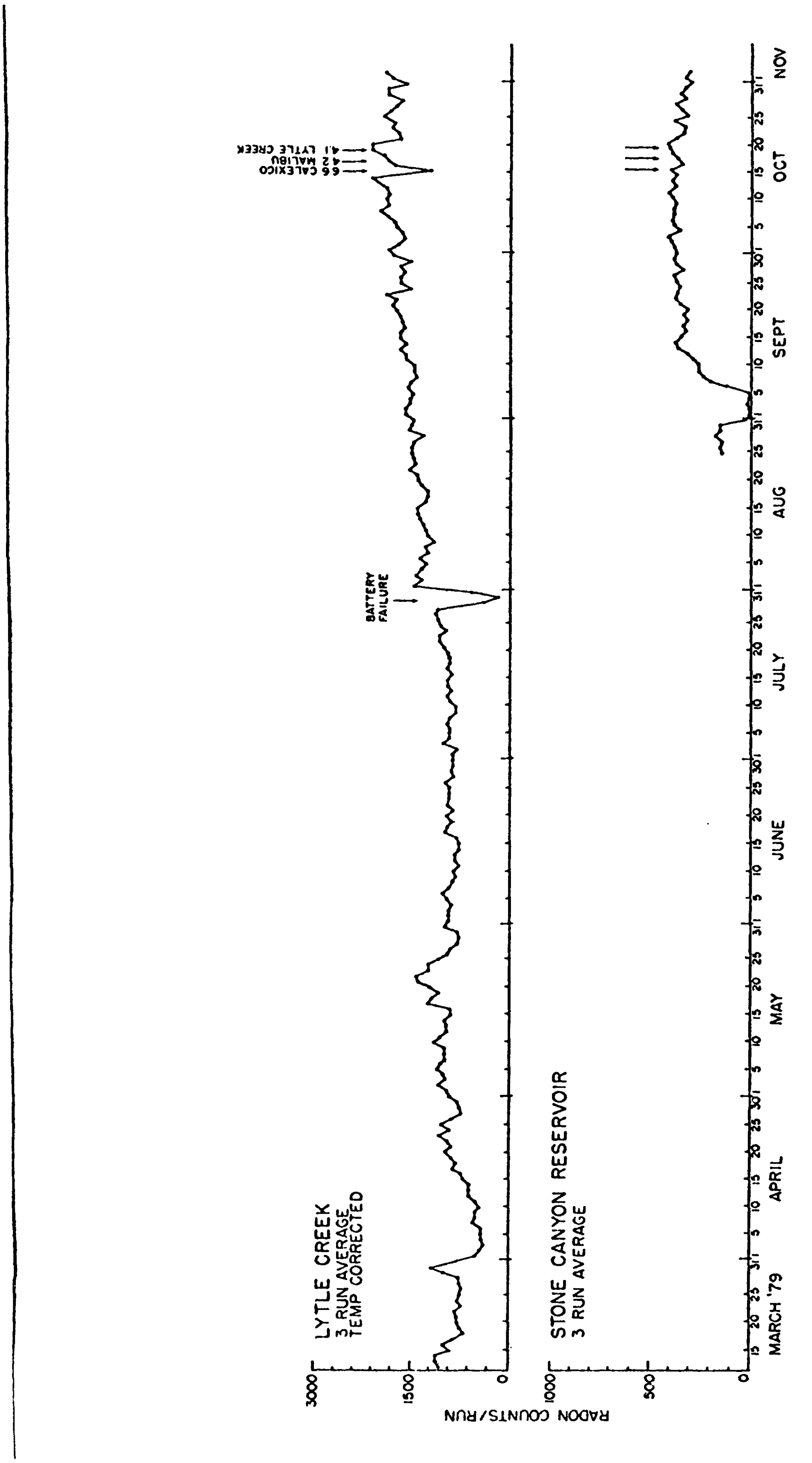
LYTLE CREEK
3 RUN AVERAGE
TEMP CORRECTED
STONE CANYON RESERVOIR
3 RUN AVERAGE
RADON COUNTS/RUN
3000
1500
0
1000
500
0
BATTERY FAILURE
6.6 CALEXICO
4.2 MALIBU
4.1 LYTLE CREEK
MARCH '79
APRIL
MAY
JUNE
JULY
AUG
SEPT
OCT
NOV

Figure 2

INTERPRETATION OF DEEP CRUSTAL REFLECTION DATA FOR STRUCTURE AND PHYSICAL PROPERTIES NEAR ACTIVE FAULTS - THE COCORP PARKFIELD LINE.

Contract 14-08-0001-17717

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INVESTIGATIONS

To interpret the COCORP deep crustal reflection profile across the San Andreas fault at Parkfield for deep structure and physical properties in the vicinity of the fault by reprocessing the data.

RESULTS

The COCORP crustal reflection profile at Parkfield has defied interpretation because of the questionable data quality of the commercially produced seismic section. The poor quality of this seismic reflection data led to speculation that reflection studies across the San Andreas fault were hopeless because of the complex geology and the vertical fault position. The magnitude of the problem is illustrated by teh fact that not even the flat-lying Tertiary sediments and the underlying Salinian granite contact were brought out by the reflection profiling. Our studies have shown that causes for poor data quality are: 1) noisey field records, 2) static corrections, 3) incorrect stacking velocity, 4) complex ray paths that don't stack or ray kinking, 5) reverberations, 6) surface conditions, 7) complex geology. The first five of these degrade the data the most seriously. Surprisingly, poorly recorded data by the seismic contractor is the most serious problem. Up to one-third of the traces in the field records are noisey. This noise is not related to ground position but seems to be generated within the recording instruments. Processing was initially carried out by the personnel from the University of Wyoming and later through the generosity of Malcolm Knock of Amoco. Most of the processing was continued by Mark Bronston using Amoco's computer facilities. Since the original stacked section was produced by the contractor without any deletion of data, we have severely edited the noisey field records to produce a new stacked section. Stacking velocities have been changed, and new static corrections as large as 1000 ms were calculated. Variable range stacks were used to attack the ray-kinking problem. Deconvolution of reverberations has been attempted, but to date has not been successful. Clearly, a number of factors have coincided to degrade seismic reflection quality.

Each step in the processing has produced some improvement in the seismic section and revealed new events so that reflections in Tertiary sediments above the Salinian block and diffractions from the fault zone are visible. In fact, diffractions in the fault zone are enhanced at stacking velocities that are too high to be a true velocity in rocks. Shallow reflections are also visible in the fault gouge zone. Several more cycles of processing including hand calculated statics, a time-consuming procedure, are needed on this data because it is degraded by so many different factors, and much of the fold of the CDP stack has been lost in the severe editing of noisey records.

The seismic section at this first stage of reprocessing shows a change in character at depth below the Salinian block. This could indicate that the Salinian block is allochthonously overlying Franciscan rocks but this interpretation is tenuous because of the data quality and the early stage of the reprocessing. Successful seismic reflection studies of the San Andreas fault zone of structure relations around it cannot be ruled out on the basis of the COCORP Parkfield line. At the very least, comments from T. McEvilly and from us will probably stimulate the seismic contractor to either recorrelate and edit the field data or to reshoot the line.

REPORTS

M. A. Bronston, R. L. Zawislak, R. A. Johnson, S. B. Smithson, and E. K. Shumaker, A new study of the Parkfield, California reflection seismic line across the San Andreas fault (abs.). EOS, Trans. Am. Geophys. Un., v. 60, p. 875.

Minicomputer Systems Development

9970-02118

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Investigations

The major goal of this project is to assist the Office of Earthquake Studies in efficiently processing seismic data by means of minicomputer hardware/ software.

A minicomputer-based seismic data processing system has been developed to process local earthquakes from the USGS central California network's analog tape recording system. The goal of the system is to provide preliminary hypocenters and associated waveform data on a routine basis.

The system is designed to process events involving hundreds of seismic stations. To accomplish this, it creates a dubbed analog library tape from five 14-track on-line analog tapes. Information is recorded on those tapes in Frequency Division Multiplexing format (FDM) which allows up to 112 stations per tape.

The data flow within the system is controlled by an operator who, with the help of computer-updated files, invokes the appropriate processor as the events pass through the system. The current processing status of all events is accounted for from the time of the request until the event has been either copied onto a digital archive tape or processing has been discontinued.

The events are detected initially either by manually scanning microfilm or by an independent on-line earthquake detection system which produces request cards for the first stage of the system. The processing consists of reading the request cards, creating the dub library tape, selecting the analog channels to be processed, digitizing and displaying those channels, interactively picking first arrivals and other seismic parameters, locating the hypocenters, and creating a digital archive tape.

Results

Since the last report period, several groups have begun using the earthquake processing software on a semi-routine basis. People from the central California Network Processing project (9930-01160) are spending approximately 4 hours per day processing daily central California earthquakes; and Amy Rapport of the Microearthquake Data Analysis project (9930-01173) is spending approximately 6 hours each evening processing Coyote Lake aftershocks.

Statistics on system efficiency have been provided by Amy and by Carol McHugh. The daily central California processing averages 31 minutes per quake, while the aftershock studies requires 48 minutes per quake. The principle variation seems to be in the location, trace display-editing, and relocation phase.

In both cases, the data processing begins at the point where a Dub catalog tape and its associated 'DCAT' (dubbed catalog) file are available. From there, processing proceeds through earthquake selection, digitizing, trace demultiplexing, automatic phase picking, epicenter location, display of the traces and their associated picks and residuals, and relocation. When the analyst is satified with the last location, then she/he dumps the location, trace data and phases to magnetic tape. The details of the central Calfornia processing time averages are as follows:

Select	2.5 min
Digitize	4.2 "
Demultiplex	0.9 "
Auto-pick	1.2 "
Locate	1.9 "
Display-edit	17.8 "
Re-locate	1.9 "
Mag-tape write	0.7 "
Total	31.1 min

In addition to these projects, George Poupinet, a visiting scientist from France, has been using the system to look at Coyote Lake foreshocks.

Reports

Poupinet, G., Bakun, W. H., and Stevenson, P. R., 1980, Search for seismic precursors to the 1979 Coyote Lake, California earthquake, (abs.) SSA Seattle meeting.

Crustal Inhomogeneity in Seismically Active Areas

9930-02231

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Investigations

1. Studies into a practical method to compute the frequency-amplitude response characteristics of our short-period seismic telemetry system, in collaboration with Mary O'Neill, were completed. The method allows the response characteristics of any combination of individual components to be determined. It has been adapted to compute magnitudes of local earthquakes from amplitude/period measurements in a more convenient manner.

2. Development of an online, realtime earthquake data acquisition system for the Central California Microearthquake Network is continuing, in collaboration with Peter Ward. Decisions have been made to use a high-speed disc as the memory delay line (rather than more expensive bulk memory), and to implement a 256-station capability at first (but design for a final capability of 512 stations).

Results

1. Stewart and O'Neill (1980) describe a practical method to calculate the frequency-amplitude response characteristics of the USGS short-period seismic telemetry system, or of individual components of the system, including the discriminators used for playbacks, the recorders, and the digitizing equipment. The response of each component is represented by a complex frequency-dependent factor multiplied by a sensitivity (or gain) factor. The response of a particular system configuration is calculated by multiplying together the complex response parameters for each individual component. During the course of this study the response of the Helicorder system was determined, and a convention for maintaining an absolute calibration for this system was established. The method described by Stewart and O'Neill was adapted by Jerry Eaton (written comm., 1980) as the basis for computing magnitudes of local earthquakes more conveniently in our standard hypocenter programs.

During the course of this study, Stewart and O'Neill made use of an unpublished report by Jay Dratler, written by him in 1975 before he left the USGS. The report was revised in 1979 by Dratler, with assistance from Mary O'Neill, Sam Stewart and Bill Daul, and released as an open-file report. It is included here in the list of Reports.

2. Plans are progressing to implement an online, realtime earthquake data acquisition system for the 240+ stations in the Central California Microearthquake Network. It was decided to use the PDP 11/34 computer as the central processing element of the system, and to augment it with high-speed, high-capacity analog-to-digital converter units and moving-head disc system. The acquisition system is being designed to allow up to 512 seismic stations to be monitored, at a sample rate of 100 Hertz for each station. The initial hardware configuration will be limited to 256 stations. Procurement of the analog-to-digital equipment is underway.

Reports

Lee, W. H. K., and Stewart, S. W., 1979, Microearthquake networks and earthquake prediction: Earthquake Information Bulletin, 11, 192-195.

Stewart, S. W., and O'Neill, M. E., 1980, Calculation of the frequency response of the USGS telemetered short-period seismic system: U.S. Geological Survey Open-File Report 80-143.

Dratler, Jay, Jr., 1980, Theoretical transfer functions for stations in the Central California Seismographic Network: U.S. Geological Survey Open-File Report 80-376.

Fault Zone Tectonics
9960-01188

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Investigations

1. Maintained and upgraded creepmeter array in California.

2. Moved archived creep data to PDP 11/70 computer and wrote software for data reduction and manipulation.

3. Searched for distinctive fault creep prior to earthquakes.

Results

1. Two new wire creepmeters have been installed on the San Andreas fault near Parkfield, California, to help A. G. Lindh *et al.* forecast a moderate earthquake there. A new instrument site was selected south of San Juan Bautista on the San Andreas fault between instruments XSJ2 and HRS3, and the instrument will be installed shortly . This segment of the fault has been relatively aseismic. Several aged rod creepmeters have been scheduled for replacement. Currently 37 extension creepmeters operate, 22 of the 37 have on-site paper recorders, and 16 of the 22 are telemetered to Menlo Park.

2. All creep data, one value per day, have been moved to a PDP 11/70 computer. Software for digitizing field strip charts with a minicomputer and for reducing and manipulating the data on the 11/70 have been written and are now operational.

3. Another example of the pre-earthquake creep rate retardation noted by R. O. Burford occurred before the $M_L = 5.9$, August 6, 1979, Coyote Lake earthquake on the Calaveras fault. The average creep rate at the SHR1 instrument (located on the Calaveras fault at the south end of the aftershock zone, near the Busch fault junction) before 1976 was about 11 mm/yr, and after was about 1 mm/yr until the co- and post-seismic jump of about 15 mm. During the year before the earthquake, the rate was slightly higher than earlier, as was the nearby seismicity on the Calaveras north of SHR1.

Report

Schulz, S. S., and R. O. Burford, 1979, Catalog of creepmeter measurements in central California for 1976 and 1977: U.S. Geol. Survey Open-File Report 79-1609, 375p.

Groundwater Radon as an Earthquake Precursor

#14-08-0001-15875

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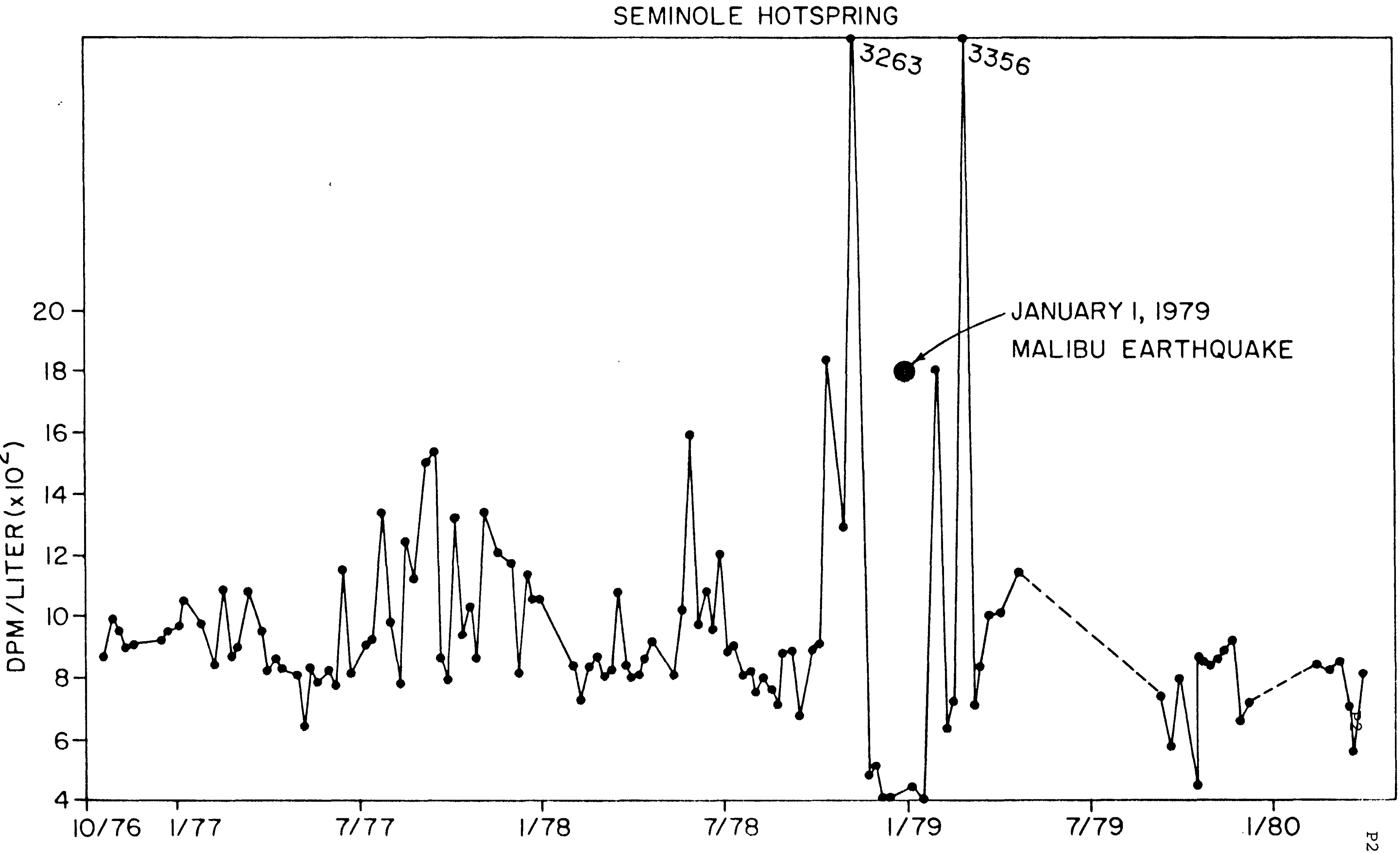
During the period from October 1, 1979 to March 31, 1980, there were no anomalies in groundwater radon content at any of our monitoring sites. Figures 1 and 2 summarize data for recent years at two key sites, Seminole Hot Spring near Malibu and Switzer Camp north of Pasadena.

Our first continuous radon monitoring system has operated nearly nine months at an artesian well site east of Riverside on the Banning fault. The system functions properly and we are now preparing additional units for field deployment.

Figure 1. Groundwater Radon content at the Seminole Hot Springs site during the period 1976-1980.



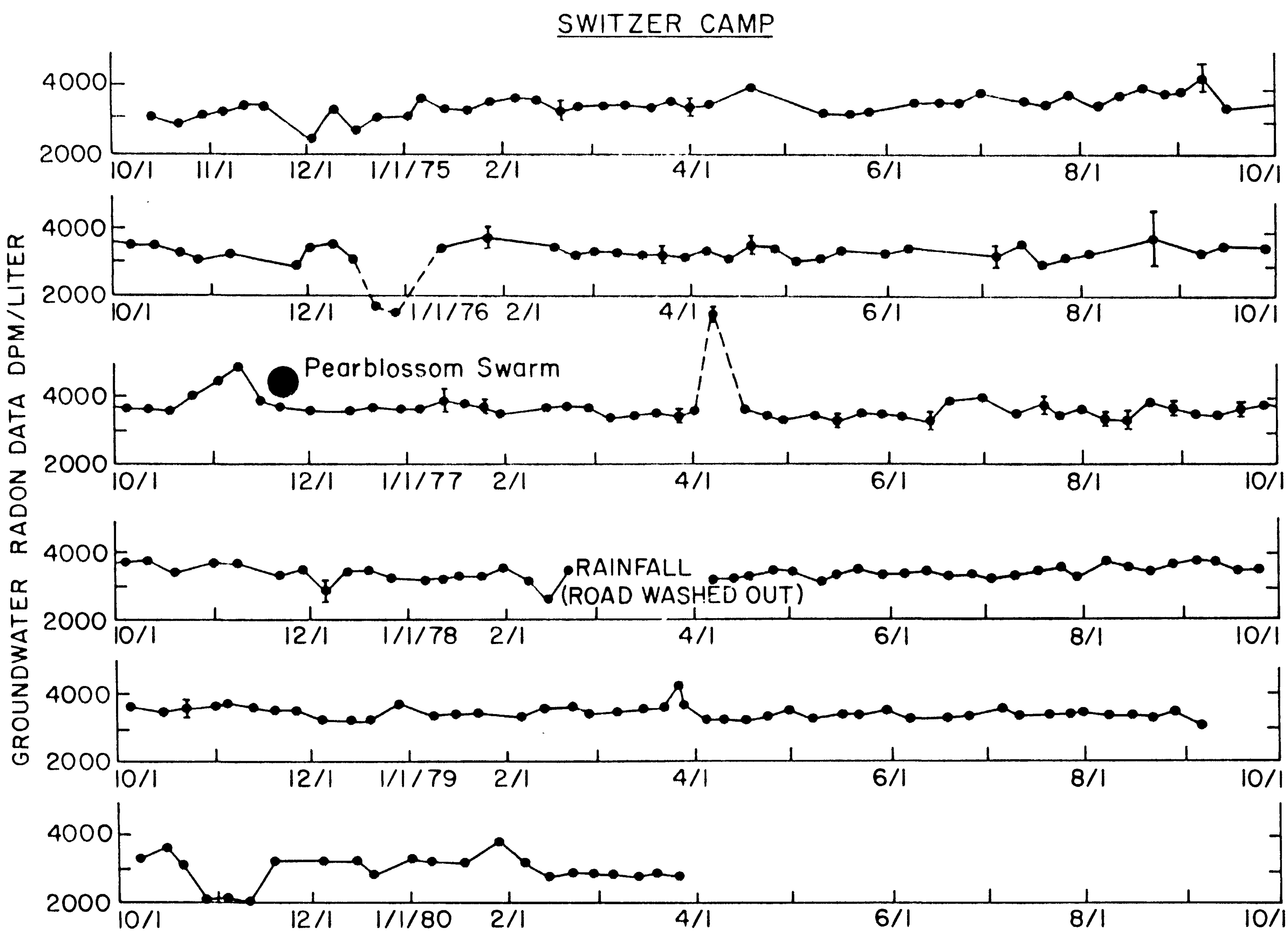


Figure 2. Groundwater Radon content at the Switzer Camp site during the period 1974-1980.

Paleogeodetics
9960-01488
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Investigations

Analysis and interpretation of repeated geodetic survey measurements relevant to earthquake-related deformation processes operative at or near major plate boundaries. Principal recent activities have been:

(1) An analysis of elevation-correlated level changes on 1700 km of level lines in Southern California;

(2) A study of historic geodetic measurements in the Tokai district, Central Honshu, Japan, an identified seismic gap with a high earthquake potential;

(3) An investigation into stress relaxation processes in the asthenosphere and fluid flow effects in the upper lithosphere that might account for the post-uplift partial collapse of the 1959-74 southern California uplift.

Results

1. 1700 km of surveys within the Palmdale Bulge were subjected to a number of independent tests in order to gauge the magnitude and effect of systematic, or accumulating, errors on thirty years of precise level surveys. Undetected rod length changes--stretching, contracting or damage to the graduated invar tapes suspended within the rod frame--cause errors of about $\pm 5 \times 10^{-5}$ x the topographic height difference, or less than ± 5 cm, for much of the southern California relevels. However, these errors do not accumulate with time or over long distances, and they are significantly smaller than the total observed uplift, which is about 25-40 cm from 1959 through 1973. No evidence has been discovered for the accumulation of differential optical refraction, or the tendency of the line of sight between instrument and rod to bend in one direction preferentially during one survey more than during a resurvey. Refraction should be more pronounced on gentle slopes than on steep slopes, and no such distinction is found. The error should be much larger for older surveys when the level instrument and rods were placed farther apart, and yet the measured errors have not changed throughout the period of measurements or uplift (Figure 1). The

fact that the Palmdale Bulge is centered on the 1 km high Transverse Ranges demonstrates that these youthful mountains are currently rising and deforming, both during and between earthquakes (R.S. Stein, S. Silverman).

2. Geodetic measurements made in this century demonstrate that modern movements in the Tokai seismic gap region of central Honshu, Japan, correlate well with deformation that has occurred during the past 2 M.Y. Both show effects of subduction and of the Quaternary collision of Izu Peninsula with Central Honshu. Westward from Suruga Bay, deformation is greatest near the coast, decreases markedly towards the uplifting Akaishi Mountains and then increases again in the conjugate block-faulted terranes of Chubu district. Quaternary faults, historic earthquakes, and the distribution of horizontal shear straining since ∿1880 all reflect this deformation pattern. Since 1900 the west coast of Suruga Bay has undergone secular subsidence, horizontal contraction, and tilting towards Suruga Trough, all typical of the strain buildup process that occurs landward of subduction zones. However, further westward, active mountain building is occurring, and the Akaishi Range are rising 3 mm/a. Unlike the episodic aseismic uplift of the Transverse Ranges of southern California, movements here have been relatively uniform. It seems likely that an increase in the tilt rate of the Suruga coast recognized since ∿1973 is part of a long term readjustment to the great 1944 Tonankai earthquake. Data show that a monotonic increase has occurred since at least 1949, and similar effects are seem adjacent to the 1944 rupture zone over 200 km southwest along the Nankai Trough. Near Suruga Bay, both the secular deformation and the post-1944 movements can be accounted for by episodic aseismic slip following 1944 and asthenospheric readjustments due to great earthquakes in 1944 and earlier. Further landward the deformation is related to effects of collision and its mechanism is unresolved (W. Thatcher and T. Matsuda).

3. The origin of the southern California uplift is investigated using models in which the viscoelastic properties of the asthenosphere and the fluid flow (poroelastic) properties of the upper lithosphere are accounted for. The uplift is presumed to be a recurrent process related to the compressional tectonics of the Transverse Ranges, which have been elevated as much as 3 km in Quaternary time. The uplift itself is modeled by aseismic slip at depth on a thrust fault dipping at a shallow angle. Introducting stress relaxation properties in the lithosphere and asthenosphere causes subsequent time-dependent deformation. In the case of asthenospheric relaxation, the post-slip movements involve further elevation of the uplifted region and approximately north-south oriented tensional strains, both of which disagree to some extent with observations. Poroelastic relaxation is simulated by abruptly decreasing the elastic moduli in the upper lithosphere once fault

slip has ceased. The result is subsidence of previously uplifted regions and continued north-south contractional straining. Although these features qualitatively agree with observations, the success of the model is mixed. Matching the measured partial collapse requires a large (factor of 3) elastic modulus change in the upper crust, introducing possible large changes in seismic wave velocities which are not observed. Whether these defects eliminate fluid flow as a mechanism for the partial collapse or merely reflect the shortcomings of an overidealized model is not yet clear (J.B. Rundle and W. Thatcher).

Reports

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Thatcher, W., T. Matsuda, T. Kato and J.B. Rundle, 1980. Lithospheric loading by the 1896 Riku-u earthquake, Northern Japan: Implications for plate flexure and asthenospheric rheology, EOS, J. Geophys. Res., 85, in press.

PROGRESS REPORT ON GRAVITY RESEARCH AT COTTRELL OBSERVATORY

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During this period, a number of changes were made on the third generation cyrogenic gravity meter. The old paper tape digitizer which was revitalized once before, quit working in the middle of an experiment. Consequently, a new 16 bit analog to digital convertor was constructed which operates in conjunction with a Pet computer. The data are recorded on a magnetic tape. The former low pass filter had too much electronic noise; to remedy the problem a new low pass filter was designed and put together. The super insulated dewar was evacuated, and two long runs showed that after temperature stabilization, the liquid helium boil off can be reduced to 3 1/2 liters per day. In spite of the fact that the super conducting ball had trapped flux, reasonably good tide data were obtained. These are presented in the report.

Field Experiment Operations

9970-01170

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Investigations

This project performs a broad range of management, maintenance, field operation, and record-keeping tasks in support of seismology and tectonophysics networks and field experiments. Seismic field systems that it maintains in a state of readiness and deploys and operates in the field (in cooperation with user projects) include:

a. 5-day recorder portable seismic systems
b. Smoked paper-recorder portable seismic systems
c. Seismic refraction trucks
d. "Cassette" seismic refraction trucks
e. Portable digital event recorders

This project is responsible for obtaining the required permits from private landowners and public agencies for installation and operation of network sensors and for the conduct of a variety of field experiments including seismic refraction profiling, aftershock recording, teleseism P-delay studies, volcano monitoring, etc.

This project also has the responsibility for managing all radio telemetry frequency authorizations for the Office of Earthquake Studies and its contractors.

Results

Network augmentation. Site permitting, telephone line ordering, and requests for radio frequency authorization have been completed for about 120 of the proposed 150 station augmentation of the California seismic networks and Oregon geothermal network.

Seismic refraction. Project personnel carried out the permitting, drill-hole monitoring, loading, and firing of 6 shots at 3 shotpoints during refraction experiments near Livermore, California in December and February.

Portable networks. Seven 5-day recorder seismic systems and several digital event recorders were operated during aftershock studies program for 7 weeks following the Livermore, California earthquake. Six 5-day recorder systems are being operated by project personnel in the Mt. St. Helens volcano study. These recorders were in place within 2 days of the initial eruption.

Reports

Van Schaack, J., 1980, A Code Generating Self-Calibrating Seismic Amplifier: U.S. Geological Survey Open-File Report 80-367.

Earthquake Data Processing

9900-90034

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Objectives

We are in the process of assembling a computer environment aimed at facilitating exchange of data and programs and aimed at facilitating analysis of data in the Earthquake Hazards Reduction Programs. The environment is built around the concept of tools where thousands of general purpose tools are available to analyze different types of data. New tools can be added and the old ones improved. The Geolab command language provides an easy interactive way to link the tools together, to create magatools, and to process data with the tools. The tools can also be linked using a compiled language such as Fortran. The objectives of this effort are described in detail in the last report.

Results

Version I of the software was delivered to the seismologic groups on April 23, 1980. This preliminary version includes:

1. The UNIX (Trademark of Bell Laboratories) Timesharing Operating System with extensions and modifications to:
   a. Operate on PDP 11/34 computers as well as 11/70 computers
   b. Operate a 100,000 baud high speed interface built by the USGS to Tektronix 4014 graphics terminals.
   c. Include a phototypesetting package for use on the Versatek printer/plotted developed at the University of California at San Francisco.
   d. Include a full screen editor and many other features developed at University of California at Berkeley.
   e. Include many enhancements to the Fortran library, compiler, tape utilities, on-line documentation, etc.

2. A preliminary version of the GEOLAB Interactive Language with virtual array capability, date-time variables, easy linkages to tools operating as separate processes, and many features for defining tools and operating on arrays of data.

3. A preliminary version of the GEOPLOT Graphics Package with Tektronix, Versatek and file outputs and facility for easy addition of other devices. Geoplot provides most of the features of major graphics systems available on large computers. When fully implemented it includes over 30 transformations, 10 fonts, map data files, general framing routines, etc. Geoplot runs simultaneously as a separate process and requires very little of the address space of the users process.

4. A very preliminary version of GEOBAS, a general purpose indexable relational style database integrated into GEOLAB that also runs as a separate process.

5. A modular tool oriented hypocenter program.

6. Tools for picking seismic first arrivals, filtering, cross-correlating and spectral analyzing time series, calculating running means, decoding time code signals, etc.

7. A preliminary copy of an eight volume set of manuals documenting the operating system with enhancements, and all tools and software packages developed.

The initial release of software is a major part of the foundation upon which a large toolshop can be built. Considerable work is still necessary, however, to firm up the foundation. There are many tools still to be fashioned and existing tools to be improved. We are anxious to work with anyone who wants to participate at any level in improving and utilizing this new truly interactive environment. The ultimate test of this effort is whether many scientists find that they can get more research done better and easier using these tools. We are convinced that once people make the effort necessary to learn anything new, they will not be disappointed.

Fault Zone Structure and Seismicity in Central California

9930-02392

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See Earthquake Data Processing report

9900-90034

STOCHASTIC SIGNAL PROCESSING AND ANALYSIS OF WATER LEVEL DATA

#14-08-0001-18210

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Investigation

To explore purposefulness of stochastic signal processing and analysis of water level data using data from presently available wells (U.S.G.S. and Lamar and Merifield).

The ultimate purpose of the overall program is to investigate the usefulness of water well data as an aid in predicting and understanding earthquakes. A major objective of this program is to enhance the usefulness of these raw or unprocessed water level records as precursors to tectonic activity through the employment of modern stochastic signal processing techniques. The goals of this enhancement are:

1) To make the anomalies observable earlier, thus providing lead time for the release of the various stages of the prediction.
2) To clarify the characteristics of what constitutes an anomaly.
3) To change the classification of some wells that might now be thought to be "precursory insensitive" or "unreliably sensitive" wells into "precursory sensitive" wells through techniques which filter out "noise" which corrupts the signal.
4) To assist in the understanding of earthquake mechanisms.

Results

The production processing of data is underway. Multiple regressions have been processed both for single component tidal models and for three component land tide models. Both methods have been used on twelve weeks of well 5N-12W-4H1 and twelve weeks of 5N-12W-14C1. This second method using the three component land tide attraction program has resulted in a major revision of EDI's "production line" multiple regression software. This was done in order to accomodate the U.S.G.S. request that EDI change its processing to embrace the new three component land tide program. This has been accomplished with some indicated improvement in the results - though part of this improvement might also be credited to the use of monthly rather than weekly segments of data. (Significant revision of the software to permit processing of monthly records was required by the need to process the much larger data sets involved when using the three component land tide attraction program.)

The improvement was at least threefold: 1) One to two percent additional fluctuation variance was removed from the residuals. 2) The T values associated with the components were, in general, larger. 3) The residuals had a better Durbin-Watson statistic, which was very close to two, indicating an almost complete lack of correlation between successive sample values.

Figures 1, 2 and 3 show typical multiple regression processing, demonstrating 99.2% removal of the water level fluctuation variance, based in part on three component land tidal attractions. These results are based on the well 5N-12W-14C1 for the week of April 8-15, 1977. Figures 1 and 2 represent the starting point in the multiple regression. Figure 1 shows a simultaneous plot of the water level and barometric pressure and Figure 2 shows three component land tidal attractions for the corresponding week. Figure 3 shows the multiple regression results in the form of residuals, observed and estimated water level fluctuations vs. time.

The extensive data that has been processed permits a summary of the procedures limitations showing places where further effort could enhance the value of the processed data. The following summarize these limitations: 1) In much of the processed data observed water level lagged estimated values by one to two hours. 2) Some evidence of multicollinearity is present in the data which affects the precision of the individual coefficients. 3) Further effort towards greater accuracy in the calibration techniques employed in taking the data is warranted.

EDI's efforts to date can be summarized: Procedures have been demonstrated that remove an average of 98.7% of the fluctuation variance from the water level fluctuations with a confidence level exceeding 99% as demonstratedby the F test. It is expected that this will increase the probability of a more certain and earlier capture of any water level precursors that may occur.

Production line software has been generated and assembled for processing on this level of precision for all of the continuous well data recorded to date in Southern California.

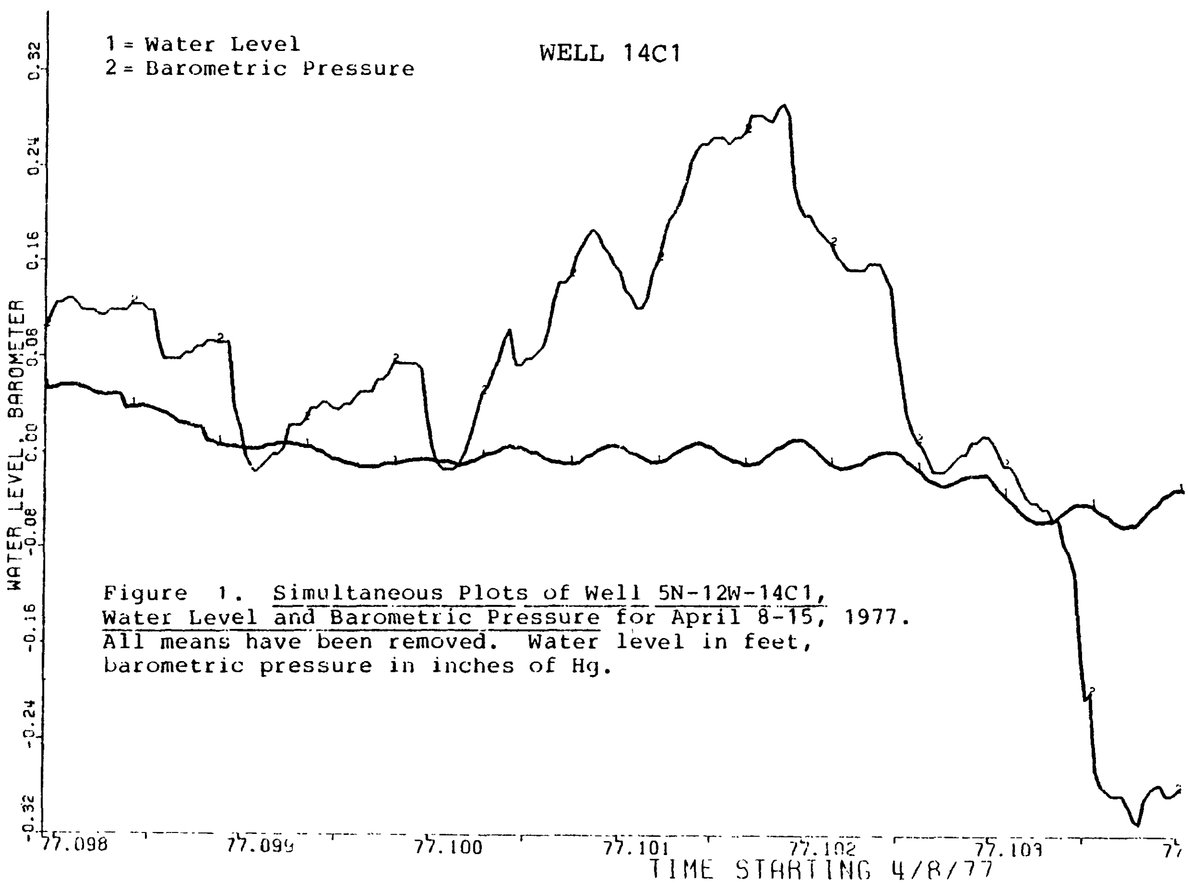

Figure 1. Simultaneous Plots of Well 5N-12W-14C1, Water Level and Barometric Pressure for April 8-15, 1977. All means have been removed. Water level in feet, barometric pressure in inches of Hg.

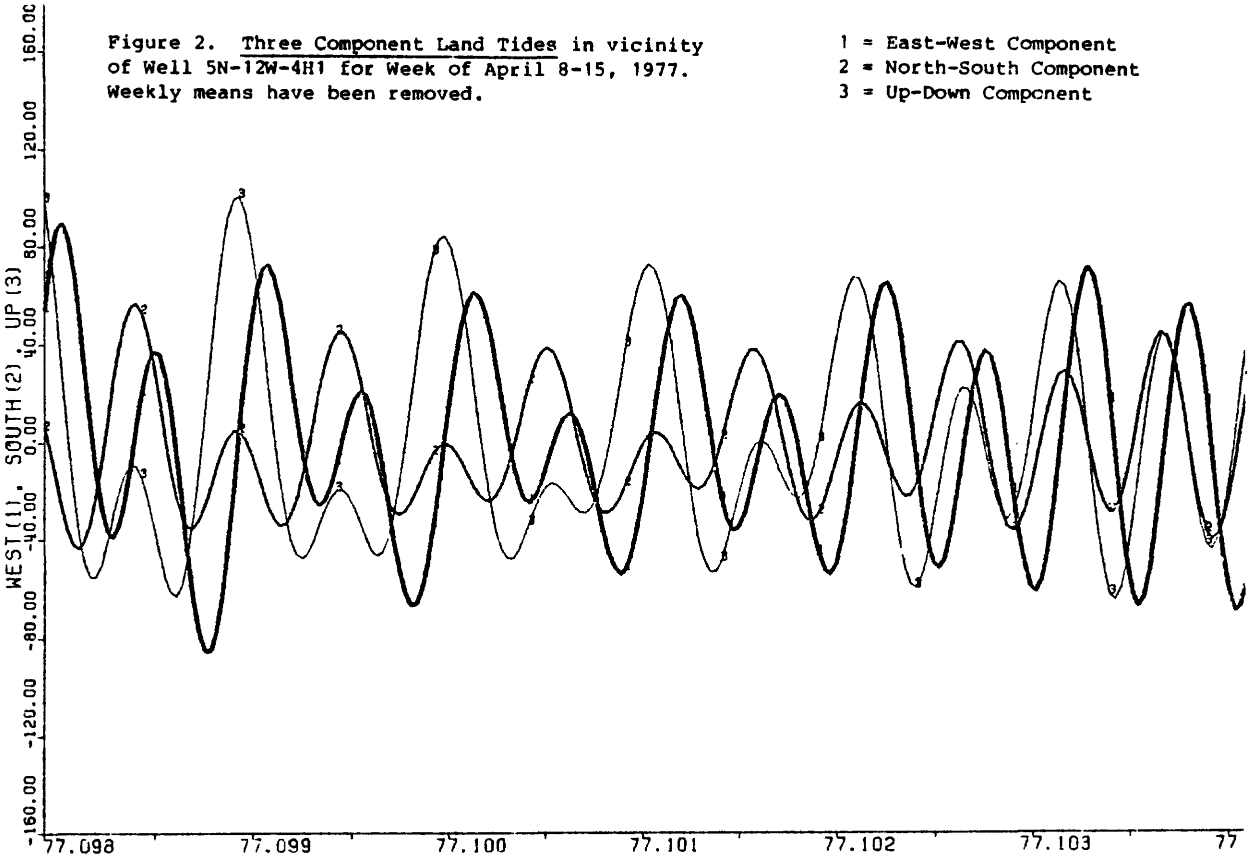

Figure 2. Three Component Land Tides in vicinity of Well 5N-12W-4H1 for Week of April 8-15, 1977. Weekly means have been removed.

