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DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

Office of Earthquake Studies

SUMMARIES OF TECHNICAL REPORTS, VOLUME VI

Prepared by Participants in

NATIONAL EARTHQUAKE HAZARDS REDUCTION PROGRAM

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1978

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UNITED STATES
DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY
OFFICE OF EARTHQUAKE STUDIES
345 Middlefield Road
Menlo Park, California 94025

TO: All Active Contractors

FROM: Jack Evernden

SUBJECT: Volume VII of Summaries

Gentlemen:

We will close Volume VII at Close of Business November 1, 1978.

Please look on inside of front cover of Volume VI for instructions on preparation of Summaries.

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Earthquake Hazard Reduction Program

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

Principal Investigators: John C. Crowell and Robert M. Norris
University of California,
Santa Barbara

Report Summary

The progress on this research has proceeded on schedule since its initiation on October 1, 1976. Most aspects of the study are now nearing completion and field mapping should be done in the next couple of months. These investigations include an evaluation of the upland surfaces in a large triangular area lying between the San Joaquin Valley, the Santa Clara River and the Antelope Valley. Detailed mapping of the younger fault traces along the San Andreas fault has been completed and some mapping, where relevant, of the bedrock exposures on either side of the main trace has been undertaken. Although there remains a small gap in the vicinity of Gorman, most of the trace of the San Andreas from east of Liebre Mountain northwest to the upper Cuyama River Valley has been mapped in considerable detail.

A number of samples have been collected from trenches and other places thought to be of value for C_{14} dating. Some of these samples have been prepared for dating and have been submitted to the Geological Survey for analysis. Additional samples from critical areas are still being prepared. It is expected that these samples will provide important information on the periodicity of seismic events along the San Andreas.

The mapping now close to completion has provided evidence of a number of elongate bulges or folds parallel or sub-parallel to the fault. Associated with these folds are thrust faults and gravity slides which have moved rocks upward along high angle reverse faults in the fault zone and downslope across the fault in some instances. At other places, branch faults curving away from the main trace were found to pass into thrust faults which have deformed and broken several erosional surfaces.

It is expected that all four of the research assistants involved in this study will have completed their field work and most or all of their report-writing by the end of September 1978. Two of the assistants have presented papers at the Tempe meetings of the Geological Society of America. John C. Crowell, Principal Investigator, has also delivered four talks dealing with neotectonics during the last six months.

Application has been made for a two-year continuation of this research grant in order to investigate the fault zone northwestward toward the Carrizo Plain. It is expected that this further study will provide useful comparisons of the so-called "locked segment" of the San Andreas in the "Big Bend" area with the straighter, more active portion to the northwest. This new grant is proposed for the period from October 1, 1978 through September 30, 1980 and will involve the continuation of Research Assistant Thom Davis as a Post-Doctoral fellow.

Activities of the Research Assistants

Robert Crippen has completed his analysis of upland surfaces between the San Joaquin Valley and the Castaic utilizing several sets of aerial photographs, both colored and black and white, standard USGS topographic maps, and geologic maps. By means of a computer analysis, he is seeking to detect evidence of Holocene deformation of this large area which can be tied to events along the San Andreas zone. Crippen is currently preparing his written report which is expected to be in hand by the end of June this year.

Derek Rust, working in the area on either side of Liebre Mountain, has completed his detailed mapping of surface breaks along the main trace of the San Andreas as well as delineation of the folded and faulted bedrock bulges on either side of the main trace. He has found conspicuous deformed surfaces on bedrock which he believes will provide a basis for documenting the history of folding and faulting. He has also found some rather important faults which diverge from the main trace of the San Andreas as much as 38° and which can be traced over 5 km. These faults become thrusts near their terminations and have clearly offset at least two erosional surfaces as much as 120 m vertically.

Rust also has been able to demonstrate that basement rocks have been deformed by folding associated with displacements in the Big Bend area. Erosional surfaces and very young deposits resting on them have been deformed by folding such that faults passing across the folds show several meters of vertical displacement at the crest, diminishing to no vertical displacements at the ends. He has found that this folding diminishes as the main strand of the San Andreas fault is approached, presumably because movement in that area has occurred as right slip instead of as compression more characteristic of either side of the main trace.

Rust has arranged for some equipment to make some cores of large oak trees growing near the most recently active trace of the fault. Because these trees have been growing in this area at least as far back as the 1857 movement and perhaps as long as the next earlier event, the cores may well reveal damage occasioned by large events on the fault.

Thom Davis has completed very detailed mapping of the fault zone west of Frazier Park as far as the upper Cuyama Valley. He has found not only much evidence of active right slip along the main trace and the usual array of features associated with left-stepping of individual fractures such as sags, compression ridges, and the like, but also has been able to demonstrate that compression in this portion of the San Andreas has produced a series of impressive high-angle reverse faults which fan out upward, some passing into thrusts and gravity slides. This kind of tectonic activity has produced welts or bulges sub-parallel to the main trace of the fault and in a number of instances has brought Eocene rocks over later Tertiary deposits either by thrusting or gravity sliding. He has also found that these welts or bulges are typically cut in their central portions by dominantly strike slip faulting. In addition, many of the major right-slip faults have appreciable dip slip as well.

Ernest Duebendorfer is completing his field study of the area between Frazier Park and Liebre Mountain in which he has been doing detailed mapping of the fault traces as well as the bedrock geology. He will shortly be selecting a suitable site for a trench to be cut across an active trace. In the event an appropriate site cannot be found in his area, such a trench will probably be cut in Davis' area to the northwest where several good sites seem to exist.

Participation of the Principal Investigators

Both John C. Crowell and Robert M. Norris continue to take an active part in these studies. Both have made several supervisory trips to the areas under study and both have had numerous conferences with the research assistants - Davis, Rust, Crippen and Duebendorfer. Both Norris and Crowell will be available during the coming summer to help with the work, although it is expected that only minor field work will remain and their main role will be conferring with the assistants and advising them as their writing and office work progresses.

Norris will assume primary responsibility for synthesizing the geomorphic results of this study for eventual publication. It is expected that this work will occur mainly after the conclusion of the grant and decisions as to format and suitable publication outlet have not yet been made.

Crowell has delivered several scientific lectures related to the work in progress. A talk on neotectonics with special emphasis on these San Andreas studies was given in January at the Geological Society of London. In March another talk on the History of the San Andreas fault in southeastern California, drawing on data obtained in this study, was presented at the W.W. Rubey Colloquium at UCLA. In April, at the time the Departments of Geology and Geophysics at UCLA merged, Crowell gave a further talk on rates of movement on the San Andreas fault.

Some of this material, particularly that presented in the Rubey Colloquium, will be prepared as a chapter in a forthcoming book on California Geology edited by Gary Ernst of UCLA.

Conclusions

We are pleased with the progress to date on this study. We think we will be able to add some useful information on the late Quaternary deformational history of the "Big Bend" portion of the San Andreas fault, including some new estimates of rates, amount and frequency of seismic events as well as estimates of the rates of deformation of erosional surfaces in this region. Because we believe some comparisons of significance can be drawn between the structural history of the "Big Bend" area and the straighter segment of the San Andreas northwest, toward the Carrizo Plain, we have applied for an extension of this grant for a two-year period. Thom Davis, who has mapped the western-most portion of the fault in this sutdy, has tentatively agreed to continue as a Post-Doctoral fellow if the grant is approved.

Tectonic Framework San Francisco Bay Region

8-9540-01618

Earl E. Brabb
Branch of Western Environmental Geology
U.S. Geological Survey
345 Middlefield Road, MS 75
Menlo Park, CA 94025
(415) 323-8111, ext. 2203

Investigations

1. Analysis of the relation between aeromagnetic anomalies, geologic units, and epicenters in the southern San Francisco Bay region.

2. Continuation of bedrock geologic mapping along active faults in Santa Cruz, Alameda, Contra Costa, Monterey and San Benito Counties.

3. Initiation of mapping of surficial deposits in northern Monterey County in order to eventually prepare map of liquefaction potential.

4. Continuation of investigation of timing and amount of movement along the San Gregorio fault.

5. Coordination of studies for seismic zonation in the southern San Francisco Bay region, especially slope stability studies and preparation of a paper showing how cities and counties are using USGS products for seismic zonation.

6. Editing and completion of professional paper on paleontologic techniques for dating Cenozoic deposits of the Coast Ranges.

Results

1. Aeromagnetic anomalies east of the San Andreas fault in the southern San Francisco Bay region are associated either with steeply dipping serpentinite bodies along strike slip faults or with more gently dipping and folded sheets of serpentinite along thrust faults. Correlation with epicenters for the period 1969-74 indicates that some of the linear magnetic anomalies are interrupted in areas of intense earthquake activity swarms, as if the magnetic material is in the initial period of intrusion along the fault zone. An alternate explanation is that the serpentinite acts as a lubricant in relieving stress along the fault zone and where it is absent the rocks are failing and are associated with many small earthquakes.

2. Geologic mapping of the Laurel, Los Gatos, Chittenden and Watsonville East quadrangles along the San Andreas fault has been completed and will be released in open files by summer. Geologic mapping of Castle Rock Ridge, Loma Prieta and Tres Pinos is nearly complete.

3. A conference involving 41 paleontologists from 9 counties was held in Menlo Park last October to discuss various methods of dating and determining the paleobathymetry of Cenozoic deposits in the Coast Ranges. These studies are expected to help unravel the amount and timing of movement along the major strike-slip fault systems.

Reports

Dibblee, T. W., Jr., Brabb, E. E., and Clark, J. C., 1978, Preliminary geologic map of the Laurel quadrangle, Santa Cruz and Santa Clara Counties, California: U.S. Geological Survey open file report 78-84.

Poore, R. Z., and Brabb, E. E., 1977, Eocene and Oligocene planktonic Foraminifera from the upper Butano Sandstone and type San Lorenzo Formation, Santa Cruz Mountains, California: Journal of Foraminiferal Research, v. 7, no. 4, p. 249-272.

Brabb, E. E., 1978, Paleogene correlated: Geotimes, v. 23, no. 3, p. 20.

Nilsen, T. H., and Brabb, E. E., 1977, Slope stability studies in the San Francisco Bay region, California: Geological Society of America Reviews in Engineering Geology, v. 3, p. 235-242.

Newman, E. B., Paredis, A. R., and Brabb, E. E., 1978, Feasibility and cost of using a computer to prepare landslide susceptibility maps of the San Francisco Bay region, California: U.S. Geological Survey Bulletin 1443.

THE UNIVERSITY OF ARIZONA
TUCSON, ARIZONA 85721

DEPARTMENT OF GEOSCIENCES
TEL (602) 884-1819

TECTONIC GEOMORPHOLOGY OF THE SOUTH FRONT OF THE SAN GABIREL MOUNTAINS, CALIFORNIA

William B. Bull, Geosciences Department,
University of Arizona, Tucson, AZ 85721
Contract #14-08-0001-G394 May 24, 1978

SUMMARY

The tectonic geomorphology model that was used with considerable success for mountain fronts bounded by strike-slip and normal faults in the Mojave Desert and the adjacent Basin and Range Province was applied to the thrust faulted terrain on the south side of the San Gabriel Mountains of southern California. The initial attempts to use the model revealed that a new approach will have to be devised for thrust faulted terrains. The principal problems are as follows:

(1) Uplift along a thrust-faulted mountain front varies in both time and space, which is in marked contrast to the Mojave Desert where repeated movements occur along the same fault zone.

(2) Because uplift apparently occurs first on one fault, and then on other faults that may be either farther back in the mountains or closer to the piedmont, the standard indices for identification of relative tectonic activity classes cannot be used in many situations. Thus, for studies of fault-controlled internal fronts, parameters such as degree of incizement of alluvial fans and mountain-piedmont junction sinuosity will be de-emphasized or replaced by other quantitative paramenters of landscape description.

(3) The identification of piedmont foreland areas and multiple mountain fronts is essential, and each of these fronts will have to be analyzed.

(4) Because of the complexity and high degree of tectonic activity, the three relative classes of tectonic activity used for the Mojave Desert study will have to be expanded to at least five classes.

Active Faults and Regional Deformation in the Western Mojave Desert, California

9940-02090

Dennis B. Burke
Branch of Ground Motion and Faulting
U. S. Geological Survey
345 Middlefield Road
Menlo Park, California 94025
(415) 323-8111, Ext. 2048

Investigations

The region under study is the western wedge of the Mojave Desert between the San Andreas and Garlock faults, from near their intersection east to about the longitude of Barstow, in southern California. The objectives of this project are to locate, document, and assess the tectonic activity of potentially hazardous geologic structures in the region, to determine whatever possible of crustal kinematics of the province as a whole, and to compile first-approximation seismic response maps for the included Antelope Valley area. Results thus far have been reported in these Summaries as part of the work in M. M. Clark's project (Quaternary Faulting in Southern California).

Results

Mapping of the wall of a backhoe trench in the Garlock fault zone in Fremont Valley indicates that displacements in the zone have there occurred at least nine times, and perhaps as many as seventeen times, during the past 14,700 C-14 years (work conducted in this report period as part of M. M. Clark's project).

Paleomagnetic directions obtained from a suite of later Cenozoic volcanic rocks in the Opal Mountain area (north of Barstow) suggest counterclockwise rotations of blocks bounded by right-lateral faults in the Mojave region of as much as 30°. This is permissive evidence for southern California crustal kinematics proposed by Garfunkel (1974, G.S.A. Bull., v. 85).

Airphoto and field studies in the areas of the Mirage Lake, Llano, Willow Springs, and Rosamond faults show that N-S to NE-SW crustal shortening in the interior portion of the Mojave wedge is accommodated by movement on a network of numerous small fractures that trend subparallel to the Garlock fault and to the central Mojave NW-SE system of faults. Rates of deformation are largely unknown as yet. Generation of large earthquakes in the region appears unlikely, but potential for small fault displacements is widespread.

Publications

Burke, D. B., and Hedel, C. W., 1978, Active Structures in the western Mojave Desert, California: G. S. A., Abs. with Programs, v. 10, no. 3, p. 98.

Burke, D. B., in press, Log of a trench in the Garlock fault zone, Fremont Valley, California: U.S.G.S. MF map, scale 1:20.

Vertical Tectonics

8-9950-01484

Robert O. Castle
Branch of Earthquake Tectonics and Risk
U. S. Geological Survey
345 Middlefield Road
Menlo Park, CA 94082
(415) 323-8111 ext. 2482

Investigations

1. Continued studies of historic crustal deformation based on repeated spirit levelings and both continuous and discontinuous water-level measurements and its relations to the late Cenozoic tectonics of southern California.

2. Began intensive investigations of historic crustal deformation in selected parts of central and northern California.

3. Began development of a regional vertical data base designed to serve the needs of the Geologic, Water Resources and Topographic Divisions.

4. Completed conversion to the Multics of the Vaníček surface fitting program.

5. Began development of applications programs for use with the evolving vertical data base.

Results

1. Results of the first year of short-line level surveys designed to monitor the changing configuration of the southern California uplift, showed that since 1974 the south flank was characterized by relatively modest down-to-the-south tilts. Continuation northward from Rosamond of the 1976 Los Angeles County leveling indicates that the 1974-76 collapse of the uplift flattened out south of Mojave and that the generally down-to-the-north tilt developed between 1974 and 1976 reversed in sense a few kilometers south of the White Wolf Fault.

2. Reconstruction of all of the pertinent survey data produced prior to the initiation of the southern California general releveling in 1978, has revealed a well-defined trough of tectonic subsidence along the south flank of the southern California uplift. The trajectory of maximum subsidence, which between 0.15 and 0.10 m with respect to a 1955 pre-uplift datum, apparently extended about 300 km along a line that lies from a few kilometers to perhaps several tens of kilometers south of the Sierra Madre, Cucamonga and Banning-Mission Creek faults.

3. Studies of vertical displacements in the Salton Sea area based on monthly measurements of water levels has produced confirmation of crustal deformation revealed through repeated spirit levelings. These water-level

measurements show a generally down-to-the-southeast tilt of almost 0.1 μrad/year that persisted from 1952 to 1967. This tilt accelerated dramatically to about 0.4 μrad/year between 1954 and 1969 and then reversed in sense about 1971 or 1972; the 1972-77 down-to-the-northwest tilt has averaged about 0.4 μrad/year.

4. Preliminary tests of applications programs designed to tap the veritcal data base indicate that the base has indeed been formatted in a way that will permit computer manipulation of the vertical data in a variety of ways.

Reports

Wilson, M. E., and Wood, S. H., 1978, Salton Sea water-level records (1952-1977) and the southern California uplift (abs.): Trans. Amer. Geophys. Union, v. 58, no. 4, p. 242.

Castle, R. O., Elliott, M. R., McMillan, J. F., and Stone, R. E., 1978, Tectonic downwarping along the south flank of the southern California uplift (abs.): Abs. of Papers, 73rd Ann. Mtg., Seismol. Soc. America, Earthquake Notes, v. 49, no. 1, p. 48.

Wood, S. H., and Elliott, M. R., (in press), Early twentieth century uplift in the Peninsular Ranges of southern California: Tectonophysics.

Vaníček, Petr, Elliott, M. R., and Castle, R. O., (in press), Four-dimensional modeling of recent vertical movements in the area of the southern California uplift: Tectonophysics.

Burford, R. O., (in press), The sixth international symposium on recent crustal movements, Palo Alto, California, July 25-30, 1977: Tectonophysics.

Quaternary Faulting in Southern California

9940 01293

Malcolm Clark
Branch of Ground Motion and Faulting
U. S. Geological Survey
345 Middlefield Road
Menlo Park, California 94025
(415) 323-8111, Ext. 2623

Investigations

1. Map and analyze strata exposed in the walls of trenches that cut the main trace of the Garlock fault in order to determine history of late Pleistocene and Holocene behavior (such as fault geometry, displacement rates, recurrence interval, expected magnitude) of this part of the Garlock fault.

2. Monitor, record and analyze continuing and new creep along the Garlock fault zone in Fremont Valley. Although the cause probably is drawdown of ground water levels, the timing, distribution and style of creep should help us understand both this sort of subsidence and tectonically induced subsidence.

Results

1. We dug two trenches across the Garlock Fault near the east margin of the playa of Koehn Lake, 45 km NE of Mojave, California. The trenches lie 300 and 700 m SW (toward the center of the playa) of a gravel bar constructed offshore in Pleistocene Lake Koehn. The trenches expose lacustrine and fluvial sediments of Pleistocene and Holocene age.

The bar has been cleanly offset about 80 m left-laterally and uplifted several meters on the SE side since it was formed. The terrain at the trench sites has also been uplifted 1/2--1 m on the SE side of the fault. The prospect of vertically offset lake beds prompted our excavations. Both trenches were 3-4 m deep and reached a massive lacustrine clay, which we assume was deposited in Pleistocene Lake Koehn when the bar was being formed. Massive to thinly-bedded lacustrine sands, silt and clays overlie the bottom clay and are in turn capped by deltaic (?) and fluvial sediments 1-2 m thick. The bottom clay contains ostracods that yield a ^{14}C age of 14,700 + 130 years (USGS 388). Tiny amounts of charcoal occur throughout the sediments. Jack Hillhouse has collected samples from which we may be able to get usable records of secular paleomagnetic variation. (Tufa in the offset bar yields ^{14}C ages of about 10,000 years, but a soil developed on the bar suggests to some observers an age greater than about 50,000 years). Trench #1, 300 m west of the bar, was logged by Dennis Burke and others and is described in his report.

Trench #2 was logged by Clark and others, but filled with runoff and collapsed before logging was complete. At this site the fault zone is marked by a shallow (1/2--1 m) graben 20-34 m wide. The trench reveals a zone of fractures 34 m wide. Concentrations of fractures at both sides of the graben are consistent in position and vertical offset with surface scarps. The main rupture, however, is in the center of the graben and has no surface expression, but shows vertical separation in the trench walls of more than 1 m. Fluvial (and lacustrine ?) erosion and deposition along the axis of the graben may account for the lack of a surface scarp here. Trench #2 also records evidence of possible sand blows.

Below a depth of about 1 m from the surface, most of the fractures in Trench 2 (and many in Trench 1) show essentially uniform offset with increasing depth. This implies either 1) recurrence intervals of more than several thousand years for faulting events or 2) very rapid late Pleistocene/early Holocene deposition of sediments deeper than 1 m.

In trench #1, Dennis Burke finds evidence for at least 9 probable and 8 more possible faulting events above the 14,700-^{14}C-yr layer, for a total of 17 events. These figures should be treated more as minima than maxima, because of the likelihood that some events may not have been recorded in the strata exposed in the trenches. Corresponding average recurrence intervals are about 1700 y (19 events) and 900 y (17 events). If we additionally assume that the 14,700-^{14}C-yr layer is contemporary with the offset gravel bar, these events had an average lateral slip of about 9 m (9 events) and 4.5 m (17 events).

2. Creep continues along tectonic fractures of the Garlock fault zone in Fremont Valley. (See report in V. 5 of this series). Maximum observed modern dip slip now exceeds 600 mm and is accumulating at about 50 mm yr. Several new fractures have opened since September 1977, and the heavy rain of the past winter caused widespread collapse of the walls of many active fractures, converting them into prominent fissures. Level lines were established across the center of the creeping zone late in 1977 to get a better idea of the distribution and timing of future subsidence and associated creep.

Tom Holzer and Earl Pampeyan have discovered 2 wells that now protrude 100-200 mm above the surface. This sort of evidence generally is taken to indicate shallow-based subsidence.

Aerial photos of Fremont Valley taken at irregular intervals since 1943 show that significant westward tilt of the playa of Koehn dry lake started between 1952 and 1965, and it continues today. The low point of the playa is now next to the playa's former western edge and represents a westward shift of the low point of more than 3 km.

The protruding wells and recent tilting of the playa surface is additional evidence that recent major lowering of ground water levels west of the playa is causing the subsidence and related fault creep.

Reports

Clark, M. M., Buchanan-Banks, J. M., and Holzer, T. L., 1978, Creep along parts of the Garlock fault: possible relation to decline in ground water levels: Geol. Soc. America abstracts with programs, v. 10, no. 3, p. 100.

Tabor, R. W., Ellen, S., and Clark, M. M., 1978, Geologic Hazards Map, Washoe City Folio: Nevada Bureau of Mines and Geology, Environmental series, Washoe Lake area, map no. 4 An.

Gravity and Magnetics of the San Francisco Bay Region

8-9730-00363

Andrew Griscom
Branch of Regional Geophysics
U.S. Geological Survey
345 Middlefield Road
Menlo Park, CA., 94025
(415) 323-8111 X2268

Investigations

1. Interpretation of aeromagnetic map of the north Bay Region (lat.37°52'30"N. to lat. 38°52'30"N.) at a scale of 1:125,000. Supporting materials at the same scale from various sources include: gravity map, contoured at 2 mgal; geologic map; seismicity map.

2. Model studies of selected magnetic anomalies from the above data. Possible models for simulation of magnetic anomalies fall into three general classes: steeply-dipping dike-like masses with great vertical extent; models with varying magnetic properties; or configurations involving gently folded sheets with relatively minor interruptions by steeply-dipping faults.

3. Collection of a few magnetic profiles by truck-mounted magnetometer across puzzling aeromagnetic anomalies that are not clearly explained by the known geology.

Results

1. The magnetic anomalies in the North Bay Region are almost entirely caused by the serpentinized ultramafic masses. Relatively few minor anomalies are caused by the Cenozoic volcanic rocks. The Franciscan volcanic rocks in general do not cause aeromagnetic anomalies.

2. The amplitude of magnetic anomalies over the serpentinite masses decreases from east to west from the vicinity of the Coast Range thrust to the San Andreas fault. Because the magnetization of the serpentinite appears approximately constant (0.0015 emu/cm^3) throughout the area, it is interpreted that the serpentinite masses generally become thinner to the west.

3. Model results favor the interpretation of most major magnetic anomalies as being caused by gently folded sheets of magnetic serpentinite, interrupted by relatively minor, steeply-dipping faults.

4. The magnetic anomalies allow tracing near-surface serpentinite masses beneath the relatively thin cover of Cenozoic rocks. The distribution of the associated magnetic anomalies is sufficiently dense that there are relatively few permissible locations for major strike-slip faults on strike with or parallel to the Hayward, Franklin, or Calaveras faults to the southeast.

Shallow Geophysical Investigations

8-9940-01897

R. M. Hazlewood
Branch of Ground Motion and Faulting
U. S. Geological Survey
345 Middlefield Rd., MS 77
Menlo Park, CA 94025
(415) 323-8111, ext. 2125

Investigations

1. Seismic refraction survey to determine near surface seismic structure in Parkfield-Cholame area. Data from this project will be used in conjunction with downhole logs of P and S velocity collected in project "Instrument Development and Geotechnical Studies" (Warrick) and numerical models developed in project "Ground Motion Modeling and Prediction" (Joyner) to synthesize the Parkfield strong motion records.

2. Seismic refraction survey in northern San Francisco Bay region to define configuration of bedrock interface.

Results

1. Exceptionally high rainfall has caused land owners to refuse entry until roads are dry. Initial preparation for experiments is complete and data collection will begin as soon as entry is possible.

Neotectonics of the San Francisco Bay Region, California

8-9540-01950

Darrell G. Herd
Branch of Western Environmental Geology
U.S. Geological Survey
345 Middlefield Road
Menlo Park, CA 94025
(415) 323-8111, ext. 2951

This project has been undertaken to provide a synthesis of geologic, geophysical and geodetic information on Quaternary tectonic movement in the San Francisco Bay region. Data on the amount, location, character, and timing of faulting and folding in the San Francisco Bay area are being evaluated to provide an understanding of the tectonic forces active in the central Coast Ranges of California.

Investigations

1. To establish the relationship of the line of fault zones, consisting of the Paicines-Calaveras-Hayward-Rodgers Creek-Maacama fault zones, with the northern end of the San Andreas fault zone at the Mendocino triple junction, a search was made for other recently active fault zones north of Laytonville which might be the northward prolongation of the line of fault zones.

2. Geologic mapping was continued along the San Joaquin Valley fault zone, a major normal fault zone bounding the west side of the San Joaquin Valley between Tracy and Los Banos. A geologic strip map (scale 1:24,000) is being prepared to document the fault zone, and to establish a history of movement along the fault zone.

3. Mapping of recently active faults in San Mateo, Santa Cruz, and western Santa Clara Counties was begun toward completion of a regional study of Quaternary faulting in the south San Francisco Bay region.

4. A detailed study of the Green Valley fault zone north of Cordelia was made to complete a map of Quaternary faulting and seismicity in the northeastern San Francisco Bay region being prepared in cooperation with W. H. K. Lee.

5. Four cores collected from Hollister Valley were sampled and described. The cores contain a record of fluctuations of ancient Lake San Benito, a large lake that was impounded in Hollister Valley behind a large landslide dam astride the San Andreas fault zone at Chittenden. Ancient Lake San Benito occupied the southern Hollister Valley near the San Andreas-Paicines-Calaveras fault bifurcation.

6. An investigation of the magnetostratigraphy of the Livermore and Irvington Gravels in Alameda County was begun by Eugene Shoemaker (Branch of Petrophysics and Remote Sensing, Flagstaff, AZ). The study is designed to provide radiometric control for the age of the gravels through the identification and correlation of geomagnetic reversals and excursions. Absolute-age control for the gravels is critically needed to decipher the history of movement along the Hayward, Calaveras, Las Positas, and Verona faults.

Results

1. The Lake Mountain and McKinleyville fault zones, two northwest-trending, recently active right-slip fault zones, were discovered east of Cape Mendocino. The two fault zones are the apparent northward continuation of the Paicines-Calaveras-Hayward-Rodgers Creek-Maacama fault zones. This line of faults, the Hayward-Lake Mountain fault system, extends past Arcata onto the continental shelf southwest of Crescent City. The Hayward-Lake Mountain fault system defines the eastern boundary of the Humboldt plate, a small northwest-elongate sliver of the North American continent bounded on the west by the San Andreas fault zone and to the north by the Gorda plate. This newly recognized plate is converging northwestward against the Gorda plate, which is being thrust beneath it.

2. The San Joaquin Valley fault zone, which was discovered late in FY 1977, was traced southward along the east flank of the Diablo Range from Tracy to Los Banos. Although a search was made along the entire west side of the Central Valley for a northward and southward continuation of the fault zone, no evidence for a prolongation of the fault zone was found.

Geologic relationships along the fault zone indicate that normal faulting along the San Joaquin Valley fault zone began after the uplift of the Diablo Range and the development of the Central Valley. The San Joaquin Valley fault zone post-dates the Tulare Gravels, Plio-Pleistocene-age gravels which rest unconformably on eastward-dipping rocks in the east flank of the Diablo Range. Differential offset of late Pleistocene stream terraces suggests a complex history of movement along the San Joaquin Valley fault zone.

3. Several previously unidentified thrust faults have been located along the foot of the hills on the west side of San Francisco Bay in Santa Clara and San Mateo Counties. These faults, which appear similar in character to the Monte Vista and Serra thrust faults, locally displace late Pleistocene terraces.

4. Geologic mapping of the Green Valley fault zone north of Cordelia has revealed that the fault zone continues northward to Cache Creek, east of Clear Lake. The fault zone strikes northerly, passing just west of Lake Berryessa. The discovery of the northward prolongation of the fault zone provides a convenient explanation for the microseismic activity (1969-1974) that has been instrumentally located in the area, but had previously been unexplained.

5. Preliminary examination and radiocarbon dating of sediments recovered from the floor of Hollister Valley have revealed the presence of at least three levels of lacustrine clays, all presumably associated with ancient Lake San Benito. The uppermost clays had been dated previously at 4000 C-14 years B.P.; the lowermost clays were recently determined to be approximately 9900 C-14 years B.P.. The 9900-radiocarbon year age for the lowermost clays indicates that the landslide dam at Chittenden, which impounded ancient Lake San Benito, is at least about 10,000 years old.

Reports

Herd, D. G., 1978, An intracontinental plate boundary east of Cape Mendocino, California: Geology (submitted for publication).

____ 1978, Map of Quaternary faulting along the northern Calaveras fault zone; Las Trampas Ridge, Mount Diablo, Dublin, Niles, and La Costa 7-1/2' quadrangles, California: U.S. Geological Survey Open-file Report 78-307, 5 sheets, scale 1:24,000.

____ 1978, Map of Quaternary faulting along the northern Hayward fault zone; Mare Island, Richmond, Briones Valley, Oakland West, Oakland East, San Leandro, Hayward, and Newark 7-1/2' quadrangles, California: U.S. Geological Survey Open-file Report 78-308, 8 sheets, scale 1:24,000.

____ 1978, Map of Quaternary faulting along the southern Rodgers Creek fault zone; Glen Ellen, Petaluma River, and Sears Point 7-1/2' quadrangles, California: U.S. Geological Survey Open-file Report 78-306, 3 sheets, scale 1:24,000.

Russ, D. P., Stearns, R. G., and Herd, D. G., 1978, Map of exploratory trench across Reelfoot scarp, northwestern Tennessee: U.S. Geological Survey Miscellaneous Field Studies Map MF-985.

Tectonics of Central and Northern California

8-9950-01290

William P. Irwin
Branch of Earthquake Tectonics and Risk
U. S. Geological Survey
345 Middlefield Road
Menlo Park, CA 94025
(415) 323-8111 ext. 2065

Investigations

1. Study of the relation between carbon-dioxide discharges and seismicity was continued in collaboration with Ivan Barnes. Final preparation of a report and map relating the global distribution of carbon-dioxide and seismicity was completed.

2. Preliminary analysis of intraplate seismicity to determine whether such seismicity is associated with distinctive geologic features.

3. Completed preparation of geologic structure section across northern California for Plate Margins Group, U.S. Geodynamics Committee.

4. Prepared a paper on the tectonic accretion of the Klamath Mountains for the Ruby colloquium (UCLA) and memorial volume.

5. Laboratory work was completed on the radiolarian cherts from various lithic belts of northern California, and the results were reported in a symposium volume on the Mesozoic paleogeography of the western United States.

Results

Carbon-dioxide discharges and earthquakes are concentrated along the boundaries of crustal plates. Along these boundaries the resistance to plate motion is expressed partly as seismic energy, and it is here also that conditions are suitable for release of carbon dioxide from marine carbonate-bearing rocks through processes of subduction and igneous intrusion. Fractures extending to sufficient depth may also yield carbon dioxide from the mantle. The generation of carbon dioxide along these tectonic zones is a long-term event, compared to the historical record of seismicity, and thus may be a useful feature in regional seismic zoning. The general lack of carbon-dioxide discharges and seismicity in cratonic regions indicates the continuance of a long history of tectonic quiescence.

Reports

Barnes, Ivan, Irwin, W.P., and White, D.E., Global distribution of carbon-dioxide discharges and major zones of seismicity: U.S. Geol. Survey, Water Resources Inv., in press.

Irwin, W.P., Jones, D.L., and Kaplan, T.A., 1978, Radiolarians from pre-Nevadan rocks of the Klamath Mountains, California and Oregon, _in_

Mesozoic paleogeography of the western United States: Soc. Econ. Paleontologists and Mineralogists, Pacific Sec., Pacific Coast Paleogeography Symposium 2, p. 303-310.

Irwin, W.P., 1977, Ophiolitic terranes of California, Oregon, and Nevada, _in_ North American ophiolites, Coleman, R.G., and Irwin, W.P., Eds.: Oregon Dept. of Geology and Mineral Ind. Bull. 95, p. 75-92.

California Institute of Technology

EARTHQUAKE HAZARD STUDY OF SIERRA MADRE FAULT SYSTEM

U.S.G.S. Contract No. 14-08-0001-15258

Barclay Kamb, Principal Investigator

1 October 1977 - 31 March 1978

Summary

Detailed geologic mapping of the Sierra Madre and Raymond Hill fault zones is essentially completed. Some additional mapping in the La Canada-Tujunga area and the Monrovia Canyon area was done and some revisions were made to earlier mapping, which result in a more complete picture of the structure of the Sierra Madre fault zone. Three new localities of Quaternary faulting were found and studied, in addition to those reported previously; all involve northward-dipping thrusts bringing crystalline basement over alluvium. New information on faulting relationships in the Sierra Madre and Raymond Hill zones has been obtained from ten trench excavations at critical localities and from the ^{14}C dates from samples collected from trenches excavated and reported on previously. Analysis of geomorphic data and the ^{14}C dates has yielded preliminary estimates of fault activity in the two fault zones. Seismicity in the study area is under detailed scrutiny through use of the CIT-USGS seismographic network; although the hypocenter pattern shows no clear clustering in relation to the known fault zones except in the aftershock area of the 1971 earthquake, focal mechanisms show a consistent north-south alignment of compression axes. Publication of results as part of a USGS Professional Paper on the Transverse Ranges has been arranged, and the preparation of our contribution is near completion.

CALIFORNIA DIVISION OF MINES AND GEOLOGY

RECENCY AND CHARACTER OF FAULTING OFFSHORE FROM METROPOLITAN SAN DIEGO, CALIFORNIA

by M.P. Kennedy
California Division of Mines and Geology
1416 Ninth Street, Sacramento, California 95814

SUMMARY REPORT - U S G S GRANT NO. 14-08-0001-16728

This report, the Semi-Annual Technical Report for U.S. Geological Survey Contract 14-08-0001-16728, documents progress on the study of "Recency and character of faulting offshore from metropolitan San Diego, California" for the period October 1, 1977 through March 31, 1978.

The initial data collecting phase of the project was completed during the month of December 1977 aboard the Scripps Institution of Oceanography Research Vessel Ellen B. Scripps. The area studied lies immediately offshore from La Jolla, California between latitudes 32° 47' and 33° 03' and longitudes 117° 15' and 117° 28', and is structurally a part of the southern California borderland (figure 1).

Major faults associated principally with an offshore part of the Rose Canyon fault zone transect the area studied and have been observed by means of high resolution, subbottom, reflection profiling. Two profiling systems were employed to give a combination of maximum resolution and moderately deep (more than .5 sec) penetration in strata with velocities between 1.5 and 3 km/sec. These systems included a 3.5 khz echo sounder and a 10 in^3 air gun. More than 2,000 km of profiles were measured along 96 individual lines (figure 1).

The ship's position was plotted along each line by means of a transponding type, near microwave frequency, ranging system. Four shore based relay stations provided resolution of $\pm$ 30 m for any given point along each line. This navigational system was kindly loaned to us by the Marine Branch of the U.S. Geological Survey.

All work associated with the first phase of data collection and development of the ship's track has been completed. The interpretation phase of the reflection data began March 1, 1978 and the sampling program is scheduled for late June and early July 1978.

All data are available from California Division of Mines and Geology on microfilm and computer cards. Upon completion of the study copies of all facts will be supplied to the Marine Branch of the U.S. Geological Survey and will be available through Open-File by the California Division of Mines and Geology.

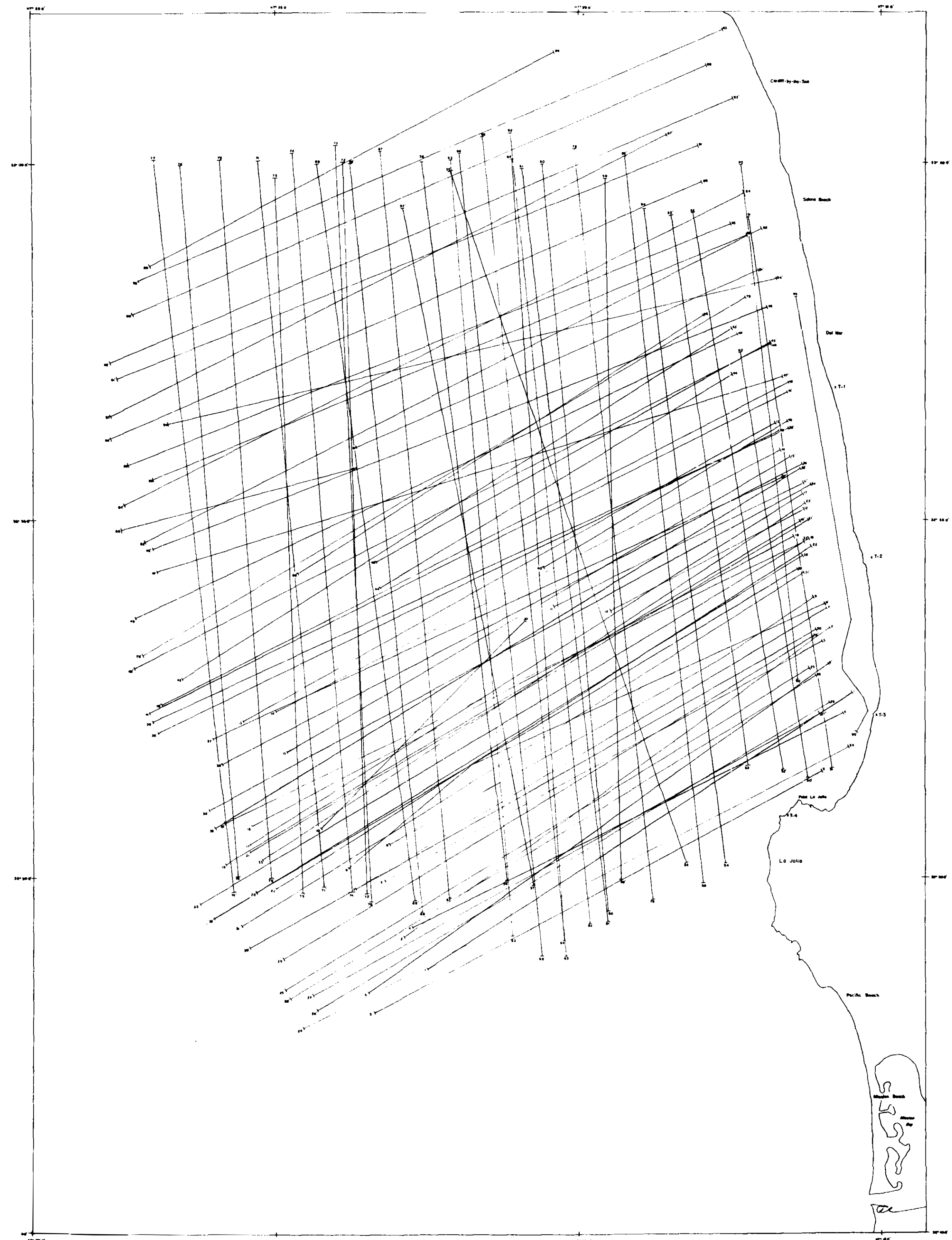

Figure 1. Index map showing locations of subbottom reflection profiles and area studied.

Coastal Tectonics, Western U. S.

8-9940-01623

Kenneth R. Lajoie
Branch of Ground Motion and Faulting
U. S. Geological Survey
345 Middlefield Road
Menlo Park, CA 94025
(415) 323-8111, Ext. 2642

Investigations

1. The objectives of the Coastal Tectonics project are to provide information on late Quaternary crustal deformation in the coastal region of the western U. S. This information is used to assess tectonic state, date fault activity, establish recurrence intervals on faults and establish style and rates of crustal deformation.

2. Continuation of mapping and dating marine terrace deposits and late Quaternary strata from numerous coastal sites in western U.S.

3. Continuation of dating lacustrine deposits, western Great Basin.

Results

1. With John Wehmiller (University of Delaware), George Kennedy (University of California, Davis), Tom Stephens (USGS), Sam Morrison (USGS), Joe Liddicoat (Lamont-Doherty Geological Observatory) and Duane Packer (Woodward-Clyde Consultants) calibrated the amino-acid kinetic model in northern California and southern Oregon using paleomagnetic data. At Moonstone Beach magnetically reversed marine beds near the base of a stratigraphic section yield an amino-acid age estimate of 710,000 years and magnetically normal beds near the top of the section yield an amino acid age estimate of 600,000 years. Normally magnetized beds in the Elk River fm at Cape Blanco, Oregon yield an amino-acid age estimate of 500,000 years. All of the amino-acid and paleomagnetic data are internally consistent and agree with correlations based on vertebrate and invertebrate fossils.

2. With John Wehmiller, Andrei Sarna-Wojcicki, Bob Yerkes and George Kennedy dated molluscan faunas from Holocene and late Pleistocene terraces in the Ventura area. Amino-acid correlation of terrace remnants across the Red Mountain thrust fault indicate at least 20 m of displacement has occurred on the fault in the past 40,000 years. A ^{14}C date of 2,100 $\pm$ 80 years confirms the Holocene age of a marine terrace at Sea Cliff. Emergent Holocene terraces occur at only one other known locality along the west coast. The anomalously high tectonic uplift rates of the 40,000 year old terrace ($\geq$7.6 mm/yr) and the 2,100 year old terrace ($\geq$6.5 mm/yr) are consistent with rates of $\geq$10 mm/yr derived from geodetic data. ^{14}C dates, amino-acid age estimates and paleontological data agree with U-series dates on molluscs derived from data published by Kaufman and others (1971). This information suggests that Kaufman and others were incorrect in concluding that the U-series technique could not be used on molluscan fossils.

3. With Wehmiller and Sarna-Wojcicki collected and dated marine fossils from the thick stratigraphic section containing volcanic ashes on the south limb of the Ventura Avenue anticline. Preliminary results indicate amino-acid age estimates are consistently too old in the lower part of the section near the Bishop ash (700,000 yrs). We believe these old ages are the result of high temperatures related to the geothermal gradient. Results from this controlled experiment may help explain old amino acid age estimates in other thick stratigraphic sections in central and northern California.

4. Fossils from marine terraces at Summerland, Santa Barbara and Gaviota yield amino acid age estimates of 85,000 years. Terrace remnants of this age have not previously been found along the Ventura-Point Conception coast.

5. With Sarna-Wojcicki and Jack Hillhouse, collected paleomagnetic samples from the stratigraphic section on the south limb of the Ventura Avenue anticline to confirm age estimates based on ash correlations and study geothermal effect on amino-acid racemization.

6. With Joseph Liddicoat, collected Paleomagnetic samples in Mono Basin and Long Valley to refine dating and correlation of tectonically deformed sediments in the Great Basin and the south coastal region. Preliminary results are consistent with other age controls and possibly correlate sediments between Mono Basin and the Tahoe basin.

7. With Keith Kvenvolden and Dave Blunt (Pacific-Arctic Branch of Marine Geology), initiated an amino-acid dating project in the Great Basin using ostracods from lacustrine sediments. Preliminary results are stratigraphically consistent. This technique may provide a new tool for dating lacustrine deposits throughout the western U.S.

8. With Steve Robinson (Isotope Branch) collected samples of tufa deposits from Mono Basin to evaluate ^{14}C dating of this material and investigate isotopic response to lake fluctuations. Preliminary dates are stratigraphically and geomorphically consistent. Oxygen isotope values vary predictably with lake fluctuations. Oxygen isotope data may prove useful in dating and correlating lacustrine deposits in other basins.

Reports

Lajoie, K. R., and Wehmiller, J. F., 1978, Quaternary uplift rates, Southern California Borderland (abs.): A multidisciplinary Symposium on the California Borderland, Abstracts for 1977 Meeting, Santa Barbara Museum of Natural History, Santa Barbara, California, February 27-March 1, 1978.

Wehmiller, J. F., Lajoie, K. R., Sarna-Wojcicki, A. M., Yerkes, R. F., Kennedy, G. L., Stephens, T. A., Kohl, R. F., 1978, Amino-acid racemization dating of Quaternary Mollusks, Pacific Coast United States (abs.): Fourth International Conference on Geochronology, Cosmochronology and Isotope Geology, Aspen, Colorado, August 1978.

Eastern Transverse Ranges Tectonics

8-9540-01616

Douglas M. Morton
Branch of Western Environmental Geology
U.S. Geological Survey
345 Middlefield Road
Menlo Park, CA 94025

Investigations

1. Completed compilation of preliminary Quaternary deposits map of the upper Santa Ana river valley, southern California.

2. Completed isotopic (K/Ar) dating of Mesozoic granitic rocks from the eastern Transverse Ranges and southern Mojave Desert, southern California.

3. Completed field mapping of the northern frontal thrust system, San Bernardino Mountains, southern California.

4. Completed photointerpretive fault maps of a number of central Mojave Desert faults.

5. Began paleomagnetic study of young basaltic rocks in the southern Mojave Desert, eastern Transverse Ranges, and northern Peninsular Ranges, southern California.

6. Continued detailed mapping in the Riverside east and Riverside west quadrangles, southern California.

7. Continued detailed mapping in the San Timoteo Badlands, southern California.

Results

1. Results of detailed mapping southeast of Loma Linda, southern California, includes recognition of an older alluvium unit offset by what may be the northwestern extension of the Banning fault. Vertical component of the displacement along this northwest striking fault appears to be locally as much as 40 m, north side up.

2. Contouring of K-Ar apparent ages of granitic rocks from the Mojave Desert, southern California, suggest that offset on strike slip faults in that region is not as large as previously thought. Garfunkle (1974) argued that the aggregate right lateral offset across the three westernmost of these faults is 35 to 45 km. Apparent age contours in the vicinity of the westernmost two faults show no right lateral offsets, but are strongly disrupted where they cross these faults. It is thought that the lack of apparent right lateral offset and the disruption of the contours at the faults indicate that there is a component of vertical displacement across the faults and that right lateral offsets are small compared to those previously suggested.

Reports

Morton, D. M., 1978, Geologic map of the Fontana Quadrangle, San Bernardino and Riverside Counties, California: U.S. Geol. Survey Open-File Map 78-19.

Morton, D. M., 1978, Geologic map of the San Bernardino South Quadrangle, San Bernardino and Riverside Counties, California: U.S. Geol. Survey Open-File Map 78-20.

Morton, D. M., 1978, Geologic map of the Redlands quadrangle, San Bernardino and Riverside Counties, California: U.S. Geol. Survey Open-File Map 78-21.

Morton, D. M., 1978, Geologic map of the Sunnymead Quadrangle, Riverside County, California: U.S. Geol. Survey Open-File Map 78-22.

Morton, D. M., 1978, Ground fissuring in part of the San Jacinto Valley, southern California: Geol. Soc. Amer. Abs. with Programs, v.

Miller, F. K., and Morton, D. M., 1977, Comparison of granitic intrusions in the Pelona and Orocopia Schists, southern California: Jour. Research, U.S. Geol. Survey, v. 5, no. 5, p. 643-649.

Basement Tectonic Framework Studies, San Andreas Fault System

8-9950-01291
D. C. Ross
Branch of Earthquake Tectonics and Risk
U. S. Geological Survey
345 Middlefield Road
Menlo Park, CA 94025
(415) 323-8111 ext. 2341

Investigations

1. Field investigations of granitic and metamorphic terrane in the Kern River area northeast of Bakersfield, California.

2. Comparative petrographic study of metamorphic rocks from the Bean Canyon Formation and the "Kernville Series" on opposite sides of the Garlock fault.

3. Thin section petrographic study of selected samples of various granitic formations in the Tehachapi Mountains.

4. Compilation of data on metallic mineral occurrences in the Salinian block and the southernmost Sierra Nevada (San Emigdio and Tehachapi Mountains) to test "compatibility" of these two terranes on opposite sides of the San Andreas fault.

Results

1. Field work on both sides of the westernmost 90 km (55 mi.) of the Garlock fault zone suggests there are no convincing basement correlations across the fault along this interval. Two granitic rock types could be grossly "refitted" across the fault zone with 50 km of "right-lateral reversal", but the framework metamorphic rocks of these granitic suites are dissimilar. On the southeast (Mojave) side of the Garlock fault the metamorphic terrane is characterized by dark hornfels and schist, andalusite hornfels, distinctive calc-hornfels, and some metavolcanic rocks. On the northwest (Sierran) side of the fault zone the metamorphic rocks feature lighter quartzo-feldspathic hornfels and impure quartzite or dark dioritic gneisses with haloed coarse garnets. Recent suggestions have been made that the lateral offset on the Garlock may diminish toward the eastern and western ends of the fault zone (Troxel, Wright, and Jahns, 1972). My basement studies so far suggest at least 50 km of offset near the western (San Andreas) end of Garlock if one accepts the rather chancy granitic correlation just described. Thus the very minimum offset near the San Andreas terminus of the Garlock fault zone is comparable to the offset determinations of 50-60 km made elsewhere along the fault (G.I. Smith, 1962; Davis and Burchfiel, 1973).

2. A cross-section across the continental margin of nearly 300 km has just been completed from offshore of Point Sur across the Salinian block

and the San Joaquin Valley for the Plate Margins Group of the U.S. Geodynamics Committee. For the first time on a regional scale the complexities of the granitic and metamorphic units of the Salinian block are shown as is the controversial possibility that the Salinian block is "detached" only a few kilometers below the present surface.

3. A series of slivers and lenses of gneissic and schistose rock, strung out for about 22 km along the Garlock fault east of Tehachapi Pass, had been noted by earlier workers, but the source terrane was not known. Recent work has shown that the dominant rock type is dark dioritic gneiss with coarse haloed garnets which undoubtedly was derived from the extensive dark gneissic terrane that extends along the north side of the San Emigdio and Tehachapi Mountains. These garnet-bearing gneissic slivers indicate at least 45 km of displacement in a left-lateral sense from the parent gneiss terrane--providing another measure of minimum displacement on the Garlock fault zone. Within the series of slivers is one discrete dark schistose sliver about 5 km long that is characterized by coarse poikilitic albite (in part "black" with graphitic inclusions) and acicular actinolitic amphibole; biotite, epidote, and quartz are also common. These rocks range from well-foliated spotted schist to impure quartzite and some are probably metavolcanic. The overall lithology suggests these rocks may be part of the Pelona terrane.

4. North of the Kern River near the western edge of the basement rock outcrop a distinctive "polka-dot" dike has been traced discontinuously for about 1 km. The polka-dots are white haloed ovoid gray masses several cm across that are sparsely sprinkled with pink garnet, and are somewhat darker than the felsic dike matrix. What makes this dike more than a mineralogic curiosity is the fact that similar polka-dot dikes in the La Panza Range and the Salton Trough have been cited as evidence for the correlation of granitic terranes across the San Andreas fault (D. P. Smith, 1977; Ehlig and Joseph, 1977). The Kern area dike does not necessarily threaten such a correlation, but it does suggest some caution. "Publicity" should help determine whether polka-dot dikes are somewhat widespread and have been till now overlooked (which seems highly unlikely) or are indeed rare and a good correlation clue (along with other supporting data).

Reports

Ross, D.C., 1977, The Salinian block--A Mesozoic granitic orphan in the California Coast Ranges: in Howell, D.G., and McDougall, K.A., eds., Mesozoic Paleogeography of the western United States, Soc. Econ. Paleontologists and Mineralogists, Pacific Sec., Pacific Coast Paleogeography Symposium 2 (in press).

Salton Trough Tectonics

8-9940-01292

Robert V. Sharp
Branch of Ground Motion and Faulting
U. S. Geological Survey
345 Middlefield Road
Menlo Park, CA 94025
(415) 323-8111, Ext. 2596

Investigations

1. Continuation of photogeologic documentation of the surface rupture on the Imperial fault that accompanied the May 18, 1940 Imperial Valley earthquake.

2. Compilation of all evidence relating to late Holocene and historic movement on the Imperial and associated faults in southern Imperial Valley.

3. Further investigation by trenching of the Imperial fault at the International Boundary, using new strategies designed to yield evidence on Holocene strike slip displacement.

4. Paleochannel study on the Coyote Creek fault at a location where surface displacement occurred during the 1968 Borrego Mountain earthquake. The objective is to establish a record of horizontal as well as vertical components of late Holocene displacement.

Results

1. Vertical and oblique aerial views of portions of the 1940 earthquake surface rupture, as well as many ground views of the fault trace, permit a fairly accurate reconstruction of the detailed geometry and distribution of slip on the Imperial fault. The compilation reveals that the rupture trace was not a linear single break as depicted on many maps, but instead consisted of a number of en echelon separate breaks. The maximum displacement occurred about 1 km northwest of the All-American Canal where the initial slip, plus an unknown amount of afterslip, totaled about 6.3 meters, one of the larger historic strike-slip displacements known. The vertical airphotos show offset crop rows along a 14 km length of the fault trace, and they provide an unusually good record of short-distance variability of fault slip.

2. A field check of man-made features that cross the Imperial fault has provided a large amount of data on post-1940 fault slip and creep. Locations of these offset features agree closely with the 1940 fault trace as revealed in 1940 post-earthquake airphotos, as well as with distinct photo linears visible on pre-1940 airphotos. Agricultural activity in Imperial Valley has destroyed the natural evidence showing the position of the fault trace, but the combination of the pre- and post-1940 photo linear and creep data yields a fairly clear picture about the locations and complexities of separate strands of the Imperial fault.

3. Trenches cut across the Imperial fault at the International boundary have exposed the two 1940 fault ruptures that are known to have extended into

Mexico. In addition to fixing the location of the breaks in a sector where little surficial evidence of the 1940 rupture has survived, the trenches showed that no fault strands other than those that moved in 1940 exist, at least within 8 feet of the ground surface. The sequence of fluvial and lacustrine strata revealed in the trenches are unusually distinctive, and no difficulties in recognizing correlative beds on opposite sides of the fault strands were encountered. A cross-cutting channel was found near the main fault strand, and its truncation of a particular stratum was picked as a linear feature to be followed into and out of the fault break. A system of trenches and pits were cut to expose the two intersections of the linear feature (the "piercing points") with the fault surface. The offset on the fault strand was found to be 3.7 m, in close agreement with J. P. Buwalda's 1940 observation of slip at the international boundary. Although this evidence suggests that the channel deposits encountered in the trench have experienced only a single episode of fault movement, that of 1940, other stratigraphic features in the pre-channel section suggest that at least one additional slip event had occurred since the last 1.5 meters of pre-channel sediments were deposited. A C^{14} age from charcoal collected at the 1.5 meter level will soon define a maximum time during which at least two seismic events with major slip have occurred on the Imperial fault.

4. A paleochannel study on the Coyote Creek fault near the midpoint of the surface rupture of the 1968 Borrego Mountain earthquake has involved to date the cutting of 13 trenches and pits in various orientations with respect to the fault traces. The purpose of the study is to define in detail the pattern of faulting in a section of late Holocene fluvial and lacustrine sediments and to search for channels that could be traced across the complex of faults. At least one channel that crosses the entire fault zone was found, and it has been offset right laterally over 11 meters by at least 13 fault breaks. Only two breaks were known to be active in 1968. The data establishes a horizontal as well as vertical record of displacement and will provide a valuable test of the validity of assumptions commonly used in estimating earthquake recurrence times for strike slip faults based on the record of accompanying vertical components of displacement.

A C^{14} age run already on a peat stratum found in two of the trenches suggests that there is a very large error in apparent ages of shells from lake deposits found along the Coyote Creek fault. A 200 $\pm$ year estimate of the recurrence time of 1968-sized earthquakes on the Coyote Creek fault by Clark, Grantz, and Rubin (1972) probably is in error (too large) by a factor of about 3 to 4. Charcoal and shells from several stratigraphic positions in the new trenches will be dated to establish a correction schedule for apparent ages obtained from shells at that location.

Reports

Sharp, R. V., 1977, Holocene traces of the Imperial fault in Brawley, El Centro, Holtville West, Calexico, and Bond's Corner quadrangles, south-central Imperial Valley, California: U. S. Geol. Survey Open-File map 77-815, 5 sheets.

Quaternary Framework for Earthquake Studies
Los Angeles, California

8-9540-016

John C. Tinsley
Branch of Western Environmental Geology
U.S. Geological Survey
345 Middlefield Road, MS 75
Menlo Park, CA 94025
(415) 323-8111

Investigations

1. Completion of drafts of surficial geologic map (scale 1:24,000) of San Gabriel Valley and San Fernando Valley. Field checks and efforts to locate site suitable for sampling of soils for laboratory analyses are continuing.

2. Continuation of 1/24,000 geomorphic/photogeologic/soil stratigraphic mapping of Coastal Plain of Los Angeles County.

3. Coordinate the assembling of textural data for (scale 1:125,000) preliminary surficial materials maps of flatland areas of Los Angeles County, Ventura County, Riverside and San Bernardino Counties, California.

4. Prepare preliminary maps (1/125,000 & 1/48,000) showing textural characteristics of surficial geologic deposits in San Gabriel Valley and San Fernando Valley.

5. Reconnaissance field surveys of soil stratigraphic relations in Cucamonga, Lytle Creek, and Day Canyon areas of San Bernardino County.

6. Selection of 20 sites for in-situ measurements of shear-wave velocities using down-hole techniques (J. Gibbs, T. Fumol, and J. Roth).

7. Selection of 42 additional instrument stations in Los Angeles County to record ground motion generated by NTS nuclear tests. (A.M. Rogers, Project Chief).

8. Preparation of a liquefaction susceptibility map (1/48,000) for parts of the San Fernando Valley, Los Angeles County, California, based on data compiled from existing sources.

9. Addition of 40 new ^{14}C dates to the compilation begun one year ago.

Results

1. Geomorphic mapping and analysis, photogeologic mapping, and pedological studies have culminated in a preliminary version of a stratigraphy for Quaternary deposits in the San Gabriel and San Fernando Valleys.

Sites for sampling of soils are being sought so that quantitative laboratory data can be developed to better define pedological correlations and soil stratigraphic units.

2. The Baldwin Hills promises to be a natural laboratory for obtaining descriptions and analyses of Late Pleistocene soil stratigraphic units in the Coastal Plain of Los Angeles County.

3 & 4. Maps (scale 1:125,000) to describe the textures of surficial materials (0-2m subsurface) are being prepared for the following Los Angeles regions:

Areas	Authors	Status
Coastal LA County	(J. Tinsley)	
San Fernando Valley	(J. Tinsley)	(Draft)
San Gabriel Valley	(J. McCalpin)	(Draft)
North LA County	(D. Ponti & D. Burke)	
Ventura County	(A. Sarna-Wojcicki & G. McCoy)	(Draft)
Upper Santa Ana Valley	(D. Morton & B. Cox)	(Draft)

Surficial deposits are arbitrarily designated as "Holocene" if the surface soil lacks a textural "B" horizon; "Pleistocene" if the surficial soil exhibits a textural "B" horizon. The following facies are recognized for "Holocene" and "Pleistocene" materials: very coarse-grained (cobbles and boulders); coarse-grained (gravelly); medium-grained (sandy); and fine-grained (silts and clays). Deformed continental and marine deposits of Quaternary or Late Tertiary age, Tertiary sedimentary bedrock, Tertiary volcanics, and Pre-Tertiary crystalline and metamorphic lithologies will also be delineated where they bound the flatlands. To the degree that velocities of shear-waves characterize differences in ground response and correspond to textural characteristics of near-surface deposits, these maps could be interpreted to provide qualitative estimates of relative intensities of ground motion in the Los Angeles area.

5. Field reconnaissance of soil stratigraphic relations exposed in the Day Canyon-Cucamonga Canyon alluvial fan sequences show that alluvial deposits which are faulted are capped by soils exhibiting minimal development of soil profiles and weathering of intermediate clasts. Certain soil profiles are of interest because they are not distinguishable from soils on Holocene floodplains in the Los Angeles basin and thus may record young (Holocene?) episodes of fault movement in the Cucamonga-Day Canyon area.

6. J. Gibbs, T. Fumol, and J. Roth are measuring in-situ velocities at 20 sites selected by J. Tinsley and A.M. Rogers in the Long Beach and San Gabriel Valley areas in Los Angeles County. The data will be used to evaluate and calibrate experiments to predict ground response as a function of near-surface geology.

7. Recordings of Nevada Test Site nuclear events were made in the Long Beach, Calif. area on sites underlain by alluvium and simultaneously on rock at sites in the Palos Verdes and Pasadena areas. These data show peak-ground-velocity alluvium-to-rock ratios as large as 7 and spectral ratios in the period band 0.2-6 sec as high as 11. Comparison of the low-strain nuclear and the San

Fernando strong-motion data at three sites indicates that for nuclear events alluvium-to-rock horizontal spectral ratios are about 1.3 times the ratios for the earthquakes. Significant trends exist in the short-period data toward higher ground response at sites underlain by high void ratios in the near-surface materials and lower ground response with increasing thickness of Quaternary deposits.

8. With the assistance of T. L. Youd, E. King, R. Preston, and M. Bennett, geologic, hydrologic, and geotechnical data is being compiled, analyzed, and incorporated into a liquefaction susceptibility map of parts of the San Fernando Valley. The preliminary interpretation is entirely consistent with patterns of liquefaction induced by the San Fernando earthquake of 2/9/71.

9. More than 40 ^{14}C dates have been added to a compilation begun one year ago. The dates help us to establish local rates of sedimentation (vertical accretion) and rates of soil formation in the Los Angeles area.

Reports

Rogers, A. M., Tinsley, J. C., Hays, W. W., and King, K. W., 1978, Evaluation of the relation between near-surface geologic units and ground response in the vicinity of Long Beach, California, (Approved by the Director for publication outside the U.S.G.S.).

CALIFORNIA DIVISION OF MINES AND GEOLOGY

INVESTIGATION OF THE NORTHWESTERN PART OF THE SAN GABRIEL FAULT ZONE, WITH REGARD TO CHARACTER AND RECENCY OF MOVEMENT, LOS ANGELES AND VENTURA COUNTIES, CALIFORNIA by F. Harold Weber, Jr.

U S G S CONTRACT NO. 14-08-0001-16600, Modification 1

SUMMARY REPORT COVERING PERIOD OCTOBER 1, 1977 to MARCH 31, 1978

Continuation of the study of the San Gabriel fault zone between its northwesterly terminus in the vicinity of Frazier Mountain and the Little Tujunga Canyon area, a distance of slightly more than 70 km (44 miles), affirms that movement has occurred along the zone during late Quaternary time (roughly the last 100,000 to 300,000 years). The principal evidence for this movement consists of approximately 15 localities along the 70-km stretch of the zone studied which show late Quaternary older alluvium, landslide deposits, and paleosols juxtaposed or apparently juxtaposed against older rocks along faults. These relationships generally imply a sense of vertical offset but not a sense of horizontal offset or movement. The offsets are not large, although comparable in size (maximum of 10 - 15 m) to similar offsets along the northwest part of the Elsinore fault in northwestern Riverside County, which the writer studied under a previous U.S. Geological Survey contract. The offsets collectively suggest that land on the southwest side of the fault has been moving upward with relationship to land on the northeast side during late Quaternary time.

Well-developed geomorphic features that would indicate periodic and substantial movement in latest geologic time do not occur consistently along the San Gabriel fault zone, however, as they do along the Elsinore fault zone. Isolated examples occur, however: Beartrap Canyon area, youthful low scarps appear to occur along faults in the center of a graben; Placerita Canyon area, a moderate sized drainage is left-deflected or offset; and Little Tujunga Canyon area, a possible scarp occurs on the De Mille fault of the zone, and nearby ground cracks on another fault may have formed during the 1971 San Fernando earthquake. The extreme linearity of major parts of the fault zone also may indicate that it is active, as surely it is not being displaced or warped by other faults; in fact, west to east-trending structures of the Transverse Ranges either terminate against the fault, or are offset by it; some evidence suggests that along the northwest part of the zone several of these structures are offset right laterally between 1 1/2 and 2 1/2 km.

Mapping in the Valencia area disclosed that conglomerate beds of the Saugus Formation, of Plio-Pleistocene age, in outcrops north of the alluvial basin of the Santa Clara River contain clasts of Pelona Schist but no anorthosite; whereas, nearby outcrops to the south contain Pelona Schist as well as abundant anorthosite. This abrupt change across the logical continuation of the trend of the Hoser fault zone beneath alluvium east-southeastward from Hasley Canyon suggests that a principal trace of the Holser fault zone may terminate against the San Gabriel fault zone near the mouth of San Francisquito Canyon; this point is nearly 5 km northwest of Bouquet Junction, the generally accepted point where the Holser joins the San Gabriel fault zone.

Department of Geology, Oregon State University, Corvallis, Oregon 97331

USGS Contract No. 14-08-0001-16747

"Subsurface Geology of the San Gabriel, Holser, and Simi-Santa Rosa Faults, Transverse Ranges, California"

Robert S. Yeats, Principal Investigator
Jill T. Schlaefer
Fred M. Nelligan

SEMI-ANNUAL TECHNICAL REPORT SUMMARY

During the first six months reporting period, we began our study of the San Gabriel fault, concentrating on the Honor Rancho oil field, where Paschall and Off (1961) published evidence that the fault is mainly dip slip, and the Placerita oil field, where a Plio-Pleistocene sequence overlies a Paleogene marine sequence which itself overlies basement rocks, previously undescribed. Data were collected for 142 wells in the Honor Rancho area and 214 wells in the Placerita area. The Honor Rancho study is being done in cooperation with the Southern California Gas Company which is using the southeast area of the Honor Rancho field as a gas-storage reservoir; this will permit us to consider reservoir pressures and gas-injection barriers in mapping subsurface faults. We are now constructing cross sections and structure contour maps in both areas. We are integrating our work with a study of the surface trace of the San Gabriel fault (Weber, 1977) and a seismicity study by Murdock (1977, 1978).

Cross sections through the Honor Rancho oil field indicate that the Saugus-Sunshine Ranch (Pliocene-Pleistocene) stratigraphy is so similar on both sides of the San Gabriel fault that individual electric-log markers can be correlated across the fault without difficulty. This suggests little or no lateral displacement along the San Gabriel fault since Saugus-Sunshine Ranch deposition. The Pico Formation is similar on both sides of the fault, but it is not possible to correlate markers across the fault thus permitting but not requiring lateral displacement of the Pico along the San Gabriel fault. Pre-Pico stratigraphy on opposite sides of the fault is different. On the west side, granitic basement is overlain by upper Miocene Modelo Formation and Miocene-Pliocene Towsley Formation. On the east side, nonmarine middle Miocene Mint Canyon Formation is overlain by shallow marine upper Miocene Castaic Formation. Coarse-grained submarine fan deposits in the Modelo Formation have an easterly source across the San Gabriel fault, but coeval Castaic Formation immediately east of the fault consists mainly of massive marine siltstone which could not have served as a source for the Modelo fan deposits. A sedimentary breccia lens in the Modelo Formation was considered to be an interbed of Mint Canyon Formation by Paschall and Off (1961), but faunal evidence from the Modelo Formation above and below the lens and from the Castaic Formation east of the fault indicates that the Mint Canyon in this area is older than the breccia lens and that the lens itself is fossiliferous. Strata with Castaic and Modelo faunas are interbedded, as suggested by Paschall and Off (1961), but this may be explained by a biofacies boundary parallel to the San Gabriel fault.

The San Gabriel fault at Honor Rancho consists of a warped western strand with little or no surface expression and a planar, east-dipping eastern strand with surface expression in late Quaternary deposits as mapped by Weber (1977). Both strands cut the Saugus, but the western strand marks the boundary between Castaic and Modelo Formation. A suggested, but speculative history of the San Gabriel fault at Honor Rancho would include: (1) formation of the western strand after Modelo and Castaic deposition but prior to Pico deposition, possibly along a steep scarp marking the eastern boundary of the Modelo deep-water basin, (2) juxtaposition of the Modelo and Castaic basins by strike-slip faulting, (3) deposition of the Pico Formation and possibly additional strike-slip faulting, (4) deposition of the Saugus Formation, (5) dip-slip movement on the western and eastern strands, and (6) continued dip-slip movement on the eastern strand to late Quaternary time. This interpretation of the San Gabriel fault implies that the fault is no longer undergoing strike slip, but it is capable of dip slip because it continues to be a zone of weakness.

Basement rocks are found in several wells in the Honor Rancho and Placerita areas. All are granitic except basement in the Mobil H & M 1 well west of Placerita which encountered hornblende-biotite amphibolite which has some similarities to Pelona Schist.

A north-trending discontinuity separates contrasting pre-Towsley (pre-Pliocene) sequences in the Placerita area. On the west side, Topanga Formation is overlain by a thick sequence of deep-water Modelo Formation including submarine fan deposits. On the east side, basement rocks are overlain by marine Paleogene strata, nonmarine beds variously referred to as Sespe, Mint Canyon, or nonmarine Topanga, and by a thin sequence of Modelo. This discontinuity intersects the San Gabriel fault near the town of Saugus and may be of value as a piercing point for determining offset along the fault.

Eleven earthquakes of magnitude 3.9 or less occurred in January and February, 1973 just west of Honor Rancho oil field and south of the San Gabriel fault (Murdock, 1977; 1978). Focal depths are 17-20 km, unusually deep for California. The distribution of events and focal mechanisms as reported by Murdock do not correspond to any known structure in the area.

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Tectonics of the Western Transverse Ranges

8-9540-01615

R. F. Yerkes
Branch of Western Environmental Geology
U. S. Geological Survey
345 Middlefield Road
Menlo Park, CA 94025
(415) 323-8111 ext.2350

Field Investigations

a. A major fault offsetting Holocene stream terrace alluvium has been mapped in Javon Canyon, in the vicinity of Pitas Point, west of the town of Ventura. Apparent vertical displacement of the terrace alluvium and bedrock platform is 4.5 m. The fault strikes approximately east-west and dips 68° to the south. Apparent movement is reverse, south side up. The stream terrace deposits grade southward to an uplifted Holocene marine terrace which has been dated at 2,455 ^{14}C years b.p. (Wehmiller and others, 1978). Three or four debris cones from the front of the fault grade laterally into terrace alluvium and indicate recurrent movement post approximately 2,500 years b.p. This fault also offsets a higher, older uplifted marine terrace, dated at 45,000 ±10,000 years b.p. (by the amino-acid racemization method, Wehmiller and others, 1978). Apparent vertical offset on the latter terrace is about 36 m. The fault is situated between two major, east-west trending, north-dipping, high-angle reverse faults, (the Red Mountain fault, about one-half mile to the north, and the Pitas Point fault, approximately 2-2½ miles offshore to the south), elements of a through-going zone typical of Transverse Ranges structure.

b. The south branch of the Red Mountain fault in the vicinity of Sea Cliff, east of Rincon Point, offsets an uplifted marine terrace dated at 45,000 ±10,000 years b.p. (Wehmiller and others, 1978). Apparent vertical offset is estimated at between 12 and 21 m, with a minimum of 7 m. Trend of the fault is approximately east-west, up on the north.

Office Investigations

1. Compiled geologic data on fault activity and 1:250,000 map of faults for one square-degree area (N. lat 33° 45'-34°45' x W. long. 119°30'-120° 30') of Ventura and Santa Barbara Counties, including Santa Barbara Channel and the provincial boundary to the south.

2. Mapped focal mechanism solutions previously derived for 2 square-degree area (N. lat. 33°45'-34°45' x W. long. 118°30'-120°30').

3. Compared and analyzed geologic-seismologic data on geologic habit, displacement, and activity of faults for the 2 square-degree area. Prepared and submitted report on results.

4. Continued field investigation and report preparation on age, correlation, and deformation of exposed marine terraces along Santa Barbara-Ventrua Coast. (In cooperation with LaJoie, OES #9940-01623).

Results

Focal mechanisms based on about 200 M_L 2 to 6 events for the six-year period 1970-1976 in the western Transverse Ranges reflect the same stress regime as larger earthquakes in the region for which records are available: Subhorizontal compressive stress directed generally normal to the big bend of the San Andreas fault. The stress is expressed chiefly by seismicity and reverse displacement along several major through-going zones of north-dipping faults (Red Mountain-San Cayetano, Pitas Point-Ventura, Mid-Channel, and Anacapa-Santa Monica); a moderate component of left-lateral strike slip also is indicated. All available evidence on rate and sense of deformation is consistent for individual faults: geologic data on age and sense of latest displacement and amount and sense of stratigraphic separation, geodetic data on tilting of coastal areas underlain by faults, uplift of dated marine terrace deposits in coastal areas underlain by faults, and associated focal mechanisms. The indicated average rates of deformation (5-10m/thousand years) are consistent for the several types of evidence and show no evidence of slowing over the last 45,000 years.