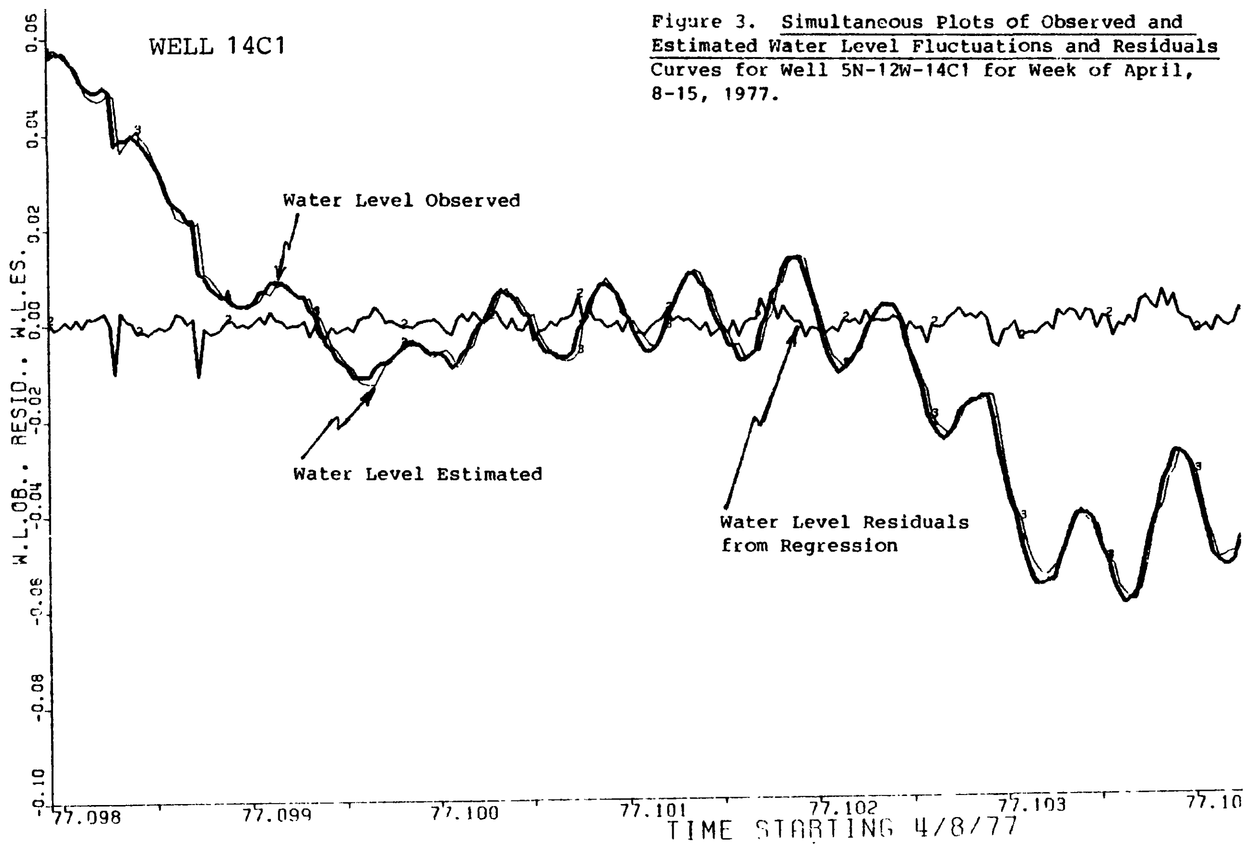

Figure 3. Simultaneous Plots of Observed and Estimated Water Level Fluctuations and Residuals Curves for Well 5N-12W-14C1 for Week of April, 8-15, 1977.

MAGNETIC FIELD MONITORING OF TECTONIC STRESS IN SOUTHERN CALIFORNIA

Contract #14-08-0001-18335

Floyd J. Williams

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INVESTIGATIONS

Magnetic total-field measurements are being taken at 43 field sites distributed across a large portion of southern California. This project, initiated in 1973, is conducted in an effort to monitor changes in tectonic stress beneath the sites. Field observations are taken along the San Andreas and San Jacinto fault zones from Quail Lake on the NW to Indio and the Anza Valley on the SE. A loop of 10 sites also extends around the eastern and northern flanks of the San Bernardino Mountains. Three complete surveys are carried out each year, and earthquake episodes are measured more frequently.

For these surveys, instruments are not placed permanently at the field sites, but buried, benchmark-like supports are utilized to relocate the magnetometer sensor from survey to survey. Readings are taken at two adjacent sites simultaneously over a 10-minute interval of time, and the mean values of the data sets are computed and differenced. The time variation of this difference of means becomes, via the piezomagnetic effect, an indicator of tectonic stress change in the earth's crust beneath the site pair.

A complete survey of the two-dimensional array of sites was completed during December 1979 and January 1980. The weather was favorable for field work, but diurnal variations were larger then desired for data taken at some sites, reflecting an abnormally high level of solar activity. Error was assessed by closing loops of sites around the San Bernardino Mountains and around the Santa Rosa Mountains. Closure error for 31 differences between sites averaged less than 0.3 gamma per site.

Another complete survey will be conducted during April 1980. Measurement techniques will be modified to further reduce closure error.

RESULTS

From April to July 1979, a relatively high level of magnetic field change was indicated, and these results were reported in the last annual report. During the period from July to December 1979, a relatively lower level of magnetic field change has occurred. However, our recent survey, completed in January 1980, indicates anomalous rates of change between: (1) Acton and Palmdale (2) Devil's Punch Bowl and Wrightwood, and (3) Day Canyon and Lytle Creek. When sites along the San Andreas fault zone NW of Cajon Pass are referenced to site #5 in San Bernardino for the interval of time July 1978 through December 1979, a 6 gamma change is indicated for the sites near Devil's Punch Bowl and Wrightwood. These changes are considered to be significant and indicative of changing tectonic stress along this portion of the fault zone.

This survey technique continues to be an effective and economical way of monitoring tectonic stress change, and it is likely that earthquake predictive characteristics will be developed.

Department of Earth and Planetary Sciences
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Cambridge, Mass.

Development of a Quantitative Model of Stress in a Seismic Region as a Basis for Earthquake Prediction

Contract No. 14-08-0001-18205

Principal Investigator: Keiiti Aki
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Goal

To investigate stress induced precursors quantitatively using incremental stress in the earth obtained by the three dimensional geodetic inversion method and to provide a base for an earthquake prediction scheme.

Investigations

Three dimensional geodetic inversion method to obtain the incremental stress in the earth is studied. Geodetic inverse problem is formulated as an elliptic operator equation with Cauchy's boundary condition applied to a body that is cut out of the earth under the surface on which displacements are known. Three dimensional finite element method provides a discretized operator while data obtained from geodimeter and levelling survey, together with a stress free condition on the free surface provide boundary conditions.

Results

The inversion scheme is tested using artificial data generated by Mindlin's buried point force solution. The result shows that currently introduced 20-nodes isoparametric element improves the accuracy of the inversion considerably.

The scheme is applied to the small area near Palmdale, California using data obtained by geodimeter network (Savage et al., 1973) and levelling survey (Castle et al., 1976) (Castle, 1978) during the period 1959 to 1976 (Figure 1). The incremental stress obtained during the period 1959 to 1962, i.e. the period of uplift, shows the dominance of horizontal tensional stress in the direction of N 48° E with magnitude 2.1 bar at the depth of 3.75 km. During the period 1974 to 1977, i.e. the period of downwarp, the maximum principal incremental stress turns to be horizontal compression in the direction of N 40° W with magnitude 2.2 bar at the depth of 3.75 km while minimum principal stress is near vertical and tension. The compressional stress increases with depth to 4.2 bar at the depth of 6.5 km and 7.0 bar at the depth of 8.75 km without changing direction so much. These incremental principal stresses are shown using Shumidt net (lower hemisphere) in Fig. 2 and Fig. 3.

The sense and direction of the principal incremental stress during the period 1974 to 1977 are consistent with the fault plane solutions obtained for earthquakes in the early period of swarm activities observed during the period 1976 to 1977 (McNally et al., 1978). The magnitude of the incremental stress is also compatible with the estimate of Johnston for a stress change to account for the observed geomagnetic change (Johnston et al., 1979).

Report

Ikeda, K. Three dimensional geodetic inversion method for obtaining stress in the lithosphere (Abs.) EOS Trans. AGU, 61, 17, p. 368, 1980

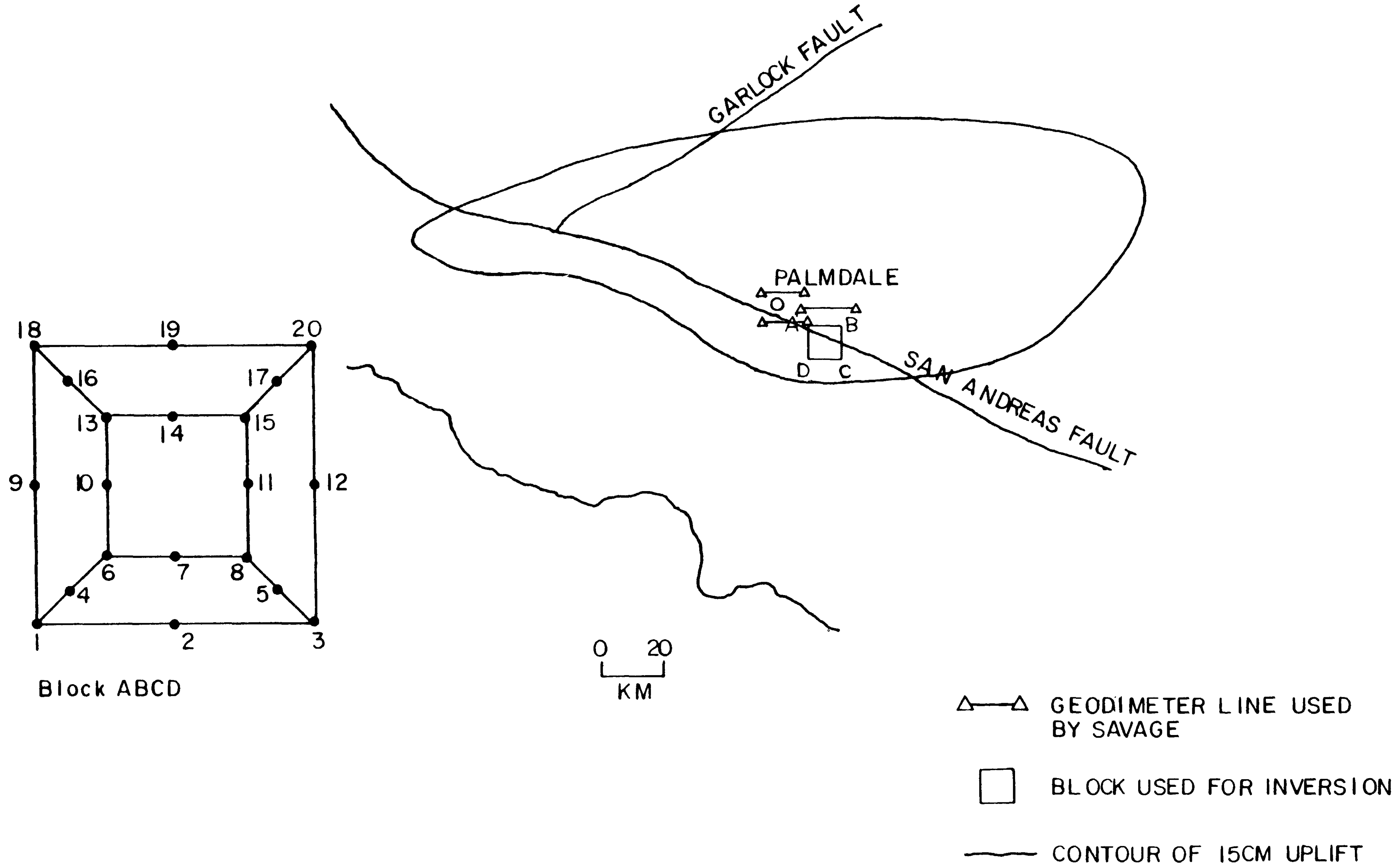

Fig. 1 Geodimeter network and block used for inversion

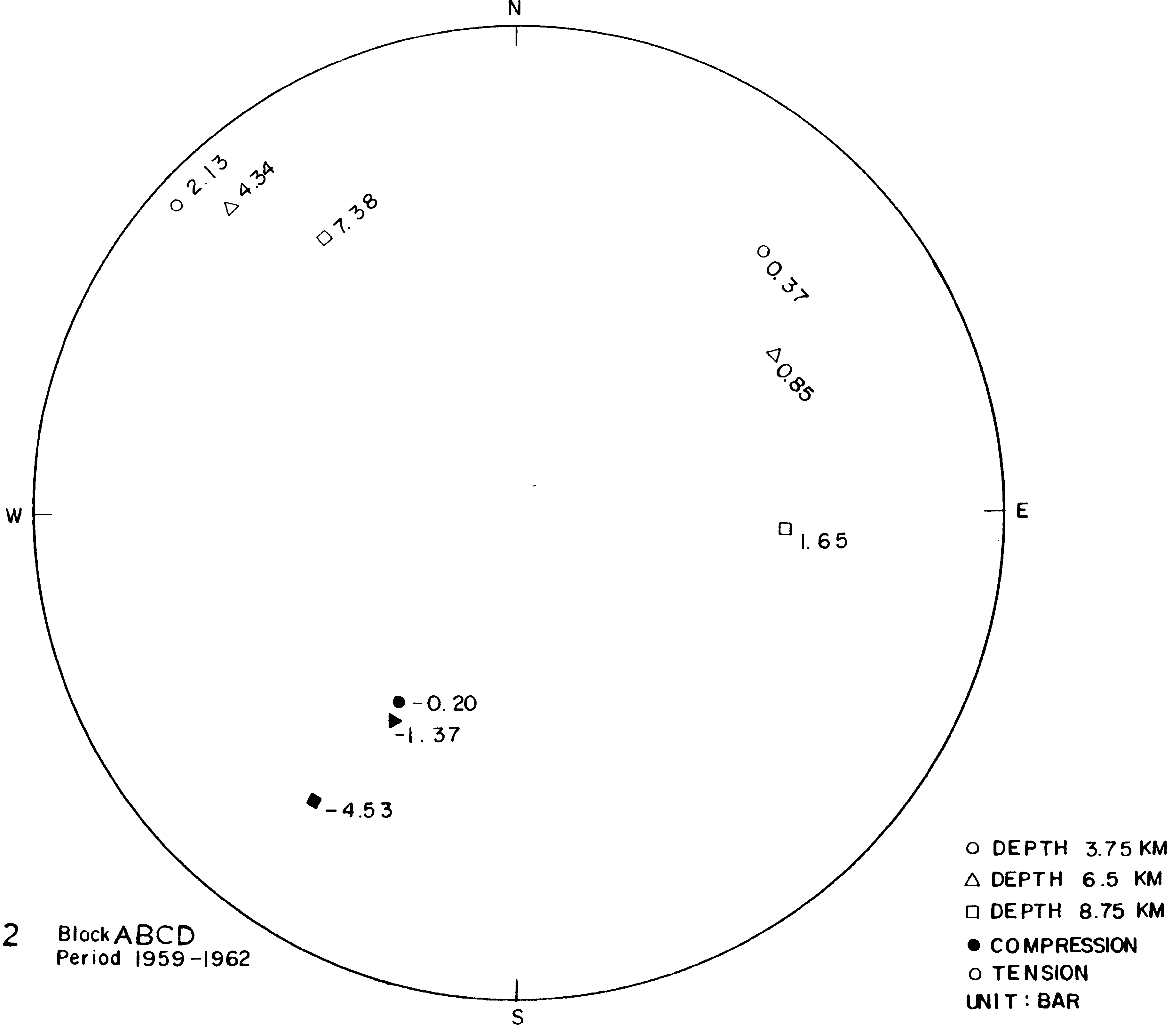

Fig. 2 Block ABCD
Period 1959-1962

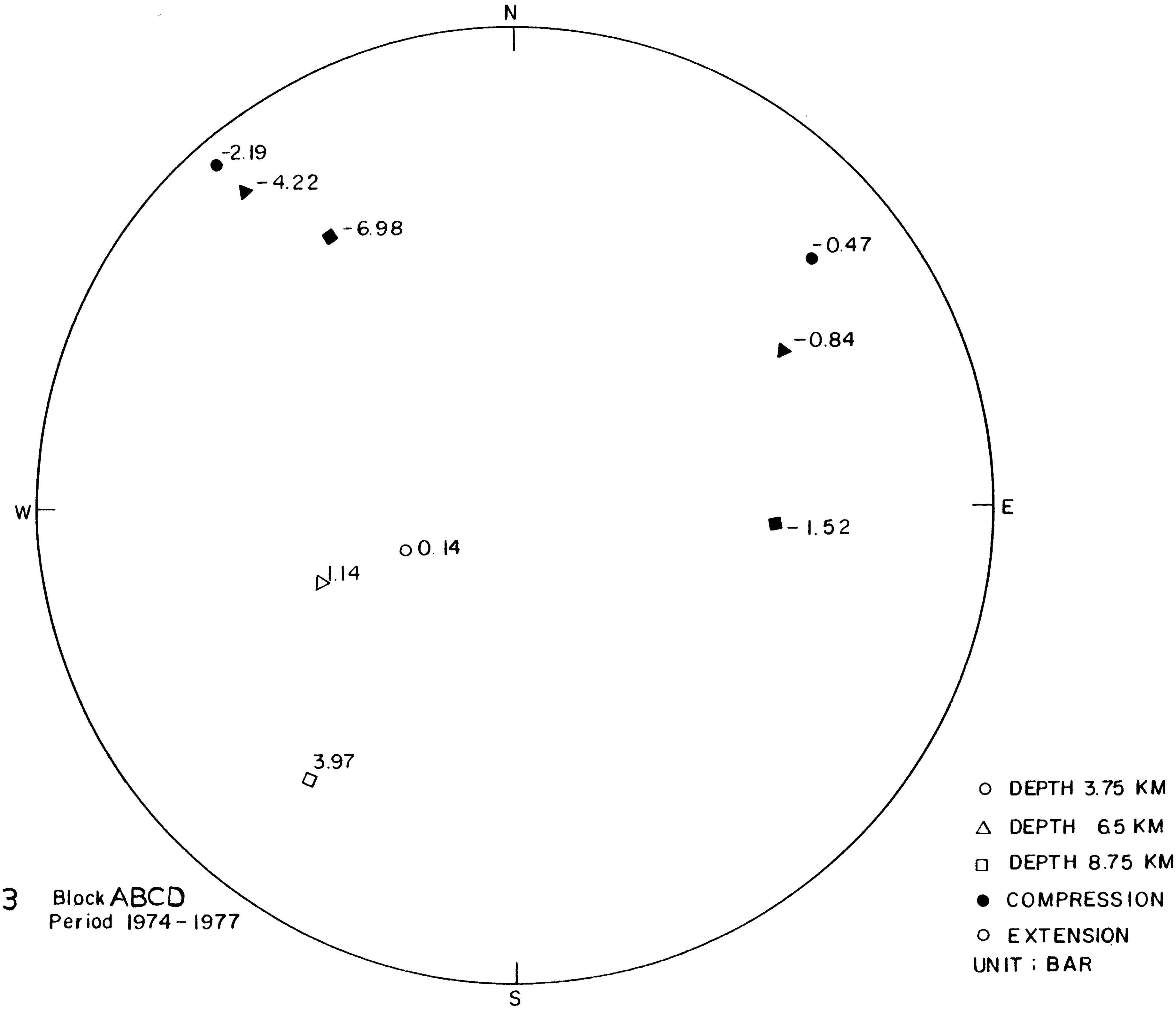

Fig. 3 Block ABCD
Period 1974 - 1977

Creep and Strain Studies in Southern California

Contract No. 14-08-0001-16718

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This semi-annual report summary covers the six-month period from 1 October 1979 to 31 March 1980. The contract's purpose is to maintain and monitor creepmeters, tiltmeters, alignment arrays, and nail-file arrays across or in proximity to active faults in the southern California region. The primary emphasis focuses on the San Andreas fault within and south of the Transverse Ranges, on the Garlock fault, and on the Imperial, Brawley, and San Jacinto faults in the Imperial Valley region.

IMPERIAL VALLEY

Creep and strain instruments in the Imperial Valley recorded an unprecedented body of data before, during, and after the M = 6.6 earthquake of 15 October 1979 on the Imperial fault. For the first time anywhere in the world, we have a continuous record of creep (or the absence thereof) along a fault prior to a major earthquake involving slip on that fault, and for the first time we have a measurement of the time interval during which the surface faulting actually took place. Straddling the segment of the fault that broke during the earthquake were 4 of our continuously-recording creepmeters (HARRIS ROAD, HEBER ROAD, ROSS ROAD, TUTTLE RANCH), 2 nail-file arrays (WORTHINGTON ROAD, ANDERHOLT ROAD), and 3 alignment arrays (KEYSTONE ROAD, WORTHINGTON ROAD, HIGHWAY 80)(Fig. 1). Results are given in Cohn et al. (in press), but to summarize: no discernible creep occurred on the fault during the minutes, hours, or days before the earthquake, and the fault slip at TUTTLE RANCH (the only creepmeter whose taut-wire was not broken by the fault slip) took place in a time interval of less than 8 seconds (Fig. 2). Continuing measurements of afterslip show that all motion is due to discrete 0.2- to 1.5-cm creep events occurring less frequently with time (Fig. 3). The accumulating displacement for the first 35 days following the earthquake is well approximated by linear functions of $\log_{10}(t)$.

Alignment arrays in the Imperial Valley were measured during the reporting period as follows, with the figures in parentheses indicating the total number of individual remeasurements during the period: ALL AMERICAN CANAL (2), HIGHWAY 80 (9), KEYSTONE ROAD (3), WORTHINGTON ROAD (4), BAILEYS WELL (1), DIXIELAND (1), SUPERSTITION HILLS (1). Nail-file arrays measured during the reporting period were: ANDERHOLT ROAD (10), WORTHINGTON ROAD (10), ROSS ROAD (4). Creepmeters serviced and read during the reporting period were: HEBER ROAD (11), TUTTLE RANCH (6), ROSS ROAD (12), HARRIS ROAD (5), SUPERSTITION HILLS (4). The 3 tiltmeters were serviced 3 times, and their records are yet to be fully analyzed.

OTHER PARTS OF SOUTHERN CALIFORNIA

No anomalous creep or strain events were detected outside of the Imperial Valley during the reporting period. Alignment arrays were resurveyed as follows: ANZA (1), DILLON ROAD (1), INDIO HILLS (1), RED CANYON (1), BERTRAM (1). The creepmeter at NORTH SHORE was also read and serviced three times.

NEW INSTRUMENTS

As part of this year's contract, two continuously-recording creepmeters, telemetering to Pasadena using TIM units, are to be installed along that part of the San Andreas fault between Whitewater and Bertram which appears to be a significant seismic gap. With the help of Dr. Kerry Sieh, sites have now been selected at NORTH SHORE and MECCA BEACH, where the fault trace is simple and where telephone circuits are available. Permitting is currently underway for these two properties, and the units should be in operation before the end of the contract year.

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, California, earthquake: U. S. Geol. Survey Prof. Paper.

Goulty, N. R., Davis, P. M., Gilman, R., and Motta, N., 1979, Meteorological noise in wire strainmeter data from Parkfield, California: Seismol. Soc. America Bull., v. 69, p. 1983-1988.

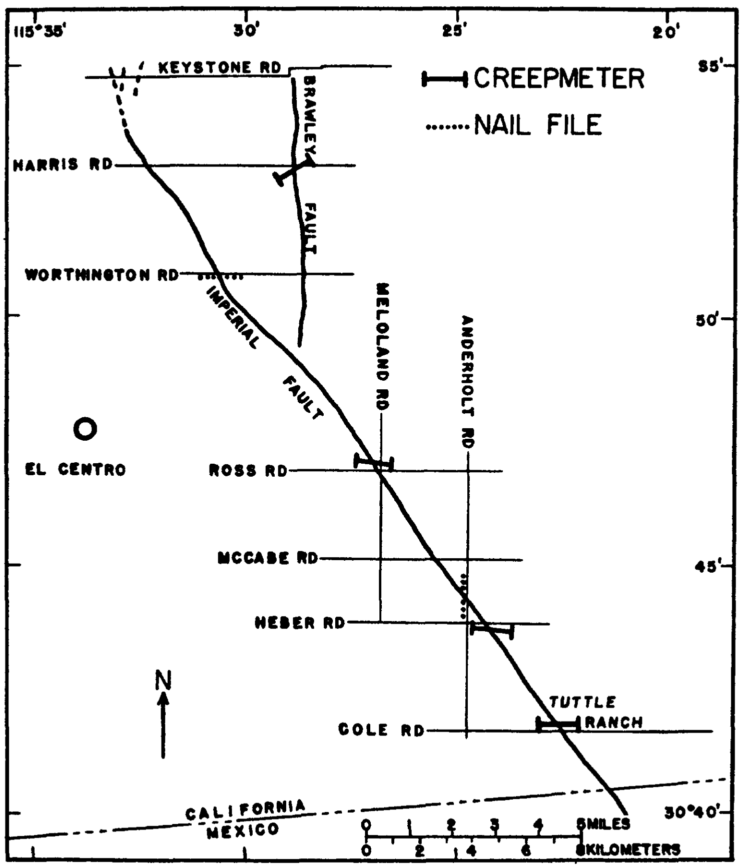

Fig. 1.--Locations of creepmeters and nail-file arrays across the Imperial and Brawley faults, California.

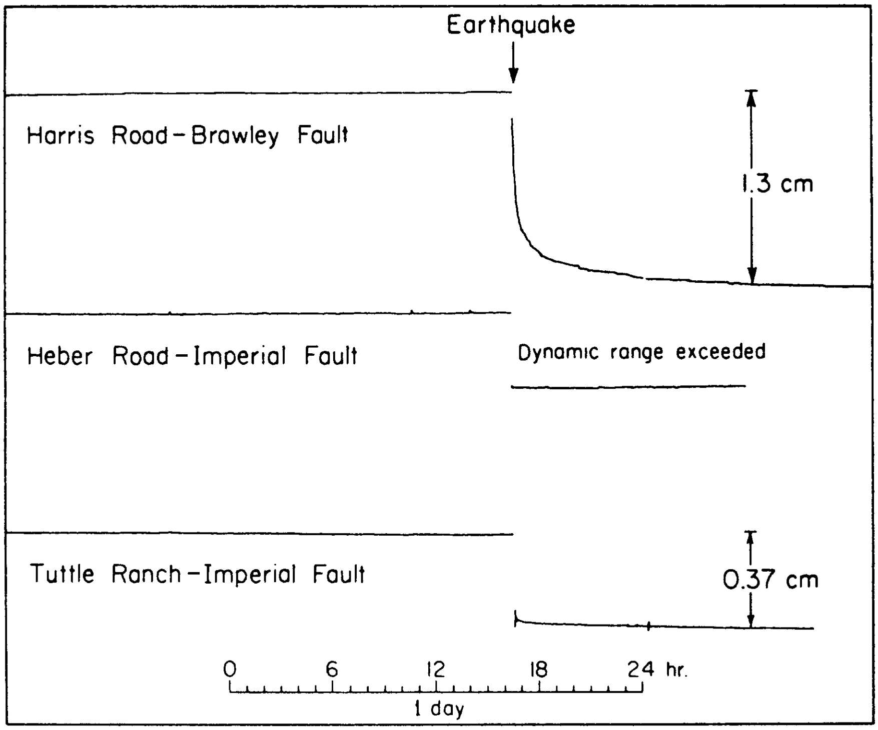

Fig. 2.--Traced copies of records obtained from creepmeters on the Imperial and Brawley faults, showing effects of the surface faulting of the 1979 Imperial Valley earthquake. Note lack of discernible creep prior to the event. Slip during the earthquake on the Imperial fault was sudden, whereas that on the Brawley fault resembled creep.

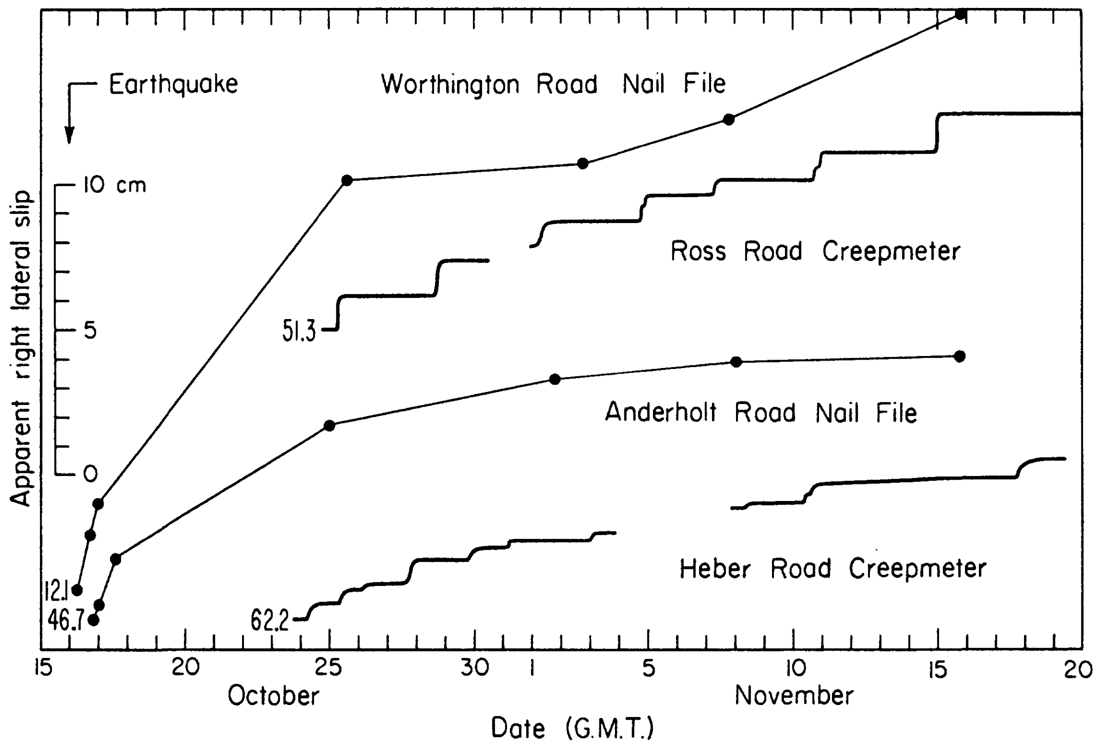

Fig. 3.--Graph of creep on the Imperial fault following the 1979 earthquake as recorded by creepmeters and nail-file surveys. Traces are at same scale, with sequence of sites from north to south arranged top to bottom. The numbers next to the beginning of each trace indicate the offset in centimeters accumulated between the pre-earthquake state and the first measurement following the event.

NEAR SURFACE STRESS MONITORING ON THE PALMDALE UPLIFT

Contract No. 14-08-0001-16720

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Investigations

Terra Tek installed one stress monitor in 1979, at an L.A. County Waterworks yard near Palmdale. Two stress monitors located at Elizabeth Lake and Little Rock Reservoir were installed last year and monitored since December, 1978. Taken together, the three sites lie on the northwest flank, southeast flank and near the center of the Palmdale Uplift.

The Terra Tek stress monitor is a near-surface stress measuring system which uses three vertical fluid filled flatjacks to detect small changes in the magnitude and orientation of the principal horizontal stresses. Small stress changes in the rock mass induce comparable pressure changes in the fluid, which are compared to a pressure reference by a differential transducer housed in the instrument bunker above. It has been shown[1] that each flatjack responds efficiently to normal stress changes perpendicular to the plane of the jack, but does not respond appreciably to transverse normal or shear stresses.

At each Southern California stress monitor, the three flatjack pressures (normal stresses) and one temperature channel are read every 15 minutes by a digital telemeter, the Terabit DA-76. When sufficient data have been collected by the telemeter, a query is made by the Terra Tek PDP-11 host computer, and the data is relayed to Salt Lake through the telephone lines. A stress rosette reduction is calculated from every triad of contemporaneous stresses collected, to resolve the magnitude and direction of the principal normal and shear stresses.

Results

The following observations can be made:

1. All seismic events of any magnitude reported by the CALTECH seismic net from Dec. 1978 through Oct. 1979 were noted, and the stress monitor data inspected for related anomalous behavior. Seismic related behavior was expected to take the form of stress build-up

or release, rotation of the principal stress or unusual variability, lasting from hours to months and somehow timed to coincide with seismicity. Although these trends are present in the data, none have been interpreted to coincide with earthquakes. So far, no earthquake has occured within about 15 km. of an operational stress monitor.[2]

2. Most of the data are highly periodic, with a strong diurnal component. The amplitude of the diurnal stress variation increased roughly 50-fold between December, 1978 and June, 1979.

3. Stress data from the Southern California sites show some correlation to temperature data from the same sites; both the diurnal and longer period trends in one can be found in the other.

4. The reduced data from the first four months of 1979 at the Little Rock site show a net rotation of the principal normal stress of approximately 15 degrees clockwise. The data from Elizabeth Lake for the same period show a net rotation of 50 degrees clockwise. The Elizabeth Lake data for May, 1979 through October, 1979 show a net rotation of 60 degrees counterclockwise.

Conclusions

1. The stability of the Terra Tek stress monitor system appears good after 10 months of operation. The flatjacks have not leaked during the 16 months since installation and only minor problems have been encountered with the transducers and electronics.

2. The data retrieval system functions well, if power is not interrupted by the utility company. The main problem with telemetry has been moisture damage to equipment supplied by the telephone utility. The data reduction system including spectral analysis, auto and cross-correlation, Fourier filtering and graphics is fully developed.

3. The sensitivity of the stress monitor (millibars) as deployed in Southern California is as good as the prototype, but thermal noise is a larger problem. This is largely due to the differences between the sites, chief among them the exposure of the Southern California stress monitors to diurnal temperature fluctuation.

4. To date no changes in the magnitude or orientation of the stress field has been correlated with seismic events recorded on the CALTECH seismic net.

Recommendations

1. Thermal noise at the Southern California sites can be significantly reduced by burying each site beneath 2-3 feet of soil. The temperature of the different components of the stress monitor system would thus be more uniform, and the amplitude of actual temperature fluctuations would be reduced.

2. A simple experiment can be done to learn more about the actual response of the stress monitor to changes in ambient temperature (thermal instrument response). The three compensators at a selected site would be drained and evacuated. The compensators would thus be disabled, and the differential transducers would become absolute transducers. Additional temperature probes would be implemented at a low cost as close as possible to the installed flatjacks. Any change in flatjack temperature which affected the internal pressure (observed stress) would be registered by these probes.

3. An excellent possibility for long term monitoring of small changes in tectonic stress is to redesign the stress monitor system in a borehole configuration. Installed in a hole deep enough to be removed from transient thermal effects and below a possible decoupled surface zone, such an instrument could be very stable. Some development of this concept has been done by Terra Tek, including laboratory calibration and prototype testing of the borehole flatjack system.

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Seismic Studies of Fault Mechanics
9930-02103

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Investigations

1. Microearthquake occurrence patterns and their relationship to active faults is being studied in the San Francisco Bay region.

2. Crustal structure studies are being conducted in central California to determine the fine-scale structure of the crust in tectonically active areas.

3. Mantle structure within the North American-Pacific Plate interface zone is being studied using three-dimensional modeling techniques.

Results

1. Microearthquake clustering patterns along the Hayward-Calaveras fault system in central California suggest that segments of the fault system have distinct, long-term mechanical properties. Significant spatial variations in the cluster production rate and the character of the clusters exhibit temporal stability over at least a 10 year period. A regional doubling in the cluster production rate appears to have begun in mid-1978 along a 100 km-long segment of the Calaveras fault. This segment of the fault produced the M 5.9 Coyote Lake earthquake of August 6, 1979. However, the possible relationship of this rate change to the earthquake is unclear at this time. No corresponding cluster production rate change has been detected thusfar in advance of the M 5.8 Livermore earthquake of January 24, 1980.

Aftershock studies of the Livermore earthquake sequence show that it involved a 30 km-long segment of the Greenville fault system. The length of the fault system activated by the mainshock exceeds the source dimension of the mainshock by a factor of 2 to 5.

2. Systematic crustal modeling studies in central California reveal that the crust is composed of a highly diverse structural assemblage. The applicability of one-dimensional earth models to structure within the region breaks down on very short (~5 km) length scales in the uppermost crust (0-3 km) and on length scales of 25-50 km at intermediate crustal depths (3-15 km). Modeling techniques currently under development suggest that available data from the central California microearthquake network will allow three-dimensional imaging of the crust on a scale length of about 5 km.

3. Three-dimensional velocity modeling of the mantle beneath the North American-Pacific Plate interface in central California reveal an east dipping low velocity body extending from approximately the San Andreas fault at the surface to a depth of over 200 km beneath the Sierra Nevada. This body occupies the probable location of the fossil Farralon Plate. However, its velocity signature, which averages 4% below the surrounding mantle, is inconsistent with the presence of a dead slab in the mantle. Rather, the structural image suggests that the "void" behind by the trailing edge of the subducting Farralon Plate fills with mobilized asthenosphere as the Mendocino triple junction migrates northward.

Reports

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Support of the Southern California Geophysical Data and Analysis Center

14-08-0001-18330

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This report summary covers the six-month period from October 1, 1979 to March 31, 1980.

Goals

1. To support the data collection and processing activities of the CEDAR (Caltech Earthquake Detection And Recording) system and CROSS (Caltech Remote Observatory Support System).

Results

1. CEDAR

CEDAR operations was originally developed and supported by this contract and its predecessors (contracts # 14-08-0001-16629,17642), is now an element of the joint USGS-Caltech SCARLET system (Southern California Array for Research on Local Earthquakes and Teleseisms). As such its product is a component of the results produced by the contract "Southern California Seismic Arrays", contract # 14-08-0001-16719. The result of this effort for the first quarter of this reporting period was the recording and processing of 3118 earthquakes effecting a digitized data base of seismic events stored on "Archive" 800 BPI magnetic tapes.

2. CROSS

This contract supplies continuing operational support for CROSS developed under the predecessor contracts (given above). During this reporting period eight TIM units have been on site. They are as follows:

SITE LOCATION	# CHAN. IN USE	TYPE of MEASUREMENTS	PRINCIPAL INVESTIGATOR
Kresge Lab.	6	tilt, gravimeter	Test site
Caltech campus	6	tilt	T. Ahrens
Palmdale	8	tellurics	T.A. Madden
Hollister	8	tellurics	T.A. Madden
Buck Canyon(1)	1	strain	B. Clark
Valyermo(1)	1	strain	B. Clark
Bouquet Reservoir	1	Gravimeter	L. Teng
Valyermo(2)	1	water well	D. Lamar/K. McNalley
Anza(2)	1	water well	D. Lamar/K. McNalley

Notes: (1) Currently out of service due to heavy rainfall and the difficulty of maintaining a dry environment. (2) Currently out of service due to poor telephone line service.

The data at these sites is collected once a day via the telephone telemetry polling procedure and is being accumulated as a data base on the Caltech Seismo. Lab. PRIME computing system. The data is available externally via a modem port on the computer system but the current method of data delivery for non-Caltech investigators is by use of magnetic tape.

AN ASSESSMENT OF REFRACTION ERROR AND DEVELOPMENT OF METHODS TO REMOVE ITS INFLUENCE FROM GEODETIC LEVELING

14-08-0001-17733

January 1980

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Background

Releveling data has been very useful in helping to detect vertical crustal movements. However, systematic leveling errors can accumulate with distance and consequently degrade the leveling to the extent that it may lose much of its value as an indicator of crustal deformation. Although some terrain or position dependent systematic errors are not worrisome because they cancel out when two levelings are compared, refraction error is a concern because it is time and season dependent. Two levelings made in different seasons, may have different amounts of refraction error and consequently yield an erroneous "apparent" vertical movement when they are compared. The objective of this study was to critically assess the influence of refraction error on levelings, and to develop methods of modeling it so that appropriate corrections can be made. Theoretically, refraction error is greatest in the western U.S., where reliable leveling results are most critical to earthquake prediction and seismic hazard evaluation.