The through-going east-trending, north-dipping reverse faults that dominate the structure of the western Transverse Ranges resemble slip surfaces between a sequence of north-to northeast-dipping shingles along which many kilometers of north-south shortening and some east-west extension has occurred in late Quaternary time. At the present rates, all the measured compressive deformation in the western Transverse Ranges could have occurred during the last 0.5 to 1 million years.

Reports

1. R. F. Yerkes and W. H. K. Lee, Late Quaternary deformation in the western Transverse Ranges, California: Chapter for U.S.G.S. Prof. Paper. Submitted to TRU 8 May 78.

2. W. H. K. Lee and R. F. Yerkes, Seismicity of the western Transverse Ranges, California (companion report): Chap. in U.S.G.S. Prof. Paper.

3. J. F. Wehmiller, K. R. Lajoie, A. M. Sarna-Wojcicki, R. F., Yerkes and others, 1978, Amino-acid racemization dating of Quaternary mollusks, Pacific Coast United States (a ten page illustrated abstract): Proceedings, Fourth International Conference on Geochronology, Cosmochronology and Isotope Geology, Snomass-at-Aspen, Colo., Aug. 1978.

4. Wehmiller, J. F., Lajoie, K. R., Sarna-Wojcicki, A. M., and Yerkes, R. F., Unusually high rates of crustal uplift in Ventura County, California inferred from Quaternary marine terrace chronology (abs.): 1978 National G.S.A., Toronto.

Southwest Utah Seismotectonic Studies

8-9950-01738

R. Ernest Anderson
Branch of Earthquake Tectonics and Risk
U. S. Geological Survey
Denver Federal Center, MS 966
Denver, CO 80225
(303) 234-5109

Investigations

1. Field studies in the vicinity of Beaver, Utah.

2. Organized and prepared road log and guide book for Geol. Soc. America field trip from Provo to Cedar City and return.

3. Compiled data on slope angles and heights of fault scarps in the Beaver and Panguitch areas.

4. Field studies with U.S. Bur. Reclamation geologists concerning suitability of sites in Clark Co., Nevada, for engineered structures.

5. Field studies with R. G. Bohannon, U.S.G.S., concerning structural and stratigraphic relationships and problems along the Colorado Plateau-Basin and Range boundary in the Lake Mead area, Nevada.

Results

1. Studies of soils, tephra, geomorphic surfaces, and geologic relationships in the vicinity of Beaver, Utah, indicate the following sequence of events during the last 0.7 m.y.: (a) deposition of lacustrine sediments and intercalated layers of ash and tephra during the 0.7-0.5 m.y. interval, (b) displacement of the sediments by at least one northerly trending fault, (c) deposition of mafic lava that erupted from a vent to the north in the Cove Fort area, (d) displacement by northerly trending faults and associated stratal tilting which, together, produced a north-trending antiformal structure characterized by "limbs" that are structurally deflated by faults that dropped strata down toward the "fold axis," (e) erosional breaching of walls of closed lacustrine basin resulting in erosional planation of the north-trending antiform by through-flowing streams and deposition of a gravel mantle on the erosion surface, (f) beginning of development of carbonate soils on the gravels, (g) renewed faulting and associated stratal tilting on same trends as for early antiform, (h) continued soil formation and erosional breaching resulting in production of a series of stream terraces on which soils developed to contrasting stages of maturity, (i) renewed faulting on northerly trends, (j) continued erosional downcutting to present.

It is not certain whether faulting and stratal tilting were quasicontinuous processes or divided into the three distinct episodes as indicated. In any case, the indicated normal displacement on individual faults during the late Quaternary is at least 25 m and may be as much as 70 m. It is hoped that continued studies will result in a closer definition of the age of the fault events. All are probably pre Holocene based on estimates made from the morphology of the fault scarps (Bucknam and Anderson, 1978). Current understanding of the chronology of events is based on a fission track age by Charles Naeser, a K-Ar age by Harald Mehnert, and an ash typing by Glenn Izett.

Reports

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Seismotectonic Analysis
Rio Grande Rift, New Mexico
8-9530-01556

Elmer H. Baltz
Branch of Central Environmental Geology
U.S. Geological Survey
Denver Federal Center, MS 913
Denver, CO 80225
(303) 234-3147

Investigations

1. Continuation of field mapping of Quaternary deposits and physiographic features, eastern front of Sangre de Cristo Uplift, to validate and refine ages of Pleistocene faulting.

2. Collection of basalt samples for radiometric age determinations, Ocate volcanic field.

3. Photogeologic mapping and compilation of new structural data on Albuquerque and Estancia Basins, Socorro 2° sheet (34°-35° N., 106°108° W.).

4. Photogeologic mapping of physiographic surfaces, and preparation of physiographic profiles and structure cross sections, Santa Fe region.

5. Petrologic and petrofabric analysis of Precambrian basement rocks, Mora-Rociada area.

6. Collection of soil-sample suite, Las Cruces and Albuquerque areas, for experimental age dating analysis by carbonate-thermoluminescence and uranium-trend methods.

Results

Results are similar to those reported in the January, 1978, summary. Project personnel are involved in data analysis and report completion.

Reports

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Machette, M. N., and Bachman, G. O., (in press), The age, morphology, and rate of accumulation of some pedogenic calcretes in New Mexico, USA: International Association of Sedimentologists, 19th International Congress on Sedimentology, Abstracts (in press).

CALCULATED STRAIN RATES AND THEIR IMPLICATIONS FOR THE DEVELOPMENT OF THE HURRICANE AND TOROWEAP FAULTS, UTAH AND NORTHERN ARIZONA

U.S.G.S. No. 14-08-0001-G364

Technical Report Summary

by

R. D. Holmes*, M. G. Best, and W. K. Hamblin
Department of Geology
Brigham Young University

The thermoluminescence (TL) method has been applied to the age dating of alkalic basalts from the eastern margin of the Basin and Range province (Holmes, in press). Locally, these basalts are cut by normal faults exhibiting recurrent movement which postdates the eruption of the lava flows. Absolute strain rates, or rates of fault displacement, have been calculated for basalts of known age and fault displacement. The results and interpretations of these calculations for thirteen such lava flows from southern Utah and northern Arizona (Fig. 1) are presented here.

Recent study of the geomorphic development of the Wasatch fault scarp (Hamblin, 1976) has shown that the displacement history of this fault is characterized by alternating periods of recurrent movement and of quiescence or tectonic inactivity. Subsequent study by Anderson (1977) has shown that these periods of active displacement and of quiescence can be correlated for more than 75 km along the length of the Wasatch fault zone. The quantitative data presented below suggest that such a pattern of alternating periods of tectonic activity and inactivity may also be typical of segments of the Hurricane and Toroweap faults some 400 km to the south.

The theoretical limitations of calculating absolute strain rates from the fault displacements of lavas of known age can be seen by a careful examination of Figure 2. In contrast to the semi-continuous record of displacement preserved by the geomorphic development of major fault scarps (see Hamblin, 1976), a measured displacement and age give only the average rate of fault displacement since that time; no specific information is gained regarding the detailed history and sequence of that displacement (Fig. 2). Moreover, the analytical uncertainties in the age determinations may make it impossible to determine details of the displacement history even when several data points are available (see, for example, Point C in Fig. 3).

Nonetheless, even when the average strain rate is the only available evidence, as is the case in this study, it may still be possible to draw some generalizations regarding the gross patterns of displacement history. Recent strain rates which are markedly different from the average rates of displacement since some older event (see Fig. 2) may allow some boundary conditions to be set on the recent patterns and history of fault displacement. For example, the strain rates recorded by lavas erupted across a fault exhibiting recurrent movement (Fig. 3) may be greater than, less than or indistinguishable from the average rates of displacement since some older event (e.g. the inception of faulting). These data, respectively, might indicate or delimit periods of active tectonism, of relative quiescence, or of "normal" fault activity.

Dated lavas from three distinct fault segments were available for analysis in this study. The dated basalts range in age from 0.09 to 1.05 m.y. The three

*Now at Department of Geology, Australian National University, Canberra, Australia.

fault segments studied are shown in Figure 1; they are the northern Hurricane fault (in southern Utah), the southern Hurricane fault (in Whitmore Wash, Arizona) and the Toroweap fault (in Toroweap Valley, Arizona). The total displacements of these faults throughout geologic time, as given by Hamblin (1970), are 2400 m (8000'), 460 m (1500'), and 240 m (800'), respectively.

The fault displacements for each of the flows dated by the TL method, together with their TL age dates and calculated rates of displacement are listed in Table 1. Also listed in Table 1 are the ages, displacements and strain rates of several older basalts from this area which have been dated by the K-Ar method. Figure 1 shows the location of these dated samples relative to the major fault zones of the area.

For the dated flows available, the average rates of displacement are 320 $\pm$ 80 m/m.y. for the northern Hurricane fault, 170 $\pm$ 30 m/m.y. for the southern Hurricane fault, and 70 $\pm$ 15 m/m.y. for the Toroweap fault. The significantly lower strain rate recorded by sample Zion-68 may be due to an error in the TL age date. Its proximity to samples Zion-20, Zion-57 and SG-81, which are only slightly greater age and which cluster near the average strain rate of 320 m/m.y., suggests that the value of 77 m/m.y. is anomalous and does not actually record a period of tectonic quiescence.

Further calculations suggest that two of these average rates of recent displacement are significantly higher than the corresponding presumed average rates of fault displacement over the last 10 m.y. McKee and McKee (1972) estimate that most of the uplift of the Grand Canyon region has taken place within the last 5-10 m.y. By assigning an arbitrary age of 6 m.y. to the inception of faulting at the three studied locations, it is possible to project these most recent strain rates back over the postulated lifetime of these faults and to calculate the total displacement that would occur (see Fig. 2). The projected displacement of the northern Hurricane fault is 1900 $\pm$ 500 m, slightly lower than but not significantly different from the observed total displacement of 2400 m. In contrast, the projected displacement of the southern Hurricane fault segment is 1000 $\pm$ 200 m, more than twice the observed displacement of 460 m; the calculated displacement of the Toroweap fault, 420 $\pm$ 80 m, is also nearly twice the observed total displacement (240 m). These calculations appear even more significant in consideration of the fact that the arbitrarily assigned age of 6 m.y. is considerably younger than either the inception of Basin and Range faulting 16-19 m.y. ago or the 10 m.y. upper limit set by McKee and McKee (1972) for the beginning of major uplift in this area. These data show that recent displacement (<0.5 m.y.) along the southern Hurricane and Toroweap faults have taken place at rates significantly higher than those typical of the preceding 5-10 m.y.

We suggest, therefore, that the southern Hurricane and Toroweap fault segments are currently undergoing a period of active tectonic displacement and that these lavas record the type of recent tectonic activity modeled by event A in Figure 3. The northern Hurricane fault, in contrast, appears to have undergone recent displacement at rates not markedly different from its presumed average rate of displacement since the beginning of Pliocene time and records the type of displacement history modeled by event C in Figure 3. These data suggest that a "stop-and-go" pattern of alternating periods of recurrent fault movement and of tectonic quiescence may have typified the displacement history of these fault segments.

Figure Captions

Figure 1 - Index map showing the location of TL and K-Ar samples relative to the major fault zones of southern Utah and norther Arizona. The three fault segmens considered in the text are the southern Hurricane fault (#1-3), the Toroweap fault (#4-6), and the northern Hurricane fault (#7-13). The Type I samples dated by the TL method are olivine tholeiite basalts; the Type II samples are alkali olivine basalts and basanites and the Type III samples are basaltic andesites. Each petrochemical type requires a slightly different TL calibration; only the Type II samples are considered in this study. Sample numbers correspond to those in Table I.

Figure 2 - The limitations of determining strain rates and displacement histories by measured offsets on lava flows of known age. Points of known age and fault displacement give little information on the actual patterns and paths of displacement.

Figure 3 - Hypothetical displacement history of a fault exhibiting alternating periods of recurrent movement and of tectonic quiescence. Events of A-D represents points of known age and displacement (i.e. faulted lavas of known age).

TABLE 1

Strain Rate Calculations

Sample	Age	Offset	Rate	Fault
Whw-2	0.088 ± 0.015* m.y.	22 m	250 ± 60 m/m.y.	S. Hurricane
Whw-6-3	0.203 ± 0.024*	25	125 ± 20	
Whw-9	0.108 ± 0.029*	15	140 ± 35	
Vulc-11	0.201 ± 0.034*	15	75 ± 15	Toroweap
Twp-17	0.284 ± 0.048*	17	60 ± 15	
Htn-18	0.297 ± 0.074*	20	70 ± 20	
Zion-55	0.73 ± 0.02+	230**	315 ± 20	N. Hurricane
Zion-57	0.36 ± 0.08+	137**	380 ± 90	
Zion-65A	1.05 ± 0.07+	377**	360 ± 30	
Zion-68	0.30 ± 0.05*	23**	77 ± 15	
Zion-20	0.26 ± 0.07+	46**	180 ± 45	
SG-81	0.244 ± 0.021+	91	370 ± 30	
"	0.282 ± 0.073*	"	325 ± 80	
Zion-69	0.44 ± 0.04	130	295 ± 30	

*Determined by the TL method.
+Determined by the K-Ar method (M.G. Best, 1978, pers. comm.).
**Represents the flow's elevation above the present drainage levels rather than its displacement where directly cut by recurrent faulting.

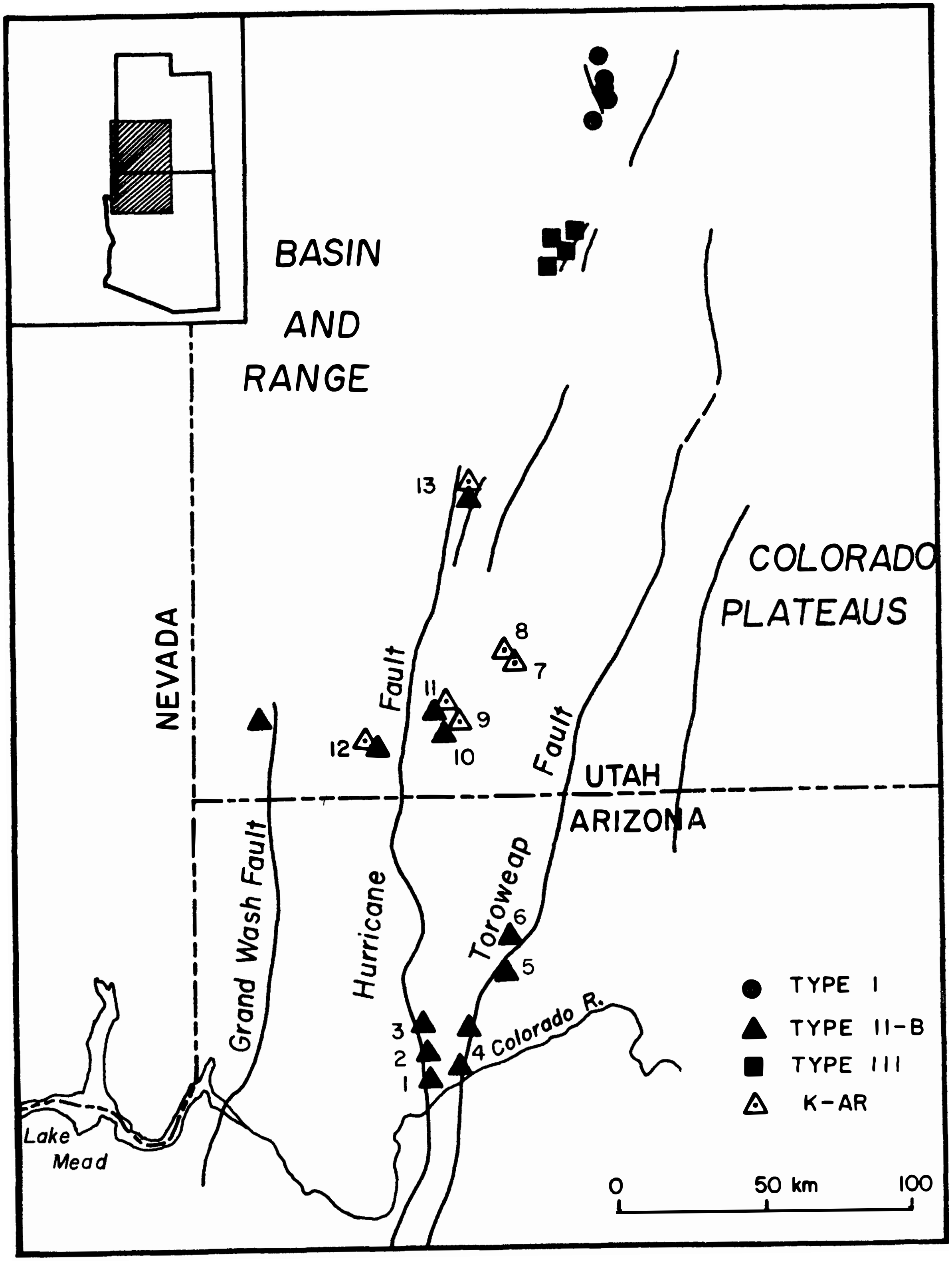
BASIN
AND
RANGE
COLORADO
PLATEAUS
NEVADA
UTAH
ARIZONA
Grand Wash Fault
Hurricane Fault
Toroweap Fault
Colorado R.
Lake Mead
1
2
3
4
5
6
7
8
9
10
11
12
13
TYPE I
TYPE II-B
TYPE III
K-AR
0
50 km
100

Figure 1

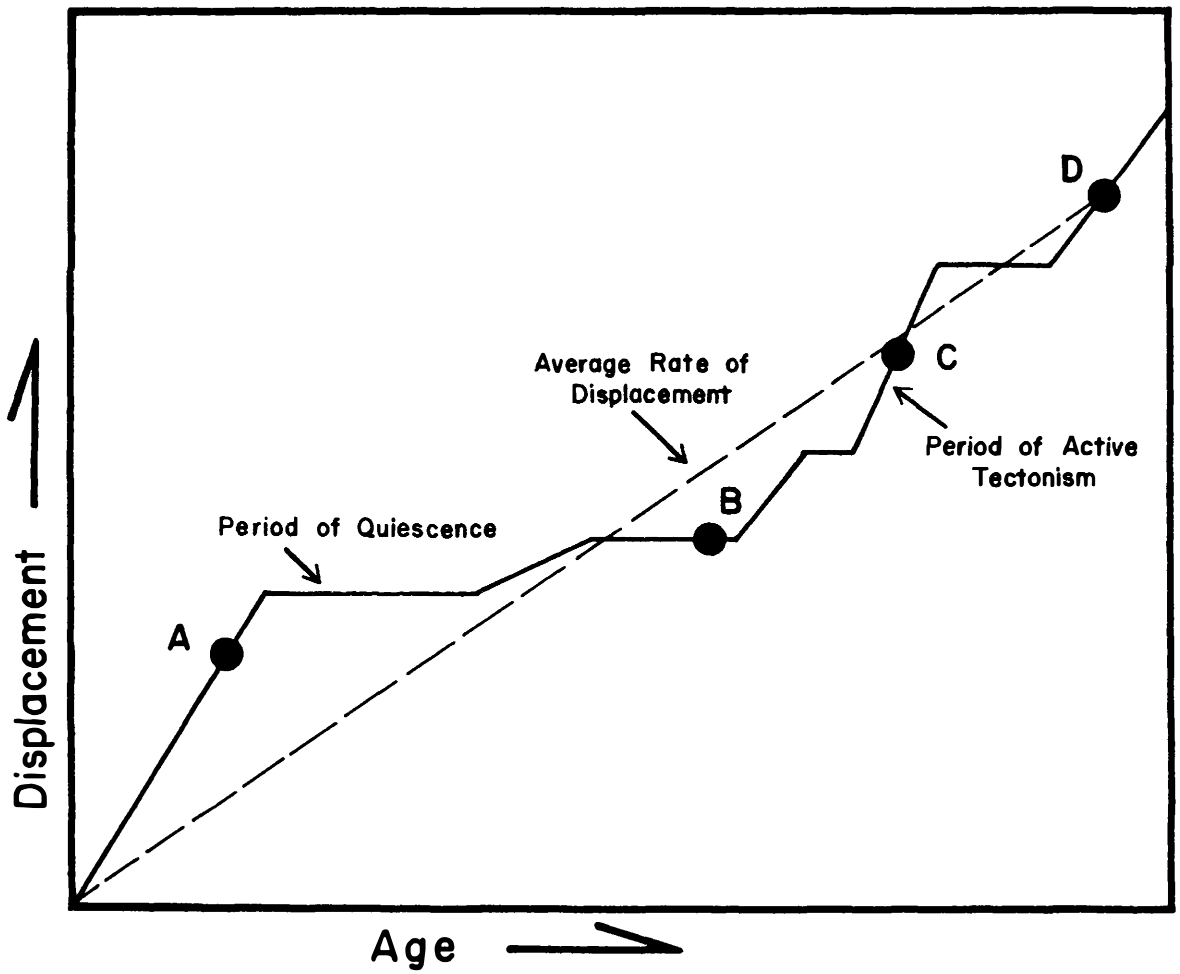
Average Rate of
Displacement
Period of Quiescence
Period of Active
Tectonism
A
B
C
D
Displacement
Age

Figure 2

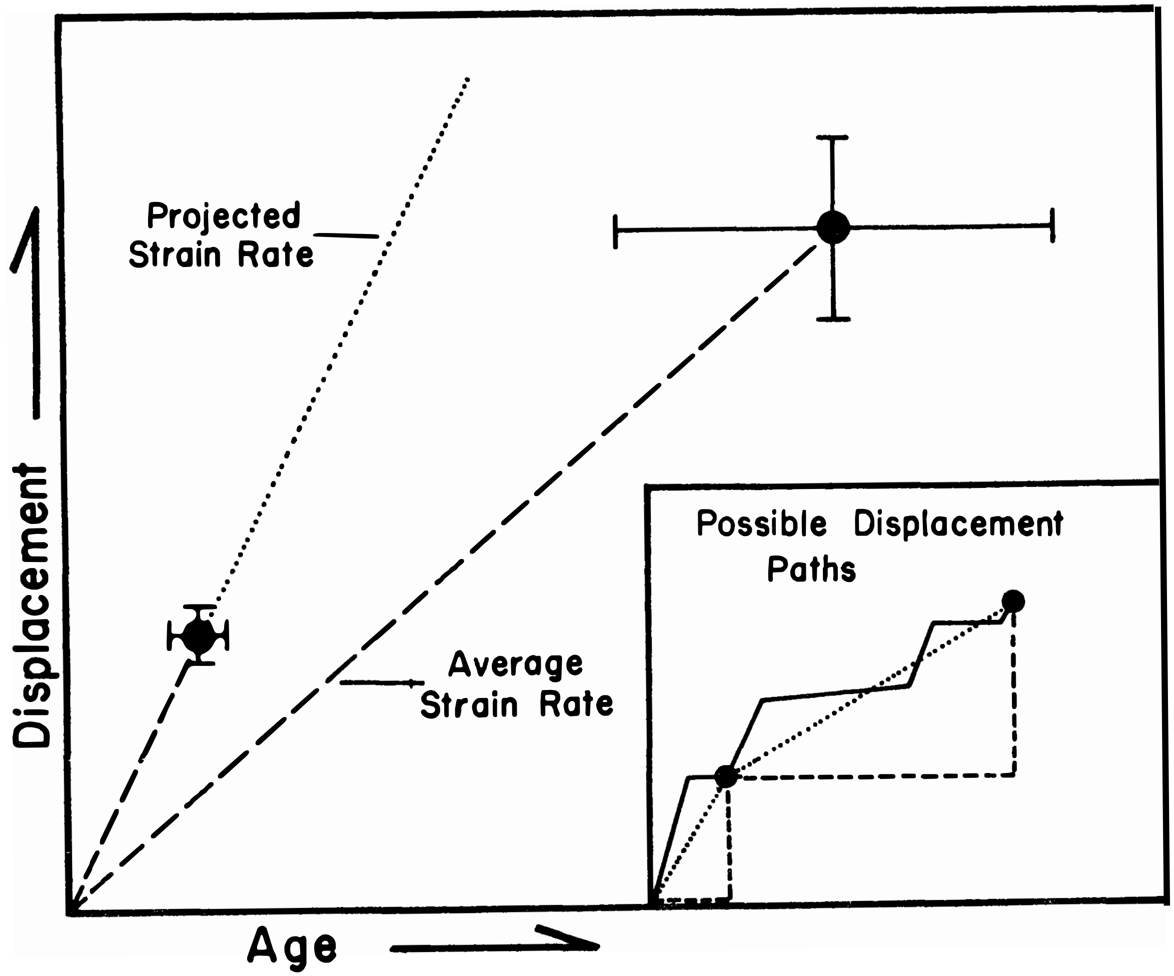
Projected
Strain Rate
Average
Strain Rate
Possible Displacement
Paths
Displacement
Age

Figure 3

Characteristics of Active Faults in the Great Basin

8-9950-01538

R. C. Bucknam
Branch of Earthquake Tectonics and Risk
U.S. Geological Survey
Denver Federal Center, MS 966
Denver, CO 80225
(303) 234-5089

Investigations

1. Profiles of fault scarps at the Fish Springs, Drum Mountains, Scipio Valley, Panguitch, and Beaver, Utah, were studied to evaluate the statistical significance of the relationship among scarp height, slope angle, and age. Additional field data were collected to augment several of the data sets.

2. Participated in post-earthquake field studies of the 1977 San Juan, Argentina, earthquake.

Results

1. Well-defined curves described by the slope profile data show that for scarps of a given age, the slope angle of the scarp is proportional to the logarithm of the scarp height. Regressions of slope angle on the logarithm of scarp height typically give standard deviations of about 2° and coefficients of determination (R^2) of about 90 percent. For scarps of a given height, there is a regular decrease in slope angle with increasing age. The relations indicate that such measurements can provide a means of ranking scarps according to relative geomorphic age. The scarps studied range in age from about 1,000 years to about 100,000 years and the procedures may provide a means of discriminating age differences of about 50 percent of the age involved.

2. Careful study by aerial reconnaissance of the epicentral region of the San Juan, Argentina, earthquake failed to locate any surface ruptures that might have been produced by the earthquake, although numerous prehistoric fault scarps in alluvium are present in the area. Liquefaction was a common phenomenon and occurred as far as at least 200 km from the epicenter. The close association of liquefaction effects such as tilted buildings, localized relative changes in elevation of the ground of 0.5 m, sand blows, and fissures at that distance adjacent to adobe buildings lacking visible damage indicates that liquefaction can occur at low intensity levels.

Reports

Bucknam, R. C., and Anderson, R. E., 1978, Use of slope angle to determine fault scarp age [abs.]: Geol. Soc. America Abs. with Programs, v. 10, no. 5, p. 211.

Bucknam, R. C., and Anderson, R. E., 1978, Estimation of fault scarp ages by use of a scarp height-slope angle relationship: Dir. approval.

Algermissen, S. T., Castano, J. C., Langer, C. J., Harding, S. T., Bucknam, R. C., 1978, A preliminary report on the western Argentina earthquake of November 23, 1977 [abs.]: Earthquake Notes, v. 49, no. 1, p. 40.

Anchorage-Susitna Lowlands Earthquake Hazards Mapping

8-9310-02078

Oscar J. Ferrians, Jr.
Branch of Alaskan Geology
U.S. Geological Survey
345 Middlefield Road
Menlo Park, CA 94025
(415) 323-8111 ext. 2247

Investigations

1. First-stage work necessary for initiating studies on new project.

2. Preparatory work for upcoming field season.

Results

1. Completed preliminary literature search for pertinent geologic reports of region and for reports relating to earthquake hazards mapping.

2. Coordinated with members of the Branch of Engineering Geology and of the Alaska Division of Geological and Geophysical Surveys who will be working on project.

3. Corresponded with members of the Municipal Geotechnical Advisory Commission and of the Planning Department of the City of Anchorage concerning the objectives and scope of the new project and of the concerns of the city.

4. Ordered, received and organized aerial photographs covering entire region.

5. Made request to the Topographic Division for new base map coverage of region at metric scale of 1:100,000.

6. Compiled geologic map of most of region based on existing mapping. Emphasis of mapping has been placed on bedrock--surficial deposits generally not subdivided, except in Anchorage area.

Seismo-Tectonic Analysis of Puget Sound Province

8-9540-02197

Howard D. Gower
Branch of Western Environmental Geology
U.S. Geological Survey
345 Middlefield Road, MS 75
Menlo Park, CA 94025
(415) 323-8111, ext. 2352

Investigations

1. Detailed high-resolution seismic profiling surveys were made of southern Puget Sound, San Juan Island area, and southern Strait of Georgia.

2. An aeromagnetic survey, flown at 2 mile flight line spacings, was made of the San Juan Island - Strait of Georgia area (48°30'--49°00'N, 123°30'--122°00'W). An analysis of the magnetic anomalies is underway.

3. Geologic mapping of Tertiary, sedimentary and volcanic rocks along the large Seattle-Bremerton gravity anomaly has been started.

4. Samples and logs of several deep oil exploration wells in the central Puget Sound area are being studied to provide information on the subsurface stratigraphy and structure of the region.

5. Photography has been obtained to investigate the validity of a suspected major tectonic structure along the prominent arcuate topographic feature in the western Cascade Range east of Seattle. Geologic field investigations of this inferred structure will begin in June, 1978.

6. Detailed gravity studies are being made in the vicinity of Seattle and in the San Juan Islands.

Results

1. Marine seismic records of Commencement Bay in southern Puget Sound were inferred by earlier investigators to show a pronounced northwest Holocene fault offsetting the sea floor. A detailed high-resolution survey, however, has shown that the features interpreted as faulting are related to down slope gravitational movement of the sedimentary deposits beneath Commencement Bay and that no Late Quaternary faulting is present.

2. High-resolution seismic profiling in the southern Strait of Georgia did not reveal any faulting in the late Quaternary deposits.

Reports

Gower, H. D., 1978, Tectonic map of the Puget Sound region, Washington, showing locations of faults, principal folds and large-scale Quaternary deformation: U.S. Geological Survey Open-File Report 78-426.

Snavely, P. D., Jr., Gower, H. D., Tagg, A. R. and Lands, Diane, 1978, Notes on acquisition of high-resolution seismic profiles in southern Puget Sound, Washington: U.S. Geological Survey Open-File Report 78-328.

U.S. Geological Survey, 1978, Aeromagnetic map of the Bellingham area, Washington: U.S. Geological Survey Open-File Report 78-354.

Wasatch Front Surficial Geology

8-9550-01622

Robert D. Miller
Branch of Engineering Geology
U.S. Geological Survey
Box 25046, MS 903
Denver, CO 80225
(303) 234-2960

Investigations

1. The purpose of this investigation is to prepare maps of the distribution and physical properties of surficial materials of an 8000-square-kilometer area along the Wasatch Front, Utah. The information will provide a basis to predict ground-motion response and could be applied to a microzonation map of seismic risk for the urban corridor. Compilation of the distribution of surficial materials on a 1:125,000-scale topographic base map has been completed in the Great Salt Lake Valley and is 40 percent complete in the Utah Lake Valley to the south. The compilation combined interpretation of high-altitude aerial photographs, published geologic maps, and soils maps on a photobase prepared by the USDA Soil Conservation Service. Photointerpretation utilized the Kern PG-2 optical plotter which permitted accurate placement of map unit boundaries of materials. Map units were selected on the basis of genetic and textural properties. Origins of unmapped deposits between areas covered by published maps were determined by standard interpretive techniques with emphasis on those geographic and geomorphic attributes that are prominent in optical stereo-device-controlled compilations. Textural characteristics of deposits in these areas were interpreted from descriptions by the Soil Conservation Service of parent soil materials. After reconnaissance field investigations to confirm interpretations, these map units were coded into the compilation according to textural characteristics and origin.

2. Laboratory physical property tests on undisturbed drill samples of the unconsolidated material along the Wasatch Front are being conducted in the Engineering Geology Branch laboratory; about 40 percent of the samples have been tested to date. Full evaluation of the test results await the availability of all test data, at which time the data will be applied to the preparation of the physical property map. Examples of tests performed include textural determinations, natural moisture content, void ratio, density, and consolidation characteristics.

3. Logs of borings on file with Water Resources Division of the USGS in Salt Lake City were obtained and plotted on the base maps.

Results

1. The preparation of a surficial geologic map from the compilation of the materials data has been 80 percent completed for the Salt Lake Valley area.

2. Descriptions of the materials beneath the drill sites have been analyzed. The descriptions confirm the anticipated distribution of textural changes of the geologic materials at depth as inferred from the configuration of the map units on the geologic map and from the USGS drilling program data.

TECHNICAL REPORT SUMMARY

October 1, 1977 - March 31, 1978

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

Jack Oliver, Principal Investigator
Report prepared by Robert Reilinger

CORNELL UNIVERSITY
Department of Geological Sciences
Ithaca, New York 14853

Purpose

The purpose of this study is to provide a better understanding of the relationship between recent crustal movments, primarily as determined by leveling, and earthquakes with the hope that improved understanding of this relationship will provide means of ameliorating the earthquake hazard.

Method

Collection of the relevant data for analysis begins by determining the routes of leveling in an area of interest for which at least two levelings separated significantly in time exist. Then the various data sheets for these specific levelings are obtained from the storage files of the National Geodetic Survey. The observed elevations of benchmarks common to the original and subsequent levelings are then coded and keypunched for computer reduction. A Fortran IV program then computes and plots differential movements and rate differences for benchmarks along the profile.

Interpretation of the data entails placing the results of the analysis in the perspective of what is known about the relevant geology and tectonics as well as evaluating existing theories in the light of the new information from leveling data.

Results

I. Relative Crustal Subsidence From Leveling Data in a Seismically Active Part of the Rio Grande Rift

Analysis of repeated leveling surveys in a part of the Rio Grande rift shows a zone of pronounced relative subsidence which appears to be associated with anomalous seismic activity north of Espanola, New Mexico. Maximum subsidence relative to nearby benchmarks was 4.4 cm between September, 1934 and March, 1939. Observed subsidence occurs over a distance of approximately 19 km extending from 4 km north to 23 km north-northwest of Espanola. The leveling anomaly does not appear to be associated with either near surface effects or leveling errors and thus most likely represents crustal deformation. Besides the correlation with seismic activity, the zone of relative subsidence occurs near some unusual post-Miocene dikes in this part of the rift. In addition, extremely high heat flow (5.3 HFU) has been reported nearby the zone of subsidence. The crustal movement anomaly appears qualitatively similar to movements observed in the Socorro, New Mexico area of the Rio Grande rift which have been associated, for a variety of reasons, with a crustal magma body. The movements reported here appear consistent with deflation of a shallow (<10 km) magma body although rapid cooling of a recent crustal pluton or normal faulting within the crust could give rise to the observed surface deformation.

II. Recent vertical crustal movements along the west coast of the U.S. from leveling and tide gauge measurements

A profile of relative vertical crustal movement has been compiled from leveling data along the west coast of the United States. The profile extends from Astoria, Oregon to San Diego, California. The movement profile is continuous except for a gap north of Point Arena, California and south of Los Angeles, California. It was not possible to obtain uniform time coverage from the available data. Vertical crustal movements along the coast were also determined from tide guage measurements. Comparison of movements indicated by leveling to those indicated by tide gauge measurements indicate discrepancies which cannot be accounted for by random measurement error. Some of this discrepancy may be due to problems associated with compiling long movement profiles from inhomogeneous leveling data.

The most outstanding feature of the coastal leveling profile is a zone of pronounced relative uplift along the San Andreas fault between San Francisco, and Point Arena, California. This section of the movement profile was derived from second order leveling surveys conducted in 1935 and 1942.7. Maximum uplift reaches about 23 ± 4 cm near Bodega, California relative to benchmarks near San Francisco. These movements may be due to post-seismic deformation associated with the 1906 San Francisco earthquake.

III. Relative vertical crustal movements in the Klamath Mountains and surrounding areas, northern California

Two profiles of relative vertical crustal movment within the Klamath Mountains in northern California have been derived from NGS leveling data. Both profiles indicate rapid uplift of the Klamath Mountain relative to points to the east within the Great Valley and Columbia Plateau. The profiles are characterized by sharp offsets which in a number of cases separate segments which show little internal deformation, suggesting decoupled, block type behavior of the crust in this area. The most pronounced offset occurs between the western Klamath Mountain and Great Central Valley indicating about 48 cm of relative uplift of the western Klamath Mountains. Our analysis indicate that these offsets are not associated with near surface effects such as benchmark instability or fluid withdrawal. However, misreadings by the field crew could conceivably be responsible for a number of features indicated by the data.

Significant movements also occur near the contact between the southern Klamath Mountains and adjacent Coast Range. These movements appear indicative of elastic rebound. Although a number of faults have been mapped in this area, all have previously been considered inactive.

IV Recent vertical crustal movements in the U.S.: a comparative analysis

In order to examine the factors which affect our understanding of estimates of recent vertical movements as derived from leveling measurements and to develop some criteria with which to evaluate their reliability, a comparative analysis is made of observed apparent elevation changes in three very different tectonic settings in the U.S.--Alaska, New Mexico, and North Carolina. The relevant measurements in the first two areas can be related satisfactorily to deformational processes consistent with what is known about their tectonic environment. Yet the observations in North Carolina, which are similar in several respects to those of the other two examples, are much more difficult to interpret in terms of plausible mechanisms. Whether or not this interpretational uncertainty constitutes a legitimate criterion for evaluating reliability is considered. Comparison of regional scale profiles of apparent vertical crustal movement shows considerable similarity between those movements in the neotectonically "active" western U.S. and the nominally "stable" eastern U.S. Uncertainties related to the role of systematic errors and the lack of easily demonstrable mechanisms are shown to be more serious for these longer baselines, and criteria are presented for evaluating their significance. The comparative analyses presented here emphasize that leveling measurements can be an important source of information on tectonic processes with significant implications for models of earth rheology, although there remains serious uncertainties as to the proper interpretation of some measurements. Of particular concern are uncertainties that can arise from the lack of adequate temporal sampling of movements which may have a complex time behavior as well as those due to poorly known systematic measurement errors. These examples also suggest that models of earth processes and rheologies should account not only for the expected differences in vertical movements in contrasting tectonic regimes, but their observed similarities as well.

INVESTIGATION OF TECTONIC DEFORMATION IN THE PUGET LOWLAND, WASHINGTON

Summary of semi-annual technical report; May 19, 1978

USGS Grant No. 14-08-0001-G-366

Associate Investigator: Robert T. Siegfried
Washington Department of Natural Resources
Division of Geology and Earth Resources
Olympia, Washington 98504

Principal Investigator: Pamela Palmer
Washington Department of Natural Resources
Division of Geology and Earth Resources
Olympia, Washington 98504

Successful terrace correlations between raised marine terrace remnants in western Whatcom and Skagit Counties would make it possible to draw conclusions about any differential vertical movements that may have occurred since the last major regression of relative sea level. During this portion of the study, identification of raised marine terraces and strandlines was emphasized for the purpose of correlating laterally separated terrace remnants within each of these counties.

Methods of investigation included terrace profiling, grain-size distribution analysis, ^{14}C-age dating, and surficial geologic mapping. A surficial geologic map of Bay View Ridge, Skagit County, Washington is presented in the report.

Absolute terrace correlations cannot be made due to the paucity of datable materials in the terrace deposits.

Tentative correlations, based on terrace profiling, grain-size distribution analysis, and possible stratigraphic similarities, are made for 20- to 30-foot (6 to 9 meters) and 40- to 60-foot (12 to 18 meters) terrace sequences in Whatcom County (Birch Bay and Lummi Peninsula).

Tentative correlations, based on elevation, are made for 90-foot (27.5 meters), 110-foot (33.5 meters), and 150-foot (46 meters) terrace sequences in Skagit County (Bay View Ridge and south of Mount Vernon).

If the tentative correlations are correct, they imply that little if any measurable differential tectonic and (or) glacio-isostatic uplift has occurred since the last regression of relative sea level in the separate areas of terrace correlation. No statements about relative movement between the two counties can presently be made.

Additional conclusions can be made when results from a pollen analysis of basal peat collected from the 150-foot bog at Bay View Ridge are available. If the peat contains dominant salt marsh or estuarine pollen assemblages, it would establish a former relative sea level at 150 feet, 11,700 years ago at Bay View Ridge.

A question relating to grain-size distribution analysis for the identification of fossil littoral sands in glaciated areas is also raised in the report. Lines drawn by Friedman (1967) separating littoral and fluvial depositional environments on the basis of comparing diagnostic statistical parameters do not apply in much of the study area. However, new lines were drawn for the study area based on parameters calculated from samples of known littoral Pleistocene sands.

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Palmer, Pamela, 1977, Investigation of tectonic deformation in the Puget Lowland, Washington, Washington Division of Geology and Earth Resources, Open-File Report, OF 77-6, 35 p.

Siegfried, R. T., 1978, Stratigraphy and chronology of raised marine terraces, Bay View Ridge, Skagit County, Washington: M.S. thesis, Western Washington University, 52 p.

Quaternary Geology of the Wasatch Front

8-9530-02174

William E. Scott
Branch of Central Environmental Geology
U.S. Geological Survey
Denver Federal Center, MS 913
Denver, CO 80225
(303) 234-5215

Investigations

A. Review of literature and compilation of existing radiometric ages to identify locations for future investigations and to evaluate state of present ^{14}C chronology.

B. Helped to organize and participated in a seminar, "Chronology of Quaternary deposits in the Bonneville basin," that was held in Denver in March. The seminar was attended by R. B. Morrison (formerly of USGS, now at University of Arizona); G. M. Richmond, K. L. Pierce, G. A. Izett, and W. E. Scott (Branch of Central Environmental Geology); R. D. Miller, R. Van Horn, and D. J. Varnes (Branch of Engineering Geology); R. E. Anderson (Branch of Earthquake Tectonics and Risk); and W. D. McCoy (University of Colorado). The subjects discussed included the inconsistencies in the ^{14}C chronology of Lake Bonneville deposits, stratigraphic and geographic locations of volcanic ashes in the Bonneville basin, new ideas on the ages of stratigraphic units, and the use of recently developed dating techniques in helping to solve problems in chronology. There was agreement among the participants that there is no method of knowing which of the available dates are reliable--especially the ^{14}C dates on shells, marl, and tufa and uranium-series ages. There is a need to develop techniques by which the reliability of dates on various materials can be assessed. Until the reasons for inconsistencies in radiometric ages are known, and new dating techniques are applied to the sequence, the chronology of Lake Bonneville deposits, with but few exceptions, remains poorly known.

C. Wood and volcanic-ash samples that were collected by R. B. Morrison from sediments of the Alpine Formation at Little Valley, Promontory Point, are being submitted for analysis. G. A. Izett is working on the volcanic ashes. The stratigraphic position of wood samples is being examined to see if the wood is suitable for ^{14}C dating by the enrichment method at the Quaternary Isotope Laboratory, University of Washington.

D. With K. A. Kvenvolden (Branch of Pacific and Arctic Marine Geology) and K. L. Pierce, experiments are being designed for the use of amino-acid racemization of diatoms and ostracodes in dating and correlation of Lake Bonneville deposits.

E. Initial fieldwork in the Bonneville basin has involved inspection of sections described by previous workers in the Wasatch Front area and work on sections in recent exposures and excavations.

Results

A. The compilation of existing radiometric dates has aided in identification of inconsistencies in the ^{14}C dating of tufas. The dates are from tufas associated with Lake Bonneville shorelines of different ages. However, the group of dates from each shoreline all have about the same ranges--about 9,000 to 25,000 or 30,000 yr B.P. Apparently one or several of the following factors account for this.

1. On any one shoreline, tufa was deposited during several intervals of time when the fluctuating lake level stood at that shoreline.

2. There is contamination by modern carbon from exchange with carbon in the atmosphere and in percolating waters, especially during recrystallization or solution and reprecipitation of carbonate minerals.

3. There is contamination with "old" (no ^{14}C) carbon from Paleozoic carbonates.

In the future, careful inspection of the stratigraphic relations within the tufa coats or masses and petrographic and X-ray analysis of the materials may aid in providing more meaningful and reliable dates from the tufas.

B. Results of initial fieldwork in the much studied area of Little Cottonwood and Bells Canyons, where faulted moraines are related to deposits of Lake Bonneville, support the conclusions of D. R. Currey (University of Utah) and W. D. McCoy (University of Colorado) that the moraines are younger than previously thought and thus would suggest greater rates of tectonism. The moraines display the characteristics of moraines mapped elsewhere as Pinedale in age. The soil developed in till of the moraines is similar to soil developed on deposits of the Bonneville shoreline (approximate age 15,000-25,000 yr B.P) nearby suggesting near contemporaneity of deposition. Earlier suggestions that a buried soil is present between the till and overlying Bonnevile deposits (and thus a significant difference in age) were not substantiated during examination of the till/lake sediment contact along the trench of Little Cottonwood Creek. Oxidation along the contact was apparently believed to indicate presence of a buried soil. The oxidation, however, is confined to certain zones within the till and extends upward into selective beds of the overlying stratified lacustrine sediments. This strongly suggests that the oxidation is caused by ground water effects along the lithologic change at the contact between the till and lake sediments and is not related to soil formation at all. Apparently the faulted moraines are only slightly older than the sediments associated with the Bonneville shoreline.

C. Examination of soils in areas along the Wasatch Front has revealed two factors that must be further explored before soils can be reliably used as indicators of relative age.

Some phases of the quartz monzonitic Little Cottonwood stock that are common as clasts in gravels and tills are relatively rich in biotite and grussify much more rapidly than less biotite-rich phases. Therefore, the degree of surface-stone weathering or degree of grussification of clasts in the soil profile is highly dependent on the content of biotite-rich clasts. Soils developed on terraces and shorelines of Provo age display variable grussification although depth of oxidation in all profiles is very nearly the same, about 70 to 80 cm. Thus the lithology of the parent material is an important consideration in evaluating degree of soil development.

The other factor influencing degree of soil development is the presence or absence of a mantle of fine-grained sediment of eolian and/or alluvial origin. This can lead to the presence of a textural B horizon unrelated to duration of weathering. The finer-grained materials may originally have a reddish-brown color and/or oxidize more intensely than coarser-grained materials and give the appearance of deeper and more intense oxidation, and therefore of a greater degree of soil development.

Both of these factors will be investigated in further detail.

Seismic hazard evaluation of large known and suspected active faults in western Nevada

by
J. D. VanWormer and A. Mohler

Seismological Laboratory
University of Nevada
Reno, Nevada
May 1978

The network of seismographs in the Mina, Nevada, area has been partially dismantled and deployed in western Nevada to cover large known or suspected faults in order to evaluate their states of activity and mode of deformation. The revised network (Figure 1) provides close-spaced coverage of faults in the populated Carson-Tahoe-Reno area.

Operation of the network during the winter of 1977 - 1978 was sporadic due to icing of antennae during severe storms. Distribution of available earthquakes mirrored that of previous reporting periods in both the Mina and Reno areas. The largest event to occur in the network during this time was a FMAG = 4 five km west of Gabbs, Nevada. Although this event was felt sharply in Gabbs there were no reports of damage or displaced objects. Ten aftershocks were located.

A cross-section of hypocenters in the Mina area projected onto an east-west plane implies that the maximum depth of earthquakes increases to the west in the direction of general crustal thickening.

Comparison of the relocated 1966 Truckee, California, aftershocks with on-going seismicity revealed that the aftershock zone has spread to the south-east. This may indicate activation of one of the NW-SE lineaments in the region since the 1966 earthquake.

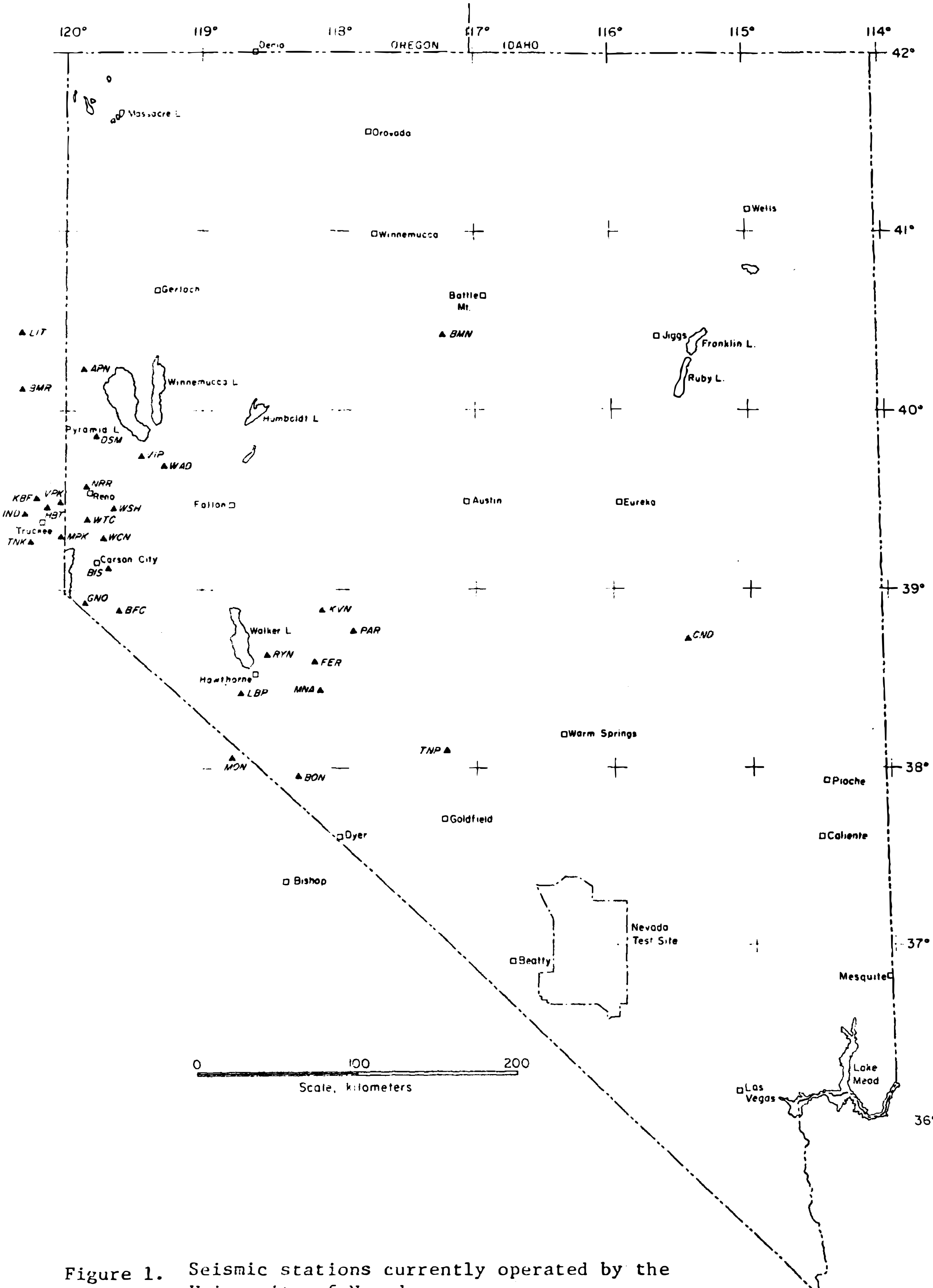


Figure 1. Seismic stations currently operated by the University of Nevada.

Offshore Aeromagnetic Studies Related to the Charleston Earthquake Problem--A Feasibility Study

8-9730-02083

John C. Behrendt
Regional Geophysics Branch
U. S. Geological Survey
Denver Federal Center, MS 964
Denver, CO 80225
(303) 234 5917

Investigations

1. Study existing aeromagnetic data collected for the Atlantic continental margin oil and gas resource assessment program to make interpretations of geologic structure which might be relevant to the Charleston Earthquake. The study area lies seaward of the coast from about 30°N to 34°N and about 76°W to 82°W.

2. Examine existing high resolution seismic profile data in the area to see if any evidence of shallow faulting or other features related to the earthquake are present.

Results

1. The 1/1,000,000 scale aeromagnetic map recently published at 50 nT contour interval shows little relevant evidence in the Charleston area. The 1/250,000 and 1/1,000,000 scale maps of the data contoured at 2 nT suggests a subtle lineation truncating or bounding anomalies with a trend of about S. 38°E projecting into the Charleston area. The obvious feature in the Atlantic with which this could be correlated is the Blake spur fracture zone whose trend, where well mapped to the east of the continental margin, is close to S. 55°E. If there were a causal relationship between these features, it would imply that at the time of initial rifting of the Atlantic about 180 m.y.b.p. a preexisting zone of weakness localized the oceanic fracture zone. If such a zone is reactivated at present as a result of stress existing with the plate it might be related to modern seismicity.

2. There is at present only one high resolution seismic line crossing the area and no obvious evidence of faulting is observed close to Charleston. There is a "break in time" discontinuity about 40 km offshore. Other suggested faults have been reported further seaward but there are insufficient data in the area of study to resolve the question. Additional high resolution seismic profiling is proposed for collection in summer 1978 designed to specifically look for evidence of recent faulting in the offshore Charleston area which may provide more information. Without multichannel seismic profiling capability, which is presently not available, the absence of evidence of faulting on these profiles will not be conclusive. The USGS will have multichannel seismic capability on the east coast within a year or so which will provide additional help.

Late Tertiary and Quaternary Shoreline Datum Planes, Southeastern U.S.

Datum Planes

8-9590-00881

Blake Blackwelder
Paleontology and Stratigraphy Branch
U. S. Geological Survey
E-501 National Museum of Natural History
Washington, D. C. 20244
(202) 343-5488

Investigations

1. Measured more than 50 sections of Pliocene and Pleistocene exposures from northern Florida to southern Virginia. Sediments and trace fossils were described and bulk samples were collected for macro- and microfaunal analyses. We have adopted the approach of trying to map, first on a large scale, later in more detail, the temporal and geographical distribution of ostracode and molluscan biofacies along the coast. In this way, we are essentially tracing the position of ancient shorelines based on faunal and lithological evidence for such environments. A map showing location and elevation of ancient shorelines is in preparation. This map will be used to interpret S.E.U.S. Coastal Plain Quaternary tectonism.

2. Laboratory preparation and faunal and floral analyses were performed on over 200 samples from these sections. In addition many auger hole samples provided by the Eastern Environmental Branch were examined. Ostracodes, mollusks, pollen, spores and foraminifers were studied for their biostratigraphic and paleoenvironmental value. Quantitative multivariate techniques are being used to analyze the ostracode and mollusk data.

3. Detailed examination of modern distribution and ecology of marine and marginal marine ostracodes of the Atlantic coast from USGS collections and the published literature permits delineation of modern ostracode biofacies which can be recognized in the fossil record and used as paleoenvironmental indicators.

4. Attended short course given by James D. Howard (Skidaway Institute, Savannah, Georgia) on coastal sedimentation in Georgia. Sedimentological and trace fossil evidence for recognizing shoreline environments in coastal Plain deposits was emphasized, providing additional criteria for estimating sea level.

5. Produced computer-drawn topographic maps for the following 1:250,000 map areas: Savannah, Beaufort, Georgetown, Florence, Norfolk and Rocky Mount. These are being used to trace geomorphic evidence for shorelines, and plot Position of measured sections.

6. Purchased equipment to perform autoflorescent microscopy of pollen. All equipment has been delivered except the photometer.

7. Attempted to integrate biostratigraphic, radiometric and amino acid racemization data for the Pliocene and Pleistocene of the ACP in order to assess the consistency of the three techniques in dating coastal plain deposits.

Results

1. Previous studies of Pliocene and Pleistocene deposits of the Atlantic Coastal Plain (ACP) have stressed geomorphology as a means of correlation of marginal marine deposits. We have found, however, that ostracode and molluscan assemblages can be used to correlate ACP deposits in the Carolinas and Virginia. Ostracodes are abundant and diverse as fossils in the ACP and evolved rapidly during the Pliocene and Pleistocene. Moreover, because they are common in brackish, as well as normal marine deposits, they are particularly useful in this region in the study of continental margin history. Results indicate that a refined level of biostratigraphy is possible with detailed sampling and faunal anlaysis. Early, middle and late Pleistocene ostracode assemblage-zones can be recognized, and these correspond to three distinct molluscan assemblage-zones. Further refinement may be possible with additional field work and sampling.

2. Environmentally distinct biofacies for both ostracodes and mollusks can also be delineated in the Pliocene and Pleistocene of the ACP which are indicative of various marginal marine environments. These environments include inner shelf, shallow subtidal, lagoon, salt marsh/estuary, and tidal flat. Environmental reconstruction from faunal assemblages is augmented by sedimentological and trace fossil evidence (including Ophiomorpha burrows). These additional data are especially critical in recognizing and interpreting unfossiliferous beach and backbarrier deposits. Using faunal and lithological data we have developed a model which depicts the typical depositional sequence encountered in the ACP Pliocene and Pleistocene (Figure 1). The age of the sequence can be determined from the fauna in the fossiliferous units, while both fossil and sedimentological data permits paleoenvironmental reconstruction. A corollary of determining the environment of deposition is obtaining a paleodepth estimation, and hence an estimation of ancient sea level for each measured section. In many sections it is possible to recognize the position of Pleistocene mean low or mean high water, thus providing more exact sea-level information than that obtained using geomorphology. We are presently applying this model along the ACP in an attempt to map the distribution of biofacies of various ages, reconstruct ancient shorelines, and thus correlate shoreline deposits.

3. Preliminary results of floral studies show that unweathered, fine-grained sediments from the ACP often contain abundant, well-preserved pollen and spores. Freshwater, brackish and marine deposits have all yielded these fossils. Terrestrial environments that were contemporaneous with marine transgressions can therefore be determined.

4. Comparison of pollen assemblages from interglacial units of early, middle and late Pleistocene deposits suggest that coastal plain deciduous forest has been dominated by pine, oak and hickory during each interglacial investigated. This discovery has significant implications for understanding the stability

of the ACP ecosystems. Although it is known that the deciduous forest in the southeast was radically disrupted during the Wisconsinan when a boreal forest migrated as far south as Georgia, it reconstituted itself during interglacials when it duplicated the Holocene forests.

5. Preliminary results indicate that pollen has biostratigraphic potential in recognizing the Pliocene-Pleistocene boundary in the ACP. It has also provided evidence for climatic change within the Sangamon Interglacial in Virginia.

6. Comparison of biostratigraphic data with those from radiometry and amino acid racemization reveals varying results. In some cases all three techniques seem to be consistent with one another. However, some deposits that can be shown to be time-equivalents of one another based on several independent lines of faunal evidence, yield widely disparate amino acid absolute ages. Detailed investigation into possible chemical alteration of molluscs on the ACP is advised in order to assess the reliability of amino acid racemization on the East Coast. Also, different genera yield different amino-acid ages for the same deposit, and additional research is required to better understand these generic effects.

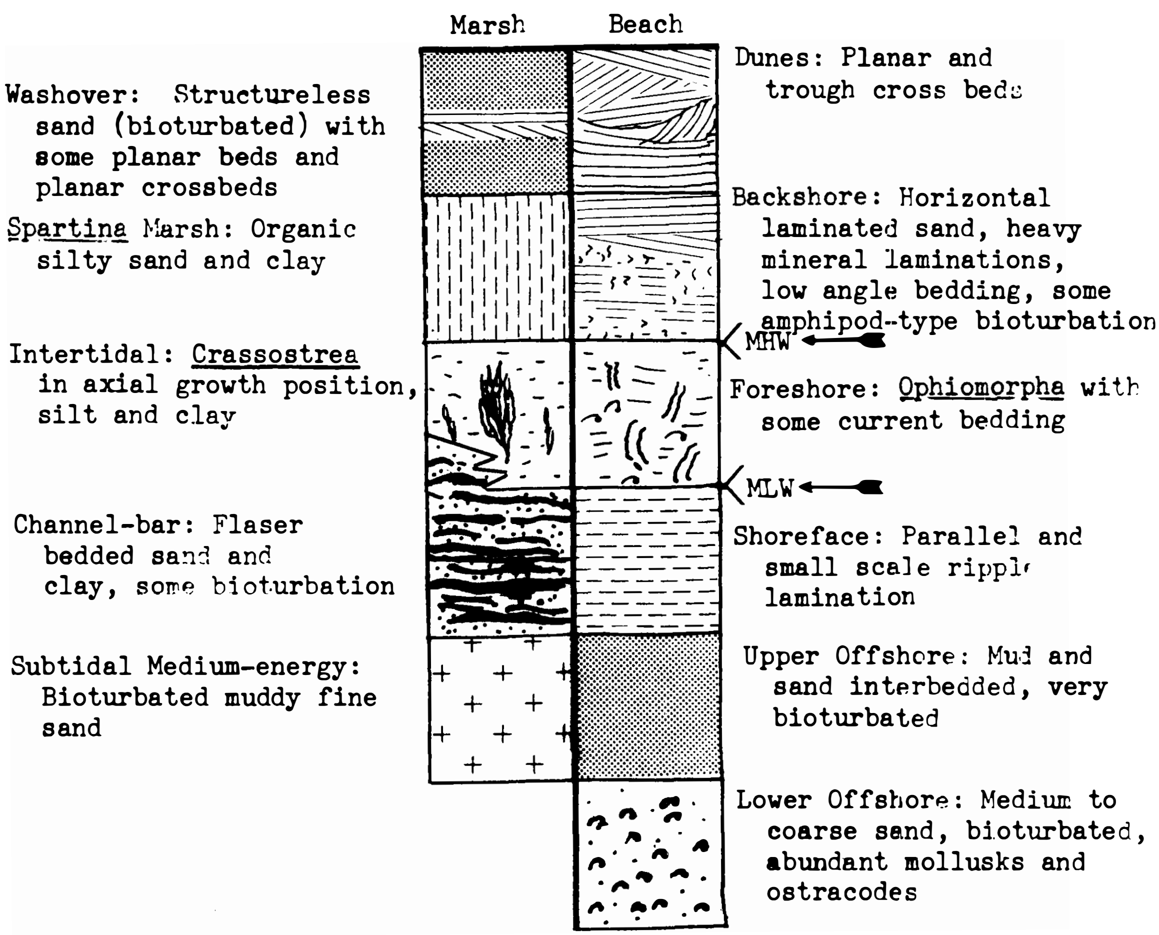
Reports

Cronin, T. M. and Hazel, J. E., (in press), Ostracode biostratigraphy of Pliocene and Pleistocene deposits of the Cape Fear Arch Region, North and South Carolina: U. S. Geological Survey Journal of Research.

Figure 1

Generalized progradational depositional sequence encountered in Pliocene and Pleistocene sediments of the central and southern Atlantic Coastal Plain. In the marsh sequence ostracode assemblages from the intertidal *Crassostrea* facies are used to date the section. In the beach sequence biostratigraphically diagnostic ostracodes and mollusks permit age determination of the section. Ancient sea levels are estimated using the various types of sedimentological, trace fossil and paleontological criteria shown in the figure. In many instances the location of mean low water/mean high water can be recognized.

PROGRADING SEQUENCE



TITLE: DAMAGE PREDICTION FOR AN EARTHQUAKE IN SOUTHERN CALIFORNIA

PRINCIPAL INVESTIGATOR: John A. Blume

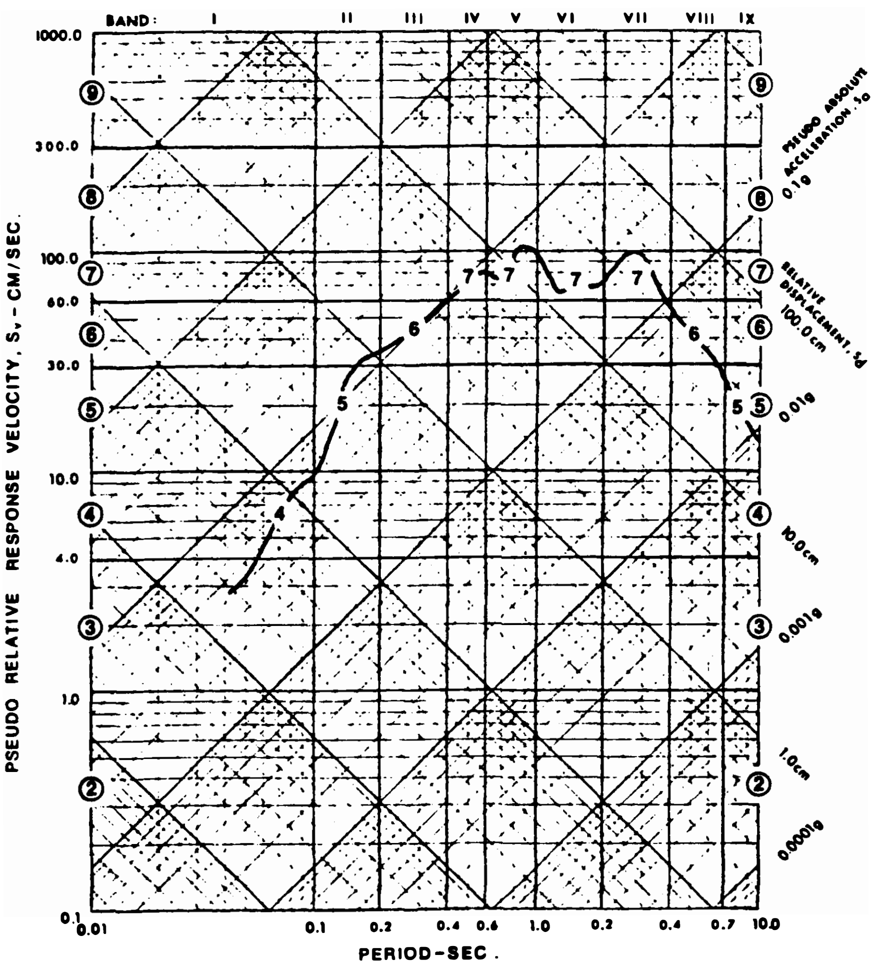
CONTRACTOR: URS/John A. Blume & Associates, Engineers

DATE: February 1978 Contract Number: 14-08-0001-15889

EXECUTIVE SUMMARY

FINAL TECHNICAL REPORT

The objective of this study was to estimate the nature and distribution of damage to structures in the southern California area caused by a hypothetical earthquake which is located on the San Andreas fault, has a rupture length of 300 km, and spans the area between Cholame to the north and Cajon Junction to the south. Its Richter magnitude was given as 8.1. The Engineering Intensity Scale (EIS) technique was used to make the damage estimation. Two unique features of the EIS technique, which establish the nature and character of the predictions made, are: (1) damage is established from response spectrum values of ground motion, and (2) damage estimates consist of a definition of the areas in which structures might be damaged and a general evaluation of the incidence and degree of damage that such structures might sustain. Detailed structure inventories are beyond the scope of this evaluation, but exposure in the affected area is generally identified.



Note: EI levels ① (0.01 to 0.1 cm/sec) and ⓪ (0.001 to 0.01 cm/sec) not shown.

ENGINEERING INTENSITY SCALE MATRIX
SUPERIMPOSED ON EXAMPLE SPECTRUM

Basic earthquake information was provided by the U.S. Geological Survey and included the length of rupture, the magnitude of the hypothetical earthquake, and the geological conditions of the affected area. Rossi-Forel intensity maps were also provided; these were used to make a preliminary estimate of the study area for structural data-gathering purposes. The procedure used for generating the EIS values was as follows. First, peak ground acceleration at a particular site of interest was determined. The parameters required to determine acceleration are distance from the causative fault, magnitude of the earthquake, and specific density and shear wave velocity of the ground at a site. Next, response spectra were generated. Four basic spectrum shapes were established to represent the influences of site geology on response spectra. Finally, EIS values for three period bands (less than 0.4 sec, 0.4 to 2.0 sec, greater than 2.0 sec) were determined from the response spectrum curves for each site.

The EIS values represent 5%-damped response spectrum amplitudes. The range of spectral velocity (S_v) and period (T) applicable to civil engineering structures is represented as a 10 x 9 matrix (see accompanying figure). The range of S_v values, from 0.001 to 1000.0 cm/sec, is divided into ten levels that are assigned EI numbers from 0 to 9. The T range, from 0.01 to 10 sec, is divided into nine period bands from I to IX.

By referring to the period columns, the EI scale can be reported as nine-digit, three-digit, or one-digit numbers, or by all three, in a standard format. The more digits reported, the greater the amount of information for the period bands. For this study, three-digit and one-digit representations were used to show the EIS values. The values were averaged within the period range of interest to obtain the three-digit representation.

For the example spectrum shown here, a nine-digit representation would be 456,777,765. A three-digit representation reduces to 5,7,6: an average EI of 5 in period bands I, II, III (less than 0.4 sec); 7 in period bands IV, V, VI (0.4 to 2.0 sec), and 6 in period bands VII, VIII, IX (greater than 2.0 sec). A one-digit EI is obtained by averaging the values of the three-digit EI. The three-digit EI of 5,7,6 is thus reduced to a one-digit EI of 6.

Structures considered in this study include buildings and other structures found in communities as well as major areawide hydraulic, transportation, and utility systems and facilities found in the study area. The structure information was obtained from various sources for the 14 counties, in southern California (Fresno, Kern, Kings, Los Angeles, Monterey, Orange, Riverside, San Benito, San Bernardino, San Diego, San Luis Obispo, Santa Barbara, Tulare, and Ventura) that are affected by the postulated earthquake. Because an EIS prediction is conceived as only a generalized damage assessment, structures were categorized according to function, type of construction, height, etc. Most of the structures in a particular community are common to all communities of the study area. Furthermore, the number of structures in a community is generally proportional to the population of the community; this premise was used extensively for making this preliminary damage estimate.

In the study area, which covers approximately 154,000 km^2, the highest three-digit EI is 7,8,8. This three-digit EI corresponds to a one-digit EI of 8-. The highest EI for a city, 6,8,8 (one digit EI: 7-), is for a community with a population of approximately 10,000. Although there are a number of large cities in the 5,7,7; 5,7,6; and 5,6,6 zones (one-digit EI: 6+, 6, and 6-, respectively), most of the major metropolitan areas (including Los Angeles) are in the 4,6,5 and 4,5,5 zones (one-digit EIs: 5 and 5-). The number of cities reported in census data for each one-digit EI zone is tabulated below. The combined population of these cities for each EI zone is also shown in the table.

The EI-damage relationships developed from the San Fernando earthquake of 1971 indicated that an EI of 6 in the short-period range (less than 0.4 sec)

NUMBER OF CITIES AND CORRESPONDING POPULATION* IN RESPECTIVE ONE-DIGIT EI ZONES

1-Digit EI Zone	Number of Cities	Combined Population of Cities (in thousands)
7+	1	9
7	-	-
7-	-	-
6+	3	36
6	2	28
6-	2	133
5+	7	149
5	14	291
5-	104	6,122
4+	37	1,232
4	23	1,221
4-	41	487
3+	13	82
3	7	77

*From 1970 census data, does not include population for small communities.

would produce a damage cost of approximately 9% of the replacement value for typical low-rise buildings. Similarly, an EI of 7 in the intermediate-period range (0.4 to 2.0 sec) would produce a damage cost of about 6.5% of the replacement value for high-rise buildings. For structures for which no EI-damage statistics were available, damage cost was estimated from a comparison of the seismic design coefficients of the structures with those of typical buildings. The damage cost for structures with special design considerations was estimated to be lower than that for typical buildings. On the other hand, some poorly constructed structures such as precode unreinforced masonry buildings, which have a lesser seismic-resistance capability, were expected to have a higher damage cost. For a typical community, the three-digit EI of 6,7,7 (one-digit EI: 7-) is estimated to produce a damage cost of 9% of the replacement value of the structures. For EIs of 5,6,6 (one-digit EI: 6-) and 4,5,5 (one-digit EI: 5-), the values are 2% and 0.3%, respectively. Although damage prediction for specific cities is not provided, a damage estimation for several EI levels is described for a hypothetical community. The procedure for applying these damage calculations to a specific community is also described.

Because residential buildings make up the major portion of the buildings in a community, losses from these buildings figure heavily in the total dollar loss to the community from an earthquake. The total damage to private buildings from the hypothetical earthquake is estimated to be about $600 million; an equal amount is estimated for damage to public buildings and other public structures. This figure is an estimate of the mean or expected damage for the entire area. The actual damage cost may vary, depending on the distribution of damage for the many communities involved. Observed statistical variations from previous earthquake studies, for both the spectral values and the motion-damage relationships, will no doubt be repeated for any future earthquake. A rigorous estimate of the statistical variation of damage for the hypothetical earthquake is beyond the scope of this study, but a one-sigma geometric variation could be several times the mean value. Error in the mean predicted value is not expected to be as large. However, the above estimate does not take into consideration the damage resulting from the possible catastrophic failure of major facilities (e.g., dam) and the secondary damage that may result.

Deaths and injuries (with the exception of immediate physiological effects such as heart attacks) are the secondary effects of earthquakes, occurring as a consequence of structure damage and failure. They may result from objects falling from buildings, collapse of buildings, failure of dams, and other primary earthquake effects. Thus a higher incidence of deaths and injuries is associated with structures that have high damage potential than with those having lower damage potential (e.g., precode unreinforced masonry buildings versus modern buildings with earthquake-resistive structural details). On the basis of past experience, deaths are not expected in areas with a one-digit EI less than 6-, but injuries could extend to areas with a one-digit EI of 5.

All of the major areawide systems and facilities of the study area would be severely affected by the hypothetical earthquake. Some of the facilities are very close to the fault, and portions of the systems closely parallel the entire fault break, actually crossing the fault at several locations. The following table summarizes the number of major facilities in the high-EI zones.

SUMMARY TABULATION OF NUMBER OF MAJOR FACILITIES* IN THE HIGH-EI ZONES

	Number of Facilities								
		One-Digit EI Zone							
Type of Facility	Study Area	5	5+	6-	6	6+	7-	7	7+
Concrete Dams	50	-	-	-	-	-	-	-	-
Earth and/or Rock Fill Dams	219	-	1	5	3	2	-	1	-
Hydraulic Fill Dams	11	-	-	1	-	-	3	-	-
California Aqueduct Facilities	15	-	2	3	1	3	-	-	2
Highway Overcrossings > 500 ft in Length	148	-	1	2	-	-	-	-	-
Public Airports	108	-	-	1	4	1	-	-	2
Military Airports	16	-	-	-	-	1	-	-	-
Natural Gas Transmission Facilities	16	-	-	-	-	1	-	-	-
Electric Power Generation and Distribution Facilities	343	3	5	5	6	12	2	5	2
Petroleum Pumping, Terminal, and Refinery Facilities	93	1	-	4	4	6	-	1	-

*Related conveyance systems are not included in the tabulation.

An EIS evaluation is only a preliminary step in the evaluation of earthquake effects on structures. EIS data and results are intended to provide only an overall identification and summary of the extent of the effects from a predicted earthquake. Should more definitive indications of an imminent earthquake appear, the data provided can be used to systematically perform more detailed evaluations.

For those areas with a one-digit EI equal to or greater than 6-, more detailed inventories and evaluations than those that were employed for this study should be made. For structures in a one-digit EI zone equal to or greater than 7-, a detailed engineering review should be carried out to evaluate the possible hazard to life and to determine remedial measures that might be implemented.

Seismotectonics of Northeastern United States

8-9950-02093

W. H. Diment
Branch of Earthquake Tectonics and Risk
U.S. Geological Survey
345 Middlefield Road, MS 77
Menlo Park, Calif. 94025
(415) 323-8111, ext. 2731

Goals

To examine geological and geophysical information relevant to the origin and distribution of earthquakes in northeastern United States with the objective of providing a better basis for seismic zoning. To identify gaps in the required information and to arrange that the gaps be filled.

Investigations

New project. Commenced compilation of regional geophysical information at a scale of 1/1,000,000

Tectonic History of Eastern Ozark Uplift

8-9530-01930

Ernest E. Glick
Branch of Central Environmental Geology
U.S. Geological Survey
Denver Federal Center, MS 913
Denver, CO 80225
(303) 234-3353

Investigations

1. Field checked and revised 4 remaining reconnaissance geologic maps (scale 1:24,000) of the Newport, Arkansas, area (Phase 1).

2. Examined and logged cuttings from 11,000 meters of hole drilled in or near the Newport and Pocahontas, Arkansas, areas (Phases 1 and 2).

3. Compiled and plotted surface and subsurface data from the Newport and Pocahontas areas of Arkansas.

Results

1. Deposits of chert gravel and glauconitic sand of probable Cretaceous age were mapped to outline ancestral embayments of the Little Red River and the White River west and northwest of the common boundary of the Ozark region and the Mississippi embayment. The sand, derived from a distant source area to the north, was deposited in broad embayments along the western edge of a sea that transgressed westward at least 40 kilometers beyond the present Ozark front. A locally derived chert gravel underlies the sand layer and a much thicker regionally derived chert gravel overlies it. Both gravels are much better rounded than is present-day stream gravel derived from the same source beds. The roundness and the patterns of distribution of the gravels indicate that they were deposited in and along the edge of the sea and, in part, were deposited as lenses in the sand.

   The surface upon which the sand and gravel was deposited is the originally continuous but now highly dissected pre-Late Cretaceous peneplain that extends beneath the Cretaceous sediments of the Mississippi embayment. One purpose of mapping that erosional surface is to determine how much it has been tilted or faulted since Late Cretaceous time and whether it has been upwarped locally by the deeply buried Newport pluton. Regional tilting of the surface in the area of outcrop was found to be on the order of 7 meters per kilometer toward the edge of the Mississippi embayment, continuous with and of about the same magnitude as that of the surface where it is buried in the embayment area. Local tilting of the surface over and around the Newport pluton is more complex. Evidence discovered this year indicates that one area of about 50 square kilometers along the western edge of the pluton has been domed, since Paleocene time, on the order of 150 meters above the regional trend. The investigation of structural and depositional anomalies of that immediate area still is in progress.

2. A detailed analysis of the evolution of structural trends in the Newport, Arkansas, area is being made. Most of the surface and subsurface data are in hand now. More than 45 Cambrian and younger formations and members are identifiable in the area, offering a wealth of control points at their contacts. Basinward depositional thickening of the units tilted the beds eastward and southeastward originally; uplift of the Mississippi embayment area during Late Paleozoic time tilted the beds westward; subsidence of the embayment area during Late Cretaecous and Early Tertiary time tilted the beds eastward; and probable post-Eocene rebound of the embayment may be tilting them westward again. The present regional attitude of each of several horizons is being determined directly from surface and subsurface data; the change of attitude through time of each of several horizons is being calculated.

Tectonic Framework of the New Madrid Seismic Zone from Geophysical Studies

8-9730-01035

Thomas G. Hildenbrand
Branch of Regional Geophysics
U.S. Geological Survey
Denver Federal Center, Mail Stop 964
Denver, Colorado 80225
(303) 234-5464

Investigations

1. Extend aeromagnetic and gravity coverage in the northern Mississippi embayment and surrounding regions.

2. Analyze the potential field data to delineate major geological structures.

3. Describe the infra-sedimentary plutonism and structure and investigate their relationship to the seismicity.

Results

1. The aeromagnetic and gravity surveys encompass areas of approximately 105,000 and 145,000 square kilometers, respectively. The resulting Bouguer gravity map and aeromagnetic map reveal several prominent anomalies that may reflect the presence of major tectonic or geological structures.

2. A broad zone of subdued magnetic and gravity expression divides a region typified by higher gradients and intensities. The graben-like expression is approximately 75 km wide and trends N45°E for about 300 km. Depth estimates of magnetic basement indicate that the subdued zone is due to 1.2-2.4 km of relief between basement outside the zone and basement inside the zone. We propose that the graben is the expression of a rift that has been active through much of geologic time since the Precambrian. The proposed rift must be intimately related to the formation of the Mississippi embayment.

3. The margins of the proposed rift are characterized by a series of magnetic and gravity highs (ranging up to 1200 gammas and 37 mgal, respectively) presumably caused by igneous features lying outside or along the boundaries of the rift. Spectral analyses indicate that these intrusions are dense and highly magnetic, possess a complex shape, and extend laterally for appreciable distances. The associated sources are probably large shallow plutons consisting of mafic or ultramafic rocks. The ages of these plutons have been determined utilizing the corresponding magnetic anomalies. Three of the plutons located south of the

Pascola arch have been dated as Mesozoic intrusions. Age determinations of two plutons north of the Pascola arch suggest that igneous activity occurred in the Paleozoic era. The Pascola arch appears to act as a structural boundary with Mesozoic igneous activity having occurred south of the arch and Paleozoic igneous events having taken place north of the arch.

4. A linear trend of concentrated seismicity strikes along the axis of the proposed rift. The axial seismicity pattern suggests that the rift is presently active or that the rift's axis represents a zone of crustal weakness along which strain produced by present-day tectonic forces, is being relieved. The epicentral line of the New Madrid earthquake series of 1811 and 1812 also lies with the margins of the proposed rift.

   In addition, earthquakes are noticeably concentrated along the southeast edge of the well-known Bloomfield intrusion possibly indicating that the pluton influences the distribution of stress in this region.

Reports

Hildenbrand, T. G., Kane, M. F., and Stauder, W., 1977, Magnetic and gravity anomalies in the northern Mississippi embayment and their spatial relation to seismicity, U.S. Geol. Survey Misc. Field Studies Map MF-914.

Engineering Geology of Metropolitan Boston, Massachusetts

8-9550-00637

Clifford A. Kaye
Branch of Engineering Geology
U.S. Geological Survey
150 Causeway Street, Room 1304
Boston, MA 02114
(617) 223-7200

Investigations

1. Information from over 25,000 foundation borings from a 14-square mile area, including central Boston and parts of Cambridge and Brookline, has been collected and analyzed. From these data a series of subsurface maps, on a scale of 1:6000, are being prepared which, when used together, provide a three-dimensional picture of the geology. There will be seven maps: one for each of the five most important stratigraphic materials units (Holocene estuarine and freshwater deposits, outwash sands and gravels, glacial clays with interbedded silt and fine sand, till and older outwash, and bedrock), and two additional maps, one showing the topography of the bedrock surface and another showing the location of all borings. With each map will be a text, a table of physical-properties data, and cross sections.

2. Surficial geology of eight 7 1/2-minute quadrangles (Lexington, Newton, Boston North, Boston South, Lynn, Hull, Marblehead South, Nantasket) has been mapped. These maps include submarine geology in the submerged portions.

3. Bedrock geology of the above eight quadrangles has been mapped.

4. Field investigations are essentially completed. The project is in report-writing phase.

Results

1. Map showing surface of bedrock beneath the central Boston area, scale 1:6000, has been completed along with text. The close correlation of the deeply buried bedrock surface and the 18th century land surface is apparent from this map. Also a correlation between softrock-alteration of bedrock and major lows on the bedrock surface is clear. The "buried valley" of the Charles and Merrimack Rivers in the map area, suggested by earlier geologists, now seems doubtful in light of the bedrock surface as it is now seen.

2. Geologic map of bedrock beneath the central Boston area is 85 percent completed. This involved studying over 350 rock cores. Several sizable faults have been inferred from the data. Some correlation of softrock alteration and faults, and faults and large diabasic dikes is indicated. More folding of Boston Basin rocks than hitherto supposed is indicated, including sizable overturned isoclinal folds in the argillites.

3. Map of Holocene estuarine and freshwater deposits of central Boston and vicinity is 75 percent completed.

<u>Reports</u>

Kaye, C. A., 1978, Surficial geologic map of the Boston area, Massachusetts: U.S. Geological Survey Open-File Report 78-111 (scale 1:100,000).

Mississippi Valley Seismotectonics

8-9950-01504

D. P. Russ
Branch of Tectonics and Risk
U. S. Geological Survey
Denver Federal Center, MS 966
Denver, CO 80225
(303) 234-5086

Investigations

1. Using trench maps and photos analyzed and determined significance of structural, stratigraphic, and liquefaction features of sediments exposed in exploratory trench across Reelfoot scarp in northwestern Tennessee.

2. Continued geomorphic investigation of Reelfoot Lake vicinity, northwestern Tennessee using air photo and map analysis.

3. Began morphometric analysis of fluviatile terraces in the upper Mississippi embayment.

4. Began compilation of published and unpublished C-14 age date data for the Mississippi embayment.

5. With M. Zoback interpreted geologic structure from seismic reflection profiles run in the vicinity of Reelfoot Lake and near Ridgley in northwestern Tennessee.

6. With S. Obermeier continued field investigations of liquefaction features and fluviatile terraces in the upper Mississippi embayment.

Results

1. Study of the sedimentary units and liquefaction features mapped in a trench across Reelfoot Lake scarp indicates that not more than 0.5 meter of the 3 meter offset exposed at the base of the scarp could have recurred during the 1811-12 sequence of earthquakes.

2. Interpretation of channel and natural levee profiles was previously reported to indicate that the Tiptonville Dome and Reelfoot scarp are of tectonic origin. Additional evidence to support this interpretation is the parallelism of the convex topographic profile of Reelfoot scarp with the convex profile of bedding planes of sediments exposed in trench walls cut across the scarp. These observations show that the greater part of the scarp is the result of structural flexing which took place during uplift of the adjacent Tiptonville dome. Breaks-in-slope across the scarp profile generally coincide with zones of concentrated soft sediment deformation (folds, faults, and liquefaction features). The geometry and distribution of the folding suggest that the folds formed by subsidence into graben-like depressions when tensional strain flexed the surficial alluvium.

3. The Mississippi River alluvium forming Reelfoot Scarp and the adjacent Tiptonville Dome contains fresh water pelecypod and gastropod shells dated by the C-14 method by Meyer Rubin as 1060-2000±250 years B.P. It is therefore concluded that 1) the tectonic uplift (3-6 m) of the dome has occurred within this time interval and 2) the age dates and faulting relationships derived from the trench define at least three episodes of earthquakes strong enough to liquify and offset surficial sediments in this area during the past 2000 years. Thus a rough recurrence interval of a little less than 700 years can be postulated.

4. Interpretation of vibroseis reflection data (accomplished jointly with M. Zoback) from eight lines shot in the vicinity of Reelfoot Lake in northwestern Tennessee reveals the presence of several north-northeasterly and northeasterly trending faults. The faults cut horizons interpreted to be upper Paleozoic, Cretaceous, and at several places, lower Eocene. Though a major fault trace parallels part of the overlying Reelfoot scarp, the overall structural fabric determined from the reflection profiles is more complex than interpretations made from surficial morphology and drill hole data might lead one to believe.

Reports

Zoback, M., Healy, J. H., Roller, J. C., McKeown, F. A. and Russ, D. P., 1977, Geophysical assessment of suspected faults in the New Madrid seismic zone (abs.): 3rd Ann. AGU Midwest Mtg., Program and Abs., 1977, Purdue Univ., West Lafayette, Ind.

Russ, D. P., Stearns, R. G., and Herd D. G., 1978, Map of exploratory trench across Reelfoot scarp, northwestern Tennessee: U.S. Geol. Survey Misc. Field Studies Map MF-985 (in TRU).

Northeast Tectonics and Geophysics

8-9730-00364

Robert Simpson
Branch of Regional Geophysics
U.S. Geological Survey
Denver Federal Center, MS 964
Denver, CO 80225

Investigations

1. Compilation of all available gravity data for the Northeast and reduction to a consistent datum. 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, electromagnetic and other geophysical data in areas of tectonic or seismic significance.

4. Modelling and interpretation of regional anomalies to infer tectonic patterns and aid in constructing a plate tectonic history.

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

Results

1. Wallace Bothner has compiled all available gravity data from New England, the Gulf of Maine, and adjacent areas including Canada and Morocco. Bouguer anomaly maps of the Boston and Portland 1^{o} by 2^{o} sheets will soon be ready, as well as a new map of the New England region at a scale of 1:1,000,000.

2. Available aeromagnetic data for New Hampshire and for the area covered by the Boston 1^{o} by 2^{o} sheet has been digitized, and this data will soon be made available.

3. Electromagnetic soundings made in N.Y., Vt., and N.H. last summer are being analyzed by Jim Towle and Victor Labson. The soundings were designed to examine the deep structure under the Boston-Ottawa seismic trend(?), but were seriously hindered by problems with cultural noise.

4. An aeromagnetic survey is being planned for areas in the Gulf of Maine to examine the offshore extensions of certain fault zones including the Clinton-Newbury and Bloody Bluff, and to give more information on the tectonic framework of the Gulf of Maine.

5. We have also been trying to compare tectonic elements in North Africa with those in the Northeastern U.S. by closing the North Atlantic and rotating Africa to its pre-drift position. It appears that the straightest extrapolation of the South Atlas fault zone of North Africa trends at an azimuth of 274^{o} into the Gulf of Maine toward Cape Ann when the Atlantic is closed. The available aeromagnetic, seismic and structural data from the Gulf suggest a fundamental difference in basement to the north and south of this extrapolation.

We are planning additional fieldwork to test the hypothesis that an extension of the South Atlas fault, or a splay thereof, continues across the Gulf of Maine and connects with the Clinton-Newbury and Bloody Bluff systems where they run offshore.

Reports

Simpson, R. W., and Bothner, W . A., 1977, Possible extension of the South Atlas fault of North AFrica into the Gulf of Maine (abs.): (Director's approval).

Neotectonic Synthesis of U.S.

8-9540-02191

Carl M. Wentworth
Branch of Western Environmental Geology
U.S. Geological Survey
345 Middlefield Road
Menlo Park, CA 94025
(415) 323-8111

Investigations

None. Extension of previous administrative assignment through the whole of the present reporting period required deferral of any work on this project until after March 31, 1978.

The objective of the project is to design and compile a neotectonic map of the conterminous United States at national scale solely from existing geologic data. Original materials and regional compilations at 1:1,000,000 will be sought and gathered from local and regional experts and from the literature and these will be recompiled at 1:5,000,000. The deformation history indicated by the geologic record for Pliocene and Quaternary time will be summarized in terms of relative movements and their amounts and rates, as permitted by the evidence. Included will be faults, folds and broader vertical and any resolvable horizontal movements, as well as indication of the available geologic control.

RECENT FAULT SCARPS ALONG THE EASTERN ESCARPMENT OF THE SIERRA SAN PEDRO MARTIR, BAJA CALIFORNIA, MEXICO

GRANT NO. 87177

Gordon Gastil

Lawrence G. Brown

Carl Strand

Susan L. Faulkner

San Diego State University, San Diego, California 92182

(714) 286-6211

INVESTIGATIONS

1. Made map of fault scarps at the southwest corner of Valle Chico on a scale of 1/7,000, measuring, angle of scarp slope, height of scarp, noting exposures of slip surface where exposed.
2. Made reconnaissance of young fault scarps along the entire western edge of Valle Chico, and at selected points further north, noting scarp height, slope angles, number of individual fault steps, and their relation to stream terraces.
3. Used a bulldozer to excavate three trenches across the trace of the fault to search for buried soil horizons and charcoal.
4. Determined uplift-related knick points on drainages crossing the fault scarps, and delineated stream terrace levels abandoned by fault related entrenchment.
5. Collected the oldest wood from iron wood trees, Olneya tesota, living on each of five such terraces for radio-carbon dating.
6. Collected carbon from paleosoils buried by subsequent fault motion for radio-carbon dating.
7. Carried out one magnetic and one gravity survey: the former in the vicinity of the detail scarp mapping, and the latter across the medial lineament of Valle Chico

8. Carried out a micro-seismic investigation in the detail map area.
9. Interrogated local residents for memory of recent seismic events in the immediate area.
10. Searched seismograph records for evidence of recent epicenters along the fault zone.
11. Carried out a literature search (still in progress) to find all printed and unprinted accounts of major earthquakes in northern Baja California in an attempt to learn more about the epicenters of major earthquakes prior to 1900.

RESULTS

The foot of the eastern escarpment of the Sierra San Pedro Martir has broken repeatedly during the past thousand (?) years over a distance of least 100 kilometers. Aggregate offset of recent alluvium is approximately 20 meters over much of the distance. At some points the entire 20 meters is confined to a single slip surface in others the slip is divided into a few or many individual planes, and in some localities it is distributed across a zone up to a kilometer in width. Observation of the fault plane where it cuts basement rock, and magnetic traverses across the trace where it is within the alluvial fan, demonstrate that these recently active planes have a much longer history of displacement.

Excavation of the alluvium in front of a fault scarp has revealed two buried soil horizons: one related to the most recent movement, and a second about one meter deeper. Chips of carbon, possibly limiting the age of the earlier of these two events, have been sent for C-14 dating.

All observed fault planes dip at angles between 56 and 89 degrees to the east. Movement is dip slip, down to the east. The amount of vertical displacement having occurred at a given event probably ranges up to several meters, and possibly more. Sets of stream terraces produced where drainages cross a fault trace are believed to relate to successive uplift along the fault. Since the maximum age of a tree which could be rooted on a terrace would be the age of creation (by downcutting) of that surface, we selected the oldest wood from iron wood, <u>Olneya tesota</u>, trees on a succession of terraces. If the C-14 ages yield a succession of older ages on the older terraces, it may provide a clue to the recurrence interval of fault motion.

Examination of the slope morphology of the escarpments, and the size of iron wood trees which have grown on the floors of the most recent erosional incisions convinces us that there has not been an offset of more than one meter in the past several hundred years. On the other hand, it seems equally evident that 20 meters of motion has occurred during an interval of around one thousand years, involving at least four distinct uplifts of several meters each.

The fault is microseismically inactive. Seismic records indicate that an event of magnitude, 5.5, may have been centered near the study area on November 22, 1974. Terrified local residents, reporting swaying trees and bushes, fled to San Felipe for ten days. Historical research, while turning up many accounts not mentioned in seismological literature, has not yet helped to locate epicenters for the strong historic earthquakes, such as the one of February 23, 1892.

REPORTS

Brown, Lawrence G., 1978, Recent fault scarps along the eastern escarpment of the Sierra San Pedro Martir, Baja, California: Masters thesis, San Diego State University (in preparation).

Faulkner, Susan L., 1978, Reconnaissance magnetic survey of the San Pedro Martir fault and medial suture in Valle Chico, Baja, California: Senior Report, San Diego State University.

Keller, Bruce T., 1977, Results of a gravity and magnetic survey San Felipe Valley, Baja, California: San Diego State University, unpublished.

Collaborative Dating

8-9740-00374
8-9740-00377
8-9740-00379
8-9740-01568

B. R. Doe, M. Rubin, M. A. Lanphere, C. W. Naeser, and S. Robinson
Branch of Isotope Geology
U.S. Geological Survey
Denver Federal Center, MS 963
Denver, CO. 80225
(303) 234-4003

Investigations

The age of faulting and fault recurrence are recognized to be important to assessing future earthquake hazards. The Branch of Isotope Geology is participating with various field geologists in determining the age of faulting by various standard techniques. The dating techniques are radiocarbon, potassium-argon, and fission track. In addition, we will be working on development of new dating methods.

Results

The ages determined by standard techniques are reported in the individual reports of the field geologists working on neotectonics and they will not be repeated here.

Paleomagnetic Studies of Holocene Fault Displacement

8-9930-02158

Gary S. Fuis
Branch of Seismology
and
E. M. Shoemaker
Branch of Petrophysics and Remote Sensing
U.S. Geological Survey
% California Institute of Technology
Seismological Laboratory 252-21
Pasadena, CA 91125
(213) 795-6811, exts. 2957 and 2455

Goals

1. To further develop a paleomagnetic technique for dating Holocene sediments based on the secular variation of the geomagnetic field.
2. To apply this technique to a study of the displacement history of faults in southern California showing Holocene offset.

Sufficient work on the Holocene history of secular variation of the geomagnetic field in western United States has now been completed to attempt to use our knowledge of this history in dating Holocene sedimentary deposits. Useful control exists for a period extending back from the present to about 7000 B.P. (radiocarbon years). At present there are significant gaps in this record, but even at this early stage it appears worthwhile to test the application of this concept to the problem of the displacement history of active faults and the recurrence intervals between earthquakes.

Investigations

1. Approximately 400 oriented samples have been collected from 7 clay, silt, and peat units exposed in trenches and creek banks at Pallett Creek, 6 km south of Pearblossom, California. At this location, a sedimentary sequence containing these units is offset by the San Andreas fault. Evidence of paleoearthquakes is preserved in these sediments in the form of buried fault scarps, sandblows, and liquifaction features (K. Sieh, EOS (Am. Geophys. Union Trans.), v. 57, p. 899). Radiocarbon dates on peat beds which occur at many horizons throughout this section provide excellent brackets on the ages of these paleoearthquakes. Our samples were collected from a variety of units in the section. Most were collected from units which were well bracketed in age by peat beds which had been dated and which, because of their fine grain size, promised to yield reliable primary paleomagnetic field directions. However, we also collected from dated peat beds. Most of our samples were collected from units which showed the least evidence of deformation or liquifaction, but some samples were collected from liquified units and some even from sandblows. Most samples were collected from locations as far from fault traces as feasible in the trench; this

distance ranged from less than one meter to more than 15 meters. On the other hand, some samples were deliberately collected near the fault traces to investigate the possibility that they had been rotated by right-lateral shear near the traces. At most sample sites, a group of 25 samples was taken from a single thin depositional unit. Several sites were sampled in some units.

2. All samples were analyzed in laboratories in Flagstaff, Arizona or Pasadena, California. Progressive demagnetization was performed on one or two samples from each group of samples to determine the stability of remnant magnetic directions, and then all samples were demagnetized to the levels of their magnetic stability in an attempt to remove viscous magnetic components. Structural corrections for bed attitude were applied, and virtual geomagnetic pole (VGP) positions were calculated and plotted for samples of each group; average VGP's and associated error ellipses were also calculated for each group.

Results

1. Some groups of samples have relatively poor magnetic stability; their directions of magnetization wander randomly upon demagnetization above 50 Oe. Other groups of samples have relatively high magnetic stability; they show tightly clustered VGP's to 100 Oe demagnetization and occasionally even to 400 Oe.

2. Sample groups with relatively high magnetic stability have VGP's that cluster in areas as small as 15^{o} on a side. The α_{95}s for the directions of magnetization of well clustered groups are in the range of 2^{o} to 3^{o}.

3. Sample groups with relatively high magnetic stability have VGP's that, in general, deviate from the present VGP by 10^{o} to 25^{o} after demagnetization.

4. Groups of samples from the same unit at different sites commonly behave quite differently magnetically. Some groups are magnetically unstable; some are stable. Some show a change in average VGP on demagnetization and some do not move. Some have similar VGP's and others, different. A study of these groups of samples from different sites in the same unit is frequently enlightening in that it permits one to distinguish certain groups of samples as magnetically unstable, and it permits one to piece together the magnetic history of the unit from other groups of samples which exhibit a stable magnetic component.

5. In the case of one unit, for which various groups of samples give interpretable results and for which VGP clustering is tight and stable on demagnetization, we find agreement, within statistical error, between the VGP of the unit and the VGP predicted for a unit of its age by the archeomagnetic curves of Dubois (unpublished data).

6. Contrary to our impression from preliminary results, in the case of the unit described above, there appears to be no evidence for rotation (greater than 5°) due to right-lateral shear. Samples near the fault and at some distance from the fault give consistent directions which agree with the predicted direction.

7 Samples from a sand blow indicate magnetic complexity. More work will be necessary before the paleomagnetic observations at the sand blow are interpretable.

8. The majority of the units sampled yield an interpretable characteristic direction at magnetization, and we believe that they may prove to be datable by the secular variation method.

Correlating and Dating Quaternary Sediments by Amino Acids

8-9460-01996

Keith A. Kvenvolden
Pacific-Arctic Branch of Marine Geology
U.S. Geological Survey
345 Middlefield Road
Menlo Park, CA 94025
(415) 323-8111, ext. 2817

Investigations

1. Collected specimens of *Saxidomus giganteus* and *Ostrea lurida* at seventeen localities at Willapa Bay, Washington, and continued detailed investigations of amino acid racemization in these shells from the estuarine deposits there. The objective is to establish the temporal relationships of the shell deposits.

2. Initiated a study of the age relationships in an archeological excavation on Amaknak Island, Alaska. The work was undertaken to attempt to use amino acids in shells for dating events, in this case cultural habitations, during the last 10,000 years.

3. Determined the degree of racemization in "zero-age" marine sediments in order to establish initial conditions for amino acid dating of older marine sediments.

4. Measured degree of racemization of amino acids in bones from the Yuha burial, an early-man site in southern California, to determine relationships between amino acid dates and radiometric dates.

5. Participated in interlaboratory comparison of analyses of amino acid racemization in fossil bones with Scripps Institution of Oceanography.

6. Initiated feasibility studies on bulk sediment from Searles Lake and Mono Lake to establish if these kinds of samples can be used for amino acid dating.

7. Purchased, installed, and calibrated an automated, ion exchange, amino acid analyzer to provide quantitation of concentrations of individual amino acids including isoleucine-alloisoleucine which is a useful pair in amino acid dating.

Results

1. Amino acid dating techniques have been applied to estuarine assemblages of fossil shells exposed in terraces along the east side of Willapa Bay, Washington. The shell deposits are composed mainly of *Ostrea lurida* along with at least nine other species of pelecypods including *Saxidomus giganteus*. The extent of racemization of amino acids in *Saxidomus* and *Ostrea* has been measured for samples from twenty localities. The results show that the extent of racemization of amino acids in *Saxidomus*, although variable, is sufficiently consistent to permit correlation of isolated shell deposits in the area. The extent of racemization of amino acids in *Ostrea* is quite variable, thus limiting the usefulness of this fossil in amino acid dating. At twelve localities the extent of racemization of amino acids in *Saxidomus* confirm that the shells are from a correlative stratigraphic unit. At two isolated localities the extent of racemization of amino

acids in Saxidomus is significantly greater; these measurements provide evidence for a second, older estuarine shell deposit for which the present stratigraphic record is very limited. Amino acid racemization clearly establishes the relative ages of the shell deposits. The absolute ages can only be assigned tentatively because of the lack of a good calibration site and the uncertainty of the temperature history. By using calibrations from dated terrace deposits elsewhere and assuming linear, first order kinetics and an effective diagenetic temperature of 8°C, the younger shell beds at Willapa Bay are interpreted to be about 100±30 x 10^3 years old (Sangamon Interglacial Stage). The other shell deposits are about 90±20 x 10^3 years older.

2. A large and significant archeological site was uncovered by staff from the University of Alaska Museum in 1977 on Amaknak Island at the location of a proposed bridge to span the narrow channel between Amaknak and Unalaska Islands of the Aleutian chain. At two occupational levels within a midden at the site we collected samples of Saxidomus giganteus in order to obtain an age assessment by amino acid racemization techniques. To estimate ages several assumptions were made: (1) The racemization reaction follows linear first order kinetics. (2) The Arrhenius equation with an assumed activation energy of 29.4 kcal/mole adequately relates rate constants and temperatures. (3) Bainbridge Island, Puget Sound, served as a proper calibration site (Saxidomus with ^{14}C age of 3,260 ± 80 years; effective annual temperature of 12.5°C) and (4) the effective temperature (5.4°C) for Amaknak Island can be calculated from the climatological records of the Southwestern Islands Division, Alaska. The ages of the occupational levels were determined from these assumptions and the degree of racemization of aspartic acid to be 3800 and 5600 years. Based on the recovered stone tools, the archeologists estimate that the minimum age at the site is about 3000 years and that portions of the site may be as old as 6000 to 7000 years. The agreement between these independently obtained ages is encouraging. Radiocarbon ages are being obtained from wood and shells from this site. These anticipated results will provide a means of evaluating the validity of the ages already obtained.

3. Studies by others of amino acids in soils and modern lake sediments indicate that some of these amino acids may have bacterial sources because of the high concentrations of certain D-amino acids that are found. For amino acid dating the extent of racemization is determined by measuring the ratio of D- to L-amino acids. The presence of D-amino acids from bacterial sources will cause errors in age calculations if it is assumed that the D-amino acids represent only the results of the racemization reaction. We have found, based on two samples from offshore California, that modern marine sediments also may contain significant concentrations of D-alanine, and D-aspartic acid and to a lesser extent D-glutamic acid. These compounds probably are derived mainly from the cell walls of bacteria. The results suggest that in future dating of marine sediments by amino acid racemization, corrections may have to be applied to account for the possible initial input of D-amino acids from bacterial sources.

4. Skeletal remains from the Yuha burial in Imperial County, California, may represent a site where man was present in the New World prior to 12,000 years ago. ^{14}C and ^{230}Th dating of caliche at the burial yielded concordant absolute dates of 22,125 ± 400 and 19,000 ± 3000 years respectively. The degree of racemization of amino acids in bones from the Yuha skeleton was measured in order to determine if the amino acid age would be consistent with the ^{14}C and ^{230}Th ages. Because of the absence of detailed temperature information and reliable local calibration the uncertainties associated with an age determination by amino acid

racemization are quite large here. Nevertheless, the results of our analysis show that the minimum conservative age is about 8000 years and the probable age is 20,000 years as also indicated by the radiometric results on caliche. An additional observation that has implications for future work with amino acids from bones in general is that for each bone from the Yuha skeleton the extent of racemization was different. For example, the D/L ratio of aspartic acid ranged as follows: clavicle, .44; metatarsal, .41; femur, .52. The fact that all parts of a given skeleton do not show the same extent of amino acid racemization may limit, to some degree, the usefulness of future applications of amino acids in bones to problems of correlations and chronology.

5. In the development of a new laboratory technique such as amino acid dating it is essential to establish interlaboratory comparisons to assure that the basic numbers generated are reproducible by more than one group of investigators. To this end we have compared analyses of racemization of amino acids in fossil bones and in extracts of fossil bones from the collection at Scripps Institution of Oceanography. D/L ratios of aspartic acid, glutamic acid, and alanine were determined for six bones and four bone extracts. The results show good agreement between our U.S.G.S. laboratory and Scripps. For example:

	D/L Aspartic Acid		D/L Glutamic Acid		D/L Alanine	
	Scripps	USGS	Scripps	USGS	Scripps	USGS
Tarkhan, Egypt (extract)	0.48	0.48	0.18	0.16	0.22	0.13
Buhen Horse, Sudan (extract)	.47	.48	.16	.16	.14	.09
Tarkhan, Egypt (bone)	.45	.44	.31	.14	.18	.24
Vertessozollos, Hungary (bone)	.5	.48	.2	.24	.5	.45

Interlaboratory comparison with other laboratories is now in progress.

6. Bulk sediment samples offer one of the least satisfactory matrices for the study of the degree of racemization of amino acids. The collection of amino acids in sediments may represent products from many sources, and the mineral content may yield high salt concentrations during sample processing. Desalting prior to analyses can become a major problem. To determine if bulk sediments can be used in amino acid dating two sets of samples have been studied. Five clay samples from a deep core at Searles Lake, California, were examined. (Samples provided by J. Liddicoat, Lamont-Doherty Geological Observatory). These samples from depths of 1397 to 2188 feet span an age from 2 to 3 x 10^6 years. In these samples amino acids could not be identified unequivocally. It is probable that these samples are too old and have experienced too high a temperature (present average borehole temperature in the interval sampled is 39°C) to be of use for amino acid dating.

Three sediment samples containing ostracodes from localities at Mono Lake, California, were provided by Ken Lajoie, U.S.G.S. These three samples all contain measureable quantities of amino acids. The extent of racemization generally increases with increasing depth and time. D/L ratios for three amino acids are:

Sample	Age	D/L Leucine	D/L Aspartic Acid	D/L Glutamic Acid
679-53	13,300 ^{14}C	0.05	0.23	0.12
679-25	23,300 ^{14}C	.05	.33	.17
679-1	~32,000 est.	.07	.4	.26

The results suggest that these kinds of samples may be useful in amino acid geochronology.

7. An automated, ion exchange, amino acid analyzer was acquired to enhance the capabilities of our U.S.G.S. laboratory. The instrument is equipped with automatic sampling capabilities so that as many as thirty samples can be run in sequence without operator intervention to provide quantitation of individual amino acids. Of particular interest for amino acid dating is the quantitation of the ratio of isoleucine to alloisoleucine. Isoleucine undergoes racemization (more correctly called epimerization) to mixtures of varying proportions of isoleucine and alloisoleucine. Preliminary work with the new instrument has shown that for Saxidomus at Willapa Bay, Washington, the average ratio of alloisoleucine/isoleucine is 5% greater than the average ratio of D-leucine/L-leucine. This information if of interest for currently used models where extrapolations are made to correct for the difference in the extent of racemization of these amino acids (Wehmiller et al., U.S.G.S. Open File Report 77-680).

Reports

Kvenvolden, K.A., Blunt, D.J., and Clifton, H.E., 1977, Application of amino acid stereochemistry to the correlation of Late Pleistocene deposits at Willapa Bay, Washington: Abstracts with Programs, Geological Society of America, v. 9, p. 1062-1063.

Bischoff, J.L., Childers, W.M., Kvenvolden, K.A., and Blunt, D.J., submitted, Racemization of amino acids in the Yuha skeleton: implications for age and temperature history: Earth and Planetary Science Letters.

Pollock, G.E., and Kvenvolden, K.A., submitted, Stereochemistry of amino acids in surface samples of a marine sediment: Geochimica et Cosmochimica Acta.

Approved for distribution

David W. Scholl, Chief,
Pacific-Arctic Branch of Marine Geology

Soil Correlation and Dating, Western Region
9-9540-02192

Denis E. Marchand
Branch of Western Environmental Geology
U.S. Geological Survey
345 Middlefield Road, MS 75
Menlo Park, CA 94025
(415) 323-8111 x2009

Investigations

1. Merced River chronosequence (arkosic) (northeastern San Joaquin Valley, California): completed except for cation, particle size, trace element, and phosphorous data on existing samples. Two additonal sites will be added.

2. Dry Creek chronosequence (volcanic) (northeastern San Joaquin Valley, California): field reconnaissance completed; sampling areas selected.

3. Stanislaus River chronosequence (mixed arkosic and volcanic) (northeastern San Joaquin Valley, California): field reconnaissance underway..

4. Salinas Valley-Central California Coast chronosequences (arkosic, mixed): field reconnaissance underway.

5. Cowlitz chronosequence (volcanic) (western Washington Cascades): field reconnaissance underway.

6. Western Sierra Nevada Foothills chronosequence (mixed, basic rocks): all sampling and analyses completed; interpretation in progress.

7. Many soil descriptions and analytical data for several good time sequences have been provided to us by L. H. Gile for southern New Mexico (desert soils, arkosic, mixed) and by E. J. Ciolkosz for central Pennsylvania (sedimentary, mixed).

Results

1. In the Merced River chronosequence, a clear progression of changes with time in soil morphology and analytical properties is evident. Some properties such as bulk density, B horizon thickness, maximum color index, total profile hydrogen ion content, ratio of B horizon free iron oxides content to that in A horizon, and percentage kaolinite plot on smooth curves vs. absolute time with moderate to minimal scatter. Some soil properties are useful as age indices only in young soils, others only in old soils, and some properties are useful over a broad age span.

2. Soils in the western foothills of the Sierra Nevada appear to form much more rapidly than those of similar age on comparable parent materials in the northeastern San Joaquin Valley and along the east side of the Sierra Nevada. This contrast is probably due at least in part to higher precipitation in the foothills than in the adjacent areas.

Publications

Harden, J. W. and Marchand, D. W., 1977, The soil chronosequence of the Merced River area in Singer, M. J., Soil development, geomorphology, and Cenozoic history of the northeastern San Joaquin Valley and adjacent areas, California: Guidebook for the joint field session of the American Society of Agronomy, Soil Science Society of America and the Geological Society of America, Chap. VI, p. 22-38, published by the Amer. Soc. Agronomy at Davis, California.

Quaternary Dating Techniques

8-9530-01559

Kenneth L. Pierce
Branch of Central Environmental Geology
U.S. Geological Survey
Denver Federal Center, Mail Stop 913
Denver, Colorado 80225
(303) 234-2737

Investigations

1. A group of 27 Survey scientists was assembled in Denver to discuss current and future experimental Quaternary dating studies. Following this meeting information was gathered for a users guide to the different dating techniques and for a table showing the potential of various Quaternary sequences for experimental dating studies.

2. As part of a general study of soil development with time, changes in B-horizon characteristics of soils were analyzed for 7 chronosequences of Pleistocene glacial deposits in the Rocky Mountains.

3. Continued compilation of a U.S. Environmental Overview Series map for the National Atlas, entitled "Quaternary deposits and their dating potential," at a scale of 1:7,500,000.

4. Continued investigation of the age of Hayden Creek and Salmon Springs glacial deposits in western Washington.

5. Described and submitted a suite of 20 ash samples from Idaho, Wyoming, Oregon and Washington for tephrachronologic analyses.

6. Paleomagnetic analyses with R. L. Reynolds of mid-Quaternary sections in Wyoming, Idaho, and Oregon.

7. Continued studies of stratigraphy and ages of loess sheets in Idaho and Wyoming, and arranged for combined work with Prof. Maynard Fossberg, Univ. Idaho.

8. Investigation of the progression of surface weathering of basalt flows on Mauna Loa, Hawaii. The study includes field and laboratory examination of a widespread series of surface flows, mostly in the 0-10,000 year old range as controlled by numberous C-14 dates, from the southwest rift of Mauna Loa.

9. Investigation of landform modification with time of stream terraces in the eastern U.S. Initial work is concentrated on the Rappahannock River, Va., where such characteristics as terrace scarp morphology, drainage density, and degree of dissection are being measured for a sequence of stream terraces.

10. Preparation of a report entitled "Weathering rinds on andesite and basalt as a Quaternary dating technique, western United States." The report documents weathering rinds as an excellent relative-age indicator, and their potential, with calibration, as an approximate numerical age method.

Results

1. The conference on experimental Quaternary dating techniques resulted in wider understanding of the methods being investigated, and in a plan to try to design future studies upon systematic consideration of the dating opportunities and dating control of all the major Quaternary sequences in the United States. A 23-page users guide was prepared and circulated that describes the salient points in the application of 14 experimental dating methods. A table in matrix form listing the important characteristics of about 50 areas with Quaternary sequences has been outlined and is now being filled out by various Quaternary stratigraphers. This table lists 30 different attributes of each area that are important to experimental dating studies, including the types of stratigraphic sequences present, the established numerical ages, and applicability of different experimental methods. It will provide a synoptic overview of areas being considered for future dating studies, especially where several experimental methods can be evaluated and compared.

2. Field descriptions and grain-size analyses indicate that the degree of B horizon development increases with the age of the parent material. Oxidized C horizons (Cox), cambic B horizons (Bs), or weak textural B horizons (Bt) have formed in the upper half meter of Pinedale till (about 15,000-30,000 years old). In post-Pinedale soils, Bt, Bs, or Cox horizons in the B horizon position show an average increase in clay of 2.5 percent, relative to fresh to slightly oxidized till at depth, and average 15 cm in thickness. Soils formed in Bull Lake till ($\sim 10^5$ years old) have moderately developed Bt horizons with an average increase in clay of 9 percent (relative to slightly oxidized till at depth) and average 50 cm in thickness. A soil formed in pre-Bull Lake till (about half a million years old) has a well developed 90-cm-thick Bt horizon characterized by a 17 percent increase in clay (relative to strongly oxidized till at depth).

The equivalent thickness of clay was determined for the above soils by multiplying relative increase in percent clay times the B-horizon thickness times the percent less than 2 mm-size material. Values ranged from less than 0.5 cm for most post-Pinedale soils to about 1-3 cm for most post-Bull Lake soils, to about 7 cm for the pre-Bull Lake soil.

3. The map entitled "Quaternary deposits and their dating potential" and the report entitled "Weathering rinds on andesite and basalt as a Quaternary dating technique, western United States" have been submitted for technical review.

4. Field observations indicate that the basalt flows on the southwest rift of Mauna Loa, Hawaii, exhibit systematic changes with time due to surface weathering. These changes include surface color changes from black to red-orange and a thickening of the surface weathering crust, presumably due to oxidation and hydration, and destruction of fine surface textures and structures. These processes appear to be strongly affected by local climate and rock texture. Samples collected from flows of different ages will be analyzed to document chemical and mineralogic changes with time. Numerous C-14 dates will provide calibration for determining the time-functions of the weathering processes.

5. The collection of morphologic data for the terraces along the Rappahannock River, Va., has just begun, but preliminary observations suggest that there are systematic modifications of these landforms. Continuing data collection and analysis will attempt to document changes in scarp morphology, drainage density, degree of dissection, and other parameters with age.

6. In southeastern Idaho near Pocatello, a change from normal polarity downward into reversed polarity was determined (with R. L. Reynolds) in alluvium underlying 4 loess sheets. This reversal is probably the Brunhes-Matuyama reversal dated at 730,000 years old, and to our knowledge is the first determination of this polarity change in surficial materials in this region. At nearby sections two volcanic ashes also have been identified near the base of the loess units; they have been provisionally identified as Bishop (700,000 years old) and Type O Pearlette (600,000 years old).

Reports

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Pierce, K. L., in press, History and dynamics of glaciation in the northern Yellowstone National Park area, Wyoming and Montana: U.S. Geological Survey Prof. Paper 729 (269 ms p., 50 figs. 5 pls).

Uranium Series Dating

8-9740-00378

J. N. Rosholt
Branch of Isotope Geology
U.S. Geological Survey
Denver Federal Center
Denver, CO. 80225
(303) 234-4201

Investigations

A. Uranium-trend dating

A new concept in uranium-series dating called uranium-trend dating has been tested extensively over the past year to determine the reliability of this technique in estimating the time of deposition of alluvium 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. In each sample an accurate determination of the abundances of U-238, U-234, Th-230, and Th-232 is required. 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 resulting slope, $\Delta(^{234}U-^{238}U)/\Delta(^{238}U-^{230}Th)$, increases 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.

B. Radioactive disequilibrium in ferruginous fault gouge material and in ferruginous coatings on conglomerates is being investigated to determine the applicability of this type of material for estimating the age of faulting or fault recurrence. Samples of fault gouge material below alluvium that has been dated were collected from the Golden Fault, 1.2 km northwest of Golden, Colorado. Collection was made from an exploratory trench provided by the Colorado Geological Survey. Samples of ferruginous coatings on conglomerates are expected to be provided by Dave Russ.

Results

A. Uranium-trend dating. Analyses of alluvium sections overlying the Golden Fault indicate that there were two periods of alluvial deposition on top of outwash gravel that was deposited earlier and subsequently faulted. The deposition of the unit that has a surface soil developed was dated at 260,000 years ago and the deposition of the underlying silt was dated at 350,000 years ago.

B. Preliminary results have been obtained on the $^{238}U-^{234}U-^{230}Th-^{226}Ra$ system in fault gouge material in the Golden Fault. Interpretation of these results suggest an important mechanism of radio isotope fractionation that may be useful in characterizing the degree and length of time over which uranium mobility has occurred in porous zone of hard rocks or sediments. As ^{238}U and ^{234}U atoms dissolved in water decay by alpha disintegration, recoiling nuclides of ^{230}Th, ^{234}Th, ^{234}Pa, and ^{234}U produced by beta recoil are adsorbed on adjacent particles or driven into particles at their interface with uranium-bearing water. After sufficient time, this mechanism (uranium emplacement) results in rock material adjacent to fractures that have $^{234}U/^{238}U$ and $^{230}Th/^{238}U$ ratios significantly higher than sediments that are not exposed to the greater volume of water that flowed along the faults. Soil samples collected above the fault zone all have a uranium content of 2 ppm, near equilibrium $^{234}U/^{238}U$ ratios, and $^{230}Th/^{238}U$ plus $^{226}Ra/^{238}U$ ratios near 1.3. Four samples of fault gouge material have very high $^{230}Th/^{238}U$ and $^{226}Ra/^{238}U$ ratios as shown in the table below.

Sample	^{238}U (ppm)	$\frac{^{234}U}{^{238}U}$	$\frac{^{230}Th}{^{238}U}$	$\frac{^{226}Ra}{^{238}U}$	$\frac{^{226}Ra}{^{230}Th}$
R-10	6.26	1.23	8.30	7.3	.89
R-11	17.5	1.32	4.01	2.4	.61
R-12	11.7	1.31	5.53	2.6	.47
R-16	16.5	1.26	3.29	2.3	.70
R-17	12.9	1.32	2.06	3.1	1.50
R-18	8.50	1.27	2.51	2.4	.94

Tephronochronology of the Western Region

8-9540-01947

Andrei M. Sarna-Wojcicki
U.S. Geological Survey
Menlo Park Center, MS 75
Menlo Park, CA 94025
(415) 323-8111 x2745

Investigations

Tephra samples (ashes and tuffs) were collected from localities in California, Nevada, Oregon, and Washington. Samples were processed for analysis and fission-track dating. Tephra was analysed petrographically while volcanic glass separated from the tephra was analysed by neutron activation and electron microprobe methods. Fission-track analysis on zircon crystals extracted from tephra samples was begun. Major project items include the following:

1. A suite of well-dated (^{14}C) samples of Wisconsinan and Holocene age tephra was collected from Mount St. Helens (in cooperation with D. Mullineaux, Branch of Engineering Geology) to test resolution of chemical fingerprinting technique on tephra erupted within a short time interval, and to provide chemical and age reference standards for down-wind tephra sampled in eastern Washington, Oregon, and Nevada (items 2, 3).

2. A suite of Quaternary tephra samples was collected from central Washington (in cooperation with R. Waitt), to determine age of Quaternary deposits and geologic events by correlation with reference section at Mt. St. Helens and other Cascade Range sources.

3. Samples of Quaternary ashes and tuffs were obtained from Lake Lahontan basin of northwestern Nevada (in cooperation with Jonathan Davis, Nevada Archeological Survey, Univ. of Nevada, Reno) to correlate with Cascadian sources of Quaternary age.

4. Samples of Pleistocene tephra were collected from lake beds of pluvial Lake Tecopa, in the Armagosa Valley of southeastern California (in coordination with paleomagnetic work by J. Hillhouse, Branch of Petrophysics and Remote Sensing). Preliminary data and previous work indicate that this section is a "Rosetta stone" reference section for early and middle Pleistocene tephra for southern California (items 5, 6).

5. Correlation of early and middle Pleistocene tephra in the Ventura basin of southern California was continued (in cooperation with R. Yerkes, Branch of Western Environmental Geology, and K. Lajoie, Branch of Ground Motion and Faulting, and J. Wehmiller, Univ. of Delaware.

Results

1. A widespread Pleistocene ash erupted in the vicinity of Mount Lassen, California, has been identified and correlated for a number of localities in northern California and Western Nevada by means of instrumental neutron activation analysis of separated volcanic glass and petrography. Near-source exposures of this unit, mapped by previous workers as the informally-named Rockland pumice tuff, consist of a pumice-ash flow and associated air-fall and water-laid facies. Two members of this unit, previously mapped as the Lassen Lodge and Manton members, were believed to be of different age on the basis of earlier K-Ar analyses. However, they are probably a single eruptive unit since they have essentially identical trace- and minor-element glass compositions, similar fission-track ages (C. Naeser, Branch of Isotope Geology, Denver), identical petrography, and are not superposed.

Near-source exposures of this unit, interbedded with volcanic and pyroclastic rocks near Mount Lassen, are correlated with air-fall and water-laid ash facies interbedded with marine, estuarine, and fluvial deposits at San Francisco, Woodside, and Hollister, and with glacial and glaciofluvial deposits near Bridgeport, California, and Washoe, Nevada.

Results of recent paleomagnetic work (in cooperation with J. Hillhouse), as well as earlier K-Ar and fission-track ages on zircons, indicate the ash is 0.6±0.1 million years old.

2. Six ashes in a stratigraphic sequence have now been identified for the Ventura Avenue anticline and the South Mountain area. Similarities in chemical characteristics of five of these ashes indicate they were erupted from an area east of the central Sierra Nevada, while the source of the sixth (oldest) ash is unknown. Despite the similarity of the five ashes, they can be identified and distinguished from each other on the basis of the trace element chemistry of their volcanic glasses. Two of the ashes, exposed north of the town of Ventura, the second and third from the top of the section, are correlated with near-source exposures north of Bishop. Radiometric ages of three of these ashes, as established by chemical correlations with previously dated exposures, are 1.2, 0.9(?), and 0.6 m.y. The ages are in good stratigraphic agreement with recent amino-acid racemization ages (determined by J. Wehmiller, in cooperation with K. Lajoie and R. Yerkes) on three fossil beds stratigraphically above these ashes (AAR ages of 0.37, 0.27, and 0.19). The age of a deformed marine terrace incised into the south dipping section is 80-120 thousand years, consistent with the other ages. The ages indicate rapid uplift and deformation of the Pleistocene section in this area of recent crustal compression.

3. Results of electron microprobe analyses of volcanic glass shards for a number of previously-analysed tephra samples (C. Meyer, this project), for Ca, Fe, K, Mg, Mn, Na, Ba, and Cl indicate that it is possible to identify source areas of tephra units by this method of analysis, but that it is difficult or impossible to uniquely distinguish individual, chemically similar tephra units erupted from a single volcanic province (for instance, several closely related volcanic ashes erupted from the Long Valley-Mono Basin area, such as the "Bailey" ash and the Friant Pumice). These results differ somewhat from those of several other workers who use electron microprobe analyses to fingerprint volcanic ashes. The application of the electron microprobe method to tephra fingerprinting may be limited to certain volcanic provinces within which tephra from successive eruptions is sufficiently differentiated to result in detectable differences in concentrations for the major and minor elements.

Reports

Wehmiller, J. F., Sarna-Wojcicki, A. M., Yerkes, R. F., and Lajoie, K. R., 1977, Anomalously high uplift rates along the Ventura-Santa Barbara coast, California--tectonic implications (abs.): 1977 International Symp. on Recent Crustal Movements Stanford University, July 25-30, 1977.

Sarna-Wojcicki, A. M., Hall, N. T., Bowman, H. W., Naeser, C. W., and Russell, P. C., 1977, Correlation and age of a widespread Pleistocene ash bed in northern California and western Nevada (abs.): Geological Society of America Annual Meeting, Program with Abstracts, Seattle, 1977.

Earthquake-Induced Structures in Sediments

8-9950-01294

John D. Sims
Branch of Earthquake Tectonics and Risk
U. S. Geological Survey
345 Middlefield Road, MS 77
Menlo Park, CA 94025
(415) 323-8111

Investigations

1. Laboratory studies and analysis of cores and sediments collected in Alaska, San Fernando, CA, and Koehn Lake, CA.

2. Completion of annotated bibliography of penecontemporaneous deformational structures in sediments.

3. Investigations of field localities in ancient Lake Bonneville and Lake Lahonton sediments to determine presence of probable earthquake-induced deformational structures.

4. Continuation of development of new lake sediment coring apparatus capable of coring to 15 m depth in water up to 30 m deep.

5. Instituted studies on laboratory production of deformational structures in sediments by simulated earthquake shaking.

6. Preliminary field investigations of sag ponds on the San Andreas between Cholame and Cajon Pass by Mike Rymer.

Results

1. Deformational structures occur in Upper Van Norman reservoir near the site of original discovery of earthquake-induced deformational structures in sediments. These structures may be correlated with the original ones described by Sims (1973). Deformational structures were also found in Koehn Lake, CA, which is cut by the Garlock fault. The structures consist of small scale (5-20 cm) diapir-like structures, load casts, ruptured and deformed lamination and clastic dikes. The structures occur in a dominantly clayey and silty sequence exposed in two trenches dug for Malcolm Clark, Dennis Burke and Chuck Hedel.

2. The analysis of cores from Alaska shows that a number of deformational structures are present in these sediments from several lakes. The cores point up the difficulty of correlating structure zones without adequate stratigraphic markers. From this suite of samples I also discovered a deficiency in my sampling technique. Cores do not always intersect recognizable parts of zones of structures. I have found that groups of closely spaced cores are more likely to yield the needed information rather than evenly spaced individual cores.

3. An extensive review of the literature on penecontemporaneous deformational

structures was required to compile the annotated bibliography. The completed bibliography contains approximately 400 entries. In becoming familiar with the body of literature, several heretofore unknown key references to earthquake-induced deformational structures were found. I was able to correlate different approaches to aspects of the problem of liquefaction and resedimentation of liquefied sediments which resulted in an enhanced insight to my project goals (Sims, in press).

4. Sites for detailed investigations in ancient lakes Lahonton and Bonneville have been identified. Visits to the sites for detailed inspections and sampling will be made this summer.

5. Two lines of investigation into experimentally produced deformational structures by simulated earthquake shaking are being pursued. One is based on the mechanical shaking of laminated sand and silt in the laboratory. The second is placing containers of similarly laminated materials at the Nevada Test Site for shaking by shocks from underground nuclear tests. In this latter approach, samples will be placed at varying distances from the "epicenter" to determine the effects of distance with the type of structure produced as well as the effects of grain size and lamina thickness.

6. M. Rymer is initiating a study of sag ponds along the San Andreas fault zone between Cajon Pass, San Bernardino County and Cholame, San Luis Obispo County. The study is aimed at determining recurrence intervals of fault movement by examining carbon-rich and dateable sediments in selected sag ponds. To date, four sag ponds have tentatively been selected for coring and detailed examination: Still and Twisselman Lakes (near Cholame), an unnamed sag pond (near Camp Dix), and Lost Lake (near Cajon Pass). The coring apparatus to be used in the study is under construction and should be completed soon.

Reports

Sims, J.D. and White, D.E., 1978, Mercury in the sediments of Clear Lake: Geological and environmental implications: Geol. Soc. America Abstracts with Program, v. 10, p. 147.

Sims, J.D., 1978, Mercury analyses of sediments from cores in Clear Lake, Lake County, California: U.S. Geol. Survey Admin. Report, 7 p.

Sims, J.D., 1978, Mercury analyses of sediments from cores in Clear Lake, Lake County, California: U.S. Geol. Survey Open-file Report 78-116, 7 p.

Sims, J.D., in press, Environments of formation of earthquake-induced deformational structures in sediments: Tenth International Congress on Sedimentology-Jerusalem, Abstracts.

Sims, J.D., in press, Annotated bibliography of penecontemporaneous deformational structures in sediments, 1819 - April, 1978: U.S. Geol. Survey Open-file Report 78-

Calzia, J.P., and Sims, J.D., in press, Deformational structures in the Plio-Pleistocene Baos Formation near Vidal, southeastern California:

Tectonic Analysis of Active Faults

8-9900-01270

Robert E. Wallace
Office of Earthquake Studies
U. S. Geological Survey
345 Middlefield Road, MS 77
Menlo Park, CA 94025
(415) 323-8111, ext. 2751

Investigations

1. Continued photogeologic analysis of young faults in north-central Nevada, especially in the Cortez Mountains, Sulphur Springs Range, Fish Creek Mountains, Carico Lake Valley, and Simpson Park Mountains.

2. Calculated seismic moments and local magnitudes from dimensions of selected sets of scarps.

3. Compared seismic flux derived from density of fault scarps to flux derived from historic seismicity in the Great Basin.

Results

1. Completed first draft of map of young faults in the Winnemucca 2° sheet and eastern part of Lovelock 2° sheet (40°-41° N., 116°-118°30' W.).

2. The seismic flux in the Great Basin province, as determined from the distribution of Holocene faults, appears to be at least an order of magnitude lower than the flux in historic time. The part of the province in eastern Nevada and western Utah appears devoid of fault scarps that could have accompanied large earthquakes ($M \geq 7$).

3. In the area of the northern Shoshone Range, Crescent Valley, and Cortez Mountains, a set of older fault lineaments trending N. 15°-20° W. makes a rectilinear pattern with scarps which trend N. 20°-50° E. Both sets of faults have young scarps along certain segments, but many segments may have been inactive for as long as several hundred thousand years.

4. Young fault scarps appear to be absent along the Beowawe scarp where the Beowawe geysers occur.

Reports

Wallace, R. E., 1978, Size of larger earthquakes, north-central Nevada (abs.): Seismological Society of America, Abstracts of Papers, 73rd Annual Meeting, April 6-8, 1978, Sparks, Nevada; Earthquake Notes, v. 49, no. 1, p. 23.

Wallace, R. E. (in press), Geometry and rates of change of fault-generated range fronts, north-central Nevada: U. S. Geological Survey Journal of Research.

Revision and Studies of Modified Mercalli Intensity Scale

8-9950-02145

S. T. Algermissen
Branch of Earthquake Tectonics and Risk
U. S. Geological Survey
Denver Federal Center, MS 966
Denver, CO 80225
(303) 234-4014

Investigations

The entire U.S. earthquake catalogue for larger events ($I_o \geq V$) is being reviewed. The objective is to improve estimates of maximum Modified Mercalli intensity, earthquake location, and related parameters.

A committee has been formed to study and recommend possible revision of the Modified Mercalli intensity scale.

Results

Progress on the U.S. catalogue has been satisfactory. The analysis of the eastern United States is nearly complete.

The committee reviewing the criteria currently used in the Modified Mercalli scale has selected about 30 well-investigated earthquakes as source material and as the basis of possible recommendations for revision of the scale.

Regional and National Seismic Hazard and Risk Analysis

8-9950-01207

S. T. Algermissen
Branch of Earthquake Tectonics and Risk
U. S. Geological Survey
Denver Federal Center, MS 966
Denver, CO 80225
(303) 234-4014

Investigations

The effects of parameter uncertainty on mapped values of acceleration in rock as presented in the probabilistic 50-year exposure time, 90-percent extreme probability acceleration map for the contiguous United States have been examined. Length of faulting (as it affects ground acceleration) was taken into account in the original map only in California. A point source model of earthquake occurrence was used for the remainder of the country. Alternate source zone modeling for the Puget Sound, Washington, area were also considered.

Earthquake losses by class of construction in the San Francisco Bay area were investigated.

Results

a. Assumed length of faulting rather than fault orientation is the more important parameter in mapping ground motion. Assumption of fault lengths of about 150 km for magnitude-7.3 earthquakes in the Mississippi Valley increased the 50-year 90-percent probability level acceleration by about 75 percent over the values computed using a point source. An assumption of a shorter fault length (50 km) for a magnitude-7.3 event resulted in an increase of ground motion of only about 40 percent over the point-source estimates. Similar results were obtained for the Charleston, S.C., area.

b. Attenuation of acceleration in the Puget Sound area for large shocks at depths of about 60 km was reviewed. It was concluded that the attenuation previously used for the United States acceleration map are satisfactory with minor changes.

c. Source zones were changed to reflect the possibility of larger magnitude earthquakes in central Washington than previously modeled. The result is a broadening of the 15-percent g contour in Washington State if the large earthquakes are assumed to have a depth of 60 km. If the large shocks (magnitudes as great as 7.3) are allowed to occur at shallow depths, the accelerations increase to 50-60-percent g.

d. Open-file reports containing the estimates of losses to buildings in the San Francisco Bay area have been completed and a rapid method for the estimation of losses presented.

Reports

Algermissen, S. T., Steinbrugge, K. V., and Lagorio, H. J., 1978, Estimation of losses to buildings other than single family dwellings: U.S. Geol. Survey Open-File Rept. 78-441.

Algermissen, S. T., McGrath, M., and Hanson, S., 1978, A Technique for the rapid estimation of earthquake losses: U.S. Geol. Survey Open-File Rept. 78-440.

Physical Constraints on Source of Ground Motion

8-9940-01915

D. J. Andrews
Branch of Ground Motion and Faulting
U. S. Geological Survey
345 Middlefield Road
Menlo Park, CA 94025
(415) 323-8111, ext. 2752

Investigations

1. Deterministic modeling of a ground motion pulse radiated by a patch of high stress drop.

2. Statistical modeling of irregular stress on a fault.

3. Investigation of numerical Green's function methods.

Results

1. It now appears that no useful constraints on peak acceleration can be found from deterministic modeling. The motivation of this investigation has been the hypothesis that nonelastic yielding at the source, having the effect of smoothing out singularities that exist in analytic solutions, will have a similar effect on the far field wave form. Then a peak amplitude might be related to shear strength. The random nature of the source at short wavelengths was to be modeled by superposition of pulses radiated from patches of different stress drops, ranging up to the shear strength of the rock.

Finite strength does not impose any constraint on peak acceleration in the pulse radiated from a patch rupturing coherently. From some simple analytic considerations it can be seen that self-similar coherent growth of rupture, even with the rupture front smeared out, will produce a far-field acceleration that can be arbitrarily large as the rupture velocity approaches the shear wave velocity and the azimuth approaches the direction of rupture propagation. If any useful physics constraint in peak acceleration is to be found, it will come from attenuation along the propagation path or from nonelastic yielding near the surface, where shear strength may approach zero.

It may be more reasonable to seek constraints on peak particle velocity from deterministic modeling. Abrupt stopping of rupture can produce a delta function in acceleration and a step in particle velocity in the far field at some azimuths. Three dimensional finite difference calculations have shown that finite strength beyond the edge of a ruptured patch will allow a rupture to stop gradually, and will limit the magnitude of the radiated step in velocity.

In this deterministic approach the problem remains of determining the statistical summation of radiated pulses. The high frequency ground motion spectrum is not determined by this approach.

2. Work is in progress to relate the ground motion spectrum to the space-time spectrum of the stress drop function on the fault. In the limit of very high frequency, where stress drop is not correlated between different points on the fault, root-mean-square particle velocity in the radiated field is proportional to root-mean-square stress drop on the fault. At lower frequencies, where there may be some correlation of stress drop between different points, analysis is much more difficult. An important question for which there may be no simple answer concerns the link between the directivity effect of coherent models and the incoherent radiation from random high frequency models.

3. Some preliminary investigations have been made of the feasibility of numerical Green's function methods for source calculations. Such methods may be more accurate than finite difference methods.

4. Advice has been given to Paul Delany on finite difference calculations of pore pressure increase in country rock due to heating from dike intrusion.

5. Review talks and papers were prepared for the Conference on Fault Mechanics sponsored by USGS in December 1977 and for the Symposium on Fracture Mechanics sponsored by the American Mathematical Society in March 1978.

Reports

Andrews, D. J., (in press), Application of rupture propagation theories to earthquakes: Proceedings of Conference III--Fault mechanics and its relationship to earthquake prediction, U. S. Geol. Survey Open-File Report.

Andrews, D. J., (in preparation), Capabilities and limitations of numerical modeling of rupture: Proceedings, American Mathematical Society.

Interactive Data Processing Center

8-9940-02085

Roger D. Borcherdt
Branch of Ground Motion and Faulting
U. S. Geological Survey
345 Middlefield Rd., MS 77
Menlo Park, CA 94025
(415) 323-8111, ext. 2755

Investigations

Develop interactive data processing center to analyze and archive seismic data recorded on portable arrays designed to study earthquake source mechanisms, wave propagation, strong motion data, and crustal structure. The center is being designed in conjunction with the design and development of portable arrays of low power, microprocessor based, digital cassette recording systems (see Warrick, Instrument Development and Geotechnical Studies, 8-9940-02089). The Seismic Engineering Branch is participating in development of the center.

Results

Center design, personnel support, and hardware purchases have been completed. Delivery of equipment is expected in July, 1978. Software conversion and development is planned to start in June.

Reports

None

Dynamic Soil Behavior

8-9550-01630

Albert T. F. Chen
Branch of Engineering Geology
U.S. Geological Survey
345 Middlefield Road
Menlo Park, CA 94025
(415) 323-2605

Investigations

1. Continued a parametric study on the use of available stress-strain relations in nonlinear and equivalent-linear ground-motion computations.

2. Continued laboratory testing and data interpretation of the one-dimensional dynamic behavior of San Francisco Bay mud.

3. Continued laboratory testing of the three-dimensional dynamic behavior of San Francisco Bay mud.

Results

1. Computations based on equivalent-linear analyses suggested that the use of Hardin-Drnevich relation (H&D) consistently leads to lower response values than those obtained by applying Seed-Idriss relations (S&I). The most significant difference is in the fundamental period. For a 25-meter normally consolidated clay deposit, the fundamental period based on H&D is 0.6 sec for the low-strain case (with a maximum input acceleration of 0.07g) and 1.4 sec for the high-strain case (0.7g) versus respectively 1.1 sec and 2.1 sec based on S&I.

2. The Ramberg-Osgood representation of stress-strain relations for soils is only adequate to moderate strain levels (<0.5 percent) regardless of the type of analysis intended.

3. A threshold degradation strain of 0.01 percent for San Francisco Bay mud was established. Below this strain level, load cycling has no effect on the shear modulus and the damping ratio.

4. An increase in shear modulus with time at a constant confining pressure was observed in the laboratory for strain levels up to 0.1 percent. Such an increase indicates that field moduli based on laboratory values should be corrected accordingly. Procedures for this type of correction were proposed and examined.

Reports

Stokoe, K. H., and Lodde, P. F., Dynamic response of San Francisco bay mud: American Society of Civil Engineers, Geotechnical Engineering Division Specialty Conference on Earthquake Engineering and Soil Dynamics, June 1978 Proc. (in press).

Seismic Wave Attenuation in Conterminous United States

8-9950-01205

A. F. Espinosa

Branch of Earthquake Tectonics and Risk
U.S. Geological Survey
Denver Federal Center, MS 966
Denver, CO 80225
(303) 234-5077

Investigations

1. Continuation of regional compilation of seismograms for selected events in the U.S. to be used in the seismic wave attenuation study in progress.

2. Continuation of data reduction and analysis of twenty-five earthquakes recorded by the Long Range Seismic Measurement Stations in different geological environments in the U.S..

3. Continuation on the attenuation study of short-period waves from twenty-nine earthquakes recorded on strong motion instruments in the U.S..

4. Continuation on the attenuation study for nine historical earthquakes in conterminous U.S..

5. Completion of a detailed revised intensity distribution map for Guatemala City and vicinity.

6. Completion of a map for the Republic of Guatemala showing the intensity distribution and area that sustained ground deformation effects after the February 4, 1976 earthquake.

7. Investigation of the possible conceptual extension, using computer applications, of evaluating M_o (earthquake moment) from strong motion recordings. (Brune, Espinosa, Oliver, 1963, and Wyss and Brune, 1968)

8. Developed a mathematical procedure, and programmed it on the Multics system, to compute the time duration and the instrumental intensity evaluation of the digitized accelerograms of Western U.S. earthquakes.

9. Completed a preliminary attenuation curve for Guatemala.

10. We are in the process of investigating the methodology to follow on data handling and retrieval and procedures for analyzing and displaying these results.

11. Investigation of the decay of short-period seismic signals with distance is being pursued using a theoretical model (finite difference).

Also, a parametric study is being conducted with this model to ascertain variations in the wave amplitudes due to hypocentral distance and source-time function duration.

Results

1. Studies of the attenuation of short-period waves due to the San Fernando earthquake of February 9, 1971, have allowed us to determine a number of first order approximation equations which correlate particle horizontal velocity with epicentral distance and with modified Mercalli ratings. Also, a number of relations have been determined, correlating the level of ground motion for a given spectral component to epicentral distance and MMI ratings.

2. Attenuation curves have been constructed for nine historical U.S. earthquakes which occurred in different parts of the Union. These curves, particle velocity as a function of distance with MMI as a parameter, are helpful in specifying the ground motion level in different regions. Further work will follow to update this set of attenuation curves.

3. A new procedure has been developed to calculate the time duration of ground shaking from the digitized recordings of the accelerograms of the Long Beach earthquake, March 10, 1933, through the San Fernando earthquake, February 9, 1971 data base. Some of the results from this study are in a form of numerical equations which correlate particle velocity, epicentral distance, MMI ratings with time duration of strong shaking.

4. A preliminary attenuation curve for Guatemala has been derived from the intensity distribution of the February 4, 1976, damaging earthquake. This curve will be of assistance to the local engineers, and can be used in conjunction with earthquake seismic hazard mapping of Guatemala.

5. A full documentation has been done of the inconsistencies found in the Modified Mercalli intensity scale in Guatemala. A completion of a map for Guatemala showing the intensity distribution in that nation and the areas that were affected by liquefaction, surface breakage, landsliding, and also areas where bridges collapsed, rails bent appreciably etc., are displayed visually in a 1:500,000 scale map.

6. Study of the attenuation of a newly proposed instrumental intensity has been extended to obtain the intensity in the velocity- and displacement-time domain. It has been evaluated using recordings from different magnitude earthquakes and it has been correlated with other ground motion parameters, and with other instrumental intensities. One of the main results in this study is that our proposed instrumental intensity has less scatter than any previous proposed instrumental intensities. Also, that the procedure in evaluating this instrumental intensity is rather simple and can be duplicated with a 10 percent variation in the final results.

7. Results from the attenuation of the particle velocity of short-period waves as recorded at near- and intermediate-epicentral distances have shown that the level of motion for a spectral component of 0.1 sec. changes rather fast from distance of 10 km to 100 km. Also, we have been able to attach a vibrational dependence to the MMI ratings by obtaining a correlation among horizontal particle velocity for a given spectral component as a function of Modified Mercalli intensity ratings and epicentral distance (see figure 1.). Another result in our attenuation study (Espinosa, 1977) is that the horizontal particle velocity (cm/sec.) from the San Fernando earthquake as a function of epicentral distance (km) and of MMI ratings yields results similar to those obtained using all the western U.S. strong motion data (Krinitzsky and Chang, 1977). These results are shown in figure 2 of this brief report.

Reports

Espinosa, A. F., 1977, Particle velocity attenuation relations: San Fernando earthquake of February 9, 1971: Seismol. Soc. America Bull., v. 67, p. 1195-1214.

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Lopez-Arroyo, A., and Espinosa, A. F., 1977, Deterministic and probabilistic approaches to seismic risk determination (abs.): Symposium of the analysis of seismicity and seismic risk, Czechoslovak Academy of Sciences, Liblice, Czechoslovakia, October.

Berrocal, J., and Espinosa, A. F., 1978, Seismological and geological aspects of the Mantaro landslide in Peru: Nature (in publication).

Espinosa, A. F., Asturias, Jose, and Quesada, A., 1978, Applying the lessons learned in the 1976 Guatemala earthquake to earthquake hazard zoning problems in Guatemala: (invited paper) International Symposium on the February 4, 1976, Guatemalan earthquake and the process of reconstruction, Guatemala.