Results

A. Solar Radiation

Leveling refraction depends on temperature stratification near the ground (Kukkamaki, 1939). The temperature gradients near the ground, i.e., the lowest three meters, have traditionally not been measured. Consequently, it is necessary to model the vertical temperature profile using information from weather stations. The National Weather Service (NWS) has recorded solar radiation receipts for a period averaging 30 years at 192 well-distributed stations in the U.S. Average daily totals of solar radiation, for each month, associated with the latitude and longitude of the appropriate weather station were used as input to a least squares adjustment of a time-varying surface which enables prediction of mean daily total solar radiation anywhere in the conterminous U.S. This has been successfully accomplished. Other equations are necessary to convert the predicted daily total to instantaneous solar radiation. This involves calculation of the zenith distance, and azimuth of the sun, given time and date. The known slope of the terrain, in the direction of leveling, is then used to calculate the angle at which the sun's rays are intersecting the ground. The final value generated is then solar radiation appropriate for the time, season, and the direction and slope of the level route.

B. The Vertical Temperature Profile

The construction of the vertical temperature profile, from computed solar radiation is complex because many factors are involved; e.g., clouds, breezes, moisture and reflectivity of the ground, and roadside foliage. In the leveling records there is crude information about clouds and wind. Other factors must be ignored or standard values assumed.

To construct the vertical temperature profile, solar radiation is converted to net radiation using an equation given by Rosenberg, 1974. Upward sensible heat flux is calculated by subtracting heat flux into the ground, and evaporation flux, from the net radiation. A formula provided by Fraser, 1977, is used to compute the temperature at two particular heights. The temperature gradient is then computed and inserted into Kukkamaki's refraction formula for leveling. The algorithm for accomplishing this has been developed successfully.

C. Testing the Modeled Temperature Profile

Δt is the temperature difference between heights of 50 cm and 250 cm, and is predicted by the model for input to the refraction correction. To evaluate whether Δt was modeled successfully, three sets of real temperature data were used as truth for comparison. The data were obtained at three different locations: (1) California, December 1977; (2) Gaithersburg, Maryland, August-September 1979; and (3) Maui, Hawaii, June-August 1979.

Recorded sun and wind information was incorporated by forming a weather factor. The sun code is 0,1, or 2 depending on whether it is overcast, partly cloudy, or clear. The wind code is 0,1, or 2 corresponding to calm, breezy, or windy. The modeled Δt is multiplied by 0.7 if the suncode is 0, and again by 0.7 if the wind code is 2.

Table I. - Summary: Comparison of Observed and Predicted Δt Values

Location	Maryland -NBS-	California	Maui	Model Type
*Mean Deviation	+ .31	+ .27	- .22	Solar Radiation Model by Holdahl
RMS	± .40	± .67	± .90	
*Mean Deviation	- .28	- .72	- .59	Table by A.C. Best
RMS	± .38	±1.01	±1.02	
No. of Observations	838	714	3760	

* A positive mean deviation means the predicted values were generally higher than the observed values.

The RMS value is an indication of the average instantaneous agreement whereas the Mean Deviation is an indication of the tendency for over-prediction or under-predication to predominate. A zero mean deviation is desired.

The scatter of the real Δt measurements about a smooth curve is high, the RMS averaging about .65° for the test data sets. However, the smooth curve (representing the mean) is what we wish to model. Because the mean deviation is reasonably small, considering all the test data sets together, we can conclude that the modeled Δt will produce a refraction correction which is nearly as good as one computed with real Δt measurements.

D. Testing the Refraction Correction

Two of the most important results of this investigation are the verification of the need for the refraction correction, and the verification of the accuracy of the modeled Δt which scales the correction. These confirmations were derived from an experiment conducted at the National Bureau of Standards (NBS). The experiment was designed to both induce and detect leveling refraction error. The test consisted of setting up an instrument which looked at nine level rods set at prescribed distances and relative heights. Height differences and temperatures were measured. As the day continued, refraction error would bias the height differences in a very systematic way. This experiment was done to assess the real influence of refraction rather than relying on a strictly theoretical estimate of the extent to which it should manifest itself. This last type of testing was conclusive in determining the need for a refraction correction and in helping to select the best model for the correction.

Table II: Summary of NBS Refraction Testing

Height Difference (m)	2	2	2
Sighting Distance (m)	30	50	60
No. of Observations	233	211	218
Accumulated Error Observed - Standard (mm)	-18.84	-39.14	-74.50
With Garfinkel Correction (dt Observed)	-2.00	-1.27	-20.72
With Kukkamaki Correction (dt Observed)	-5.36	-5.18	-21.79
With Kukkamaki Correction (dt from Best Table)	-4.62	-4.40	-20.93
With Kukkamaki Correction (dt from Solar Radiation)	-3.87	-2.49	-20.78

The Table II shows how much error accumulated for each sightlength. The "true" or "standard" height differences between rods were determined by carefully leveling between the rod locations with sightlengths of ten meters or less when the observed vertical temperature gradient was very small. It is noteworthy that the accumulated error increases almost exactly proportional to the square of the sighting distance, from 30 to 60 meters, as the original Kukkamaki refraction model dictates. All four types of refraction corrections, listed in the above table, were effective in beating down the refraction error by 75% or more. Of paramount importance to geophysicists, is the fact that the modeled temperature profiles actually produced a correction of refraction error that was as successful as that produced using the observed temperature profiles. If the testing were done again in a different location it would be unlikely that the table of temperature differences developed by A.C. Best would work so suitably. However, because the model developed under this grant is based on local solar radiation it can be expected to work well anywhere in the conterminous U.S.

Recommendations

The refraction correction has been shown to be needed in Maryland, where extreme vertical temperature gradients are not characteristic. It is needed even more in lower latitudes and regions that are more arid; for example, the southwestern U.S. A model for calculating the vertical temperature profile has been successfully developed. It is based on existing solar radiation data, and it can be used effectively for correcting leveling data in order to remove refraction error. With this in mind, it is recommended that all old leveling data be corrected for refraction prior to being used by geodesists or other geo-scientists to calculate vertical crustal motions, or to study other possible systematic leveling errors.

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Interpretation of Geophysical Data Premonitory of Earthquakes

8-0001-17687

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Investigations

We have continued to analyze leveling data for southern California to determine whether the vertical motions implied by these data are tectonic, surficial, or caused by systematic errors. We have examined data for the loop Saugus-Lebec-Bakersfield-Mojave-Palmdale-Saugus, as well as the profiles Santa Monica-Ventura-Santa Barbara, Ventura-Maricopa, and Long Beach-Saugus. On these lines we have searched for correlations between apparent change and topography that would indicate systematic errors. We have also made a study of the methods used to correct leveling data for rod calibrations, and we have studied the effects of temperature on leveling observations.

We have analyzed magnetic survey data for southern California published by Johnston et al. (1979) to estimate the effects of magnetic secular variations and to identify likely causes of the 10 nT anomaly observed at Wrightwood. For secular variations we used the model $\Delta B_{ij} = \Delta X_i \Delta H_j$, where i is a station index, j a time index, ΔB_{ij} the anomalous total magnetic flux density, ΔX_i a local susceptibility variations, and ΔH_j the time varying magnetic force (assumed to have external origin).

Results

We find that correlations between apparent elevation change and topography are pervasive in southern California, with apparent changes on the order of 10^{-4} topography. The ratio between change and topography varies along the profiles. Abrupt changes occur at some places where rods were changed, and at some places where they were not (see Figure 1). Our study of rod calibration procedures indicates systematic errors due to rod calibration may be as large as 10^{-4} and may depend on topographic slope in a nonlinear fashion. We also find an apparent dependence of elevation on temperature greatly exceeding that estimated by the NGS in computing their standard refraction correction (see Strange, 1980). We suggest that both rod calibration and atmospheric refraction may cause significant errors in leveling. Correcting the data to remove the correlation with topography significantly reduces some of the larger loop misclosures in southern California.

The magnetic variations observed by Johnston et al. (1979) were extremely well fit by the secular variation model proposed above. The rms variations were reduced from over 4 nT to less than 2nT by the model (see Figure 2). More important, the large magnetic anomaly near Wrightwood is very well explained. The local susceptibility variations ΔX_i are correlated with the local static magnetic field anomalies. We propose that the Wrightwood anomaly may be the result of local amplification of secular variations rather than by tectonomagnetic effects.

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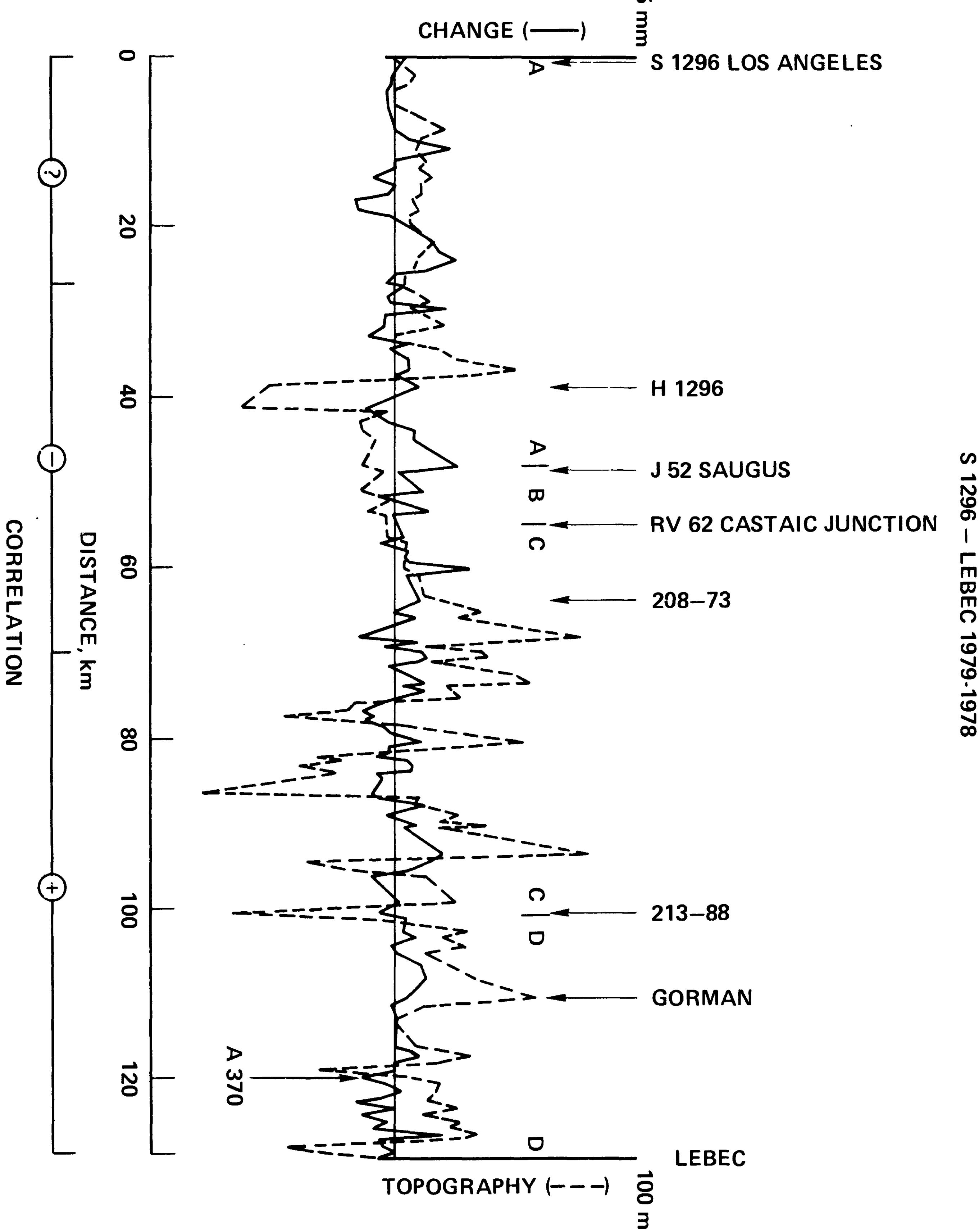
Fig. 1 Apparent elevation changes between successive benchmarks (change) and elevation differences between same benchmarks (topography) on profile Los Angeles-Saugus-Lebec. Rod usage is indicated by letters A-D; the sign of the correlation between change and topography is marked at the bottom. The largest change in correlation does not occur where rods were changed.



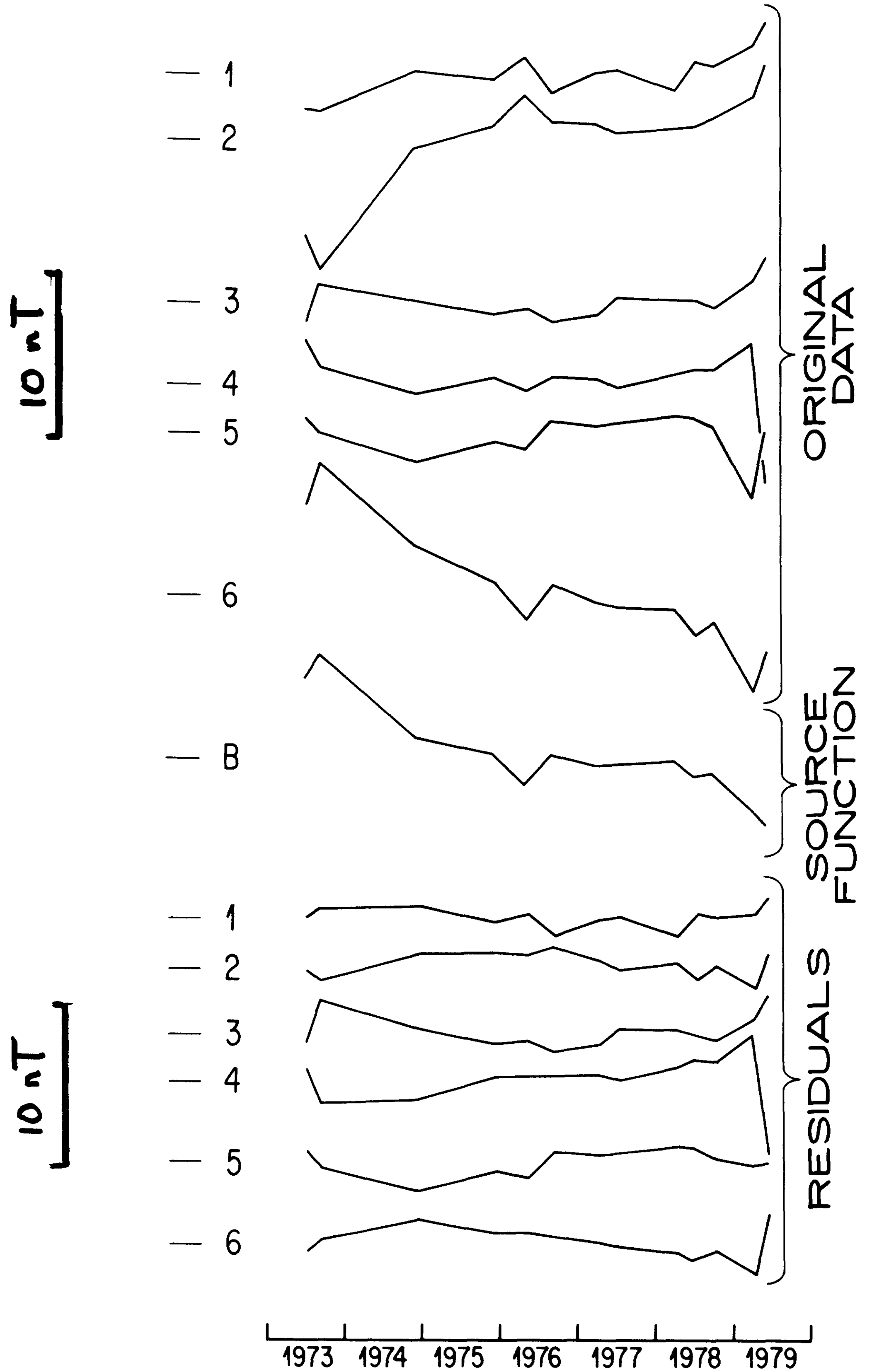


Fig. 2 Variation of total magnetic field with time at several stations (top) and residuals after correction for secular variations (bottom). The curve marked "source function" is the estimated variation of external magnetic force about its mean.

NUMERICAL METHODS IN SEISMOLOGY: RAY-TRACING AND INVERSE PROBLEMS

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Contract No. 14-08-0001-16777

Completely new methods for fast accurate ray tracing in piecewise constant, heterogeneous, media have been devised. These methods do not require the numerical solution of the ray differential equations but employ the exact solutions (straight line segments in this case). Given source and receiver location, all the rays making contact (either reflection or transmission) with specified interfaces in a specified order are computed. The signal amplitudes, travel times and phases are determined. In this way extremely realistic artificial seismograms are produced. These techniques are to be employed in codes designed to solve various geophysical inverse problems. Extensions to three dimensions offer no difficulties. Also an earth composed of piecewise plane stratified media, with different directions of stratification and linear variations in the direction normal to stratification can be easily included in our procedures.

Heat Flow and Tectonic Studies

9960-01176

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Investigations:

1. Energetics of the San Andreas fault zone. Heat-flow holes are now being drilled in the Salton Trough region of the San Andreas fault zone. Thermal and mechanical models for the fault zone are being refined.

2. Regional heat flow and tectonics of the western United States. Analysis of regional data and the results of some site-specific geothermal evaluations continue.

3. Studies of possible premonitory and other fault-related transient thermal events. Development of equipment for monitoring temperatures in selected wells is being hampered by delays in the acquisition of vital electronic components. Reports of sudden changes in well-water temperatures are being solicited and followed up.

Results:

1. Sonoran Desert. Preliminary determinations of heat flow in deep (1 to 1.5 km) holes drilled by DOE in the sedimentary rocks of central Arizona indicate substantial agreement with measurements obtained from shallow (100 to 200 m) holes in crystalline basement in the same region.

2. Modoc Plateau - California Cascades - Northern Sierra. A preliminary interpretation of thermal data indicate a general agreement with the regional interpretation of Figure 1. There is a suggestion that the Southern Cascades high may merge with the Battle Mountain high (BMH, Figure 1) within the Modoc Plateau province in northeastern California and adjoining Nevada. In the Cascades province, the shallow (~200 m) thermal regime seems to be dominated by regional hydrologic recharge with large areas of very low heat flow (0-30 mWm^{-2}). The discharge might occur at very low temperatures (~20°C or less) in some very large springs in the region.

3. Crustal radioactivity and thermal regime. Additional theoretical studies support the view that radioactive heat production generally diminishes exponentially with depth in the crust; they provide greater confidence for estimates of the crustal thermal regime from surface observations of heat flow.

4. Alaska. All available heat-flow data from Alaska have been pulled together, and a preliminary manuscript is in preparation. The preliminary results indicate that heat flow is low to normal (30-60 mWm^{-2}) with some areas of high heat flow associated with Tertiary and Quaternary tectonic features and some for which there is no obvious explanation.

5. Temperature changes in wells possibly associated with seismic events. Two reports of sudden temperature changes in well water, one previous to, the other during and shortly after the January 24 Livermore earthquake, were investigated and confirmed. At a location in Port Costa, a household irrigation well had a temperature rise of about 15°C at some time between August and the end of 1979. The other report described "steaming water" issuing from a well being drilled in Livermore a few hundred meters west of the Greenville fault. The apparent change in water temperature was noticed very shortly after the earthquake.

6. Warner Valley. We have measured heat flow in 10 holes drilled to depths of 60-100 m in lake sediments of Warner Valley, Oregon. A preliminary interpretation indicates a regional heat flow of approximately 75 mWm^{-2} (well within the range expected for this region of the Basin and Range) and a complex pattern of heat flow with values ranging from 43-690 mWm^{-2} believed to arise from hydrothermal circulation supporting the numerous hot springs throughout the valley.

7. Mono Lake - Bodie Hills. To provide background information for a geothermal assessment of Mono Lake KGRA, 11 heat-flow measurements were made in the lake sediments around Mono Lake (north of LV, Figure 1) with the in situ heat-flow probe. These data together with additional heat-flow values from five boreholes in the Bodie Hills area and four boreholes drilled in granite reveal an average regional heat flow of 80 mWm^{-2}, typical for this region of the Basin and Range heat-flow province. In addition, the data reveal a complex local pattern of heat flow with values ranging from 10-800 mWm^{-2} associated with the warm springs along the eastern shore of Mono Lake. The warm springs are probably in a stable stationary phase supported by high regional heat flow with the fluid flow governed by the configurations of fractures and permeable formations and forced by a regional piezometric gradient controlled by topography and precipitation.

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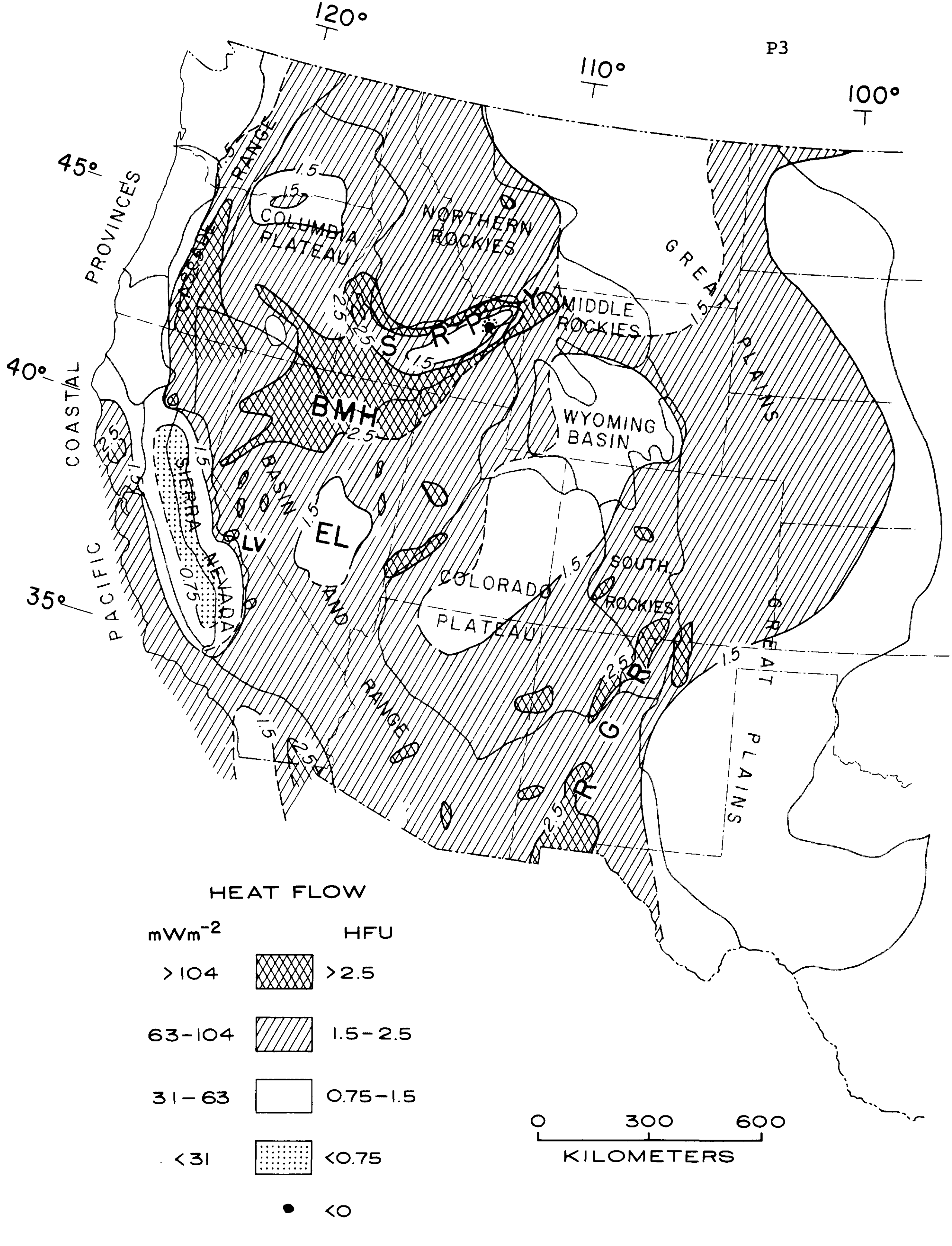

Figure 1. Map of the western United States showing heat-flow contours, heat-flow provinces, and major physiographic divisions. SRP, Snake River Plain; BMH, Battle Mountain high; EL, Eureka Low; RGR, Rio Grande Rift zone; Y, Yellowstone; LV, Long Valley.

Active Seismology in Fault Zones

9930-02102

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Investigations

1. Determination of the P-wave velocity structure of the Imperial Valley, southern California, based on the analysis of seismic refraction data collected in early 1979.

2. Combined aftershock - controlled source study of velocity structure and tectonics in the epicentral region of the January 24, 1980 earthquake on the Greenville Fault.

3. Continued study of the velocity structure in the epicentral region of the Coyote Lake earthquake of August 6, 1979.

4. Analysis of seismic refraction data collected in Saudi Arabia during February, 1978.

5. Development of efficient methods for the calculation of ray amplitudes and travel times in laterally inhomogeneous media.

Results

1. Four reversed profiles and one unreversed profile crossing the Imperial Valley and bordering mesas at different azimuths have been modeled. All models have in common a sedimentary section (modeled in one to three parts), a transition zone, a basement, and subbasement. Sediment velocity appears to increase with depth without discontinuities but with changes in gradient. In the valley itself, velocity increases from 1.8 km/s at the surface to about 5 km/s at the base of the sediments. Along the axis of the trough, sediment thickness ranges from about 4.8 km at the U.S.-Mexican border to 3.7 km along the southwest shore of the Salton Sea. Across the valley between Brawley and El Centro, sediment thickness undergoes more or less abrupt changes from an average around 1.4 km on West Mesa to 4.5 km in the center of the valley to around 3 km on east Mesa. The changes in thickness occur at buried scarps located at or near the shorelines of ancient Lake Cahuilla, which separates the valley from the mesas. Sediment velocity contours generally dip toward the center of the valley.

Smooth continuity of the travel time curves from low apparent velocities to apparent velocities ranging from 5.55 km/s to 5.80 km/s is modeled by a transition zone in which velocity increases from that at the base of the sediments to that of upper basement over an interval of 0.5 to 1 km. Upper basement apparently has a velocity of around 5.6 km/s in the center of the trough, but southwest of the Imperial fault and certainly on West Mesa, its velocity is 5.8 km/s. No evidence of velocity anisotropy was discovered over the limited range of azimuths sampled in the central valley. Because of structural complications, however, our resolution threshold is only 3.5 percent. Velocities in the lower basement range from about 6.0 km/s in the central valley to 6.6 km/s on West Mesa.

Evidence for a subbasement is seen on all profiles longer than about 40 km. Strong to weak second arrivals at distances beginning between 25 and 40 km followed by cross-overs at between 40 and 55 km to first-arrival branches having apparent velocities to 7.2 to 8.5 km/s indicate the presence of subbasement at depths ranging from 11 to over 14 km. This body can be modeled by a velocity jump from that of lower basement to between 6.6 and 7.0 km/s. This jump is followed by a rise to 7.2 km/s within about 1 km. The subbasement appears to have an overall dip of as much as 10 to the north or northeast from an 11 km depth between Brawley and El Centro. A 12.5 km inferred depth southeast of El Centro may imply a dip reversal to the south, making the vicinity of the convergence of the Imperial, Brawley, Superstition Hills and Superstition Mountain faults a subbasement high.

2. Following the Greenville fault earthquake of January 24, 1980, one hundred portable short-period seismographs were operated in the epicentral region. During a recording period of two hours over a dozen aftershocks were recorded. Locations and focal mechanisms will be derived for a number of these. The aftershock array was calibrated by an explosion shot at a location ~ 15 km east of Livermore, California and to date two reversed refraction profiles have been recorded in the epicentral region. A preliminary velocity structure for the epicentral region is (number pairs indicate velocity in km/s, thickness in km): 2.0, 0.4; 3.7, 1.8; 4.4, 1.8; 5.7, 3.8; 6.6, unknown determined thickness.

3. Shot points and profile lines have been chosen for a preliminary seismic refraction investigation near Gilroy, California. A combination of detailed short profiles and two longer profiles should begin to provide information on the velocity structure. Analysis of aftershocks has clearly indicated a high degree of lateral velocity variation in both P-wave and S-wave structure in and near the Calaveras fault. A new model for the Diablo Range P-wave structure is in progress based on a reinterpretation of the data of Stewart (1968).

4. A crustal and upper-mantle velocity model across the Saudi Arabian-Red Sea Rift at ~ 17 N. The M-discontinuity at the Red Sea shot point is 8 km deep and dips at ~ 5 towards the shield, reaching 18 km depth at the rift margin, where an abrupt crustal thickening occurs. Crustal thickness on the continental side of the rift zone is ~ 40 km and the average velocity is ~ 6.7 km/s.

5. A practical algorithm for the computation of synthetic seismograms in laterally varying media has been developed (with G. McMechan). Zero-order asymptotic ray theory has been modified to incorporate the amplitudes of rays that turn in a velocity gradient, as well as reflected waves. The method is general in that synthetic seismograms may be computed for any structure through which rays can be traced. Seismic refraction data from the Imperial Valley have been modelled by the application of this method.

Working independently, R. Clayton and G. McMechan have inverted USGS Imperial Valley refraction data via a novel wave field imaging technique and J. Orcutt and A. Olson have performed an inversion on this data based on a modified tan-p formalism.

All of these methods are of potential use in our on-going analysis.

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Retrieval of Earthquake Source Mechanisms Using Southern California Seismic Networks

14-08-0001-17749

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Investigations

1. Produce software designed to retrieve the seismic moment tensor from local digital recordings of earthquakes.

2. Analyses of the November, 1978, Oaxaca earthquake and the October, 1979 Imperial Valley earthquake.

3. Trial-and-error modeling of near field data using complete synthetic seismograms computed using the Wavenumber Integration and Discrete Wavenumber/Finite Element methods.

4. Investigate the role of source depth and local structure in the inverse problem of inferring the source mechanism directly from seismic recordings.

Results

1. Software has been developed to compute the inverse problem in the time domain using L^1 and L^2 norms. Future investigations will involve testing of the technique in the frequency domain where the lower frequency and more stable portions of the seismograms can be readily treated.

2. The methods have been applied to the Oaxaca, Mexico earthquake of November, 1978. We conclude: 1) The moment lies between 2.4 and 3.5×10^{27} dyne-cm; 2) The event is shallow, less than 25 km deep; 3) The slip vector corresponds to the well-known relative motion vector between the Cocos and North American plates; 4) The dip is small, less than 20°; 5) The effective time constant for the shear waves is larger than for the compressional waves.

3. In order to stabilize the inverse problem it has been necessary to normalize all data to the same peak-to-peak displacement and to heavily weight the initial part of the seismogram.

4. Experiments with different velocity-depth models in the Imperial Valley clearly show substantial differences in the synthetic seismograms in all parts of the wavetrain for a very shallow source in the sediments. The differences become less apparent as the source depth increases.

5. The effect of varying source depth, a non-linear constraint on the Inverse Problem, can be adequately accounted for through cataloging synthetic seismograms for several possible depths and allowing human intervention in the problem to decide which is most adequate.

6. Trial-and-error fitting of complete synthetic seismograms which include all near field terms, body and surface waves and leaky modes has been encouraging. In particular, a synthetic fit to a station from the 1977 Brawley swarm yielded a source moment corresponding to an M_L of 2.1 while the southern California network reported 2.2.

7. Two papers have been written, to date, sponsored by this contract and a third is in the final states of preparation.

8. Analysis of the extensive USGS explosion seismology experiment in the Imperial Valley during the summer and spring of 1979 has produced a reliable velocity structure for use in synthetics computations. The results of this work and the implications for strong motion modeling were presented at the Fall and Spring AGU's and the annual SSA meeting.

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MEASUREMENT AND ANALYSIS OF THE NEAR SURFACE STRESS FIELD IN THE VICINITY OF ACTIVE FAULTS IN SOUTHERN CALIFORNIA

14-08-0001-17705

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The immediate objective of this research program is to determine if tectonic stress can be measured near active faults using near-surface in situ techniques. The method we use is a strain-relief technique developed by the U.S. Bureau of Mines. In actuality strain is directly measured and stress is calculated from the strain and measured rock moduli.

Data were obtained in the field during summer 1979 and winter 1980. A total of forty individual stress measurements were made at four sites with the greatest depth 10.5m. Doorstopper in situ stress measurements (a different strain-relief technique) were previously made at two of the sites. Similar orientations were observed with both methods.

The most significant development this season is the marked difference in strain and therefore stress measured at one site from summer to winter. This site was the first site occupied during the summer and the first at which we used the Bureau of Mines technique. Technical problems prevented us from collecting as much data as desired. This site was tested again in January to obtain more data. To our surprise the strain values were very small and averaged about a factor of five less than the previous summer. We checked and double-checked the equipment, but everything was working fine. The observation certainly seems to be valid. As a further check the stress magnitudes observed during the summer were similar to those at a site 2 km away in the same rock type. We suspect thermally induced stress is the cause of this difference. The continuous recording stress meters in the area (Bruce Clark, personal communication, 1980) showed no significant change, so we did not think the stress change was tectonic.

Hooker and Duval (1971) investigated this phenomenon and noted that the effect of the seasonal temperature change should be significant near the surface and should diminish with depth to zero at about 8 m. Plots of the theoretical variation of temperature with depth for the summer and winter are attached. The dashed line is the calculated stress for an elastic half-space rigidly confined at its sides. The stars and squares are the average stress at the noted depths for one winter site and two summer sites. The tensile stresses shown in the winter would not be observed because of the presence of joints. In a perfectly homogeneous half-space the thermal stresses would be the same for both horizontal components, and could easily be eliminated from our data.

To understand the influence of fractures, consider a single set of joints that are parallel. If the rock expands the joints will close relieving strain. This will yield a lower stress perpendicular to the joints than parallel. An in situ stress measurement between joints will thus produce a deviatoric stress. In the rocks sampled there are generally two to three joint sets. We expect the thermal expansion will produce a deviatoric stress that depends on the character and orientation of the joints. Other effects such as rock anisotropy may also be important in modifying thermal stress. The influence of residual and topographic stress have been either minimized or found not significant at these sites.

Future work is planned to more conclusively determine the effect of thermally induced stress. We want to know how deep we must go to avoid it and how joints and rock anisotropy modify it. This summer we will make measurements to depths of 30 m at each of two sites in different rock types. During the winter, we will drill parallel holes at both sites and compare the data. The stress values should converge below the thermally active zone.

Reference

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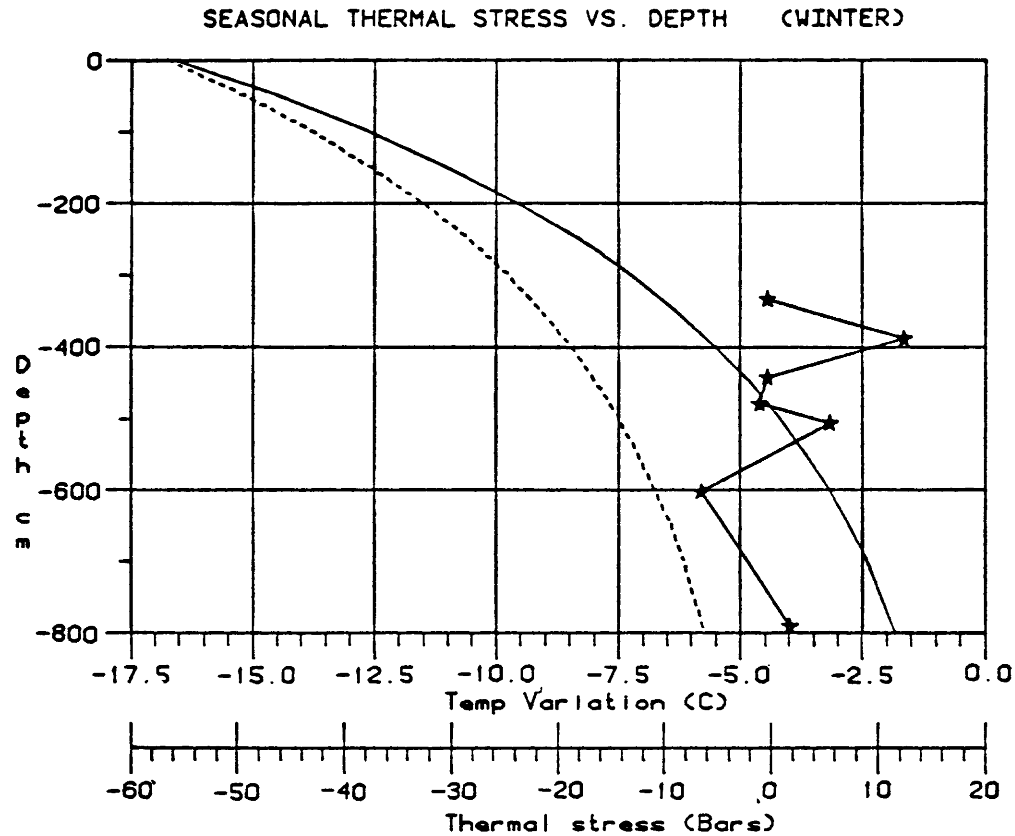
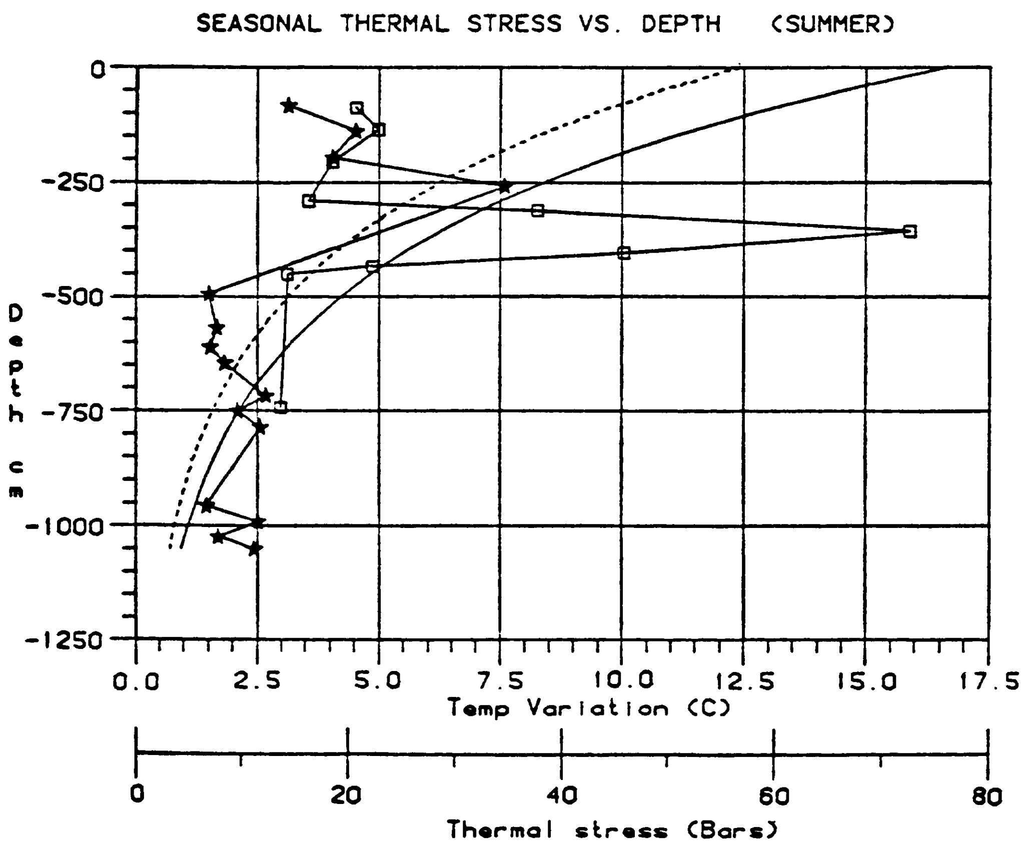

SEASONAL THERMAL STRESS VS. DEPTH (WINTER)
Depth cm
0
-200
-400
-600
-800
-17.5 -15.0 -12.5 -10.0 -7.5 -5.0 -2.5 0.0
Temp Variation (C)
-60 -50 -40 -30 -20 -10 0 10 20
Thermal stress (Bars)


SEASONAL THERMAL STRESS VS. DEPTH (SUMMER)
Depth cm
0
-250
-500
-750
-1000
-1250
0.0 2.5 5.0 7.5 10.0 12.5 15.0 17.5
Temp Variation (C)
0 20 40 60 80
Thermal stress (Bars)

U.S. Geological Survey Contract No. 14-08-0001-17705

MEASUREMENT AND ANALYSIS OF THE NEAR SURFACE STRESS FIELD IN THE VICINITY OF ACTIVE FAULTS IN SOUTHERN CALIFORNIA

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The measurement and analysis of stress near active strike-slip faults may be useful in the identification of areas of high strain accumulation, and hence high rupture potential. Photoelastic modeling (Barber and Sowers, 1974), and finite element modeling undertaking as part of this project, indicate that strain accumulation along a strike-slip fault results in a rotation of the tectonic stress field near the fault. Based on these ideas, we have made a series of stress measurements along the 1857 break of the San Andreas fault near Palmdale, California, for the purpose of identifying and quantifying a rotation of the stress field and establishing the presence of strain accumulation. During a six week summer field season we made fifty successful strain relief measurements at four sites, ranging from a km to 35 km for the San Andreas fault. The magnitudes of the principal stresses varied from 11 to 25 bars. The directions of the principal stresses, though showing considerable scatter, generally indicate a N-S to NE-SW trend away from the fault and a more NW-SE trend very near the fault. Finite element analysis of strain accumulation along the San Andreas fault system produces stress orientations consistent with the date, although scatter in the data precludes a quantitative estimation of the rotation of the stress field.