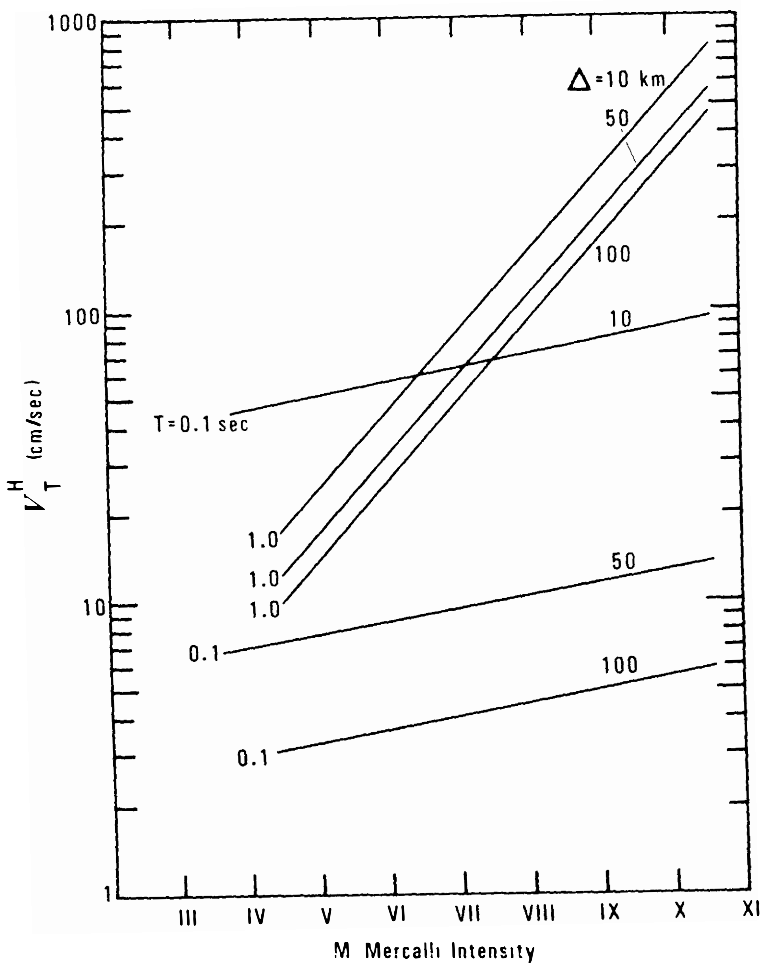

Figure 1. Horizontal spectral velocity of the San Fernando earthquake for periods of 0.1 and 1.0 sec. as a function of MMI ratings. The different curves are for epicentral distances varying from 10 to 100 km (Espinosa, 1973).

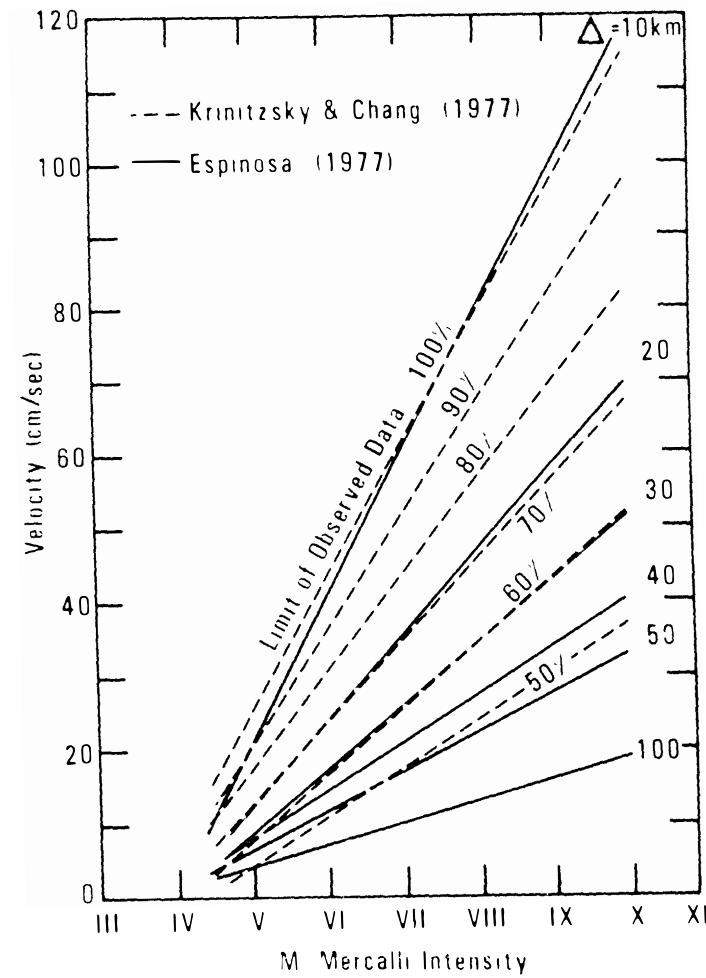

Figure 2. Comparison of the observed data obtained in the time-domain from the San Fernando earthquake (Espinosa,1977) with the results obtained by Krinitzsky and Chang (1977) using all the Western U.S. strong motion data base. Particle velocity as a function of MMI. Parameter epicentral distance (km).

Regional Shear Wave Studies

8-9940-02087

J. F. Gibbs
Branch of Ground Motion and Faulting
U. S. Geological Survey
345 Middlefield Rd., MS 77
Menlo Park, CA 94025
(415) 323-8111, ext. 2030

Investigations

1. Investigate dependencies of measured site amplification, observed 1906 earthquake intensities, and logged physical properties of near surface geologic units on downhole seismic shear wave velocity logs to develop generalized guidelines for predicting earthquake ground motions on a regional scale. These studies are designed to develop improved methodologies for seismic zonation of the San Francisco Bay region.

2. Collect seismic velocity data, physical property data, and geologic data in 20 drill holes to develop an improved data base for seismic zonation of the metropolitan Los Angeles Basin.

Results

1a. Shear-wave velocities (SVEL) are found to correlate with measured site amplification (AMP) determined from seismograms of nuclear explosions according to

$$AMP = -11.4 \log (SVEL\ (m/sec)) + 33.6$$

b. Intensity increments (SI) as determined from the 1906 San Francisco earthquake are found to correlate with shear-wave velocity according to

$$SI = 0.0027\ (SVEL\ (m/sec)) + 2.25$$

The investigation is continuing into using the above type of relationships for seismic zonation studies and also as a pliable method of extrapolating intensity data from one region to another.

c. Seismic wave velocities measured at 59 sites in the San Francisco Bay region have been compared with several readily determined physical properties of the materials. Shear wave velocity was found to correlate with these properties more strongly than P-wave velocity. Correlations obtained suggest a classification scheme useful in defining seismically distinct geotechnical units.

For unconsolidated to semiconsolidated sediments, texture has the most significant effect on shear wave velocity. Several of the textural groups which show relatively wide velocity ranges can be subdivided using standard penetration resistance as a measure of consistency (clays-silty clays) or relative density (sands). Several of the groups show distinctly lower velocities in the near-surface (< 12m) than at depth (12-30m).

For the bedrock materials, fracture spacing has the most significant effect on shear wave velocity. Hardness also affects S-wave velocity and lithology is important in differentiating strong sedimentary from strong igneous rocks.

The classification schemes based on physical properties can be used to regroup the map units defined for the San Francisco Bay region into seismically distinct groups. The range of seismic velocities for a given map unit is dependent on the variety of materials which have been included in the unit, which is largely a function of age of the deposit. Each of the Holocene map units show a distinct and relatively narrow range of shear wave velocity. Older sedimentary deposits and bedrock materials, which have been strongly affected by diagenetic changes and tectonism, show relatively wide and overlapping velocity ranges.

For the unconsolidated to semiconsolidated sedimentary deposits, eight seismically distinct geotechnical units have been defined while the bedrock materials have been differentiated into five broad groups.

d. Consideration of the correlations discussed above suggests that a generalized site amplification and earthquake intensity can be predicted for seismic zonation purposes on the basis of the identified seismically distinct geotechnical units.

2. Seismic and geologic logs have been collected for 5 30 m holes in the Long Beach area. Permitting has been completed for an additional 14 holes, and 10 holes are in process of being drilled.

Numerical Modeling of Ground Motion

8-9940-01896

Samuel T. Harding
Branch of Ground Motion and Faulting
U.S. Geological Survey
Denver Federal Center MS 966
Denver, CO. 80225
(303) 234-5090

Investigations

Complete the development of a hybrid finite element-finite difference computer program to model seismic wave propagation problems. The program is being extended to incorporate heterogeneous boundary conditions.

Objectives of this work include studies of source models, layering effects, and responses of alluvial basins. These studies are designed to improve techniques for predicting strong earthquake ground motions.

Results

A hybrid computer program has been used to model a point source in a half-space overlain by a layer with a parallel interface, a layer with a step discontinuity, a layer with a linear ramp segment, and a layer with a semi-circular basin.

Ground Response, Salt Lake Region

8-9940-01919

W. W. Hays
Branch of Ground Motion and Faulting
U.S. Geological Survey
Denver Federal Center, MS 966
Denver, CO. 80225
(303) 234- 4029

Investigations

1. Continuation of data processing and analysis of nuclear explosion ground motion data acquired at 31 recording sites underlain by rock and alluvium in the Salt Lake City area.

2. Acquisition of nuclear explosion ground motion data at 11 sites in the Provo area.

3. Selection of 18 sites in the Ogden area to locate instruments for future nuclear explosion ground motion measurements.

4. Evaluation of an inventory of single-family dwellings completed in September, 1977, for the Salt Lake City area.

5. Initiation of effort to construct ground response and seismic risk maps for the Salt Lake City area.

Results

Preliminary analysis of the broadband ground motion data acquired at the 31 sites in the Salt Lake City area shows that: (1) the relative ground response between pairs of stations is highly repeatable from event to event, (2) the ground response at rock sites is essentially identical over the period range 0.1-6 seconds, and (3) the ground response at sites underlain by a thick, water-saturated clay and sand section is significantly greater (factor of 8 to 10) than at sites located either on rock or underlain by a thin water-saturated gravel and sand section. The physical explanation for the ground response is still being developed.

Reports

Hays, W. W., 1978, Ground response maps for Tonopah, Nevada: Seismol. Soc. America Bull., v 68, p 451-469.

Hays, W. W., 1978, A general procedure for estimating earthquake ground motions: Proceedings of Conference on Engineering Design for Earthquake Environments, London, England (in press).

Hays, W. W., King, K. W., and Park, R. B., 1978, Duration of nuclear explosion ground motion: Seismol. Soc. America, v 68 (in press).

Hays, W. W., 1978, The earthquake problem in the United States; a review: The Valuer Liner, Newsletter of the Association of Federal Appraisers (in press).

Hays, W. W., S. T. Algermissen, and King, W. W., 1978, Ground response maps for the Salt Lake City, Utah, area (abs.): 2nd International Conf. on Microzonation, San Francisco, Calif. (in press).

King, K. W., and Hays, W. W., 1978, Examples of the effect of local geology on the duration of ground motion: Earthquake Notes, v 49, p 11.

Ground Motion Modeling and Prediction

8-9940-01168

W. B. Joyner
Branch of Ground Motion and Faulting
U. S. Geological Survey
345 Middlefield Rd., MS 77
Menlo Park, CA 94025
(415) 323-8111, ext. 2754

Investigations

1. Shallow refraction profiles and downhole P and S velocity surveys in the Cholame area to provide additional data for modeling the strong motion records from the Parkfield-Cholame earthquake (R. E. Warrick, R. M. Hazlewood, and W. B. Joyner).

2. Analysis of data from downhole P and S velocity surveys in young sediments in the San Francisco Bay area (R. E. Warrick and W. W. Joyner).

Results

1. Development of an approximate theory for computing synthetic down-hole records from an artificial shear-wave source at the surface. The theory takes account of geometric spreading, multiple reflections, and anelastic attenuation. It is hoped that accurate estimates of Q in the sediments can be made by matching synthetic and real records (R. E. Warrick and W. B. Joyner).

2. Release of open-file documentation of a computer program for computing nonlinear seismic ground response in two dimensions (W. B. Joyner).

3. Release through NTIS of a digital tape containing data from the Ravenswood downhole array for all the well-recorded earthquakes (A. A. Oliver, III, W. B. Joyner, and R. E. Warrick).

Reports

Joyner, W. B., 1978, Fortran programs for calculating nonlinear seismic ground response in two dimensions: U.S. Geol. Survey, open-file report 78-287, 69 p.

Joyner, W. B., Warrick, R. E., and Oliver, A. A., III, 1977, Seismic data for 15 earthquakes recorded on a downhole array in sediments near San Francisco Bay: Magnetic tape, PB-275 360, National Technical Information Service, U.S. Dept. Commerce, Springfield, Virginia, 22161.

Data Acquisition in Support of Ground Motion Projects

8-9940-02091

K. W. King
Branch of Ground Motion and Faulting
U.S. Geological Survey
3060 South Highland Drive
Las Vegas, Nevada 89109
(702) 598-3416

Investigations

1. Los Angeles, California - Seismic background and ground motions from nuclear events were recorded at 37 different sites during the last 6 months to investigate geographical variations in ground response. Several sites were reoccupied to establish repeatability.

2. Salt Lake-Provo, Utah - Several quarry blasts and nuclear events were recorded at 20 sites in the Salt Lake-Provo area to examine variations in ground response. Eleven additional sites were occupied just previous to October 1. A five-station array was deployed for 3 weeks to determine attenuation using the seismic activity at Saltair as a source.

3 Southern Nevada - Thirty-six sites at distances ranging from 1.7 km to about 100 km from nuclear events were occupied to study duration of ground motion. Data from 12 previous events were also reanalyzed.

4. South Carolina - Two earthquakes were recorded on a five station linear array installed to measure spectral attenuation.

Results

1. The data from Los Angeles and Salt Lake are being analysed in cooperation with A. Rogers and W. Hays.

Reports

Hays, W. W., King, K. W., and Park, R. B., 1978, Duration of nuclear explosion ground motion: Seismol. Soc. America Bull. (in press).

King, K. W., Hays, W. W., 1978, Examples of the effect of local geology of the duration of ground motion (abs.): Earthquake Notes, v. 49, p. 11.

Hays, W. W., Algermissen, S. T., King, K. W., 1978, Ground response maps for the Salt Lake City, Utah area (abs.): Second International Microzonation Conf., San Francisco, Calif. (in press).

Rogers, A. M., Tinsley, J. C., Hays, W. W., and King, K. W., 1978, Evaluation of the relationship between near surface geological units and ground response in the vicinity of Long Beach, California: Seismol. Soc. America Bull. (in press).

Topical Studies in Seismic Risk

8-9950-01733

R. K. McGuire
Branch of Earthquake Tectonics and Risk
U. S. Geological Survey
Denver Federal Center, MS 966
Denver, CO. 80225
(303) 234-2874

Investigations

1. Design, implementation, and testing of FORTRAN computer program for seismic risk analysis which accounts for length of the rupture zone and for uncertainties in maximum earthquake size, location, rupture length for a given magnitude, and ground motion amplitudes at the site as a function of source location, size, orientation, etc.

2. Comparison of several methods of assessing hazard of seismically-induced liquefaction in saturated sand deposits. Methods include risk analysis based on empirical observations, and probabilistically comparing estimated dynamic shear strengths of the soils with shear stresses estimated from surface accelerations.

3. Examination of published definitions of strong motion duration, and calculation of values of duration according to these definitions for a set of strong motion accelerograms. Calculation of damage potential of the same accelerograms using calculated responses of inelastic structural models. Correlation of damage with duration and peak amplitudes to determine which definition of duration is most useful, if any, and what procedure for seismic risk mapping is most appropriate.

Results

1. A computer program which accounts for all variables (and the uncertainty in those variables) which are thought to be important in probabilistic seismic hazard calculations is available. It is currently being documented for public release.

2. Approximate methods of calculating seismic liquefaction risk are available. Further work is necessary to extract information from empirical observations (for instance on the effect of the duration of shaking) to account for important effects not represented by available analytical techniques.

Reports

McGuire, R. K., Tatsuoka, T., Iuvsaki, T., and Tokida, K., 1978, Probabilistic procedures for assessing soil liquefaction potential: Bull. of the Public Works Research Institute, Tokyo, (in press).

Earthquake Intensity and Recurrence

8-9940-01784

Robert Nason
Branch of Ground Motion and Faulting
U. S. Geological Survey
345 Middlefield Road
Menlo Park, CA 94025
(415) 323-8111, ext. 2760

Investigations

1. Gathered data for an evaluation and improvement of the Modified Mercalli scale of seismic intensity, with particular attention to the proper interpretation of ground failures.

2. Gathered and compiled data on the seismic damages in the 1906 San Andreas earthquake from the official report by Lawson and others (1908) and from books and newspapers of 1906 (where much additional data occurs).

3. Prepared and evaluated a more precise formulation of the seismic intensity scale for better analysis and understanding of the 1906 damage patterns.

4. Examined in detail the 1906 damage data to determine if the seismic damages were worse at the fault zone, as is assumed in the maps of 1906 and in most earthquake risk maps.

5. Began compilation of the experiences of people in the 1906 earthquake, as written in letters, newspapers, and books. Publication of these experiences (in cooperation with the California Historical Society) will provide seismologists and the general public with basic information for earthquake safety and hazard reduction.

6. Continued preparation of a map of expected earthquake intensities in the Los Angeles region.

7. Gathered additional information on the earthquake history of California, particularly with regard to earthquake recurrence.

8. Completed the research and interpretation of "Vertical Movements at Los Angeles Harbor before the 1933 Long Beach Earthquake."

Results

1. The precision of the seismic intensity scale is improved greatly by downrating the occurrences of ground failures such as landslides or liquefaction and making other changes.

2. The seismic damages at the fault zone of the 1906 earthquake were approximately the same as elsewhere within 10 kilometers of the fault, which indicates that the assumption of unusual intensities along fault zones is mistaken. This finding agrees with new theoretical suggestions that the intensities should be equal, based on the focal depth of the earthquake and the possible propagation patterns of seismic waves.

3. The seismic activity in northern California was much greater before the 1906 earthquake than at any time since. This suggests that the northern San Andreas fault is probably still in a dormant condition after the 1906 earthquake and a significant increase of activity can be expected in the future.

4. Tide gauge measurements at Los Angeles harbor show elevation changes of 6 cm in the years before the 1933 Long Beach earthquake. The first movement was 6 cm downward in 1924, followed by a 6 cm movement upward in 1928, and then a similar downward movement in 1931. The foreshocks of the earthquake began in 1931. The 1924 elevation change is confirmed by leveling measurements, which also show that the movement involved vertical displacement at the Palos Verdes fault. It is interpreted that the movements resulted from changes of elastic strain before the 1933 earthquake, which was on the nearby Inglewood fault. The elevation changes cannot be explained by pre-earthquake dilatancy processes.

Reports

Nason, Robert, 1978, Seismic intensities in the 1906 earthquake fault zone (abs.), Earthquake Notes, v. 49, no. 1.

Expansion of PDP-11 for Digital Input

8-9940-02088

R. B. Park
Branch of Ground Motion and Faulting
U. S. Geological Survey
Denver Federal Center, MS 978
Denver, CO 80225
(303) 234-5070, ext. 5070

Investigations

1. Expand PDP 11/40 system to include input of digital cassette recordings and interactive graphic data processing .

2. Develop and modify software for digital(as opposed to hybrid) data processing utilizing interactive graphics.

Results

1. Discussions with vendors and literature search suggests microprocessor based controller offers greatest flexibility in the processing of various data formats on digital cassette tapes. Hardware for interactive graphics is on order.

2. The new operating system (RSX-11) for digital processing has been generated and present programs rewritten for the new system. Development of additional software is underway.

Reports

None

Seismic Zonation Studies in Los Angeles Basin

8-9940-01730

A. M. Rogers
Branch of Ground Motion and Faulting
U. S. Geological Survey
Denver Federal Center, MS 966
Denver, CO 80225
(303) 234-2869, ext. 5604

Investigations

Regional measurement and analysis of ground response in L.A. Basin using ground motions generated by nuclear explosions and the 1971 San Fernando earthquake. This study has several objectives: comparison of ground response determined from strong motion recordings of the 1971 San Fernando earthquake with those from nuclear explosions, determination of average ground response for various geologic units, derivation of important physical parameters for characterizing ground response at specific sites, development of a regional data base for purposes of seismic zonation.

Results

1. Four additional Nevada Test Site nuclear explosions have been recorded in Los Angeles and vicinity during the last 8 months at 45 locations using a three-component wide-band seismograph. This brings the total number of sites occupied to about 110, not including sites that were reoccupied. Approximately 20 sites were occupied more than once. These data are currently being processed to produce psuedo-relative velocity response spectra, Fourier spectra, alluvium-to-rock spectral ratios, and time history playouts of ground velocity.

2. Short-period (0.2-0.6 seconds) spectral ratios show a strong dependence on void ratio and thickness of Quaternary sediments, being directly proportional to the former and inversely proportional to the latter for thicknesses between 200 and 400 meters.

3. Short-period spectral ratios also indicate some dependence on age of deposition (the mean short-period response on sites underlain by Holocene is higher than sites underlain by Pleistocene).

4. Comparison of the short-period response in Long Beach, Las Vegas, and Salt Lake City indicates that high-percent water content in alluvium is correlated with high ground response.

5. The short-period ground response at sites underlain by gravels may be one-fifth that on fine-grained sediments.

6. The short-period response on alluvium and marine sediments is always greater than 1.0 and sometimes as high as 20.

7. Comparison of the long-period (0.6-3.0 seconds) response in Long Beach, Las Vegas, and Salt Lake City indicates that it is strongly affected by the thickness of alluvium. As the thickness of alluvium increases from about 300 meters to 1-1.5 km, the long-period spectral ratios increase from 2 to 10. Depth-to-basement may play a similar role, increasing the long-period response by factors of 2-5 as depth-to-basement increases from 1-6 km.

Reports

Rogers, A. M., Tinsley, J. C., Hays, W. W., and King K. W. (in press), Evaluation of the relationship between near-surface geologic units and ground response in the vicinity of Long Beach, Calif.: Submitted to Seismol. Soc. America Bull.

Rogers, A. M. and Hays, W. W., 1978, Ground response studies in three western United States cities: Sixth Symposium on Earthquake Eng., University of Roorkee, Roorkee, India.

Rogers, A. M. and Hays, W. W., 1978, Ground response in San Fernando Valley, California: Second Int. Conf. on Microzonation, San Francisco, Calif.

Instrument Development and Geotechnical Studies

8-9940-02089

R. E. Warrick
Branch of Ground Motion and Faulting
U. S. Geological Survey
345 Middlefield Rd., MS 77
Menlo Park, CA 94025
(415) 323-8111, ext. 2757

Investigations

1. Instrumentation Development--A highly portable, low-power, micro-processor based, digital seismic recording system is being developed to meet a broad range of seismic recording needs including studies of microearthquakes, crustal refraction, strong motion, and near-surface seismic exploration. Central control by a micro-processor, 16-bit resolution, modular design and a universal bus system yield maximum adaptability of system to additional applications and permit relatively easy modification of the system for state-of-the-art improvements. System is being developed with the advice of William Prothero, UC Santa Barbara; Robert Nickerson, Cal Tech; Robert Moore, Scripps; Thomas McEvilly, UC Berkeley and designed for compatibility with UC Santa Barbara ocean bottom system and Cal Tech TIM system.

2. Geotechnical Studies--

   a. To develop improved methods in in situ geophysical measurements especially those utilizing seismic shear waves.

   b. To make controlled source seismic studies at critical sites.

Results

1. Instrumentation Development--Specifications for the system have been drawn up by R. Borcherdt, J. Fletcher, and R. Warrick, reviewed at a preliminary stage both in-house and by outside consultants, modified, and submitted to potential bidders. Current schedule calls for final testing of prototype to be completed near end of current calendar year.

2. Geotechnical Studies--

   a. A signal enhancement seismograph was tested and peripheral equipment is being designed for its use in shear wave studies.

   b. Field work has been delayed by the unusual, but welcome, heavy rains. Field investigations will proceed once the soil stabilizes sufficiently to allow access to the sites (Cholame Valley and Hamilton Field).

Reports

Wilson, R. C., Warrick, R. E. and Bennett, M. J. (in press), Seismic velocities of the San Francisco Bayshore sediments: Proceedings of the ASCE speciality conference on earthquake engineering and soil dynamics, Pasadena, CA, 19-21 June 1978.

Borcherdt, R. D., Fletcher, J., Warrick, R. and others, 1978, Microprocessor based recording system: U. S. Geol. Survey RFP 491W.

Earthquake-Induced Landslides

8-9550-01452

Edwin L. Harp
Branch of Engineering Geology
U.S. Geological Survey
345 Middlefield Road
Menlo Park, CA 94025
(415) 323-2557

Investigations

1. Continued analysis of landslide data from the 1976 Guatemala earthquake.

2. Continued development of electronic piezometer-recording system for measurement of seismically generated pore-water pressures in landslide materials.

3. Completed study and analysis of fieldwork, laboratory test data, airphoto-interpretation, and instrumental measurements from landslide deposits near La Honda in San Mateo County, California.

4. Continued monitoring of selected San Francisco Bay area landslides in cohesive soils. Measured displacements and displacement rates at landslide site near San Andreas fault south of Hollister, Calif.

Results

1. Landslide inventory and landslide concentration maps at 1:12,500 scale were prepared for the Guatemala City area. If the landslide distribution from the 1976 earthquake reflects the physical site conditions, then the landslide concentration map can be used to make a hazard map.

2. Tips for the electronic piezometer have been developed for emplacement in clays as well as in sandy materials. Field testing has shown it to be well suited for measuring transient pore-water pressures in clays. The piezometer is currently deployable with a portable strip-chart recorder to measure pore-water pressure response in landslide materials during seismic shaking. The piezometer is designed to be adapted eventually to a digital recording system currently under development.

3. A statistical analysis of landslide slopes has revealed that critical slope angles exist for each of the geologic formations in the La Honda area of San Mateo County. These are minimum slope angle values below which landslides do not occur. The critical slope angles for each unit are consistent with their respective residual strengths as measured in the laboratory. Geology, slope, and critical slope angles were used to produce a landslide susceptibility map for static (non-seismic) conditions. Criteria developed from landslide occurrence in previous post-earthquake investigations were used to develop an experimental seismic-induced landslide susceptibility map for this area. The criteria used to prepare these maps are general enough to be understood by urban planners as well as geologists.

4. Actual displacement recordings and piezometric data of a landslide located at Bear Valley in San Benito County, California, have shown that movement occurs as a result of saturation and subsequent rises in pore-water pressures. Movements occur as surges with little or no pre-surge creep. Displacement rates of as much as 2.25 cm/hr have been measured, which decrease logarithmically with time.

Reports

Wieczorek, G. F., 1978, Static and seismic landslide susceptibility: Geological Society of America Abstracts with Program, v. 10, no. 3, p. 153.

Ground Failures Caused by Historic Earthquakes

8-9550-02161

David K. Keefer
Branch of Engineering Geology
U.S. Geological Survey
345 Middlefield Road
Menlo Park, CA 94025
(415) 323-2557

Investigations

1. Information on ground failures caused by earthquakes which have occurred during the historic period is being reviewed and analyzed. The main objectives of this work are to determine which types of ground failure are most common in earthquakes and which geologic and seismic environments are most likely to produce ground failures. It is anticipated that data from at least 24 major earthquakes and many minor earthquakes will be analyzed during the course of this project. A comprehensive review of published information has begun, and data on ground failures are being extracted and put into a form suitable for analysis. This is a new project which was initiated in October 1977.

2. Field investigations were carried out on landslides and liquefaction-induced failures caused by the M 7.4 earthquake which occurred on November 23, 1977, near San Juan, Argentina. This work included detailed studies of liquefaction damage at five selected sites in the San Juan area.

Results

1. A method for cataloguing data on earthquake-induced ground failures has been developed.

2. Catalogues of ground failures have been prepared for five major recent earthquakes (West Nelson, New Zealand, 1929; Hawkes Bay, New Zealand, 1931; Hebgen Lake, Montana, 1959; Chile, 1960; Inangahua, New Zealand, 1968).

3. Several types of liquefaction-induced failures were studied in the San Juan, Argentina, area. These included blocks of ground with very low surface slopes (about 0.1 percent) which oscillated back and forth on liquefied layers, bearing capacity failures, large sand boils which were localized by water pipes, and differential settlement of buildings due to compaction. Using portable hand augering equipment, subsurface conditions were explored at four sites of liquefaction damage. Several observations and measurements of particular interest were made during this study; these include the following: The volumes of sand and water in a sand boil which erupted inside a house were measured. Measurement of the surface slope of one of the oscillating failure blocks indicated that its final motion was actually in the upslope direction. One small building was totally undermined by a large sand boil. The effect of a M 6.0 aftershock on the water table in a liquefiable sand was measured directly. Samples for determination of in situ density of liquefied materials were obtained from below the water table at two sites.

4. Examination of landslides in mountainous areas around San Juan revealed that shallow rockfalls and rockslides were the most common types of slope failures. Most of these occurred on slopes greater than 45° in dry materials. The rockfalls deposited boulders on talus slopes which had been built up over long periods of time. Many talus slopes were resting at their angles of repose, and renewed movement could easily be triggered by future earthquakes. The region of greatest landslide concentration was some distance away from the epicenter even though the epicenter was in a mountainous area.

Reports

Keefer, D. K., 1977, Earthflows at Davilla Hill, Alameda County, California: Association of Engineering Geologists Abstracts with Programs, 20th Annual Meeting, p. 29.

_______1977, A model for earthflow: Geological Society of America Abstracts with Programs, v. 9, no. 7, p. 1045-1046.

Keefer, D. K., and Youd, T. L., 1978, Damage due to liquefaction in the November 23, 1977, earthquake in San Juan, Argentina [abs.]: Seismological Society of America Program, 73rd Annual Meeting.

Interactions Between Ground Motion and Ground Failure

8-9550-01628

Raymond C. Wilson
Branch of Engineering Geology
U.S. Geological Survey
345 Middl-field Road
Menlo Park, CA 94025
(415) 323-2967

Investigations

1. Studied correlation between seismic "shaking intensity" and the onset of ground failure.

2. Developed computer software for numerical simulation of the dynamic behavior of earthquake-induced landslides.

3. Continued investigation of the physical basis for seismic intensity and developed a nonlinear instrumental intensity scale.

Results

1. Field investigations after the 1976 Guatemala earthquake (M 7.5) indicate that the onset of earthquake-induced ground failures, either liquefaction or landsliding, occurs at a much lower shaking intensity than described in the Modified Mercalli Intensity (MMI) scale. According to both the 1931 and 1956 versions of the MMI scale, significant ground failures do not occur unless the shaking intensity equals or exceeds MMI IX. Estimates of shaking intensity from the 1976 Guatemala earthquake were based primarily on observations of structural damage, especially to adobe dwellings. An attempt was also made to separate shaking damage from damage resulting from ground failures in the foundation. According to the 1956 version of the MMI scale, damage to adobe structures begins at MMI VI, serious damage occurs at MMI VII, and collapse begins at MMI VIII. While adobe structures were destroyed or seriously damaged over a wide area during this earthquake (Espinoza, 1976), there were a number of localities with severe ground failures, either liquefaction-induced lateral spreads or slope failures on steep pumice slopes, yet relatively little shaking damage to nearby adobe structures. It appears, therefore, that seismic-induced ground failures may occur at shaking intensities of MMI VI, and perhaps as low as MMI V.

2. The development of computer software for numerical simulation of the dynamics of seismic-induced landslides continued with the transfer and adaptation of a number of programs from the HP 9815A programmable calculator to the USGS Multics computer. The following programs have been written and tested: (a) seismic response (acceleration, velocity, and/or displacement) of a visco-elastic oscillator (seismoscope) to an acceleration time series input (strong motion record); (b) calculation of the Arias

intensity (an integration of the square of the accelerations in a strong-motion record); (c) adaptations of existing slope stability analysis programs; and (d) a new algorithm for the displacement of landslide blocks by strong seismic shaking by the method of Newmark (1956). A "repertoire" of strong motion seismic records is also being compiled, primarily from the recent California earthquakes. The objective for developing this software is to be able, given the appropriate slope stability information and a design earthquake, to calculate the expected downslope displacement (if any) of an existing landslide mass or potentially unstable slope.

3. A number of schemes for instrumental measurement of seismic intensity was analyzed using numerical simulation techniques. One type of instrumental intensity measurement is based on the peak response of a seismoscope (a viscous-damped pendulum) to strong seismic ground motion. Numerical studies of the response of damped pendulums with various response periods using acceleration records from several California earthquakes indicate that the peak displacement of short-period seismoscopes appears to correlate with peak acceleration, while longer period seismoscopes are more sensitive to peak particle velocity. However, it was also found that seismoscope response is not a reliable predictor of either ground failure or damage to structures. One reason for this discrepancy may be that linear instruments such as seismoscopes or accelerographs do not reflect the nonlinear effects of mechanical damage. Thus, a study was begun to develop an intensity scale based on "damage" (irreversible work) to simple nonlinear mechanical systems. A numerical model which calculates the displacement of a friction block by accelerations applied to the base may form the basis for a nonlinear instrumental intensity scale. This new intensity scale may show a higher correlation with seismic-induced ground failure than either Modified Mercalli Intensity or existing linear instrumental intensity scales.

Reports

Wilson, R. C., 1977, The effect of scale on seismic-induced landslides: Association of Engineering Geologists Abstracts with Programs, 20th Annual Meeting.

Wilson, R. C., Warrick, R. E., and Bennett, M. J., Seismic velocities of the San Francisco Bayshore sediments: American Society of Civil Engineers, Geotechnical Engineering Division Specialty Conference on Earthquake Engineering and Soil Dynamics, June 1978, Proc. (in press).

Experimental Mapping of Liquefaction Potential

8-9550-01629

T. Leslie Youd
Branch of Engineering Geology
U.S. Geological Survey
345 Middlefield Road
Menlo Park, CA 94025
(415) 854-7117

Investigations

1. Continued research on techniques for mapping seismically induced liquefaction potential.

2. Began work on two pilot projects to compile liquefaction potential maps. One project is in the San Fernando Valley, California, and is being conducted in cooperation with John Tinsley, Branch of Western Environmental Geology. The other project is in the San Juan, Puerto Rico, metropolitan area and is being conducted in cooperation with Watson Monroe, Branch of Eastern Environmental Geology.

3. Conducted a field investigation of liquefaction effects in the San Juan, Argentina, area following the November 23, 1977, magnitude 7.3 earthquake that struck that area.

Results

In cooperation with D. K. Keefer, Engineering Geology Branch, investigations were made following the November 23, 1977, San Juan, Argentina, earthquake. These investigations revealed that liquefaction occurred rather extensively over an area of about 6000 km^2 and was a major cause of property damage during that earthquake. Five specific sites of liquefaction-induced damage were investigated in some detail including augering exploratory holes to sample soils beneath these sites. The investigations revealed that at two sites blocks of relatively stiff surface materials, as wide as 200 m and thicker than 6 m, detached from the surrounding soil and riding on a liquefied layer, oscillated back and forth in a horizontal direction relative to the underlying and surrounding soil. This action caused considerable damage and effects such as sand boils to be concentrated at the margins of the blocks. At the other three sites liquefaction led to loss of strength and bearing capacity in soils supporting buildings and tanks. Several of these buildings and tanks settled and tipped, while others suffered severe differential settlements. At one site, water venting to the surface, to relieve subsurface pore-water pressures associated with the liquefaction, found paths along well casings at two locations. The flowing water eroded large cavities beneath a pump and a pump house structure, respectively, at the tops of the casings. Those two structures then tilted and fell into the open cavities.

Reports

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Statistical Analysis and Geometry of Surface Faulting

8-9940-02086

M. G. Bonilla
Branch of Ground Motion and Faulting
U. S. Geological Survey
345 Middlefield Road
Menlo Park, CA 94025
(415) 323-8111

Investigations

1. Compilation and evaluation of data relating to historic surface faulting (M. G. Bonilla).

2. Statistical analysis of the relations among surface fault length, displacement, earthquake "size" and other parameters (R. K. Mark).

3. Characterization of the statistical variation in displacement and surface width along main faults (R. K. Mark, E. B. Newman, M. G. Bonilla).

4. Statistical characterization of the position and size of subsidiary faults with respect to the main faults (R. K. Mark, E. B. Newman, M. G. Bonilla).

Results

1. Compared maps, measurements, and descriptions from two reports on the 1957 Gobi-Altai earthquake and selected data judged to be most reliable.

2. Reviewed data on historic faulting and assigned quality estimates to length and displacement figures. Use of medium- to high-quality data rather than all data resulted in substantially higher correlation coefficients in regressions of magnitude on length and displacement.

3. Began estimating possible range in lengths of historic faults using various published descriptions, aftershock patterns, and geodetic data where available.

4. Began comparison of magnitude determinations made by various observatories in order to estimate variance in reported magnitudes.

5. Designed plan to digitize data on A) displacement, width, and azimuth of main fault as related to position along fault, and B) displacement and angle of subsidiary faults with respect to position and orientation of the main fault.

6. Developed computer programs to enter and check this data, and to analyze and display compilations.

7. Work is almost complete on digitizing the 1975 Gobi-Altai and 1968 Coyote Creek faults.

8. Began review of the statistical problems associated with regression analysis of data that has both measurement error and stochastic variation.

9. Developed computer program to enter earthquake magnitude, fault length and displacement data, and to perform regression analyses of it.

10. Began preliminary regression analyses of preliminary data.

Reports

Mark, R. K., in press, Incomplete formulations of the regression of earthquake magnitude with surface fault rupture length--Comment: Geology, in press.

Seismological Field Investigations

8-9950-01539

C. J. Langer
Branch of Earthquake Tectonics and Risk
U. S. Geological Survey
Denver Federal Center, MS 966
Denver, CO 80225
(303) 234-5091

Investigations

1. Guatemala aftershock study--completed analysis of aftershocks during the time interval February 9-17, 1977, at the western end of the Motagua fault system.

2. Guatemala aftershock study, followup--continued location and analysis of hypocenters during the time interval April 20-May 20, 1977, south of the Motagua fault between the eastern boundary of the Guatemala City graben and Chimaltenango.

3. Peru aftershock study--continued analysis of data with emphasis on focal mechanism solutions, space-time variations, and relocation of teleseismically located aftershocks which had no regional control.

4. Uinta Basin, Utah, aftershock study--detailed investigation of the aftershocks of the magnitude-5.1 (M_L) earthquake of September 30, 1977, approximately 35 km north-northwest of Duchesne, Utah.

5. Argentina aftershock study--regional investigation of the aftershocks of the magnitude-7.1 (M_S) western Argentina earthquake of November 23, 1977, approximately 90 km northeast of San Juan.

Results

1. Composite focal mechanism solutions for the Tecpan and Chimaltenango lineaments and the Mixco fault system in Guatemala were recomputed using additional data. There were virtually no changes from the earlier solutions, i.e., NE-SW normal faulting. Therefore, the previous conclusions remain unchanged, that is, the observed splaying pattern of aftershock epicenters away from the western end of the Motagua fault and the normal faulting mode of these splay earthquakes may be explained by a theoretical pattern of tensile fracturing at the terminus of a strike-slip fault.

2. A detailed investigation of the seismicity along the Chimaltenango lineament and the Mixco fault system was conducted during April and May 1977, approximately 15 months following the main shock of February 4, 1976. The general pattern of seismic activity inferred by more than 100 epicentral locations is consistent with the results obtained from the aftershock study.

3. Aftershocks of $M_{bd} \geq 3.6$ resulting from the October 3, 1974, Peru earthquake (M_S=7.8) define a 'T'-shaped zone of approximately 10,000 km^2 (10^{14}cm^2), implying an equivalent main shock magnitude of M_S=7.7 (Utsu relationship:

$\log_{10}A=M_S+6.3$). A recomputed composite focal mechanism solution for aftershocks in the vicinity of Chilca and oceanward to the southwest indicates a strong component of right-lateral strike-slip motion along a northeast-trending nodal plane. This implies that a more complex rupture process was operative than what was previously reported (primarily underthrust motion).

4. The magnitude-5.1 (M_L, NEIS) Uinta Basin, Utah, earthquake of September 30, 1977, occurred near the boundary between the southern flank of the Uinta Mountains and the Uinta Basin. Aftershock data were recorded by a 12-station seismograph network which surrounded the source area. The final network configuration was approximately rectangular with stations spaced at about 5-km intervals. Spatial distribution of the aftershock epicenters indicate a very small but dense zone of activity about 5 km in length (NE-SW) and 4 km wide. Hypocenters are generally confined between 4 and 8 km in depth and have an apparent dip to the northeast. The main shock focal mechanism solution indicates normal faulting along north-northwest striking nodal planes and is supported by a composite focal mechanism solution of the 10 largest aftershocks.

5. Aftershocks of the magnitude-7.1 (M_S) western Argentina earthquake of November 23, 1977, occurred over a broad region extending between about lat. 29.5°-31.3° S. and long. 67.5°-68.0° W. Preliminary locations determined by a nine-station regional aftershock network, indicate that the majority of seismic activity was primarily confined to the eastern half of the Sierra Pie de Palo. Depths range from about 15 to 40 km.

Reports

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Relations between Ground Motion, Losses, and Damage in Structures Subjected to Earthquakes

8-9950-01740

R. Husid
Branch of Earthquake Tectonics and Risk
U. S. Geological Survey
Denver Federal Center, MS 966
Denver, CO 80225
(303) 234-2833

Investigations

1. A damage ratio study of earthquake related damage in Guatemala City and vicinity was performed. Damage ratio is defined as the cost of repair divided by the replacement cost.

2. The mathematical formulation, selection of principal dimensionless parameters and computer programs for the study of the collapse of non-linear structures subjected to earthquake excitation have been prepared. Plotting routines have to be developed. All the programs are being modified in order to use the PDP11 computer.

3. A detailed analysis of the earthquakes considered as input will be made, considering not only the total duration of the accelerogram, but also the different phases of ground motion, frequency content of the recordings, and how the level of ground motion varies as a function of time. The corresponding computer programs have already been completed.

4. Using dynamic characteristics (T) that were experimentally determined, an analysis of correlations and regressions was performed.

5. Participated in the USGS committee which studies possibilities of changes of the MMI whose chairman is Ted Algermissen.

Results

1. The types of construction found in Guatemala City and vicinity are adobe, bajareque (it consists of a wood frame covered with lath, the wall space being filled with mud, and plastered), wood, unreinforced and reinforced masonry, reinforced concrete, and steel. There was severe damage to adobe and unreinforced masonry houses and some reinforced concrete and steel structures completely collapsed.

2. For each municipal zone of Guatemala City, information about the number of dwellings that sustained damage was obtained for three classes of building on the basis of construction material. Most of the severe losses that occurred in Guatemala City were due to heavy damage to adobe buildings.

3. Information to calculate damage ratios was obtained from local engineeers who provided the cost of repair as a percent of total replacement cost for buildings of various classes in Guatemala City.

4. Significant differences between the damage ratios and the mapped intensities were found. The intensity map appears to be rather generalized in its representation of damage and is, in some cases, in conflict with the damage-ratio map. As an example, zone 1 was assigned predominantly intensity VII, and zone 2, predominantly intensity VIII. The damage-ratio data yield a larger number of adobe buildings with damage ratios greater than 0.80 in zone 1 than in zone 2. One reason for the observed differences in the estimated damage using the intensity map and the map based on damage ratios may be the manner in which the two maps were prepared. The intensity map is based on data from questionnaires compiled from interviews with a large number of people and thus represents some weighted average of the results of these questionnaires. Most of the questionnaires were the result of interviews with people who would not ordinarily be considered to be skilled observers of earthquake damage. The detailed damage survey and the resulting damage ratios are based on the author's study of the damage and, therefore, if biased, probably are biased in a systematic way.

5. The results of this investigation clearly show that in urban areas particularly, where significant building damage occurs, intensities should be carefully assigned on the basis of the best damage-survey information available. Estimation of damage ratios for individual buildings is recommended when time and personnel for the task are available, because information of this type greatly improves the data base for the determination of damage versus intensity-of-ground-shaking relations used in earthquake-loss studies.

Reports

Husid, R., Espinosa, A. F., and de las Casas, J., 1977, The Lima earthquake of October 3, 1974: Damage distribution: Seismol. Soc. America Bull., v. 67, no. 5, p. 1441-1472.

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Heat Flow and Tectonic Studies

8-9960-01176

Arthur H. Lachenbruch
U.S. Geological Survey
345 Middlefield Road
Menlo Park, California 94025
(415) 323-8111 ext. 2646 or 2272

Goals

To investigate relations among heat flow at the earth's surface, the thermal regime of the lithosphere, and the energetics of tectonic processes including those that generate earthquakes. Our field and laboratory activities are directed primarily toward determing heat flow in tectonically active portions of the United States.

Investigations

Danville, California - A heat-flow hole was drilled near Danville in the center of the region where earthquake swarms were studied by Weaver and Hill.

San Andreas Fault, Palmdale, California - Thermal measurements were made in a line of holes drilled for stress measurements by Mark Zoback's group near the San Andreas fault east of Palmdale.

Mojave Block - Follow-up measurements of temperature were made in the 30+ holes drilled for heat flow in granitic rocks of the Mojave block. Measurements of thermal conductivity and radioactive heat production on samples from the holes are continuing.

Arizona - Permits were obtained for 45+ drilling sites in granitic rocks in the half of Arizona that lies within and adjacent to the Basin and Range physiographic province. Drilling and the initial temperature measurements have been completed at 15 sites. The results are to be compared with those from the Great Basin and Mojave Block, parts of the Basin and Range Province with different tectonic histories.

Interpretive Studies - A theoretical study was completed on convective heat transport in the lithosphere in regions of normal faulting and extensional tectonics. The results were applied to heat-flow observations in the Great Basin of the western United States and to southeastern Australia.

Results

Danville - Although a confident interpretation of these data is not yet possible, preliminary results show no evidence for a magmatic heat source. Such a source would be a consequence of one mechanical model of the earthquake swarms observed at the site.

San Andreas Fault, Palmdale - Preliminary results show no significant variation in heat flow along this line of holes which crosses the main trace at the San Andreas Fault and extends 30 km into the Mojave Block. Negative results of this kind have implications for the dynamics of the San Andreas Fault system.

Mojave Block and Arizona - These data are being reduced and interpreted and we have nothing new to add to our last report.

Interpretive Studies - In regions of normal faulting and tectonic extension, vertical convective transport of heat in the lithosphere is inevitable. The resulting departure of lithosphere temperature and thickness from conduction-model estimates depends upon the mechanical mode of extension and upon how rapidly extension is (and has been) taking place. The high and variable regional heat flow and the intense local heat discharge at volcanic centers in the Basin and Range province could be accounted for by regional and local variations in extensional strain rate without invoking anomalous conductive heat flow from the asthenosphere. Anomalous surface heat flow typical of the province could be generated by distributed extensional strain at average rates of about 1/2 to 1 %/m.y. (0.005-0.01 microstrain per year). This is similar to average strain rates that have been estimated by summing displacements on normal faults throughout the Great Basin during its 17 m.y. history. To account for the higher heat flow observed in subregions like the Battle Mountain High, these rates should be increased by a factor of about 3, and for local heat loss at active bimodal volcanic centers, by an order of magnitude more. These thermo-mechanical considerations are consistent with recent results of Weaver and Hill who deduced rapid crustal spreading at the Coso Volcanic Center from studies of local seismicity.

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Sass, J. H., and Lachenbruch, A. H., 1978, Thermal regime of the Australian continental crust, in McElhinny, M. W., ed., The Earth--its origin, structure and evolution, Academic Press, in press.

Sass, J. H., and Ziagos, J. P., 1977, Heat flow from a corehole near Charleston, South Carolina, U. S. Geol. Survey Professional Paper 1028-H, p. 115-117.

Summary of Semi-Annual Technical Report

14-08-0001-G-399

Earthquake Risk Analysis Using Numerical and Stochastic Models of Time-Dependent Strain Fields

Albert T. Smith
University of California, Santa Cruz

April 24, 1978

There are essentially two approaches to earthquake prediction. The first is a search for precursory phenomena, while the second is derived from an understanding of earthquake mechanisms and their causes. These two approaches complement one another: Using approaches to prediction such as migration and seismicity gaps, a rough estimate of the occurrence can be established in order to direct continuous monitoring of possible precursors at that location.

Since large earthquakes migrate along certain plate boundaries (Delsemme and Smith, 1977), it becomes possible to extract this regularity and extrapolate it into the future. What is forecast is not the earthquake, but the regular underlying process causing the earthquake. It is only when both time and space are considered that earthquakes are seen to migrate; thus, forecasting must be done in at least two-dimensions, space and time. The forecasting literature is almost exclusively applied to one-dimensional temporal problems (Gilchrist, 1976). To forecast in two- or more dimensions, Wold's decomposition or the Box-Jenkins' method (1976) is being modified to incorporate additional spatial dependence.

To understand the underlying process, three-dimensional finite element models will be completed. Substructuring and out of core solution methods will realize savings in computer time and allow large problems.

In-situ Stress Measurement Project

8-9960-01184

Mark Zoback
U. S. Geological Survey
345 Middlefield Road
Menlo Park, CA 94025
(415) 323-8111 ext. 2034

The intent of this project is to examine the state of crustal materials in and near active fault zones. We seek to determine the magnitude and orientation of the tectonic stress field and to determine the mechanical and fluid flow properties of the materials at depth.

Palmdale Uplift Studies

In-situ stress has been measured in three of six wells drilled in the western Mojave desert. The wells are all about 250 m deep and are arranged roughly along a N-S profile extending from a site 2 km from the San Andreas fault near Valyermo to a site near Rogers Lake, 52 km from the fault. Analysis of the results so far obtained indicates that the least horizontal compressive principle stress exceeds the lithostatic (vertical) stress, the direction of maximum horizontal compression is approximately N15°E, and horizontal shear stress increases with distance from the San Andreas. Implications of these measurements are quite interesting. The direction of horizontal compression and large magnitude of the horizontal compressive stresses suggests that Palmdale budge results from horizontal compressive stresses. The increase in shear stress with distance from the fault is consistent with predictions of thermo-mechanical models of the San Andreas fault zone in which the average shear strength of the fault is on the order of several hundred bars.

Charleston Studies

Interpretation of stress measurements made to depths of 344 m in Atlantic Coastal Plain Sediments near Charleston, South Carolina indicate that the magnitude of the least principal compressive stress is sufficiently below lithostatic as to result in normal-type fault motion on favorably oriented faults. Because stratigraphic evidence suggests the existence of normal faults in the area, we interpret our results to suggest that normal faults in Coastal Plain sediments near Charleston are currently active. However, we do not know if this process is related to either the 1886 Charleston earthquake or the current seismicity.

New Madrid Studies

Interpretation of 32 km of 24-fold seismic reflection profiles from the vicinity of Reelfoot Lake, Tennessee, is underway. Seismic refraction profiling indicated that the Paleozoic rocks underlaying embayment sediments are faulted at the western edge of Reelfoot Lake. The purpose of the reflection work was to determine the detailed nature of the fault(s) and whether or not the younger embayment sediments were also offset. Clear reflections are apparent from the Tertiary-Cretaceous and Cretaceous-Paleozoic contracts and vertical offsets greater than about 5 milliseconds (approximately 5 m) are easily visible in these reflectors. The quality of reflections corresponding to younger sediments is significantly poorer. The results indicate the presence of a major north-trending fault coincident with the scarp at the edge of the late plus a set of northeast-trending faults some of which splay off of the major fault. In addition, three north-trending faults occur 3.5 km west of the scarp. All of the faults indicate that both Cretaceous and Paleozoic rocks are offset. On several profiles, Tertiary rocks are also seen to be offset. There is approximately 55 m of relief (east side down) across the faults coincident with the scarp. A reflection profile located 10 km to the south of the lake indicates that the major fault may extend at least that far. An interesting aspect of the faults is that at some places the offset of the Cretaceous and Paleozoic reflectors is nearly the same, while at other places the offset progressively decreases with age. Thus, while some of the faulting is clearly post-Cretaceous, some is apparently associated with pre-Cretaceous structures. Although the dips of the faults cannot be clearly determined, the down-dropped graben-type blocks and the overall pattern of faulting seems to indicate that extensional tectonics was responsible for their occurrence.

Publications

Zoback, M. D., Healy, J. H., Gohn, G. S., and Higgins, B. B., 1978, In-situ stress in the South Carolina Coastal Plain near Charleston: Geol. Soc. America Abs. with Prog.

Zoback, M. D., Healy, J. H., Roller, J. C., Gohn, G. S., and Higgings, B. B., 1978, Normal faulting and in-situ stress in the South Carolina coastal plain near Charleston: Geology, v.6, p. 147-152

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A FIELD STUDY OF EARTHQUAKE PREDICTION METHODS IN THE CENTRAL ALEUTIAN ISLANDS

E.R. Engdahl and Carl Kisslinger
Cooperative Institute of Research
in Environmental Sciences
University of Colorado
Boulder, Colorado 80309

Contract No. 14-08-0001-16716

SUMMARY

The work of monitoring seismicity within the region covered by Adak local network continues. All locatable events through 1977 have been processed, as well as much of January-March, 1978. The damage to the network caused by a severe storm in October 1977 has reduced our detection and location capabilities to events larger than about m_b 2.5. An attempt to restore as much of the network as possible without access to the remote stations is described in this report. "b"-values and current seismicity by subregion are being monitored.

Much of the effort in the period covered by this report was devoted to a detailed investigation of seismological precursors of the magnitude 6.5 event of November 4, 1977, which broke along a segment about 40 km long, the largest event to occur within the network since operations began and the only event this large to occur within any U.S. network set up for prediction research. Events large enough to be located with teleseismic data, as well as teleseismically recorded events before network operation began, and microearthquakes located by the local network have been investigated. The results are not conclusive, but patterns in the time-space variation of seismicity do suggest precursory changes. The teleseismic pattern is not clear, but a gap for events larger than m_b 4 is suggested from the time operations began to August, 1976. Events in the magnitude 5 range occurred at the end of the future rupture zone two to three months before the main shock. A pronounced gap beneath Adak Canyon persists.

The microearthquake studies show a strong surge of activity from mid-November 1976 to mid-January 1977, tightly clustered at the future epicenter. This location, which had been fairly quite for the preceding two years remained somewhat more active until the main shock, with a secondary surge in August - September, 1977. Attempts to find diagnostic characteristics of the events in this surge have not yet been successful.

A detailed sutdy of the deeper events, occurring mostly in the eastern half of the region, has confirmed the existence of the double seismic zone and clarified some of its features.

Analyses of S-to-P amplitude ratios have shown further the potential value of these data in the prediction problem. A set of events that occurred in Bear Valley, California were selected for study because of the better knowledge of focal mechanisms and velocity structure there than at Adak. The factors influencing the amplitude ratios and ways to use these data are demonstrated by the results. One conclusion is that the focal mechanism and velocity structures must be known very well if the propagation in an elastic earth is to be calculated, and the use of these data for studying Q variations for P and S is not likely to be successful, except for controlled sources.

Branch of Global Seismology

Date: April 18, 1978

Project No. 9920-02141 Title Prediction Monitoring and Evaluation

Project Chief Roger N. Hunter

Mailing Address and Phone No. U.S. Geological Survey, Branch of Global Seismology, Stop 967, Box 25046 DFC, Denver, CO 80225

(303) 234-4041

Report Period October 1, 1977 to March 31, 1978

1. Investigations and Results:

This project monitors and evaluates earthquake predictions from any source. The intent is to provide statistical evaluations of any author making such predictions which can be used in answering questions from the public about such authors. Approximately 2000 earthquake predictions from over 200 different authors were collected and evaluated. Of these, statistical tests show that only a few are above the 1% level; more are below due to a modification in the evaluation methods.

Since the majority of individuals are so far below chance expectation, predictions from non-scientists will no longer be evaluated. Such predictions will be accepted and filed for future reference if needed. All predictions through 1977 will be evaluated and a final report will be prepared. In the future the program will concentrate on scientific predictions as they become available.

2. Reports:

"The Prediction Monitoring and Evaluation Program: A Progress Report," by Roger N. Hunter and John S. Derr, Earthquake Info. Bull. (in press).

3. Goals:

To provide statistical evaluations on anyone making public earthquake predictions to any individual or agency who needs such information.

UNIVERSITY OF SOUTHERN CALIFORNIA

SUMMARY REPORT

U. S. G. S. Contract No. 14-08-0001-16745

DEEP-WELL MONITORING OF STRAIN-SENSITIVE PARAMETERS OVER THE GREATER SOUTHERN CALIFORNIA UPLIFT

1 October 1977 to 1 May 1978

Thomas L. Henyey, Ta-liang Teng, Douglas E. Hammond, Charles G. Sammis, Principal Investigators

Results from four facets of our research effort under this program are reported here.

A. Deep Wells

During the first 1½ years of its deep hole recovery program, the twenty-one holes listed in Table 3 have been secured by USC for use in deep-well research. Previous USC Technical Reports described the methods used in securing and preparing these sites. Working depths as of 5/1/78 are given in column 3. Selected holes are being made available to other scientists for down-hole experiments. The Skelton, Del Sur, Virginia Lee, Handley, Alberta, Wright-Kovaleski, HCL, Fairmont and Brady wells are in operation or are being prepared as primary research facilities.

B. Water Sampling

Water samples from wells are being analyzed for radon and major element chemistry. The radon results are reported in separate USGS technical reports. We have begun monitoring water chemistry at four sites (Table 2). It is too early to interpret most of this data. However, one anomaly is worth noting (Haskell 1-18-78). Cl^- and Ca^{+2} showed large decreases, suggesting that the sample may reflect dilution during the heavy rains prior to sampling. K^+ and Na^+ were unchanged, suggesting that the ion exchange capacity of the soil for these two elements may be so large that it masks large inputs of rain water.

C. Borehole Temperatures

An interesting and important finding involves measurements made at the LH-2 well. Temperatures obtained by the USGS (Table 1) at this site, when compared with data gathered in 1967, shows no appreciable change at the 0.01°C level (within the limits of reproducibility and precision of calibration of the instruments). This ten year gap represents an appreciable period of the time during which the southern California uplift has developed. LH-2 is within 5 km of the San Andreas near Lake Hughes and the hole is entirely within crystalline rock. Two conclusions with respect to strain along the San Andreas are suggested by this data: 1) anomalies at the 0.01°C level or greater probably do not occur at this site (this would include temperature changes due to groundwater movement), and 2) the lack of apparent anomalies at the 0.01°C level enhances the feasibility of resolving strain-related temperature changes at the 0.001 to 0.0001°C level in this well and at other sites.

D. Field Cryogenic Magnetometer

Supplementary funding of the project by the USGS has made it possible for us to compare the long term stability characteristics of a fluxgate and cryogenic magnetometer. A three month field test will be carried out in cooperation with UCLA between September 1, and December 1, 1978. Appropriate sites are still under consideration An external 3-axis test coil assembly (quartz substrate with gold windings), together with telescopic sighting and a biaxial tilt-meter, will be used to monitor movements of the instruments.

TABLE 1

Comparison of Temperature Measurements at LH-2

Henyey (5-11-67) °C	Depth (m)	USGS (4-8-77) °C
17.16	120	17.18
17.35	130	17.37
17.56	140	17.58
17.76	150	17.79
17.97	160	17.98
18.19	170	18.20
18.40	180	18.42
18.62	190	18.63
18.84	200	18.84
19.06	210	19.04
19.28	220	19.27
19.50	230	19.50
19.72	240	19.72
19.95	250	19.95
20.17	260	20.17
20.40	270	20.40
20.62	280	20.63
20.85	290	20.84
21.09	300	21.07
21.32	310	21.32
21.56	320	21.57
21.79	330	21.80
22.03	340	22.05
22.28	350	22.30
22.52	360	22.52

Table 2. Major Element Chemistry in Groundwater from Radon Monitoring Sites.*

Site	Date	K^+	Na^+	Mg^{++}	Ca^{++}	Cl^-	Rn^{222}	Rainfall**
Palmdale	7/27/77	1.67	23.41	4.85	26.19	5.24	626±7	0.00
	8/10/77	1.69	21.77	4.80	26.86	3.47	710±80	0.00
	8/31/77	1.71	22.51	4.80	26.12	2.37	635±10	1.25
	9/15/77	1.66	20.46	4.74	26.52	2.99	623±5	0.00
	9/29/77	1.63	21.71	4.70	25.95	3.84	609±1	0.00
	11/2/77	1.62	24.00	4.60	24.98	2.11	602±24	0.00
	11/16/77	1.60	24.06	4.55	25.80	2.24	592±2	0.03
	11/30/77	1.61	23.28	4.55	25.70	2.08	639±16	0.00
	12/14/77	1.58	22.51	4.58	25.80	3.19	639±16	0.00
	1/24/78	1.61	23.93	4.37	29.06	2.54	589±20	5.50
Paradise I	11/7/77	2.72	808.7	36.15	25.37	33.60	390±6	0.26
	12/6/77	5.76	832.9	42.62	22.59	35.80	-----	0.00
Paradise II	11/7/77	1.89	745.7	0.561	0.771	78.30	318±6	0.26
	12/6/77	2.08	735.6	0.253	0.382	145.6	-----	0.00
Haskell	11/3/77	0.375	64.88	0.047	4.27	14.5	596±57	0.00
	11/11/77	0.186	60.46	0.047	0.381	13.1	556±20	0.07
	11/19/77	0.234	62.49	0.106	0.385	13.6	531±14	0.00
	11/26/77	0.143	61.48	0.038	0.075	13.0	479±8	0.00
	12/7/77	0.156	62.12	0	0.482	13.0	487±19	0.00
	12/13/77	0.171	62.23	0	0.146	13.1	568±5	0.38
	1/18/78	0.175	61.01	0	0.024	6.94	339±4	10.82

* Data are in ppm except for radon which is in dpm/l.

** Rainfall data are from NOAA sites at Palmdale, Sandberg Weather Station (for Paradise Wells) and L.A. Airport (for Haskell Well). Data is the number of inches falling between sampling dates or for the month prior to sampling.

TABLE 3

Name	Location	Depth	Diameter	Casing	Lithology
Skelton	34°43'N 118°31'W	1140'	9-7/8"	200'	Granite
Munz	34°42'N 118°22'W	1240'	8-3/4"	200'	Granite below 600'
Del Sur	34°39'N 118°14'W	2300'	6-5/8"	2300'	Sediments
Virginia Lee	34°30'N 117°49'W	1280'	13"	440'	Sediments
Chief Paduke	34°30'N 117°59'W	1300'	4"	1298'	Fault gouge
Pratty	34°31'N 118°17'W	1008+'	6-1/2"	?	Granite
Guyton	34°31'N 118°39'W	500+'	10-3/4"	100'	Sediments
HCL	34°25'N 118°25'W	560'	11-3/4"	200'	Sediments
Handley	34°25'N 117°35'W	6300'	5-1/2"	6300'	Sediments, granite
Alberta	33°57'N 117°03'W	3180'	10"	1100'	Sediments
Brady	34°10'N 115°56'W	1350'	4"	1125'	Sediments
Fairmont	34°46'N 118°27'W	650'	14"	650'	Sediments
Roy Christenson (Palmdale #1)	34°32'N 118°02'W	1100'	?	1100'	Sediments
Wright-Kovaleski	34°31'N 118°21'W	0'	6-5/8"	2600'	Granite
Paradise #1	34°34'N 118°41'W	1150'	8-1/2"	1150'	Sediments
Paradise #2	34°34'N 118°41'W	875'	8-1/2"	875'	Sediments
SB-2	34°15'N 117°19'W	1510'	1-1/4"	1510'	Granite
LH-1	34°44'N 118°23'W	710'	2-3/8"	None	Granite
LH-2	34°41'N 118°26'W	1200'	1-1/4"	1200'	Granite
LH-3	34°39'N 118°29'W	1200'	1-1/4"	1200'	Granite
LV-1	34°37'N 116°43'W	2300'	1-1/4"	2300'	Granite

Seismic Studies for Earthquake Prediction

8-9930-01727

C. G. Bufe
D. H. Warren
U. S. Geological Survey
345 Middlefield Road
Menlo Park, CA 94025
(415) 323-8111 ext. 2567

Goals

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. Sub-damaging earthquakes will be predicted in the testing of mechanistic models. Such predictions are useful in designing experiments to detect precursors and in the interpretation of precursors. Other project goals are foreshock recognition and an understanding of why some earthquakes have foreshocks and/or aftershocks and others don't.

Investigations

Project effort has been directed toward research on recognition of foreshocks and induced seismicity, determination of earthquake recurrence intervals, investigation of local and regional stress orientations, and examination of spatial variations in foreshock and aftershock characteristics. Project personnel have participated in the Willits aftershock study, the Reelfoot Lake microearthquake study, the Saudi Arabian refraction profile, and the Auburn Dam earthquake safety review.

Results

Temporal variations in stress orientation

Fault plane solutions were obtained by Warren (1978) for 80 microearthquakes in a 900 square km area centered on the Busch fault during a one year period preceding the Thanksgiving Day, 1974 Hollister earthquake. Mechanisms for these events are shown in Figure 1. Sixty-five of the events were strike-slip, most occurring at active spots along the Sargent, Castro, Busch, and Calaveras faults. Eleven thrust and four normal mechanisms were also observed. Azimuths of the compressional axis are plotted as a function of time and source fault in Figure 2. Fault orientations in the wedge between the San Andreas and Calaveras faults are such as to permit focal mechanisms with a range in azimuth of compressional axes of about 90°; no discernable rotation of compressional axes was observed to precede the Thanksgiving Day earthquake.

Another study of temporal variation in stress orientation is underway at The Geysers geothermal development north of San Francisco. The Geysers is a highly fractured region of intense microearthquake activity on the southwest flank of the Clear Lake gravity low. The seismogenic zone in this region is anomalously shallow. The absence of microearthquakes below 5 km may be due to elevated temperatures associated with a magma body at depth. Thus The Geysers lies in a zone of crustal weakness which may be very sensitive to changes in regional stress. Bufe, et al. (1978) examined focal mechanisms of earthquakes between June 1975 and September 1977 at The Geysers and in the surrounding region. They found a stress orientation rotated clockwise 30° from that producing maximum right lateral shear on faults subparallel to the San Andreas. Preliminary focal mechanism results for earthquakes in late November and early December 1977 indicate that the stress pattern may have changed to favor movement on the San Andreas and Maacama systems, which have been unusually active since September 1977.

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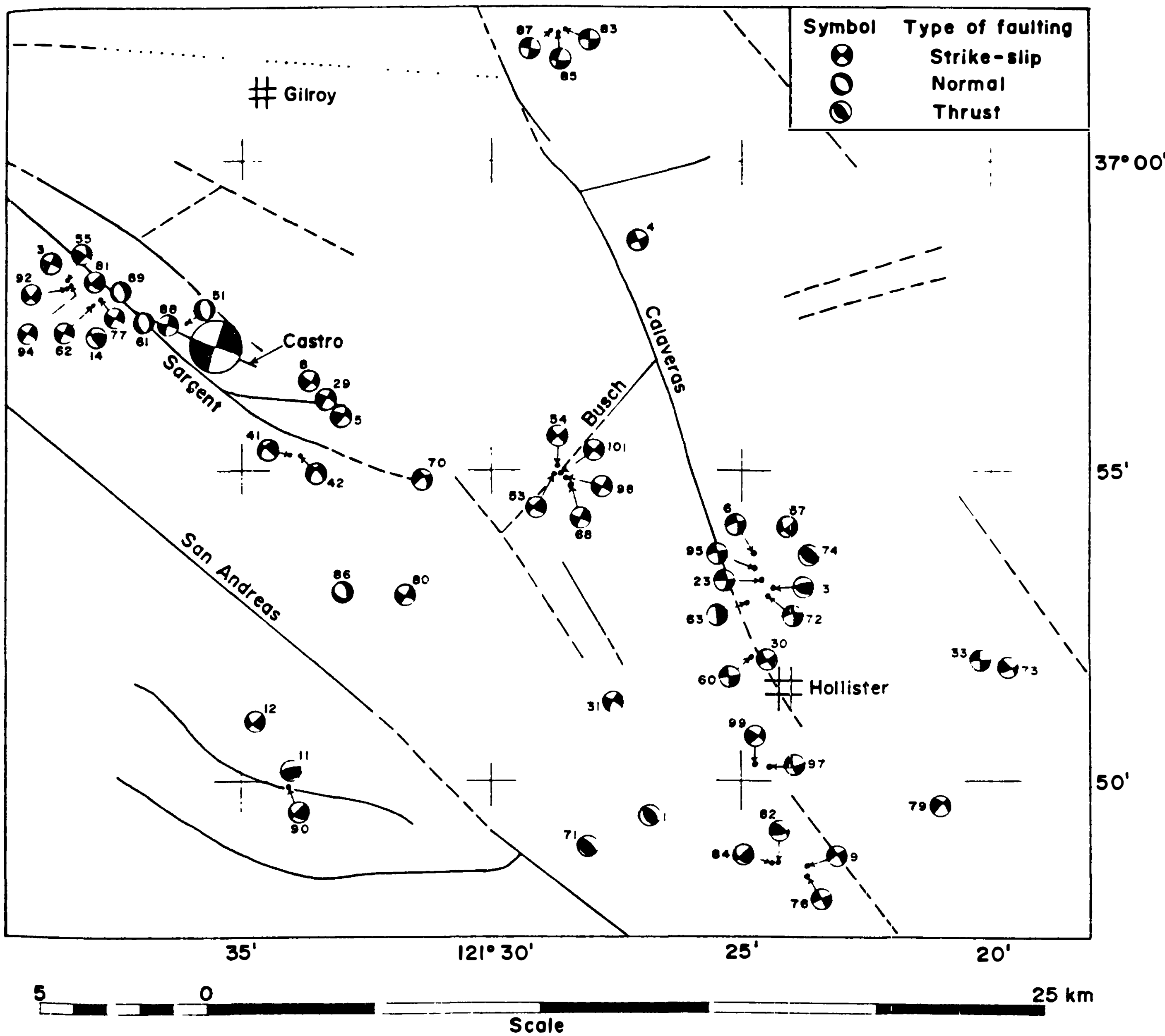


Figure 1. Fault mechanism map from November 1973 through November 1974. Faulting is from the Geologic Map of California, San Francisco and San Jose sheets. Compressional quadrants are shown as black areas and dilatational quadrants are shown as open areas within the circles, separated by the nodal planes. The large circle on the Castro fault encloses a composite solution of 22 strike-slip events. Within this circle there were also four thrust events and one normal event.

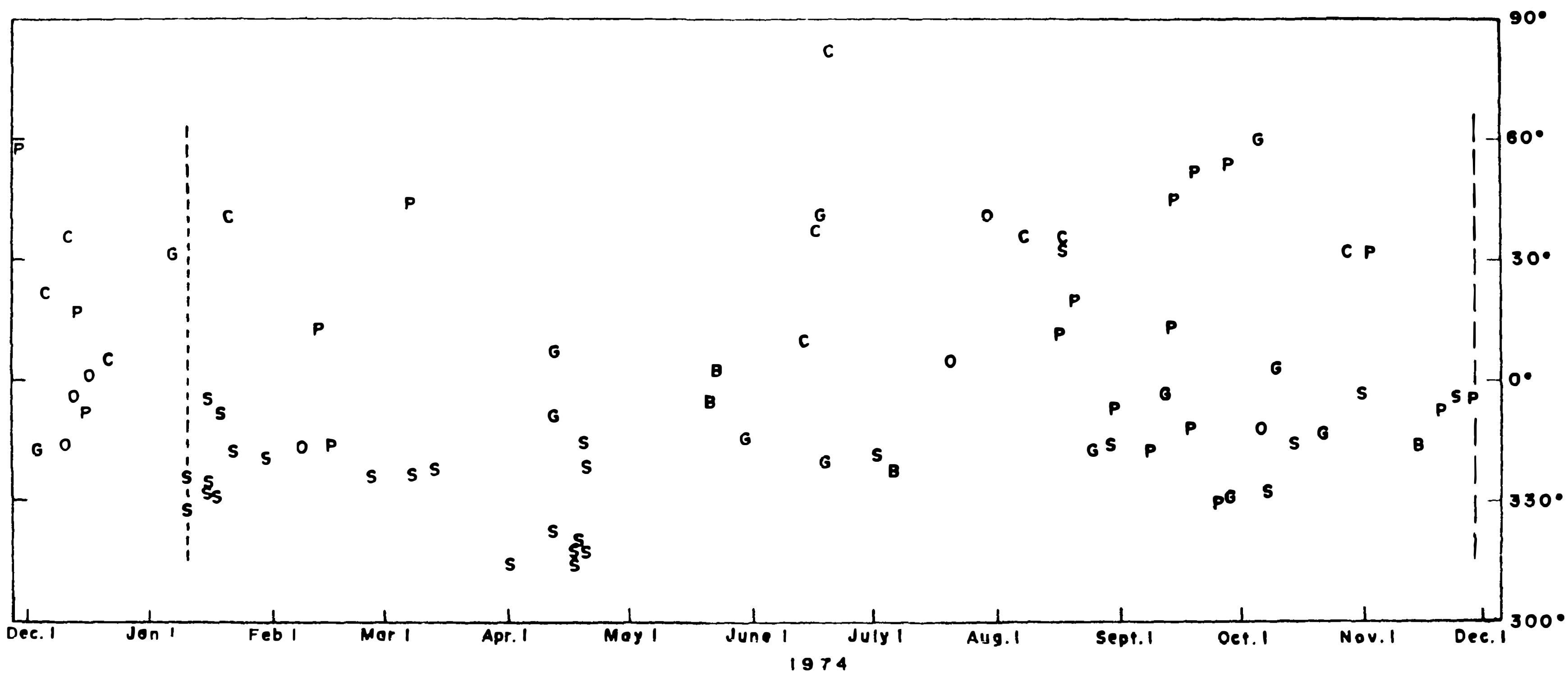


Figure 2. Plot of azimuth of the compressional axis as a function of time. Letters represent earthquakes on faults, as follows: B, Busch fault; C, Calaveras fault; G, Sargent fault; S, Castro fault; O, other known faulting; P, not on known faults.

SEMI-ANNUAL SUMMARY

Branch of Global Seismology

Date:

Project No. 9920-02142 Title Teleseismic Search for Earthquake Precursors

Project Chief James W. Dewey

Mailing Address and Phone No. U.S. Geological Survey, Branch of Global Seismology, Stop 967, Box 25046 DFC, Denver, CO 80225

Report Period October 1, 1977 to March 31, 1978

1. Investigations and Results

Glen Reagor has created a computer file of P-wave arrival times reported to the International Seismological Centre (ISC) for 1964-1974. This file greatly increases the speed with which we can locate the earthquakes of a particular region under study, even though it is still necessary for us to enter by hand arrival-times for phases (such as S or pP) other than the first arriving P-phase.

Jim Dewey and Bill Spence are in the midst of the revision of hypocenters of earthquakes occurring offshore of Peru in the regions of the major shocks of Oct. 17, 1966, May 31, 1970, and Oct. 3, 1974. The purpose of this relocation is to obtain hypocenters of maximum precision for small and moderate shocks preceding and following the large earthquakes to see: (1) If there are identifiable patterns of precursory seismicity prior to the large earthquakes and (2) what the effect is on the seismicity of an incipient source region of a major earthquake occurring nearby.

At this stage we must restrict enumeration of "results" to methodology used in redetermining hypocenters - focal depth in particular:

(1) There is a tendency for focal depths of shocks offshore of Peru to be systematically overestimated by routine location methods. This overestimation is a consequence principally of the unbalanced distribution of seismographic stations with respect to the earthquakes being located. (Many of the Peruvian earthquakes are not recorded by a single station located at an azimuth away from the coastline.) In addition, P-wave data collected with a temporary network by C. Langer and W. Spence for aftershocks of the 1974 earthquake suggest that P-wave arrival-times to many of the regularly reporting permanent stations of Peru and Bolivia are systematically delayed by anomalously low velocities above the subduction zone. Because the regional stations are crucial in determining focal depths in the absence of reported depth-phases, the systematic delays to the regional stations produce a tendency for overestimation of focal depth.

(2) The standard error of pP-times reported for Peruvian earthquakes is ± 3 sec., corresponding to a variation of ± 10 km in the focal depth.

(3) Having pointed out that routinely-determined depths are frequently overestimated, we must emphasize that our results to date are still consistent with a tectonic model proposed by Abe (Phys. Earth Planet. Interiors, 5, p. 367) for the earthquakes of 1966 and 1970 - namely, the 1970 earthquake occurred at depth within the underthrust Nazca plate whereas the 1966 earthquake occurred at the thrust contact between the Nazca plate and the South American plate.

Reports: None completed

Goals: To test whether the present global seismograph network is capable of detecting unusual patterns of seismicity precursory to major earthquakes.

To test whether moderate and large subduction zone earthquakes tend to nucleate in the same small regions of a subduction zone.

To determine the effect, on the seismicity of an incipient source region, of a major earthquake occurring nearby, and to interpret the presence or absence of such seismicity in terms of models of the preparation of source regions for major earthquakes.

Garm Source Mechanism Studies

8-9930-02100

Fred G. Fischer
U.S. Geological Survey
345 Middlefield Road
Menlo Park, CA 94025
(415) 323-8111, ext. 2321

Goals

Several questions of current interest to Soviet and U.S. investigators involved in joint studies for earthquake prediction involve properties related to the source mechanisms of local earthquakes. This project will collect sufficient data and perform the analysis necessary to answer the following questions: 1) How variable is the seismic source spectrum from station to station? 2) What are the important propagation effects and how can they be corrected for in analyzing the source spectrum? 3) After corrections are made for the effects of propagation and near-station effects, do the estimates of the source spectrum show a dependence on azimuth and take-off angle relative to the focal mechanism? 4) What is the limit of resolution in estimating seismic moment and stress drop using local earthquake data? 5) Do the parameters of the seismic source vary systematically in space and time within a relatively small region?

Investigations

Preparation of the equipment and programs to be used in the summer of 1978 inside the Soviet Union are underway. Designs for 10 new 3-component, 2-level stations including calibrators for the S5S Russian seismsometers were completed. These seismometers have adjustable free periods, set to 4 seconds for the experiments to be performed both in the Soviet Union and California.

A digitizing multiplexer was designed to interface the analog records collected in the USSR and a new microcomputer to be delivered in early June. BASIC programs are being written for this system to perform data analysis and spectral plotting while in Garm, Tadjikistan.

A study is in progress of recording site effects, wave propagation characteristics and microearthquake radiation patterns in the Garm region for data recorded in 1977 and should be completed by July 1978.

Semi-Annual Technical Report

1 October 1977 to 31 March 1978

Hiroo Kanamori and Karen McNally

Seismological Laboratory
California Institute of Technology
Pasadena, California 91125

SUMMARY

The U.S. Geological Survey Contract No. 14-08-0001-16711 was awarded in response to the proposal by the California Institute of Technology which was divided into four separate efforts. The results are summarized below.

1. P-velocity Change (quarry blasts)

No changes in P-velocity exceeding 2% have been observed along any paths in southern California except for the path from Mojave to PYR. However, there was no earthquake $M_L \geq 5.0$ in southern California during the period October 1, 1977 to March 31, 1978; the question of whether a detectable premonitory change occurs or not remains unresolved. However, small but systematic changes found for Victorville, Mojave and Gorman blasts seem significant. The path from Mojave to PYR showed a large delay in recent months. However, it is not clear at present whether this change is due to a complex blasting pattern at the quarry or a change in the crustal velocity. These changes are not correlatable to any individual seismic event, but may be related to a more regional stress accumulation along the San Andreas fault, especially along the great bend. Figure 1 shows the results for the Mojave, Victorville and Cypsum Canyon blasts.

2. Crustal Structure

Extensive analysis of teleseismic P delays and surface waves have been made. The P-delay study revealed (1) high mantle velocities beneath the Sierra Nevada and most of the Transverse Ranges (2) low-velocity regions in the mantle beneath the Imperial Valley, and (3) a low velocity region at depth trending northwards from the Salton Sea into the Mojave Desert.

Teleseismic Rayleigh wave phase velocity data for both the southern Mojave-central Transverse Ranges and the Peninsular Ranges are inverted to obtain regional S-wave velocity models. Poisson's ratio as a function of depth is calculated for these two regions. The comparison with laboratory ultrasonic studies requires a quartz-rich crust within the southern Mojave-central Transverse Ranges and a mafic crust within the Peninsular Ranges.

3. Microearthquake Survey and Related Problems

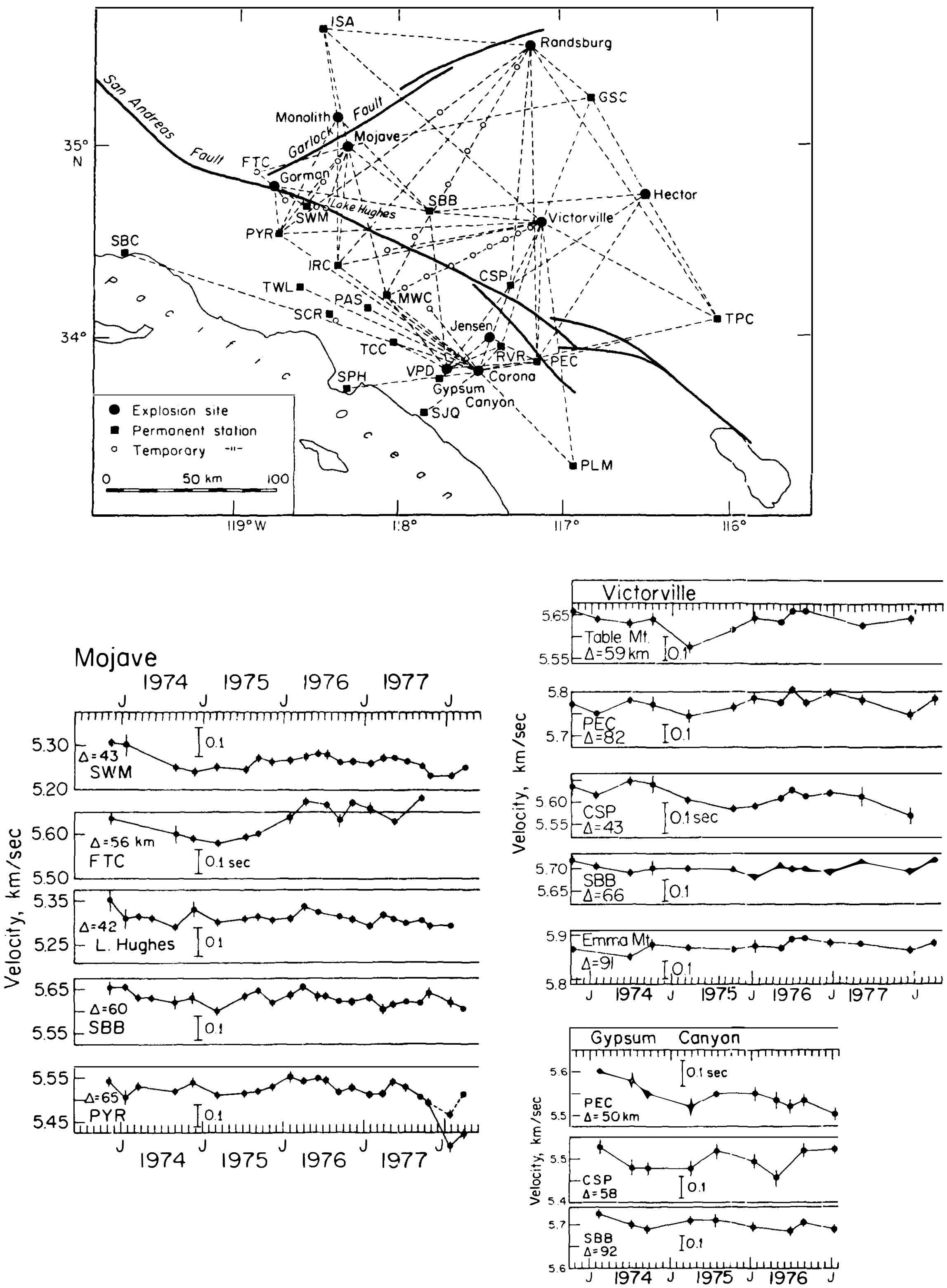
The Caltech seismographic trailers have been installed near Juniper Hills for more than a year, beginning in November 1976, and have recorded about 700 events ($M \geq 0$) in 12 months.

An important feature of the Juniper Hills activity is its swarm-like character. Figure 2 summarizes the result. Most earthquakes in the 1976-1977 swarm, including the three largest events, are clustered in a small area approximately 3 km in maximum dimension (see Figure 2) and at a depth of about 8 km. The cluster is slightly elongated in a direction perpendicular to the San Andreas and is centered 2 km SW of the mapped surface trace. Faulting may be along the main San Andreas or along one of several subparallel faults and lineaments which splay southward from the main fault trace near the cluster location. Epicenters of the recent (1976-1977) earthquakes near Lake Hughes scatter between the traces of the San Andreas and Clearwater faults.

Although the dominant displacement on the San Andreas fault has been right-lateral strike-slip, thrust mechanisms were observed for the three largest swarm events at Juniper Hills and for the largest event at Lake Hughes (see Figure 2). The focal mechanism for the first larger ($M \geq 2$) event in the Juniper Hills cluster, however, shows strike-slip motion on WNW or NNE trending fault planes (see Figure 2), suggesting that the swarm was initiated by a slip event on the San Andreas or a NNE trending conjugate fault. The strike of the fault planes for the three large thrust events at Juniper Hills rotate clock-wise with time from N 36° E ± 10° on 1 January 1977 to N 85° E ± 11° on 7 March 1977 to N 104° E ± 12° on 6 September 1977, giving a total rotation of 68 ± 22°.

4. Seismicity Study in Southern California

A systematic study on seismicity in the San Fernando region in the west-central Transverse Ranges, California, has been made. Most of the recent activity within the San Fernando zone has been thrust faulting at depths shallower than and south of the mainshock. One event located slightly deeper than and several km north of the main event suggests shear along a flat plane. Transport of the upper block is south. This event is very similar to another deep, $M_L = 4.5$, earthquake 30 km west of San Fernando. If these events are typical of midcrustal deformation, the west-central Transverse Ranges may be a form of decollement. A rapid increase in seismicity ($M_L \geq 3.0$) in the region south of San Fernando suggests an increase in regional strain that either was contemporaneous with or immediately followed the San Fernando earthquake.



ISA
Randsburg
GSC
San Andreas Fault
Garlock Fault
Monolith
Mojave
FTC
Gorman
Lake Hughes
SWM
SBB
Victorville
Hector
PYR
SBC
IRC
TWL
CSP
PAS
MWC
SCR
TPC
Jensen
TCC
RVR
PEC
VPD
Corona
SPH
Gypsum
Canyon
SJQ
PLM
Explosion site
Permanent station
Temporary -"-
0 50 km 100
35° N
34°
119°W
118°
117°
116°
Mojave
1974 1975 1976 1977
Δ=43 SWM
Δ=56 km FTC
0.1 sec
Δ=42 L. Hughes
Δ=60 SBB
Δ=65 PYR
Velocity, km/sec
Victorville
Table Mt. Δ=59 km
PEC Δ=82
CSP Δ=43
SBB Δ=66
Emma Mt. Δ=91
Gypsum Canyon
PEC Δ=50 km
CSP Δ=58
SBB Δ=92

Fig. 1

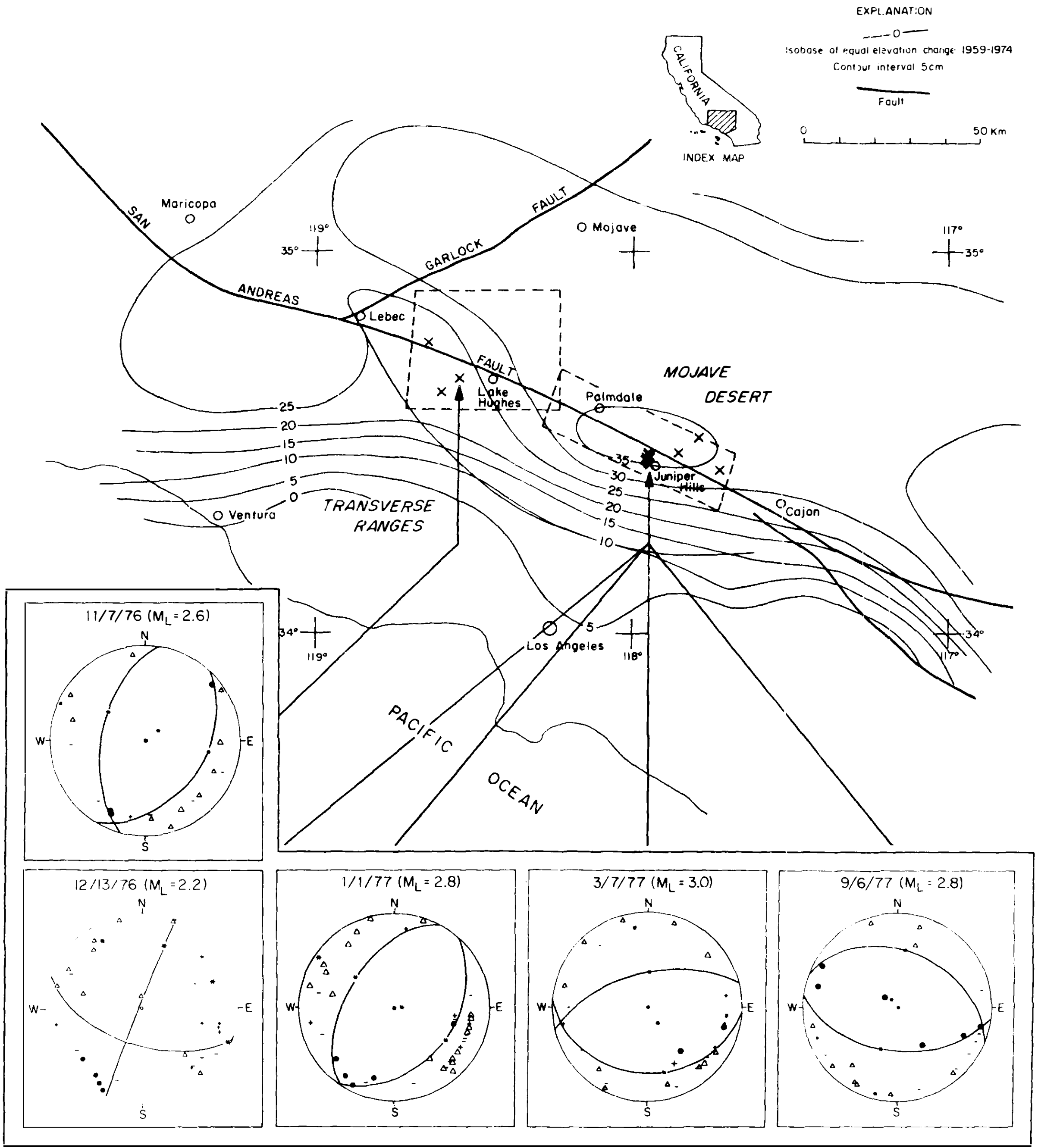

EXPLANATION
Isobase of equal elevation change 1959-1974
Contour interval 5cm
Fault
0 50 Km
CALIFORNIA
INDEX MAP
SAN ANDREAS FAULT
GARLOCK FAULT
Maricopa
Mojave
Lebec
Lake Hughes
Palmdale
Juniper Hills
Cajon
Ventura
Los Angeles
MOJAVE DESERT
TRANSVERSE RANGES
PACIFIC OCEAN
11/7/76 (M_L = 2.6)
12/13/76 (M_L = 2.2)
1/1/77 (M_L = 2.8)
3/7/77 (M_L = 3.0)
9/6/77 (M_L = 2.8)

Fig. 2

Microearthquake Data Analysis

8-9930-01173

W. H. K. Lee
W. L. Ellsworth
U. S. Geological Survey
345 Middlefield Road
Menlo Park, CA 94025

The primary focus of this project is the development of state-of-the-art computation methods for analysis of data from microearthquake networks. Our ultimate goal is the application of these methods to earthquake data to 1) detect seismic precursory phenomena useful for earthquake prediction, and 2) relate seismicity, and earth structure to geologic processes.

Our principal effort during the past year has been to address the problem of determining earth structure from surface array observations of body wave travel times. To this end, several families of computer programs have been developed to trace rays in three-dimensional velocity structures, and to solve a linearized system of equations relating travel time observations to unknown parameters that characterize the velocity structure and source coordinates.

To date, three basic programs have emerged:

(1) A generalized inversion package that will solve the over-determined system of equations $Ax = b$ by singular value decomposition for very large systems of equations without resort to normal equations ($A^tAx = A^tb$).

(2) A three-dimensional ray tracing package that will trace a minimum time path between two points, and compute the traveltime and its derivatives.

(3) An iterative three-dimensional modeling program employing ray tracing in heterogeneous media that determines lateral velocity heterogeneities beneath a receiver array from teleseismic body wave travel times.

Work is now in progress on a fourth basic program to iteratively determine both three-dimensional velocity structure and earthquake focal parameters when the seismic sources lie within the volume for which information on velocity heterogeneity is sought. Unlike the problem of modeling structure from teleseismic travel time data, this problem requires the application of ray tracing in heterogeneous media and iterative improvement of trial solutions to provide meaningful results.

A new approach for evalutaing the accuracy and limitations of these three-dimensional modeling programs is being developed. Both iterative and non-iterative modeling programs that use only teleseismic sources have been verified using simple artificial velocity structures such as a cylinder embedded in a halfspace. Because velocity inhomogenaities in the crust and upper mantle have a statistical distribution which behaves as a random medium, it is appropriate to examine the implications of an artifical velocity structure so characterized for the inversion methods. To accomplish this, we begin with a velocity model defined in terms of fourrier wave numbers

$$V(x,y,z) = \sum_{k,l,m} V_{klm} e^{i(kx + ly + mz)}$$

where the coefficients V_{klm} are selected by a random number generator. Rays are then traced through this specific velocity structure to give a suite of arrival times that are then inverted in the usual manner. Comparisons formed between the model solution and the "unknown" medium give a quantitative measure of the success with which the method recovers the broad scale features of the velocity distribution.

Microearthquake data in the western Transverse Ranges, California during the period from 1970 to 1975 were systematically analyzed. We found that the distribution of earthquake hypocenters delineates active faults and that most fault-plane solutions indicate reverse faulting. These seismic results are in full agreement with geologic data.

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World-Wide Earthquake Research Databases

8-9930-02104

W. H. K. Lee
U.S. Geological Survey
345 Middlefield Road
Menlo Park, CA 94025
(415) 323-8111, ext. 2630

The main goal of this project is to provide up-to-date information which will facilitate research on earthquakes. Three major topics are now under investigation:

1. Feasibility study of the establishment of a seismogram library of significant earthquakes (especially those before 1963),
2. Organize and maintain a bibliographic database and retrieval system on current earthquake literature, and
3. Compile an accurate catalog of worldwide earthquakes.

Seismogram Library. Dennis W. Ciul prepared a report on "portable photocopying systems for reproducing seismograms". Ciul investigated three portable systems which could be used to photocopy historical seismograms; and samples of acceptable quality were obtained. The cost per seismogram was estimated to be about one dollar per record. Gordon S. Stewart prepared a report on "past, present, and future usage of seismograms recorded before the establishment of the WWSSN in 1963". In this report, Stewart reviewed the various seismological research works based on historical seismograms and examined the strategy in selecting earthquakes and stations.

Under contract from this project, the National Geophysical and Solar-Terrestrial Data Center, NOAA, will undertake the construction of a portable photocopying system and do preliminary work on gathering station information. A scientific advisory group is now being organized under the auspices of the International Association of Seismology and Physics of the Earth.

Bibliographic Database and Retrieval System. A database and retrieval system for earthquake literature has been completed using the SPIRES system at the Staznford Linear Accelerator Center's Computer Center. Since January 1978, current earthquake literature (CEL) has been systematically entered into the CEL database and a monthly index has been distributed shortly after the end of each month. This monthly index will keep readers aware of pre-prints, reports, and reprints of articles of interest to seismologists. A copy of all the articles indexed is kept on file at the OES library so that it is very simple to read or make a copy of any current article.

Earthquake Catalog. We have collected over 50 earthquake catalogs totaling about 500,000 entries. Because of unavoidable errors in transcribing data into a form readable by computers, we are now in the process of data verification. Each catalog must be prepared independently twice. A comparision is then made by computers and any discrepancies will be resolved by consulting the source materials. We have developed most of the computer programs needed to translate data of various formats into a standard one, to compare two sets of data, and to merge the data into a master file. Although this massive data-gathering, data-verification and selecting best estimates will take several years, we are making a steady progress. This sub-project is being carried out jointly with Wilbur Rinehart of NGSDC, NOAA.

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Premonitory Amplitude Changes

8-9930-02098

Allan G. Lindh
Constance E. Mantis
U.S. Geological Survey
345 Middlefield Road
Menlo Park, CA 94025

Goals

Establish utility of systematic changes in P and S amplitudes from small ($M < 2$) earthquakes recorded at local stations in the identification of foreshock sequences.

Investigations

1. Detailed study of the amplitude characteristics of the fore- and aftershocks of the magnitude 5.7 Oroville earthquake of August 1, 1975. Principal result of this work is the establishment of a systematic change in the P/SV ratio of waveforms recorded at two local stations at the time of the main event. This was observed by comparing the foreshock amplitudes to those from aftershocks near the same location and is due to changes in focal mechanism orientation. The aftershocks in the vicinity of the foreshocks have focal plane solutions that strike 10° to 20° east of north and dip 60° to the west. This agrees very well with the local orientation of the fault plane as determined from aftershock locations. While predominantly of dip-slip character, they usually have a small left-lateral component of slip. The foreshocks, on the other hand, strike 10° to 50° west of north and sometimes contain a right-lateral component of slip. This difference is speculatively attributed to the foreshocks having occurred on an offset on the main fault plane at which stress had accumulated due to aseismic deformation elsewhere. A short report on this work has been accepted for publication by *Science* (Lindh *et al.*, 1978a) and a longer version to be submitted to *BSSA* is in internal review.

2. A major by-product of the Oroville work has been the compilation of an earthquake catalog for the Oroville sequence. It covers the period June 28, 1975 to July 31, 1976 and is as complete as we can make it (95 to 99%?) down to the following thresholds:

Time Period		M_L	
June 28 to Aug. 1, 1975	20:20 GMT	0.6	Foreshocks
Aug. 1 to Aug. 31, 1975		1.2	Aftershocks
Sept. 1 to Oct. 31, 1975		1.1	Aftershocks
Nov. 1., 1975 to July 31, 1976		1.0	Aftershocks

This catalog is a cooperative effort of several groups and incorporates phase arrival times from the California Department of Water Resources, Woodward-Clyde Consultants and various USGS personnel. These were collated, checked for completeness, and kicked into final shape by Connie Mantis of the USGS. A well-located set of the aftershocks is shown in Figure 1 and a histogram summarizing the time history of the activity is shown in Figure 2. Some preliminary observations are as follows:

a. The foreshocks located near the center of the aftershock zone at a depth of 7-8 km within a small volume no more than 2 km in diameter. There is a suggestion of a southward migration of epicenters within this volume prior to the main event.

b. The aftershocks occurred in at least three distinct zones:

i. The main fault plane, which included the foreshocks and main event. It is a single planar feature no wider than 1 km, striking N 10 E and dipping 60^{o} to the west. It is well defined by aftershocks around its outer perimeter but is almost totally devoid of located earthquakes within its central region throughout the 12 months of the aftershock study.

ii. A northern fault plane, which strikes due north and dips 80^{o}-90^{o}. It first appeared a week after the main event, and was the site of several larger aftershocks, including a magnitude 4.7 event on September 25, 1975 which extended it 1-2 km to the north. It also appears to be a single planar feature of no more than 1-2 km width. The point at which it intersects the main fault plane at a depth of 8-9 km was also the site of many larger aftershocks.

iii. A southern zone, which is composed either of a large number of subparallel fault planes, or includes events distributed throughout a 2-dimensional volume, or both. This was the site of the most numerous and persistent aftershock activity. The main event appears to have initiated on the main fault plane just north of its intersection with this southern zone. An open-file report detailing this work is in internal review and plans are to distill it into (another) Oroville aftershock paper for BSSA.

3. Minor by-products of the Oroville work are:

a. A study by Connie Mantis in which zero crossing times (Δt = time from first break to 2nd zero crossing) vs. log coda length (pseudo stress drop plots, a la O'Neill and Healy) have been plotted for two Oroville foreshocks and a large number of aftershocks. To our astonishment above magnitude 3 the aftershocks are reasonably well behaved and most fall along a single line; the foreshocks lie off this line to the longer zero-crossing time (low stress drop) side (Fig. 3). (Below magnitude 3 ($\tau \sim 130$ sec) the Δt's all scatter about 0.25 sec; this represents the peak system response.) The two larger foreshocks have Δt's approximately 30 percent greater than aftershocks with the same coda length. If we assume that zero crossing time scales like source dimension, and log coda like M_o, then Brune's model implies that the foreshocks have stress drops roughly one-half those of the aftershocks. The data are insufficient, of course, to establish this with much confidence; they are difficult to reconcile, however, with foreshocks having higher stress drops than the aftershocks.

b. A brief study of several small ($M \sim 1$) aftershocks which occurred on a small (but well-defined) conjugate fault that branches off the main fault near its intersection with the northern fault plane. The few events that occurred on this plane correlate temporarily with larger aftershocks ($M \geq 3.5$) on the main fault plane (in 4 of 6 cases occurring within 10 days before the large aftershocks) and also correlate very well in 2 cases with two small earthquakes that located at a depth of 40 km down-dip from the Oroville aftershock zone (Marks and Lindh, 1978). The data suggest, albeit weakly, that the larger aftershocks were preceded by accelerated strain accumulation (due, for instance, to deformation on the aseismic central portion of the main fault plane), which triggered the activity on the small conjugate plane. Even more speculative is the inference that in 2 cases this accelerated strain might have been preceded by deformation propagating up dip from 40 km depth with a velocity of about 10 km/day. A careful search is underway of the Develocorder films for three months prior to the main event to see if it too, might have been preceded by anomalously deep seismicity.

4. A pilot study to detect seismic precursors to the next Parkfield earthquake. The Parkfield area has been the site of four magnitude 6 earthquakes in this century (1901?, 1922, 1934, and 1966). The last three have had identical M_o's and have involved ground breakage along the same section of the San Andreas, along the northeast edge of the Cholame valley. At least the last two have had foreshock activity, including one magnitude 5 foreshock in the final minutes before each main event. Surface creep and geodetic measurements make it clear that strain is accumulating along this stretch, and we are now past the minimum interval between magnitude 6's in this century. As the zone that broke in 1966 has been the site of continuing microseismicity up to the present, including a cluster of activity near the 1966 epicenter, this region seems to us eminently suitable for a detailed prediction experiment. We plan to use the techniques described above, and others, to characterize the ongoing microseismicity, in hopes of identifying the foreshocks to the next magnitude 6. In cooperation with Bill Bakun (8-9930-02101) we are in the process of installing two new 3-component, dual-gain seismic stations in the Parkfield area, both about 5 km off the San Andreas on the Gabilan side; one near Parkfield, and the other near Cholame. In addition, the existing station at Gold Hill has been upgraded to 3-component (high-gain). During this fiscal year we plan to

a. Make a detailed study of P and S arrival times from a well-recorded set of Parkfield earthquakes. We will use these travel times to adopt Eaton and Stewart's 1966 aftershock model to the present station configuration and assess its applicability farther north along the San Andreas.

b. Use the model and station corrections developed to relocate the earthquakes in the Parkfield area since 1969. These relocations will be compared to Eaton's 1966 aftershock distribution and used for a space-time-magnitude study.

c. Begin tabulation of amplitude/focal plane and zero-crossings vs. log code data for selected zones of activity in the Parkfield area.

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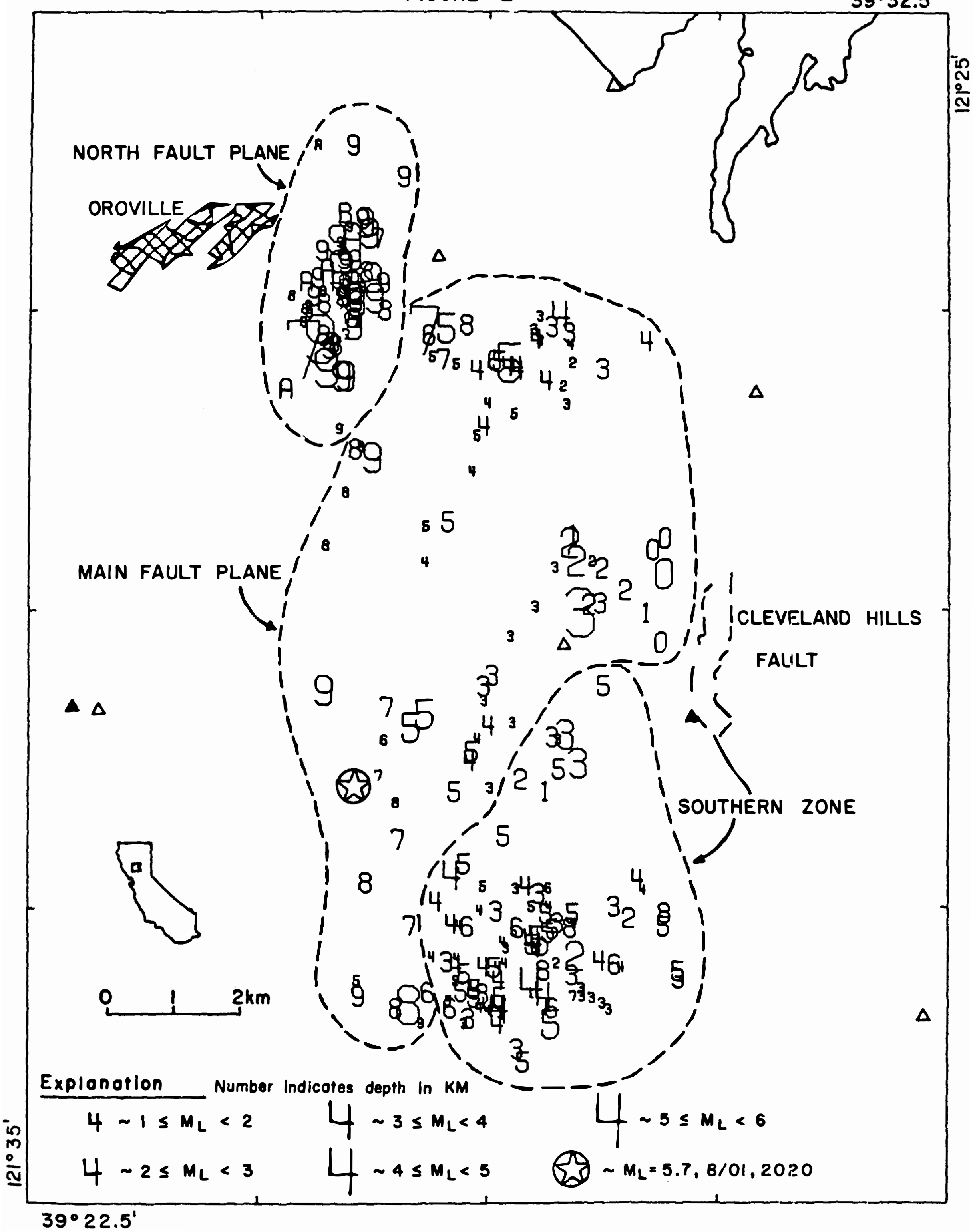
FIGURE 1



OROVILLE AFTERSHOCKS. A & B SOL

AUG 6-15, 1975

FIGURE 2

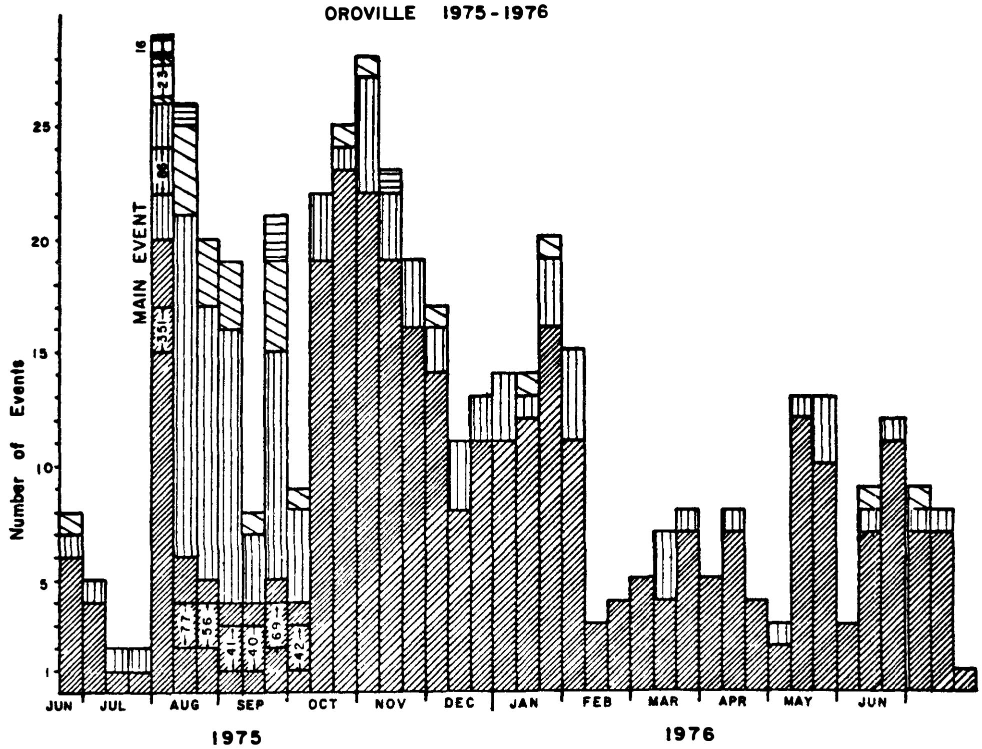
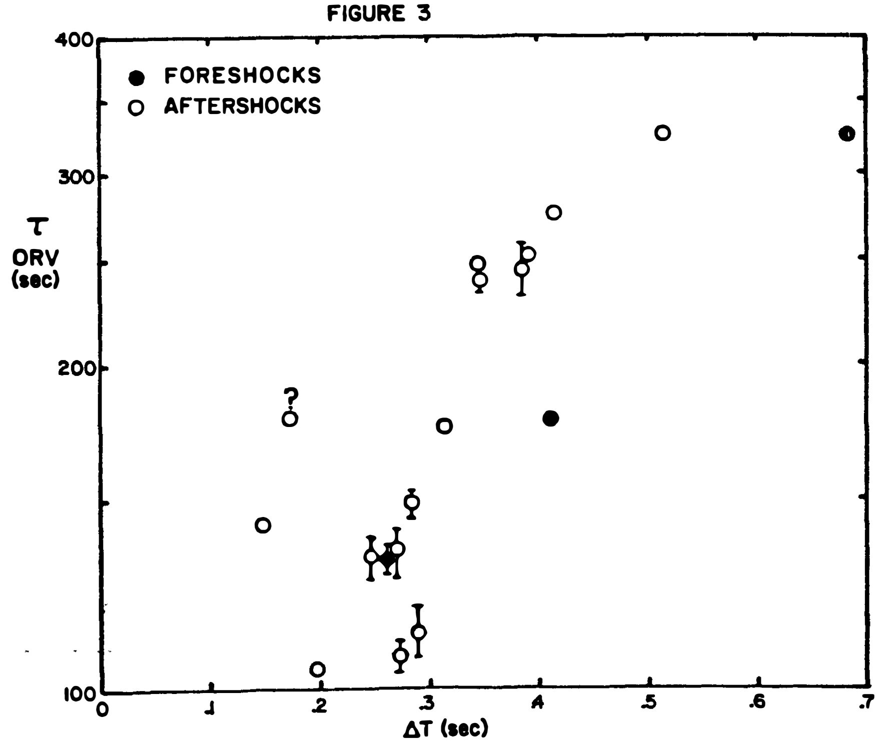


FIGURE 3



TECHNICAL REPORT SUMMARY

(01 Oct 77 - 31 Mar 78)

In-situ Seismic Wave Velocity Monitoring

Principal Investigator: T.V. McEvilly
Seismographic Station
Dept. of Geology and Geophysics
University of California
Berkeley, California 94720

Continued monitoring through the past winter (when weather permitted) has confirmed that spurious travel-time variations, both long-term and short-term, are severely limiting the precision of our measurements, and are perhaps masking events of real interest, namely velocity variations due to stress changes at depth.

Long-term seasonal variations, which have been discussed in previous technical reports for the deep Bickmore Canyon monitoring and in the Event Summary, vol. 1 for all sites, occurred throughout the winter. Changes amounted to a slowing of about 0.2% of the travel-time or 18msec for the 8-sec arrival at Bickmore Canyon, and about 1% for the first arrivals along both shallow paths at the winery site (9 msec on the N-S path and 5 msec on the E-W path). Variations are clearly rainfall related, substantiating our belief that they are caused by changes in water-table depth. However, the sense of the velocity change is opposite to what we would have expected, i.e., as the water table rose with increased rainfall, the travel-times increased at all sites, and are now decreasing again as the water-table drops.

We are experimenting with the use of down-hole geophones below our vibrator sites to compensate for very-near-surface changes, both by simply monitoring down-hole times, and by using the down-hole signal as the reference signal in cross-correlation.

The short-term variations observed since midsummer of last year are a scatter of about 5×10^{-4} of the travel-times measured at all sites during repeated runs made over a number of hours. This is an order of magnitude greater than that observed in the spring of 1977.

During the fall and winter, two sources of noise, transient electrical spikes on the geophone signal and 60 Hz noise on the correlated seismograms, increased markedly. The basic causes of each were discovered, and both were effectively eliminated. This improved data appearance, but did not reduce significantly the travel-time data scatter.

As part of these noise investigations, many parts of the vibrator and recording systems have been tested for stability and found to be functioning properly. The remaining candidates for the instability evidenced by the scatter are:

1. Vibrator reaction-mass instability due to improper feedback control.
2. Source spectrum variations, causing travel-time variations either due to geophone amplifier group delay variations with frequence, or to changing the interference pattern in the source pulse generated in the near-surface.
3. Telemetry transmitter radio and/or antenna problems, either direct variations, or possibly a complex interaction affecting the vibrator control system.

UNIVERSITY OF SOUTHERN CALIFORNIA

SUMMARY REPORT

U. S. G. S. Contract No. 14-08-0001-16704

Research on Earthquake Prediction and Control in the Los Angeles Basin and Adjacent Area
1 October 1977 to 31 March 1978
Ta-liang Teng, Principal Investigator

A complete catalog of microearthquake activity, occurring during 1973-1976, has been compiled for the Santa Monica Mountains, Santa Monica Bay and northern Los Angeles basin. Earthquake relocations were accomplished by applying an improved crustal velocity structure and individual seismic station correction constants to the revised HYPO 71 computer program. The data base is generated from all seismic networks operating in southern California.

The Santa Monica Mountains, Santa Monica basin and northern Los Angeles basin are physiographic features located at the juncture of differing structural terranes which became juxtaposed during Mesozoic and Cenozoic tectonic episodes. From the 423 earthquakes relocated in this study, individual and composite fault-plane solutions (Figures 1 and 2) and directions of local compressive stress (Figures 3 and 4) have been derived which support hypotheses proposed to explain the present seismotectonic pattern evolving in coastal southern California. Preferred fault-plane solutions comprise a summary of the correlation between seismicity and known faults with known sense of displacements. The study area is presently responding to a local northeast-southwest compressive stress field with the tensional stress axis aligning along the trace of the Santa Monica fault system, which includes the Santa Monica fault, the Malibu Coast fault, the Dume fault, and the Raymond Hill fault. South of the Santa Monica fault system, response to this compression is manifested by the concentrations of seismicity aligned along the Newport-Inglewood fault zone and along the Palos Verdes fault and its northwest extension in the Santa Monica Bay. In the Hollywood area, current seismic energy release occurs around the intersection of the northwest trending Whittier fault and the Santa Monica fault. These seismicity trends do not project to the north, across the Santa Monica fault system, suggesting that the northwest-trending structures are probably terminated by this fault system and that the Santa Monica Mountains are acting as a passive and coherent structural block.

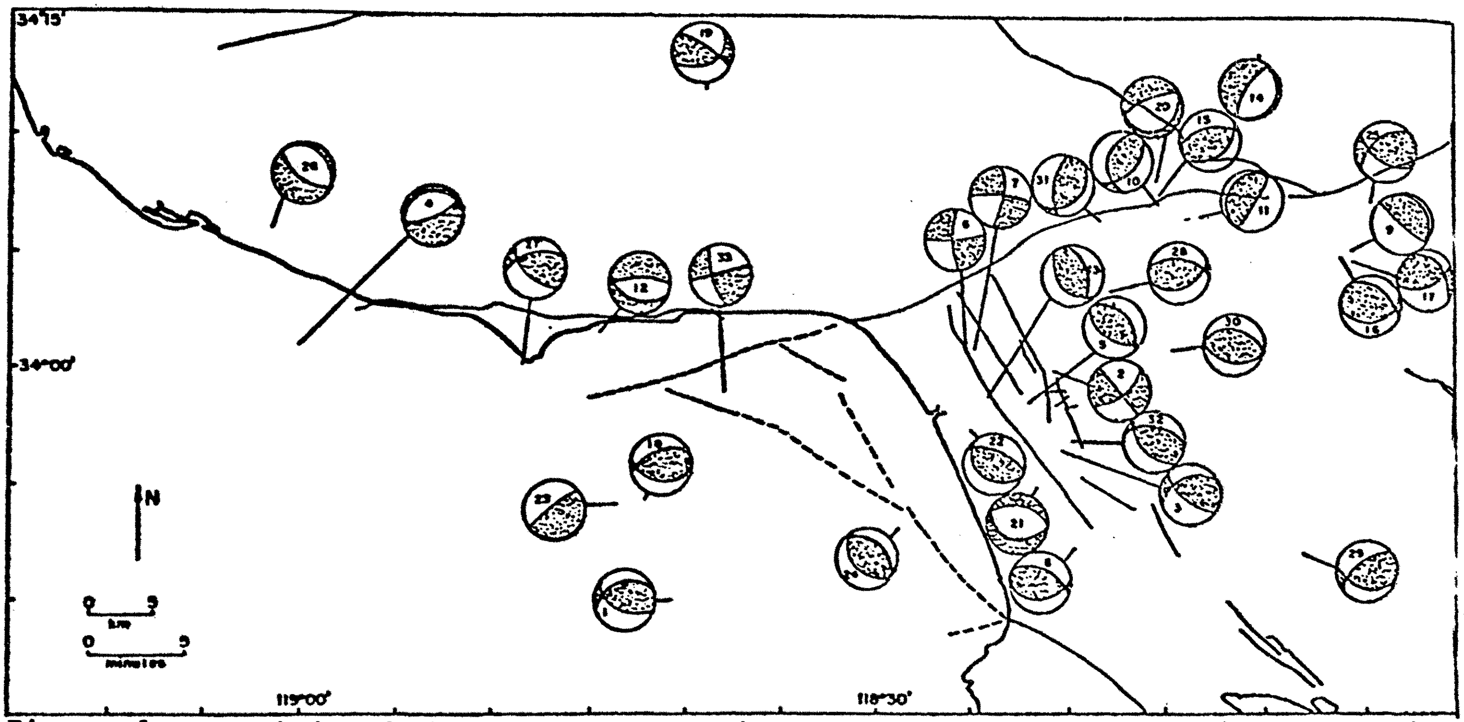


Figure 1. Individual fault-plane solutions, 1973-1976, numbered in sequential order. Stippled quadrants equal compression, blank equals dilitation. ---Only major faults outlined.

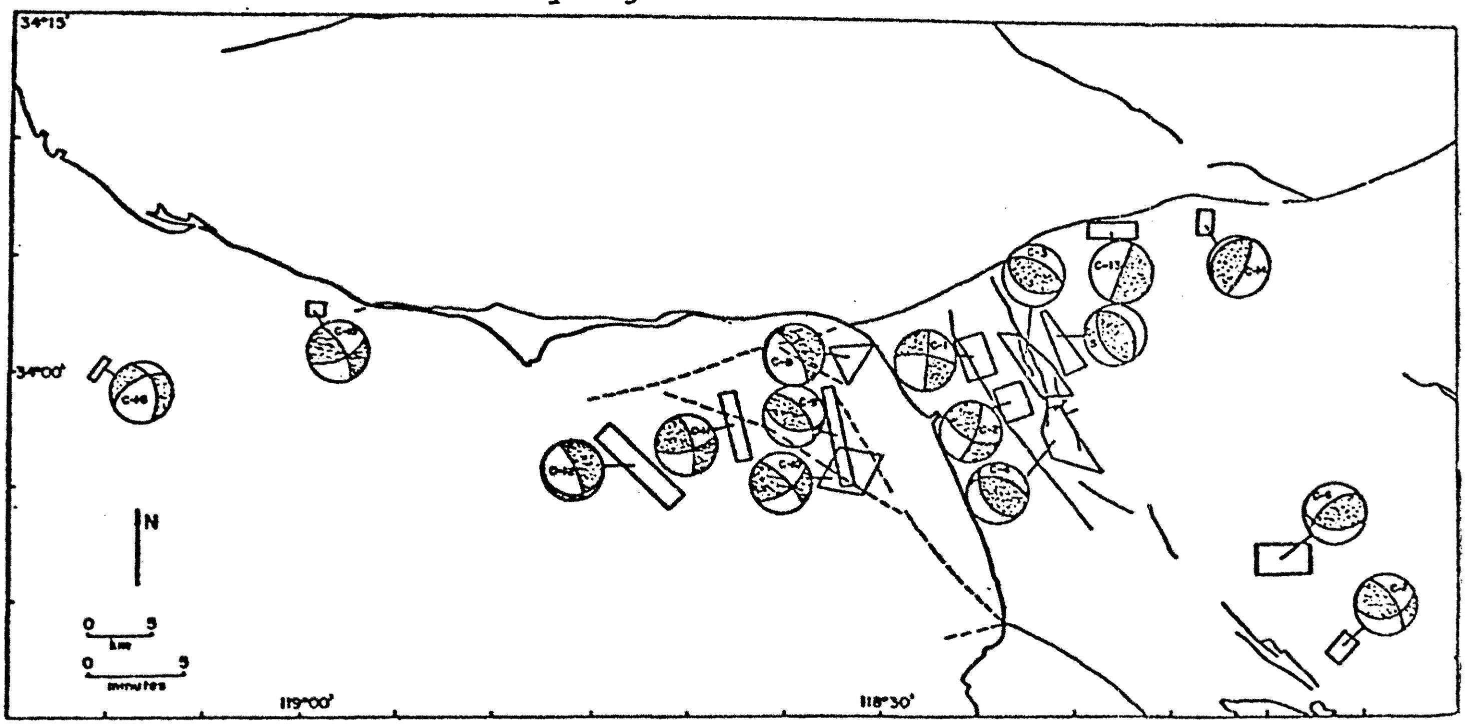


Figure 2. Composite fault-plane solutions, 1973-1976.

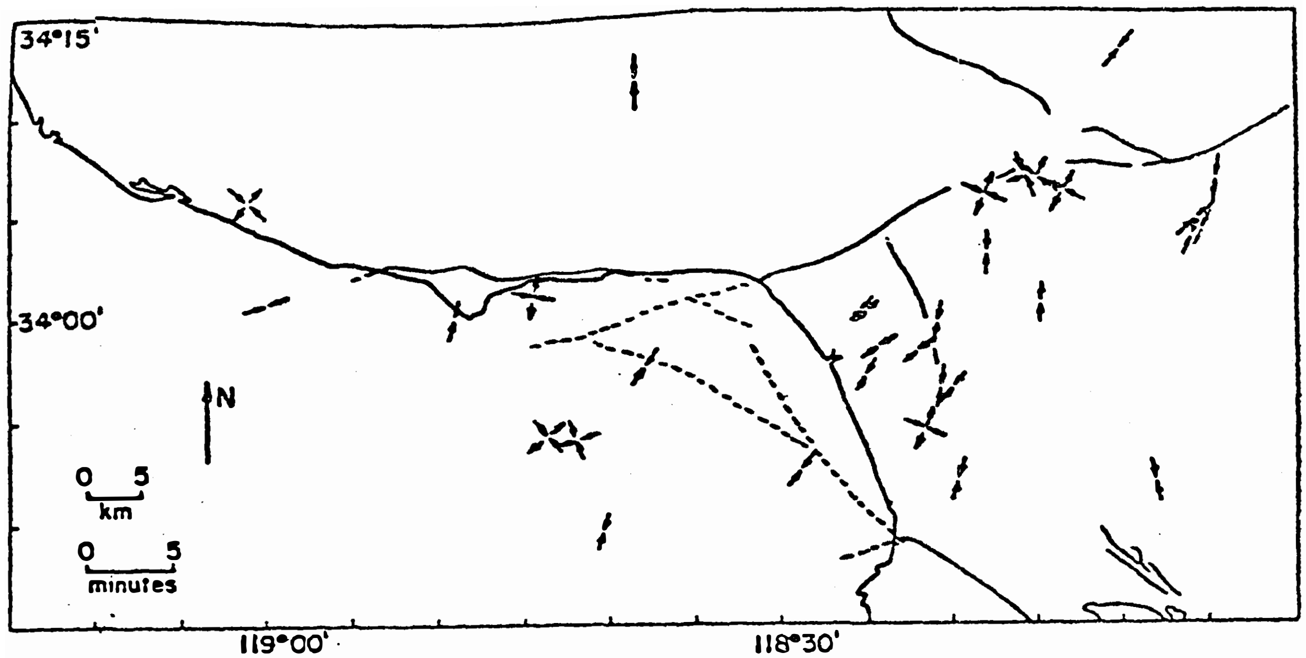


Figure 3. Directions of compressional stress derived from individual fault-plane solutions. Only the projected horizontal component is shown (arrows not to scale).

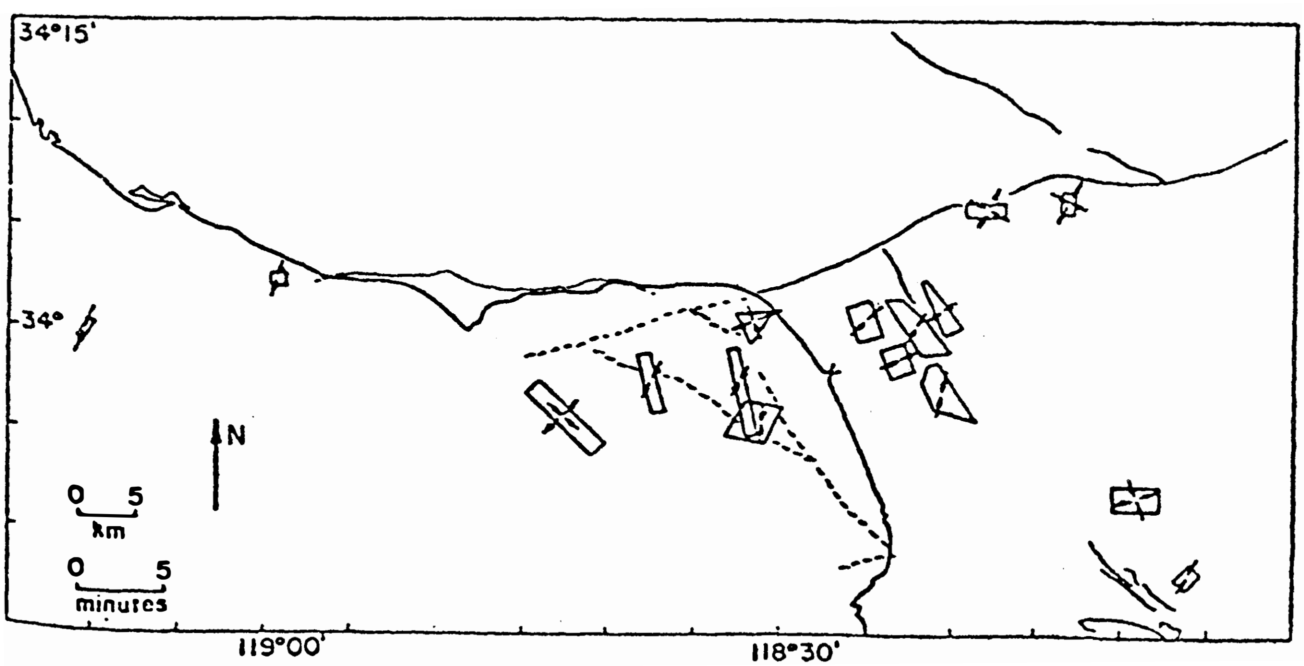


Figure 4 Directions of compressional stress derived from composite fault-plane solutions.

SEMI-ANNUAL TECHNICAL REPORT SUMMARY

1 October 1977 - 31 March 1978

U. S. Geological Survey
Contract No. 14-08-0001-16718

Clarence R. Allen
Seismological Laboratory
California Institute of Technology
Pasadena, California 91125

Neil R. Goulty
School of Physics
The University
Newcastle upon Tyne, England

In the Imperial Valley, Caltech has installations of four biaxial tiltmeters, six creepmeters and several alignment arrays. No further creep has been observed on the Imperial fault since April 1977, but one creep event with 1.5mm of right lateral slip occurred at the southern end of the Brawley fault on 30 October 1977. No anomalous signals have yet been recorded on the tiltmeters.

In Cholame Valley, until the recent flooding following heavy rains, Caltech has had six biaxial tiltmeters, four strainmenters, three creepmeters and three alignment arrays. Three of the tiltmeters and all four strainmeters have had to be removed because of an unexpected change in farming plans on the Jack Ranch, but the strainmeters are shortly to be reinstalled in a new array to the southwest.

A total of eighteen months of data was obtained from the strainmeters, and much of the noise correlates well with the temperature record. On 9 November 1977 a fourth set of signals was obtained by the strainmeter array due to the repeating dislocation previously observed on the San Andreas fault. A week later creep began on the Carr Ranch creepmeter, totalling 3mm, which follows the previous pattern.

The first few months of data from the tiltmeters appear to be substantially noisier than the strainmeter data.

TILT MEASUREMENTS IN THE NEW HEBRIDES ISLAND ARC: SEARCH FOR ASEISMIC DEFORMATION RELATED TO EARTHQUAKE GENERATION IN A MAJOR ZONE OF LITHOSPHERE SUBDUCTION

Report prepared by Bryan L. Isacks, Principal Investigator
Department of Geological Sciences
Cornell University
Ithaca, New York 14853

TECHNICAL REPORT SUMMARY

During the period covered by this report no large earthquake (M_s >5.5) occurred close to the tiltmeter network. The moderate activity characteristic of the past twenty months of tiltmeter operation has continued, but has produced no clearly detectable precursory signal. The largest and closest events so far recorded include five events with magnitudes (m_b) between 5.0 and 5.4, recorded at straight-line distances between 37 and 60 km from the nearest tiltmeter station. Four of these were shown in Report #2, and the fifth is reported here. Further examination has also been made of the large September 4, 1977 event (M_s = 6.5) located 155 km from the nearest tiltmeter station. No clear precursory signals are seen for these events at a resolution of about 10^{-7} for periods up to several hours, as determined on the original Rustrak records. Digitization and replotting of the data at compressed time scales indicates increase noise at longer periods, and the resolution worsens to about several microradians. Rainfall is clearly the dominant source of transient noise in the range of periods between several hours and several weeks. The continuous recording of rainfall accumulation that has been successfully initiated at several stations will significantly increase the signal detection capability.

This report covers a six-month period after the field season of August-September, 1977. The new tiltmeter station (Tukutuk) on Vate island worked reasonably well, as did five of the remaining seven stations. Two of the initially rainfall sensitive stations have shown increasing problems with rainfall in spite of attempts to improve the stability of the site. It appears that the local ground conditions are simply not adequate for tiltmeter stability, and these stations will have to be moved during the forthcoming field season.

Experiments were performed at the Devil's Point tiltmeter station to determine the cause of the long term drift characteristic of one of the components of that station. As described in Report #1, the leveling results did not verify the drift indicated by the tiltmeter. Experiments included a substitution bridge to replace the tiltmeter bubble-level and a prototype electronics of the improved design loaned to us by Kinemetrics. The experiments show that the drift is not tied to the electronics, nor is it improved by the newer electronics, but appears to be either in the bubble level itself or in the immediate siting of the instrument. If the latter case is right, then it must be considered a somewhat remarkable coincidence that the direction of drift is so closely aligned to one of the tiltmeter components.

The new tiltmeter recording systems, including an additional slow-speed Rustrak which records both tilt and rainfall, has proven to be very effective. Improved versions of the system have been constructed and tested and will soon be installed at all stations. Development of the microprocessor controlled digital recorder has continued and production of these units will begin after the further testing of the second prototype. In addition to the advantages of digital recording, the microprocessor unit will be a key component in linking the tiltmeter data to a central base station via the new VHF telemetry system that will be installed for the seismograph network.

A study of the tidal signals recorded by the tiltmeters has been completed and the manuscript is being prepared for publication. The study shows that the large tidal signals are caused by loading of the ocean tides in an area close to the tiltmeter. This effect can be explained by a two layer model with a low-rigidity near-surface layer. The anomalously large amplitudes at one station appear to be an effect of the large amount of porosity of the coral rock at the site, an effect which either reduces the rigidity of the rock or allows the load to be applied closer to the tiltmeter than the nearby coastline.

A Lamont-type sea level recorder was installed at Southwest Bay in September 1977. Three months of record are available for this instrument. It is operating in a sand beach and utilizes the sand as a tidal filter. Unfortunately the filter is too effective, and the tides are just barely perceptible at a full-scale sensitivity of 10 cm in water level. This implies an excessively long time constant, and the instrument will be moved to a location closer to the water in an attempt to decrease the time constant. Comparison of the sea level record with the nearby tiltmeter shows a correlatable small amplitude oscillatory signal with a period of one to three weeks. The relative polarities of these signals are in agreement with an ocean loading effect.

Levelings of the two arrays of benchmarks were done during the period of the report. The Devil's Point array remains stable at the microradian level. The Ratard results are still being reduced. Three additional benchmarks were installed at Devil's Point to strengthen that array, and were included in the most recent levelings.

Work of potentially great significance to the tiltmeter program is being done in cooperation with A. Bloom and F. Taylor in their studies of uplifted coral terraces in the New Hebrides. Preliminary results of this work was presented at the Miami meeting of the AGU (April, 1978). The pattern of uplift associated with the sequence of large earthquakes in 1965 was examined and found to be consistent the longer term pattern of Holocene and Late Pleistocene uplift. Evidence is found both in the earthquake related movements and the longer term motions for possible block-like units defined by discontinuities in tilt alone as well as by presumed discontinuities in vertical motions.

Tilt, Strain and Magnetic Field Measurements

8-9960-01189

Malcolm Johnston
U. S. Geological Survey
345 Middlefield Road
Menlo Park, CA 94025
(415) 323-8111 ext. 2132

Goals

a. Understanding active fault behavior and attempting to predict earthquakes by detection of regional stress, strain, and tilt changes as they occur before and during earthquakes.

b. Development and testing of physical models of fault behavior, particularly those that allow calculations of tilt, strain displacement and magnetic field changes expected prior to both seismic and aseismic failure of active faults.

c. The most important goal is reliable earthquake prediction.

Investigations

a. Integration of data from arrays of tilt, strain, magnetic field, creep, seismic and other measurements.

b. Development of techniques to identify the near surface noise spectrum and wave number spectrum for tilt and strain measurements with a number of 50 to 200 m deep boreholes containing tilt and strain instruments. A prototype of these instruments has been built. These data will be used in conjunction with data from existing clusters of instruments.

c. Maintenance and expansion of the digital data system used to collect, display and analyze these data. Installation of an interrogatible, special purpose μ processor based digital telemetry system at several sites for field testings. The prototype system is presently working over commercial-grade telephone lines.

d. Continue an attempt at regional monitoring of crustal stress-variations using a repeated magnetic survey techniques.

e. Develop tectonomagnetic models of particular sections of active faults where magnetic field changes have been observed.

f. Develop tectonic models of further types of crustal behavior along active faults.

g. Continue large scale continuous crustal tilt measurements using a system differential level measurement on existing dams and aquaducts.

h. Continue searching and testing specifically defined earthquake precursor functions. With the present analysis system it is expected that at least 50% of earthquakes, $M_L > 3.5$, that occur near instruments will be identified before they occur. However, unless more moderate magnitude earthquakes occur within instrument arrays these studies will be restricted to the minor earthquakes where the signals are small and ambiguous.

Results

a. Comparison between local variations in magnetic field, long term changes in creep rate, and local earthquakes along the San Andreas fault indicate that. 1) earthquakes with magnitudes less than 4.0 do not appear to correspond in time to local changes in magnetic field greater than 0.75 gamma or to variations in the creep rate. 2) there are indications of correspondence, in both space and time, between the long-term changes in creep rate and variations in magnetic field.

b. Changes in stress related to the surface expression of fault creep on the San Andreas fault can be estimated from dislocation models fit to observations of simultaneous strains and tilts at points near the fault. These stress values are generally less than one bar. For these stress levels and with the apparent limited extent of surface failure, tectonomagnetic models of creep events indicate that simultaneous observations of related magnetic field variations at detectable levels of a gamma or so are unlikely. Slip at greater depth may occur more smoothly and would load the near-surface material to failure. Simultaneous creep and magnetic field records have been obtained for more than 60 creep events that have occurred since early 1974. In contrast to the conclusions of Breiner and Kovach (1968) no clear magnetic transients or offsets are observed simultaneous with or preceding the occurrence times of these creep events by up to a day or so.

c. Data from an array of proton magnetometers in central California indicate that a systematic decrease in magnetic field of about 2-gammas in 5 years has occurred in a localized region near Anzar, California, just north of the creeping section of the San Andreas fault. This field change has most likely resulted from changes in crustal stress in this region. Tectonomagnetic models have been developed using dislocation modeling of slip on a finite section of fault. Assuming a fault geometry and rock magnetization, these models relate changes in stress, fault slip, and fault geometry to surface magnetic field anomalies. A large-scale anomaly, opposite in sense to that observed but of similar amplitude, would be expected to have accumulated in this area during the past 70 years. A localized 5-bar decrease in shear strain on the fault resulting from about 2 cm of slip on a 0.25 km square patch at a depth of 1-km beneath the surface trace of the fault opposite the magnetometer could explain the observed data and still be compatible with the geodetic strain measurements in the area. Other models of limited local slip are equally possible. The occurrence of a moderate magnitude earthquake in this region will allow comparison of stress changes estimated by different techniques.

d. Tilt changes associated with 1 to 5 mm of fault creep have been detected at several different locations on the San Andreas fault on tiltmeters within five hundred meters of the creep observation point. The creep related tilts have amplitudes of $\lesssim 0.5$ μrad and durations comparable to the creep events. No changes $\gtrsim 10^{-2}$ μrad have been observed on tiltmeters at distance $\gtrsim 1$ km from the fault at the time of the creep events. Dislocation models capable of replicating the creep-related tilt events have been constructed to examine the relationship of the model parameters to details of the tilt waveforms. The tilt time histories, source-station configuration, and the displacement time history can be used to infer the type and amount of the displacement, the propagation direction and depth of the slip zone. The shallow depth and finite size of the slip zone indicated by these models contrasts with the horizontal extent over which many creep observations occur. Slip of longer duration and larger extent at depths below a few kilometers that loads the surface material to failure could explain these observations.

e. Continuous strain measurements from 3 three-component invar wire strainmeters installed 1200, 1500, and 1700 m from the San Andreas fault indicate no observable strain change at the instrument resolution ($<10^{-8}$) during 10 episodic creep events on the fault. These strain observations indicate that the slip area responsible for the creep observations is near surface and of quite limited extent. Deeper slip on the San Andreas fault apparently is smoother than would be inferred from the duration of episodic creep observations. Unfortunately, signal discrimination capability gets worse at longer periods and needs improvements if slow deformation waves are to be detected at strain levels below 10^{-7}.

f. Local earthquakes with magnitudes of $\lesssim 2.5$ and within 20-50 km of tiltmeters along the San Andreas fault typically generate offsets in tilt, tilt seismograms, and impulsive tilt behavior at the time of the earthquake. Data from an array of instruments are compared to that predicted by dislocation models. Almost all observed coseismic offset amplitudes are 1-3 orders of magnitude larger than the predicted amplitudes. Similar results occur for teleseismic earthquakes. A lack of agreement in the observed offset amplitudes across the array indicates that tilt changes are triggered at or near the instrument site by the passage of seismic waves. No significant agreement was obtained between the direction of coseismic tilts and either the secular tilt trends or local geologic features. Triggered movement on near-surface cracks, fractures, and minor faults appears the most viable physical explanation for the observed offsets. Short-base-line near-surface tiltmeters, appear inadequate for measuring tilt displacement fields generated by local earthquakes. Deep borehole installations appear necessary for this measurement. Coseismic tilt transients appear to be caused by seismically induced water table perturbations near the tiltmeter site.

g. Three years of continuous records of surface tilt preceding a moderate earthquake ($M_L = 4.3$) on January 8, 1977, have been obtained at a point 5.5 km from the earthquake epicenter. A possible short-term percursive tilt to the southwest started December 18, 1976 and reached a maximum amplitude of 2 radians relative to the tilt trend at this time. Other changes of this amplitude are evident, however, in the 3-year record. The sense of tilt changed abruptly following the earthquake, gradually returning to the general tilt trend. A substantial postseismic tilt of 10 μradians is consistent with aseismic slip of the Hayward fault, or on any of several other faults local to the tiltmeter in this region. The data are insufficient to discriminate between these possibilities, and accompaning surface displacements are apparently too small to be detected in the geodetic records. Short-term accelerated tilting just preceding the seismic events, as proposed by Wood and Allen (1971) are not apparent in these data. An observed coseismic tilt step of 0.14μ radians does not agree with that expected from current fault-failure models.

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Tilt Operations

8-9960-01801

Carl E. Mortensen
U.S. Geological Survey
345 Middlefield Road
Menlo Park, CA 94025

Goals

The Tilt Operations project will operate extensive networks of telemetered tiltmeter sites in central and southern California, and a few sites in Alaska, along seismically active and creeping faults in order to study the mechanics of seismic and aseismic fault slip and other processes which may relate to earthquake prediction. Goals for the second half of FY 78 include continued upgrading of system performance and upgrading the quality of existing data to ensure future data quality. The development and deployment of a long-baseline tiltmeter system at several locations is planned. This experiment relates to another important goal - the characterizing of surface tilt signals and noise with respect to wavelength, period, and depth dependence.

Important non-scientific goals of the project include providing logistic and technical support to ther projects, particularly the magnetometer, strainmeter and creepmeter programs. Technical support will also be provided to contract maintenance personnel throughout the life of the maintenance contract.

Investigations

The tilt operations project continued the search for tilt precursors to earthquakes in California and Alaska, specifically by operating and monitoring the tiltmeter arrays in central and southern California, totalling 80 sites, and an array in Alaska consisting of three sites. The investigation into surface tilt signal and noise characteristics by comparison of parallel records from three sites with redundant tiltmeters in central California was expanded with the installation of redundant tiltmeters at three additional sites. One new meter was installed at both the Sargent and Dry Lake sites, and two new instruments were installed at the Nutting Ranch site.

Quality control was provided on tilt data received by monitoring telemetered data and occasional comparison with level array data. Upgrading of existing data was conducted through calibrations and interactive cleaning in order to provided an important data base for future analysis. The cleaning proved to be an extremely tedious and unrewarding task due to the overtaxed and unreliable computing facilities at LBL. A program for the calibration of instruments in southern California was begun.

Highly sensitive pressure transducers were installed at oppositve ends of San Andreas Lake, a reservoir near Millbrae, California, which is directly on the San Andreas fault. The tranducers record in differential mode, and interface with the standard U.S.G.S. low-frequency digital telemetry network. Pressure differences are computed by an 8-bit onsite microprocessor, recoded from BCD to binary format and fed directly to the Larse modem of a digital transmitter with the multiplexing circuitry deactivated. A D-to-A converter and Rustrak recorder provide an onsite record. The system provides a continuous monitor of ground tilt with respect to the lake surface.

A prototype long-baseline borehole tiltmeter has been designed and constructed. A Rockwell bubble-level tiltmeter and a Hughes TM-3 tiltmeter were installed in two 20-foot-deep boreholes in close proximity to one another.

Bias steppers were installed at many southern California tiltmeter sites. A program of evaluating and upgrading or eliminating sites in southern California was begun. Assistance was provided to contract maintenance personnel in central and southern California to evaluate and repair flooding damage to tiltmeter sites and equipment caused by torrential winter rains.

Results

Preliminary examination of data from a Rockwell bubble-level tiltmeter and a Hughes TM-3 tiltmeter installed in separate 20-foot-deep boreholes in close proximaity to one another indicates good agreement prior to the rainy season and possibly improved thermal response. Unfortunately this site, which is near Lake Hughes, California, flooded and the equipment was damaged beyond repair during recent torrential rains in southern California.

A comparative study, previously reported, of data from three central California tiltmeter sites with redundant instruments was continued and expanded. Low-pass and high-pass Butterworth digital filters, of the recursive type, originally programmed by Kieth McCamy of Lamont and made available by Joe Fletcher, were modified and adapted to accommodate typical low-frequency digital geophysical data and to operate within Jim Herriott's Geolab program. This program and a simple cross-correlation program, which was also adapted to run within Geolab, provide the tools to complete this study and should prove to be generally useful in the future.

A system for emplacing short-baseline, shallow borehole tiltmeters utilizing an expansive grout has been tested at one location in central California. Results indicate that long term stability achieved with this technique is not as good as with the standard technique of packing the instrument in fine silica sand.

An inexpensive (about $50) raingauge has been developed and is operating at a tiltmeter site in central California. Six additional raingauges are being assembled and will be deployed throughout the tiltmeter network in order to provide a more relevant and timely monitor of rainfall than the NOAA monthly summary.

The Stanwick Corporation was awarded the contract for the maintenance of instrument networks in southern California. Training of these personnel was patterned after the successful training conducted last year for the maintenance personnel in central California.

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Crustal Strain

8-9960-01187

James C. Savage
U.S. Geological Survey
345 Middlefield Road
Menlo Park, CA 94025
(415) 323-8111 ext. 2633

Goals

Crustal strain project is designed to measure both the spatial and temporal dependence of strain accumulation along the San Andreas fault and other major faults in California and Nevada. Measurements of surface deformation provide strong constraints upon possible fault models although those measurements by themselves are not capable of defining the model. The principal measurement will be distance determinations between geodetic monuments 10 to 30 km apart with a precision of better than 0.5 ppm. Repeated measurements of this type define the strain accumulation field. The principal importance of the project in the earthquake prediction program is that it provides a stable measurement of strain changes and could detect precursive strain anomalies if they exist.

Investigations

Analysis of strain accumulation in central and southern California was the principal subject of investigation, although some analysis of networks in New Mexico, Utah, Montana, Washington, and Nevada was undertaken. A detailed search of Geodolite measurements was made to detect possible earthquake precursors with negative results.

Results

1. Prescott, Savage and Kinoshita (1978) have summarized strain rates measured in western United States by Geodolite surveys in the period 1970-77. No significant strain accumulation was detected across Puget Sound near Seattle, near Hanford in eastern Washington, or across the Rio Grande rift near Socorro, New Mexico. North-northeast extension at a rate of about 0.20 ± 0.06 μstrain/a was observed near Hebgen Lake, Montana, and east-northeast compression at a similar rate was observed across the Wasatch fault near Ogden, Utah. The strain at Hebgen Lake is quite consistent with the known pattern of normal slip on east-west striking faults, but the compression perpendicular to the Wasatch fault is unexpected. The average tensor shear strain accumulation along the San Andreas fault is only 0.12 μstrain/a. In southern California the measured strain is predominantly a north-south compression at the rate of about 0.3 μstrain/a.