Two strain relief techniques have been used to measure stress during the project. They are the U.S. Bureau of Mines borehole deformation gage and the C.S.I.R. doorstopper techniques. Both techniques measure stress indirectly by measuring the strain in a rock as it is removed from an in situ stress field. To determine stress, elastic moduli are measured using a radial compression chamber which allows for a first order correction for rock anisotropy. Most of the field measurements were made with the U.S. Bureau of Mines technique, although when both techniques were used, similar results were obtained. Also, when U.S. Bureau of Mines measurements were made where doorstopper measurements had been made two years ago, similar results were obtained (Sbar et al., 1979).

Up to twenty measurements were made at each site, although statistically meaningful average stress orientations were only obtained at three of our four sites. The measurements varied in depth from about 0.5 to 10 meters. Principal strain and stress orientations showed considerable scatter about the average directions, typically $\pm$ 15-20°. The scatter may be attributed to a variety of causes, including coupling of stress across fractures, topographic effects and residual stresses.

In order to develop a theoretical basis for the magnitudes and degree of rotation of the tectonic stress field expected near Palmdale, a finite element model is being developed. The grid, consisting of 368 plane strain elements, covers a 500 square kilometer area including the San Andreas and Garlock faults. Grid spacing is approximately 25 km along the fault. Along the fault, element properties are varied to concentrate strain along the fault compared to the rest of the model. Variable properties include Young's modulus, plate thickness, and pinning grid points to approximate locked portions of the fault. Displacements corresponding to relative motion between north American and Pacific plates since the 1857 earthquake are applied to the edges of the model. Calculated stresses vary from a few bars to approximately 100 bars, depending on plate thickness. Calculated strain rates of a few times 10^{-7}/yr are similar in orientation and magnitude to observed values (Prescott et al., 1979). Along the fault, a counterclockwise rotation of the principal compressive stress results in N-S to NW-SE orientations, consistent with our measurements. Away from the fault, calculated directions are more N-S to NE-SW, again in agreement with our data. Along the fault, lowered elastic moduli by a factor of 10 and reduced plate thickness by a factor of 10 have similar results for stress orientations. Unfortunately, the scatter in our data does not permit resolution of the models.

Our field results indicate that we are capable of measuring the orientation and magnitude of principal stresses. The data indicate a spatial variation in the stress field, but scatter in the data makes it difficult to resolve various models for the variation.

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14-08-0001-G399

Earthquake Risk Analysis Using Numerical and Stochastic Models of Time-dependent Strain Fields

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In this research we have developed a solution method to treat the potential mechanisms causing the Palmdale uplift. In this report I outline the progress, consider defects in the approach of other investigators, and emphasize the necessary features to explain the Southern California uplift. The problem is not resolved as yet; however, the work does offer some constraints.

Previous models of the Southern California uplift suffer from inappropriate assumptions and numerical errors. Using the post-seismic deformations for the 1946 Nankaido earthquake, we indicate the origin of these difficulties and develop the requirements for a model in Southern California. First, the viscoelastic half-space used by Thatcher and Rundle (1979) for the asthenosphere gives unsatisfactory models. In addition, numerical instabilities invalidate their solution using an elastic bulk modulus. A constant lambda and viscoelastic bulk modulus are also inappropriate for the asthenosphere. Finally, lateral heterogeneities strongly effect the deformations and invalidate any simple analytical models if compared to detailed geodetic data.

Using an improved geodetic data set, the 1946 Nankaido earthquake does provide constraints for the viscosity structure of the asthenosphere.

(1) A 30 to 40 km thick elastic lithosphere.

(2) A thin, 20 km thick low-viscosity channel with an effective viscosity of 10**21 poise.

(3) A higher viscosity mesosphere with an approximate viscosity of 10**21 poise or greater.

(4) A zone or layer of low effective viscosity within the asthenosphere adjacent to the subducting slab. Within the zone the viscosity is less than 2.x10**19 poise.

These results offer important constraints for models of Southern California. They suggest that both Kosloff's (1977) and Rundle's (1979) solutions for the Southern California uplift are incorrect: The first ignores relaxation in the asthenosphere and assumes an elastic problem, while the second model contains numerical instabilities and incorrectly assumes a half-space with a viscoelastic bulk modulus. These assumptions will strongly effect the resulting deformations.

Our proposals and reports (Smith, 1977, 1978, 1979) suggest a combination of the following mechanisms generating the unusual pattern of vertical and horizontal movements in Southern California:

(1) Complex fault geometry represented by the San Andreas fault and branch faults.

(2) Stress relaxation in the asthenosphere originating from a low-viscosity channel and lateral heterogeneities.

(3) Coupling of aseismic slip between faults and fault segments.

Kosloff (1977) has treated the first of these for the elastic case, while the final mechanism adopts greater importance in light of Mavko and Stuart's (1979) solution for coupling of aseismic creep between the San Andreas and Calaveras faults. The time scale of the vertical and horizontal deformations, however, require including the second process, stress relaxation in the asthenosphere.

To allow solution of a general problem, the finite element method was chosen as the solution method. A three-dimensional code has been developed to include the following conditions:

(1) General, linear viscoelastic media.

(2) Nonlinear constitutive relation along the fault.

(3) Complex fault configurations including intersecting thrust and strike-slip faults.

(4) Lateral heterogeneities within the crust and asthenosphere.

To differentiate the effect of mantle relaxation from fault creep and to demonstrate the utility of the computer code for three dimensional problems, we solve a simple model of a strike slip fault within a layered media. In our computations asthenospheric stress relaxation cannot account for the deformations occurring in Southern California; complex fault geometries and fault creep are also necessary. Relaxation, however, will perturb the deformations by at least 5 centimeters.

To allow direct comparison to observed geodetic data, we are now constructing a model of Southern California which includes aseismic fault creep or instabilities, complex fault geometries, and stress relaxation. Using the approach of Mavko and Stuart (1979), the solutions will place constraints on the contribution of each factor.

14-08-0001-18368

A Time-Dependent, Finite Element Model of Southern California Strain Fields

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Our initial research concentrates on the development of a model configuration under the limitations imposed by computer resources. First, the CDC 7600 at LBL places a limit on our model resolution. A test problem using 4000 degrees of freedom for a strike slip fault indicates an upper limit for the problem size even using our out-of-core solution method. Unless a specific number of rows from the stiffness matrix are contained in large core memory, the program becomes inefficient and bound by input/output operations. It is not feasible to directly alleviate this problem; consequently, two approaches are taken to minimize its impact on our Southern California models.

The finite element method only models a portion of the earth; artificial boundaries such as fixed displacement must be introduced at a significant distance from the zone of interest. Thus, the artificial boundaries normally used in the finite element method demand a large number of elements and degrees of freedom. To reduce these we have developed infinite elements for our two- and three-dimensional problems (Bettess, 1977). The elements effectively extend the boundary to infinity using an interpolation function. Instead of artifically fixing a boundary at depth, the infinite element approximates an infinite half-space. Fewer elements reduce both computer storage and CPU time.

Even with infinite elements, additional simplifications are necessary if the element configuration represents the Southern California geodetic net used by the USGS. The simplest model uses a lithospheric plate constructed of elements with varying thickness overlying our viscoelastic half-space. The model would minimize the number of degrees of freedom; however, a viscoelastic half-space is a major approximation (Smith, Final Report, Oct. 1979, USGS #14-08-0001-G399). In addition, a single layer of elements will not give a good approximation to potential fault interactions. Yet the model's simplicity warrants its development for comparison to later models.

Development of our advanced model addresses these assumptions using the same surface configuration of elements. Additional detail will be added in depth: The lithosphere will be represented by at least two layers of three-dimensional elements, while the asthenosphere will be incorporated as a distinct layer over the infinite elements. Using the current USGS trilateration network and corresponding leveling data, this would represent the most detailed model using the computer facilities at our disposal.

Studies of the Seismic and Crustal Deformation Patterns of an Active Fault: Piñon Flat Observatory

14-08-0001-17764

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Investigations have continued into the interpretations of a wide variety of seismic and crustal deformation data from Piñon Flat Geophysical Observatory (PFO). This work includes actively monitoring the tectonic activity in an area of high seismic risk and the development of new stable and sensitive instrumentation.

The problem associated with measuring seismotectonic activity on (or near) the surface may be characterized as a signal-to-noise problem. Our goal has been to observe changes in the stress (strain or associated deformation) of the crustal rocks that are associated with tectonic activity. But these changes are masked by noise such as instrumental noise, or environmental site noise, and we are attempting to identify and eliminate these noise sources in order to observe the underlying signals of interest. This is one of the principal reasons for a geophysical observatory; a diverse complement of instrumentation--all attempting to measure the same phenomenon but via different approaches (see Table 1). The inter-comparisons of the results provide a picture not otherwise obtainable.

Table 1.

Instrumentation at PFO		Under Construction (Jan 80)	
4	Biaxial shallow borehole tiltmeters	1	Long baseline tiltmeter (Lamont-Doherty)
3	732 m laser strainmeters		
1	50 m fluid tiltmeter	1	Long baseline tiltmeter (Cambridge)
1	25 m horizontal optical anchor		
3	Dry tilt arrays (UCSB)	1	500 m fluid tiltmeter
2	Precision leveling linear arrays (UCSB)	2	Vertical benchmark strainmeters (Lamont-Doherty)
5	Strainmeter end pier tiltmeters		
2	Electrolevel tiltmeters	2	Vertical laser optical anchors
2	Superconducting gravimeters		
1	Project IDA gravimeter		
1	Strong motion accelerograph (USGS)		
1	Long period horizontal accelerometer		
3	Long period seismometers		
1	Short period vertical seismometer		

Figure 1 presents the strain observations recorded by the three 732 m laser strainmeters at PFO and the geodetic observations produced by J. Savage from a subsection of the Anza geodimeter network. A comparison of the average strain rates is presented in Table 2.

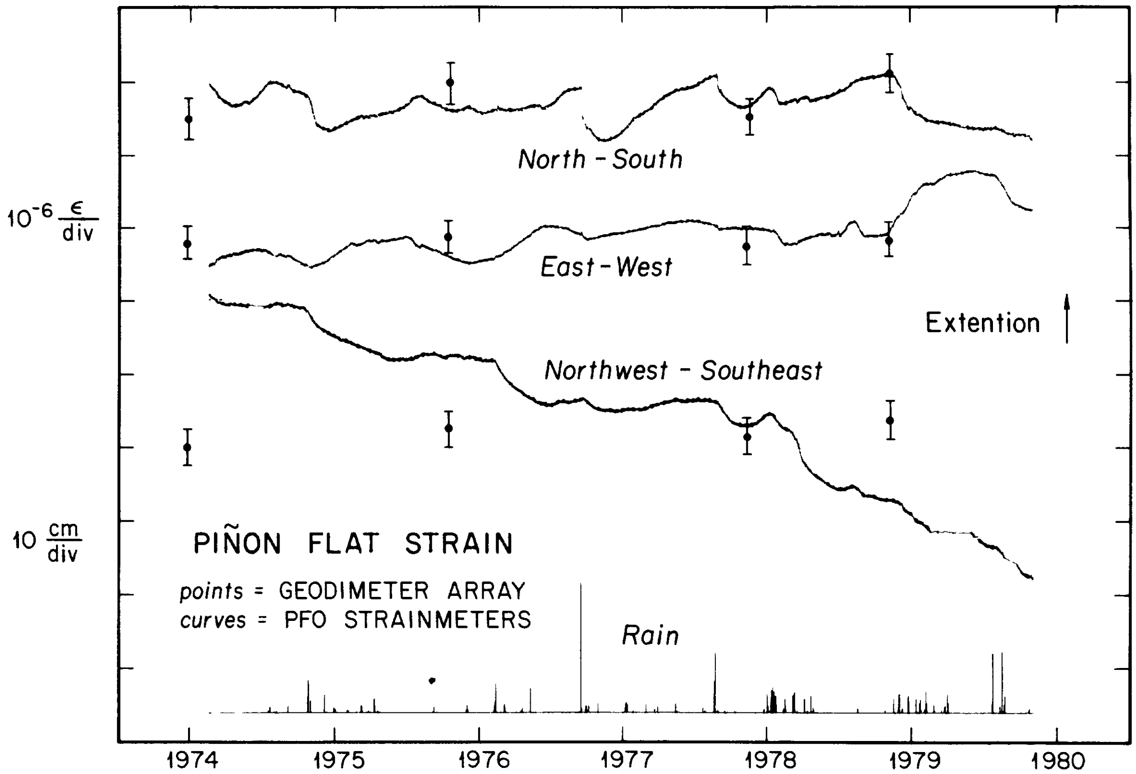

Figure 1.

Table 2. PFO Strain (Units 10^{-6} $\Delta\ell/\ell$)

	Laser Strainmeters		Geodimeter Array (USGS)
	Average Strain Rate	Standard Deviation	Average Strain Rate
North-South ($\dot{\varepsilon}_{22}$)	-.017/yr	.22	.06 ± .05/yr
East-West ($\dot{\varepsilon}_{11}$)	.16/yr	.19	.00 ± .04/yr
Northwest-Southeast ($\frac{1}{2}(\dot{\varepsilon}_{22}+\dot{\varepsilon}_{11})-\dot{\varepsilon}_{12}$)	-.61/yr*	.25	.06 ± .05/yr

*Dominated by rain induced effects

With the exception of the NW-SE strain rate, there is general agreement between the results of these two methods. It is important to realize that individual survey line lengths were averaged to produce the geodetic array strain rates. This procedure establishes a meaningful description of the average strain field but does not necessarily reflect the local strain at PFO. Unfortunately, most of the large excursions of the observed PFO strain are artifacts associated with large rainfalls. We are currently investigating the apparent source of this noise by measuring directly the stability of the near surface layers. Nonetheless, these measurements put an upper limit on the temporal fluctuations of the crustal strain about a linear trend. These limitations, at the lower frequencies, are near the limit of resolution of current geodetic techniques (2×10^{-7} $\Delta\ell/\ell$). Hence, continuous and highly sensitive observations may be essential in order to identify episodic and secular behavior particularly as they are related to earthquake activity.

The continuous long term strainmeter observations also allow us to investigate the stability of the regional elastic response to tidal signals. It is well known that small changes in the elastic properties of the near surface rocks (induced by processes such as dilatancy) will produce large changes in the observed strain and tilt tides. These changes will be observable some distance away from the anomalous region. For example, a 10 percent velocity ratio change in a region would be expected to produce observable changes in the strain tides up to a distance of five times the source dimension.

Figure 2 shows the tidal admittance at PFO for the principal lunar semi-diurnal tide M_2 from early 1973 until the present. Each estimate is obtained by examining 137 days of tidal signals. Although there have been a number of significant seismic events and possible tectonic activity (sòuthern California uplift) in this period, no obvious deviation from a strain line is evident.

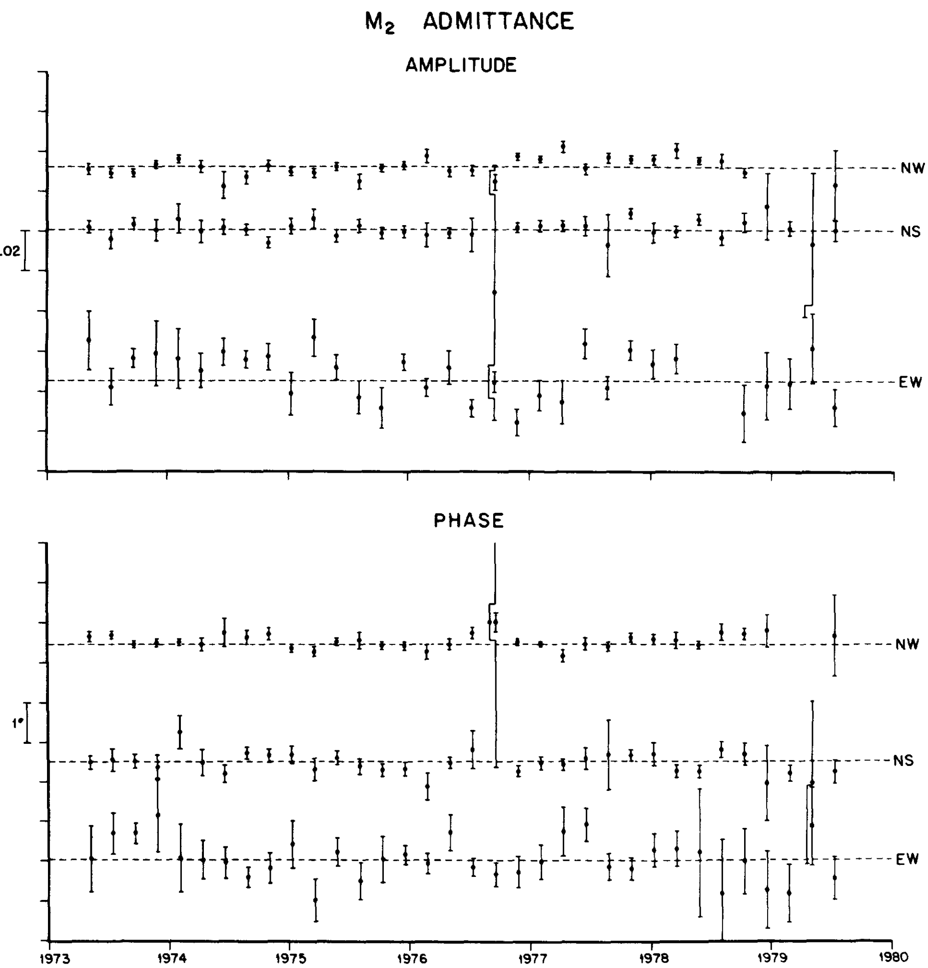

Figure 2.

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Crustal Deformation Measurement Near Yakataga, Gulf of Alaska

USGS 14-08-0001-18272

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The Yakataga region in the Gulf of Alaska is a seismic gap in which there is a high probability of a major earthquake occurring soon. In that the location and size (8.1 $\pm$ 0.2) of the event have been forecast, two of the three requirements for predicting an earthquake in the region have been met. The time of occurrence of the event, however, is poorly known and estimates vary from less than a year to more than a decade. For this reason we have installed continuously monitoring strainmeters at three locations along the coast above the expected rupture zone to monitor possible precursory deformation indicative of imminent seismicity. Three 17 m carbon fiber strainmeters were installed in August 1979 at each of the following locations: Katalla, Cape Yakataga, and Icy Cape. The instruments are equipped with local strip chart recorders and satellite telemetry to enable remote monitoring of hourly data. It is anticipated that the strainmeters will enable the detection of precursory deformation should this occur in the period range 2 hours to 20 days. At longer periods instrument noise is predicted to be greater than estimated precursory strain rates.

An attempt was made to monitor sea level along the coast but the sea level monitors we had planned to use were unsuitable for the combination of tidal range and beach profile we encountered. Radon monitoring has been initiated at Cape Yakataga and at Icy Cape in conjunction with scientists at G.E. Schenectady. A levelling line was measured from Cape Yakataga to the casing of a capped well 2 km to the north.

A study of trees on marine terraces at Icy Cape has revealed that trees close to the seaward edge of the 16 m elevation terrace indicate a dramatic change in growth after 1899. We interpret this to be seismically induced by the historical events that occurred at the turn of the century. The result is important since it demonstrates that uplift may have occurred at Icy Bay in 1899. The distribution of trees on terraces at higher levels is related to their distance from the coast, the highest terrace supporting the oldest tree (Beavan et al., 1979). A coseismic uplift model to explain these data was proposed but is now considered erroneous due to the discovery of 700 year old horizons in the base of the 60 m terrace on which 460 year old trees are growing. The distribution of the trees on the Icy Cape terraces requires further study since the palynological record for the area for the last 10^4 years also shows a periodicity that suggests a relationship with the marine terraces. Biological, storm-surge, and tsunami mechanisms for removing low-level trees selectively in the last several centuries are being appraised in order to explain the observed dendrochronology.

Continued Monitoring of Stress Chaness Near Active Faults in Southern California

14-08-0001-18372

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Investigations

Continued monitoring at the six existing sites was accomplished by means of both telemetry and manual readings. The telemetry operations continued to be intermittent and the backup manual readings were determined to be of greater long-term value. Additional sensors were installed as replacements for faulty sensors at Little Rock Dam and Elizabeth Lake. The revised installation procedure permits new sensors to be installed without destroying the remaining sensors in the hole.

Two new sites were chosed for instrumenting along the Sierra Madre fault zone on the southern margin of the San Gabriel Range. The new sites will be at Lytle Creek, to replace the abandoned site near the junction of the San Andreas, San Jacinto and Sierra Madre fault system, and at Dalton Canyon, in conjunction with an array of strain measuring instruments being installed by the University of Southern California.

Results

The most significant result was the recording of an anomaly associated with the 1979 Lytle Creek earthquake on all three sensors at San Antonio Dam (Figure 1). The Lytle Creek earthquake was a right-lateral strike-slip event on a small fault parallel to the northwest-trending San Jacinto fault. Readings taken on November 3 showed large changes on all three sensors, although the magnitude and sign of the changes were different on each, reflecting their different azimuthal orientations. At its maximum, the anomaly consisted of 2.4 bars compression in the N12°E direction and 1.2 bars decompression in the N78°W direction. By January 3, 1980, the sensor readings had all returned to their original long-term trend levels.

The anomaly detected at San Antonio Dam is a part of a record of approximately 2.5 years of consistently increasing stress levels (approximately 3 bars/year) in a north-south orientation. The minimum principal change (E-W) is also compressive. The long-term changes at San Antonio Dam are the largest of any of the four Stressmeter sites and are consistent in orientation with a stress pattern expected to induce thrust movement along the frontal faults at the southern edge of the San Gabriel Mountains, in a densely populated urban area.

Reports

Clark, B. R., Preseismic and Coseismic Stress Anomaly Accompanying Lytle Creek, California Earthquake of October 19, 1979: EOS, V. 61, p. 293.

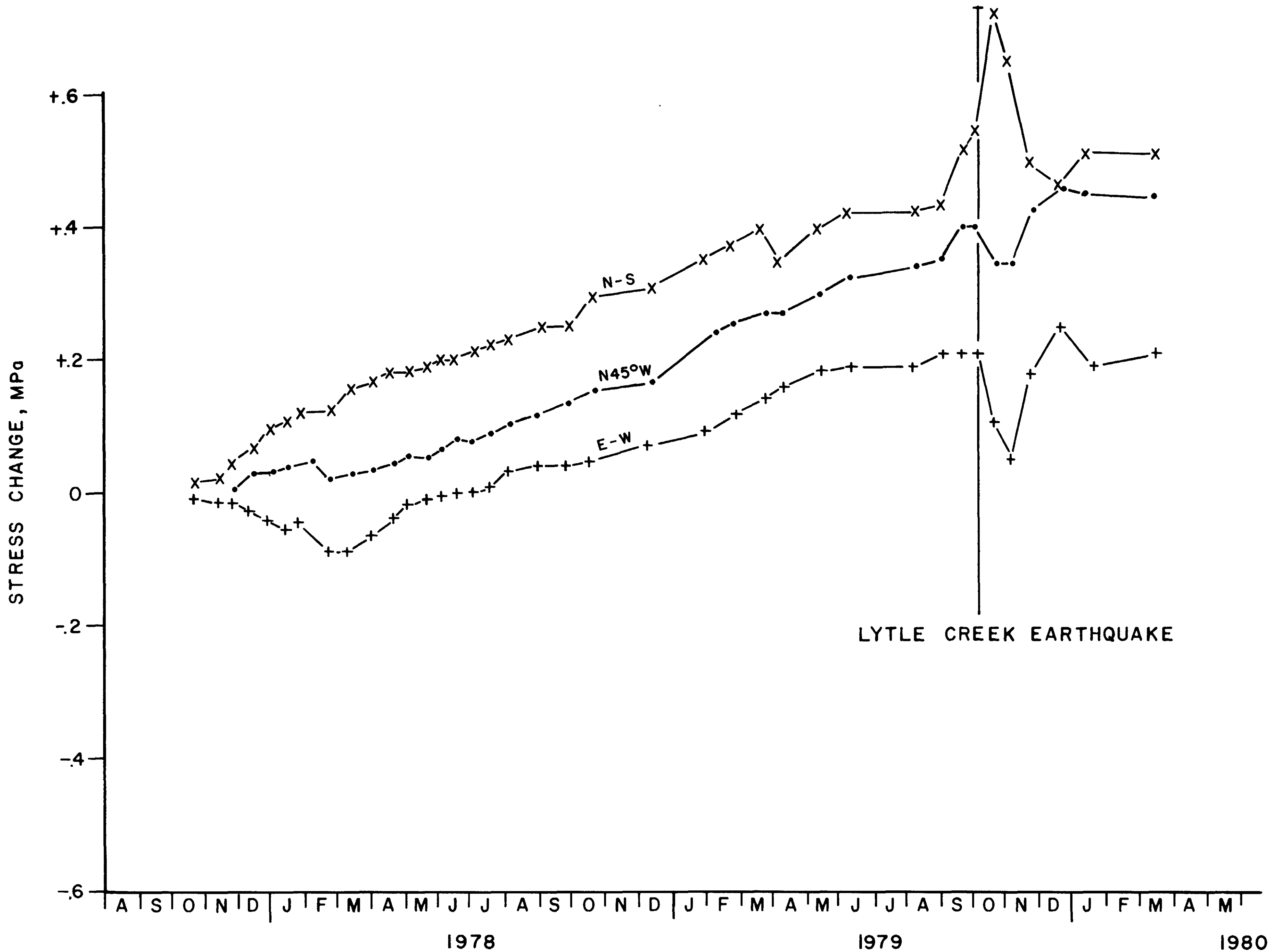

Figure 1 - Preseismic and Coseismic Stress Change Anomaly Associated with the Lytle Creek Earthquake of October 19, 1979 (M_L = 4.1)

Construction and Use of a Transportable VLBI Electronics System to Monitor Transcontinental Strain Accumulation and the Rotation of the Earth

14-08-0001-16759

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A compact, transportable very-long-baseline interferometer (VLBI) electronics system has been constructed for monitoring transcontinental and intercontinental strain accumulation. This system is of the "Mark III" design developed by the Haystack Observatory/MIT/Goddard Space Flight Center VLBI group. The system includes (1) a dual-frequency (S- and X-band) microwave feedhorn and low-noise receiver, which are mounted on the antenna, (2) a recording terminal located on the ground, and (3) a calibration subsystem for measuring the phase and group delays through the electronics and cables. The recording terminal consists of three subunits: a 28-track instrumentation tape recorder, a rack of equipment that generates the 28 tracks of digital data from the receiver output signal, and a minicomputer that controls and monitors the system operation and logs auxiliary (weather, calibration, etc.) data. A complete VLBI station that includes a Mark III system, prime-focus antenna, hydrogen maser clock, and water vapor radiometer can be used to measure baseline lengths with estimated errors below a few centimeters.

In November 1979 the transportable VLBI system (minus the minicomputer) was installed at the 100-meter-diameter telescope near Bonn, Germany. A three-day, five-station Mark III VLBI experiment involving the Bonn antenna and transportable system took place during November 23-26, 1979. The terminal and receiver performed well during the experiment; nearly all the tapes from that experiment have now (April 1980) been processed through the Haystack Mark III correlator. The full set of fringe phases and rates obtained in the experiment has not yet been analyzed to determine the various baseline vectors. Preliminary results have been obtained for some baselines for limited subsets of the data. The observed rms post-fit residuals are consistent with the level expected from the known error sources.

U. S. Geological Survey Contract No. 14-08-0001-17703

MEASUREMENT AND ANALYSIS OF THE NEAR SURFACE STRESS FIELD IN THE VICINITY OF ACTIVE FAULTS IN SOUTHERN CALIFORNIA

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The measurement and analysis of stress near active strike-slip faults may be useful in the identification of areas of high strain accumulation, and hence high rupture potential. Photoelastic modeling (Barber and Sowers, 1974), and finite element modeling undertaken as part of this project, indicate that strain accumulation along a strike-slip fault results in a rotation of the tectonic stress field near the fault. Based on these ideas, we have made a series of stress measurements along the 1857 break of the San Andreas fault near Palmdale, California, for the purpose of identifying and quantifying a rotation of the stress field and establishing the presence of strain accumulation. During a six week summer field season we made fifty successful strain relief measurements at four sites, ranging from a km to 35 km for the San Andreas fault. The magnitudes of the principal stresses varied from 11 to 25 bars. The directions of the principal stresses, though showing considerable scatter, generally indicate a N-S to NE-SW trend away from the fault and a more NW-SE trend very near the fault. Finite element analysis of strain accumulation along the San Andreas fault system produces stress orientations consistent with the data, although scatter in the data precludes a quantitative estimation of the rotation of the stress field.

Two strain relief techniques have been used to measure stress during the project. They are the U. S. Bureau of Mines borehole deformation gauge and the C.S.I.R. doorstopper techniques. Both techniques measure stress indirectly by measuring the strain in a rock as it is removed from an in situ stress field. To determine stress, elastic moduli are measured using a radial compression chamber which allows for a first order correction for rock anisotropy. Most of the field measurements were made with the U. S. Bureau of Mines technique, although when both techniques were used, similar results were obtained. Also, when U. S. Bureau of Mines measurements were made where doorstopper measurements had been made two years ago, similar results were obtained (Sbar et al., 1979).

Up to twenty measurements were made at each site, although statistically meaningful average stress orientations were only obtained at three of our four sites. The measurements varied in depth from about 0.5 to 10 meters. Principal strain and stress orientations showed considerable scatter about the average directions, typically $\pm$ 15-20°. The scatter may be attributed to a variety of causes, including coupling of stress across fractures, topographic effects and residual stresses.

In order to develop a theoretical basis for the magnitudes and degree of rotation of the tectonic stress field expected near Palmdale, a finite element model is being developed. The grid, consisting of 368 plane strain elements, covers a 500 square kilometer area including the San Andreas and Garlock faults. Grid spacing is approximately 25 km along the fault. Along the fault, element properties are varied to concentrate strain along the fault compared to the rest of the model. Variable properties include Young's modulus, plate thickness, and pinning grid points to approximate locked portions of the fault. Displacements corresponding to relative motion between

North American and Pacific plates since the 1857 earthquake are applied to the edges of the model. Calculated stresses vary from a few bars to approximately 100 bars, depending on plate thickness. Calculated strain rates of a few times 10^{-7}/yr are similar in orientation and magnitude to observed values (Prescott et al., 1979). Along the fault, a counterclockwise rotation of the principal compressive stress results in N-S to NW-SE orientations, consistent with our measurements. Away from the fault, calculated directions are more N-S to NE-SW, again in agreement with our data. Along the fault, lowered elastic moduli by a factor of 10 and reduced plate thickness by a factor of 10 have similar results for stress orientations. Unfortunately, the scatter in our data does not permit resolution of the models.

Our field results indicate that we are capable of measuring the orientation and magnitude of principal stresses. The data indicate a spatial variation in the stress field, but scatter in the data makes it difficult to resolve various models for the variation.

References

Baker, D. W., and G. M. Sowers, A photoelastic study of the effects of surface geometry of fault movements, Advances in Rock Mechanics, Proc. 3rd Congr., Natl. Soc. Rock Mech., 585-590, 1974.

Prescott, W. H., J. C. Savage, and W. T. Kinoshita, Strain accumulation rates in the western United States between 1970 and 1978, J. Geophys. Res., 84, 5423-5435, 1979.

Sbar, M. L., T. Engelder, R. Plumb, and S. Marshak, Stress pattern near the San Andreas fault, Palmdale, California from near surface in situ measurements, J. Geophys. Res., 84, 156-164, 1979.

A MULTI-PURPOSE CRUSTAL STRAIN OBSERVATORY, DALTON TUNNEL COMPLEX, SAN GABRIEL MOUNTAINS

Contract No. 14-08-0001-18339

UNIVERSITY OF SOUTHERN CALIFORNIA

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Facilities:

1) Permits for extended use of the tunnel and construction of on-site facilities have been obtained from the Los Angeles County Flood Control District.

2) The tunnel has been "barred down" and the loose debris removed by a commercial contractor. Low spots in the floor have been filled and the drainage improved.

3) The tunnel has been inspected by OSHA and deemed safe for general use as proposed.

4) An electronics blockhouse and access bridge have been designed and constructed. This work has been a cooperative effort by personnel at U.S.C. and outside contractors.

5) AC power has been installed and an application for telephone data lines is pending.

6) Pier design has been completed and construction should begin shortly.

Equipment: Installation of equipment is awaiting phone line hookup, installation of instrument piers and completion of closure doors (Figure 1). It is anticipated that this work will be completed by May 1, 1980. Present instrument status is as follows:

1) Lacoste tidal gravimeter - standing by; temporarily monitoring at our Bouquet Reservoir facility.

2) Acoustic emission recorder - installed.

3) Two carbon fiber strainmeters - under construction at Lamont; will be completed by July 1, 1980.

4) Two fluid level tiltmeters - under construction at U.S.C. - will be completed by July 1, 1980; end station calibration underway at L.A. County Museum of Natural History.

5) Two bubble tiltmeters - under modification at Caltech, will be completed by May 1, 1980.

6) Two Press-Ewing long period seismometers w/D.C. transducers (garden gate tiltmeters) - standing by at Caltech.

7) Ground temperature monitoring array - is being installed.

8) Meteorological station - standing by at U.S.C.

9) Borehole for water level transducer - not yet drilled, instruments standing by at U.S.C.

10) Continuous Radon monitor (α-counter) - standing by at U.S.C. (M. Shapiro of Caltech is currently monitoring Radon (β-counter) near Dalton Observatory in a shallow well).

11) Telemetry interface modules, digital and analog recorders - standing by at Caltech and U.S.C.

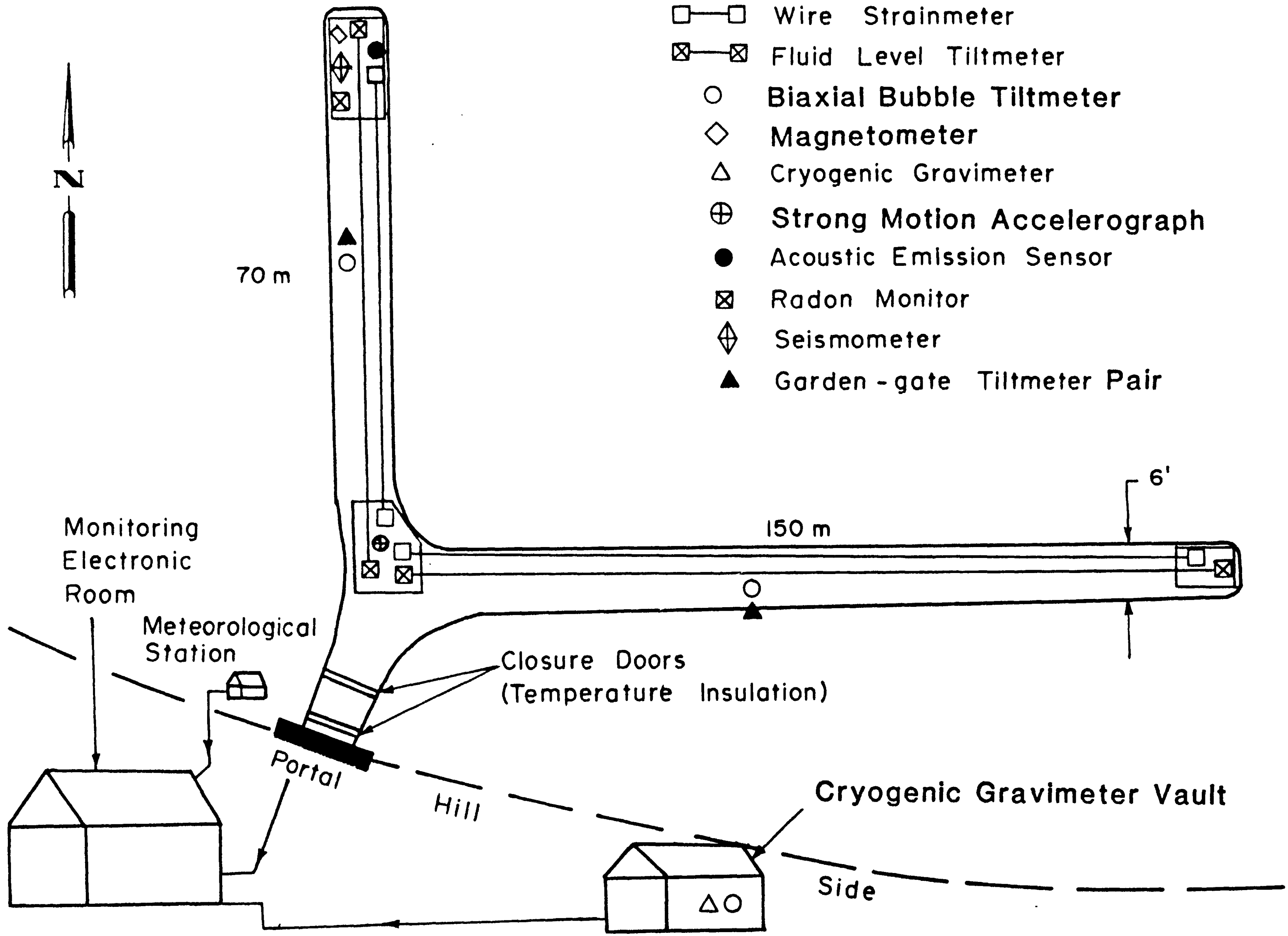


Figure 1. Schematic drawing of Dalton Observatory

UNIVERSITY OF SOUTHERN CALIFORNIA

Thomas L. Henyey, Ta-liang Teng, Douglas E. Hammond and Charles G. Sammis, Principal Investigators

Contract No. 14-08-0001-16745

DEEP-WELL MONITORING OF STRAIN-SENSITIVE PARAMETERS OVER THE GREATER SOUTHERN CALIFORNIA UPLIFT

Current research under this contract is summarized as follows:

1. Groundwater radon-Chemistry Studies. During the past six months, we have extended our chemical analysis at three sites in the USC radon network. The patterns observed were similar to previous data. The station at Big Pines showed changes in chemistry related to rainfall, while radon was unaffected. Ten days prior to the Big Bear earthquake (M = 4.9, 6-30-79), a single sample showed a 50% increase in radon, but no change in chemistry. At Arrowhead Springs, a station closer to the earthquake epicenter, no change in radon or chemistry was observed prior to this event. The station at Seminole Hot Springs, which showed fluctuations in radon prior to and following the Malibu earthquake (M = 5.0, 1-1-79), showed no change in chemistry throughout this period. These observations suggest that for the Big Bear and Seminole Springs sites, major element chemistry and radon concentrations are fixed in different zones, and that the concentration of these species may be controlled by the water residence times in each of these zones.

The re-designed deep-well water sampler was used at several sites during the summer. Radon activities in these sites were surprisingly low, but generally increased with increasing depth. This indicates that the residence time of water in these holes must be quite long and that flow may be upward from below the deepest samples taken.

A brief manuscript summarizing our results to date is being prepared.

2. Precursory Seismic Velocity Anomalies. We have attempted to repeatedly measure, to an accuracy of .1% or better, the travel times of elastic waves between fixed points near Palmdale, California. The elastic wave source, a 1000 in^3 airgun, is located in Bouquet Reservoir and the receiver sites are 4 borehole seismometers at distances of 13, 18, 22, and 40 km. Several arrivals have been observed and timed at each site. Our most extensive data are from the sites at 13 and 18 km, with over 150 data points at each site within a 14 month period. To date, no permanent travel time changes greater than our resolution have been observed.

A program to determine the origin and nature of secondary arrivals seen at the receivers has been undertaken. The results of this later study were summarized by Malin and Leary (1979). In particular, secondary arrivals may be variously identified as: P waves reflected from the surface above the borehole emplaced seismometer, S waves generated at the reservoir's water-sediment interface, and finally, reflections from various horizons within the crust. The details of these results and the methods of their determination (involving vertical travel time control in the boreholes) will be prepared for publication.