2. Savage and Prescott (1978) have noted that the measured distortion between 1924 and 1957 of a geodetic quadrilateral near the epicenter of the 1927 Lompoc, California, earthquake provides some constraints upon the source mechanism of that earthquake. The distortion is not consistent with right-lateral slip on the Hosgri fault, but rather suggests thrust faulting on a more northerly striking fault. However, the measured distortion is only marginally significant and could possibly be produced by an unidentified systematic bias.

3. Lisowski and Savage (1978) analyzed a retriangulated network near Juniper Hills, California, site of anomalous seismic activity in 1976-78. The strain changes in that area for the 1966-78 interval were comparable to the changes observed at a nearby network at Palmdale where anomalous seismic activity did not occur. Thus within the precision of measurement, no anomalous strain accumulation was detected near Juniper Hills.

4. Savage and Prescott (1978) extended the earlier work of Nur and Mavko on strike-slip faulting on a vertical fault in an elastic layer (the lithosphere) overlying a viscoelastic substrate (the asthenosphere) to include a sequence of earthquakes. The following conclusions were drawn: 1) The surface deformation produced by visoelastic relaxation in the asthenosphere due to faulting in the lithosphere can be reproduced identically by a reasonable distribution of slip at depth on the fault so that the two modes of postearthquake readjustment would be difficult to separate. 2) In a periodic sequence of earthquakes the principal observable effects of viscoelasticity in the asthenosphere are to produce a rapid postearthquake deformation and to concentrate strain accumulation and relaxation even closer to the fault than in an elastic half space model.

5. Savage and Walsh (1978) have calculated the work done against gravity in faulting. As might be expected strike-slip faulting involves negligible change in the gravitational energy, but the change in the gravitational energy in dip-slip faulting will typically be three orders of magnitude greater than the earthquake energy as estimated from the Gutenberg-Richter energy-magnitude relation. The gravitational energy increases for reverse slip and decreases for normal slip. The actual energy released by the earthquake (e.g., energy radiated, work done against friction, new surface energy) is similar to the Gutenberg-Richter energy estimate. The very large change in gravitational energy is closely balanced by a change in the initial elastic energy so that the energy released is simply the difference between these two large quantities.

6. Lisowski spent two months in Guatemala advising a Guatemalan survey crew on survey procedures in resurveying a triangulation arc perpendicular to the Motagua fault. Comparison of this new survey with a preearthquake survey should determine a strain release profile across the 1976 rupture (magnitude 7.3).

7. Savage spent two months as a visiting scientist at the University of British Columbia, Vancouver, Canada. One of the projects undertaken while there was planning a resurvey of a triangulation network near the epicenter of the 1946 Vancouver Island earthquake (magnitude 7.3). Recent work by Rogers and Hasegawa suggests that shallow rupture on the Beaufort Range fault may have been the source of that earthquake. This suggestion of shallow focal depth is in contrast to the 60-km depths assigned the nearby Puget Sound earthquakes of 1949 (magnitude 7.) and 1965 (magnitude 6.5). The resurvey of the triangulation network provides a critical test of the Rogers-Hasegawa hypothesis. A first estimate of strain accumulatin on Vancouver Island (shear components $\dot{\gamma}_1 = 0.06$ μradians/a and $\dot{\gamma}_2 = 0.01$ μradians/a both with standard deviation 0.03 radians/a) was determined from some retriangulation already completed in Johnstone Strait. Although this strain determination is only marginally significant, it is consistent with what would be expected for northwestward motion of the Pacific plate relative to the North American plate.

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APPLIED PHYSICS LABORATORY OF THE UNIVERSITY OF WASHINGTON
L.E. Slater, Principal Investigator
1 October 1977 - 31 March 1978

MWDM STRAIN MEASUREMENTS IN CENTRAL CALIFORNIA

SUMMARY

The resolution of small changes in baseline length is of particular importance in the study of deformation. Structural deformation may precede the failure of large man-made structures such as dams. Since strain energy must accumulate before it can be released, it is reasonable to assume that the earth's surface must deform before a major shallow earthquake can occur.

This report deals with two important aspects of the measurement of deformation. First, the techniques used with electromagnetic distance-measuring (EDM) instruments are discussed. The analysis of uncorrected single-wavelength EDM data and the results obtained using the ratio technique to correct these data are discussed in detail. This analysis is based on direct comparison of the results obtained with the ratio technique and data obtained on the same baselines using the high-precision multiwavelength EDM (MWDM) instrument. Second, the very important, and often ignored, question of benchmark stability is addressed. The response of benchmarks and/or local surface materials to locally heavy rainfall is specifically discussed.

The high-precision MWDM instrument was installed near the mid-point of the Hollister creepmeter array in September 1975. The MWDM instrument has exhibited a capability to make measurements over baselines several kilometers long to a precision of 1 part in 10^7. The Hollister MWDM array consists of nine primary baselines arranged in a radial pattern from the central instrument site. The baselines range in length from 3 to 9 km, and are measured daily whenever visibility permits. These baselines terminate at permanently installed, passive retro-reflectors located 100 m to 7 km from the Calaveras Fault.

The MWDM instrument has allowed a direct evaluation of the single-wavelength ratio technique. The results indicate that this technique may improve the resolution of small changes in baseline length within properly designed arrays. While it appears that it would be difficult to routinely achieve a precision of better than 1 ppm within a radial array of substantial size (>10 km diam), the technique does offer promise for studies where all baselines can be restricted to a reasonably small solid angle.

The stability of benchmarks and, in particular, the response of the near-surface material in the immediate vicinity of the benchmark to locally heavy rainfall, appear to be a significant problem in obtaining high-precision geodetic measurements. There is a great need for further study of this problem. It may be desirable to redesign benchmarks and modify installation procedures depending on whether vertical or horizontal deformation data are desired.

TILTMETER ARRAY IN NEW MADRID

Contract 14-08-0001-15848

Saint Louis University

William Stauder and Sean-Thomas Morrissey

Summary of Semi-Annual Technical Report

The objective of the New Madrid tiltmeter array is to monitor crustal tilt in an area of active seismicity with a view toward identifying precursor patterns on the crustal behavior that may lend themselves to a capability for predicting earthquake occurrence. Concurrent with the operation of the New Madrid tiltmeter array, we are engaged in a joint program with CIRES of Colorado University for the technical support of a tiltmeter array at Adak in the Aleutian Islands. The advantages of this arrangement stem from the similarities of environmental problems encountered, and the consequent adaptation and modification of the instrument system to function satisfactorily in such conditions.

In working toward the ultimate objective stated above, a series of more immediate objectives have arisen out of experience with the tiltmeters when installed in hostile environments involving extremes of meteorological conditions and water saturation on flooding of tiltmeter sites. Consequently, the major effort has been directed to achieving the required operating sensitivity and stability of the instrument under field conditions. The aim here is to demonstrate that with proper modification of the electronic systems and with proper instrument-emplacement procedures, the Kinemetrics TM-I Tiltmeter can operate with a sensitivity sufficient to detect a precursory tilt rate of 5 μ radian per year. Our procedure for field testing the capability of tiltmeters has been to install the

tiltmeters of the two ten-instrument arrays (one array in New Madrid, one on Adak) in pairs. We are endeavoring to show that instruments placed 10 meters apart have a capability of tracking one another within 10^{-8} radian/month and 10^{-7} radian/year. The program has proceeded through six tasks.

Task 1. Instrument qualification and preparation program. Previous reports have dealt in detail with this activity. Each TM-1 tiltmeter has been adapted and tested for operation over extremes of -30°C to +40°C with instrumental error reduced to $\pm$ 0.2 μ radians over this range.

Task 2. Interfacing with the environment. Installation procedures involve drilling a vertical hole, lowering the tiltmeter into the hole, and packing it into the earth with a special sand that is added slowly and is tamped into place. In the process of installation the TM electronics system is used as an indicator that vertical alignment is maintained. Experience in this process shows that an unstable region is encountered about two-thirds of the way up the pipe. Beyond this point response to tamping reverses itself from the expected tilt, and the tilt sensitivity to tamping increases. After installation this same ambiguity of response to horizontal shear pressures at the top of the pipe (surface effects) persists. We are presently testing a preliminary finding that burial and tamping to only the two-thirds mark increases the reliability of the instrument by an order of magnitude.

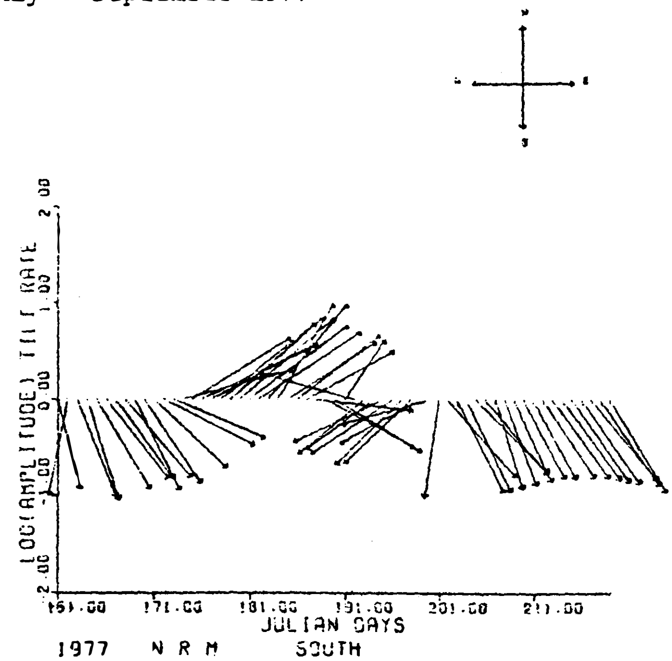
Task 3. Effects of other physical processes (meteorological and hydrological) on the instrument and its environment. Each instrument pair is being monitored by a meteorological package which records wind-speed and direction, barometric pressure, temperature, and water level on one strip chart.

Task 4. The digital acquisition system. When fully deployed a ten-element array as described above will generate over 34 megabytes per year of data (at a 10 minute sampling interval). To provide remote recording of the array we have developed with the Henize Interactive Control Corporation of Dayton, Ohio, digital field recording units, telemetry links to a central receiving site, and a discriminator-microprocessor for I/O programming and monitoring, mass storage on 9-track tape or disk, and analogue output. The system is presently on order.

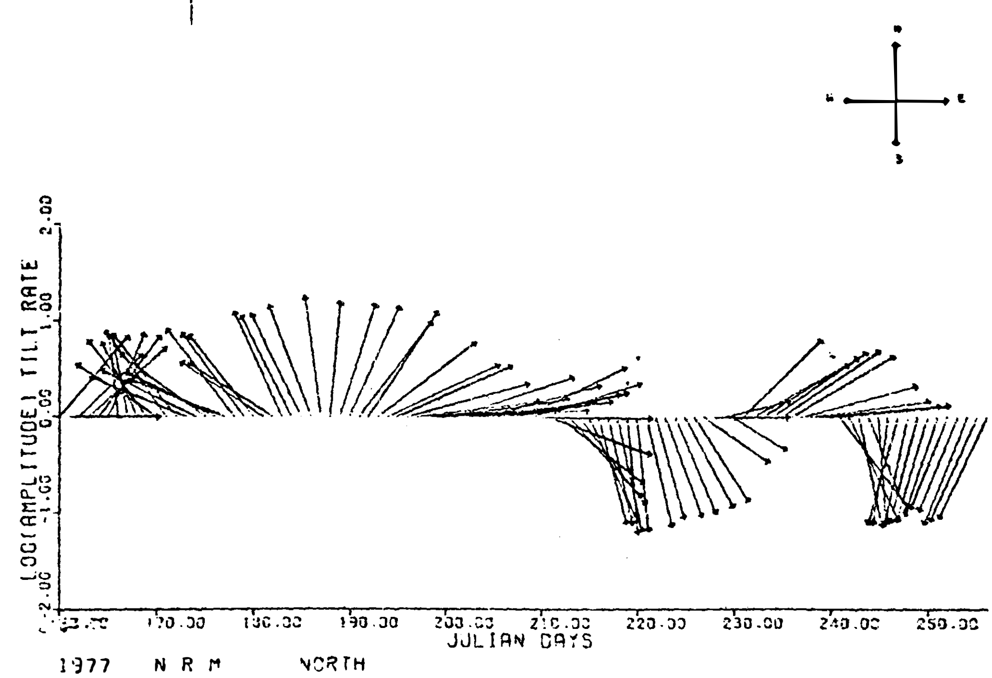
Task 5. Data reduction. Our initial effort here is to demonstrate the reliability of tilt data by the comparison of co-sited pairs of instruments. In addition to conventional procedures of two-component (NS and EW) analogue recording of tilt versus time, or tip-to-tail presentation of tilt vectors over increments of time, we have developed a new method of presentation of the data. In as much as the tilt rate, or change in tilt rate, may be the more meaningful precursory quantity to monitor, we have devised a procedure for plotting the 10 day mean in tilt rate (change in both amplitude and direction) as determined for each day. The result is then plotted versus time as a sequence of vectors initiating from points along the time axis. This mode of presentation allows easy comparison between instruments, and ready detection of what might be a seismic related tilt. See accompanying figure.

Task 6. Data interpretation. To date no more than coarse analysis of Adak or New Madrid data has been accomplished.

New Madrid Tiltmeter Data
May - September 1977



Log tilt rate, NRM South unit



Log tilt rate, NRM North unit

Plot of daily rate of tilt averaged for 10-day running mean versus time.

TECHNICAL REPORT, SEMI-ANNUAL

DRY TILT AND NEARFIELD GEODETIC INVESTIGATIONS OF CRUSTAL MOVEMENTS, SOUTHERN CALIFORNIA

Arthur G. Sylvester
Department of Geological Sciences
University of California
Santa Barbara, California 93106

Effective Date of Grant: 1 October 1977
Grant Expiration Date: 30 September 1978
Date of this Report: 28 March 1978

REPORT SUMMARY

In spite of unusually intense winter storms that virtually precluded fieldwork in January, February and March, we managed to establish 8 new dry tilt sites at some key locations within the initially recognized area of the Palmdale bulge. This means that we now have over a total of 36 dry tilt arrays to give us minimally sufficient coverage over the Palmdale bulge to document the nature of regional tilt, if any.

A synoptic diagram of tilt vectors for 23 of 27 of the dry tilt arrays from late spring through November, 1977, showed apparent consistency of tilt directions within each of three major structural blocks. Thus, vectors northeast of the San Andreas fault point generally north and northwest; those within the San Gabriel Mountains block radiate outward from a point about 25 km WSW of Palmdale; and those south of the southern frontal faults of the San Gabriel Mountains show no apparent consistency of tilt direction. We need at least another year of observations to establish whether or not the observed tilts can be attributed to regional tectonics.

Six of the new dry tilt arrays surround and are superposed upon the epicentral area of an unusual swarm of small earthquakes ($M \leq 3$) observed in late 1976 and early 1977 by McNally and Kanamori (1977) in the Juniper

Hills area of the San Andreas fault zone. The two other new sites are adjacent to USGS borehole tiltmeter sites and are intended to provide comparison of the results and sensitivity of the two tilt-monitoring techniques.

Qualitative comparison of the two techniques was done in February in conversations with Malcolm Johnston and Carl Mortenson (USGS). The general conclusion was that each method is yielding tilt vectors that are similar in magnitude and direction, but there is still no compelling evidence to suspect that the observed tilts are of tectonic origin. Resurveys of dry tilt arrays over the next six months will be critical to compare with monthly data over the same time period in 1977.

We established a short level line across the Duravan Ranch fault, Mojave Desert, in 1974, and we did our fourth resurvey of the line on 10 November 1977, only six weeks after the third resurvey on 22 September, to see if an earthquake swarm on the nearby Garlock fault had any effect on the rate of vertical creep at Duravan. Our previous surveys have shown that vertical creep takes place regularly at a rate of 35 mm/yr. The fourth resurvey showed that no more offset had occurred from 22 September to 10 November than would be expected according to the previously observed rate, and it confirmed the constant rate of creep.

We have had some difficulties, some of which were anticipated. The foul winter weather not only prevented routine monthly resurveys of geodetic networks, but floods destroyed or damaged some benchmarks, and snow and landslides made five dry tilt sites inaccessible. One of the surveying helpers fell while carrying the Wild N3 precision level, causing us to lose three weeks of valuable fieldwork during otherwise good weather while the instrument was being repaired. Finally, manufacture has been discontinued of the electronic distance measuring device we intended to purchase to do horizontal surveys across faults. We expect to acquire the new, better model beofre the beginning of summer. In the meantime, we are constructing benchmark arrays for surveying when we acquire the new distance meter.

Paleogeodetics

8-9960-01488

Wayne Thatcher
U.S. Geological Survey
345 Middlefield Road
Menlo Park, CA 94025
(415) 322-8111 ext. 2120

The general goals of this project are to use geodetic measurements to determine the pattern of crustal deformation occurring along the San Andreas fault zone in California and in other tectonically active regions of the world, and to use these results to infer the mechanisms responsible for the observed deformation. Measurements used comprise largely historic triangulation and leveling observations, and where overlap exists, work is carried out co-operatively with R. O. Castle (Vertical Tectonics, 8-9950-01484) and J. C. Savage (Crustal Strain, 8-9960-01187).

An extensive set of geodetic observations from the 170 km long central creeping segment of the San Andreas fault has been used to constrain the broadscale deformation pattern, determine the distribution of aseismic slip along the fault, and provide estimates of the rate of relative plate motion across central California. Although small but significant departures appear to exist, rigid block displacements across the major faults provides a good first order approximation to the deformation, as concluded previously by Savage and Burford. Geodetic measurements of $\sim$60 km aperture that cross the fault zone provide a firm lower bound of 33 ± 1 mm/yr for the rate of right-lateral plate motion parallel to the San Andreas fault system since 1885. Measurements near the fault indicate rates of movement close to but still significantly less than this lower bound rate, varying from 25 ± 1 mm/yr near San Juan Bautista-Hollister to 29 ± 1 mm/yr farther southeast on the fault. There is no evidence for changes in the gross movement rate since 1885; in particular, no significant rate changes spanned the occurrence time of the great 1906 earthquake to the north, indicating that the creeping zone largely isolates the episodic movements occurring on the two adjacent locked sections of the fault. Further refinements in modeling the deformation are provided by making plausible assumptions on the fault geometry of the creep zone and the conditions appropriate for the locked portions of the fault, and using a simple dislocation model, all available data can be inverted simultaneously. Shallow slippage is close to the maximum values of observed surface creep but is smoother as a function of distance along the fault, and rates vary from about 20 to 30 mm/yr. The figure included here shows the shallow slip distribution (to 15 km depth) as a function of position along the fault and compares it with surface creep measurements (supplied by R. O. Burford of USGS). The deep slip rate, the relative plate motion rate for this model geometry, is uniquely determined in the inversion but its precise value is sensitive to the model assumptions. However, off-fault data do constrain its value to be no greater than about 45 mm/yr. Although the data do not require it, modest amounts of elastic strain accumulation on the creeping segment of the fault cannot be unambiguously precluded. The difference between the near-fault and longer range movement rates, or equivalently, the deficit between deep and shallow slip rates, is not definitively explained although it may be due to slip on minor faults or an effect of the locked ends on the fault. These differences suggest that small amounts of deformation occur off the major faults, and although this straining is too faint or inhomogeneous to be resolved with available data, its presence may be reflected in the diffuse regional off-fault seismicity.

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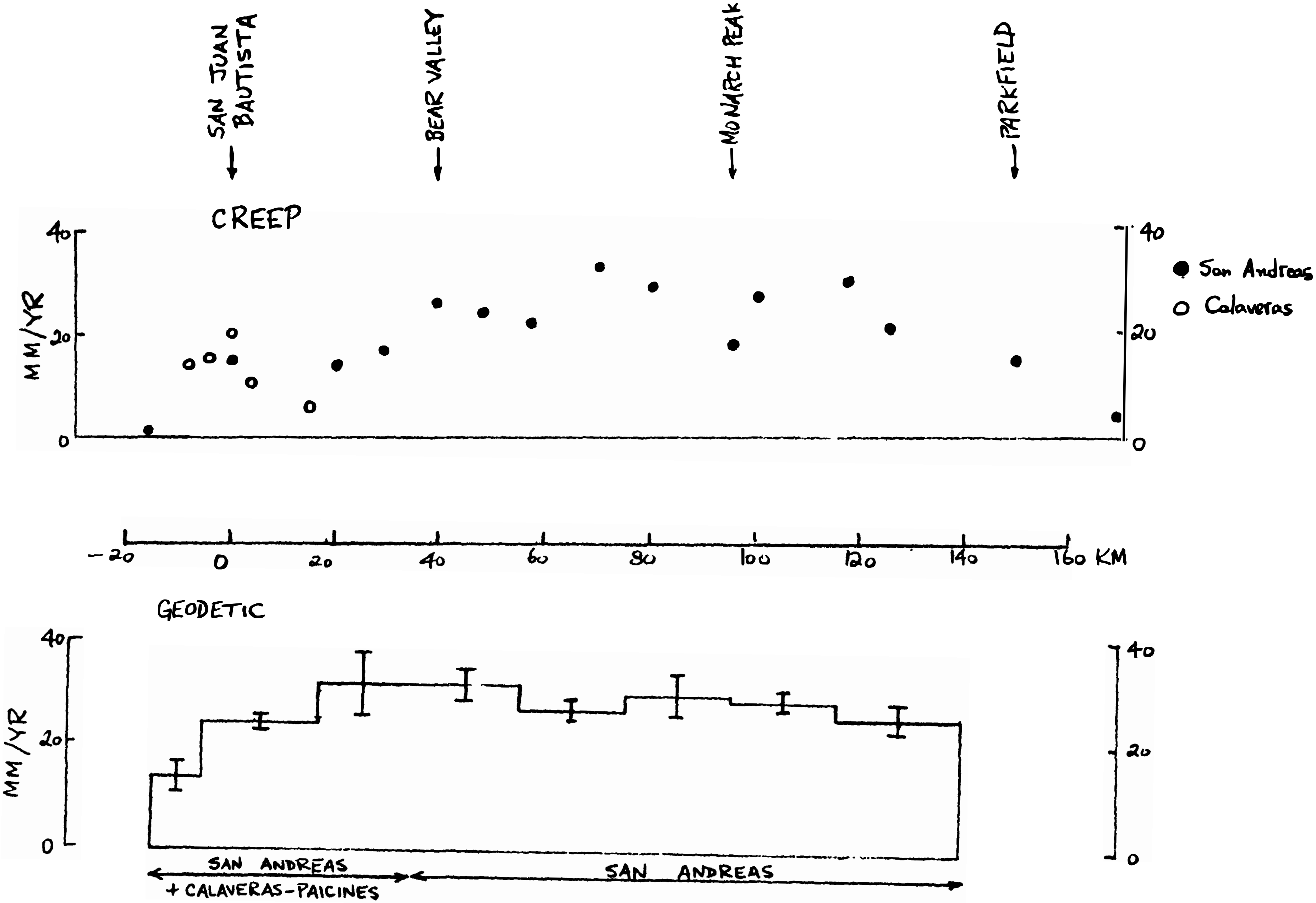
P.B.3.


SAN JUAN BAUTISTA
BEAR VALLEY
MONARCH PEAK
PARKFIELD
CREEP
MM/YR
40
20
0
San Andreas
Calaveras
-20
0
20
40
60
80
100
120
140
160 KM
GEODETIC
MM/YR
40
20
0
SAN ANDREAS
+ CALAVERAS-PAICINES
SAN ANDREAS

Summary of Semiannual Technical Report
April 1978

Periodic Precision Gravimetric Observations
in the Vicinity of the "Palmdale Uplift"
Contract No. 14-08-0001-16602

John D. Fett
Earth Science & Engineering, Inc.
27595 Santa Fe Street, Hemet, CA 92343

Eighteen months of monthly gravity observations have been completed over a network of 86 stations in the vicinity of the San Andreas Fault in Southern California. The network consists of seven lines of stations with the stations spaced about five kilometers apart. The most southeasterly line is in the Salton Sea area and the most northwesterly line extends from Ventura to Miracopa. Observations are made with two LaCoste and Romberg "Microgal" gravimeters, D3 and D19. Each station is observed twice each month with each gravimeter.

Only a few stations are located atop permeable alluvium. At those stations there was a noticable decrease in gravity as groundwater was overdrafted during the recent draught. No clear trends in gravity changes were observed at the other stations.

Several tests were made of gravimeter performance to isolate different sources of error in high precision gravity observation. In addition. a quantitative index of wind noise, ground noise and air temperature was incorporated in the data recording to aid in future statistical analysis of the data.

Summary of Semiannual Technical Report
April 1978

Evaluation of a Gravimetric Technique
as an Earthquake Precursor Technique
along the San Jacinto and San Andreas Fault Zones
Contract No. 14-08-0001-15871

John D. Fett
Earth Science & Engineering, Inc.
27595 Santa Fe Street, Hemet, CA 92343

The fifth semiannual observation of gravity has been completed over a network of 120 stations in southern California. The network consists of eight lines of gravity stations across the San Jacinto and/or San Andreas Faults. The most southeasterly line extends through the region of the 1968 Borrego Earthquake and the most northwesterly line passes through Palmdale. The network recently was expanded to cover a large portion of the Elsinore Fault Zone. Except for stations high in the San Jacinto and San Gabriel Mountains, each station is observed twice with each of two LaCoste and Romberg "Microgal" gravimeters, D3 and D19. Two Model G gravimeters have been used at those high altitude stations beyond the range of the Model D gravimeters.

For long-term repeated gravity observations, there is a distinct advantage in the use of Model D "microgal" gravimeters with adjustable ranges. Since the early observations were made with Model G gravimeters, they have drifted more than 15 milligals. There are no means available to reset the Model G gravimeters and observe on the same portion of the nulling screw. Errors in the calibration of the Model G gravimeters may introduce systematic errors in observations repeated at the same station over a long period of time.

There are no distinct trends in the gravity changes observed, with the exception of a few stations deliberately located atop groundwater basins. They have provided a good test of the system and gravity declines are noted where there was overdraft of the groundwater during the recent draught.

GRANT NUMBER:	USDI 14-08-0001-G-374
GRANTEE:	University of California, San Diego
PRINCIPAL INVESTIGATOR:	John M. Goodkind Professor of Physics
TITLE OF WORK:	Continuous Gravity Measurements in the Region of the Palmdale Uplift
EFFECTIVE DATE:	OCTOBER 1, 1977
EXPIRATION DATE:	SEPTEMBER 30, 1978
FUNDED AMOUNT:	$ 35,000
PERIOD COVERED BY REPORT:	1 OCTOBER 1977 - 31 MARCH 1978
DATE OF SUBMISSION:	24 APRIL 1978

John M Goodkind

JOHN M. GOODKIND

The previous six months work has been primarily involved with continuing problems encountered in the deployment of the superconducting gravimeters. However, we have also continued to analyze data from Piñon Flat for information about long term stability of the instruments there.

We have now reduced 3 years of data from Piñon (5 years of data has actually been obtained). The data is not as good as can be obtained now because of inadequate records of the barometric pressure and because of breakdowns in data recording systems. It is also entirely from the first Piñon instrument which had no stabilizing coils so that some drift must be removed. Thus far the drift has been removed as a linear drift rather than as the logarithmic decay that it is known to be. The data also has not been compensated for tilt except on two occasions when the tilt was readjusted manually. Correction of the data for such problems is not yet as good as it can be, but we have looked at it in its present state to see what we can measure of the long period tides. After removing the diurnal and semidiurnal tides we have fit to the residual, periodic terms at 1 and 2 cycles per month, 1 and 2 cycles per year, at the Chandler wobble period of 436 days, and at the same time the barometric pressure signal. The results are as follows:

Barometric pressure admittance		0.07	μgal/mbar
Gravimetric factors:	fortnightly tide	0.60 ± 0.31	
	monthly tide	0.91 ± 0.24	
	semi-annual tide	7.0 ± 0.6	
	annual tide	106.0 ± 3.5	
Chandler wobble amplitude		4.6 ± 0.2	μgal
Linear drift		2.7	μgal/year

The barometric pressure admittance at non-tidal frequencies reported earlier by us was about 0.3 μgal/mbar at the lowest frequencies examined (0.1 cpd). At the much longer periods included in this data we know nothing about the geographical distribution of the pressure variations. Thus it is not clear what the admittance should be, but it is not unreasonable that it should be lower than 0.3 since that is the case for the atmospheric tides.

The important implications for this work are that long term variations, such as the Chandler wobble, at an amplitude of 4 μgal can be observed. The expected amplitude for a wobble amplitude of slightly greater than 10^{-6} radians would be 4 μgal. The statistical errors shown are quite small indicating that sources of random noise in this low frequency range are small. Maximum peak to peak variation of the residual, after removing long period tides and the Chandler wobble, is about 10 μgal over the 3 years and most of this appears to be due to improper removal of the logarithmic drift. Thus, the data at Pinon continues to provide improving estimates of the lowest observable rates of gravity changes.

Our efforts to deploy the instruments we have built have not been as successful. Since the instruments were funded by NASA we have attempted, first, to get an operating system at the NASA tracking station at Otay mountain. That effort was severely hampered by the heavy rains which made the site inaccessible for a major portion of the winter. The instrument was first set into operation there in November but ran out of liquid helium because we could not get back to refill it.

We returned it to the laboratory in January to investigate an anomaly in its tilt sensitivity. Since January we have had it in and out of the laboratory 3 times, finding that although it operated perfectly in the lab it was 5 times noisier at Otay. Ultimately we traced the problem to the new dewars which we obtained for this batch of instruments. They are made of steel rather than aluminum which was used for the earlier instruments. The μmetal shielding on the instrument was becoming magnetized as it was inserted into the dewar so that an excessive amount of magnetic flux was becoming trapped in the superconducting shielding. That problem has now been solved and, at present, the instrument is operating satisfactorily at Otay and two are in operating condition in the lab. The one which is recording in the lab will be moved to Lytle Creek after another few days of testing. The solution to the shielding problem has introduced a very high Q rotational mode which we are attempting to damp.

Other problems with deployment, including such things as interference from battery chargers, adequate waterproofing of concrete vaults, etc. have also been worked out in the past 3 months so that deployment of the remaining instruments should accelerate after the first Lytle Creek station is established.

Southern California Gravity Surveys and Analysis

8-9730-01034

Robert Jachens
U.S. Geological Survey
345 Middlefield Road
Menlo Park, California 94025
(415) 323-8111 ext. 2168

Goals

The main goal of the study is to use repeat gravity observations to detect, monitor and study temporal changes in elevation and changes in subsurface density that accompany many forms of crustal deformation. This requires the development of techniques and operational procedures which will allow measurement of gravity differences reliably to a few microgals.

Investigations

(1) A four-month field program of high precision gravity surveys in southern California was conducted in cooperation with the National Geodetic Survey and the Defense Mapping Agency. The purpose of the program was to establish a high precision gravity datum concurrent with the new vertical datum being established under the Southern California Releveling Program. The gravity program contained three related projects:

i) The National Geodetic Survey conducted a continuously cycled gravity survey of 29 stations located near the primary level line junction points using 2 microgal gravimeters and helicopter transport. All stations were tied directly to a primary reference station in Riverside, California. This survey was conducted throughout the duration of the leveling and other gravity work and was designed to detect any changes in gravity and any deformation during the course of the program.

ii) Field parties from the National Geodetic Survey, Defense Mapping Agency and the U.S. Geological Survey measured gravity at bench marks approximately every 3.2 km along the lines being leveled under this program. Approximately 4000 km of lines were surveyed using the helicopter gravity stations as base stations.

iii) Field parties from the U.S. Geological Survey remeasured gravity at most of the stations of the broad scale high precision gravity network established during the fall of 1976. These surveys also were conducted using the helicopter gravity stations as base stations.

(2) Gravity was remeasured at 17 stations along the California aqueduct extending from a point 25 km NW of Palmdale, California SE to the Los Angeles County line. The profile is subparallel to the San Andreas fault and crosses the area of recent earthquake activity near Juniper Hills, Ca.

(3) Gravimeter calibration tests were performed which should permit the determination of nonlinear characteristics of the meter calibration functions.

(4) Tests on gravimeters were continued in order to identify and isolate sources of uncertainty in the measurements and possible systematic errors.

Results

(1) The cooperative gravity program in Southern California carried out during the first four months of 1978 has resulted in an extensive and nearly instantaneous gravity datum against which past and future gravity observations may be compared. All stations are recoverable both in terms of location and of reading orientation. Each station has been measured twice with at least two gravimeters. All gravimeters used for this work have been standardized over the same detailed calibration range. The gravity observations were obtained concurrent with first order leveling and the combined data should provide a good foundation for future studies of crustal deformation in this tectonically active region.

(2) Remeasurement of gravity along the California aqueduct revealed that in some places gravity had increased by as much as 30 microgal between June 1976 and late September 1977. The area of gravity increase, roughly between Palmdale, Ca., and Llano, Ca., coincides with an area which has experienced a high level of recent earthquake activity. Releveling data from the aqueduct level line showed no change in relative elevation exceeding a few cm, thus indicating that the gravity increase results from an increase in density in the subsurface.

Publications

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Semi-Annual Technical Report Summary
For Grant No. 14-08-0001-G472

MAGNETIC OBSERVATIONS RELATED TO EARTHQUAKE PREDICTIONS

M. Fuller, J. Revol, R. Day
Department of Geological Sciences
University of California
Santa Barbara, California 93106

The work carried out in this program involves three projects, two of which are primarily labwork and one fieldwork. They are as follows.

1) Observation and interpretation of the magnetic response of rocks to applied uniaxial stress at confining pressures and temperatures appropriate for the upper crust.
2) Determination of the irreversible changes in magnetic properties brought about by the application of stress.
3) Analysis of magnetic field data from the Iufer three-component magnetometer network on the San Andreas to search for the magnetoseismic effect.

In this way we hope to build up an understanding of the magnetic field changes to be expected due to the stress accumulation prior to an earthquake, and to see if indeed such effects are observable.

In the initial stage of our experimental study of the magnetic response to applied stress, we used unconfined room temperature observations. There were indeed substantial effects on remanence and susceptibility, in both polycrystalline magnetite and rocks carrying multidomain magnetite. At present we are modifying our equipment so that we can apply confining pressure and vary the temperature. The new pressure cell is near completion, and we have taken delivery of the laser, which will be used to heat the samples in the cell.

Preliminary indications of the irreversible effecs of stress upon magnetic properties have been obtained using fragments recovered after failure of the samples. It is clear that the coercive force and the mean destructive field of IRM_s have both increased substantially. We have now begun a systematic study of these effects by cycling samples to stresses less than that causing failure. This avoids difficulties due to changes of sample shape and effects related to failure.

The reduction of the magnetic field data from the Iufer network is underway. In all we have received about a month's data. We have calculated daily averages and used standard difference technique to look at the ability to remove diurnal and other short period fluctuations, which may contaminate our long-term averages. We have attempted to use the transfer function method, but have found important non-stationarity in the transfer function between stations. In conjunction with Iufer, we have a new data handling system involving the inter-leaving of all components from all sites on a single file so that synchronous observations of the field can be more readily handled. The new data will come to us on a continuing basis in one month batches.

University of California, Los Angeles

SUPPORT OF THE MAGNETOMETER ARRAY IN THE PALMDALE BULGE REGION

David D. Jackson, Paul J. Coleman, Jr., and Robert L. McPherron

Contract No. 14-08-0001-16733

Summary

Our objective has been to establish an array of five continuously recording proton precision magnetometers in the "Palmdale Bulge" area. Recent heavy rains have revealed several deficiencies in the field installations. Data acquired at the nearby test sites brought out a basic instability of the instruments at the 0.25 gamma level. Fine tuning of the resonant frequencies of the instruments and sensors greatly improved the stability. We have chosen and have permission for five (5) magnetometer installation sites and are currently installing the instruments in these sites (Figure 1). Concurrent with this installation, tests are continuing in a closely spaced test array so as to determine dominant noise characteristics of the instruments.

We have also been operating a dipole-dipole array to monitor time variations in the apparent resistivity in the Lake Hughes area (Figure 2). The only major change in resistivity appears to be strongly correlated with the last winter's rains and shows no correlation with small earthquakes in the region.

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MAP ARRAY FIGURES

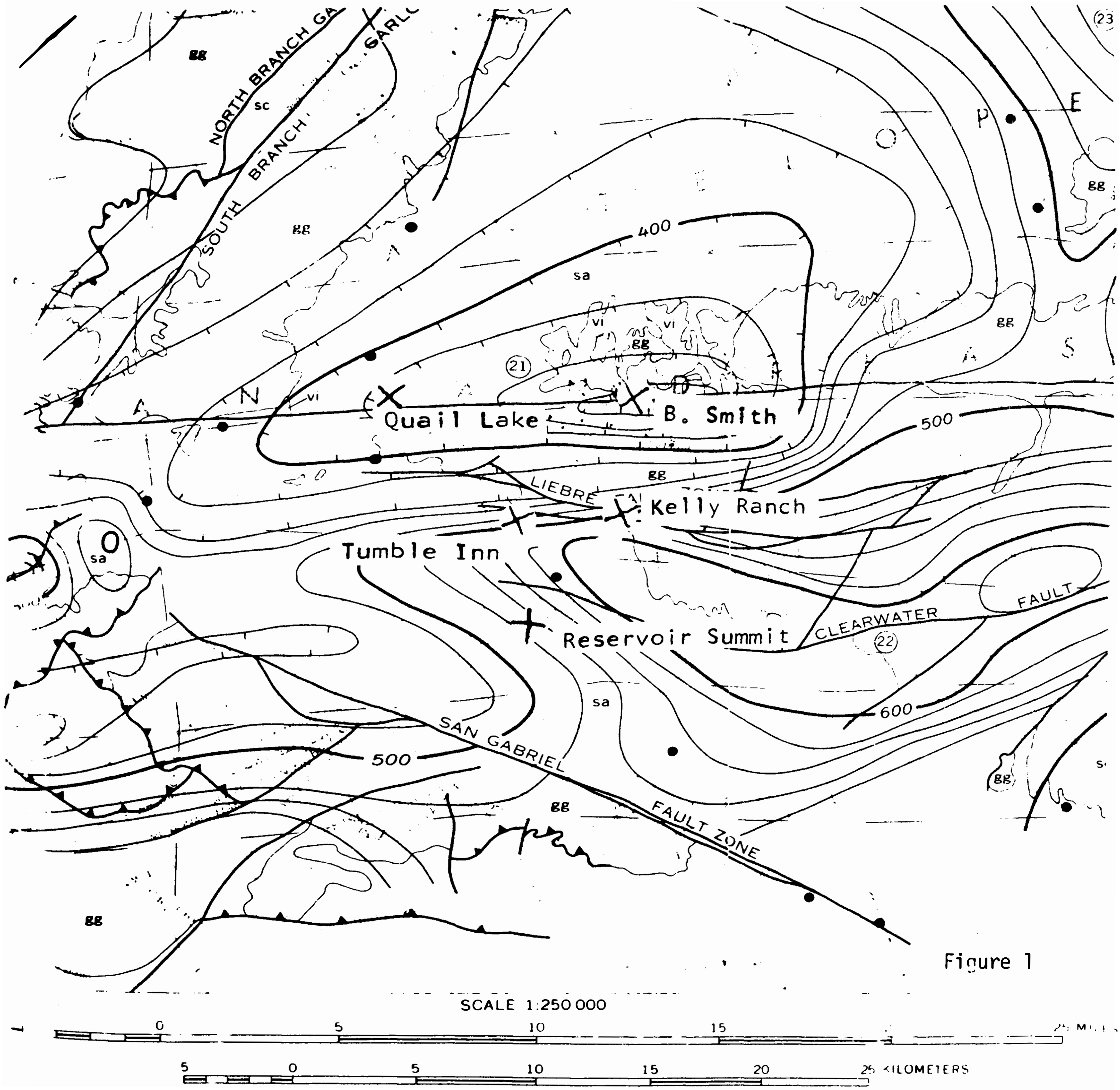
NORTH BRANCH
SOUTH BRANCH
Quail Lake
B. Smith
Kelly Ranch
Tumble Inn
Reservoir Summit
LIEBRE
CLEARWATER FAULT
SAN GABRIEL FAULT ZONE
400
500
600
gg
sa
sc
vi
21
22
23
SCALE 1:250 000
0
5
10
15
20
25 KILOMETERS

Figure 1

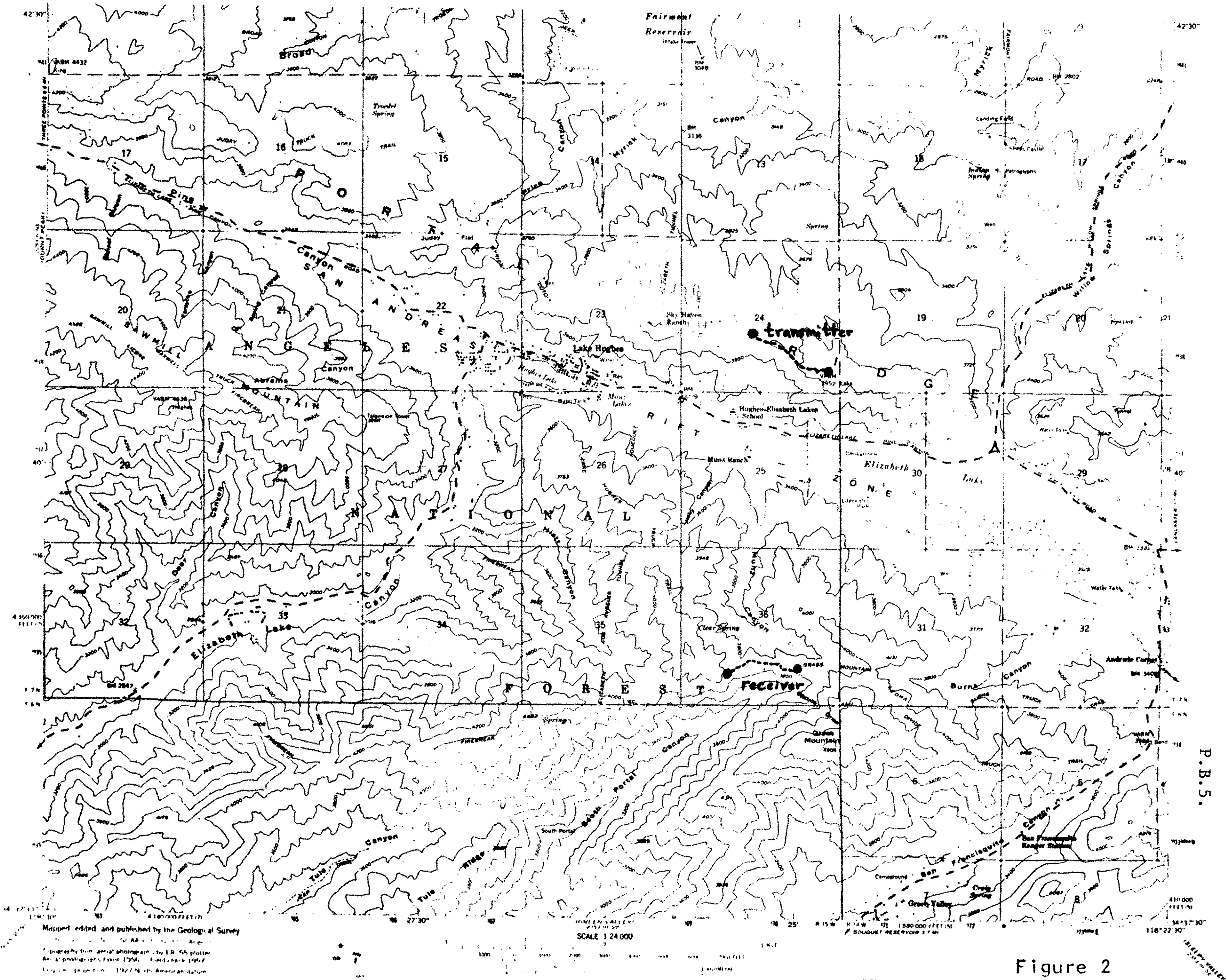
transmitter
receiver
SAN ANDREAS RIFT ZONE
ANGELES NATIONAL FOREST
Lake Hughes
Elizabeth Lake
Munz Lakes
Hughes-Elizabeth Lakes School
Munz Ranch
Sky Haven Ranch
Fairmont Reservoir
Clear Spring
Green Mountain
Andrade Corner
San Francisquito Ranger Station
San Francisquito Canyon
Green Valley
South Portal Canyon
Tule Canyon
Burns Canyon
Mapped, edited, and published by the Geological Survey
SCALE 1:24 000

Figure 2

P.B.5.

Magnetic Field Observations

8-9960-02114

Bruce E. Smith

Goals

The primary goal of this project is to determine whether observations of local magnetic field changes can be useful in earthquake prediction and in understanding fault behavior.

Investigation

The observational part of the investigations consists of two complementary data collecting systems. In both systems local variations in magnetic total intensity are identified using proton precession magnetometers that sample synchronously at a number of separate points along the fault system. Diurnal variations in the magnetic field are reduced by differencing data from two sites separated by typically 10 to 20 kilometers and then by calculating a 5 day average of the difference. The first system consists of 26 stations (including five new stations for FY78) that sample the magnetic field once each minute and telemeter the data to Menlo Park. These stations are located in central and southern California along the San Andreas fault system. Most of these stations are located in areas where magnitude 5 to 6 earthquakes are expected on the basis of crustal deformation data, historic seismicity, or other anomalous behavior. The second system, new for this fiscal year, will use 5 portable magnetometers utilizing on-site recorders. These portable magnetometers will be rotated around 60 new survey stations, sampling for 5 day intervals once or twice a year. The survey stations are designed so that they can be easily converted at a later time to a continuous sampling mode with telemetry.

The scientific investigations for FY78 are primarily concerned with making comparisons of the magnetic data to earthquakes, tilt, strain and creep data.

Results

The largest earthquakes to occur within 10 kilometers of a magnetometer station during the last 6 months had magnitudes of about 4. No significant signals were observed that could be associated with these earthquakes. One station 40 kilometers southeast of Palmdale (BUR) has recorded a 2 gamma linear trend in the past year. Six other stations have recorded significant long-term changes of about 1 gamma in the past year. The locations of these stations are: San Francisco Peninsula (BLM), 8 kilometers northwest of San Juan Bautista (ANZ), 4 kilometers southeast of San Juan Bautista (SJN), Bear Valley (BVL), and Parkfield-Chalome (GDH and AGD).

Comparison between local variations in magnetic field, long term changes in creep rate, and local earthquakes have been made for the seismically active and creeping section of the San Andreas fault between the most southern extent of the 1906 earthquake fault break and the most northern extent of the 1857 break, for the period early 1974 through mid-1977 (Smith, et al. 1978). Earthquakes with magnitudes less than 4.0 do not appear to correspond in time to local changes in magnetic field greater than 0.75 gamma or to variations in the creep rate. There is no general correspondence between creep events and magnetic variations. There is, however, an approximate correspondence, in both space and time, between the long-term changes in creep rate and the variations in magnetic field. In order to explain these observations, it appears necessary to allow for a substantial amount of deep aseismic slip without any obvious attendant changes in the time distribution or size of the local earthquakes.

Most of the 65 new sites for FY78 have been selected as of this writing. The majority of these sites are located in southern California between Palmdale and the Salton Sea along the San Andreas fault. There are a few sites near Anza, Chalome, Mustang Ridge, and the southern Hayward fault. Part of the site selection includes magnetic susceptibility measurements. The results from these measurements show that many rocks in the San Bernadino and San Gabriel Mountains have very high susceptibility (about 10^{-3} e.m.u.). The potential for observing magnetic signals in this area appear to be quite good. The rocks sampled in the San Jacinto Mountains (Anza area) are quite low (10^{-5} to 10^{-6} e.m.u.).

Improvements and checking procedures in the sensors, the sensor housing and installation procedures are currently being carried out to reduce the possiblity of any magnetic contamination in these components. The new sensors are being calibrated to 1/8 gamma. We are also installing new reference oscillators, which have a stability of 0.1 gamma, in all of the magnetometers.

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SUMMARY OF SEMI-ANNUAL TECHNICAL REPORT

Contract #14-08-0001-G-379

INVESTIGATION OF THE PALMDALE UPLIFT USING DIFFERENTIAL MAGNETIC FIELD MONITORING OF TECTONIC STRESS

Floyd J. Williams, Principal Investigator
San Bernardino Valley College, San Bernardino

February 24, 1978

Differential magnetic surveys have been conducted along the San Jacinto fault zone since July, 1973. During the past year a two-dimensional array consisting of 41 field sites has been established across the San Andreas fault zone from Quail Lake on the NW to Borrego Springs on the SE.

The field procedure is to set stations, consisting of burial benchmark-like sensor holders at approximately 15 km spacing along or across the fault zones. During a 10-minute interval of time, two adjacent stations are read simultaneously, resulting in about 76 discrete total magnetic field readings at each station. A meaningful number, related to tectonic stress in the crustal rocks, is obtained by differencing the means of the readings at the two stations. The change in this difference with time is a window via the piezomagnetic effect to changing stress conditions beneath the station pair.

Results to date clearly indicate that the method is responsive to tectonic change as evidenced by a correspondence between plots of magnetic data in form and time with plots of elevation change as interpreted from differential leveling of portions of the Palmdale Uplift.

In August, 1977, a magnitude 4.4 earthquake occured beneath one of our stations in Agua Dulce Canyon. The time plot of magnetic data for this station is responsive to the seismic event, with a reversal of slope and a decrease in the local field of about 4 gammas.

The most recent re-survey confirms the Agua Dulce Station response to the small earthquake of August, 1947 and highlights several other localities where tectonic stress is changing: (a) Big Morongo Canyon NW of Desert Hot Springs, (b) the east side of the Anza Valley, and (c) the vicinity of Day Canyon NW of San Bernardino.

Future plans involve the selection of 8 new sites on the N side of the San Bernardino Mountains.

Department of Earth and Planetary Sciences

Massachusetts Institute of Technology

Cambridge, Massachusetts 02139

High Sensitivity Monitoring of Resistivity and Self-Potential Variations in the Palmdale and Hollister Areas for Earthquake Prediction Studies

Summary of Semi-Annual Technical Report, October 1977-March 1978

Contract No. 14-08-0001-16724

Principal Investigators: Theodore R. Madden and M. Nafi Toksöz

No significant resistivity or self-potential anomalies were identified during this reporting period. Improvements in the resistivity analysis were again made and now the Hollister array resolution is about ±0.2% and the Palmdale array ±0.1% with the exception of the (Lc-Pd) dipole at Palmdale and the (SJ-H) dipole at Hollister. Noise on these lines limits the resolution to ±1.0%. The electrode potential measurement is still not satisfactorily managed, and a new technique using the reference electrode at a depth of about three feet below the surface is being tested. The improved resistivity variation requires an equivalent improvement in the calibration measurement and this is being implemented with the use of a Fluke ratiometer.

Figure 1 is a map of the two telluric arrays presently being monitored. In Figure 2, the results of analyzing the residuals of the telluric cancellations are given. This involves digitizing the Rustrak records, doing correlation analysis, and inverting the results to assign variations to individual dipoles. These results are non-unique and we have taken essentially a robust fit rather than the least square solution. Dipole B at Palmdale is known to have a noise problem which limits its sensitivity, and dipole E at Hollister appears to also have a noise problem. In fact, we believe all the results shown are presently limited by noise and digitization problems and do not represent geologic noise.

Figure 3 shows self-potential data. The Hollister data have been inverted to assign variations to individual electrodes (robust fit). The Palmdale data show the settling in drift of the electrodes, and the noise problem on B. There is also some telluric fluctuations that are not filtered out and aliased into the data. Our biggest problem still, however, is correctly measuring the electrode potentials and probably accounts for most of the apparent drift in self-potential.

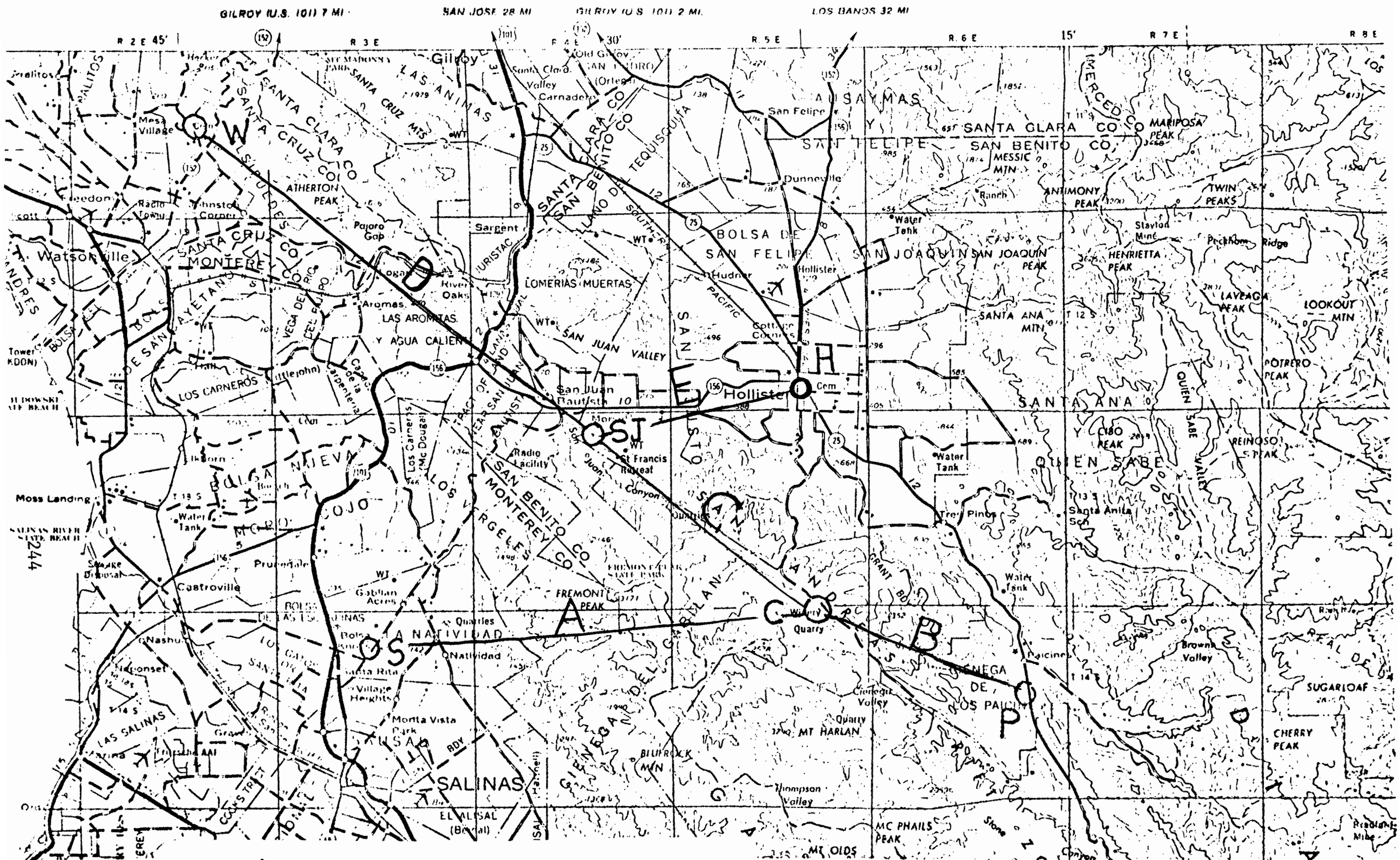
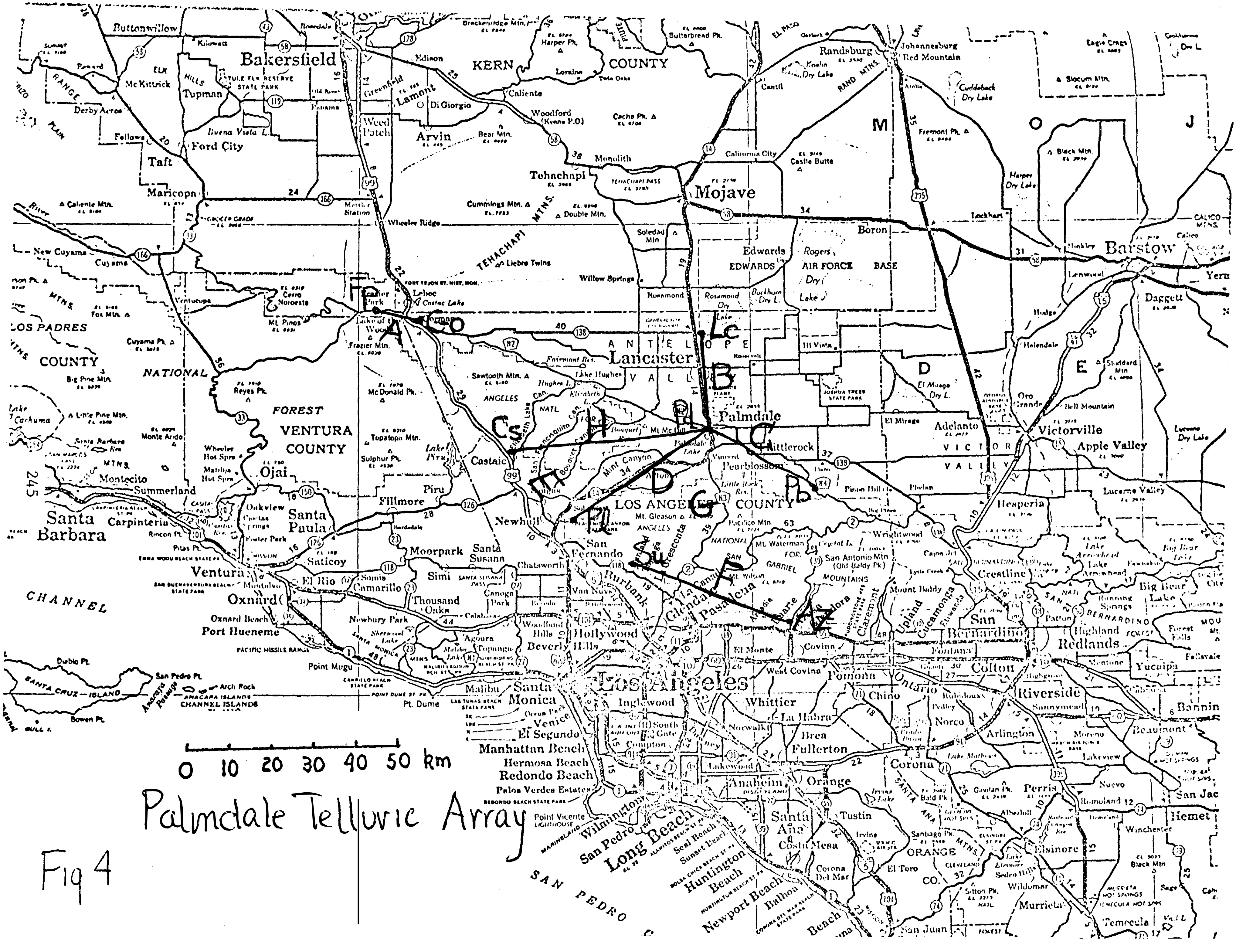


Fig 2. Hollister Telluric Array

20 STATUTE MILES

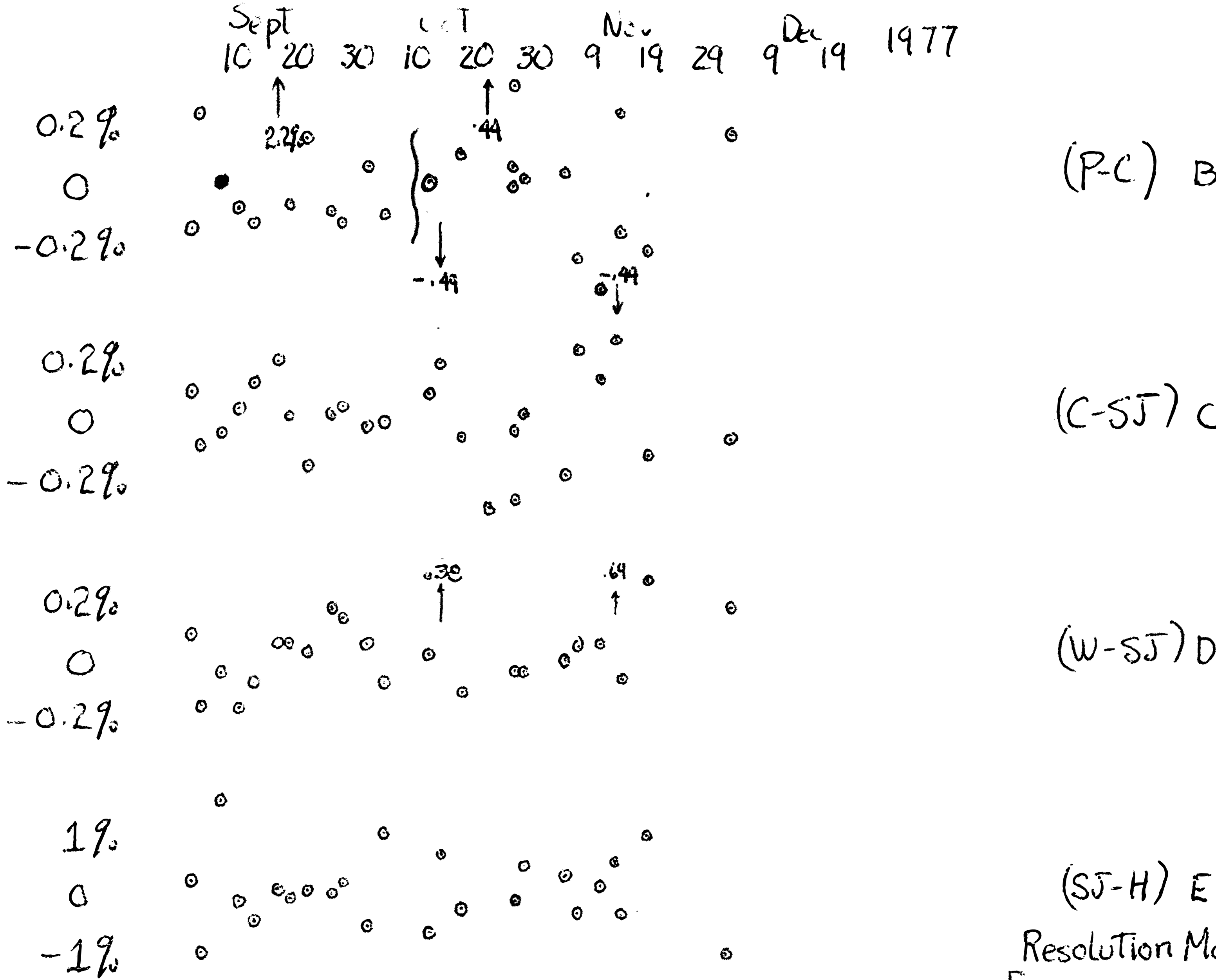
30 KILOMETERS

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
SHORELINE SHOWN REPRESENTS THE APPROXIMATE LINE OF MEAN HIGH WATER



Palmdale Telluric Array

Fig 4

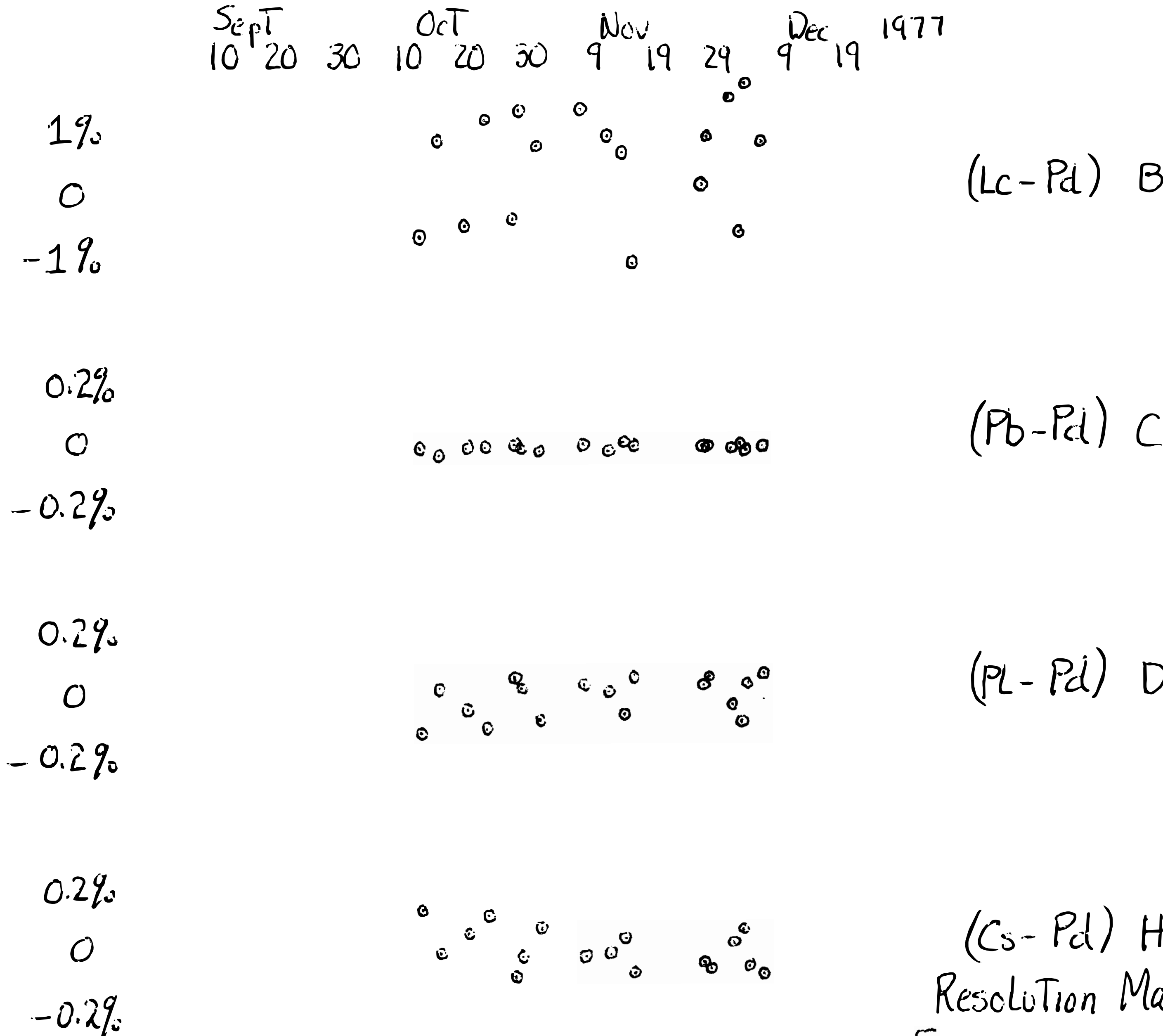


Resolution Matrix

.607	-.340	0	-.042
-.340	.693	0	-.038
0	0	1	0
-.042	-.038	0	.966
B	C	D	E

Resistivity Variations relative To (S-C) Hollister Array

Fig 3

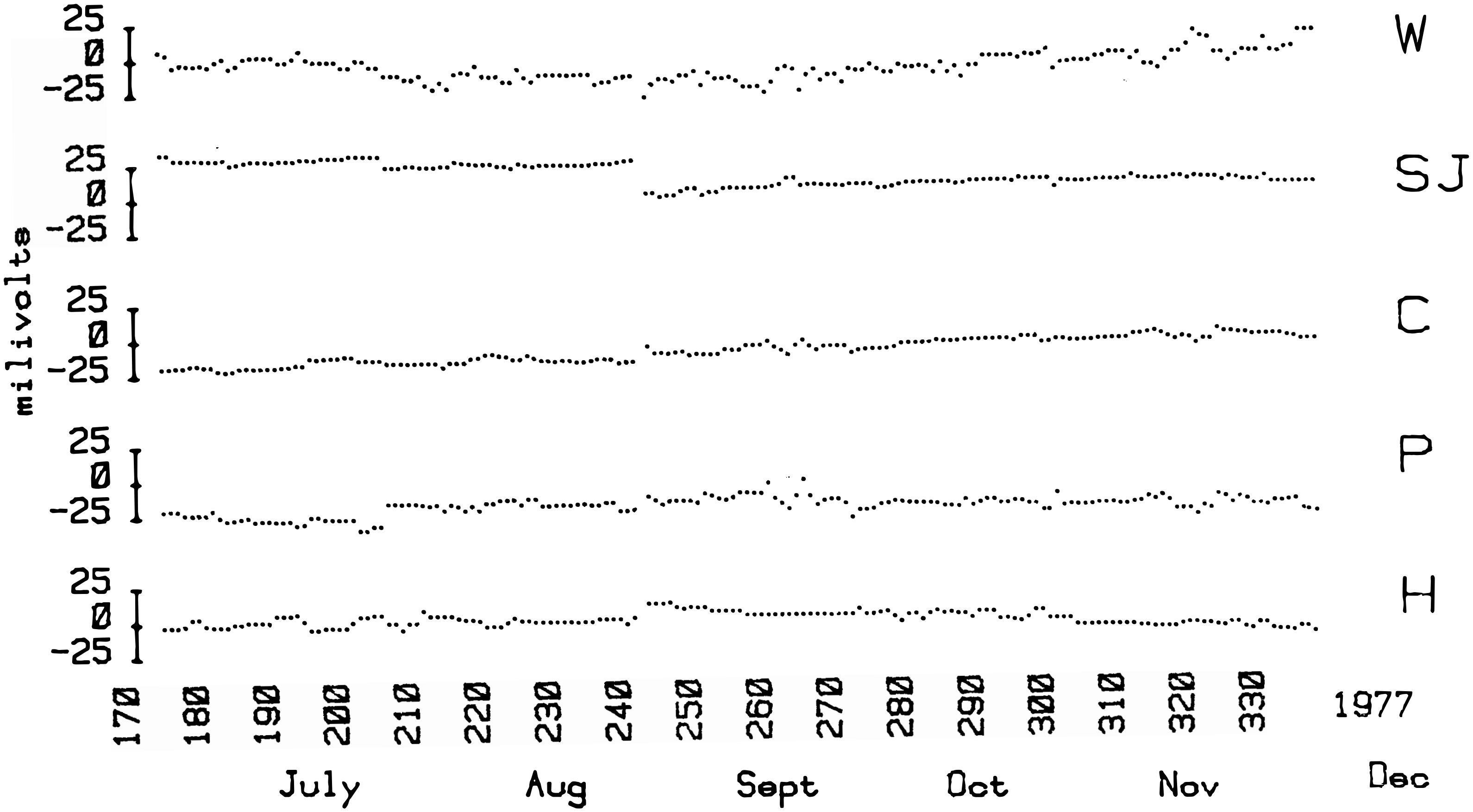


Resolution Matrix

$$\begin{array}{cc} \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & .237 & -.185 & -.218 \\ 0 & -.185 & .662 & -.319 \\ 0 & -.218 & -.319 & .664 \end{bmatrix} & \begin{array}{c} B \\ C \\ D \\ H \end{array} \end{array}$$

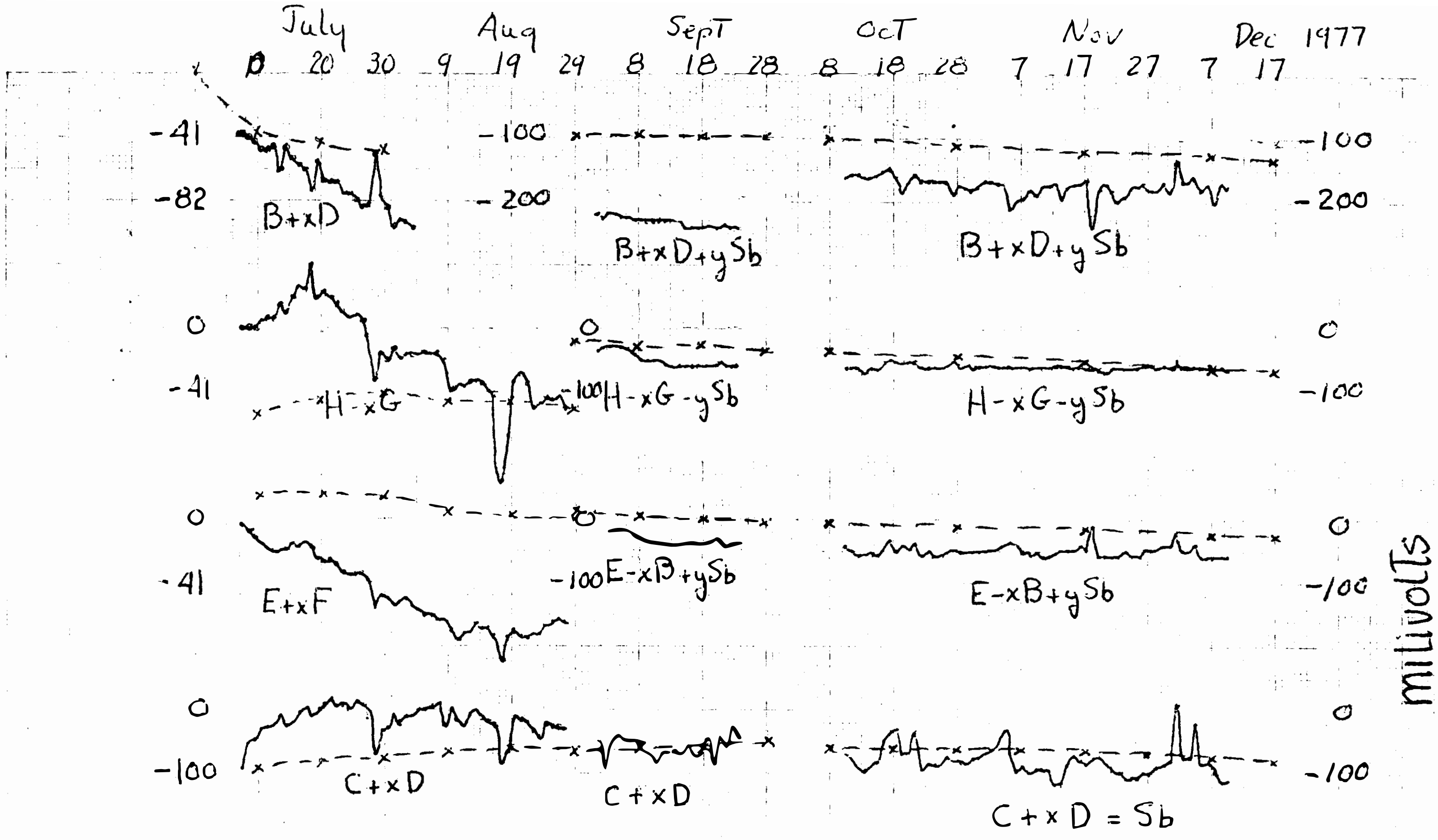
Resistivity Variations
Palmdale Array

Fig 5



HOLLISTER ARRAY Self Potentials

Fig 8



Self PoTenTials on Palmdale Array
—— observed
- - - electrode poTenTial conTribuTion

Fig 9

The Study of Temporal Resistivity Variations on the San Andreas Fault

Grant #: 14-08-0001-16778

H.F. Morrison

University of California, Berkeley

Summary

During this report period we have continued the routine acquisition of resistivity data from a network of 3 transmitters and 8 receivers in the San Andreas Fault zone south of Hollister, California.

The values of apparent resistivity in a six month period prior to December 15, 1978 have been as constant as those of any equivalent time period since 1973. The error bars (95% confidence limits) for most data points are less than 1% but week to week variations are roughly within an envelope of ±2%. On December 15 at 1115 GMT a magnitude 4.0 earthquake occured at a depth of about 7 km, roughly 1.0km north of the magnitude 4.2 event of 1973. Within the ±2% accuracy range described above there were no variations in apparent resistivity on any of the transmitter receiver pairs encompassing this epicenter. By coincidence a semicontinuous measurement run between one of the transmitters and three receivers neatly bracketed this earthquake in space and time. This data did not show any short term resistivity variations within the same ±2% accuracy range.

These data present a clear negative correlation between a magnitude 4 earthquake and resistivity variations of greater than 1 or 2 percent. One conclusion that can be drawn is that, in this seismically active area at least, much higher accuracy will be required to determine whether resistivity variations are associated with earthquakes with magnitudes as low as 4.0.

We have also continued to monitor self-potentials on the various electrode pairs of the network and no significant self-potential variations were seen to precede this earthquake at any of the sites.

We have now begun a concerted effort to improve the overall accuracy of the measuring array.

INVESTIGATION OF RADON AND HELIUM AS POSSIBLE FLUID-PHASE PRECURSORS TO EARTHQUAKES

H. Craig, J. E. Lupton, Y. Chung,
R. M. Horowitz, and R. Poreda

Grant No. USGS 14-08-0001-G-470

Scripps Institution of Oceanography
University of California, San Diego
La Jolla, California

REPORT SUMMARY

In this report we present the analyses of 250 hot spring and well waters from locations in our monitoring networks for dissolved nitrogen and argon as well as for helium and radon. It is found that in both the springs and wells, the N_2-Ar-He data form linear arrays representing two-component mixtures of gases. In the spring samples, the high He, N_2, Ar component is the original meteoric water saturated at $\sim$15°C, 1 atm. pressure, to which helium, radon, and generally some nitrogen have been added during the subsurface flow. The low-concentration component of the springs is the surface water of the spring itself, in solubility equilibrium with air at the spring temperature, and with essentially zero helium and radon concentrations. The mixing of these two end-members produces linear dissolved gas correlations in which the He-Ar array goes to zero helium at the Ar concentration at which the N_2-Ar array intersects the atmospheric solubility curve at the spring temperature.

Surprisingly, very similar linear arrays are observed in the wells, even though the fluids sampled are generally two-phase systems in which bubble trapping and loss contribute to the observed concentration variations. The array slopes in the wells appear to

be determined by the gas ratios in bubbles although gas-liquid solubility equilibrium does not appear to be present for at least one of the three gases He-N_2-Ar.

The discovery of the linear correlations of He, and in some cases also radon, with N_2 and Ar provides a major increase in the sensitivity with which both wells and springs can be monitored for precursory effects. The very large noise level in the helium records, amounting to variations of factors of 5 or more in concentrations observed in monthly sampling, are reduced to 5 to 10% effects by normalizing the helium data to nitrogen or argon, thus removing the irregular fluctuations of the proportions of the end-member components. The immediate result of this greatly increased signal enhancement is that we should be able to see precursory helium and radon variations associated with much lower magnitude seismic events, perhaps down to M=3 or even less.

In addition to N_2 and Ar, methane has been detected in significant concentrations in many of our network sites and has been added to the list of constituents being monitored. This report also includes the tabulated radon and helium measurements for the Southern and Palmdale networks accumulated since 1 October 1977. Two new wells - one on the south end of the San Jacinto fault and one in the Juniper Hills area near Palmdale - have been added to the monitoring networks.

Light Stable Isotopes

8-9740-00382

Irving Friedman and Joan Blackwell
U. S. Geological Survey
Box 25046
Denver Federal Center
Denver, Colorado 80225
(303) 234-3876

Goals

To determine if we can predict earthquakes by monitoring helium fluctuations in ground water.

Investigations

For the past year, the U. S. Geological Survey, Isotope Geology Branch, has been operating a volunteer collection network for earthquake prediction. The volunteers sample well water daily and send the samples to the laboratory for helium analysis. Most wells are used domestically, although a few are used for irrigation or for municipal water supply.

In the sample procedure we now use, the volunteer fills a hypodermic syringe with 9 cc's of water and injects the sample into an evacuated sample tube (Vacutainer). To prevent leakage, the rubber stopper is immediately sealed with RTV rubber sealant. The tubes are placed in a foam plastic mailing device which holds five samples. When the volunteer has collected five tubes, the mailer is sent to the analytical lab in Denver.

At present, the network consists of approximately thirty-three stations along the San Andreas fault in California from San Francisco to fifty miles south of Hollister and three geothermal stations in the Imperial Valley. In addition, there are eleven collection stations in the vicinity of West Yellowstone, Montana. These areas are seismically active and we hope to correlate helium fluctuations with earthquake data.

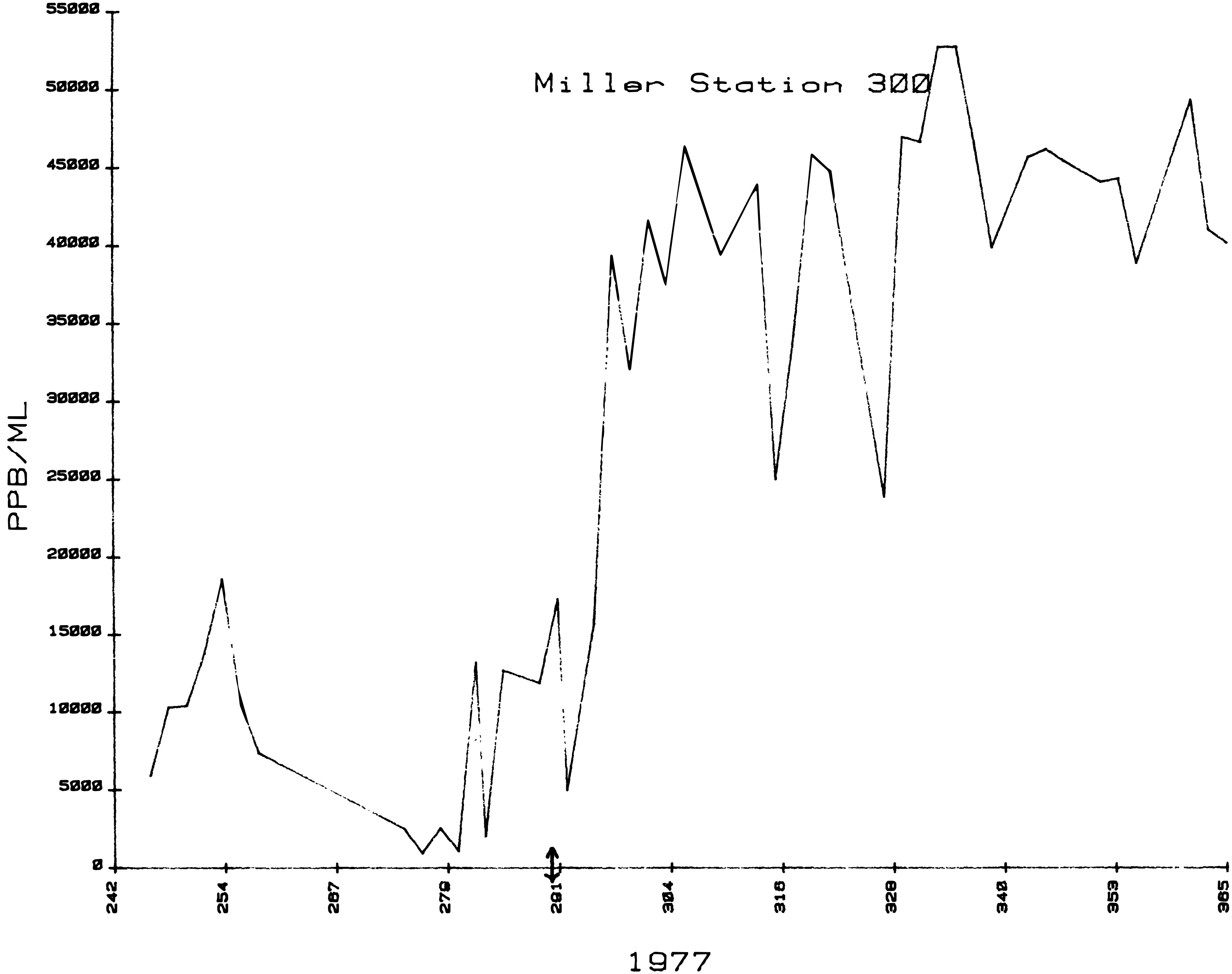
We are also developing an automated sample taking and analyzing device which will be located at the most promising station, Miller Well, near Gardner, Montana. The results will be transmitted via GOE satelite every three hours to Denver.

Results

Preliminary results indicate that the best wells in the seismic areas are in general, thermal wells and artisian wells. We have expanded our project therefore, to include a general survey of the thermal and artisian wells in the California earthquake-prone areas. Volunteers participating in this phase of the project include local HAM (amateur radio) operators and students in the State University and Community College systems. The HAM operators contact local well owners and obtain locations and some technical data. Students then sample the prospective wells, and send the samples to Denver for analysis. In this way, much preliminary screening is being done by volunteers.

From the data on the Miller well (see Figure 1) the helium concentration appears to fluctuate sharply prior to the event (an Oct. 19, 1977; Julian date, 290, earthquake of magnitude 4.7) then rise steeply during the event whose epicenter was 50 km to the S.W. The data is plotted as parts per billion of helium per milliliter of water sample on the y-axis against time (Julian date) on the x-axis. This was not the only station which showed an effect from the earthquake. Another site, 50 km farther north showed a large change in helium concentration from samples collected eight days before and eight days after the event. Due to sampling problems however, only three of the eleven stations were sampling during this period.

We are still trying to obtain baseline data from stations in California. With better stations (those high in helium) in the seismic areas we hope to be able to see significant changes in helium levels.


Miller Station 300
PPB/ML
55000
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
242
254
267
279
291
304
316
328
340
353
365
1977

P.B.7.

Radon and Water Wells Monitoring

8-9960-01485

Chi-Yu King
U.S. Geological Survey
345 Middlefield Road
Menlo Park, CA 94025
(415) 323-8111 ext. 2706

The purpose of this project is to search for possible premonitory changes in soil gas and ground water that may be useful for earthquake prediction. Parameters being monitored so far are radon content of soil gas and ground water, water level, temperature, salinity, electric conductivity and pH value.

Radon content of soil gas is being monitored by a Track Etch method at about 65 sites in central California (Figure 1), 25 sites in southern California (in co-operation with USC and UCSB) and 10 sites on the Island of Hawaii (with HVO). The radon content recorded by the various networks continues to show large temporal variations, which are spatially coherent along fault segments of lengths over tens of kilometers but less than about 100 km. Periods of high radon concentration generally coincides with periods of high local seismicity. Figure 2 shows, as an example, the radon data recorded by the first array of 20 station (stations 1-20) located between Hollister and San Benito. It also shows weekly count of earthquakes of magnitude 1.0 or larger that occurred within 30 km of the network. The three largest earthquakes ($M \geq 4.0$, indicated by arrows) occurred at about the same times as the three prominent radon peaks (Dashed lines indicate preliminary data).

Two continuous ground-water radon monitors have been installed, in cooperation with H. Wakita of the University of Tokyo. One monitor is located at an artesian well in San Juan Bautista (WRN1 in Figure 1), where a Lawrence Berkeley Laboratory monitor has been in operation for about two years. Data from the two instruments, which are of different design, appear to be in good agreement. The other monitor is installed at another artesian well near Banning in southern California in cooperation with T. Teng of USC, who periodically samples the water for radon and other kinds of analyses.

Among the several water-quality parameters mentioned above, the electric conductivity seems to have shown some premonitory changes for several cases.

Publications

King, C.-Y., 1978, Radon Emanation on San Andreas fault: Nature, v. 271, p. 516-519.

King, C.Y., 1978, Radon Emanation in tectonically active areas (abs.): The Natural Radiation Environment III, Book of Summaries, p. 27-28.

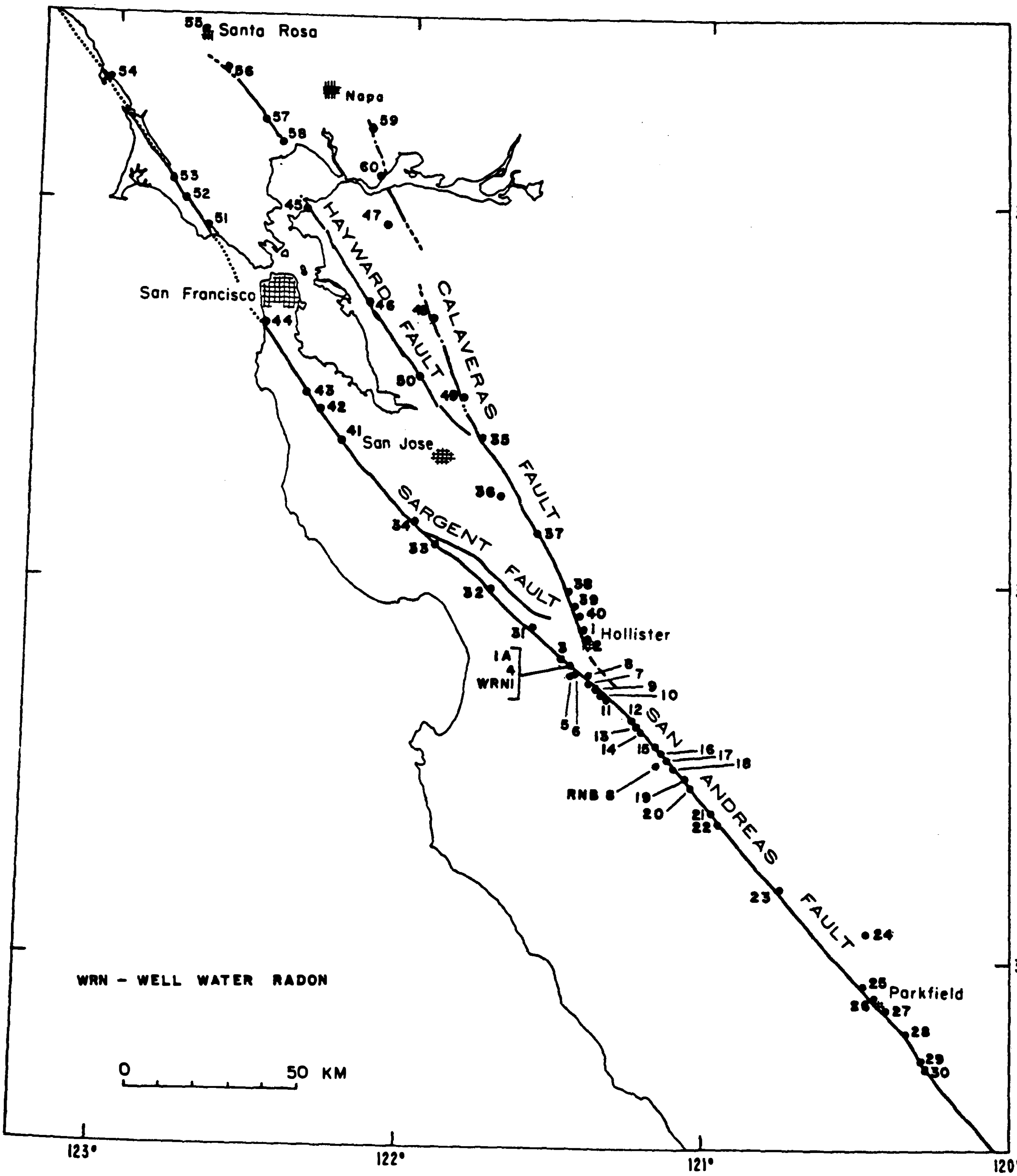

Santa Rosa
Napa
San Francisco
San Jose
Hollister
Parkfield
HAYWARD FAULT
CALAVERAS FAULT
SARGENT FAULT
SAN ANDREAS FAULT
WRN - WELL WATER RADON
0 50 KM
38°
37°
36°
123°
122°
121°
120°

Figure 1

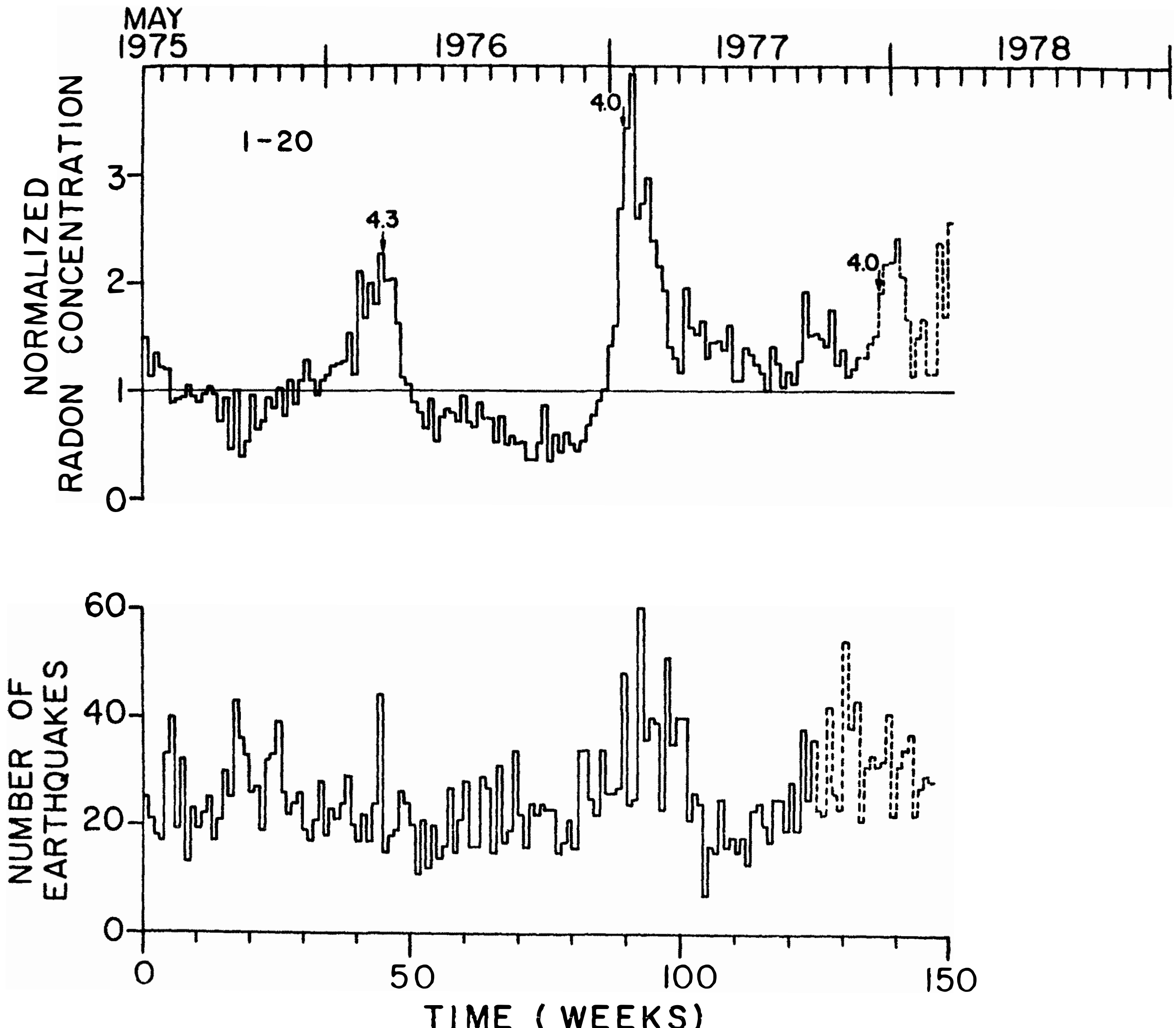

MAY
1975
1976
1977
1978
NORMALIZED
RADON CONCENTRATION
1-20
4.3
4.0
4.0
0
1
2
3
NUMBER OF
EARTHQUAKES
0
20
40
60
0
50
100
150
TIME (WEEKS)

Figure 2

Stable Isotope Variations

8-9740-00383

James R. O'Neil
U.S. Geological Survey
Menlo Park, California 94025
(415) 323-8111 ext. 2598

Goals

The purpose of these studies is to measure routinely the D/H, $^{13}C/^{12}C$, and $^{18}O/^{16}O$ ratios of fluids in seismically active regions of California with the hope of:

1. Observing anomalies in these ratios which are premonitory or otherwise related to seismic events.

2. Providing information concerning rock-fluid interactions in these regions.

3. Identifying various groundwater acquifers by their isotopic signatures as an aid in locating and spacing sampling sites for other geochemical stuides of seismic zones.

Investigations

1. Candidate waters are analyzed for D and ^{18}O contents. If the isotopic signatures of the waters indicate possible contributions from recent precipitation, they are rejected. Water samples are sent to us by C. Y. King (USGS), H. Craig (UCSD), and T. F. Henyey (USC).

2. Isotopically suitable waters are analyzed on a regular basis and any anomalies observed are compared with geophysical and other geochemical data taken over the same interval in surrounding areas.

3. CO_2-rich waters are collected for ^{13}C analyses.

Results

1. The hydrogen mass spectrometer was fully automated and equipped with more modern amplifiers and other electronic devices such that our precision has been increased by a factor of two ($\pm$ 0.2°/₀₀).

2. A system has been developed for field collection of CO_2-rich waters and extraction of the CO_2 in the laboratory for isotopic analysis. We are now ready to begin our planned program of ^{13}C analyses.

3. Regular sampling and analyses are now made in the following areas: Northern California (Stone Canyon, Slack Canyon, St. Francis Retreat, Swanson Ranch, Cienega Winery, Gold Hill, Parkfield, San Juan Bautista), Southern California (several wells in the Palmdale area; several deep oil wells being investigated by the USC group).

4. Initial results at Oroville (fig. 1) and Gold Hill (fig. 2) suggested that δD values increased in response to earthquake and creep events. It was postulated that hydrogen-containing (but not oxygen-containing) gases like H_2, H_2S, or CH_4 were either released or produced prior to or during some deep-seated event and that these gases exchanged hydrogen isotopes with the ground water on ascent to the surface. In figure 3 samples collected at San Juan Bautista during 1977 again show deuterium variations with little or no variation in oxygen isotope ratios. These variations are indeed anomalous but show little correlation with local seismicity during this period. At San Jaun Bautista it would appear that, if anything, the δD value <u>decreases</u> during events with magnitudes greater than 3. Much more data is needed before a proper assessment can be made of these unusual variations.

<u>Publications</u>

O'Neil, J. R., 1977, Stable isotope variations in earthquake prediction: American Geophysical Union Transactions, v. 58, p. 437.

GILLEY WELL-OROVILLE

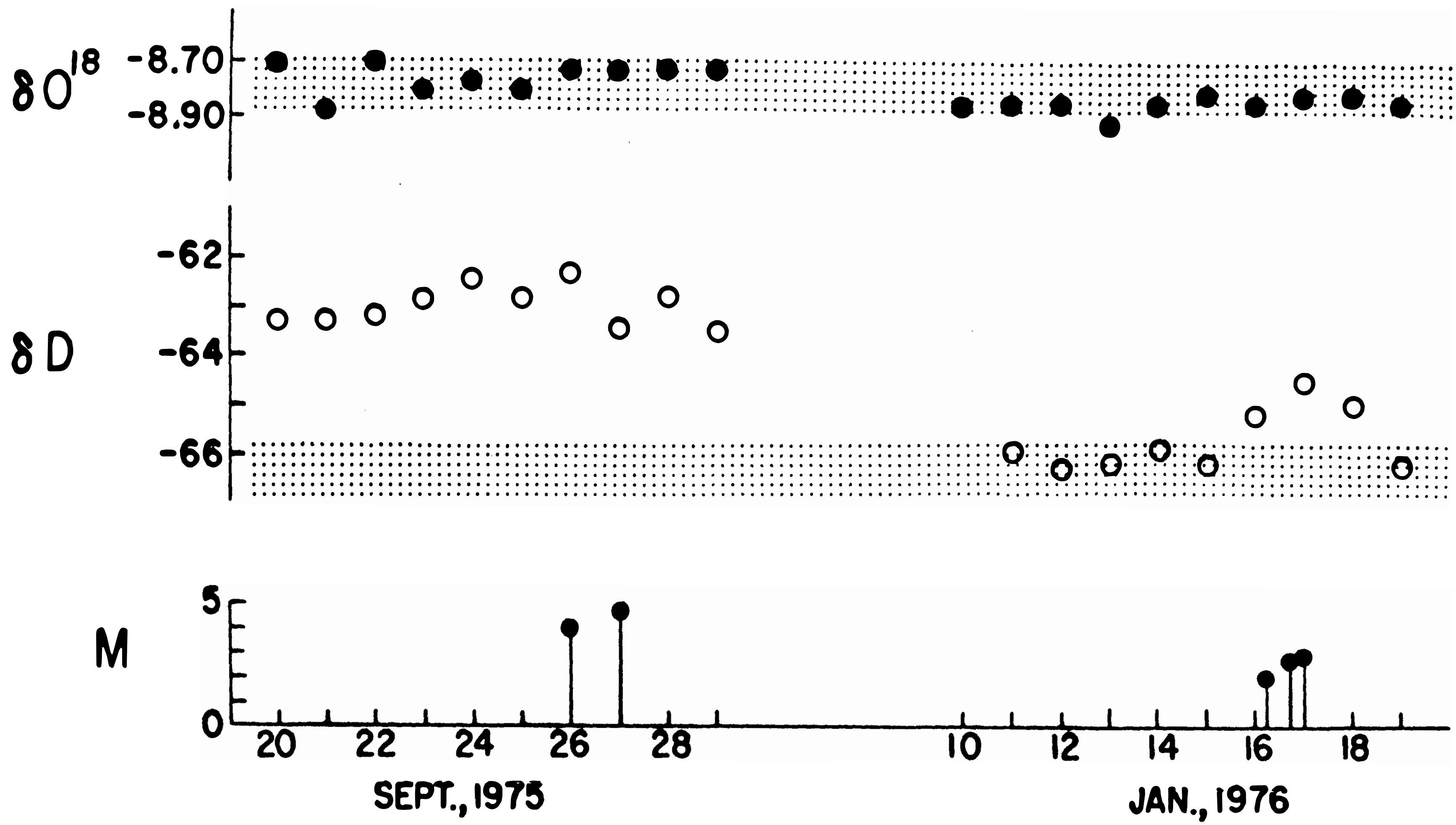


Fig 1.

P.B.7.

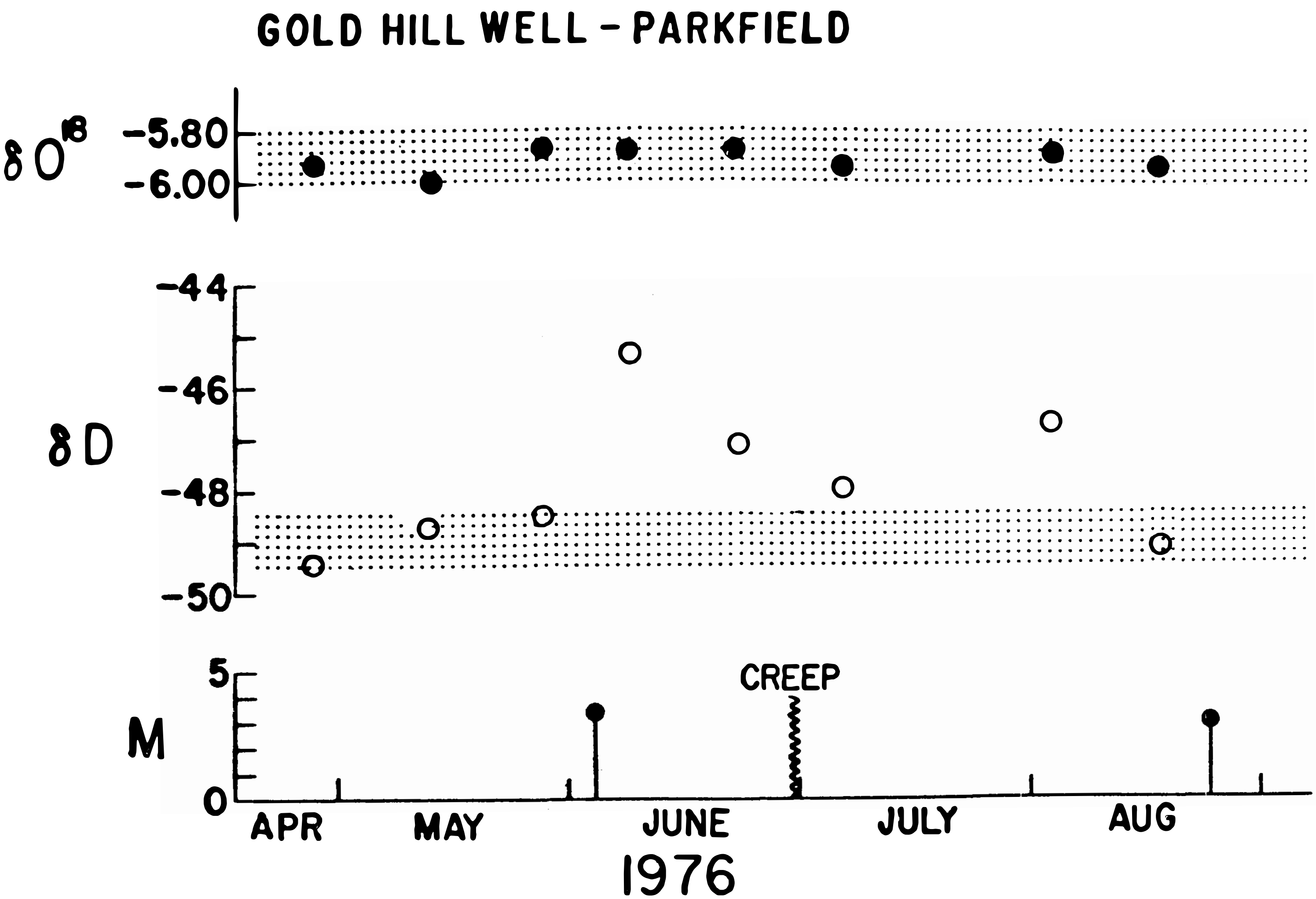

GOLD HILL WELL - PARKFIELD
δO^{18}
-5.80
-6.00
δD
-44
-46
-48
-50
M
5
0
CREEP
APR
MAY
JUNE
JULY
AUG
1976

Fig 2

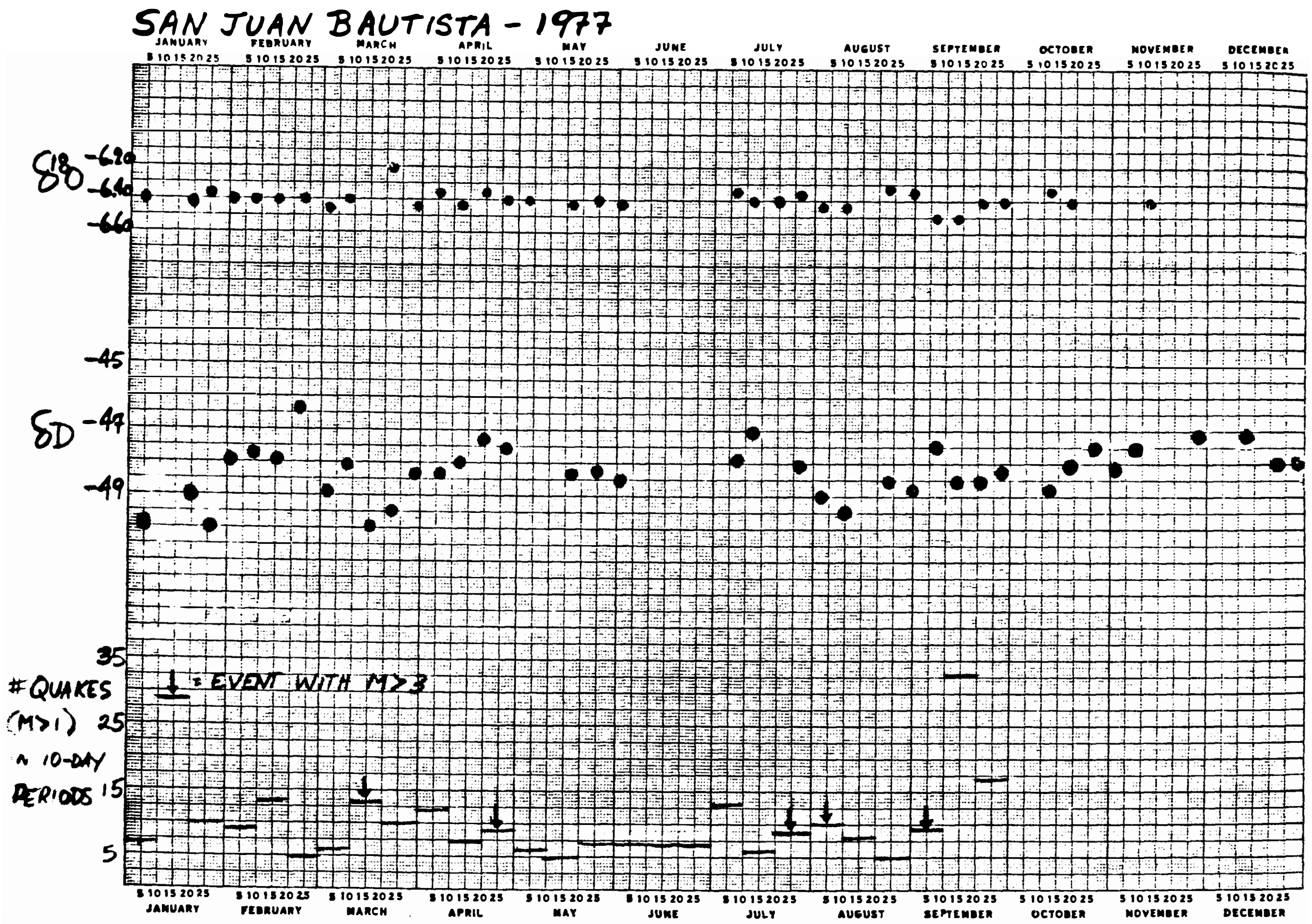

SAN JUAN BAUTISTA - 1977
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER
5 10 15 20 25
$\delta^{18}O$
-6.20
-6.40
-6.60
-45
δD
-47
-49
35
#QUAKES
(M>1)
25
IN 10-DAY
PERIODS
15
5
= EVENT WITH M>3

Figure 3

Helium Monitoring for Earthquake Prediction

8-9440-01376

Michael Reimer

U.S. Geological Survey
Box 25046
Denver Federal Center
Denver, Colorado 80225
(303) 234-5146

Goals

The main objective of this project is to obtain data regarding the natural behavior of helium in soil gas and its relation to seasonal, diurnal, and meteorological factors. Radon in soil gas will be monitored at some of the helium-sampling locations, and helium and radon in water will also be measured where possible. Correlation between helium concentration in soil gas and earthquake activity will be sought and models developed to explain the helium behavior.

As an additional objective, methods to implement on-line monitoring of helium and other soil gases, and various sampling techniques will be evaluated as experience is gained with this proposed project.

Investigations

The manpower and most of the major equipment for this project is being supplied by the Branch of Uranium and Thorium Resources. Special equipment, such as meteorological recording devices and 2 meter probes are now on hand and the field work is about to begin.

The initial field investigation will begin approximately on April 15, in Weld County, Colorado, and continue through mid-May. This period is one of extreme and rapidly moving Spring weather systems and should provide the most variation in meteorological conditions for the sampling period. A second field investigation is planned for mid-June in California. The exact location will be determined after consultation with other individuals in the Earthquake prediction program.

The sampling plan for the first field investigation is to establish 20-25 permanent probe stations over an area of a known helium-in-soil-gas anomaly. Samples will be collected at four depths: 0.5, 1.0, 1.5, and 2.0 meters. Sampling will be on a timed basis in an attempt to correlate measured meteorological parameters with changes in the helium soil-gas concentration.

Publications

None to date

UNIVERSITY OF SOUTHERN CALIFORNIA

SUMMARY REPORT

U. S. G. S. Contract No. 14-08-0001-15875

Groundwater Radon Content as an Earthquake Precursor

1 October 1977 to 31 March 1978

Ta-liang Teng, Principal Investigator

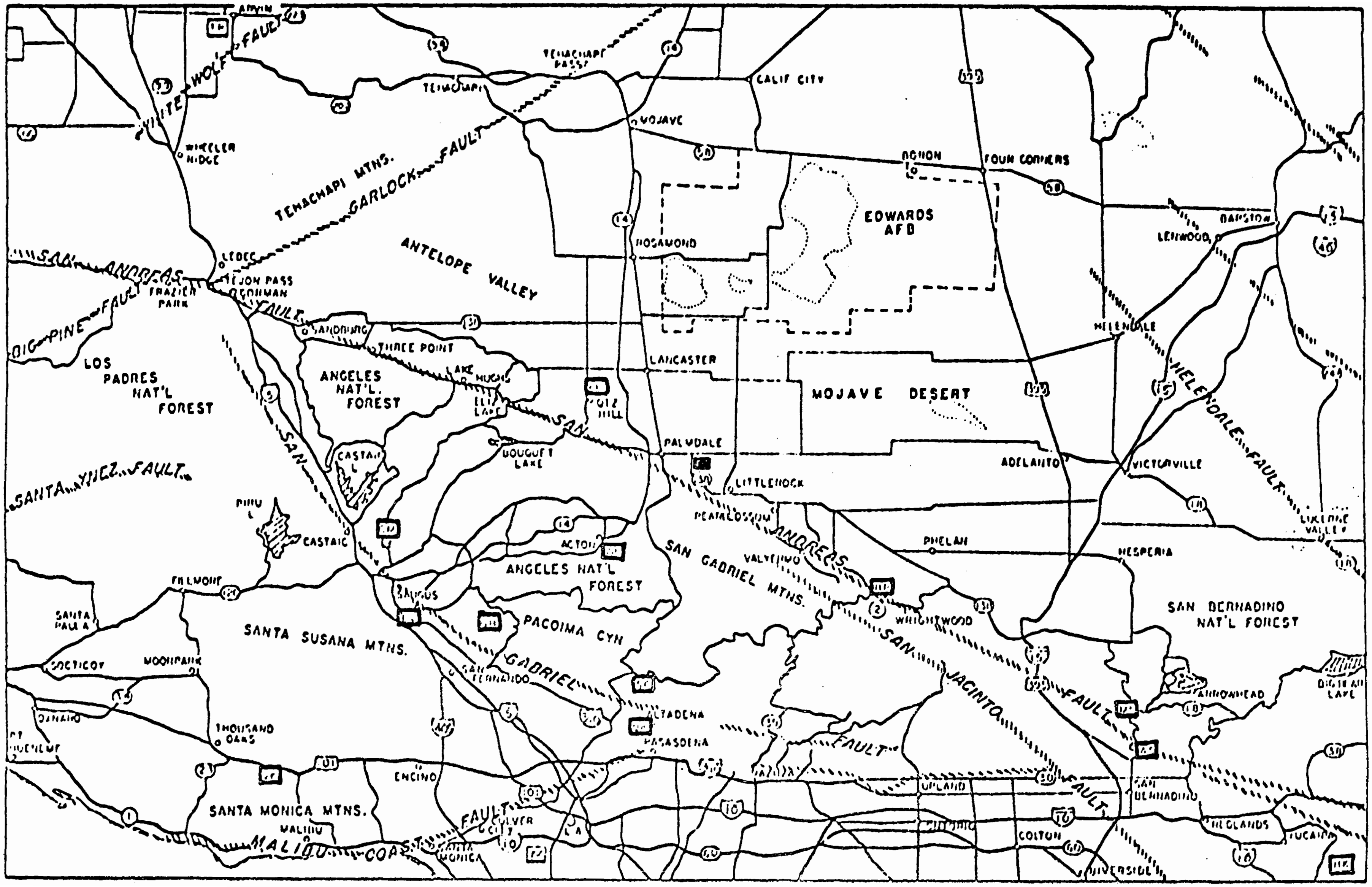
The USC radon monitoring program began in 1974 and has now developed into a multifaceted program consisting of three principal experiments.

A. Groundwater Radon Content Monitoring Network

We have established a 14-station groundwater radon sampling network (Fig. 1) covering much of the extended southern California uplift area. Weekly sampling is maintained that dates back to October, 1974. Four liquid nitrogen cold-trap radon extraction systems with scintillation counter have been constructed in our laboratory to handle the routine analysis. Radium standards are available for counting system calibration. Efforts are being made to correlate the groundwater radon results with nearby earthquake occurrences, as well as meteorological variations.

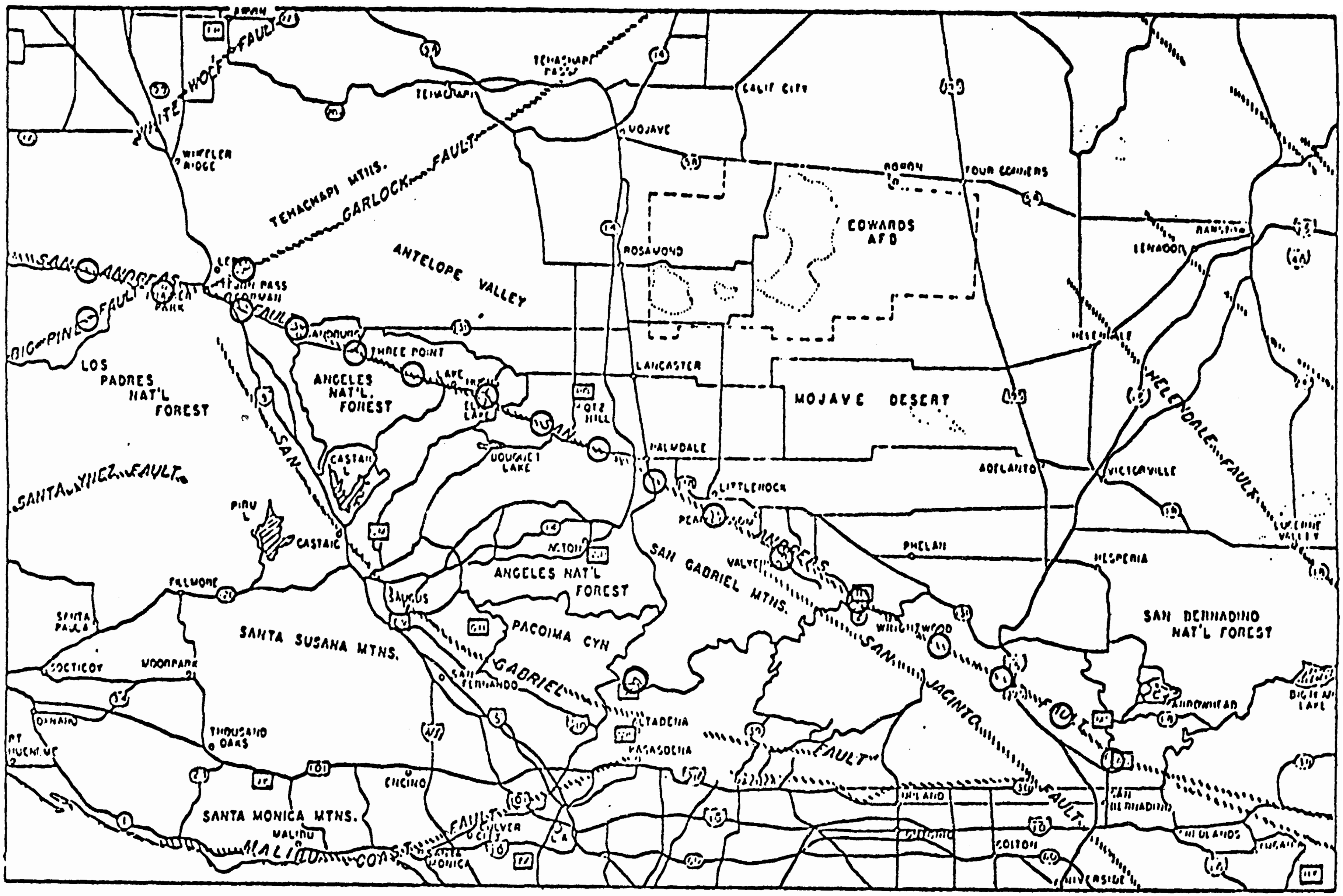
B. Soil Radon Content Monitoring Network

As a cooperative effort with Dr. C. Y. King of NCER/USGS, we have established a 20-station soil radon monitoring network (Fig. 2) using the radon cup method. Stations are mainly located in the San Andreas rift valley with a few stations on the Garlock, Big Pine, and San Gabriel faults. The soil radon content monitoring network has been in



GROUNDWATER RADON SAMPLING STATION

FIGURE 1



◯ soil RADON SAMPLING STATION

FIGURE 2

operation since April of 1975. Monthly replacement of the radon cups causes this experiment to have lower resolution than the groundwater radon measurement; however, the experimental procedure is simple and inexpensive, thus a large area can be covered.

C. <u>Design and Construction of Continuous Radon Monitoring System</u>

To augment our groundwater radon content monitoring capability, we are actively pursuing the design and construction of a continuous radon counting system. Preliminary design and prototype construction have been completed and the system is presently undergoing laboratory testing.

We are also cooperating with Dr. C. Y. King of NCER/USGS and Dr. Wakita of Japan in a project under which a Japanese continuous radon counting system has been installed and performing satisfactorily at one of our well sites, the Haskell well, which is an artesian upwelling from a depth greater than 500 meters at a location near Banning, between the San Andreas and San Jacinto faults.

A related rock mechanics experiment studying the radon release mechanism from rock is currently underway at USC under a NSF grant to Charles Sammis. Rock samples will be stressed and water percolated through the samples will be collected for precision cold-trap stripping of radon and scintillation counting. Although not directly funded by USGS, we consider this project an integral part of our overall radon research program.

PROGRESS REPORT ON WATER LEVEL MONITORING ALONG SAN ANDREAS AND SAN JACINTO FAULTS, SOUTHERN CALIFORNIA

April 1978

D. L. Lamar and P. M. Merifield
Lamar-Merifield, Geologists
1318 Second Street, Suite 27
Santa Monica, California 90401

SUMMARY

A canvass of 185 water wells along the Palmdale-Valyermo segment of the San Andreas fault and along the San Jacinto fault zone between San Jacinto Valley and Ocotillo Wells has been accomplished. Many abandoned water wells suitably located for monitoring have been found; water wells in the Palmdale area are unused because in the past few years the Palmdale Water District has installed water lines to serve the area. Many of the wells in the Palmdale area will only be used if the domestic water system fails. Because farms and ranches have been abandoned and new wells have been drilled, many suitable wells have also been found along the San Andreas fault in the Valyermo area and along the San Jacinto fault. Figure 1 shows the areas where observation wells are located.

Water levels are continuously recorded by Stevens Type F recorders installed on five wells and by two recorders which consist of a pressure-sensitive transducer and Rustrak recorder. This device is more versatile than the Stevens recorder because it can be employed in wells that are deeper and have a smaller diameter. Furthermore, the wells need not be perfectly vertical, as is the case with the Stevens recorder. Electronics, recorder and battery are housed in a 6 5/8-inch diameter plastic cylinder which is lowered into the upper portion of the well casing and attached with a chain to a bracket welded to the inside of the casing; the pressure-sensitive probe hangs beneath the cylinder and extends below water level. This configuration allows easy removal from one well to another, is less obvious to vandals and can be protected by a solid steel locking cap on the top of the casing.

Students and faculty at Antelope Valley College near Palmdale, amateur radio operators, an airline pilot and rangers at Anza Borrego State Park have been enlised to aid in weekly measurements of water level and temperature at 33 wells. Volunteers may also be used to make daily observations of wells located close to their homes. Ideas on the involvement of volunteers were

obtained at the workshop on use of volunteers for collecting earthquake precursory information conducted by Peter Ward of the U.S. Geological Survey at Menlo Park, California, February 2-3, 1978. Rainfall data from stations adjacent to the observation wells are also obtained. Weekly water levels, temperatures and rainfall data are stored on magnetic disk and displayed by computer graphics methods. Figure 2 is an example of a computer generated figure.

The observation wells penetrate a variety of rock types along and within the fault zones, including basement complex, volcanic rocks, ancient lake sediments, alluvial valley fill and fault gouge. The distribution of wells permits comparison of water level changes in different rocks within and outside the fault zones. Diurnal fluctuations in atmospheric pressure are the principal cause of short-term variations seen on the Stevens recorder charts. Long-term changes can be seen on the hydrographs of the weekly observations. Levels in most of the wells have been rising as a result of the recent rainstorms; other wells have been relatively unaffected. By study of the response to rainfall and barometric pressure, wells which may be sensitive strain meters have been identified. No relationship between microearthquake activity and water levels in the Palmdale area has been observed. Monitoring of the more recently acquired wells southeast of Palmdale has not covered a sufficient period to allow comparison with earthquake activity. Most of our observation wells are not influenced by local pumping, and the records are of sufficient quality that it should be possible to observe any detectable water level changes prior to earthquakes.

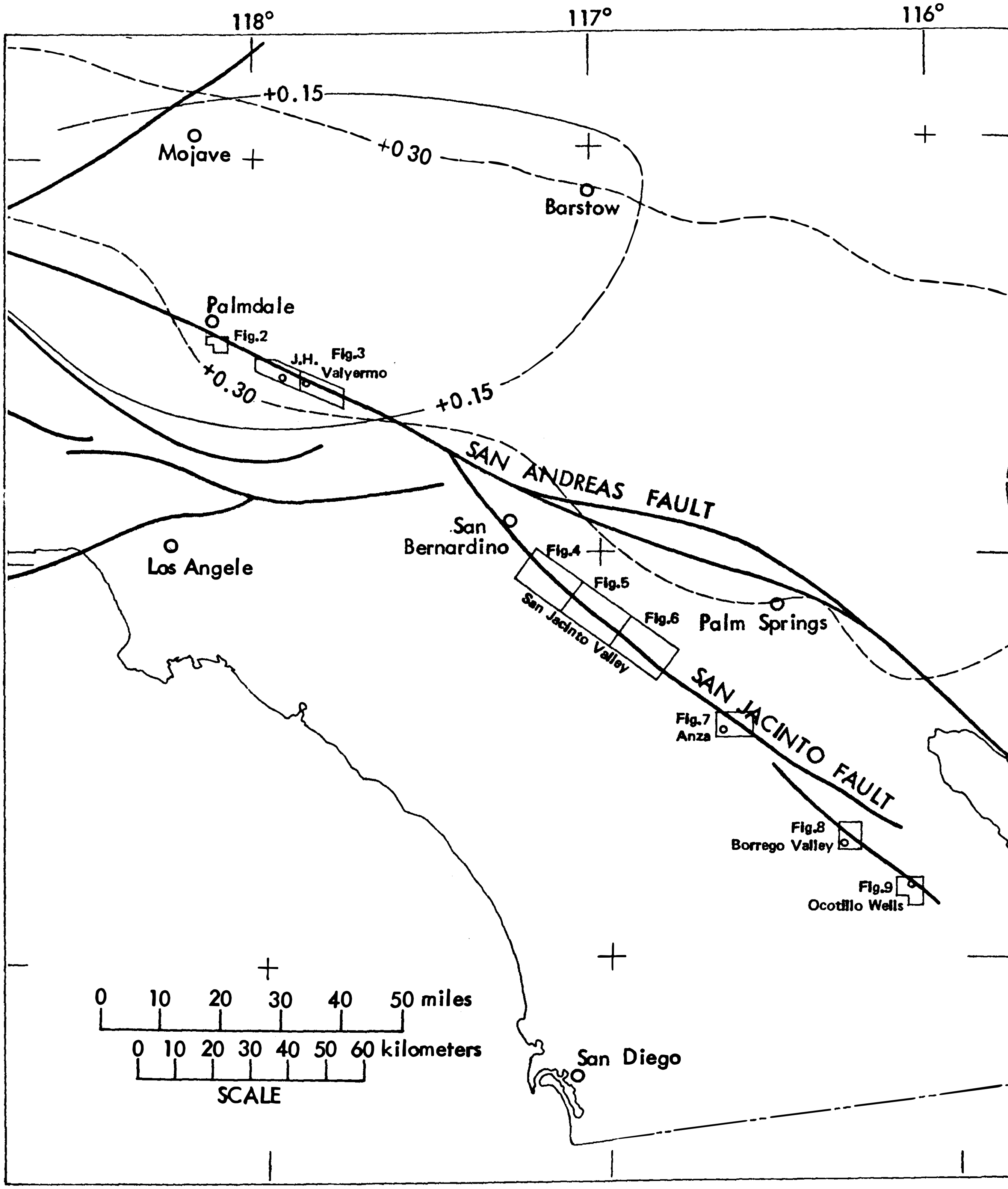


Fig. 1 - Index map showing southern California uplift (0.15 meter contour from Castle et al, 1976, and 0.30 meter contour from Bennett, 1977) and locations of detailed maps (Figs. 2-9) of observation wells along San Andreas and San Jacinto faults.

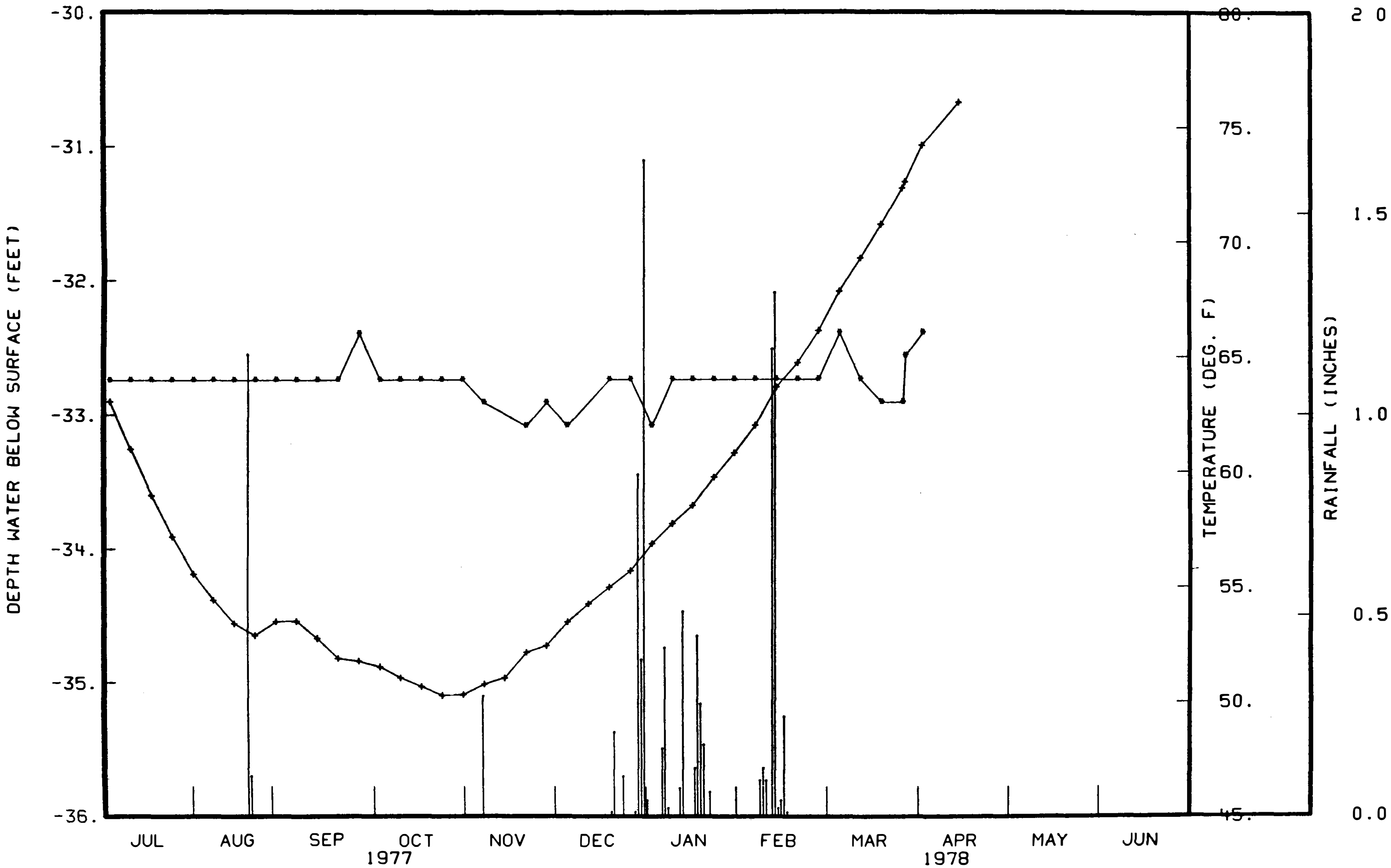


FIGURE 2 -- WEEKLY OBSERVATIONS OF WATER LEVEL (+) AND TEMPERATURE (*)
IN WELL NUMBER 5N/12W-1N1 AND RAINFALL (.) AT PALMDALE DURING 1977-1978

P.B.8.

Water-Level Monitoring in the Palmdale Bulge Area

8-4793-33300

W. R. Moyle, Jr.
U.S. Geological Survey
Water Resources Division
24000 Avila Road
Laguna Niguel, CA 92677
(714) 831-4232

Goals

The objectiv^e of the U.S. Geological Survey, Water Resources Division, water-level monitoring program for this study is to examine ground-water levels and ground-water temperatures as they might be useful as precursory data in earthquake prediction.

Investigations

Essential to the examination of water-level changes is the need to quantify the causes of "natural noise" in the system that might mask any effects due solely to an earthquake. In an effort to measure these effects, data for barometric pressure, earth tides, air temperature, rainfall, and pumpage are being collected as part of this investigation.

Presently, the water-level monitoring system consists of seven wells with continuous water-level recorders and two additional wells which will subsequently have recorders installed on them. Three former monitor wells have recently been discontinued from the program. Two of these were discontinued because of poor water-level response, and a third was discontinued as a result of being destroyed by a flash flood.

Results

Figure 1 shows the location of all wells and microbarograph recorders used in this program.

Figure 2 shows data collected for the area of well 5N/11W-24G1 in November and December 1976. This figure shows the relation of barometric pressure and earth tides to water-level fluctuations. This well seems to be responding normally for the period of record as evidenced by the inverse relation between barometric pressure and water-level change.

On February 28, 1978, an earthquake of magnitude 4.1 occurred in Lucerne Valley 58 miles northwest of well 3N/8E-29C1. Although the water-level change in the well at the time of the earthquake is not evident in the hydrograph in figure 3, a water-level fluctuation of 0.003 feet was evident on the actual recorder chart. The general overall trend shown on this chart is a direct relation between water level and barometric pressure. This relation does not normally exist, unless a nearby well is being pumped or the water level has been affected by an earthquake. Although there is a well in the area with a pump capable of affecting the water level in the recorder well, a pumpage record for this well has not been obtained; efforts are presently being made to obtain these data. The rainfall that occurred during this time period does not seem to affect the water level in the recorder well, which is 90 feet below land surface.

Figure 4 shows two examples of continuous temperature measurements made at the bottom of well 6N/13W-8Q1 located within the San Andreas fault zone. This well is 155 feet deep with a water level 20 feet below land surface. The recorder measures the relative water temperature changes to 1/100°C. The normal monthly temperature change ranges between 0.04° and 0.07°C. During the winter months when rain and snow were present the monthly change was as much as 0.10°C. During the period of record there have been no earthquakes centered near the well to show any abnormal temperature changes due to earthquake activity.

Publications

National Oceanic and Atmospheric Administration, 1976-78, Tide Tables, 1976-1978, West Coast of North and South America, including the Hawaiian Islands: U.S. Dept. Commerce, 222 p.

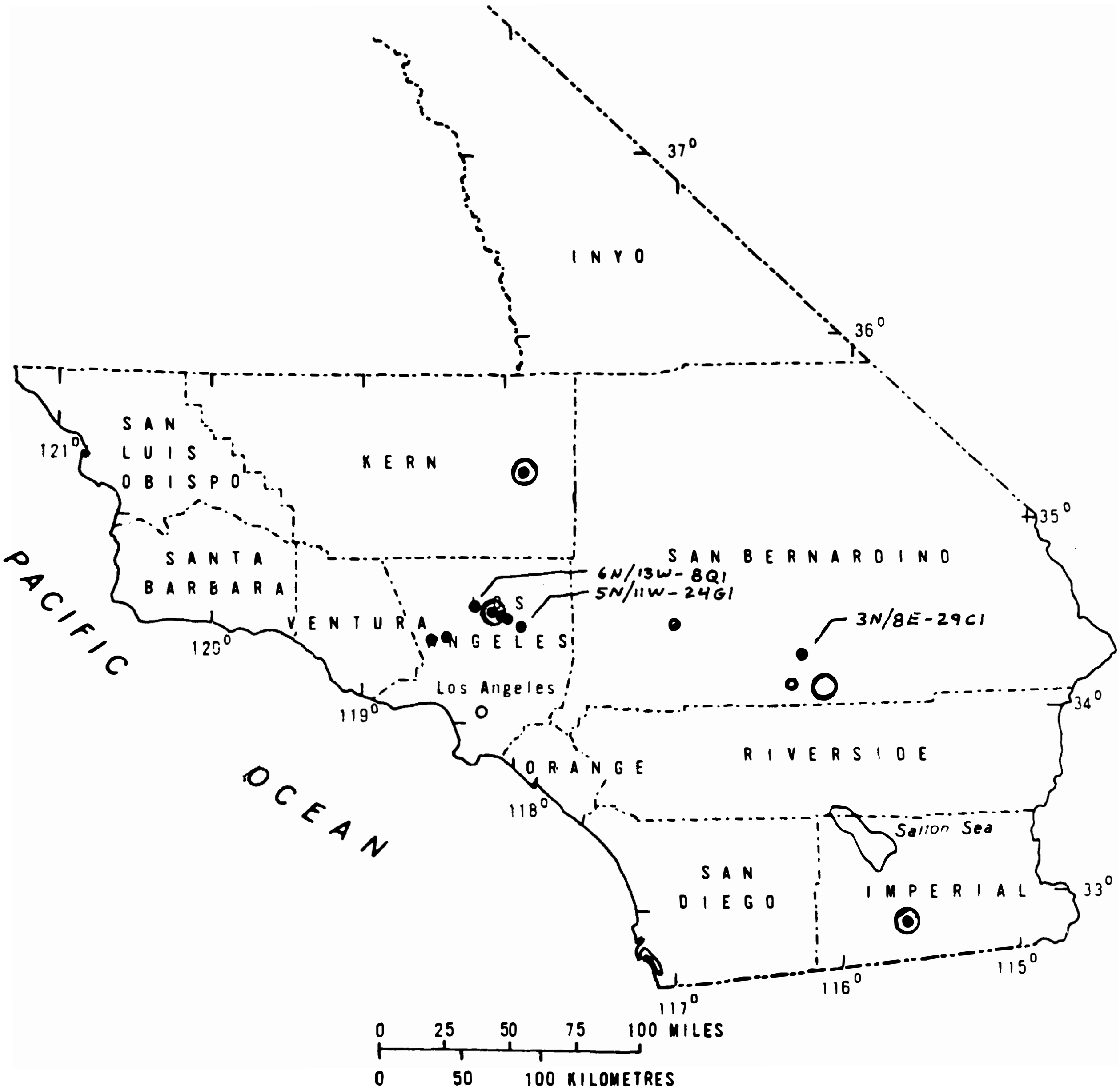


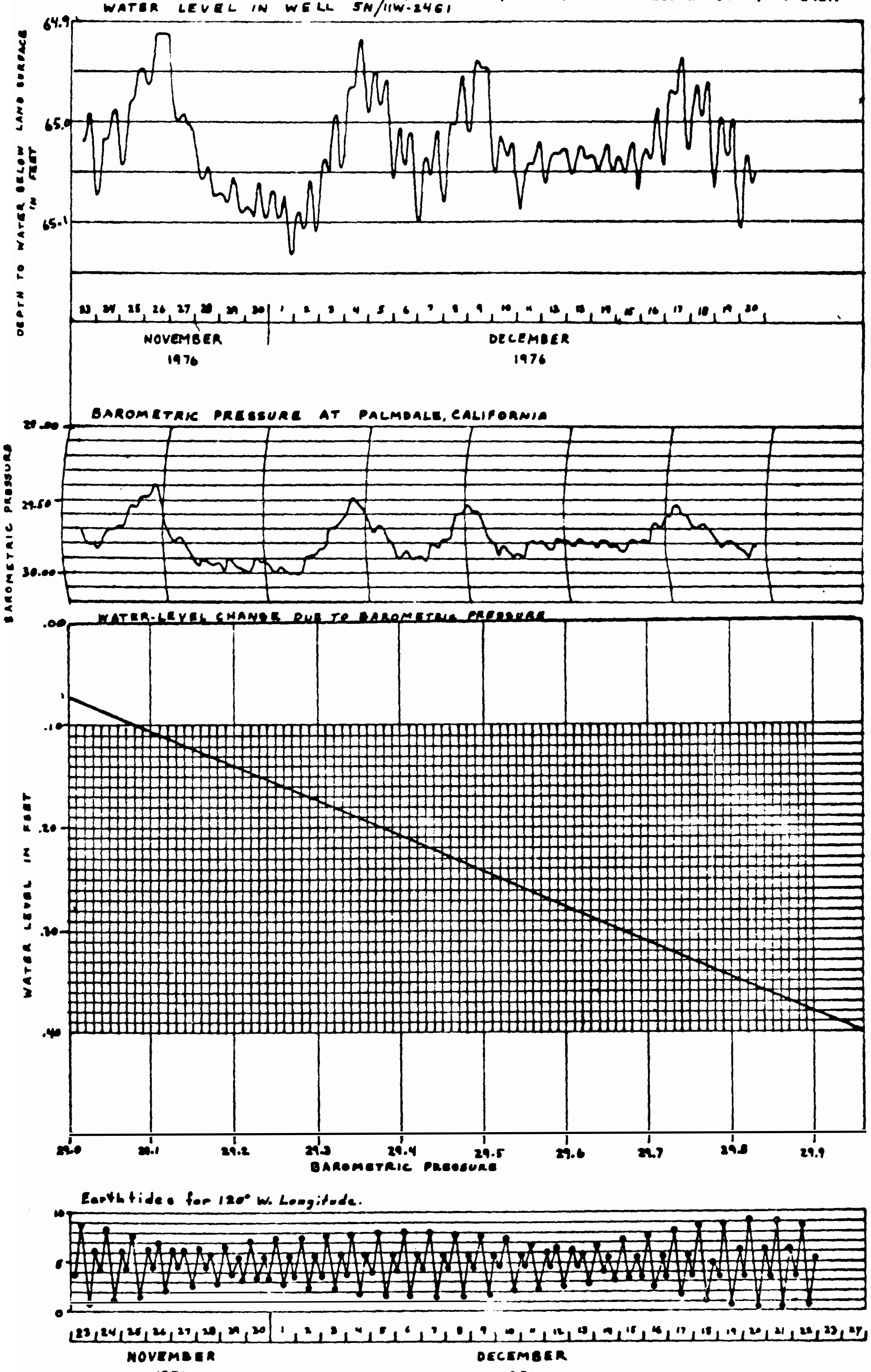
Figure 1.-- Map of southern California showing well and microbarograph recorders

● Water-level recorder

o Proposed site for water-level recorder

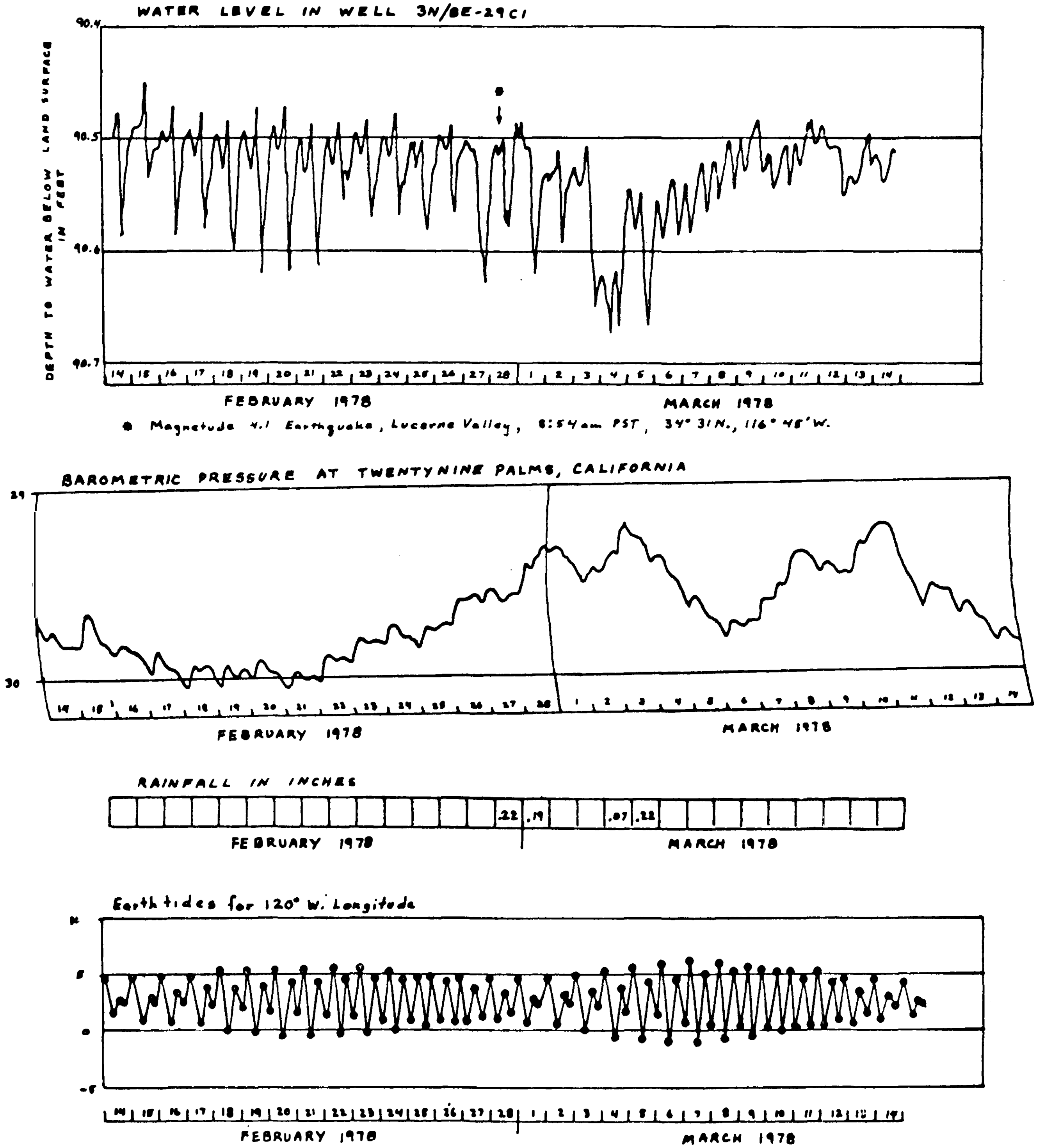
○ Microbarograph recorder

Figure 2.--- Relation between water level, barometric pressure, and earth tides at well 5N/11W-24B1.