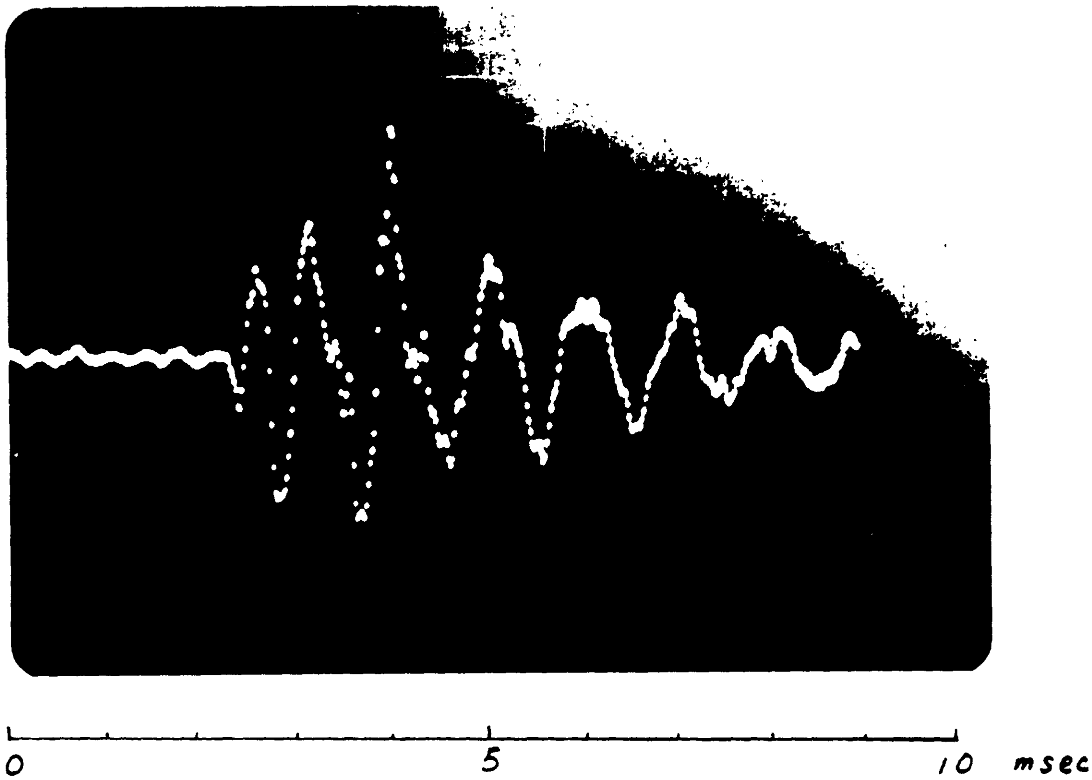
3. Acoustic Emissions. The high frequency, wide band (20 Hz-15 kHz) recording instruments for the detection of acoustic emissions which we have developed were deployed in three deep wells located within seismically active regions. Two sites are close to the San Andreas fault - the 400 meter Skelton well (uncased in granite, recently deepened to 1 km) and the 700-meter Del Sur well (cased in sediment) near Palmdale, California. The third site, a 1.1 km deep uncased well in granite near Monticello, South Carolina is of particular interest due to its proximity to a large reservoir believed to be triggering seismicity from reservoir impounding. The bottom of the Monticello well is thought to be within 1 km to the hypocenter cluster.

In all three wells, numerous acoustic emissions were detected with dominant spectral energy in the band 0.5 to 5 kHz and a peak about kHz. These events have durations on the order of milliseconds and waveforms similar to a local earthquake greatly scaled down in size. Their spectra and waveforms for different events are very similar, except for events from the cased Del Sur well. The events from the Del Sur well are more pulse-like; they may have been generated by a mechanism different from the generation of acoustic emissions through microcracking. A mechanism of casing-wall rock interaction may be involved. Signals from the other two wells are much more interesting and resemble greatly scaled-down seismic events. During the recording period, at least 30 events per day were recorded in the Skelton well and 500 events per day in the Monticello well. Due to the single station recordings, we are not yet able to ascertain how far the acoustic emission sources are from the well-bottom sensor. Efforts will be made in the future to obtain more information on the source distance using two or more acoustic sensors.

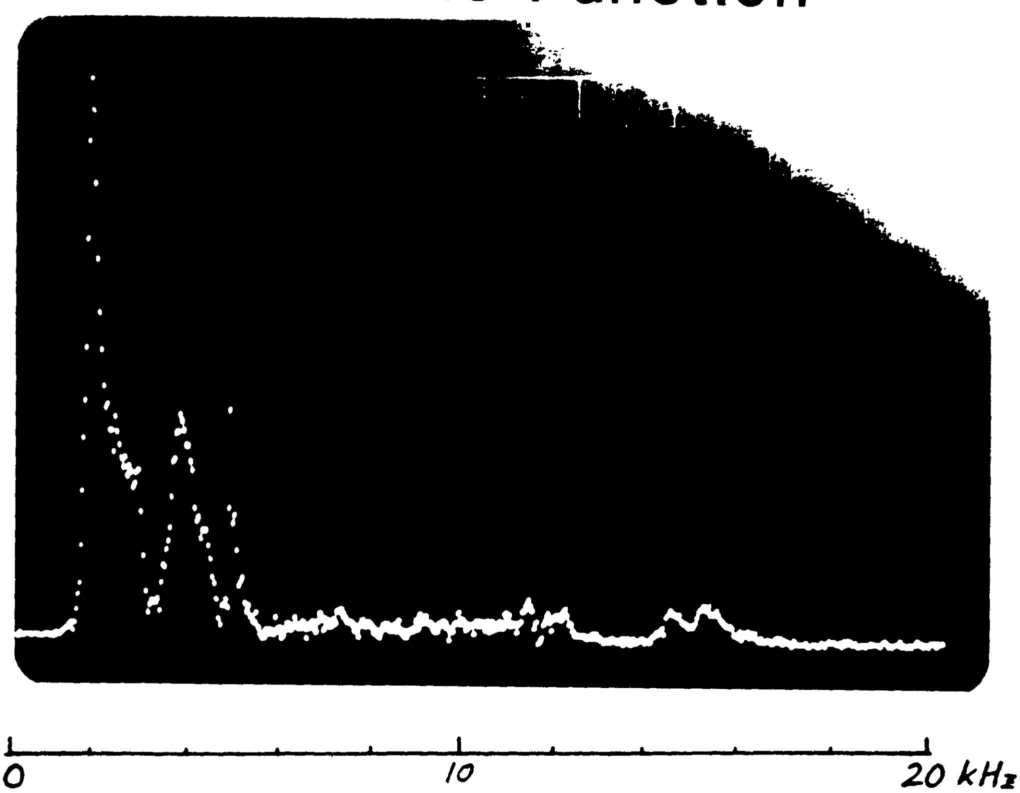
An example of the time trace and spectrum for an event from the Monticello, South Carolina site is shown in Figure A4 and for an event from the Skelton, California site is shown in Figure A9. A 1 kHz low cut filter has been applied to remove spurious noise. The duration of the waveforms is normally 5 to 10 ms and their amplitude is typically on the order of 10 μ bar. The larger events may be 5 to 10 times longer in duration; however, amplitudes are clipped which make it difficult to estimate the actual size of these clipped events. It is seen that the dominant energy peak occurs around 2 kHz and drops off sharply in the low frequency end due mostly to the low-cut filter. Toward the high-frequency end, the spectrum drops off exponentially with an occasional secondary peak. Little energy exists beyond 6 kHz. Only very rarely are there pulse-like events recorded resulting in a broad spectrum.

One interesting finding is that these acoustic signals have very similar waveforms and spectra whether they are from the Skelton well of California or from the Monticello well of South Carolina. These waveforms resemble greatly scaled-down seismic events. Assuming the validity of downward extrapolation of duration time vs. magnitude relationships, these events would have magnitudes in the range -3 to -5; and as such, we call them nanoearthquakes. Work is also presently in progress to determine the temporal relationships between individual events, and their relationships to any nearby microearthquakes - particularly for the Monticello well.

Acoustic Emission Records P4

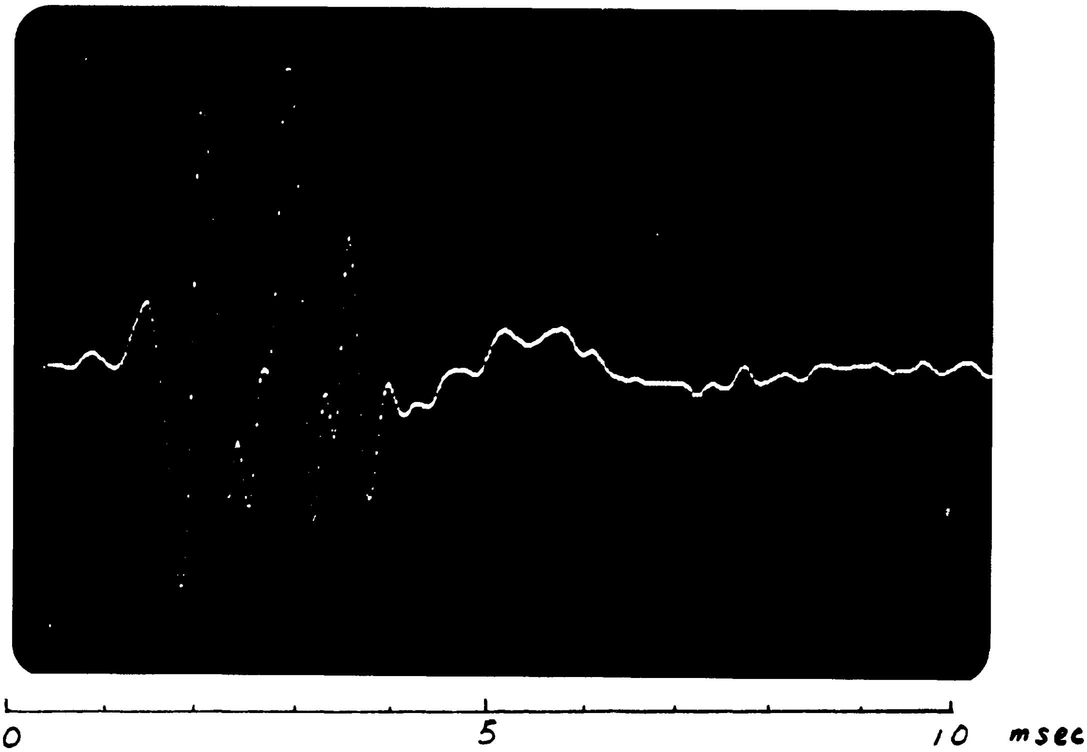


Time Function

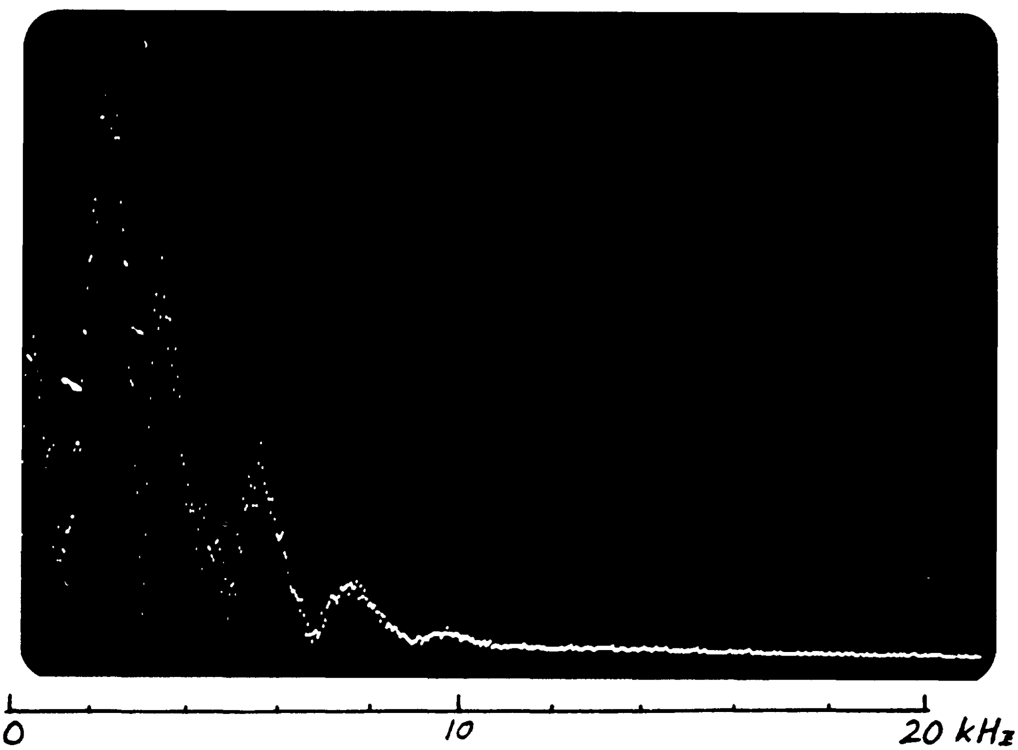


Spectrum

Acoustic Emission Records [P4]



Time Function



Spectrum

4. The Los Angeles Aqueduct As a Long Baseline Tiltmeter. Part of the Los Angeles Aqueduct system consists of an open channel 10 feet square which carries water 110 miles from the Owens Valley to a reservoir near Palmdale. The open channel course crosses, then parallels the Garlock Fault, crosses the western Mojave, and parellels the San Andreas Fault for 10 miles.

As part of aqueduct operations, water levels in the channel are measured to ± .01 foot daily or weekly at 26 stations. We have examined 24 months of such data and found numerous instances of systematic variations on time scales of weeks to months. Two variations correlate with other geophysical data:

i) Between October, 1978 and March, 1979, a .5 foot water level change appeared at seven stations south of the town of Mojave compared with stations to the north. Interpreted as regional tilt, simple hydraulics of open channels indicates a tilt of the western Mojave block down to the south with magnitude 20-30 microradians. This agrees in time and sense with USGS leveling data between Los Angeles and the San Andreas-Garlock Fault junction.

ii) Two stations near a small fault in the Mojave block changed readings between .2 and .5 feet in the three days prior to the 6.0 Goat Mountain earthquake 125 miles to the southeast. All other stations remained unchanged.

As yet uninterpreted water level data extends back to 1969. We should be able to examine this data for evidence of the Palmdale Uplift and the 1971 San Fernando earthquake.

Low Frequency Data Network

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Investigations

Tilt, strain, magnetic, telluric, and other data are being collected from instruments along the San Andreas fault system and other active areas. We are continuing to develop and enhance innovative computer controlled monitoring and telemetry systems with the goal of serving the needs of rapid access and real-time analysis of these data. More comprehensive tools are being developed on a PDP 11/70 computer with the UNIX operating system and the GEOLAB interactive research environment.

Results

We have installed a second 11/03 processor in order to increase the reliability of real-time data collection. The dual processors have been integrated such that both have access to a newly installed incremental plotter as well as network connections to the Honeywell Multics and PDP 11/70 UNIX computers.

A new version of OPLAN (Reese Cutler) Software is nearing completion which will further improve reliability as well as allow for an increased number of instruments. This software is designed to facilitate a wide variety of initiated and uninitiated users' data needs.

Data is transmitted daily from the 11/03 real-time machine to the Honeywell Multics mainframe via computer link. Here the data is archived and analysed using the GEOLAB interactive environment.

On the PDP 11/70 computer, Version One of GEOLAB/UNIX is nearing completion. Soon most of what now takes place on Multics will be moved onto the 11/70, where seismic as well as low frequency data will be equally available.

Reports

Miranda, S., and Herriot, J., 1980, Catalog of computer-based NOAA climatological data relative to USGS earthquake research in California: U.S. Geological Survey Open-File Report 80-361.

Crustal Deformation Observatory, Part A

14-08-0001-18364

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Investigations

This project is part of a larger effort to install and operate various types of strain and tilt monitoring equipment, and to resurvey level lines, in a highly redundant fashion at Pinon Flat Observatory in southern California. Objectives of this project are to test instrumentation and to solve fundamental problems limiting the accuracy of surface strain and tilt measurements. My role is to coordinate activities of the various experimenters, to make sure that an adequate test is ultimately achieved, and to analyze data as they become available.

Results

Vertical control benchmarks have been installed and surveyed twice under Part B of this project. I have analyzed data from this releveling. They show an apparent tilt of 1 μ radian down to the East between 13 Oct 79 and 26 Jan 80. However, a statistical analysis of the data indicate that this is within the expected errors of observation. These errors were estimated from the redundancy provided by forward and backward leveling between each pair of benchmarks. In addition, benchmark settling of up to 1 mm may occur.

Tiltmeter installation is somewhat behind schedule, but should be completed by 30 Sep 80. As tiltmeter data have not been available for intercomparison, we have no results to report at this time.

Contract No. 14-08-0001-18224

VERTICAL DISPLACEMENT MEASUREMENTS IN CENTRAL CALIFORNIA WITH A LONG-BASELINE TWO-FLUID TILTMETER

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The dynamic response of a multiple leg two fluid tiltmeter system has been analyzed. The effects of initial differential height in the reservoirs of the two fluid circuits has been analyzed and shown to be negligible. The effects of second order terms in the thermal expansion relationship have been derived and will be considered in the final choice of the fluids for the full scale field test system.

The prototype (10 m) system has been tested to identify operating limitations including supply voltage thresholds and data transmission rates for data stored on the data logger. The data output from the prototype must be further reduced to obtain elevation changes. A minicomputer (PDP-11) will be used initially to perform this operation. The existing prototype fluid level sensors (4 sets) and data logger are sufficient to perform full scale dynamic verification tests using one additional uninstrumented reservoir station. The field test sites proposed are at or near the planned location of the multiwavelength EDM at San Juan Bautista, California.

Instrument Development and Quality Control

9970-01726

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Investigations

During this period tests were conducted to find a faster, more efficient method of detecting seismic events on film records. This led to the development of an electronic device which optically scans the film and displays the detected events to the operator. This device has been quite successful and improvements are planned. Also under investigation is an automatic method of digitizing film records. Evaluation of the GEOS I seismic event recorder built under contract to the USGS continued in preparation for developing additional units. Methods of improving tiltmeter stability and consistency were investigated and modifications to implement these improvements have been made on 12 units which are now being field tested.

Results

One of the biggest tasks undertaken this period was removal of two CDC 1700 computers from the Cal-Net Playback Center. This involved disconnecting and removing the computers, rearranging electrical wiring and rearranging Playback Center equipment. This also included transferring 5-day tape digitizing to the Eclipse B computer and implementing control of the tape dubbing system on the Eclipse C computer. All these changes were carried out successfully with a minimum of "down" time. Documentation of the Playback Center and the modification continues.

Work has also continued on emergency power systems. A battery-powered recorder which records seismic data over direct radio links has been operating now for several months. An emergency power generator for telemetry recording systems has been acquired and is awaiting approval for installation. A short-wave radio station for communication in the event of loss of power and telephone service has been installed.

An interface which allows high-speed transfer of data from a PDP 11/03 computer to a Tektronix graphics display was constructed and is now operating. Another interface was designed which allows transfer of data from a Terra-Tech seismic playback system to a HP 9825A computer. This device is also functioning well. Also, nine Terra-Tech seismic event recorders were acceptance tested.

Modifications for improvement were made on the 100 Seismic Cassette Recorders and maintenance was performed on them during several field operations. Other continuing projects include calibration of approximately 100 seismometers, construction of 100 preamp/VCO units, testing or repair of 200 telemetry radios and construction of 50 discriminators, of a new design which exhibits one quarter of the noise output of previous designs. Two hundred of these units are now being assembled.

Tiltmeter Array in New Madrid

Contract 14-08-0001-15848

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Investigations

This has been a joint program with CIRES at the University of Colorado for the sake of economics of time and expertise in installing tiltmeter arrays in the New Madrid Seismic Zone and at Adak, Alaska. The original objective of seeking possible tilt precursors to local earthquakes has become an effort to establish the reliability and quality of the tile measurements themselves. However, after almost three years of effort we are beginning to see reasonble coherence in the closely spaced pairs at Adak, and attribute this to the results of our efforts in learning how to prepare and install the instruments in such hostile environments as New Madrid (flood plain) and Adak (the Aleutians).

The work has continued to proceed along several tasks. The progress in each task is as follows.

1) The instrument qualification program: We have a growing body of evidence that some borehole units are intrinsically unstable in one or both components. All other changes in the electronics and site of a particular borehole seems to preserve the instability. It is time to begin to test each unit for long term intrinsic stability at a test site especially prepared for such a task.

2) Interfacing with the environment: The results from the latest technique of installing the boreholes with a fast bonding sand mixture, then sealing with bentonite, have been quite encouraging. Several instruments have shown a marked decrease in rainfall sensitivity and corresponding increase in long term stability; usually the long term baseline is established with a few days of installation. There is still rainfall/thermal noise, so we will equip several instruments with thermal and soil-moisture probes to study this.

3) Meteorological monitoring: The first monitoring systems have been deployed and the data acquired in digital form; however, interpretation has been delayed until the Geolab programs are available. A problem has come up with disintegration of the plastic anemometer cups at Adak. They are being replaced with stainless steel.

4) Digital data acquisition: The digital data acquisition systems are nearing completion. The now commercially available remote unit will acquire 10 each 12 bit analogue channels, 8 each 4 bit digital words, and 32 bits of other information, at rates from 1/10-sec to 1/hour. Based on a CMOS microprocessor, the entire system, including the RS232 interface and modem for the radio transmitter, will operate on three air cell batteries for three years. While acquisition is at a constant rate, which includes reading the on-board crystal clock, transmission is at a random repetitive interleaving rate at 75 baud on a carrier below the seismic telemetry channels, allowing up to 10 remote unrelated and asynchronous units to share a single data link. The microprocessor based receive unit sorts out the data, discards redundant and erroneous transmissions, and packs the data onto floppy disks; one disk will record one remote station (at 10 minute acquisition intervals) for 42 days, or 10 stations for 4.2 days.

5) Data reduction: A microprocessor based dual floppy disk microcomputer is implemented as a super-terminal to the USGS Dec 11/70 computer, so that the tiltmeter data disks can be read, unpacked, and transferred into files in the 11/70. There, Fortran programs further clean up the data into one good transmission per hour for plotting and further analysis.

Results

6) Data interpretation: This has suffered from a lack of time to develop new programs, and an inclination not to develop software that will soon be available in Geolab. Perhaps the most complete analysis has been done at CIRES on the Adak data, utilizing programs developed by Duncan Agnew. The Adak results are quite encouraging, particularly when one examines only one to two month periods and analyzes the tidal contents. Quite surprising agreement is found between the phase and amplitude of the actual tidal data and theoretical modeling. It is expected that much more work will be done now that Geolab is available in the 11/70 system, and even more so once the digital transmitters get installed. The data from the CCMO test site has only been plotted, but no effort at interpretation has been made to analyze the long term coherence of the data, again awaiting for programs to become available.

Reports:

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Morrissey, S.-T., The Adak Winter Field Trip; December 10-14, 1979, A Special Technical Report, 15 pp.

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A Crustal Deformation Observatory Near the San Andreas Fault in Central California

14-08-0001-18370

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Investigations

1. A geodetic array near Hollister, California has been measured almost daily for the last four and one-half years using a multiwavelength distance measuring (MWDM) instrument. The array consists of nine primary lines and several secondary lines covering approximately 100 km^2. The lines are three to nine kilometers in length and radiate from the MWDM instrument site in Hollister. The Calaveras fault bisects the MWDM array. The operation of the MWDM instrument at the Hollister site will conclude in a few weeks from the date of this summary.

2. The MWDM instrument was designed and assembled in 1972-73 around a minicomputer. The minicomputer allowed considerable versatility during the initial instrument testing stage but has since become the major source of equipment caused down-time. During this reporting period we undertook to completely redesign and modernize the digital portion of the MWDM instrument.

3. It is required that we relocate the MWDM instrument. A site near San Juan Bautista was sought. Additionally we sought another site within the new MWDM array to install a new two-fluid long baseline tiltmeter. We will then be able to collect both horizontal and vertical deformation data simultaneously with state-of-the-art precision.

Results

1. The long-term changes in line lengths within the Hollister MWDM array generally occur in fairly well-defined episodes that have been ascribed to slip at depth on the nearby faults. These episodes typically last for several weeks and are interspersed with periods of relative quiescence. During this reporting period, one of these episodes occurred. It began in early December 1979 and continued at a fairly constant rate until early April 1980. Line length changes as large as 15 mm were measured during this episode. The maximum change occurred on the line to station Poison. An earthquake (mag. 4.5) occurred along the San Andreas fault on 12 April 1980 approximately 2 km from station Poison. Preliminary interpretation suggests that a least a portion of the line length change measured to station Poison was due to preseismic slip along the San Andreas fault in the vicinity of the subsequent earthquake. These episodes of rapid line length changes may provide a valuable indicator of periods of increased

seismic risk in a region.

2. During this reporting period we successfully concluded a complete redesign and assembly of the entire digital portion of the MWDM instrument. This effort resulted in a more portable, more dependable system that is easier to operate. This modernization resulted in the reduction of size, power requirement, and weight of the digital portion by at least an order of magnitude.

3. The new MWDM instrument will be moved to a hilltop near San Juan Bautista in early summer 1980. The new site is located approximately 1 km south of the town of San Juan Bautista. The size of the new array is expected to be about that of the present Hollister array. The site has been permitted and construction of a concrete block observatory building to house the MWDM instrument will begin immediately. A second site located 4 km NW of the MWDM site will be the location of the two-fluid long baseline tiltmeter. The tiltmeter will be installed in the shape of an 'L' and be approximately 500 m in length. The tiltmeter site will also contain retro-reflectors for the MWDM effort. We will then be able to collect both horizontal and vertical deformation data from this site with high precision. Protective shelters for the tiltmeter have been installed and a new thermally stable benchmark has been designed and installed at the site.

Reports

Slater, L. E. and J. Langbein, 1979. Multi-wavelength Geodetic Measurements Southeast of the Coyote Lake, California Earthquake August 6, 1979. Trans. American Geophysical Union, Vol. 60 (46).

Slater, L. E., 1979. Episodic Block Motion and Convergence Along the Calaveras Fault in Central California. Symposium on Recent Crustal Movements, IUGG XVII General Assembly, Canberra, December 1979. (To be published in Tectonophysics).

Tiltmeter Array in New Madrid

Contract 14-08-0001-15848

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Investigations

The overall objective of this project has been to explore the feasibility of monitoring crustal deformation in the New Madrid seismic zone in order to identify possible precursor patterns for use in earthquake prediction. The effort has centered on the evaluation of a bubble-borehole tiltmeter as an instrument suitable to this purpose. The research has progressed by installing tiltmeters in pairs a few meters apart in order to investigate whether pairs of instruments can be shown to track one another, and to study what factors affect instrument performance.

The present report comes after 2½ years of investigation of the factors affecting stability. The primary objective has not as yet been achieved. Considerable knowledge, however, has been obtained concerning the performance of the instruments and the effects of local site properties and of installation procedures. The work has proceeded by a series of sub-tasks.

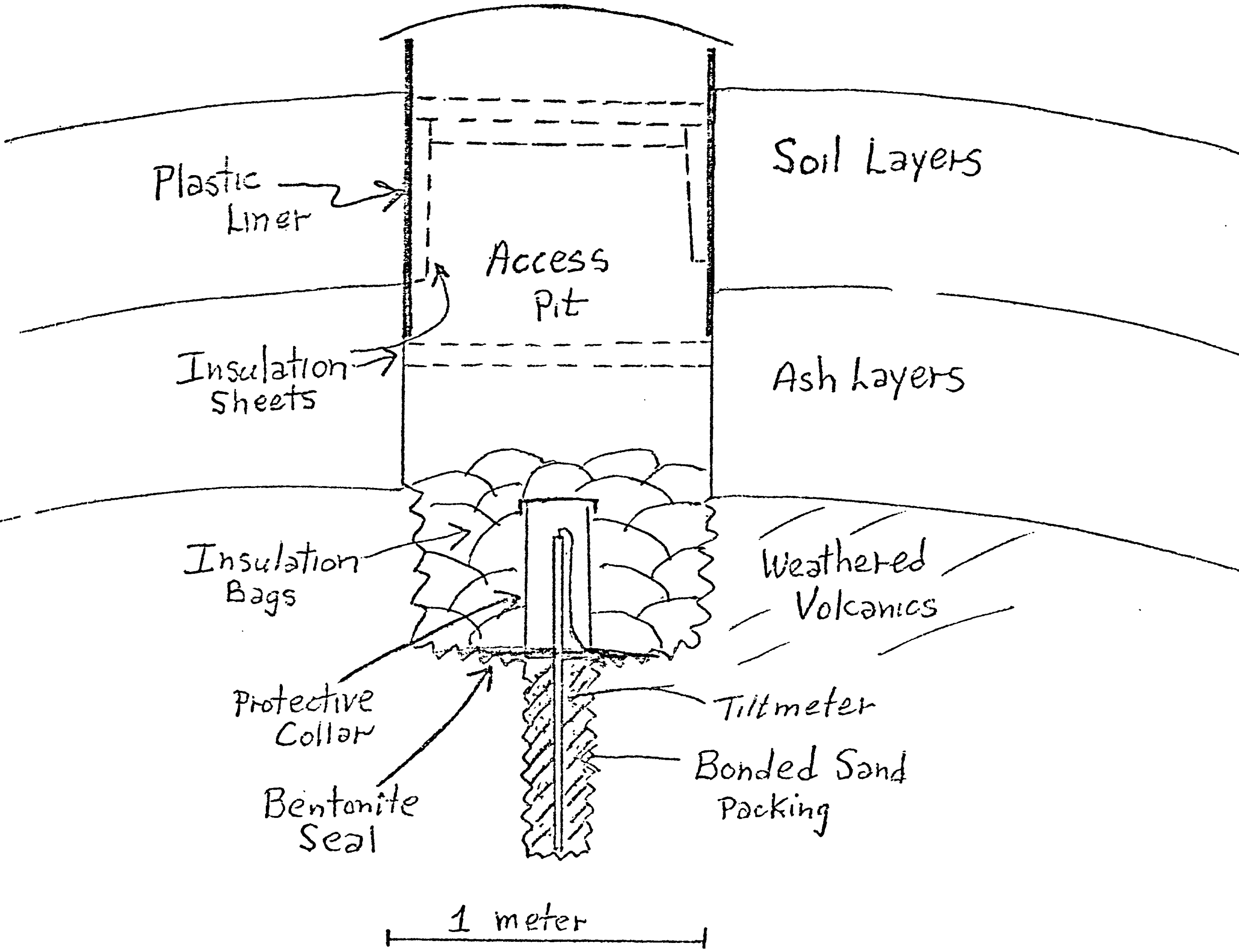
Task 1. Instrument qualification and preparation. Adjustments to the TM-1 electronics systems and in the design of the auto-zeroing system have been satisfactorily completed in order to assure stable operation under extremes of climatic conditions at New Madrid and Adak.

Task 2. Instrument installation. A major portion of effort for the past year has been devoted to studying and perfecting techniques of interfacing the instrument to the physical environment in order to achieve long-term stability. While the techniques developed have not achieved duplication of recording by two instruments located within a few meters of one another, we have been able to eliminate or minimize a number of sources of drift, and to achieve a stable zero point for individual instruments. The influences of depth of burial and packing of the instrument only half the length of the enclosing pipe were previously reported. By adding a 5% mixture of a quick setting bonding material to the sand packing the instrument can be isolated from the effect of water fluctuations. A diagram of the instrument emplacement configuration that has been developed is given in Figure 1. The process now used achieves base-line stability within 24 hours of installation.

The failure to achieve tracking of instruments located a few meters apart but consistency of operation of individual instruments suggests the area monitored may be a few cubic meters in volume rather than a broader local observation of tilt. An experiment yet to be performed is the installation of two instruments firmly joined to one another in the same hole.

Task 3. Effects of other physical processes on the instrument and its environment. Continuous meteorological data have been recorded digitally at the CCMO site. The effects of rainfall and changes in barometric pressure show visual correlations with changes in the recordings from the tiltmeter. These appear to be predictable, and

FIGURE 1.



Soil Layers
Plastic Liner
Access Pit
Insulation Sheets
Ash Layers
Insulation Bags
Weathered Volcanics
Protective Collar
Tiltmeter
Bonded Sand Packing
Bentonite Seal
1 meter

controllable as they effect the emplacement of the instrument. The largest effects and daily variations correlated with the solar radiation, yet varying at nearby sites. Numerical correlations of these effects is now being started.

Task 4. Digital acquisition system. The delivery of a 12 bit, 16 channel battery operated digital data acquisition system, as described in previous reports, has been delayed by the manufacturer. A prototype system is in operation, and a disc reproduce system has been acquired for reading the data discs and pre-processing the data for input into the PDP 11/70 (USGS) computer. The unit selected for this is a "Chieftain II" microcomputer/dual floppy disk system by Smoke Signal Broadcasting Company.

Task 5. Data reduction. Data reduction has been initiated by developing a direct reading graphical output of the data. Programs for removal of zeroing steps and appropriate modes of presentation of tilt and other environmental data are being developed.

Task 6. Data interpretation. The numerical relation of recorded tilts to ground deformation, and the numerical correlation with environmental effects has not progressed beyond the data reduction steps mentioned above. The rainfall events on the New Madrid records are very inconsistent, and will not be able to be removed from the data until environmental monitoring has begun. Work has begun on writing the programs for statistical analysis of the pressure data from several deep wells in the New Madrid area; these programs will be applicable to the tiltmeter data set.

"Dry Tilt and Nearfield Geodetic Investigations of Crustal Movements, Southern California"

Contract No. 14-08-0001-17685

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Investigations

By means of telescopic spirit leveling (dry tilt) of small aperature triangular arrays of from 3 to 6 permanent benchmarks, precision leveling of short (200-1600 m) lines across faults, and precision surveying of alignment arrays and trilateration networks, we have been monitoring the following physical phenomena in central southern California:

1) The regional pattern and timing of tilt, if any, and

2) the nature of strain accumulation and release, if any, across well-defined active and potentially active faults.

We have established 45 dry tilt arrays, 17 short level lines, two alignment arrays, and 12 trilateration arrays. Some of these lines and arrays were established 10 years ago and have accumulated as many as 12 resurveys. Others have been established only in the last year.

Results

The entire network of dry tilt arrays was resurveyed in November-December 1979, and half of them again in February 1980. No changes were detected that are significantly different from the general background noise exhibited by the arrays over the previous three years.

Intense rainstorms, flooding, snowcover, washed out roads and academic schedule conflicts have all combined to prevent resurveys of other geodetic arrays during the first half of this contract period.

"Crustal Deformation Observatory, Part B: Precision Geodesy"

Contract No. 14-08-0001-18366

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Investigations

To establish and monitor geodetic networks at Pinyon Flat as a complement and control for investigations of tilt and strain other investigators are doing by means of electronic, electro-optic and fluid systems.

Results

We have established two dry tilt arrays and an L-shaped array of 31 permanent benchmarks 1168 m long. The benchmarks are no more than 40 m apart and consist of coupled steel rods driven to refusal and capped by a rounded stainless steel nipple. Red steel fence posts, one meter long, serve as witness posts, and instrument points are marked by large boulders.

The initial survey of the array was done in fall 1979; the first resurvey was done in January 1980. The observed elevation differences between the two surveys range from 0 to 1 mm and probably reflect instability of the new benchmarks as they come to equilibrium, although a M5.3 earthquake occurred about 15 km WNW of Pinyon Flat on the San Jacinto fault system 4 weeks after the second survey. Resurveys in spring and summer 1980 will provide more complete information on the stability of the benchmarks and site background noise. Two surveys on the dry tilt arrays are inconclusive.

In-Situ Stress Measurement
9960-01184

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CIENEGA PROFILE

In-Situ stress measurements, seismic velocity measurements, and a study of natural fractures were made in three wells drilled at various distances to the San Andreas fault in the Gabilan range in Central California (figure 1). In a manner similar to a profile of stress measurements made in the western Mojave desert, the data show an increase in the magnitude of the principal stresses with distance to the San Andreas (figure 2) as well as an increase in shear stress with distance to the fault (figure 3). Briefly stated, two hypothesis put forth to explain the relatively low shear stress near the fault are 1) low shear stress simply reflects the faults low frictional strength, and 2) the difference between the shear stress near the fault and that at distance is the result of the stress drop that accompanied a past earthquake.

DEEP MEASUREMENTS IN THE WESTERN MOJAVE DESERT

A 1 kilometer deep well was drilled 3.5 km from the San Andreas fault for the purpose of making a vertical profile of stress measurements and performing related seismic velocity, fracture, and permeability studies. The results of the stress measurements are shown in Figure 4. The principal stresses clearly increase with depth in the well and below about 300m the intermediate principal stress is vertical (as expected in a strike-slip faulting region). The horizontal shear stress (as resolved onto the San Andreas fault) rapidly increases with depth at a rate of about 100 bars/km. This rate suggests that the level of shear stress at hypocentral depths of 5-15 km is of the order of 1 kilobar unless, of course, the rate of shear stress increase with depth diminishes rapidly at depths greater than 1 km. An excellent correlation was observed between the stress measurements, seismic velocity, and natural fractures in the well.

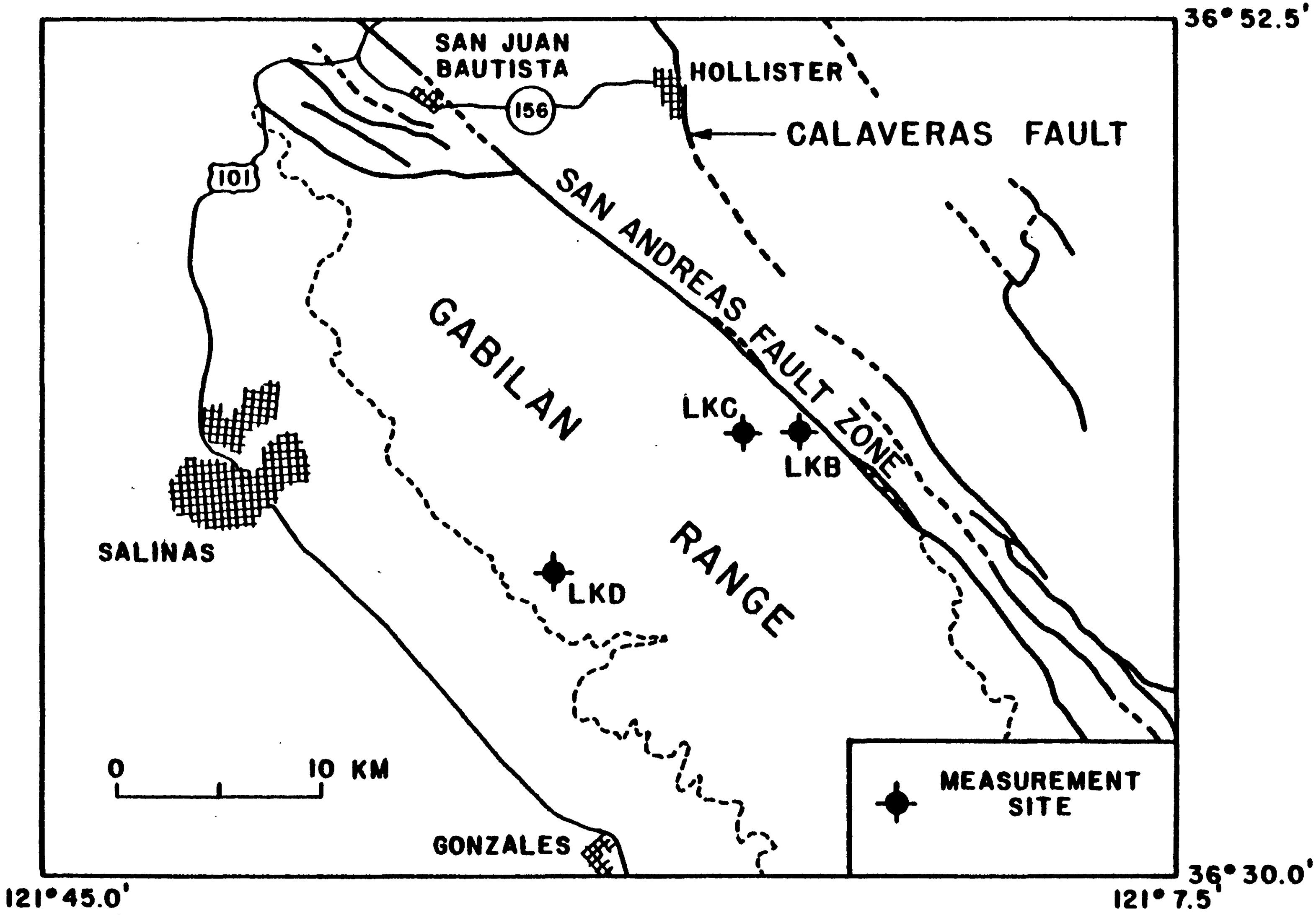

Figure 1- Location of wells comprising the Cienega Stress Profile. All of the wells were drilled in granitic rock to a depth of about 225m.

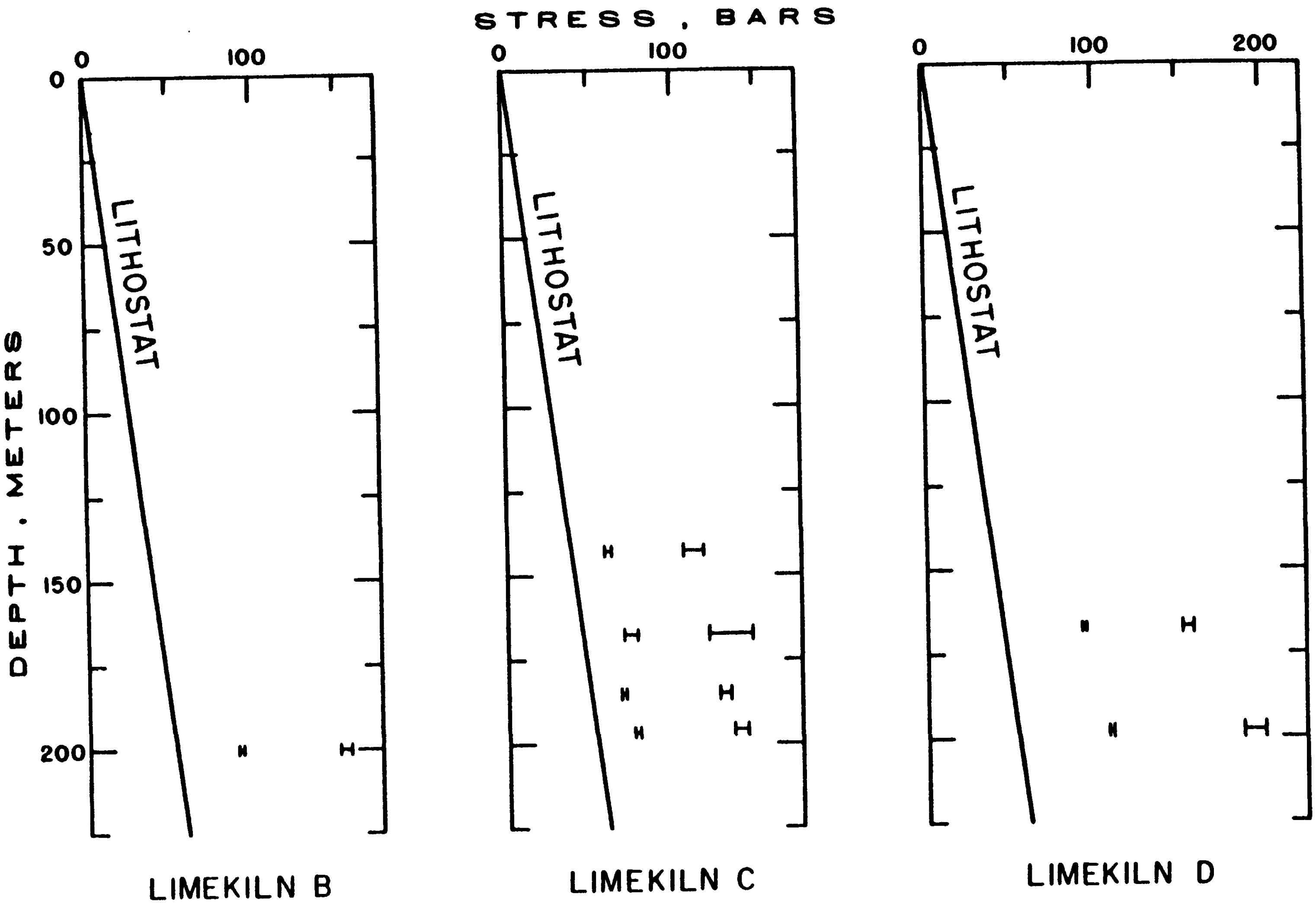

Figure 2- In-situ stress measurements in the wells of the Cienega Profile. Dense natural fracturing precluded more measurements from being made in the wells. The large and small error Bars reflect the greatest and least horizontal principal stresses, respectively.

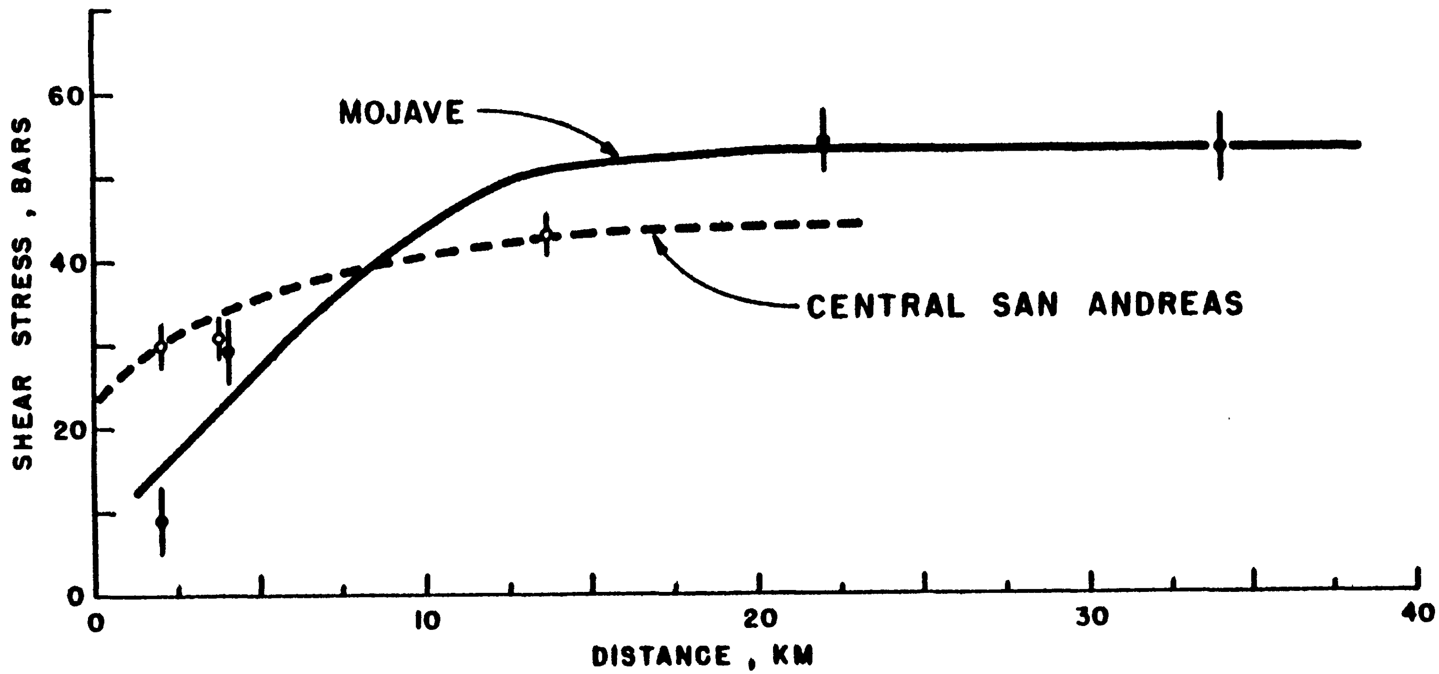

Figure 3- Variation of horizontal shear stress with distance to the San Andreas at a depth of about 200m. Open circles represent data from the Cienega Profile and solid circles represent data from the Mojave Profile. Solid and dashed line represents an attempt to fit the data with theoretical models.

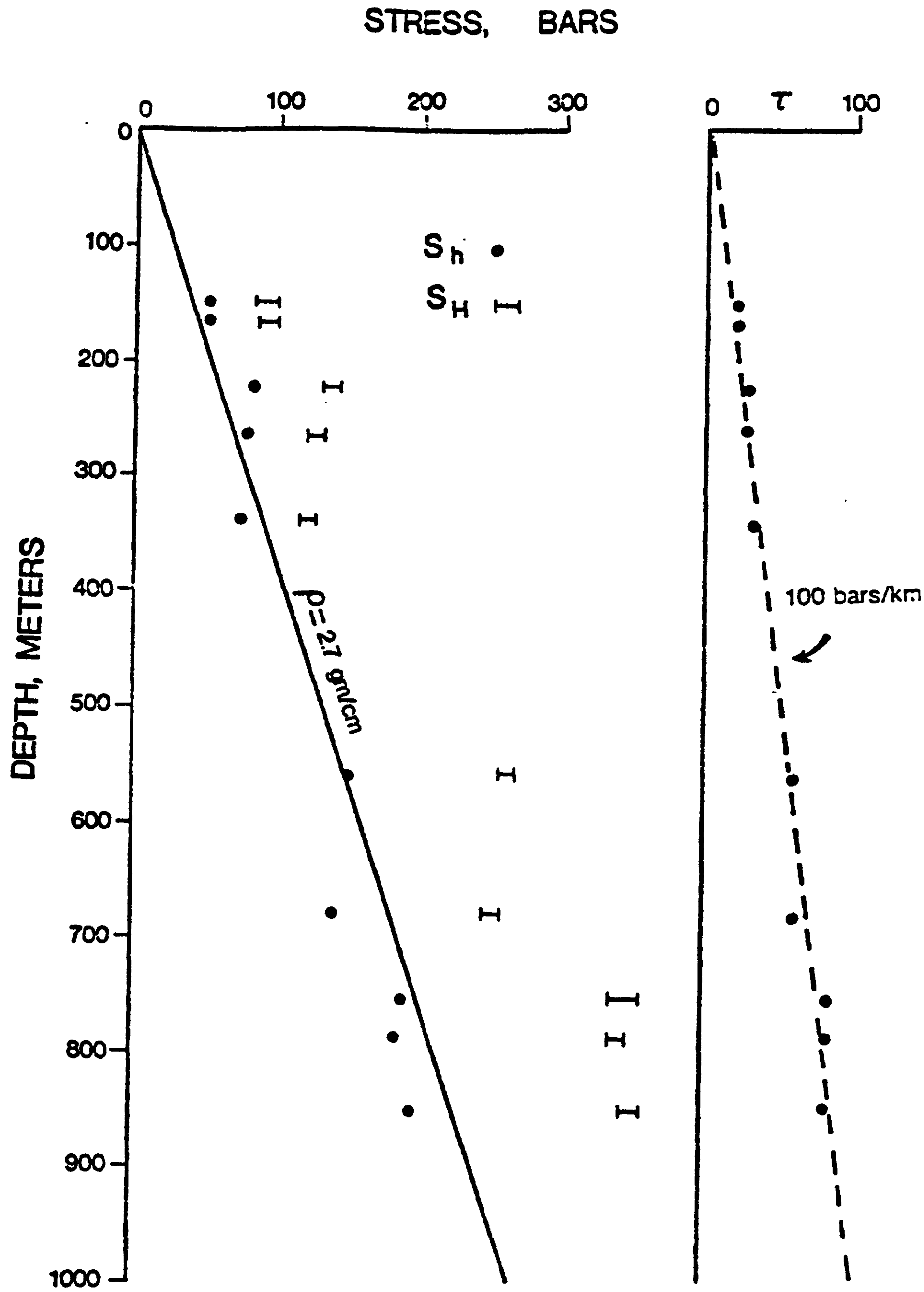

Figure 4- Stress measurements made 3.5 km from the San Andreas fault in the Western Mojave desert. The horizontal principal stresses clearly increase with depth as does the horizontal shear stress resolved onto the San Andreas fault.

PETROLOGIC COMPARISON OF CATACLASTIC ROCKS FROM SHALLOW AND DEEPER CRUSTAL LEVELS WITHIN THE SAN ANDREAS FAULT SYSTEM OF SOUTHERN CALIFORNIA

14-08-0001-17732

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The San Gabriel Fault (Fig. 1), a deeply eroded late Oligocene to mid-Pliocene precursor to the San Andreas, was chosen for petrologic study as it should provide intrafault material representative of deeper crustal levels. Cataclastic rocks along the present trace of the San Andreas in this area are exclusively a variety of fault gouge which is essentially a rock flour with a quartz, feldspar, biotite, chlorite, amphibole, epidote, and Fe-Ti oxide mineralogy representing the milled down equivalent of the original rock (Anderson and Osborne, 1979; Anderson et al., in press). Fault gouge along with breccia is likewise common along the San Gabriel Fault but only where the cataclasized zone is several tens of meters wide. At several localities, the cataclasized zone is extremely narrow (few centimeters) and the cataclastic rock type is cataclasite (Higgins, 1971), a dark, aphanitic, and highly comminuted and indurated rock (Plate 1).

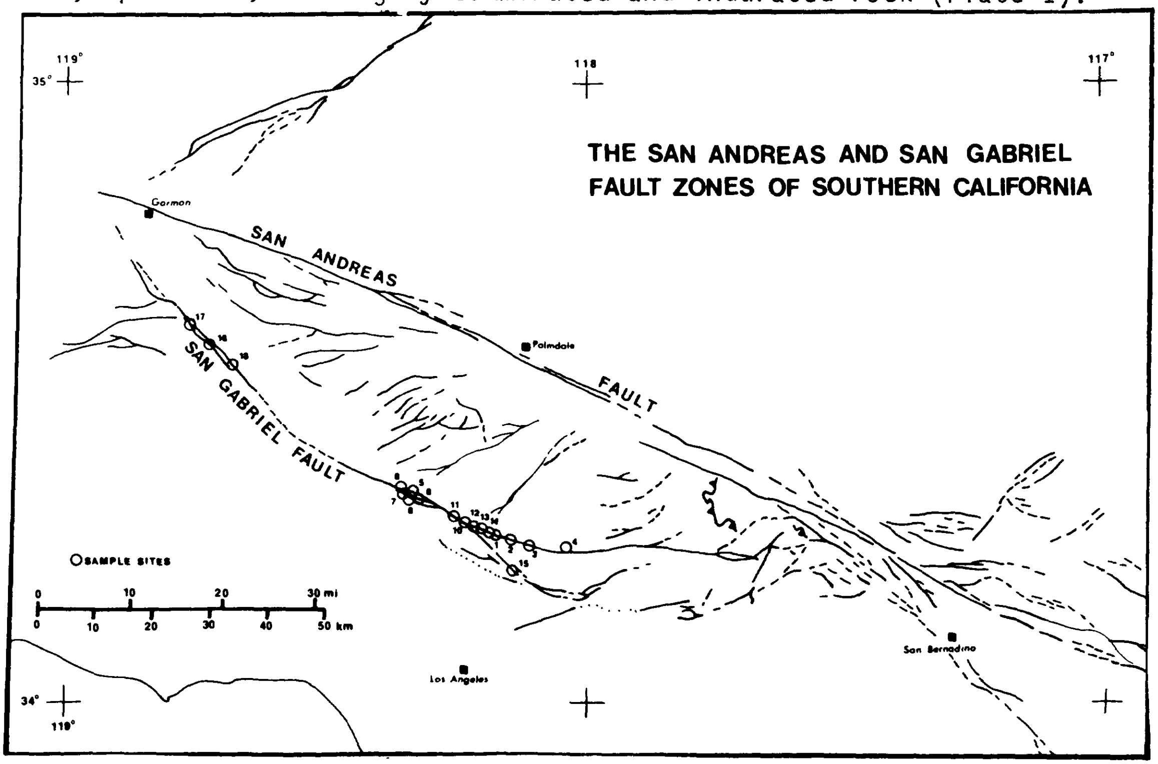

Figure 1. The San Andreas and San Gabriel Fault Zones of Southern California and sites chosen for petrologic study

Conceivably, such narrowing of the cataclasized zone and intensity of cataclasis is what might be expected in the higher confining pressure of deeper crustal levels that are experiencing brittle deformation.

The cataclasite and gouge along the San Gabriel Fault is considerably finer grained than gouge along the San Andreas. The average grain diameter for the San Andreas gouge is 0.01 to 0.06 mm whereas for the San Gabriel cataclastic rocks it ranges from 0.0001 to 0.007 mm. Moreover, while the San Andreas gouge remains particulate to the smallest grain size, the ultra-fine grain matrix of the San Gabriel cataclasite is recrystallized. This recrystallization probably occurred after cataclasis as petrofabric analysis shows that the cataclasite formed by brittle rather than ductile deformation.

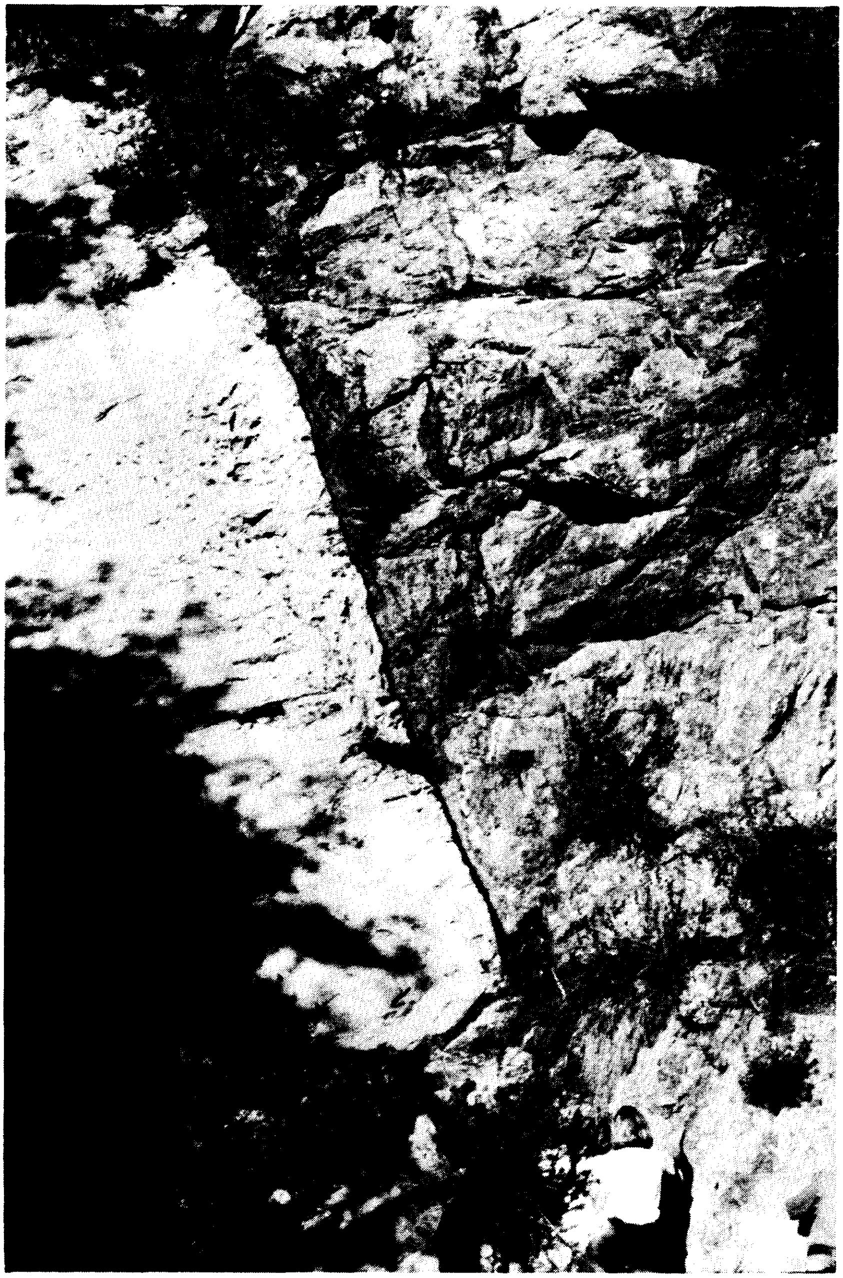

Plate 1. The San Gabriel Fault of the San Gabriel Mountains. A 1-3 cm. wide zone of cataclasite (black) separates granodiorite (left) from gneiss (right). Note person at lower right for scale.

The cataclastic rocks along the San Gabriel Fault show more mineralogic changes than observed for gouge along the San Andreas Fault. At the expense of biotite, amphibole, and feldspar there is some growth of new chlorite, low Ti celadonitic (phengitic) muscovite, stilpnomelane or biotite, hematite, ferro-pseudo brookite, laumontite, and zeolite. However, much of the mineralogy is still relict from the earlier igneous or metamorphic history of the protolith and porphyroclasts even in the most cataclasized material includes relict plagioclase (oligoclase to andesine), alkali feldspar, quartz, biotite, actinolite, allanite, and Fe-Ti oxides (ilmenite and magnetite). We have found no significant development of any clay minerals (illite, kaolinite, or montmorillonite). For most sites, the compositions of these minerals directly correspond to the mineral compositions in rock types on one or both sides of the fault.

Whole rock major and trace element chemistry (Fig. 2) coupled with mineral compositions show that mixing within the cataclasized zone is not uniform and that originally micaceous or foliated or physically more heterogeneous rock units may have a disproportionally larger contribution to the

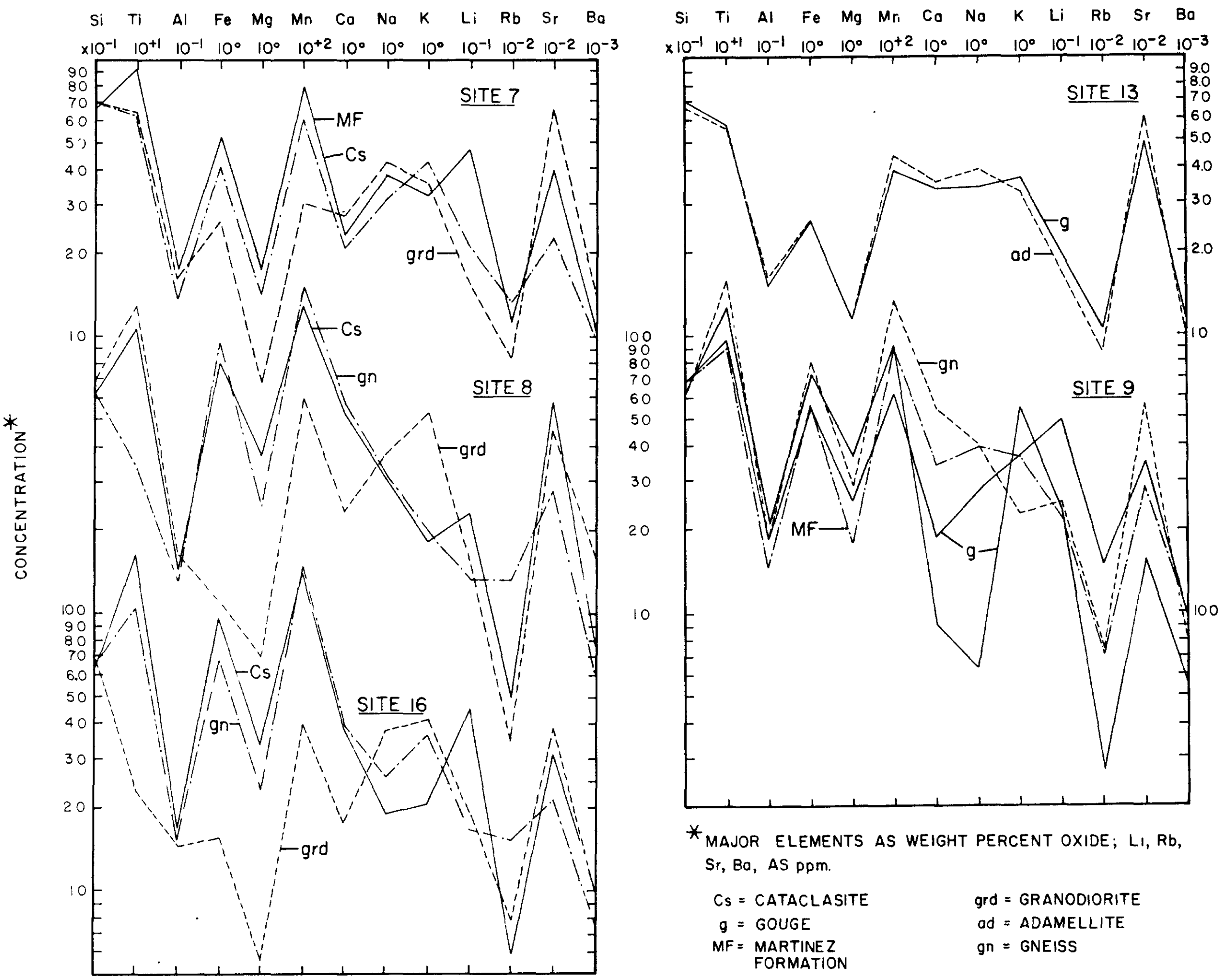

Figure 2. Major and trace element compositions of cataclastic and protolith rocks of the San Gabriel Fault. Note similarity of gneiss and Martinez Formation composition to the cataclasite and marked anomalous behavior of lithium.

final make-up of the intrafault material. As previously found for the gouge along the San Andreas, chemical mobility is not a major factor in the formation of cataclastic rocks of the San Gabriel Fault. We see no major changes for Si, Ti, Al, Fe, Mg, Ca, Na, or Ba. There is moderate mobility of K, Rb, Sr and marked mobility of Li, a probable result of the alteration and formation of new mica minerals.

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A Study of Mylonitic Rocks from Major Fault Zones

14-08-001-17757
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Investigations

1. Field sampling has been conducted in six areas of southern California. Samples of fault rocks and also uncataclasized rocks, adjacent and within fault zones, were collected. The areas studied to date are:

a. Portions of the eastern Peninsular Ranges mylonite zone in the Borrego and Palm Desert quadrangles were sampled. Cataclastic and, where present, noncataclastic rocks were collected from a number of locations in the Santa Rosa Mountains and Borrego Valley-Clark Valley area. Because the parent rocks of much of the mylonitic material are plutonic rocks of the Peninsular Ranges batholith and therefore well-behaved chemically, this zone provides an opportunity to investigate possible chemical changes due to interaction with a fluid within the fault zone.

b. A two mile wide traverse across Upper Lytle Creek Ridge from Lone Pine Canyon (San Andreas rift zone) to the canyon bottom of the North Fork of Lytle Creek in the Telegraph Peak quadrangle. Exposed along this traverse is a 2000 ft. wide cataclastic zone of the Punchbowl fault zone, plus a number of smaller cataclastic zones. The Punchbowl fault zone here consists of slices of several different rock types which are bounded by major shear surfaces.

c. Samples were collected along a 3500 ft. section across strike of a mylonite zone in the Crafton Hills northwest of the town of Yucaipa. Typical rock types here are blastomylonite and mylonite.

d. Several small shear zones on Blue Ridge (Mescal Creek quadrangle) were investigated. These zones are close to the portion of the Punchbowl fault zone that passes through this area Mylonitized Pelona schist is the major rock type.

e. Two thin thrust zones in the eastern Sierra Pelona were sampled. Fault rocks here are gouge and incoherent breccias.

f. The classic area in Cucamonga Canyon was sampled to provide comparison of the other zones with a relatively deep-seated cataclastic zone.

2. Thin sections have been prepared from samples collected. The thin sections were petrographically examined to determine the minerals present, what reactions may have occurred, and whether the reactions may have accompanied shearing.

3. Selected samples have been analyzed with the electron microprobe. The microchemical data is used to investigate mineral reactions and to determine the physical conditions of formation of fault rocks.

4. Samples of mylonitic and associated noncataclastic rocks have been analyzed for major and minor element chemical composition using rapid silicate analysis techniques. The data are being applied to the question of possible interaction between fault materials and a fluid phase within the zones.

RESULTS

1. Extensive retrograde metamorphism of the rocks has occurred in the fault zones of areas (b), (c), and (d) above. Less extensive but locally important retrograde metamorphism has affected some portions of the eastern Peninsular Ranges mylonite zone. The reactions involved are hydration, hydration/carbonation, and carbonation reactions, with hydration being the dominant process which has affected significant volumes of rock within the fault zones at a considerable range of depth.

2. No evidence of prograde dehydration or decarbonation reactions that accompanied faulting has been found. Given the assemblages present in many of the rocks, observable dehydrations should be in evidence if any significant transitory heating due to friction had occurred; hence such transitory heating seems to be ruled out in the areas studied.

3. Compositions of Ca-amphiboles (actinolite-hornblende series) from mylonitic schists from areas (b), (c), and (d) indicate that the geothermal gradient was intermediate over a range of grades from epidote-amphibolite facies through lower greenschist facies. The amphibole compositions are similar to those in rocks from intermediate P/T (or even somewhat higher P/T) regional metamorphic terrains. The presence of such amphiboles tends to rule out significant frictional heating in the Punchbowl fault zone or in the immediately adjacent portion of the San Andreas fault zone, as well as in the Crafton Hills zone.

4. The three conclusions listed above suggest that the fluid pressure was relatively close to the load pressure in the zones of the Upper Lytle Creek Ridge, Blue Ridge, and Crafton Hills areas. However, it is premature to extend this as a generalization to other parts of the San Andreas system. The relative importance of frictional heating may vary with relative differences in the fluid pressure. More fault zones need to be

studied to determine if frictional heating was important in any part of the San Andreas system or whether relatively high fluid pressures are characteristic in the fault zones at depth.

5. The whole rock chemistry work is not yet at a point where significant conclusions can be made. Preliminary results indicate that minor exchange of species such as Na_2O and K_2O can occur between fault material and intrafault pore fluid. Obviously, the addition of H_2O and CO_2 can occur on a large scale as shown by the volume of rock affected by retrograde metamorphic reactions; the CO_2 and H_2O contents of analyzed samples reflect the extent of the reactions in the studied rocks.

MECHANISMS OF FRACTURE AND FRICTION OF CRUSTAL ROCK IN SIMULATED GEOLOGIC ENVIRONMENTS

Contract No.: 14-08-0001-18325

Principal Investigators: B.K. ATKINSON, N.J. PRICE

Additional Contributions by: S.M. DENNIS, P.G. MEREDITH and R.F. HOLLOWAY

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01-589-5111, X. 1690, 1654

Investigations

1. Construction of apparatus for high-temperature (up to 500°C) and high-pressure (up to 3 kbar) apparatus for Fracture Mechanics studies of critical stress intensity factors and subcritical (stress corrosion) crack growth in crustal rocks.

2. Fracture Mechanics experiments and associated acoustic emission studies of stress corrosion crack growth in granites and basalts.

3. Experimental study of influence of pore water on sliding properties of faults in granites and basalts at conditions of temperature and pressure typical of the upper 15 km of the earth's crust.

4. Identification of active mechanisms of deformation in the above experiments.

Results

1.1 Construction of high-temperature short-rod and double torsion apparatus is well advanced. The short-rod apparatus is now being tested. A high-temperature high-pressure apparatus for testing internally pressurized thick walled cylinders is in the process of construction.

1.2 Some success has been achieved with attempts to develop means of measuring mode II and mode III Fracture Mechanics parameters.

2.1 The influence of fluid chemistry on stress corrosion in quartz has been investigated by running experiments in 2N NaOH, de-ionized water, and 2N HCl. Data were fitted to an equation of the form $v = \alpha K_I^n$, where v is the crack velocity, K_I is the mode I stress intensity factor and α and n are constants. For synthetic quartz cracked on the *a* plane in a direction ⊥ to *z* at 20°C the n-values were as follows. The figures in brackets are correlation coefficients.

Corrosion medium	n
2N NaOH	9.5 (0.971)
deionized H_2O	12.8 (0.965)
2N HCl	19.3 (0.978)

At K_I values ≙ 0.5 K_{Ic} the crack velocity can be changed by approximately 3 orders of magnitude by changing the fluid environment from 2N NaOH to 2N HCl.

2.2 Crystallography has been found to exert a strong influence on crack propagation in quartz. Comparing the data of Atkinson (1979) to that of Bruner (1979) it can be seen that at $K_I \simeq 0.65\ K_{Ic}$ the crack velocity changes by up to 3 orders of magnitude by changing crystallographic orientation. Even greater changes can be expected at lower K_I values.

2.3 A comparison has been made between the stress corrosion behaviour of a Westerley Granite in our laboratory and of the Westerley Granite used by CIRES (Swanson and Spetzler). Although the CIRES Westerley gave similar results to our sample when deformed in our laboratory, the CIRES results are rather different.

Material	Conditions	n
IC Westerley	air (30% R.H.)	39.1 (0.968)
CIRES Westerley	air (30% R.H.)	35.9 (0.999)
Westerley (Swanson, 1980)	toluene ($\simeq$ 11.3% R.H.)	51.0
IC Westerley	H_2O liq.	34.8 (0.987)
CIRES Westerley	H_2O liq.	33.7 (0.998)
Westerley (Swanson, 1980)	H_2O liq.	53.0

K_{Ic} has been determined for 3 mutually perpendicular orientations in Westerley Granite and compared with Swanson's (1980) result.

Direction	K_{Ic} ($MN{\cdot}m^{-3/2}$)	
A	1.74 ± 0.05	
B	1.67 ± 0.02	
C	1.65 ± 0.04	
unknown	1.8 ± 0.1	(Swanson, 1980)

2.4 Stress corrosion data have been obtained for the Ralston Intrusive at 20°C. Ralston is a basaltic rock with a rather high concentration of K_2O.

Conditions	n
air 28% R.H.	44.4 (0.998)
H_2O liq.	23.5 (0.994)

The K_{Ic} value for this material was 2.58 ± 0.06 $MN{\cdot}m^{-3/2}$ at 20°C.

3.1 The strength/confining pressure relationships for one block of Westerley Granite have been determined for both wet and dry specimens at pressures up to 4 kbar. Our material does not behave in a markedly different way to that used by other workers.

3.2 Stress relaxation experiments have been performed on pre-faulted specimens of Westerley Granite in both wet and dry states at an effective confining pressure of 1.5 kbar. The strength of the dry material is virtually unaffected by reducing the strain rate from 10^{-4} to $10^{-10}\ s^{-1}$. The strength of the wet material is dramatically reduced as strain rate is lowered below about $10^{-7}\ s^{-1}$. The rate of strength reduction is accelerated by increasing the pore fluid pressure from 0.2 to 1.0 kbar, whilst maintaining the effective confining pressure constant.

3.3 The above results for Westerley Granite are comparable to results obtained earlier for Tennessee Sandstone and Mojave Quartzite and which were reported in earlier technical reports. We are undertaking micro-structural studies of the deformed specimens at present so we do not feel able to identify the mechanism responsible for the strength reduction at this stage. In the light of earlier work, however, we feel confident that some combination of stress corrosion and pressure solution must be involved.

3.4 Very slow constant strain rate experiments (10^{-9} s^{-1}) are now under way to generate relatively highly strained material for further micro-structural analysis. These are expected to last up to 6 months.

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Investigations

Laboratory experiments are being carried out to study the rheological properties of fault gouge. The goal is to identify the physical mechanisms responsible for stable-sliding, stick-slip, and the time dependence during frictional sliding on faults.

Results

Cylindrical Westerly granite specimens containing sawcuts simulating faults oriented at 30 degrees to the cylindrical axis were deformed under 300 MPa confining pressure. Sawcuts contained a 1 mm thickness of crushed Westerly granite; specimens were vacuum dried prior to each experiment and vented to the atmosphere during experiments. The effect of large changes in strain rate was studied in stepped constant strain rate experiments in which the strain rate was varied over 4 orders of magnitude from 10^{-7}/sec to 10^{-4}/sec during a single experiment. Frictional stress increased nearly logarithmically with increased strain rate with an increase of approximately 10% of the frictional strength with strain rate increased from 10^{-7}/sec to 10^{-4}/sec. Extrapolating these results to geologic strain rates of 10^{-4} implies the possibility of very low frictional strength in situ. A physical model is proposed, based on time dependent cracking of gouge grains, which explains the strain-rate-dependent strain strengthening observed in the stepped constant strain rate experiments. This model has implications for the time-dependent deformation of faults under constant differential stress. It implies that creep should be of very small magnitude at low differential stress but increase with increased differential stress; and the creep should be of large magnitude but insensitive to the stress level at elevated differential stress. A number of creep experiments were conducted under the same experimental conditions as were the stepped constant strain rate experiments. They confirm the predictions of the physical model, regardless of the loading history of the experiment.

Reports

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TRANSIENT CREEP AND SEMIBRITTLE BEHAVIOR OF CRYSTALLINE ROCKS P5

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In anticipation of beginning experimental work on transient creep of granitic rocks at moderate to high temperatures, most of the time spent on this project has been devoted to a survey of the extensive literature on the topic. Especially time-consuming recently has been a review of the enormous literature on low-temperature creep of granite. This review follows on treatments of creep of rocks in general, given by Carter and Kirby (1978) and Handin and Carter (1980), reviews that focused mainly on high temperature creep. The main results of the present survey are outlined below with a more detailed discussion given in the annual report.

Low-temperature creep of granitic rocks generally appears to follow a logarithmic flow law although the time dependence is not yet firmly established (Kranz and Scholz, 1977). The creep strain is accomplished by microfracturing and the rate-controlling process for the microfracturing is believed to be chemical corrosion of stressed crack tips leading to time-dependent fracturing. Associated with the microfracturing are acoustic emissions and changes in permeability, electrical resistivity, magnetic moment, gas emission, longitudinal, radial and volumetric strains, and acoustic velocities and anisotropies (Byerlee, 1978). The stress-induced cracks are dominantly extensile in nature, resulting from elastic mismatch and stress concentrations at boundaries at high angles to the maximum principal compressive stress σ_1,(Tapponnier and Brace, 1976; Kranz, 1979a,b). These cracks appear to develop preferentially in weakened zones inclined to σ_1, and may link up in various ways with each other with other minerals and with crushed grain boundaries to produce a throughgoing fault (Kranz, 1979b). Apparently, a critical crack density, associated with a critical volumetric strain, are required for the onset of accelerating creep and eventual fracture instability (Cruden, 1974; Kranz and Scholz, 1977). Kranz (1979a) pointed out a fundamental difference in crack development in constant stress and constant strain rate tests, the former type, he believes,to be most applicable to natural deformations. The difference is that at constant strain rate, crack growth and development are limited by the rate at which stress is applied; whereas, in creep tests, crack growth is limited by the rate at which corrosive agents can decrease crack-tip strength.

The addition of temperature alters the nature of the deformation and of the flow laws in many important ways. The most obvious effect is the introduction of thermal cracks resulting from differential thermal expansion of adjacent minerals, the volume of new cracks increasing either exponentially (Simmons and Cooper, 1978) or linearly (Friedman et al., 1979) with temperature. Friedman et al. (1979) showed, however, that the most important effect of temperature, under 50 MPa confining pressure, is its influence on the stress-induced fracturing process. Rock strengthening can result if corrosive agents are driven off by increases in temperature (Wu and Thomsen, 1975) and permeability may decrease in a pore pressure gradient, at elevated temperature, by dissolution and precipitation of minerals down the gradient (Summers et al., 1978). There must also exist physical conditions at which corrosive and embrittling effects of H_2O give way to ductile effects by facilitating the motion of slip dislocations and diffusion (Carter and Kirby, 1978; Tullis and Yund, 1977, 1979).

A most important effect of elevated temperature is the thermal activation of dislocation and diffusion processes and these can serve in various ways either to enhance or retard fracturing processes. When thermally activated processes participate in fracturing, the overall behavior is termed semibrittle and, for crystalline rocks, this type of behavior and transient creep are expected to dominate at mid- to upper-crustal conditions, if not throughout the crust. Few data are available for transient creep of granitic rocks at elevated temperature and in none of the three studies (two at atmospheric pressure), for which flow parameters could be estimated, were the deformational processes determined. A fit of existing data to a power-law transient creep equation and extrapolation to crustal conditions of interest indicates that appreciable transient creep strains can take place over a reasonable geological time-frame. What is clearly mandated now is a careful evaluation of transient creep of crystalline rocks, under modest pressure at elevated temperature, and under both dry and controlled fluid-pressure conditions. Concomitant with the mechanical study must be detailed determinations of the flow processes both for comparisons with natural processes and to provide a firm physical basis for the transient creep law derived. Such a research program is currently underway in our laboratory and the initial work was supported by the U.S. Geological Survey.

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Investigations

1. Water weakening of quartz.
2. Plasticity of rock-forming minerals.
3. General inelastic mechanical behavior of rocks and minerals.
4. Apparatus development.

Results

1. The effects of two major experimental parameters on the plasticity and rheology of synthetic quartz crystals were explored: (A) Creep rates increase systematically with increasing concentration of grown-in water (Kirby and Linker, 1979). A linear relationship is suggested by the data. Water concentration has no effect on the relative contributions of the operating slip systems over the range $6x10^{-3}$ to $6x10^{-1}$ weight percent water. (B) We are nearing the end of a systematic investigation of the effect of the orientation of compression on the plasticity and rheology of quartz. The results to date confirm earlier work that those crystals compressed in orientations which promote slip parallel to < c > creep at higher rates and show lower activation energies for creep than those orientations of compression which promote other slip systems. We believe that this behavior stems from the higher diffusion rate and lower activation energy for diffusion in the < c > direction compared to directions normal to < c > (Linker and Kirby, 1980).

2. In collaboration with Jacques Castaing and Jean Cadoz of the CNRS Laboratory, Meudon, France, we have plastically deformed synthetic corundum at low to moderate temperatures and high pressure. These measurements have established the yield strength and plasticity of this mineral over a far wider range of temperatures than were possible in tests at atmospheric pressure (Castaing, Kirby, and Cadoz, 1980).

3. A major comprehensive new review and compilation of the inelastic mechanical properties of rocks and minerals has been completed (Kirby and McCormick, 1979). New features of the review include a modern summary of time-dependent mechanical behavior and effects of water on the mechanical properties of earth materials.

4. Our new 10 kilobar triaxial gas apparatus is nearing completion after a long shakedown and re-design phase. We anticipate results from experiments during the next reporting period.

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Project Title: Stress Analysis of a Deeply Eroded Analog of the San Andreas Fault

Contract Number: 14-08-0001-17772

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We are continuing to study deformation-induced microstructures in quartz-bearing rocks from three deeply eroded shear zones that are possible Precambrian analogs of the San Andreas system. The investigation has included optical and transmission electron microscopy studies of quartzites and quartz-feldspar gneisses from the shear zones. We have measured recrystallized grain size, sub-grain size and free dislocation density in quartz grains in rocks from the shear zones in order to determine paleostress levels along the faults. Thus far, our results have indicated different tectonic and thermal histories for the three shear zones.

The Ikertoq shear zone in western Greenland is approximately 40 km wide and trends ENE from near Holsteinsborg to Sondre Stromfjord. The rocks now exposed at the surface were at a depth of 15 to 30 km and temperatures of 600 to 800°C when they were deformed. Samples collected from this shear zone near Sondre Stromfjord consist of quartz, plagioclase, potassium feldspar, hornblende, and biotite. Dislocation densities, sub-grain sizes and recrystallized grain size of quartz grains in the deformed gneisses yield stresses of 50 to 110 MPa, 20 to 40 MPa, and 20 to 40 MPa, respectively. The microstructures suggest that some post-deformational recovery has occurred and that the stress values indicated by the recrystallized grain size and sub-grain size reflect recovery following a major deformation event, while the dislocation densities reflect a late, short-duration stress pulse.

The Mullen Creek - Nash Fork shear zone in southeastern Wyoming separates older Precambrian basement rocks (2.4 b.y.) northwest of the shear zone from younger basement rocks (1.75 b.y.) southeast of the shear zone. The shear zone varies in width from 1 to 5 km and can be traced for over 40 km through the central Medicine Bow Mountains. Rocks in the shear zone that are now exposed at the surface were probably deformed at depths of 15 to 20 km and temperatures of 500 to 600°C. We have measured free dislocation densities in a collection of rocks made across the shear zone from quartzite, west of the shear zone, into a quartz-feldspar gneiss, east of the shear zone. The dislocation densities ranged from $5 \times 10^8 cm^{-2}$ to $13 \times 10^8 cm^{-2}$, with the highest values occurring in rocks from the margins of the shear zone and the lowest values occurring in rocks from near the center of the shear zone. The trend in dislocation densities suggests that after a major deformation event, the microstructure began to recover and that recovery proceeded most rapidly in the center of the shear zone where the temperature was the highest.

The Idaho Springs - Ralston shear zone extends for over 40 km through the central Front Range in Colorado. The shear zone varies in width from approximately 1 to 3 km and cross-cuts Precambrian quartzites, granites, gneisses and schists. Most of the rocks exposed at the surface in the shear zone were deformed at depths of 10 to 15 km and temperatures of 500 to 600°C. Within the sheared quartzite, small zones of completely recrystallized rock, approximately 1 meter wide, occur. These zones are spaced a few meters to a few tens of meters apart. The grain size of the recrystallized quartz in these bands is the same as the recrystallized grain size of the quartz in the rest of the shear zone. The stress levels determined from the dislocation density, recrystallized grain size, and sub-grain size are in good agreement with one another, and the magnitudes of these paleostress levels vary very little throughout the shear zone. The good agreement among the three paleopiezometers suggests that the microstructural features recorded in these rocks were generated during a major episode of deformation.

Publications:

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Laboratory and Field Investigation of Fault Gouge

14-08-0001-17677

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Investigations

The overall objective of this project is to investigate fault mechanics of gouge-host rock systems through controlled laboratory experiments and correlated field studies with the emphasis on understanding the operative physical principles that govern shallow focus earthquakes. In this report we discuss the results of investigations into three areas: (1) the generation of fracture fabrics within gouge zones; (2) finite element analysis of Riedel shear zones using an elastic-plastic constitutive equation; and (3) studies of ultrafine simulated gouge material.

Results

The generation of fracture fabrics within gouge zones. We have continued to use the direct shear sample assembly to study the development of fractures within shear zones. The sample assembly consists of a right circular cylinder of Tennessee sandstone, cut in half parallel to the cylinder axis, along which a layer of calcite simulated gouge is placed. Previously, we had studied the sequential development of the fracture types as a function of shear displacement. Our results agree well with those of other direct shear type experiments, where it is observed that the Riedel shears are the first to form, followed by the P fractures and, finally the Y (wall parallel) shear fractures. Because there remained some doubt whether the fractures are as a function of shear displacement or shear strain, we have conducted experiments to investigate the fracture development as a function of shear strain.

Samples with different gouge thicknesses (0.5, 1.0, 2.0 mm) were deformed to an equal shear strain. The fabric that developed in these is characterized by the R1 Riedel shears. In a second group using also different thicknesses of gouge, samples were deformed to an equal shear displacement. These resulted in different values of shear strain and in different fracture types. The development of second order fractures in shear zones is clearly a function of shear strain. In order to calculate the values of shear strain, in these experiments, we assume a condition of homogeneous simple shear. Although this is a crude approximation to explain the detailed deformations, overall, these boundary conditions satisfy the bulk deformation observed. This result should aid us in guiding field studies of natural fault zones.

Finite element analysis of Riedel Shear zones using an elastic-plastic constitutive equation. To gain insights into the deformation within shear zones, finite element studies have been used to supplement laboratory investigations. Originally, a model was designed to simulate a precut specimen with a layer of quartz gouge placed along the precut and oriented at 35° to the cylinder and load axes. For this model a linear elastic constitutive law was used for all elements and the elements differed only in the elastic modulus ascribed to each. The results showed that the σ_1 stress trajectory reorients to 45° at the shear zone boundaries, and to 50° at the Riedel shear-gouge boundaries. Yet there was some doubt as to the validity of these results, since qualitatively the stress reorientation could also be explained by the effect of welded boundaries joining elements of greatly differing elastic moduli.

In the present study we ascribe to the gouge and Riedel shear elements in the mesh an elastic-plastic constitutive law, with a von Mises yield criterion and an isotropic work hardening rule. In this second model, all elements have the same elastic moduli. The results are similar to those obtained in the first model. The σ_1 stress reorientation is observed at the shear zone and Riedel shear-gouge boundaries. Thus, it appears that the contact of a highly deformable material with a less deformable material causes the reorientation of the stress tensor. The implications of this study are that (1) the calculations of the coefficients of friction from the far field stresses (as is commonly done) will lead to values which may be as much as 25% too high, and (2) the stress-strain behavior of the gouge cannot be modeled from the far field measurements.

Studies of ultrafine quartz shear zones. Our investigations of ultrafine (< 1 μm) quartz have been extended to elevated temperatures under conditions which now closely approximate those expected along a fault at 10 km depth: 250 MPa confining pressure, 100 MPa pore water pressure, and temperatures to 600°C. The higher temperatures are realistic if one trades time and temperature in order to investigate low strain rate behavior. Our present results have provided useful insights into the mechanisms of frictional strengthening and weakening, which we feel are fundamental to a general understanding of frictional processes, in accord with the ideas of Dieterich (1979) and Johnson (1980).

Shear stress-shear displacement curves for tests conducted at 25°, 300° and 600°C, do not exhibit a weakening with increasing temperature as had been expected. At 300°C, the frictional shearing strength is 12.5% higher than at room temperature, while at 600°C, strengths are comparable with those at room temperature. However, microstructural observations indicate that significant changes in deformation mechanisms occur within the temperature range investigated: room temperature shear zones deform by displacement along discrete Riedel shears, while at 600°C, there is evidence for quartz solution and redeposition and/or recrystallization, in the form of abundant quartz veining. We offer an explanation for the lack of temperature activation revealed by constant shearing strength at constant external driving rate in terms of arguments concerning the real area of contact at grain junctions within the shear zone. This analysis is consistent with the analyses of time-dependent friction advanced by Dieterich (1979) and Johnson (1980). Transients in frictional strength following creep or relaxation portions of our tests are consistent with those observed by these authors. We are currently attempting to model frictional behavior as functions of both temperature and deformation rate, taking into account both constitutive equations for the asperities, and the dependent, geometric effects of changing real area of contact.

Reports

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The Role of Heterogeneities in Faulting

Contract No. 14-08-0001-16721

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Investigations

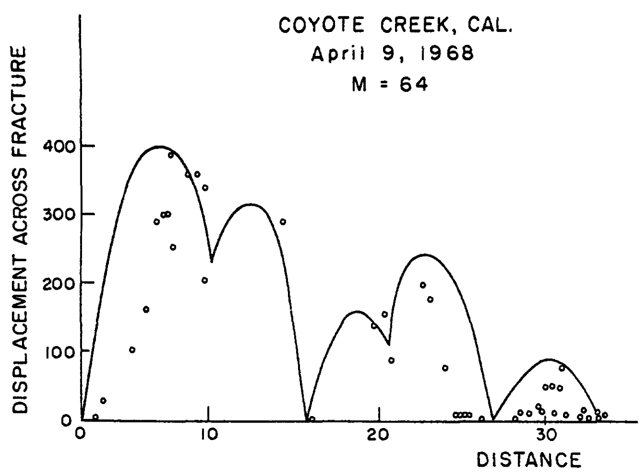
Very general considerations suggest that spatial heterogeneities in either stress or fracture energy are required to explain observed seismic faulting characteristics, such as the frequency-magnitude relations, non-uniform fault slip, multiple events, and random ground acclerations.

Results

In order to obtain a full dynamic solution to greatly heterogeneous faulting, we used a one-dimensional continuum model in which the total stress and the fracture energy varied along the fault, and employed the method of characteristics. The results clearly demonstrate that the process of rupture in a heterogeneous system is closely linked to the stopping phase of the motion.

We found that heterogeneous rupture can be due either to initially non-uniform stress or to spatially non-uniform frictional strength. However, non-uniform stress drop - the difference between tectonic stress and frictional strength - tends to become smoother with increasing slip, a condition which is clearly not observed in nature.

Spatially variable fracture energy, however, can produce and maintain a heterogeneous effective stress. We conclude that spatially variable fracture energy may be responsible for the heterogeneous nature of earthquake faulting. Non-uniform stress by itself cannot indefinitely maintain the heterogeneous nature of faults.



Comparison between theoretical and observed offset for the Coyote Creek earthquake.

Reports

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Rocks Under Geothermal Conditions
9960-01490

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Investigations

Development of a direct stress-strain apparatus for determining the internal friction (Q^{-1}) of rocks at seismic frequencies (0.1 to 10 Hz) and at seismic and large strain amplitudes (5×10^{-8} to 10^{-5}).

Results

The original Q apparatus [Peselnick et al., 1979] was modified: (a) The press plattens and weights for applying the pre-stress were eliminated. Instead, the pre-stress was obtained using a fine-threaded screw (80 turns per inch) placed in series with the sample column. This modification was required for future use of the Q-apparatus inside a pressure vessel.

(b) The stress transducer (solenoid) was placed in series with the sample column. (This change was also dictated by requirements for future use within a pressure vessel.) The solenoid was redesigned for larger force-current sensitivity and for reduction of friction using ball-bearing guides.

(c) An analog function amplifier was constructed to correct for the non-linear (force - current squared) characteristics of the solenoid.

(d) The strain sensitivity was increased to about 5×10^{-8} by reduction of the capacitor electrode separation from 0.017" to 0.005".

The modified apparatus (QA-II) was tested for energy dissipated in the apparatus - An apparatus Q of 1000 was obtained and this permits Q measurements in rocks having Q's of 100 or less.

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The Magnetic Response of Rocks to Uniaxial Compression - Effect of Confining Pressure

Contract No. 14-08-0001-G473

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The magnetic response to stress of a number of rocks has been studied. Two types of experiments have been carried out. Initially a simple uniaxial press constructed of PVC was utilized. Subsequently, a Be Cu press, built in conjunction with Dr. S. Pike of USC, was used. This press permitted the application of confining pressure during the uniaxial stress experiment. All magnetic measurements were made with the horizontal access SCT magnetometer, into which the presses were inserted. During the experiments three components of magnetization were monitored continuously. The stress response is defined in terms of the stress sensitivity parameter, s,

$$s = \frac{1}{M_0} \frac{\Delta M}{\Delta \sigma} \ cm^2 \ kg^{-1}$$

where $M\sigma$ is the initial magnetization and ΔM the change in magnetization brought about by the stress change $\Delta\sigma$ (Nagata, 1970). We have found that the stress response is controlled primarily by the grain size of the particular magnetic phases present. The samples used in the study were therefore magnetically characterized in terms of the well known hysteresis parameters.

In Table 1 some typical results of the simple uniaxial compression experiment are presented. Note that the "s" value is a minimum for the Andesite (WP), which has the most single domain-like characteristics. As one progresses from it towards more and more multidomain material, the s value increases, until, with the Gabbro (D) which has typical soft multidomain parameters, it reaches 2.5×10^{-3} cm^2 kg^{-1}, a factor of thirty greater than the response of the single domain andesite. Such variation in the sensitivity to stress is consistent with earlier work we carried out with synthetics dispersed in artificial matrix (Kean et al., 1976). In that work we found that titanomagnetite in the grain size range of 70-100μ had an s-value of 3×10^{-3} cm^2 kg^{-1}, but that fine grain titanomagnetites had a value more than an order of magnitude smaller. These results suggest that whereas the stress response of single domain magnetic phases will give rise to very limited effects, that of multidomain phases will be much larger. It should also be noted that the sign of s is not always positive: in some samples the stress increases the total remnant moment.

Table 2 presents results of experiments in which the uniaxial compression was applied in the presence of confining pressure. The results reveal a similar relationship between hysteresis characteristics and stress sensitivity, as did the simple uniaxial experiment. Samples from the same rocks studied in the experiment with confining pressure were also exposed to simple uniaxial compression in the Be Cu press. Again the results were very similar with a marginally larger effect in the unconfined experiment. These experiments demonstrate (1) that the addition of 500 bars of confining pressure did not seriously affect the stress response, and (2) that the earlier experiments using the simple uniaxial press are consistent with the later work.

In Table 2, two values are given for the stress sensitivity parameter. s is the value on the first cycle of compression and s' that observed during later cycles. It is well known that the effect of stress on the first cycle of compression is large compared with all subsequent cycles (e.g. Nagata, 1970; Carmichael, 1968). Frequently, all subsequent cycles show a common smaller value. However, sometimes the value continues to fall with additional cycles.

The experiments reported above and others carried out in conjunction with Dr. Pike suggest that the most common response to the stress is approximately isotropic demagnetization. However, there are exceptions in which the application of stress brings about an increase in remanence even in the absence of a magnetic field.

As a result of our earlier work (Revol et al., 1978, 1979), carried out under the auspices of the U. S. Geological Survey, we found that in polycrystalline magnetite the remanence increased markedly parallel to compression axis provided that the magnetization was small compared to saturation remanence (IRM_s). IRM_s itself demagnetized isotropically. We therefore carried out similar experiments with rock samples and found a similar effect in certain samples. This was most clearly seen in the serpentinite sample.

The most important results of our work are as follows:

(1) It is once again made clear that the response to stress of rock samples is strongly dependent upon the grain size of their magnetic phases present. This aspect of the phenomenon has been largely neglected. In fact, ironically, much of the theoretical effort (e.g. Hodych, 1970) has been made for the single domain or the pseudosingle domain case, which is clearly of very little interest in earthquake prediction, since the effects are demonstrably so small.

(2) For the samples studied, not only does the magnitude of the stress response vary by a factor of thirty, but the sign of the response can change. The anomalous increase in remanence has also been observed by Martin et al. (1978) in a slightly different experiment. Hence, contrary to U. S. Geological

Survey "wisdom," as reflected by their review panels, the phenomenon does not seem to be very well described. In fact, it may well be that, if there is any hope for an interpretable magnetic precursor to earthquakes, it lies in a better experimental description and deeper understanding of the magnetic response to stress of rocks. For this we certainly need more data!

(3) The theoretical interpretation of the stress effects must reflect the dominant processes observed in the phenomenon. From our own domain observations (Kean et al., 1976), and more importantly, from the much more extensive studies of Bogdanov and Vlasov (1966) and Dijkstra and Martius (1953), it is clear that the processes involved in order of initiation are (1) wall motion, (2) wall nucleation, and finally (3) domain rotation. Presently popular models such as Stacey and Johnston (1972) consider only the third process, which does not even take place until far higher stress than is of interest. They must therefore be replaced by models deriving from the Brown (1949) and Brugel and Rimet (1966) approaches which recognize the importance of wall motion. Our initial approach has been to add to the Brugel and Rimet model the effect of the demagnetizing field. It seems evident from the dependence of the response to stress of weak and strong magnetization that the demagnetizing field is an important factor which contributes to the definition of the sign of the effect. Preliminary results are qualitatively successful (Revol, 1979).

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Table 1. Simple uniaxial experiment

Sample	NRM ($G\ cm^3\ g^{-1}$)	X ($G\ cm^3\ oe^{-1}\ g^{-1}$)	J_r ($G\ cm^3\ g^{-1}$)	J_s ($G\ cm^3\ g^{-1}$)	H_c (oe)	H_{rc} (oe)	$\frac{J_r}{J_s}$	$\frac{H_{rc}}{H_c}$	Tc (^oC)	SD/MD	s ($cm^2\ kg^{-1}$)
Andesite (WP)	4.2×10^{-3}	9.0×10^{-5}	1.72	2.77	323	400	0.62	1.24	340	SD	6.4×10^{-5}
Granodiorite (OSU)	3.4×10^{-5}	4.6×10^{-4}	3.6×10^{-3}	1.1×10^{-2}	394	680	0.33	1.75	540 (330)	SD (MD)	-2.5×10^{-4}
Basalt (DSDP 61.1)	3.7×10^{-3}	4.6×10^{-4}	0.17	0.75	102	128	0.22	1.25	-	SD (MD)	2.8×10^{-4}
B (LNR-100)	0.7×10^{-3}	-	0.26	1.78	107	-	0.15	-	556	MD (SD)	3.0×10^{-4}
Serpentinite (SB)	1.0×10^{-3}	4.1×10^{-4}	0.13	0.75	185	450	0.18	2.43	-	MD (SD)	-1.45×10^{-3}
Gabbro (D)	9.2×10^{-5}	1.36×10^{-3}	0.019	2.16	21	228	0.009	10.8	-	MD	2.5×10^{-3}

Table 2. Uniaxial compression with confining pressure

Sample	NRM ($G\ cm^3\ g^{-1}$)	X ($G\ cm^3\ oe^{-1}\ g^{-1}$)	J_r ($G\ cm^3\ g^{-1}$)	J_s ($G\ cm^3\ g^{-1}$)	H_c (oe)	H_{rc} (oe)	$\frac{J_r}{J_s}$	$\frac{H_{rc}}{H_c}$	Sd/Md	s	s'
Basalt (V1-2)	5.1×10^{-3}	4.5×10^{-4}	0.17	.52	180	310	0.33	1.7	SD	3.0×10^{-5}	4.0×10^{-6}
Basalt (37-2)	1.0×10^{-3}	2.1×10^{-3}	1.0×10^{-1}	0.5	183	435	0.20	2.4	SD (MD)	1.5×10^{-4}	2.0×10^{-5}
Basalt (10-2)	8.7×10^{-4}	2.3×10^{-3}	8.1×10^{-2}	0.53	170	345	0.15	2.0	SD (MD)	1.4×10^{-4}	5.0×10^{-6}
Gabbro (GA-2)	1.04×10^{-4}	2.0×10^{-4}	4.2×10^{-3}	0.04	98	352	0.11	3.6	SD (MD)	1.0×10^{-4}	1.0×10^{-4}

P5

FUNDAMENTALS OF DEFORMATION AND RUPTURE PROCESSES IN POROUS GEOLOGICAL MATERIALS

14-08-0001-17664

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Investigations:

1. Constitutive relations for inelastic rock deformation and rock friction

2. Mechanisms of tectonic loading of seismic zones

Results:

1. Work on constitutive relations for rock masses (M. Kachanov [1] and J.R. Rice) has led to new results, permitting a comparison between theoretical model predictions and experimentally observed aspects of inelastic behavior of rock masses which undergo dilatant and shearing deformation by a brittle microfracturing process discussed in the previous Summary Report.

Two features of the results relate to a triaxial test under axial compressive stress p and lateral confining stress $q(<p)$. The value of p at the onset of dilatancy, called p', may be related to q, K_{Ic}, and the diameter of initially present penny-shaped cracks. Table 1 shows experimental results for p' for Westerly granite, at various confining pressures, as taken from the results of Wawersik and Fairhurst [2] and Brace et al. [3]. The last column gives the values which K_{Ic} would have for agreement with the theoretical estimate of p', assuming a crack diameter of 0.5 mm ($\approx$ grain size) and $\mu = 0.6$.

The fact that K_{Ic} is relatively constant and, further, has values in the range of those determined directly from crack propagation fracture tests by Atkinson [4], lends support to the validity of the model.

Figure 1 shows a plot of ε^{in}/ρ versus p at various confining pressures where ε^{in} is inelastic dilatant strain and ρ is a crack density parameter, defined so that if each crack were instead a sphere of the same diameter, ρ would be the volume fraction. The plot assumes an initial crack diameter of 0.5 mm, $K_{Ic} = 1$ MPa $m^{\frac{1}{2}}$, Young's modulus = 500 kbar, and Poisson's ratio = 0.25. These curves seem to have shapes that are realistic in terms of experiments [2,3], although the model cannot be extended too far because the interaction and joining of cracks, which ultimately results in a peak strength level for p, has not been included in the analysis.

1.2 A number of remarkable and surprisingly simple results have been obtained in our experimental studies into sliding friction on smooth rock surfaces (A. Ruina in collaboration with J.H. Dieterich at the latter's laboratory at USGS, Menlo Park) and further experiments are now being performed so as to guide concurrent theoretical developments. First, as shown in fig. 2, for sliding of a (sandwich-type) quartzite specimen at a uniform speed V^*, the friction coefficient μ ultimately settles down to a fixed value dependent only on V^*. The various points represent different previous sliding histories, in some of which previous slip was at a rate greater than V^* and in some of which it was smaller only. Thus for steady slip (at fixed normal stress) μ approaches a (decreasing) function of V^* which is independent of previous history; we represent this symbolically by

$$\mu = g(V^*) \quad \text{for steady slip at rate } V^*$$

and an approximate form of the function $g(V^*)$ is given in the figure.

Next, if the slip velocity is suddenly changed from V^* (at which a steady state has been achieved) to another speed V, maintained uniform after the change, the sudden change $\Delta\mu$ in the friction coefficient is positive for $V>V^*$ and negative for $V<V^*$. Results for $\Delta\mu$ as a function of V/V^* suggest that $\Delta\mu$ is approximately a function only of V/V^*, independently of V^*. When the level of μ is plotted against slip distance, it is found that the result for a transition from speed V_1 to V_2 is very nearly the mirror image of that for a transition from V_2 to V_1.

Two other significant features of the results are that the long term relaxation of frictional resistance to the steady state value $g(V)$ was found to depend only on the difference between μ and $g(V)$. Results for initial speeds of 0.01 to 0.1 μm/sec superpose on one another when the speed is changed to 1 μm/sec, and there is a very close fit to simple exponential decay with characteristic length $d_\ell = 5.2$ μm. Thus, if we write μ_ℓ for the long term value of μ (after the short time transients have decayed), then the results are fit well by

$$d\mu_\ell/dt = -(V/d_\ell)[\mu_\ell - g(V)] \quad .$$

The total μ can be written as $\mu=\mu_s + \mu_\ell$, where μ_s is the short-term component of frictional resistance. Since μ_ℓ as defined cannot change discontinuously with velocity, the sudden increases in friction associated with $\Delta\mu$ is an increase in μ_s. The short-term decay of μ_s is also fit tolerably by an exponential decay but with a characteristic slip distance $d_s \approx 0.32$ μm, much smaller than d_ℓ. The observed results can thus be fit approximately by a relation of the form

$$d[\mu_s - f(V)]/dt = -(V/d_s)\mu_s$$

where $f(V)$ represents a direct velocity dependence associated with the sudden increases in friction with rapid velocity increases discussed here.

The two differential equations for μ_ℓ and μ_s, together with the steady state resistance function $g(V)$ and the function $f(V)$ giving the direct, sudden velocity dependence seem to provide an adequate constitutive model for the results so far observed.

2. A generalized Elsasser-type/plate foundation model allowing for a visco-elastic (Maxwellian) asthenosphere was formulated earlier [5] and has since been analyzed by F.K. Lehner, V.C. Li, and J.R. Rice for spatial and temporal stress alterations associated with suddenly introduced or migrating (crack-like or dislocation-like) rupture events along transform- and subduction-type plate boundaries [6]. The initial slip displacement (averaged over the plate thickness H) associated with a sudden stress drop $\Delta\sigma$ over a segment ℓ of a transform fault is shown in fig. 3, free sliding being allowed everywhere behind the "crack tip." It is seen that the maximum normalized slip displacement for $\ell=2H$ amounts to about 3/4 of the maximum slip for $\ell\to\infty$; for typical values for Poisson's ratio and the shear modulus, a stress drop of 100 bar, and a value of H=90km, this would correspond to a maximum slip displacement of about 18 m ($\ell/H=2$) and 26 m ($\ell\to\infty$), respectively.

The stress distribution ahead of a suddenly introduced rupture depends on the amount of postseismic slippage along the fault after rupture. The extreme possibilities are: (a) full slippage as required to maintain a permanent stress drop $\Delta\sigma$ along the the segment ℓ , and (b) no further slippage with a permanently arrested dislocation distribution equal to the initial slippage along the fault. Solutions for these cases show that while the initial stress ahead of the fault coincides in both cases, a much less pronounced build-up in stress is observed in case b. This is due to the ability of the fault to sustain the load shed back to the lithosphere by the relaxing asthenosphere. Nevertheless, at sufficient distance from the fault tip, the relative rise in stress may still be significant, thus setting a time scale for the transfer of stress to neighboring segments of the plate boundary.

Relaxation times associated with this process make it clear that the tectonic loading of segments of a seismic belt involves a component consisting of stress transferred from recently ruptured neighboring segments at a rate much higher than the average rate of tectonic loading associated with mean plate velocities. A picture thus emerges in which a plate boundary at some overall critical level of tectonic stressing may rupture in a series of relatively closely clustered (in time) events followed by an extended quiescent period of build-up in tectonic load. This indeed appears to be a pattern emerging from studies of historical seismicity, e.g., along the North-Anatolian fault and circum-Pacific belt. The implication of such a triggering mechanism would seem far reaching for existing models for cyclic earthquake rupture, which link repeat times of ruptures to the uniform tectonic loading provided by mean plate velocities. Here a new dimension is added by the possibility, revealed in our recent work, of a delayed triggering effect associated with stress transferred along strike from an adjacent rupture. Both the difference in time scale and the emphasis on migrating rather than stationary preminotory phenomena is fundamental to this type of triggering.

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Table 1

q (kbar)		p' (kbar)		K_{Ic} (MPa $m^{1/2}$)	
Ref. [2]	Ref. [3]	Ref. [2]	Ref. [3]	Ref. [2]	Ref. [3]
.035	.5	2.4	2.2	1.6	.77
.10	1.0	2.8	3.3	1.8	.79
.20	1.0	2.8	3.9	1.6	1.2
.31	1.5	3.1	5.2	1.7	1.4
.81	1.5	3.9	5.2	1.5	1.4
1.54	1.62	5.6	5.0	1.6	1.1
	2.0		6.25		1.4
	2.0		6.5		1.5

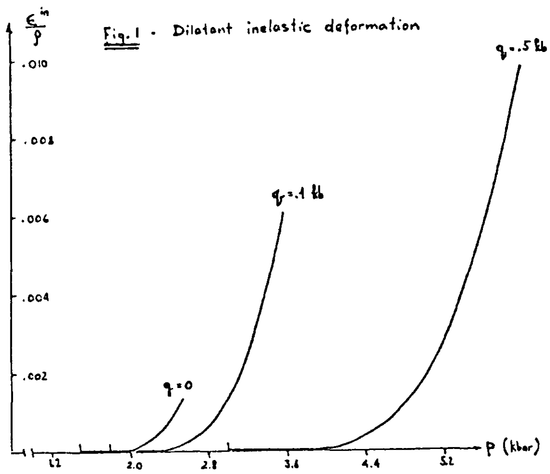


Fig. 1 - Dilatant inelastic deformation

Fig. 2 - Friction coefficient vs. steady-state sliding velocity.

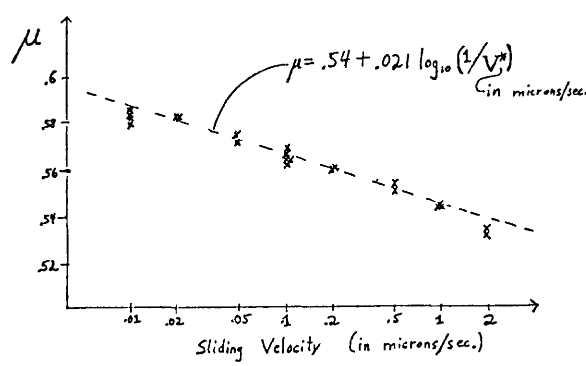
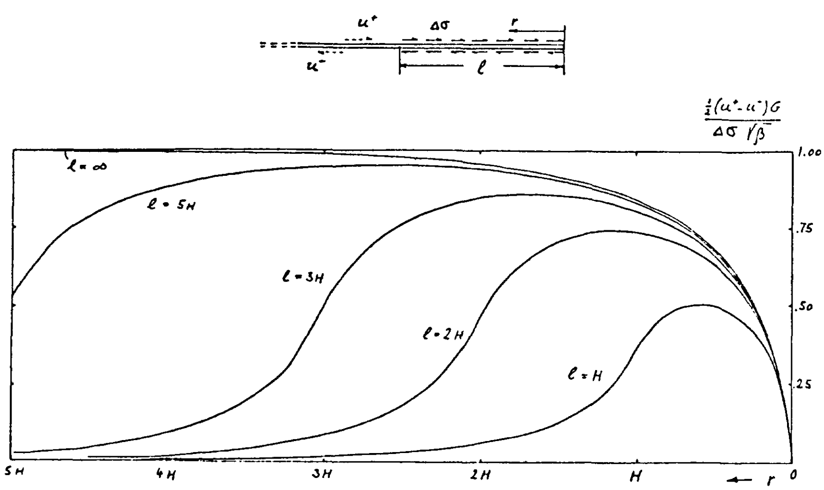


Fig. 3 - Normalized initial slip displacement following sudden stress drop Δσ on segment ℓ of semi-infinite fault.



IMPROVED STRESS DETERMINATION PROCEDURES BY HYDRAULIC FRACTURING

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Summary

The hydraulic fracturing technique as a method for determination of in-situ stresses has the advantage over other stress measuring methods in that it can be used at considerably greater depths from a point of access. However, hydraulic fracturing will not give correct results below a depth where the bedrock experiences an horizontal shear stress in the vertical plane exceeding the shear strength of the rock, as long as breakdown pressure is used to estimate the state of stress. Even at lesser depths, breakdown pressure cannot be relied upon for accurate determination of in-situ stress because it relies on the concept of "tensile strength" of rock and thus is a structure sensitive property as well as being controlled by rock composition. One must depend, therefore, only on reopening pressure and shut-in pressure to determine the state of stress, since they are structure insensitive properties. However, reopening pressure and breakdown pressure will be influenced by the flow rate of pumping fluid.

In general, the borehole axis is not parallel to a principal stress direction. The interpretation of hydraulic fracturing data in such cases with respect to both stress magnitudes and directions has been unclear. This research was conducted to probe the possibilities of determination of rock stress by using reopening pressure and to investigate the effects of borehole inclination with respect to the in-situ stress field and of flow rate. Experiments were carried out on relatively large specimens of brittle, competent and impermeable rock containing either vertical or inclined boreholes. These specimen were fractured hydraulically under biaxial loading and the fractures reopened by cycling the pressure at different flow rates. Numerical analyses were also carried out on the experimental configurations to assist in the interpretation of experimental data.

A summary of the significant findings to date is as follows:

(1) Pressure-time records from hydraulic fracturing fall into two categories. The first type occurs when a fracture is initiated vertically at the borehole wall and extends past the sealing elements forming a fluid flow path back into the free part of the borehole. The second type occurs with either horizontal or sub-vertical initiation followed by fracture extension away from the borehole without breaching the packers or forming a re-entrant fluid path. The distinction between these types of fracture as reflected in the pressure time record on reopening yields important information on the in-situ stress field.

(2) In the case that a fracture is initiated by fluid pressure for the first time, a fracture parallel to the borehole axis will be created, provided that borehole inclination to the in-situ stress field is slight or that differences between principal stresses are small. The least normal stress component perpendicular to the borehole axis can then be estimated from a reopening test pressure-time record, in which a relatively low flow rate has been employed. Use is made of analytical solutions of the hydraulic conductivity equations, enabling prediction of the pressure-flow relationship, to provide a linear multiplier relating fluid pressure and the normal stress magnitude. The fracture direction is obtained from observation of the trace on the borehole wall.

(3) If it is possible to create a fracture in a specified direction perpendicular to the borehole axis prior to hydraulic fracturing (for example, through the use of a mechanical tool), stress components perpendicular to this fracture can be determined. In the case that the direction is chosen to be perpendicular to a formerly induced fracture, with the mechanical fracture being created in another section of the same borehole, the maximum normal stress in the plane perpendicular to the borehole axis will be determined.

Where a fracture has already been induced by the drilling of the borehole, as in the case of very high in-situ stresses, it is possible to estimate the normal stress component perpendicular to the fracture from the pressure-time record obtained from a reopening test employing low flow rates. In general, a pre-existing fracture in the hydraulic fracturing chamber will enable an estimate of the normal stress perpendicular to the fracture to be made, although the fracture must parallel the borehole axis to some extent.

(4) The minimum principal stress can be determined from a second type of pressure-time record which indicates the presence of a fracture with no fluid outlet back into the free borehole, whether or not this fracture was induced by hydraulic pressure. This second type of pressure-time trace is obtained by using a relatively high flow rate of pressurizing fluid.

Where the initial fracture is initiated by hydraulic fluid pressure, the fracture path will be perpendicular to the minimum principal stress in cases where the borehole is considerably inclined to the in-situ stress field and where differences in principal stress magnitudes are large. The direction of minimum principal stress may then be determined by observation of the fracture trace on the borehole wall.

The complete stress state can be determined by following the above procedures. From tests on three fractures the minimum principal stress as well as the maximum and minimum normal stresses on the plane perpendicular to the borehole axis, can be determined in magnitude and direction. In the case where there is a pre-existing fracture the number of known quantities is decreased. A pair of tests, using boreholes with differing inclinations, will then be required to determine the complete state of stress.

Large Scale Rock Fracture Experiment

14-08-001-18307

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The first phase of this research project, which has been fully realized, was to create an acoustic emission monitoring system which would be suitable for "seismological" studies of large rock fracture. The second phase of the study involves a joint experiment with the Russians utilizing the big press in Moscow and sample sizes of approxiamtely, $1m^3$. The objectives of the first phase have been carried out and what follows will be a description of some preliminary experimental findings which indicate some of the capabilities of the system and suggest future areas of research interest.

A number of preliminary acoustic emission (AE) experiments have been carried out on various rock types, ie., Westerly granite, Ralston basalt and pyrophyllite. During these experiments actual AE wave forms were captured in real time. In addition, a number of AE statistics were automatically monitored, e.g., the cummulative number of events and their rate of occurrence. In the processes of measuring these statistics we were forced to develop a digitial discriminator (Sondergeld, 1980). This circuitry provided electromagnetic moise immunity and yielded a reliable signal for each event. The AE statistic showed a strong dependence upon rock type. For example, there was a factor of 10 difference in the cummulative event count for basalt and drastically different dependencies as a function of normalized stress (normalized to failure strength), and the recorded waveforms for each rock type displayed different spectral characteristics. Initially, for the same event amplitude, the wavetrains recorded from pyrophyllite "rang" much longer than those for basalt. Casting this more quantitatively in the form of the ratio of magnitude estimated from duration to that estimated from amplitude, provided us with a meaningful discriminator of rock type. More important was the use of this ratio in predicting failure in pyrophyllite, as it was observed to change by a factor of 3 to 5 just prior to failure.

Past measurements of the rate of AE activity suffer from various shortcomings. We developed a rate monitor which has a variable gate window. With its use, it was found that the rate of AE activity is not simply a reflection of loading or strain rate but in reality is comprised of discrete bursts of activity with interveening periods of quiescence.

Digitial oscilloscopes were used in an analogous fashion to seismic stations. Piezoelectric sensors were affixed to a specimen of Westerly granite undergoing deformation in a double torsion apparatus (Williams and Evans, 1973). A single macrocrack was made to propagate within the plate-shaped specimen thus providing an excellent means of checking our hypocenter determinations.

The reading error in picking first airrivials was often less than 0.05 u sec. Location determinations with the new system proved to be quite good and helped explain some of the phenomena associated with "single crack" propagation in rocks. Polarities of individual arrivals were easily descernible; this gives us hope in using our system for fault plane studies of individual AE events.

With the bulk of our technical objectives accomplished, we are eagerly awaiting the opportunity to carry out the scheduled large scale fracture experiment.

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ROCK PHYSICS

9960-01181

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Goals

Measurement of compressional and shear wave velocities in crustal rocks as functions of temperature, pressure, fluid pressure, rock type, fabric, density. Development of systematic relations between elasticity and other geophysically or geologically observable quantities (e.g., density, bulk chemistry). Application of results to determination of lithology, fluid pressure, and stress in crustal rocks of tectonically active areas, including fault zones.

Investigations

1. Investigation of systematic relations between wave velocity and other physical properties of Franciscan rocks.

Results

High fluid pressures generated by fluid-producing reactions in Franciscan rocks have been postulated to explain fault creep on the San Andreas fault in Central California. Since high fluid pressures affect wave velocities in rocks, raising compressional velocity relative to shear velocity, laboratory and field velocity measurements can be used to test for high fluid pressure. Acustic velocities measured in dry Franciscan rocks with normal mineralogies show that the ratio of compressional to shear velocity (Vp/Vs) varies from 1.70 to 1.75 at midcrustal pressures, and that this value is not sensitive to temperature. Theoretical considerations and measurements of velocity in saturated rock suggest that a Vp/Vs ratio of 1.8, which available data suggest in Franciscan rocks *in situ*, can be achieved in the laboratory samples only if fluid pressure is within a few hundred bars of confining pressure. These results are consistent with ubiquitous high fluid pressure in the Franciscan terrain.

Reports

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Theoretical Mechanics of Earthquake Prediction

9960-02115

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Investigations

1. Constructed two-dimensional elastic models to study interaction of faults in the Hollister, California, area. If models are consistent with past seismicity, fault creep, and geodetic data, the models will be used to estimate parameters of future earthquakes.

2. Devised a simple method for using repeated geodetic measurements to estimate nearness of earthquake instability.

Results

1. Model simulations were made to help clarify the relations among seismicity, fault creep, the orientation of fault strands, and the regional principal stresses. In the model, fault strength obeys a pressure dependent "friction" law. Observed moderate earthquakes are included in the simulations by imposing abrupt drops in frictional strength. A close fit of observed creep with calculated slip suggests that most changes in creep rate (persisting for more than 3 months) are caused by moderate earthquakes lying within 10-20 km, even when the creepmeter and earthquake are on different faults. That is, separate fault segments interact. In particular, the model predicts periods of anomalously low creep rate before most earthquakes as a direct result of earlier earthquakes elsewhere in the fault system.

2. In the method, a single scalar variable R is estimated from changes of geodetic measurements. In theory, R increases with time and reaches unity at earthquake instability. The equation for R is derived from an instability criterion (such as those used in strain softening instability models), conventional elastic dislocation solutions, and a regional strain field. R requires a specified fault geometry and, at most, one elastic constant for an isotropic crust, but is independent of fault properties and magnitude of shear stress.

References

Mavko, G., 1979, The influence of local moderate earthquakes on creep rate near Hollister, California (Abstract): Earthquake Notes, 50, 4, p. 71.

Stuart, W. D., 1980, Stiffness method for anticipating earthquakes (Abstract): Earthquake Notes, 50, 31.

Stuart, W. D., 1980, Stiffness method for anticipating earthquakes: Bull. Seismol. Soc. Am., in press.

An Experimental Study of the Rheology of Crustal Rocks

14-08-0001-15247

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Investigations

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 transitions 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; and to compare the microstructures of the specimens with those from naturally deformed rocks along ancient faults.

In the first half of this year we have continued our investigations on the effect of water on deformation at crustal conditions, and we have investigated two types of faults which form at very high temperatures and pressures (Shelton and Tullis, 1980). Our results are summarized below.

Effect of Water on Deformation

In previous studies we discovered that there is a marked pressure effect on hydrolytic weakening (Tullis et al., 1979), and that the temperature of the transition from microcracking to dislocation creep for Westerly granite and Hale albite rock is lowered by the addition of trace amounts of water (Tullis and Yund, 1979 and in press). More recently we have been exploring the effect of drying samples prior to deformation, in order to remove the trace amounts of water that must reside along grain boundaries and within fluid inclusions, and which may therefore diffuse into the crystal structure during deformation experiments. We have found that vacuum drying samples of Hale albite and clinopyroxenite prior to deformation greatly increases their strength, and allows a return to substantial microcracking even at very high temperatures and pressures (see below).

Given this great sensitivity of flow strength to water content it is important that different materials be compared for exactly the same fluid pressure and composition. To achieve this we have done several 'sandwich' experiments in which the sample consists of a central disc of one material and end discs of a second material. Two tests were done to check a suspected difference in the hydrolytic weakening behavior of Hale albite rock (An_1) and Bushveld anorthosite (An_{65}). In one test talc discs were used between the sample discs in order to supply a trace amount of water during the deformation; in the other test the sample discs were vacuum dried and no talc was used. In the case of the 'wet' experiment, for the imposed strain rate of 1.3×10^{-6}/sec the central albite disc strained 56%, for an actual strain rate of 3.3×10^{-6}/sec, whereas the two end anorthosite discs each strained 14% for an actual strain rate of 8.5×10^{-7}/sec. The 'dry' experiment showed no such dramatic difference between the central albite disc and the end anorthosite disc.

The conclusion appears to be that Hale albite and Bushveld anorthosite deform very similarly when dry but the albite shows significantly more hydrolytic weakening (at the conditions tested). We are in the process of exploring possible reasons for this difference in behavior, and of doing 'sandwich' sample comparisons on other rock types.

<u>Faults at High Temperatures and Pressures</u>

Faulting has generally been observed as a phenomenon of low temperature and confining pressure. In previous tests on hot plate dried materials, we have found that when confining pressure is increased at low temperature, there is a transition from formation of a discrete fault surface to distributed microcracking or cataclastic flow, apparently because the increased normal stress makes it as easy to produce new fracturing as to produce frictional sliding on old fractures. We have also found that when temperature is increased at relatively high confining pressure, there is a transition from distributed microcracking to distributed dislocation glide and climb, because the latter is a thermally activated process able to operate at a lower stress than fracturing, when the temperature is sufficiently high. These transitions have been demonstrated for a number of materials (Tullis and Yund, 1977; Kronenberg and Shelton, in press). However, recent results indicate that extreme strain localization, and strain rate instability under constant load, can occur at the highest temperatures and pressures tested - up to 1100°C and 15 kb. Two types of high temperature and pressure 'faults' have been observed.

The first type of high temperature and pressure fault is extremely sharp, and lies at about 45° to σ_1. As the fault forms, soon after yield, the strain rate is observed to increase markedly in the creep experiments, and the stress to drop gradually in the constant strain rate experiments. These sharp faults have so far been observed only in samples of Hale albite which have been vacuum dried at 800°C for 24 hours prior to deformation. They have been found in the only experiments done to date on this vacuum dried material, namely two creep experiments at 1100°C and 15 kb, and constant strain rate experiments at 900° and 1000°C and 15 kb.

Very similar appearing sharp faults were previously observed in a number of hot plate dried (at 160°C) materials deformed at constant strain rate at a confining pressure of 5 to 7.5 kb and temperatures of 600° to 900°C (Tullis and Yund, 1977). The same materials deformed in the same temperature range but at 15 kb confining pressure show no faults, but homogeneous dislocation creep. The reasons for the difference in behavior is believed to lie in a pressure effect of hydrolytic weakening (Tullis et al., 1979): the concentration of water in the crystal structure increases with increasing pressure, and at 5 kb it is not sufficient to accomplish hydrolytic weakening, whereas at 15 kb it is.

We believe that the sharp faults in the high temperature and pressure vacuum dried Hale albite samples are also due to a lack of water. TEM of one of the 1100°C samples shows abundant microcracks and only occasional dislocations, the same as is seen in a sample of hot plate dried Hale albite deformed at about 600°C. Thus even temperatures close to the melting temperature are not enough to ensure steady state dislocation creep if there is not a trace of water present. Tullis and Yund (in press) showed that the addition of trace amounts of water to hot plate dried samples of Hale albite caused a decrease of about 150°-200°C in the temperature of the transition from dominantly microcracking to dominantly dislocation glide and climb. In this study we have shown that the removal of trace amounts of water from the Hale albite samples causes an increase of about 500-600°C in that transition temperature. A remaining problem concerns why the deformation of these samples does not occur as cataclastic flow, instead of discrete faults. However, the samples have a very low coefficient of friction, and the faults lie at about 45° to σ_1.

The second type of high temperature and pressure fault has been observed in hot plate dried samples of various rock types which have been deformed at 1100°C and 15 kb, both in creep and in constant strain rate. These faults consist of one or several bands of fine-grained material cutting through the sample, at various angles. The bands vary in width, and the fine-grained material within them is variable in grain size. Constant strain rate tests sometimes show a small gradual stress drop, and creep tests may show a small strain rate increase, apparently associated with this faulting. Similar faults have <u>not</u> been observed in the same materials deformed at lower temperatures in constant strain rate runs; instead these materials show cataclastic flow at low temperatures (600°-800°C), and ductile, homogeneous dislocation creep at intermediate temperatures (900°-1000°C). Thus there is an anomalous transition from ductile to brittle behavior with increasing temperature.

The reason for this second type of high temperature and pressure fault is not understood. There is a sizeable strain (3-8%) prior to stress drop or strain rate increase, suggesting a strain softening mechanism. Partial melting is not observed. It may be that grain size reduction could allow a transition to superplasticity in the fault zones. There is little recrystallization observed in these samples, but some samples do inadvertantly fracture during loading, and this would produce an irregular surface or set of surfaces with fine-grained material along it. Superplasticity is enhanced by fine grain size and high temperature, which may explain why intermediate temperature samples show homogeneous deformation by dislocation creep whereas the high temperature samples show strain softening and localization along the faults. On the other hand it may be that water plays a role in this type of faulting as well. Although the samples are only hot plate dried, during loading they were held at 800°C (so that the calcite confining medium would be weak), and this may drive off almost all water. Thus the fine-grained material in the fault zone may be deformed by cataclastic flow. TEM studies are needed to resolve these questions, and they are currently in progress.

The results of these studies on experimental high temperature and pressure faults have important implications, for deformation deep in the crust. Recent COCORPS results (Smithson et al., 1979) appear to show faults extending to great depths under the Wind River mountains, for example. It may be that high pore pressures are not the only way in which faulting can occur at great depth, but that extreme dryness, due to granulite facies metamorphism, may prevent silicates from deforming in a ductile fashion by dislocation creep, even at temperatures near the melting point and pressures characteristic of the mid to lower crust.

<u>Reports</u>

Shelton, G.L., and Tullis, T.E., 1980, Faulting at high temperature and pressure: Trans. Amer. Geophys. Union, v. 61, p. 376.

Local Changes in the Gravity and Magnetic Fields Due to Tectonic Strain

14-08-0001-18212

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Investigations and Results

Surface displacements and tilts and local changes in the gravity and magnetic fields provide complementary sources of information about tectonic events at depth. I have been analyzing the changes in the gravity and magnetic fields due to tectonic strain using an elastic half-space as an earth model. I have four analyses in progress; these are:

(1) Derivation of the influence functions relating the change in the magnetic field at the earth's surface with a dislocation at depth in an elastic isotropic half-space. Magnetism is due to the earth's field, assumed uniform, acting on magnetic minerals uniformly distributed throughout the half-space.

(2) Derivation of the influence functions relating the change in gravity measured at the earth's surface to a change in the body force field. The earth is assumed to be a uniform elastic half-space.

(3) Derivation of the influence functions relating the change in gravity at the surface to a dislocation at depth in a half-space with a low-density surface layer but with uniform elastic properties.

(4) Calculation of the effective piezomagnetic behavior of sample having a mixture of magnetic and non-magnetic grains using a new approach.

Reports

There have been no publications.

ROLE OF FAULT GOUGE IN THE MECHANICS OF FAULTING

14-08-0001-18213

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Investigations

1. The geochemistry of gouge clays and their stability under high temperature - high pressure environments.
2. The mechanical behavior of clays under high pressures.

Results

1. Field evidences that various clays, including some higher-temperature trioctahedral ones, are an important part of most fault zones., continue to accumulate.
2. Ca-montmorillonite, with double hydration layers are found to be the weakest under confining pressure of 2 kb. Na-montmorillonite, with single layer water is about twice as strong. Hectorite, a trioctahedral smectite is about twice as strong as Na-montmorillonite.
3. Kaolinite compressed at 2 kb (σ_c) and then put under differential stress with 2 kb confining pressure (σ_3) show characteristics common to unstable soil mass. When $\sigma_c > \sigma_3$ such phenomenon disappears.
4. Fracturing is common for smectite. While kaolinite fractures may anneal.

Reports

Wu, F. T., Fault zone materials above 15 kilometers depth and tectonic stresses, submitted to J.G.R., 1980.

Golden Seismological Data Processing Center

9920-02496

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Goals

This project is administrative in nature. It is the collection point for the Branch of Global Seismology contribution to the operation of an in-house inter-branch data processing facility (comprising a PDP11/70, a PDP11/40, and a number of dedicated micro processors). The contributions from the Branches of Ground Motion and Faulting and Hazards and Seismicity are collected in the Data Processing, OES, Golden project (9940-02088) headed by Bob Park.

Investigations

While no investigations are done directly under this project it provides hardware, software, and consulting support for nearly every project in the above mentioned branches which are based in Golden, CO.

Results

The data processing center provides currently the following facilities and/or services:

1) digital time series analysis
2) small scale theoretical computations
3) analog to digital conversion of magnetic tapes
4) digital format/media conversion
5) real time data aquisition
6) digitizing table

Reports

Not applicable.

GLOBAL DIGITAL NETWORK OPERATIONS

9920-02398

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Investigations

The Global Network Operations continued to provide technical and operational support to the SRO/ASRO/HGLP observatories, which includes operating supplies, replacement parts, repair service, redesign of equipment, training and on-site maintenance, recalibration and installation. Maintenance is performed at locations as required but also each station is scheduled a visit by a technician every few months for preventative maintenance and training purposes.

The SRO systems at Ankara, Grafenberg, Bangui, Bogota, Guam, Chiang Mai, Taipei, Narrogin, Wellington, and the ASRO systems at Kabul and Kongsberg were maintained and recalibrated.

Agreements have been received from the College, Kipapa, Longmire, Afiamalu, Scott Base, Godhavn, State College, Brasilia, Pretoria, Toledo, Kevo, Tasmania and Lembang WWSSN stations wishing to participate in the DWWSSN program. The installation of Longmire has been scheduled to begin the first week of April. Because of resignations of several contract personnel who had been trained for this program, the remaining digital stations will not be installed until a new maintenance contract becomes effective October 1980.

Results

The network provides improved geographical coverage with highly sensitive short- and long-period seismic sensors with analog and digital magnetic tape recordings.

USGS AND COOPERATIVE OBSERVATORIES

9920-01261

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Investigations

Field activities consist of occasional visits to the seismic stations for the purpose of maintenance, calibration, or installation of new instrumentation. Stations are provided with advice on operation, maintenance, and calibration. Also all stations are provided with spare parts, operational supplies and replacement modules.

Results

These observatories contribute essential data to the NEIS both routinely and on a rapid basis when required. The locations were selected to fill gaps in station locations and to provide better coverage for local events. All data are available for other seismologists when required.

WORLD-WIDE STANDARDIZED SEISMOGRAPH NETWORK (WWSSN)

9920-01201

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Investigations

1. The Global Network Operations continued to provide technical and operational support to the WWSSN observatories as funding and staffing permitted.

2. During this period, 154 WWSSN modules were repaired and 202 separate shipments were made to support the network. Seventy-six stations were supplied with annual shipments of photographic supplies and emergency shipments were made to four stations.

3. Howell Butler visited the Copenhagen, Jerusalem, Eilat, Addis Ababa, Nairobi, Pretoria and Grahamstown WWSSN stations to discuss the Global Network programs and the shipping of parts and data to/from the host stations.

Results

A continual flow of high quality seismic data from the network of 115 observatories for use by the seismological community.

U. S. Seismic Network

9920-01899

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Investigations

U.S. Seismicity:
Continuously monitor U.S. seismicity using data recorded by the U.S. Seismic Network.

Worldwide Seismicity:
Data from the U.S. Seismic Network is used to obtain a preliminary location of significant earthquakes worldwide.

Results

As an operational program, the U.S. Seismic Network operated normally throughout the report period. Data was recorded continuously in real time at the NEIS main office in Golden, Colorado. At the present time 68 channels of SPZ data are being recorded at Golden on Develocorder film. This includes 9 channels of Alaskan data telemetered to Golden via satellite from the Alaska Tsunami Warning Center, Palmer, Alaska. A representative number of SPZ channels are also recorded on Helicorders to give NEIS real time monitoring capability of the more active seismic areas of the U.S. In addition, 9 channels of LPZ data are recorded in real time on multiple pen Helicorders.

Later this spring, 2 channels of real time NORSAR data from Norway will be added to the network. The NORSAR data is transmitted via satellite to the Vela Seismological Center, Alexandria, Virginia. Two channels of data will be retransmitted to Golden over an existing data line.

Data from the U.S. Seismic Network is interpreted by record analysts and the seismic readings are entered into the NEIS data base. The data is also used by NEIS standby personnel to monitor seismic activity in the U.S. and worldwide on a real time basis. At the present time, all earthquakes large enough to be recorded on several stations are worked up using the "Quick Quake" program to obtain a provisional solution as rapidly as possible. Finally, the data is used in such NEIS publications as the "Preliminary Determination of Epicenters" and the "Earthquake Data Report".

Development work is continuing on an event detector to monitor the U.S. Seismic Network in real time. Current plans are to use several PDP 11/03 micro computers to monitor the data and pass events on to a PDP 11/23 for further processing.

The goals of the U.S. Seismic Network are to upgrade the quantity and quality of the data received to make possible more rapid and accurate location of U.S. earthquakes and significant earthquakes worldwide.

DIGITAL NETWORK-DATA PROCESSING

9920-02217

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Investigations and Results

1. The primary effort in this project is the processing of digital seismic data recorded on magnetic tapes by the Global Digital Seismograph Network. During the past six months, 202 digital tapes were edited, checked for quality, corrected when feasible, copied and distributed to data users.

2. The Network-Day Tape Program is now in operation. This program assembles the data from the entire digital network for a specific calendar day onto one magnetic tape. This tape also includes all the necessary station parameters, calibration data, time correction and comments on data quality for each station in the network. These tapes enable the data analyst to obtain all of the available digital data for a specific event on one tape without delay. As many of the recording stations are located in remote overseas locations, actual assembly of the network-day tapes is normally eight to ten weeks after the recording day. Distribution of these day tapes is being handled by the Branch of Global Seismology and also by the Environmental Data and Information Service, NOAA in Boulder, Colorado.

Reports

Hoffman, John P., The Global Digital Seismograph Network-Day Tape; Open-File Report 80-289, 37 p.

SEISMICITY OF THE RIO GRANDE RIFT

9920-01774

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Investigations and Results

1. The major effort in this project was directed at installing an instrumentation network around the San Juan Basin. The network became operational during the first week of January 1980. The five stations monitoring the San Juan Basin are located near Mt. Taylor, near Fort Wingate, at Washington Pass, on Huerfano Mesa, and near Dulce. A sixth station was installed in eastern New Mexico at Palomas Mesa between Tucumcari and Santa Rosa. This site was installed to provide data for comparing crustal and upper mantle parameters in the high plains, Rio Grande Rift, and the San Juan Basin.

2. It is much too early to estimate the contemporary seismicity in the San Juan Basin. A count of microearthquakes occurring near each station in the network, however, suggests that the number of events per given time interval would probably be highest near Mt. Taylor. This area would be followed by Ft. Wingate and Washington Pass. No microseismicity has yet been observed near Huerfano or Dulce.

3. On the basis of this limited recording period, the field studies being planned for this summer will probably be concentrated along the southern margin of the San Juan Basin.

Reports

Jaksha, L. H., Locke, J., and Gebhard, H. J., 1980, Microearthquakes near the Albuquerque Volcanoes, New Mexico, submitted to GSA Bulletin.

Sanford, A. R., Olsen, K. H., and Jaksha, L. H., 1980, Earthquake activity in New Mexico (1849 through 1977), New Mexico Bureau of Mines and Mineral Resources Circular (in press).

ALBUQUERQUE OBSERVATORY

9920-01260

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Investigations and Results

1. Seismic refraction measurements were made in the Datil-Mogollon volcanic field using explosions at two copper mines for energy sources. The mines are located at Morenci, Arizona, and Miami, Arizona. Nine of the sites occupied for the DICE THROW explosion (1976) were reoccupied to record the Morenci and Miami shots. The origin time for the shots was estimated from a seismic system operating within about 100 m. of the first hole to be detonated. The project was generally successful.

2. The new observatory at Albuquerque is very near to being completed. The incoming and outgoing telemetry are fully operational. Nine channels of data are presently displayed on helicorders. The primary and secondary timing systems are fully operational. Work continues on the power system, the calibration circuits, and the develocorders.

3. The Geosciences staff at New Mexico Tech is fabricating a 4-channel RF telemetry link that will transmit data between our LP site in Woods Tunnel and the Tech campus. The data will be put on a telephone circuit between the campus and Albuquerque Seismological Laboratory.

Reports

Jaksha, L. H. Garcia, A., and Tilgner, E. E., 1980, Seismic refraction data taken in southwest New Mexico and southeast Arizona (in review).

Jaksha, L. H., 1980, Seismic refraction studies in southwestern New Mexico and southeastern Arizona (in review).

Murdock, J. N., and Jaksha, L. H., 1980, P-Wave velocity of the uppermost mantle of northcentral New Mexico (in review).

GLOBAL SEISMOGRAPH NETWORK-EVALUATION AND DEVELOPMENT

9920-02384

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Investigations

1. Work has been completed on documenting the test and calibration of the Seismic Research Observatory and the results have been published.

2. Major work continues on the documentation of the Global Seismograph Network, a comprehensive technical description of the GSN beginning with the WWSSN.

Results

1. Major results of SRO test and calibration studies have been summarized in an Open-File report. The report contains detailed descriptions of test and calibration procedures, a derivation of system transfer functions, and analyses of system noise and linearity.

2. A draft of the report on the Global Seismograph Network is partially complete. Early sections have been completed including a section of the WWSSN which contains a description of the stations and instrumentation, data format, calibration procedures, transfer functions, and an analysis of calibration stability.

Reports

Peterson, J., C. R. Hutt, and L. G. Holcomb, 1980, Test and calibration of the seismic research observatory, U. S. Geological Survey Open-File Report 80-187, 86 p.

Seismic Observatories

9920-01193

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Investigations

Recorded and provisionally interpreted seismological and geomagnetic data at observatories operated at Newport, Washington; Cayey, Puerto Rico; Adak, Alaska; and Guam. At Newport, Washington and Guam, 24-hour standby duty was maintained to provide input to the Tsunami Warning Service operated at Honolulu Observatory by NOAA.

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.

Newport Observatory now serves as a part of the National Earthquake Information Service's, Early Earthquake Reporting Service. During off duty periods this observatory, by performing standby duty, reports to government agencies, news media, and the public, information on felt and damaging earthquakes in the United States and on world-wide events of magnitude 6.5 or greater.

National Earthquake Information Service

9920-01194

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Investigations and Results

The weekly publication, Preliminary Determination of Epicenters, was removed from the Seismic Data Analysis System (SEDAS), operating on the Honeywell Multics, and put on the DEC 20 with Energy Enterprises, an outside contractor. The PDE continues to be published on a weekly basis, averaging about 50 earthquakes. We originally attempted to publish most epicenters within 10 days of the earthquake, but found that this was not feasible because of the flow of seismic data from around the world; presently we are publishing all earthquakes which have data available within 30 days of the earthquake. Efforts are being made to speed up the flow of data from all of our contributors in order to be able to meet the 10-day deadline in publication of most epicenters on the PDE.

Changes in data flow since the last report include the receipt of telegraphic data from the USSR on magnitude 6.5 or greater earthquakes within a couple of days after the occurrence.

The catch-up on the backlog of Monthly Listings of earthquakes and Earthquake Data Reports began in June of 1979, starting with January of 1978. To date, the Monthly Reports and Earthquake Data Reports, through August of 1979, have been completed and are being printed and mailed.

Modifications have been made to the quick-quake location program which has been transferred from the Honeywell to the PDP 11/70.

The text files are being entered on the 11/70 (and processed later on the Multics) and the rework and publish instruction files are now being entered on the 11/70 for the DEC 20. Programs are now on the 11/70 to: (1) listen to the ARS line and create data files and (2) send messages over ARS, including earthquake news releases and data to the Air Force.

The present earthquake location programs are being rewritten and hopefully will be ready for use on the 11/70 in the very near future.

The cost of the program on the DEC 20 is considerably less than on the Honeywell Multics and not nearly as time consuming.

We continue to provide services on recent earthquakes in response to increasing demands from the general public.

Reports

Preliminary Determination of Epicenters (24 weekly publications-October 1979 to present). Compilers: W. Leroy Irby, Reino Kangas, John Minsch, Waverly Person, Bruce Presgrave.

Monthly Listing of earthquakes and Earthquake Data Reports (12 publications-October 1978 to September 1979). Compilers: W. Leroy Irby, Reino Kangas, John Minsch, Russell Needham, Waverly J. Person, Bruce Presgrave.

Goals

Provide more rapid and comprehensive hypocenter location services to the government and the scientific community.

Complete the Monthly Listing of earthquakes and Earthquake Data Report backlog by June 1980.

Provide more rapid notification of significant or damaging earthquakes to relief agencies, the press, the scientific community, and the general public.

Seismic Review and Data Services

9920-01204

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The quality control, and technical review of 123,500 seismograms (674 station-months) generated by the World-Wide Standardized Seismograph Network (WWSSN) were carried out.

The annual Station Performance Reports which detail instrumental operations covering precision in timing and sensitivity, noise patterns and intensities, label data, unusual problems, recording quality, and records received were sent to 59 network stations. Operational standards are being maintained. Seoul, Korea (SEO) has improved considerably with the restoration of both a timing system (excellent accuracy), and SP and LP calibrations. Lormes, France (LOR) has resumed operations and is operating a much improved station. The SP's at 100 K and the LP's at 1.f K are well maintained giving good quality recordings.

Some problems with polarities still exist. At Georgetown (GEO), the long period vertical, and at Stuttgart (STU) the short period horizontals remain unchanged. Seoul, Korea (SEO) has corrected its polarity problems. Bulawayo (BUL) shows calibration reversals on all of the short periods starting in July 1979.

Seismograms continue to be received from the Kabul, Afghanistan WWSSN and ASRO stations KBL, and KAAO. The Iranian WWSSN and ASRO stations are not forwarding their seismograms but are providing readings by mail to the NEIS.

The microfilm library is being set up to handle the various formats (70mm chip, 35mm roll, 16mm roll, and 105mm fiche) used in the WWSSN, SRO, ASRO, HGLP, and Historical Files. There is a problem in fragmentation due to a lack of space to house the entire facility. We are also working with the microfilming service to improve the microfilming quality of the fiche copies being received by users.

United States Earthquakes

9920-01222

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Investigations

1. Thirty-six earthquakes in 12 states were canvassed by a mail questionnaire for felt and damage data. In addition, a field investigation was made of the October 15, 1979, Imperial Valley, California and the January 24, 1980, Livermore, California. They were respectively located at 32.64N, 115.33W, depth 7 km, magnitude 6.8 MS USGS, 6.6 ML PAS and at 37.85N, 121.82W, depth 11 km, magnitude 5.8 MS USGS, 5.5 ML BRK.

2. The United States earthquakes for the period October 1, 1979 - March 31, 1980 have been located and the hypocenters, magnitudes, and maximum intensities have been published in the Preliminary Determination of Epicenters.

3. The data for the seismicity maps of Maryland, Pennsylvania, West Virginia, Virginia, South Carolina, North Carolina, and New York have been compiled.

Results

The maximum Modified Mercalli intensity assigned to the October 15, 1979, Imperial Valley, California earthquake is VII at Calexico, El Centro, Imperial, and Brawley; however, a IX was assigned to the damaged Imperial County General Services Building in El Centro. This building was designed under the 1967 provisions of the Uniform Building Code. The damage estimates for the Imperial Valley was about $30 million. Much of this was damage to irrigation ditches and buried systems. The greatest damage to structure occurred to brick commercial buildings in the downtown areas.

A maximum Modified Mercalli intensity of VII was also rated at the Lawrence Livermore Laboratory for the January 24, 1980 earthquake in central California. The press reported about $10 million damage at the Lawrence Livermore Laboratory and about $500,000 in Livermore.

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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.

Results

1. The joint USGS/NOAA TSUNAMI project for installing four satellite tide systems on the Western South American coast is in progress. The GOES satellite radio transceiver sets have been received from the manufacturer. These radio units were shipped with the wrong channel frequencies and were returned for proper channel frequencies. The units are now undergoing three weeks of test operation over the GOES satellite system for each unit at the Albuquerque Seismological Laboratory by actual operation with a TS-4 Seismic System. The TT-3 Tide Systems normally operate with the Bristol type tide meters. One of the South American tide stations will be modified to operate with a pressure type tide meter. Some of the South American tide stations will be powered with solar panel power units. Installation of these units will begin in late June/early July time period if travel is approved.

2. The tests for evaluation of a standard TS-4 Seismic System at Guam have been completed. The TS-4 Seismic System is designed to operate with WWSSN short-period seismic signals. Due to the very low short-period magnification and the large microseismic background at Guam, the TS-4 Seismic System was only partially successful. Preliminary tests indicate that a modified TS-4, modified to operate with long-period seismic signals, would be the best seismic picker system for Guam. The Guam TS-4 Seismic System has been returned to the Albuquerque Seismological Laboratory for long-period modification.

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 short-period event detector program was rewritten and tested in the WWSSN Digital Recording System. A new intermediate-period band event detector program was also written and tested. Both programs are working satisfactory and they will be the final version of the event detector programs for the WWSSN Digital Recording System.

2. Initially the WWSSN Digital Recording System was designed to operate in a fixed mode of recording three long-period channels, three intermediate-period band channels, and one short-period channel. A switch selectable feature will allow the Digital Recording System to record the following combinations:

Switch Ø	Three continuous LP channels, three IP event detected channels, and one SP event detected channel.
Switch 1	Three continuous LP channels, one continuous SP channel.
Switch 2	Three continuous LP channels, three continuous IP channels.
Switch 3	Three continuous LP channels, three continuous IP channels, and one continuous SP channel.

Switch 4-14 Three LP continuous channels.

Switch 15 End of file mark (indicate end of tape marker).

3. A special WWSSN calibration monitor feature was added to the WWSSN Digital Recording System. Any time the WWSSN calibration switches are activated, a calibration bit is set in the appropriate LP, IP, or SP header byte.

4. Rod vibrations in the Fault Monitor System required extensive redesign of the microprocessor based recording system. Due to the vibrations of the rod spanning the fault, the two line signal monitor of the shaft encoder had to be expanded to 16 lines. This required the microprocessor system to be expanded to provide two additional input ports and associated control hardware. The front panel was modified to provide data viewing of the four digit up/down counter display. The up/down counter adds and subtracts the rod vibrations and eventually provides the final valle of fault motion. This project is a joint effort between the Branch of Global Seismology and the Branch of Earthquake Tectonics and Risk.

5. The 2400 and 4800 baud modems are being tested for use with the new digital telemetry system being designed at the Albuquerque Seismological Laboratory. This program was delayed somewhat due to the Guam TS-4 test program.

Seismicity and Tectonics

9920-01206

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Investigations

1. Peru Seismicity and Tectonics. Determine focal mechanisms of key earthquakes occurring since 1974 and integrate with results of relocated seismicity, 1963-1979.

2. Mantle Structure Beneath the Rio Grande Rift. Use a 3-D, seismic ray tracing algorithm to invert a set of teleseismic P-wave delay data, with the objective of determining the maximum depth and degree of velocity anomaly in the upper mantle beneath the Rio Grande Rift.

3. February 28, 1979 St. Elias Earthquake. Investigate the radiation pattern of surface waves and mantle waves from this seismic gap earthquake, using WWSSN seismograms and SRO digital data.

Results

1. Peru Seismicity and Tectonics. The 1974 aftershock series occurred in two segments, separable spatially and each with distinctive focal mechanisms. The parallel-to-coast segment contains the $M_S = 7.8$, thrust-faulting main shock of October 3 and the $M_S = 7.1$, thrust-faulting aftershock of Novermer 9. The perpendicular-to-coast segment has a composite focal mechanism that indicates right-lateral and reverse faulting along a trend that is parallel to this segment.

2. Mantle Structure Beneath the Rio Grande Rift. The upper mantle beneath the Rio Grande rift, and perhaps eastward as far as the Front Range, has a P-wave velocity that is 4-6% lower than that of the adjoining High Plains Province, down to a depth of 200 km $\pm$ 15 km. At a depth interval of 90-130 km beneath a 150 km length of the NE-trending Jemez shear zone (which includes the Jemez volcanic field), there is a layer of concentrated low velocity material. Beneath the Socorro, NM area, at a depth interval of 40-80 km, there is a layer of relatively high velocity material.

3. February 28, 1979 St. Elias Earthquake. Revised magnitude estimates are $M_S = 7.2$, based on 20-sec Rayleigh waves and $M_S = 7.1$, based on 20-sec Love waves. Both these magnitude estimates are considerable smaller than the initial

estimate of M_S = 7.7, which primarily was based on pure continental path Raleigh waves. Extensive analyses of R_{1-5} and G_{1-6} mantle waves, recorded at ten SRO stations, have resulted in a moment estimate of $M_o = 2.2 \times 10^{27}$ dyne-cm.

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Induced Seismicity and Earthquake Prediction Studies at the Koyna Reservoir, India

9930-02501

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The aim of this project is to set up 13 portable seismic stations (10 Teledyne Portacorders and 3 Digital Event Recorders) in the Koyna Dam region of Maharashtra State, India. Work will be done jointly with the National Geophysical Research Institute, Hyderabad, India. It is hoped to locate precisely the hypocenters of earthquakes occurring in the region, and relate their locations, numbers, magnitudes, fault-plane solutions, moments, migration patterns etc. to the water-level fluctuations in the Koyna reservoir and other relevant factors. Attempt will also be made to develop prediction techniques for the larger earthquakes. The project is awaiting approval by the Government of India.

As a support to this project, W. H. K. Lee is compiling an accurate catalog of Koyna earthquakes from the WWSSN station POO (Poona) located about 100 km away. A sophisticated data processing system developed by Lee is used to handle the film chips. P and S arrivals, first P motion, and signal duration will be read for all identifiable earthquakes. The completed catalog will have about 100,000 earthquakes, with a threshold magnitude of 2.0, that have occurred at Koyna during the 14 year period from 1964 to 1977.

"A Seismic Spectral Discriminant for Reservoir Induced Earthquakes"

Contract No. 14-08-0001-17713
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The object of this research has been to evaluate a spectral discriminant which might allow identification of other areas where new reservoirs would induce significant seismic activity. The discriminant is the high-frequency slope of the displacement spectra of earthquakes occurring in the vicinity of a new or proposed reservoir. An ω-cube slope from earthquakes in the vicinity would predict that nearby reservoirs would induce earthquakes and an ω-square slope from earthquakes in a region would predict that reservoirs in the vicinity would not induce earthquakes. This association of ω-cubic decay with induced reservoir seismic activity and ω-square decay with areas where reservoirs do not induce seismic activity was observed first in studies of seismic spectra of Southeastern United States earthquakes. Earthquakes occurring in the Folded Appalachians have an ω-square high-frequency decay and reservoirs in that region are not known to induce seismic activity. Earthquakes observed in two Piedmont Province reservoirs which have induced seismic activity show ω-cubic spectral decay. Hence, the limited data for the Southeastern United States indicated that the high-frequency spectral decay may be a viable discriminant for the identification of other areas susceptable to induced seismic activity. In this study one objective was to test the generality of the discriminant for identifying other areas of induced seismic activity.

Fundamental to this study was an investigation of whether there exists a theoretical basis for the discriminant. Most theoretical studies on the radiation of high-frequency seismic energy indicate that the high-frequency energy is controlled to a large extent by the slip velocity on the fault. At the rupture front, velocity changes which may be related to variable stress conditions or fault irregularities enrich the spectra with high-frequency energy. In contrast, a lubricated fault plane moving under low-compressive stress conditions would not possess the same intensity of high-frequency energy. Hence models of the former predict ω-square decay and models of the latter predict ω-cube decay. The latter corresponds to conditions expected for the shallow reservoir-induced earthquakes.

In our literature review only two reliable examples of spectra were found from which we could measure the high-frequency slope. Detailed spectra from the Oroville aftershock sequence show ω-cube decay giving credence to the claim that these events were reservoir induced. Spectral studies of Lake Mead earthquakes showed S-wave high-frequency decay of $\omega^{-1.2}$ to $\omega^{-1.8}$ but the conclusion of the authors was that these were natural, rather than induced, events. In an attempt to supplement the data we obtained new spectral data from southeastern United States reservoir areas. Seventeen new spectra from the Monticello (S.C.)

reservoir area and 32 spectra from the Clark Hill (Georgia-South Carolina) Reservoir area were obtained. These spectra showed $\omega^{-3.0}$ decay and are from areas of induced reservoir activity. We also obtained 22 new spectra from the Lake Sinclair, Georgia, area, an area of suspected but unproven induced seismic activity. These spectra show generally a $\omega^{-2.0}$ decay. The Wallace Dam (Lake Ocoee) on the eastern branch of Lake Sinclair has been carefully monitored for seismic activity but none has been detected after one year of loading.

We were unable to come to definite conclusions concerning the spectral discriminant because of the sparsity of data. Where appropriate data could be examined, the spectral slope did discriminate areas where reservoirs induce earthquakes from areas where reservoirs do not induce earthquakes. Theoretical models of the seismic source allow a rational explanation for the discriminant based on the character of the rupture velocity and the relation between frictional resistance and driving shear stress. Models which are based on a uniform, transonic rupture along a smooth circular fault best satisfy the spectra from areas of reservoir induced seismicity. We uncovered no contradictory evidence that could not be explained. The success of the limited data and the theoretical rational and compelling circumstantial evidence supporting the discriminant.

We recommend two to three years of high-quality digital recording of seismic data prior to the filling of reservoirs. We recommend also the evaluation of spectral signatures as a function of depth to test whether this might be a significant factor in the apparent success of the discriminant.

Crustal Loading and Induced Seismicity At the Yacambu Reservoir, Venezuela

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Contract No. 14-08-0001-17644

Investigations:

The Yacambu experiment is a cooperative venture between Venezuelan engineers and ourselves to monitor surface deformation and subsurface pore pressures in the vicinity of a reservoir that is soon to be filled in the Venezuelan Andes. Several faults exist near the reservoir that are associated with the 2 km wide Bocono fault zone 10 km to the north; one of these faults passes directly beneath the reservoir. There is a strong possibility that seismicity will be induced on this or on associated faults soon after impounding of the Yacambu Reservoir.

Results:

We have modelled the local topography near the reservoir using finite element techniques and conclude that the submerged fault beneath the reservoir will be subjected to significantly reduced normal stresses. We have planned an array of strainmeters, tiltmeters, and geodetic measurements that can monitor strains across the fault and surface deformation in the region, and these are presently being installed as and when engineering work permits. Four strainmeters will operate across the submerged fault and the bulk of the remaining instruments will be installed in tunnels within an abutment adjoining the dam structure.

Three strainmeters are presently operating in order to provide a baseline estimate of earth-tidal magnitudes before impounding. Changes in rock stress that will occur at the time of impounding will cause variations in tidal admittance that can be used to assess changes in elastic modulii in the foot of the dam passing close to the submerged fault. Pore pressure variations near the reservoir will be monitored by piezometers at various depths in two 1 km deep holes drilled for this purpose by the Venezuelan authorities.

Induced Seismicity at Toktogul Reservoir and Seismotectonics of the Talas-Fergana Fault

Contract USGS-14-08-0001-16844

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Toktogul Reservoir is located on the Naryn River in central Kirgizia. The main body of the reservoir will cover an area extending 60 by 20 km along the northeastern side of the Talas-Fergana fault. The 215 m high concrete dam is located at the end of a narrow canyon, 15 km downstream from where the reservoir crosses the fault.

The Talas-Fergana fault system comprises one of the major tectonic features of Central Asia (Simpson et al., 1980). The fault extends for over 800 km from Kazakhstan in the northwest through Kirgizia southeast into western China. The November 2, 1946 Chatkal earthquake (M = 7.6) occurred near the intersection of the Talas-Fergana and Chatkal faults, approximately 65 km northwest of Toktogul Dam.

The Institute of Physics of the Earth, Moscow, and the Kirgiz Institute of Seismology, Frunze, have operated a network of 4 to 11 stations near Toktogul since 1965. The largest earthquake during this time period was a magnitude 5.6 event in the Chatkal zone in 1971. The largest earthquake near the reservoir was of magnitude 4.6 in 1966, close to te dam site.

The reservoir began to fill in 1974 but no increase in activity near the dam was observed until late 1977, when there was a significant increase in the number of smaller earthquakes recorded by a seismic station approximately 7 km east of the dam. A clear increase in the number of earthquakes followed the first sustained filling to over 100 m in October 1977. As the water level increased to approximately 115 m in mid-January 1978, the number of events increased to an average of five per day. At that time the water depth leveled off as the filling rate decreased, and the rate of seismicity also decreased. The seismicity abruptly increased again as the water level rose to a new maximum of 150 m in early July 1979.

A joint Soviet-American project to study induced seismicity at Toktogul began with the installation of a telemetered network in 1978. Preliminary epicenters located using data from the network for the period October 1978 to October 1979 show a strong concentration of events in a narrow zone, approximately 10 km long, centered directly beneath the dam. The epicenters form a northeast-southwest lineation, parallel to the strike of the Naryn River canyon and mainly confined to the 2-5 km depth range. The proximity of these events to the deepest part of the reservoir and the correlation of the onset of activity with the time when the reservoir first exceeded a depth of 100 m, clearly indicate that this seismicity is reservoir-induced.

The largest of the earthquakes near the dam since October 1977 has been magnitude 2.5 The activity is concentrated in the immediate vicinity of the dam at very shallow depths and is clearly related to changes in water level. The water level near the currently active area will increase a further 50 m before the reservoir is filled. The water level where the reservoir crosses the Talas-Fergana fault, 15 km upstream from the dam, did not exceed 100 m until late 1979, and induced activity could begin along the Talas-Fergana as the water level increases further. The occurrence of low-magnitude activity near the dam indicates that at least part of the region is in a state susceptible to failure triggered by loading of the reservoir.

One of the main factors controlling whether or not induced seismicity occurs at a given site is the geological and tectonic environment of the reservoir. Studies of the regional tectonics of the Talas-Fergana fault (Simpson et al., 1980) and Central Asia are being undertaken to assess the seismic potential and mode of deformation in the Toktogul area. Studies to date have included the analysis of seismicity patterns prior to earthquakes on the Gissar-Kokshal fault, south of Toktogul (Kristy and Simpson,1980); focal mechanism studies of the Gazli earthquakes in Uzbekistan (Kristy et al., 1980) and an analysis of deformation in the Pamir-Tien Shan region (Bilham and Simpson, 1980).

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Project Title:	Induced Seismicity at Toktogul Reservoir and Seismotectonics of the Talas-Fergana Fault.
Contract Number:	USGS-14-08-0001-16844
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Investigations

1. A seven station telemetered network was installed around Toktogul Reservoir in October 1978. Two additional stations were added in 1979. Six of the stations are high-gain vertical channels with constant velocity response. Three stations have three orthogonal components with high-gain velocity response and one low-gain vertical channel with constant displacement response. The network surrounds the deepest part of the reservoir, where low level induced seismicity is now occurring.

2. Earthquake catalogues from regional studies by Soviet groups in the Toktogul area have been studied to investigate temporal and spatial variations in seismicity along the Talas-Fergana fault from 1965 to the present. Data are being collected on the two largest recent earthquakes in the Toktogul area the magnitude 7.5 Chatkal earthquake in 1946 and the magnitude 5.1 Toktogul earthquake in 1971.

3. Earthquake catalogues for 1900 to the present are being studied to investigate seismic patterns in Central Asia and premonitory changes in seismicity prior to recent large earthquakes.

Results

1. Low magnitude induced seismicity is occurring beneath the deepest part of Toktogul Reservoir. Soviet data show that this activity began in late 1977, as the water level in the reservoir first exceeded 100 meters. More than 600 events can be located using data from the telemetered network since recording began in October 1978. Most of this activity is concentrated in the immediate vicinity of the 215 m high dam. The activity extends to 5 km depth and is elongated parallel to the canyon of the Naryn River, upstream from the dam. Activity as recorded on telemetered network reached a maximum of more than 40 events per day in July 1979, as the water depth approached a seasonal maximum of 155 m. The water level where the reservoir crosses the Talas-Fergana fault, 15 km upstream from the dam, has not yet reached 100 m and seismicity along the Talas-Fergana has not shown any change related to filling of the reservoir. There will be a further increase in water level of 60 m before the reservoir is filled.

2. Changes in seismicity have been observed before two of the largest recent Central Asian earthquakes — the Markansu earthquake of August 11, 1974 (M = 7.3) and the Zaalai earthquake of November 1,1978 (M = 7.0). A cluster of activity is observed in the future epicentral region approximately 6 years before the Markansu event and 3 years before the Zaalai earthquake. Both of these clusters include earthquakes of magnitude 5. The future epicentral region remains essentially quiescent above the magnitude 4 level between the cluster of earthquakes and the occurrence of the main shock. Data from regional Soviet catalogues are being used to refine these observations.

Induced Seismicity, Earthquake Prediction and Crustal Structure Studies in South Carolina

Contract No. 14-08-0001-17670

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1. Induced Seismicity at Lake Jocassee (Oct. 79-March 80)

In this period the seismic activity was monitored on 3 permanent stations. Very low level seismicity continued, with 30 events being located, of which 10 had a magnitude between 1.0 and 1.8.

2. Induced Seismicity at Monticello Reservoir (Oct. 79-March 80)

In this period the low level activity was interrupted by a swarm of activity in October 1979. In October 1979, over 700 events were recorded with 19 having $M_L \geq 2.0$. The level of activity was the greatest since February 1978. A large part of this activity was located to the west and southwest of the center of the reservoir. The nature of the activity was that of a swarm.

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b. C. Duc, P. Talwani, D. Amick and J. Fletcher, Source Properties of Monticello Reservoir.

c. Hutchenson, K. D. and P. Talwani, Gravity Survey of Irmo quadrange, South Carolina.

d. Logan, W. R., D. C. Amick and P. Talwani, Seismic refraction survey in Bowman area, South Carolina.

e. Taylor, K. B., and P. Talwani, An isoseismal study of the August 25, 1979, Lake Jocassee earthquake, Oconee County, South Carolina.

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