Time in Universal Time Coordinates (UTC). Subtract 8 hours for Pacific Standard Time (PST).
Data from U.S. Department of Commerce, Tide tables 1976.

Figure 3.-- Relation between water level, barometric pressure rainfall, and earth tides at well 3N/8E-29C1.



Time in Universal Time Coordinates (UTC). Subtract 8 hours for Pacific Standard Time (PST).
Data from U.S. Department of Commerce, Tide tables 1978.

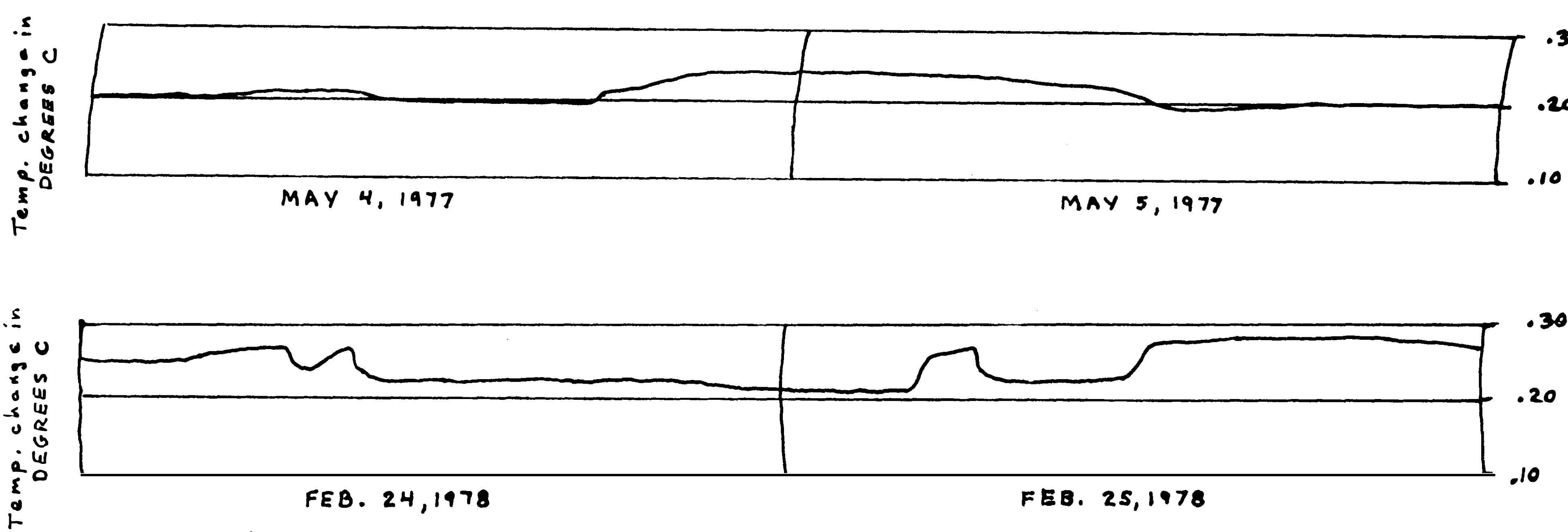


Figure 4. RELATIVE TEMPERATURE MEASUREMENTS MADE IN WELL 6N/13W-8Q1

UNIVERSITY OF CALIFORNIA, LOS ANGELES

BERKELEY • DAVIS • IRVINE • LOS ANGELES • RIVERSIDE • SAN DIEGO • SAN FRANCISCO SANTA BARBARA • SANTA CRUZ

Semi-Annual Report Summary

Institute of Geophysics and Planetary Physics
Los Angeles, California 90024

Contract #14-08-0001-16715

April 26, 1978

Can Animals Predict Earthquakes? A Search for Correlation between Changes in the Activity Patterns of Two Fossorial Rodents and Subsequent Seismic Events

Durward D. Skiles, Principal Investigator
Institute of Geophysics and Planetary Physics

Robert G. Lindberg, Co-Investigator
Environmental Science and Engineering
Laboratory of Fisheries and Marine Biology

During the reporting period we continuously recorded the gross motor activity of seven pocket mice (Perognathus longimembris) located out-of-doors in artificial burrow systems and approximately twenty kangaroo rats (Dipodomys merriami) located indoors in running wheel cages at our study site in Morongo Valley, California. No earthquake of sufficient intensity to be felt at the site occurred during this period.

The earthquakes of 22 September 1977 (M=3.5, 0141 PST; M=2.7, 0155 PST), whose epicenters were about 22.5 km due south of the study site, remain the only earthquakes that have been felt at the site since our monitoring facilities became partially operational in January 1977.

In our report for the period ending 30 September 1977 we noted that all of the kangaroo rat activity records and five of the pocket mice records lacked reasonable evidence of behavioral anomalies immediately prior to the September earthquakes. Certainly no evidence was forthcoming of anomalous behavior comparable to the dramatic anecdotal reports which are often cited in the literature. However, during the days or hours immediately preceding the earthquakes, the records of two pocket mice showed distinct departures from the activity patterns which had been characteristic of the previous two or three weeks of September. (Owing to the heavy rains of August 1977, records prior to 2 September 1977 are either not available or not useful for purposes of comparison).

Examination of records obtained since our last report reveals that while these two occurrences still stand out as departures from the usual activity patterns, both animals have exhibited similar behavioral anomalies which were not followed by an earthquake. Figure 1 shows the above ground activity record of one of these animals (PM1) for the period 2 September 1977 to 3 December 1977. From at least 2 September until 21 September PM1 did not appear above ground although he was quite active underground (Fig. 2). But on the evening of 21 September, a little over four hours before the earthquakes, PM1 appeared on the surface, was quite active for about two hours, and continued to exhibit sporadic surface activity for about one week. Since that time, he has largely avoided the surface but has briefly visited the surface for an hour or so on several occasions. None of these surface visits, however, was followed by a nearby earthquake. (Note, however, that the only period during which PM1 made daily visits to the surface for several days was immediately after the 22 September earthquakes. This lends tenuous support to the notion that PM1 was indeed disturbed by the earthquakes or related phenomena).

It is not surprising that only one of several instances of 'unusual' behavior in each of these pocket mice was associated with subsequent nearby seismic activity. It simply confirms what we and others have often stated - namely, that the unusual behavior allegedly exhibited by certain animals prior to earthquakes is generally normal behavior which appears unusual either by virtue of its occasional or irregular nature or by virtue of its unusual time or place of occurrence.

There is little doubt that we have objectively recorded, immediately prior to a nearby earthquake, an event of unusual animal behavior. The mere recording of this event, however, can hardly be said to have brought us significantly closer to the answer to the fundamental question of whether the behavioral event was related to, or merely fortuitously coincidental with, nearby seismicity.

While the 'unusual' animal activity events shown in Figure 1 are immediately obvious to the casual observer, it is clear that subtle changes in a record such as that shown in Figure 2 could easily go unnoticed. Hence the major accomplishment during the last six months was the fabrication and installation of our tape cassette event counting and recording systems. These systems are far superior to the pen and ink recording systems which produced Figures 1 and 2, as the data are now both quantitative and immediately accessible for computer processing. For each kangaroo rat we are recording the total number of events (running wheel revolutions) every 5 minutes; for each pocket mouse we are recording the total number of events (activity switch gate closures) every twenty minutes. During the coming months we shall develop programs for numerically processing of these data and for displaying the raw data in a format similar to that of Figures 1 and 2.

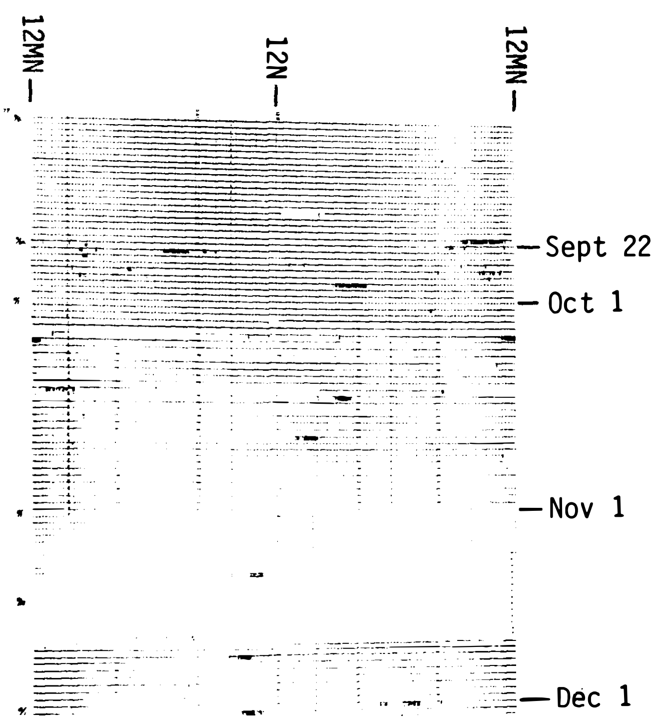


Fig. 1. Above ground activity of pocket mouse PM1.

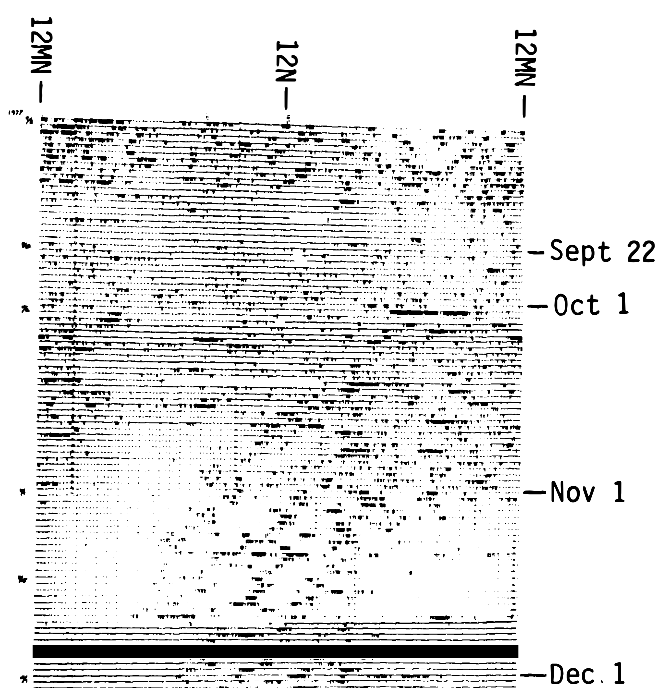


Fig. 2. Activity of PM1 76 cm underground.

Data Processing Service

8-9970-01499

Clearthur Lee
U. S. Geological Survey
345 Middlefield Rd
Menlo Park, CA 94025
(415) 323-8111 Ext. 2080

Goals

A. Data Processing Service is striving toward implementing more advanced processing systems, so that the processing of seismic data can greater enhance the scientists' research efforts.

B. Automatic Data Switching System; being implemented so that when mechanical or electronic failure occurs within seismic telemetry recording systems, all data will be transferred to a back-up system.

C. Implementation of an automatic restart system if a power failure occurs for seismic data recorders.

Investigations

A. This project provided the Data Processing Services to the user scientists analyzing and interpreting the scientific data gathered during the period.

Results

A. Converted "H" Eclipse playback and digitizer system to up-grade of four (4) pass system via one (1) pass.

B. Computer users terminal room has been up-dated with high speed data communications with U.S.G.S. Multics computer.

C. Complete interface of digitizer room with Multics.

D. Incorporated a compatibility between Data General Corporation Mini-Computer Systems.

Reduction of Noise in Precursor Measurements

9960-02111

J. Alan Steppe
U. S. Geological Survey
345 Middlefield Road
Menlo Park, CA 94025
(415) 323-8111 ext. 2479

The objective of the project is to develop procedures for reduction of the noise in measurements of earthquake precursors caused by sources that are not earthquake related. Removal of these extraneous effects will help produce accurate uncontaminated observations of tectonic phenomena that are important to the development of a scientific understanding of the physical processes that precede earthquakes. Reduction of noise will also aid in the development and application of procedures for classifying a data set as premonitory or not premonitory to an earthquake.

Currently an effort is underway to develop techniques to remove from the data of tectonomagnetic experiments the geomagnetic variations not caused by changes in crustal stress. This investigation utilizes concepts of statistics, signal processing, and time series analysis.

It has been found that noise in tectonomagnetic experiments caused by geomagnetic variations due to nonlocal sources can be reduced by applying multivariate linear regression to data from a network of magnetometer sites. Residuals obtained by subtracting from the observed values at a particular site the values calculated from a regression expression using the simultaneous values at a number of other sites tend to have nonlocal variations suppressed and hence to emphasize effects local to that particular site. For total field data from central California, at periods greater than a day, this method provided a moderate reduction of the noise below the level obtained by two-site differencing. The effectiveness varied considerably from site to site, with an average improvement in the standard deviation of the corrected time series of roughly a factor of two, compared with two-site differences. No other linear instantaneous procedure using the same data can achieve a smaller RMS residual. The sensitivity of the method to missing data can be reduced somewhat by using subset regressions. It was possible to find regression expressions that remove most of the long-period variations (longer than about 100 days) from the available data, although they may not be statistically reliable.

Minicomputer Systems Development

8-9970-02118

Peter R. Stevenson
U. S. Geological Survey
345 Middlefield Rd
Menlo Park, CA 94025

Goals

A major goal of this project is to significantly assist the Office of Earthquake Studies in efficiently processing seismic data by means of minicomputer hardware/software.

The main emphasis of the past six months has been on the implementation of a comprehensive data processing system for Central California microearthquakes.

A minicomputer-based seismic data processing system is being developed to process local earthquakes from the U.S.G.S 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 within 24 hours of the occurence of the earthquakes.

The system is designed to process events involving hundreds of seismic stations. To accomplish this, it creates a dubbed analog library tape from three 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 a computer-updated "Event Progress Log", 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 request until the event has been either copied onto a digital archive tape or processing has been discontinued.

The events are detected initially 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 of the events. This tape is designed to be read on the U.S.G.S. Multics computer.

Other goals of the project include enhancement of the geothermal system, incorporating programs and revisions developed for the California Network Processing (CNP) System. A secondary level of enhancement includes the implementation of a spectral analysis package, a seismic section plotting program for the Varion States plotter, and a stand-alone digitizing program for the ½" field tapes.

Activity

During this report period, the major effort was spent on developing the CNP system, utilizing the A/D conversion, Disk access interactive plotting, and Hypocenter software developed for the geothernal system. A file driven system was designed, exploiting the file handling facilities of RDOS, the manufacturers supplied operating system. Stevenson gave a paper at the spring AGU meeting on the CNP system.

Also during the report period, a 92 megabyte disk and additional memory was acquired for the A and B machines. Modifications of the applications software was required in order to be compatable with a major revision at the manufacturer's operating system.

A significant amount of time was spent by Hobson on working with Data General on the hardwar/software installation of the new Disk and on converting to Rev. 6 of RDOS.

Stevenson and Jackson spent several weeks on a committee which were writing specifications for a new dual processor system being planned at the office level.

In addition, Jackson consulted at length with Fletcher, Bufe, and Briscoe on interfacing their digital recording systems and with C. Lee, Jensen and Van Schaak in an effort to complete the B system patchpanel.

Hobson has spent 30% of his time acting as an eclipse consultant for the various users, especially Fred Klein and Stevenson.

Results

All of the modules of the CNP system are completed except for the Archive tape program. It is in the final stages of debugging. Earthquakes have been processed as far as outputing locations on the Tektronix hardcopy. The Geothermal System now in use has remained static during the report period.

Publications

Stevenson, P.R., Jackson, T.C, Hobson, J.L., Haken, R.L., Fang, S.K. 1978.

A computer-based processing system for seismic network data (abs.): EOS (Am. Geophys. Union Trans.) V 59, No. 4, pg 316.

Theoretical Mechanics of Earthquake Precursors

9960-02115

William D. Stuart
U.S. Geological Survey
345 Middlefield Road
Menlo Park, CA 94025
(415) 323-8111 ext. 2756

Theoretical models for earthquake instabilities and associated precursors are being constructed and analyzed to provide a method for anticipating earthquakes using ground deformation measurements. Two- and three-dimensional, vertical, strike-slip models and two-dimensional thrust models invoking strain softening fault zone properties are in various stages of development, analysis, and testing. For certain values of geometric and constitutive parameters, the models admit inertia-limited instability of fault slippage - an earthquake analog - but stable quasi-static slippage otherwise. Because theoretical time-dependent ground deformation is generally different between stable and unstable deformation, inversion of observed deformation should determine if instability is possible in situ. In other words, a physical model is used to decide if observed anomalous ground deformation is necessarily precursory to an earthquake.

Two types of antiplane strike-slip instability models have been studied. In both models the earth surrounding the fault zone is approximated by elastic plates and regional forcing is by a remotely applied horizontal shear displacement. In the first case the remote displacement is applied also at the plate bottom. Solutions are obtained with the finite element method. In the second case, the stress-free plate bottom allows use of analytic theory for continuous distributions of screw dislocations. By postulate (with modest support from laboratory data) the constitutive law for fault zone material contains a peak stress followed by strain softening to a residual level at large strain. The peak stress itself is assumed to first increase, then decrease with depth. Simulations show that with growing remote displacement, an inertia-limited instability or sudden fault slip, can occur if the fault weakens rapidly enough or the elastic plates are sufficiently compliant. The most unstable simulations show that just before instability, surface shear strain rate is accelerating near the fault trace (within a focal depth), but decelerating farther away. For model parameter values appropriate for great earthquakes and geodetic strain measurement precision of 10^{-6}, it appears that certain cases of instability can be inferred in advance of the earthquake with geodetic data. Prior to instability, fault slip rate accelerates quasi-statically. The position of greatest slip velocity and acceleration is slightly deeper than the point of greatest peak stress and is identified as the earthquake focus. These models will be further studied to evaluate the effects of different strain softening laws, geometry, and viscoelastic response of the asthenosphere.

The two-dimensional thrust fault version of the above models employs a strain softening law on the fault where the peak stress increases down dip to a maximum and then decreases. Forcing is by growing horizontal compressional displacements applied remotely. Preliminary solutions using the finite element method show that, as with the strike-slip models, instability is possible only for certain model parameter values. Prior to instability, a region of growing uplift migrates toward the future epicenter from the projected down dip direction. Total elevation change before the instability is an order of magnitude less than the unstable (earthquake) change at the fault trace. The increasing uplift, its migration, and the ratio of pre- to co-seismic elevation change are in reasonable agreement with similar changes observed prior to the 1971 San Fernando earthquake.

For strike-slip earthquakes of magnitude less than about five, a three-dimensional model is required. In this case, fault peak stress is assumed to vary both horizontally and with depth. Field data for testing appear to be available, but no model solutions have been obtained yet.

All models will be modified so that dynamic rupture may initiate at instability. Thus a single model will be available to relate quasi-static precursory deformation with earthquake parameters for each fault geometry.

Publications

Stuart, W. D., 1978, Review of theories for earthquake instabilities, submitted to Jour. Geophys. Res.

SEMI-ANNUAL REPORT SUMMARY, Contract No. 14-08-0001-16719
1 October 1977 to 31 March 1978
"SOUTHERN CALIFORNIA SEISMIC ARRAYS"

Clarence R. Allen and James H. Whitcomb
Seismological Laboratory, California Institute of Technology

This semi-annual report covers the six-month period from 1 October 1977 to 31 March 1978. The contract's purpose is the partial support of the seismographic 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 employees stationed at Caltech. According to the contract, the primary visible product will be a joint Caltech-USGS catalog of earthquakes in the southern California region during the contract year, although quarterly preliminary maps and catalogs are also required. Figure 1 shows preliminary epicenters of events that were detected and located by SCARLET during the first half of the contract period, and quarterly catalogs accompany the complete reports.

Some of the seismic highlights in the southern California region during the 6-month period are these:

Number of located events: 3897
Number of earthquakes reported to the Seismological Laboratory as having been felt: 63
Number of identified quarry blasts: 476
Largest earthquake: $M = 5.0$ (3-11-78, near Victoria, Baja California)
Number of earthquakes of $M = 4.0$ and above: 15, all but 2 of which were in the Imperial Valley area
Smallest earthquake reported felt: $M = 2.2$ (12-3-77, Hollywood)
Significant swarms: (a) near Cerro Prieto, Baja California, early March 1978, $M_{max} = 5.0$; (b) near Brawley, California, late October 1977, $M_{max} = 4.2$ (c) near Brawley, California, mid-November 1977, $M_{max} = 4.3$

Perhaps the most striking feature of the 6-month seismicity map (Fig. 1) is the conspicuous "hole" centered northwest of the Salton Sea in the Coachella Valley area. This feature has existed since at least 1950 and possibly represents a temporal seismic gap along the adjacent segment of the San Andreas fault. With the exception of the Imperial Valley and San Jacinto fault areas, much of the rest of the epicenter map looks as though a shotgun had been fired at it. That is, despite the high precision of current epicentral locations, most smaller shocks are not aligned along major active faults. It is too early to draw firm conclusions, but it seems that a somewhat different pattern is emerging in much of southern California as compared to that in the central part of the state near San Francisco, where there is a much more obvious alignment of small shocks along principal faults.

Since the beginning of the contract year, Caltech and USGS personnel have been participating on a half-and-half basis in the CEDAR (Caltech Earthquake Detection and Recording) timing and location routine, alternating on 2-hour shifts. The daily routine has taken an average of 7 hours, and the shared responsibility seems to be working well. Archiving, relocations, and magnitude assignments have continued to be carried out by Caltech.

By the end of calendar year 1978, we expect to have located perhaps 6500 events, and it is interesting to compare this projected total with those for some previous years (Fig. 2). It is clear that the CEDAR system, together with the expanded network, is permitting far more completely documentation of southern California seismicity than has ever before been possible.

Although magnitudes for larger events are still being obtained by reference to paper records from various telemetered stations (including those with simulated Wood-Anderson instruments), two independent efforts are currently underway at the Seismological Laboratory for the assignments of computer-based magnitudes. One of these, developed by Carl Johnson, is already being used routinely in a prototype experiment. It is based on coda amplitudes recorded in successive 5-second time samples, related to the P-time in a manner consistent with the duration magnitude. One of the interesting preliminary results from this study is the map of Figure 3, which contours levels of detectability throughout the southern California region. On the magnitude 2.0 contour, for example, 90% of all shocks of magnitude 2.0 and greater are being routinely detected by the CEDAR system as presently operated. It might be noted that although the density of seismic stations is greatest in the Imperial Valley area, the highest level of detectability is instead in the area north of Los Angeles -- simply reflecting the background noise levels and the gains at which individual instruments can be operated and the records effectively read. For the first time, we are gaining an accurate statistical evaluation of the network's capability in terms of levels of detection.

During the reporting period, 6 stations were permanently removed from SCARLET (FTM, LGA, PIC, SLU, CHM, WH2), and 3 stations were added (JNH, MOV, LJB). In addition, telemetry was established from BAR for the first time, and low-gain, 3-component telemetered instruments were added at LJB. At the end of the reporting period, 147 signals were being recorded by the CEDAR system at the Seismological Laboratory's computer center, and 142 signals continue to be recorded on Develocorders. Develocorder films, however, are no longer being routinely scanned.

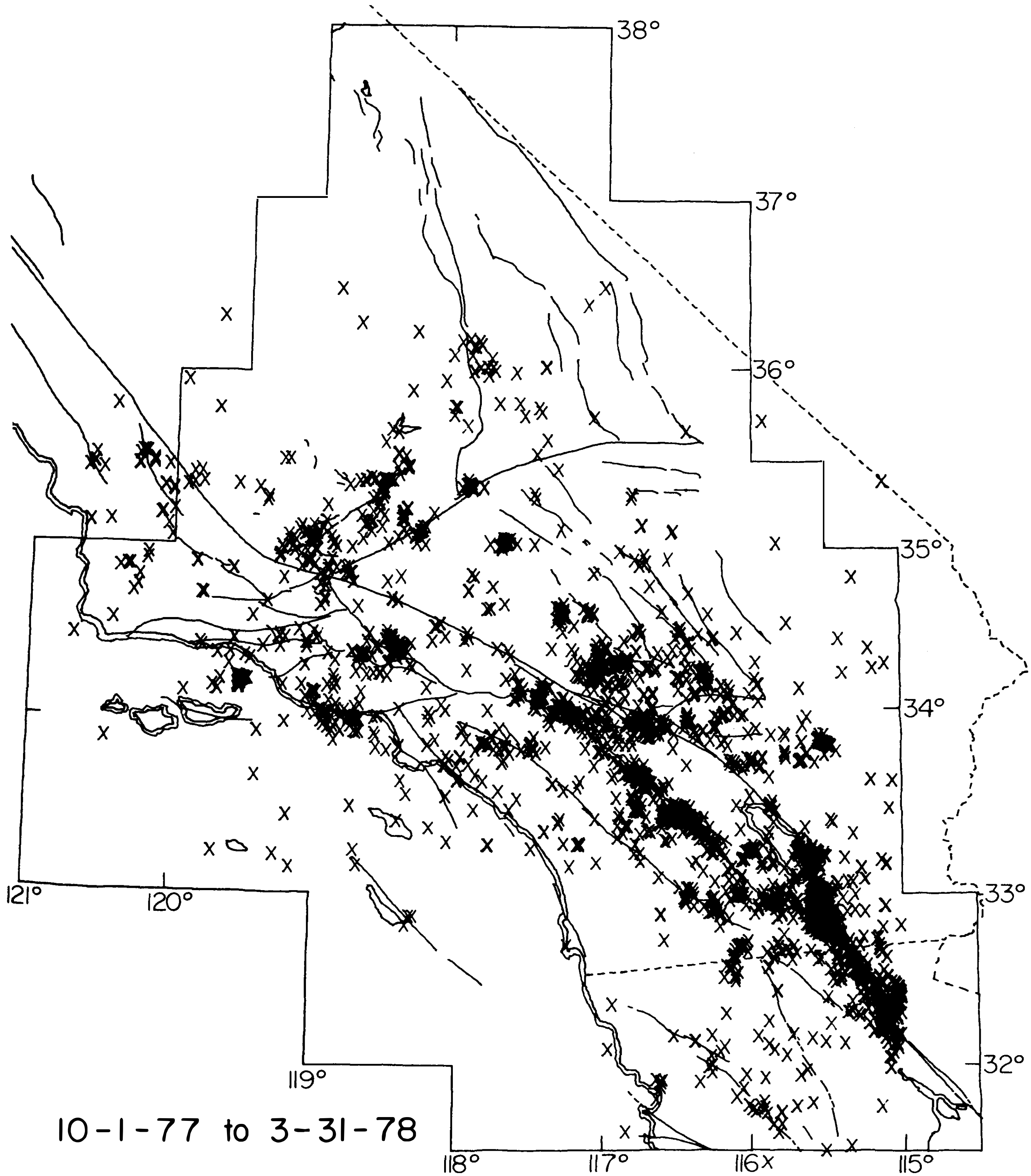


Fig. 1--Preliminary epicenters of events in the southern California region, 1 October 1977 to 31 March 1978. Quarry blasts have not yet been removed

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     NUMBER OF CATALOGED EARTHQUAKES

       NO. OF
YEAR   EVENTS          2000          4000          6000
            +             +             +             +
1978   6458 ********************************
1977   5042 *************************
1976   3260 ****************
1975   2877 **************
1974   1264 ******
1973   1414 *******
1972    747 ****
1971    837 ****
1970    472 **
1969    674 ***
1968    577 ***
            +             +             +             +

 1978 PROJECTED FROM FIRST QUARTER
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Fig. 2--Number of local earthquakes cataloged by SCARLET for individual years since 1968

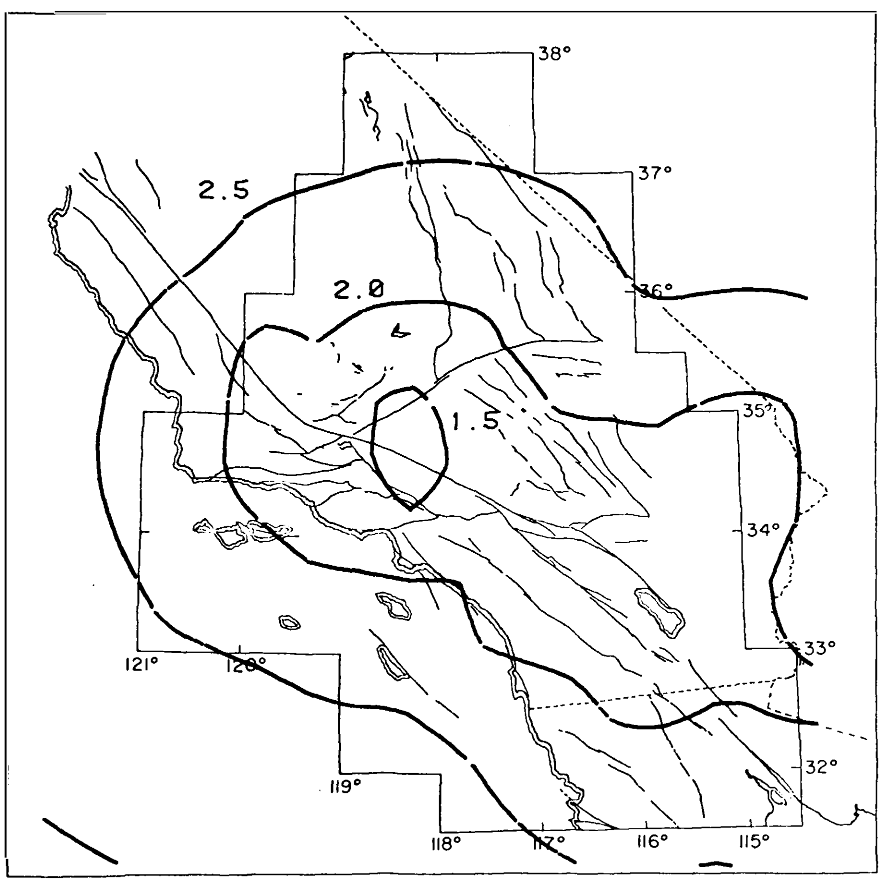


Fig. 3--Contours of 90% detection capability

Microprocessor Based Seismic Processing

8-9970-02119

Rex V. Allen
U. S. Geological Survey
345 Middlefield Rd
Menlo Park, CA 94025
(415) 323-8111 ext. 2240

Goals

A. Complete development of systems for detection, timing, and processing of earthquakes on a single seismic trace. The system will be based on a low-power microprocessor for field use where required.

B. Using a set of these systems build an improved automatic on-line earthquake detection and location system operation with the existing USGS telemetered data. This will be an office-based system.

C. Develop a field unit based on the above system which records and transmits only seismic events, or descriptors derived from them.

D. Using all the above mentioned equipment examine a large suite of small earthquakes for precursors to large events.

Investigation

The event picker for use in an in-house system was written to allow one microprocessor to process up to four seismic inputs. The hardware including multiplexers and real-time clock handling capability was designed and built by Jim Ellis. Hardware and software have been checked out and operates satisfactorily.

This 4-input system is now in routine operation on-line processing four stations from the Geysers area each night or whenever the system is not busy during the day. From these results we expect to be able to improve picker performance and also to develop a better system for estimating reliability of picks with a minimum memory requirement.

A 10-processor, 40-input system is now being built to a design capable of expansion to several hundred inputs. This will be the prototype for the planned in-house automatic processor.

The principal short-term objectives we are pursuing at this time are investigation of multiprocessing techniques as applied to automatic seismic processing, and a detailed study of factors affecting the reliability of time and first motion picks by automatic pickers.

Publications

Allen, R.V., and Ellis, J.O.

"A Discriminating Trigger for Automatic Seismic Recording".

Earthquake Notes V 49, No. 1, pg 80 March 1978

LAMONT-DOHERTY NETWORK OF STATIONS IN NEW YORK STATE AND ADJACENT AREAS

SEMI-ANNUAL TECHNICAL REPORT
Contract No. 14-08-0001-16750

SUMMARY

Lamont-Doherty currently operates a network of about 40 short period, single component seismic stations located in New York, New Jersey and Vermont. The ensuing data are routinely analyzed and bulletins listing earthquake locations are published on a quarterly and annual basis. The quarterly bulletin, ending 31 March 1978, is now available upon request. The annual bulletin for the year 1977 is nearing completion and should be available soon.

A number of focal mechanism solutions for earthquakes in northeastern North America were obtained using the data from the network. The solutions are either of thrust or strike slip type; no evidence is found for normal faulting.

Earthquakes in the Adirondacks and adjacent Canada predominantly show thrust faulting on north-northwest trending planes. In some cases, the shocks can be related to known geologic or topographic features.

In southeastern New York and northern New Jersey earthquake locations correlate remarkably well with mapped faults and faults inferred from aero-magnetic data. High angle reverse faulting on NNE trending planes is indicated. Focal mechanism solutions for an earthquake in Rhode Island and another in New Hampshire are almost identical to those found for earthquakes in the greater New York City area; suggesting that the principal stress directions are relatively uniform over a large area.

A paper discussing the maximum compressive stress directions and the interrelationship between seismicity, stress and geologic features in eastern North America is in preparation.

Yash P. Aggarwal

Lamont-Doherty Geological Observatory
of Columbia University
Palisades, New York 10964

University of Washington

Geophysics Program

EARTHQUAKE HAZARD EVALUATION IN THE PACIFIC NORTHWEST

R.S. Crosson and S.W. Smith

Contract No. 14-08-0001-16723

During the first six months of the current contract period, the western Washington network operated in a stable configuration of 22 stations. Review was completed on earthquake data bases for 1977 and a bulletin manuscript was completed for that year. Routine processing is on a stable and current basis and bulletin preparation, beginning in 1978, is being done on a quarterly, preliminary basis. No major changes in the regional pattern of seismicity have occurred, however, several minor swarms have been identified. The largest magnitude earthquake in the central Puget Sound basin to be recorded with the current network occurred on 11 March 1978 in south Kitsap County. Additional study of this earthquake is underway.

Work proceeded on the earthquake source modeling problem. Emphasis here is primarily directed toward understanding the physics of rupture initiation and arrest. Work is currently proceeding on adapting computer codes to model various rupture initiation processes.

Work continued at a reduced level to adapt previously developed three-dimensional velocity modeling procedures using non-linear least squares, to the three dimensional structure problem. A three dimensional travel time program has been written which uses a first order correction of a layered reference model to simulate model lateral variations in velocity. Initial tests of this routine have been made.

Improved U.S. Earthquake Catalog

8-9920-01901

James W. Dewey
Branch of Global Seismology
U. S. Geological Survey
Denver Federal Center, MS 967
Denver, CO. 80225
(303) 234-4041

Investigations

1. Jim Dewey and Dave Gordon are continuing their relocation of instrumentally-recorded earthquakes in the Eastern U.S. using arrival-time data reported in seismological bulletins and data they have interpreted themselves from records of WWSSN stations.

2. The joint hypocenter determination (JHD) program was rewritten to make use of "calibration stations" rather than calibration events. Calibration stations are assumed to have zero arrival-time bias. For Eastern U.S. earthquakes, we are designating as calibration stations those stations within 3^{o} from the nearest earthquake of a given source region.

Results

1. All eight regionally or teleseismically recorded earthquakes occurring through 1976 within 100 km of Charleston, South Carolina have been relocated to lie within or very near to two small zones of seismic activity defined by the recently installed South Carolina network. These zones are the Middleton Place Zone, thought to be the source of the destructive 1886 Charleston earthquake, and the Bowman Zone, located about 50 km NW of the Middleton Place Zone. The fact that these zones, identified on the basis of microearthquakes, also account for all the regionally or teleseismically recorded earthquakes from the Charleston area, supports the hypothesis that significant seismic activity in the Charleston area is restricted by some mechanism, perhaps by stress concentrations near mafic intrusions, to occur in relatively few source regions rather than randomly throughout a broad zone of the coastal plain.

2. The South Carolina earthquake of July 26, 1945 is relocated to lie both in the inferred Eastern Piedmont Fault Zone, recently proposed by Hatcher, Howell, and Talwani (Geology, 5, p. 636) and near the reservoir Lake Murray, which was completed in 1930. Reservoirs in other parts of the South Carolina Piedmont seem to have triggered earthquakes and it is therefore possible that the 1945 shock was triggered by the filling of Lake Murray.

3. We have reliably located several shocks in West Virginia and Kentucky to lie immediately north of the faulted part of the Appalachian fold belt, in regions where the USGS Geologic Map of the United States shows no faults whatsoever.

4. There is an elongated east-west zone of instrumentally-determined epicenters roughly coincident with the Virginia-West Virginia border between 80.4°W and 81.7°W at approximately 37.3°N latitude. The suggestion of an east-west zone of activity is not new for this part of the country. Bollinger (Bull. Seism. Soc. Am., 63, p. 1785) postulated an EW oriented Virginia seismic zone between 77°W and 79°W centered on 37.5°N latitude. The zone extending from 80.4° to 81.7°W has two characteristics that must be weighed before a geophysical explanation of the zone can be proposed. First, notwithstanding its strong east-west elongation, the zone also has a significant north-south spread. Therefore, the zone cannot be attributed to slippage on a single fault. Second, the west end of the zone lies in a coal-mining region and the possibility must be considered that the seismicity at the west end has been triggered by mining.

5. The later-arriving phases recorded at regional distances, Pg, S, and Lg, are valuable supplements to the initial P-wave in locating small and moderate earthquakes. Because these later arriving phases have slower velocities than the initial P-wave, a given error in the interpreted arrival time produces less of an error in epicentral location than it would in the arrival-time of the initial P-wave.

Reports

Dewey, J. W., and Gordon, D. W., 1977, Redetermination of epicenters of instrumentally recorded earthquakes in the eastern U.S: (abs.): Earthquake Notes, v. 48, p. 12.

Dewey, J. W., 1978, Joint hypocenter determination using calibration stations: Application to eastern North America, (abs.): Earthquake Notes, v. 49, p. 35.

Central California Seismic Network

8-9930-01160

Jerry P. Eaton
U. S. Geological Survey
345 Middlefield Road
Menlo Park, CA 94025
(415) 323-8111, ext. 2575

Goals

1. To identify and delineate active faults in central California and to assess their potential for producing a damaging earthquake.

2. To develop improved models of the processes that generate earthquakes and of the mechanics of their sources.

3. To provide a high quality source of unreduced and reduced data on earthquakes in central California as a basis for more detailed seismic studies and for related non-seismic studies: dubbed magnetic tape library of network records of important earthquakes; earthquake phase readings and hypocenter determinations on punch-cards, computer tape, and computer mass-data storage cells; earthquake catalogs, epicenter maps, etc.

4. To develop effective seismic techniques for earthquake prediction.

Investigations

Recordings from 200 stations of the multi-purpose 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 earthquake mechanics and prediction. A magnetic tape library of "dubbed", unprocessed records of the network for significant local earthquakes and teleseisms is prepared to facilitate further detailed studies of crust and upper mantle structure and physical properties and of the mechanics of earthquake sources.

In addition to its primary role in earthquake hazards and earthquake prediction studies, the network contributes to research on the sources of geothermal energy (network in The Geysers/Clear Lake region) and provides seismic monitoring for environmental hazards studies around 1) the Warm Springs Dam site northwest of Santa Rose, 2) around the Oroville and Melones Dams and Auburn Dam site in the western foothills of the Sierra Nevada mountains between Chico and Modesto, and 3) around Lassen volcano.

Results

The primary products of this project are:

1. Annual volumes for 1974 - 1976,	June '78.
2. Annual volumes for 1975,	September '78.
3. Annual volumes for 1977,	February '79.
4. Quarterly volumes for 1978,	July '78, October '78, etc.

Publications

Eaton, J. P., and Simirenko, Marie, 1978, Current microearthquake activity in the Sierra Nevada foothills near Sacramento, California (abs.): Earthquake Notes, v. 49, no. 1, p. 84.

Criley, Ed., and Eaton, J. P., 1978, Five-day recorder seismic system (with a section on the Time Recorder Generator, by Jim Ellis): U. S. Geol. Survey Open-File Rept. 78-266, 86 p., 20 figs.

Eaton, J. P., 1978, Playback Station #2 for Cal net and 5-day-recorder tapes: U. S. Geol. Survey Open-file Rept., 48 p., 23 figs.

Southern California Cooperative Seismic Network

8-9930-01174

Gary Fuis
U.S. Geological Survey
% California Institute of Technology
Seismological Laboratory 252-21
Pasadena, CA 91125
(213) 795-6811, ext. 2957

Goals

Develop, maintain, and utilize a seismic network in southern California in close cooperation with CIT in order to develop a detailed understanding of the seismicity of southern California, and to provide an instrumental basis for the prediction of earthquakes in this region.

Investigations

1. Investigations conducted using stations of the southern California cooperative seismic network exclusive of the Imperial Valley stations are reported here for the period October 1977 - March 1978. Data from these stations, currently numbering 110, are now analyzed routinely using the Caltech Earthquake Detection and Recording (CEDAR) system (refer to C. Johnson, EOS (Am. Geophys. Union Trans.), v. 59, p. 316).

2. We compiled quarterly seismicity maps for southern California for FY77 and have drafted a preliminary catalog of earthquakes for this period.

3. We studied a swarm of earthquakes near Palmdale, California, which appears to be anomalous in the instrumental seismic history of that area.

4. We continued *in situ* timing of blasts at several quarries in southern California in order to monitor any changes in seismic velocity that might have occurred.

5. We installed or will shortly install 10 new high-gain, vertical-component, short-period (1-second) seismometer stations in southern California. These were added to 1) fill in holes in the existing network, at Desert Hot Springs, Morongo Valley, and the central Peninsula Ranges of southern California, 2) increase coverage of the Palmdale earthquake swarm, and 3) expand the network into the northern Mojave Desert. In addition, we added or will shortly add horizontal and low-gain-vertical components to 4 seismometer stations along the San Andreas fault from Palmdale to Desert Hot Springs to be of use in 1) depth determinations, 2) P/S amplitude studies, and

3) other research. Regrettably, owing to funding cutbacks, we had to eliminate 3 stations in the easternmost Mojave Desert and 3 stations in Yuma, Arizona area.

6. We have undertaken an investigation of focal mechanisms of earthquakes in the San Bernardino and Little San Bernardino Mountains. This investigation will be coupled with a microearthquake survey of the Little San Bernardino Mountains which is aimed at 1) determining accurate locations for earthquakes in the Little San Bernardino Mountains, which appear to lie in a NW-SE band northeast of the Mission Creek fault, 2) improving depth determination for these earthquakes, and 3) discovering, if possible, how the active, east-west left-lateral faults in this area mesh with the NW-SE Banning-Mission Creek fault system.

Results

1. Quarterly seismicity maps of southern California for FY77 (Figs. 1 - 4) plus a map summarizing seismicity for the whole year (Fig. 5) have been compiled and will soon be open-filed. Numbers on the summary map (Fig. 5) indicate important seismicity features in eastern California. Continued seismicity is seen in the vicinity of the Galway Lake earthquake (M_L = 5.2)-aftershock sequence, 1, and in the vicinity of the Goat Mountain earthquake (M_L = 4.7 and M_L = 4.7)-aftershock sequences, 2. Seismicity on the West-Calico - Mesquite fault, 3, was absent during the previous 1-1/4 years. Continued seismicity is seen on the eastward extension (?) of the Porcupine Wash fault in the Eagle Mountains, 4, and on the Smoketree Wash fault zone, 5. The Desert Hot Springs seismicity belt, 6, continues to be active. This belt is located northeast of the Mission Creek fault. Continued seismicity is also seen in the east-west-trending seismicity belt through the southern San Bernardino Mountains, 7. A seismicity gap, 8, persists between the Little San Bernardino Mountains and the Chocolate Mountains. The Brawley fault in Imperial Valley, 9, continues to be highly active. A seismicity boundary, 10, between seismically active and inactive parts of the Mojave Desert is parallel to the dominant structural grain of the Mojave Desert between latitudes of about 34° and 35° and conjugate to the dominant structural grain south of 34°. One definite earthquake, just above the number "10", occurred east of this boundary. Epicenters shown in the Yuma, Arizona area, 11, are blasts. Only blasts at Eagle Mountain mine and Hector quarry have been systematically eliminated from these maps (Figs. 1 - 5).

2. Small earthquake activity has increased by more than an order of magnitude along the San Andreas fault near Palmdale, California since November 1976. More than 700 small earthquakes ($0 \leq M \leq 3$) have been recorded during the period November 1976 - January 1978, with clustering in a small area approximately 2 to 3 km in dimension, centered at about 8 km depth, on or very near the San Andreas fault.

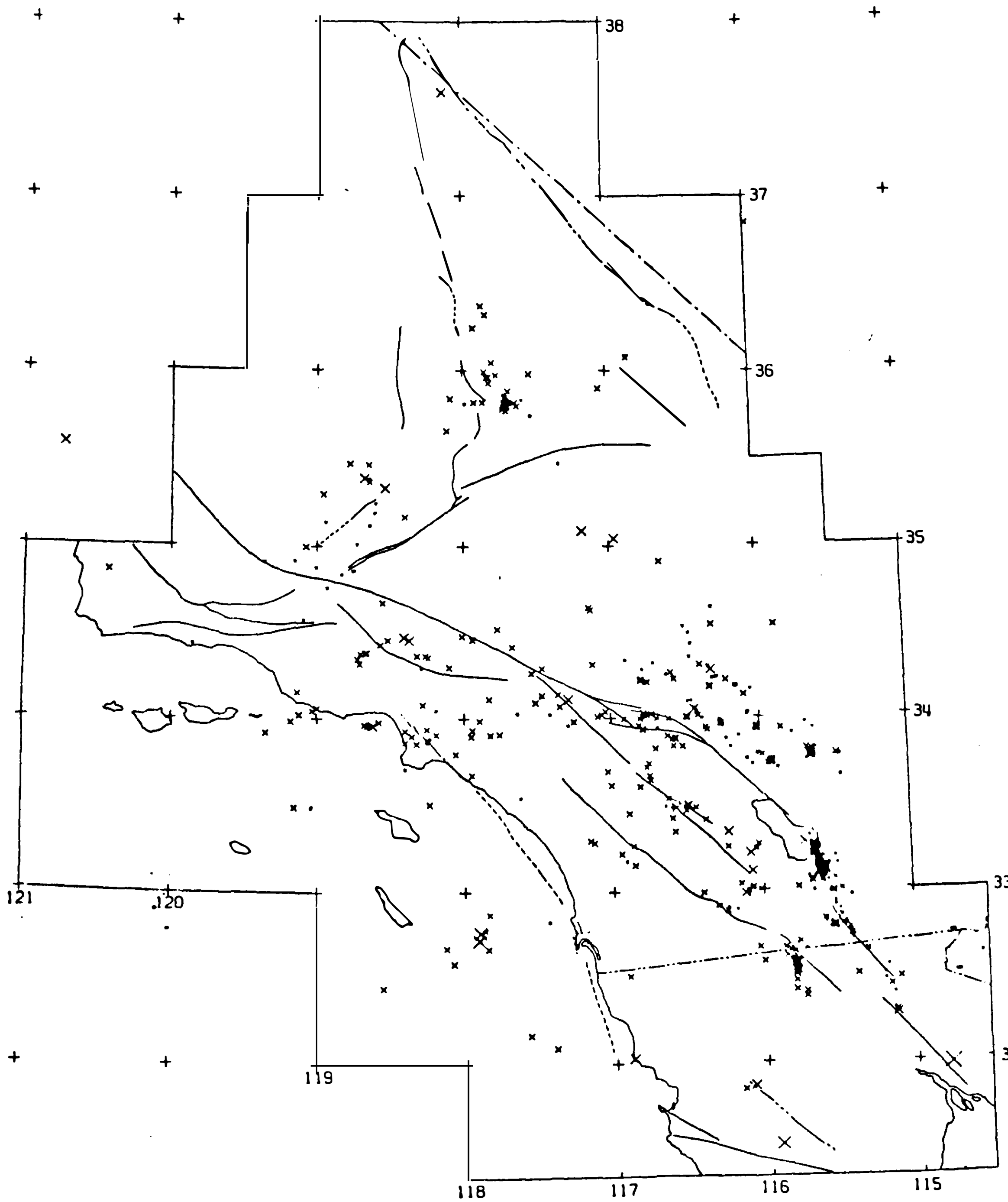
Some activity extends as much as 24 km ESE and 13 km WNW of the cluster, along the fault. Thrust fault mechanisms are observed for most of these events. For the three largest events, fault-plane strikes rotate successively from northeast to east to east-southeast, as determined from first-motions. Concomitant with this rotation, P/SV amplitude ratios measured at two stations at $\Delta < 30$ km trend slowly with time except for a short period about 2 weeks before and 3 to 5 weeks after the largest event ($M_L = 3$), when rapid variations are observed. The ratios change with time by as much as 1-1/2 orders of magnitude. Theoretical values of P/SV for fault-plane orientations indicated by first motions for the 3 largest events agree well with observed values. Activity increases are observed prior to each larger ($M_L = 2.7$ to 3) earthquake within this sequence; an increase also accompanied the extension of the activity ESE along the San Andreas fault in July 1977.

Publications

Lindh, A., Fuis, G., and Mantis, C., 1978, Seismic amplitude measurements suggest foreshocks may have different focal mechanisms from aftershocks: Science (in press).

McNalley, K., Fuis, G., French, M., Pechman, J., and Kanamori, H., 1978, Patterns in space, time, and focal mechanisms in the 1976-1977 earthquake swarm near Palmdale, California: Earthquake Notes, v. 49, no. 1, p. 32.

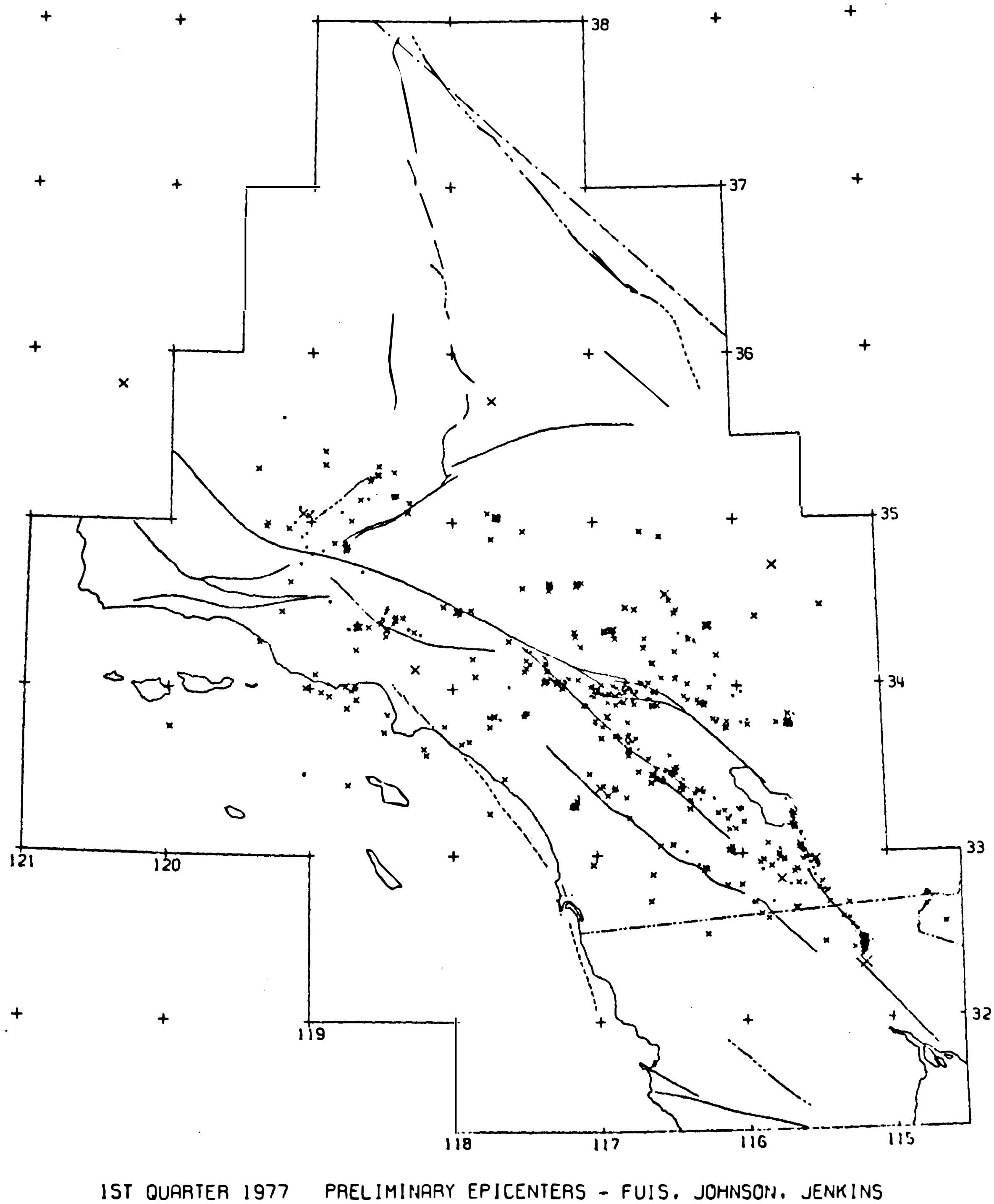
Johnson, C., 1978, CEDAR - an approach to the computer automation of short-period local seismic networks: EOS (Am. Geophys. Union Trans.), v. 59, p. 316.



4TH QUARTER. 1976 - PRELIMINARY EPICENTERS--FUIS. FRIEDMAN. & HILEMAN

M .LT. 2 ·
M .GE. 2 ×
M .GE. 3 ×
M .GE. 4 ×
M .GE. 5 ×
M .GE. 6 ×

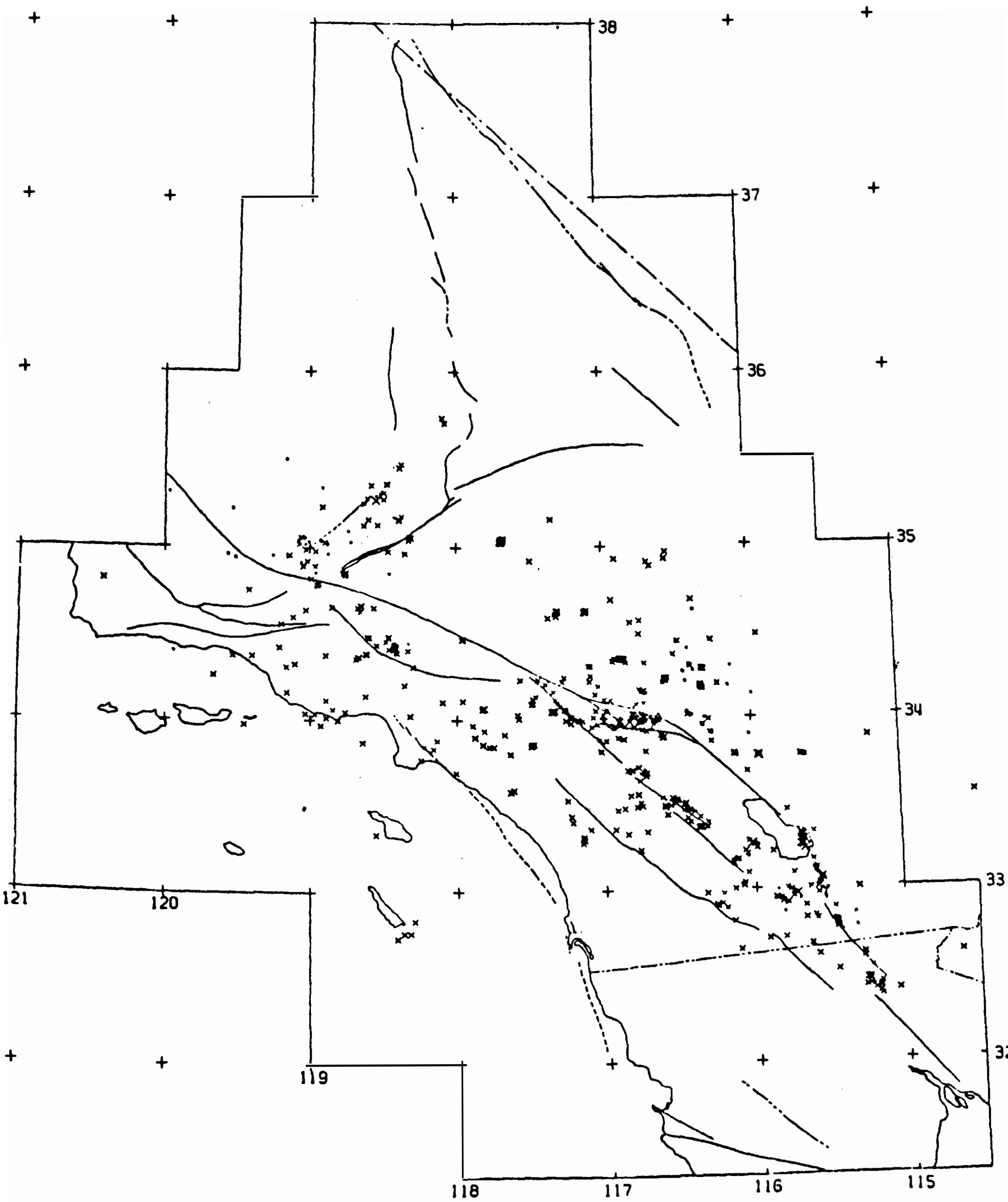
Figure 1.



1ST QUARTER 1977 PRELIMINARY EPICENTERS - FUIS, JOHNSON, JENKINS

M .LT. 2 ·
M .GE. 2 OR NOT CALCULATED ×
M .GE. 3 ×
M .GE. 4 ×
M .GE. 5 ×
M .GE. 6 ×

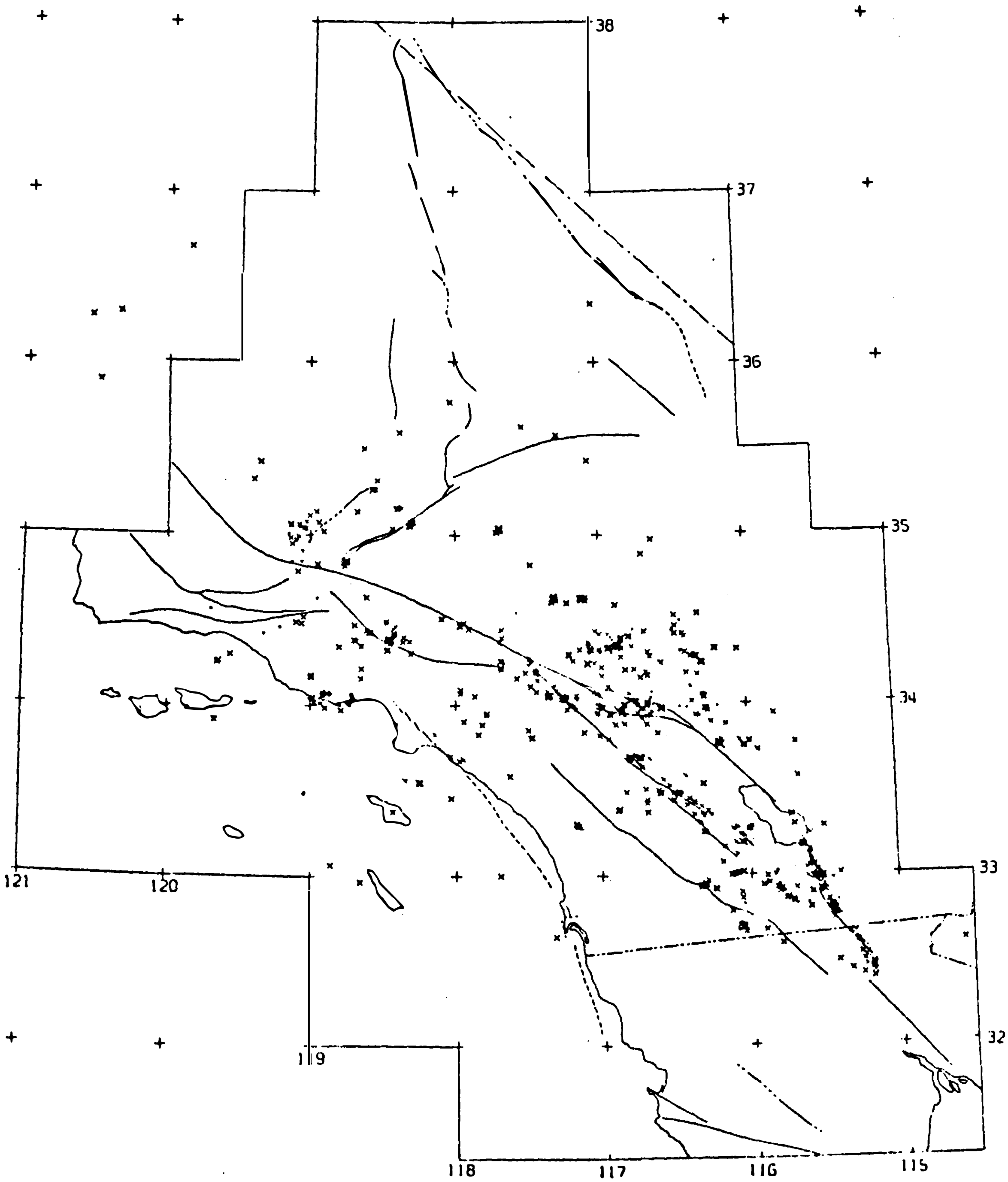
Figure 2.



2ND QUARTER, 1977 - PRELIMINARY EPICENTERS -- FUIS, FRIEDMAN, & HILEMAN

M .LT. 2 ·
M .GE. 2 OR NOT CALCULATED x
M .GE. 3 x
M .GE. 4 x
M .GE. 5 x
M .GE. 6 x

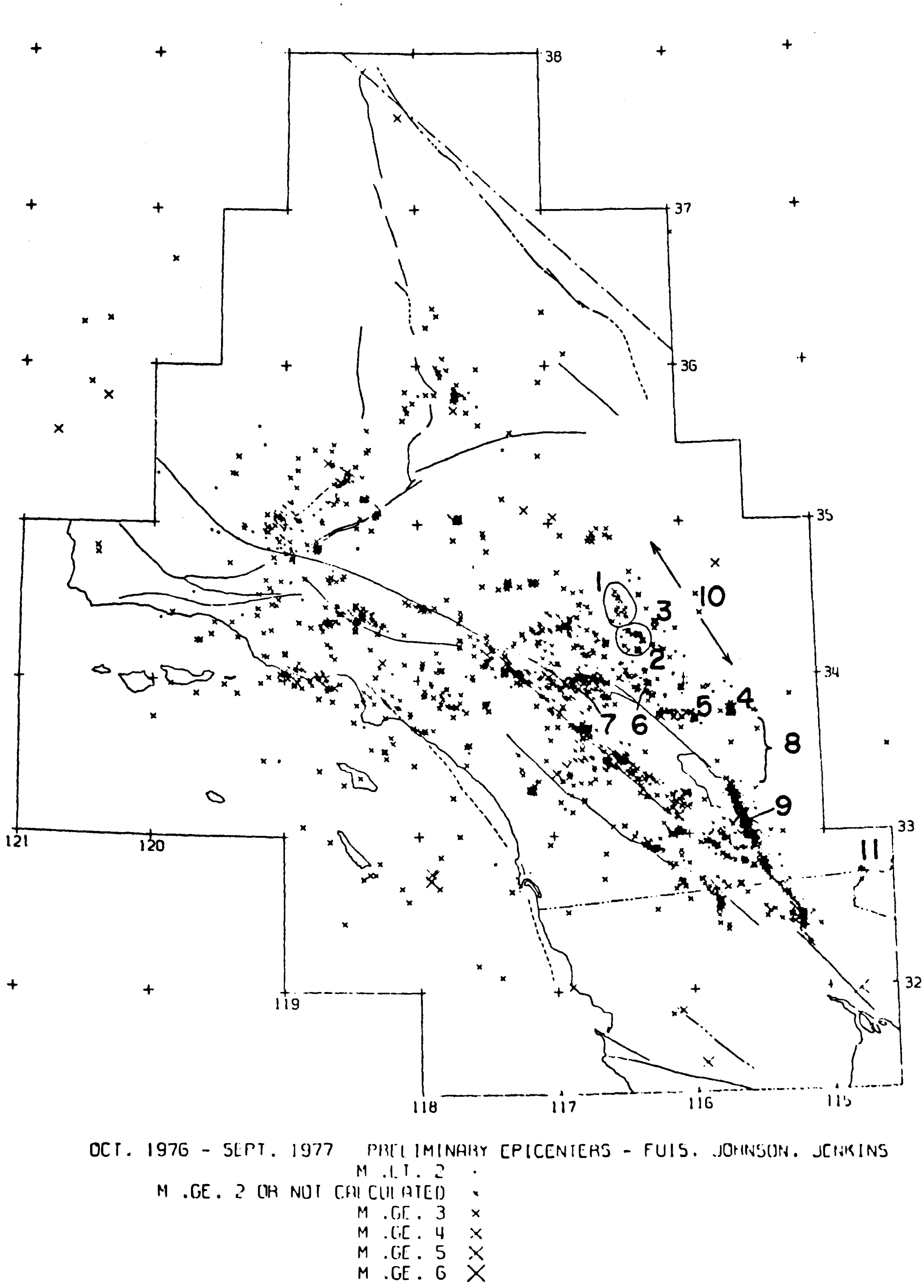
Figure 3.



3RD QUARTER 1977 PRELIMINARY EPICENTERS - FUIS, JOHNSON, JENKINS

M .LT. 2 ·
M .GE. 2 OR NOT CALCULATED ·
M .GE. 3 ×
M .GE. 4 ×
M .GE. 5 ×
M .GE. 6 ×

Figure 4.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OCT. 1976 - SEPT. 1977 PRELIMINARY EPICENTERS - FUIS. JOHNSON. JENKINS
M .LT. 2
M .GE. 2 OR NOT CALCULATED
M .GE. 3
M .GE. 4
M .GE. 5
M .GE. 6

Figure 5.

SEMI-ANNUAL SUMMARY

C.A.

Branch of Global Seismology

Date: April 10, 1978

Project No. 9920-01774 Title Seismicity of the Rio Grande Rift

Project Chief Lawrence H. Jaksha

Mailing Address and Phone No. U.S. Geological Survey, Albuquerque Seismological Laboratory, Building 10002, Kirtland AFB-East Albuquerque, New Mexico 87115 (505) 474-3785

Report Period October 1, 1977 to March 31, 1978

1. Investigations and Results:

Routine analysis of seismicity data from the 13-station network around the Albuquerque Basin continued. Records have been read through 1977. These data are being formatted for computer solution and final analysis.

Very little field maintenance was required by the network during the report period. The station at Golden, New Mexico was down briefly due to pack rats chewing on the power cables.

The portable tape recorders were deployed near Mt. Ladron for 10 days during March. One well-recorded earthquake occurred within the temporary network. This earthquake had a focal depth of less than 3 km. The event was not large enough to obtain a solution from the permanent basin array.

2. Reports:

Jaksha, L. H., Locke, Jerry, Thompson, John B., and Garcia, Alvin, 1977, Albuquerque Basin seismic network: USGS Open-File Report #77-865.

Jaksha, L. H., Locke, J., Thompson, John B., and Garcia, Alvin, 1978, Reconnaissance seismology near Albuquerque, New Mexico: USGS Open-File Report #78-339.

3. Goals:

The goal of this project is an evaluation of the seismotectonics of the Rio Grande rift near Albuquerque, New Mexico. This includes study of the seismicity, seismic risk, and crustal structure of the area around Albuquerque.

Hawaiian Seismic Studies
Including Seismic Studies at Lassen Volcancic National Park

8-9930-01497

Fred W. Klein
U. S. Geological Survey
345 Middlefield Road
Menlo Park, CA 94025
(415) 323-8111 ext. 2569

Goals

Assist the Hawaiian Volcano Observatory (HVO) in operation of the seismic net, processing of earthquake data, and bulletin preparation.

Analyze seismic data from Hawaii and Lassen to look for possible earthquake precursors and seismic precursors to eruptions.

Investigations

The project attacks the problem of determining the structure and tectonics of the island of Hawaii from seismic data and examining earthquake data for possible earthquake precursors and seismic precursors to eruptions. The project is responsible for continuing to process high quality earthquake data from HVO in Menlo Park until HVO becomes self-sufficient in its own earthquake processing in a year or so. Preliminary monthly lists and plots of epicenters are now being generated for internal distribution. Hawaii is one of the most seismically active regions in the U.S., and maintaining continuity of high quality data analysis is an important part of monitoring trends and possible precursors preceding eruptions and earthquakes.

The project has also been instrumental in preparing an Eclipse minicomputer, its programs for handling earthquake data, and the accumulated Hawaiian data for self-sufficient use at the Hawaii Volcano Observatory.

In addition to the Hawaiian investigations, the project monitors and studies seismic activity in and near Lassen Park both to establish normal background seismic patterns and to monitor anomalous seismicity relevant to volcanic and geologic hazards in the park.

Results

1. Project efforts have been directed primarily toward preparation and programming an Eclipse minicomputer soon to handle all seismic analysis at HVO. The Eclipse is now able to handle the analysis and display of seismic data after the reading of seismograms.

A new location program, HYPOINVERSE, was written to locate earthquakes within the Hawaiian and other networks. In addition to being small (from 22,000 to 28,000 words of core storage, depending on station capacity), the program uses a generalized inverse method which permits eigenvalve manipulation, principal error calculation, and output of actual information content of each station's arrival time. HYPOINVERSE also allows crustal models with layers containing linear gradients and an imbedded low-velocity zone.

Until recently, the crustal model which best fit the Hawaiian earthquake data was a homogeneous layer model with a low-velocity zone at the base of the crust developed by Crossan (1976). A model containing 3 crustal layers with linear gradients and a depressed crust-mantle boundary has been developed which improves the fit to earthquake data and the stability of the final locations.

An interactive system for storing, manipulating and displaying seismicity data on the Eclipse minicomputer is now under development. All Hawaiian earthquake data and many program modules are now available on the Eclipse.

2. A small seismograph network of six stations now monitors earthquakes in and near Lassen Volcanic National Park. The first 14 months of recording has revealed a northwest-trending seismic zone passing through the park. This zone is the resolved equivalent of a diffuse zone of historical epicenters passing through Lassen Park and Truckee, California, and is parallel to nearby lineaments in California, Oregon, and Nevada recognized from surface geology. Three dense concentrations of earthquakes correlate very closely with three geothermal areas. One concentration also outlines the north and east sides of the 4 km-diameter Mt. Tehama caldera. The recent dacite plug domes of Lassen Peak and Chaos Crags are nearly aseismic, however. Several approximate focal mechanism solutions indicate primarily normal faulting with east-west extension. This implies the northwest-trending seismic zone is undergoing extension and right-lateral shear. Extension directions near the center of the network display a radial symmetry that could be caused by a broad updoming or magma injection centered near Lassen Peak or Chaos Crags.

Publications

Hawaiian Volcano Observatory (1978). Seismic and Tilt Summary 74, January to December 1974.

Hawaiian Volcano Observatory, (1978). Seismic and Tilt Summary 75, Janaury to December 1975.

Hawaiian Volcano Observatory, (1978). Seismic and Tilt Summary 76, January to December 1976.

Klein, F. W., (1978). Earthquakes in Lassen Volcanic National Park, California, submitted to Bull. Seismol. Soc. Am.

Alaska Seismic Studies

8-9940-01162

John C. Lahr
Branch of Ground Motion and Faulting
U. S. Geological Survey
345 Middlefield Road
Menlo Park, CA 94025
(415) 323-8111, Ext. 2510

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 and the related seismic hazards 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, and one station is located in Canada under a cooperative agreement with the Seismological Service of Canada.

3. Evaluate seismic hazards in the populated and developing areas of south-central Alaska, including the Anchorage, Palmer and Valdez areas and the Kenai Peninsula, as well as in areas of possible future development, such as the coastal region of the eastern Gulf of Alaska.

4. 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 moderate-to-large earthquakes.

Results

1. Data processing has been switched to the USGS Honeywell Multics computer. Both Hypoellipse, the earthquake location program, and GPP3, the hypocenter plotting program, are now operational.

2. Earthquake data collected over the past 5 years in the vicinity of Willow, Alaska, the proposed future site of the Alaskan capitol, have been extracted from our data base and relocated. This data will be checked carefully and then released in the near future, as it is pertinent to the development plans for the region. A preliminary review of the hypocenters indicates the Benioff zone dips 25^{o} to the WNW and is about 40 km deep below Willow. There are also shallow earthquakes, most with focal depths of 20 km or less, scattered throughout the region. These events do not seem to be more than randomly associated with known faults, such as the Castle Mountain fault, which passes within 17 km of Willow.

3. Fabrication of well-calibrated, auto-gain-ranging, crystal-controlled seismic station electronic units is under way and the first 25 will be

installed this summer. In temperature cycle tests of the voltage-controlled-oscillator circuit, no degradation of performance was found between -75^{o} F and + 150^{o} F. All units will be temperature cycled in order to insure correct operation in the harsh Alaskan environment.

Reports

Roger, J., M. J. S. Johnston, C. Mortensen, and G. Myren, 1977, A Multi-Channel Digital Telemetry System for Low Frequency Data, U.S. Geological Survey Open-File Report 77-490, 10 p.

Lahr, J. and C. Stephens, 1978, Earthquake Activity and Ground Shaking in and Along the Eastern Gulf of Alaska, Summary report presented at the OCSEAP review meeting, 5 p.

Puerto Rico Seismic Program

8-9950-01502

C. J. Langer
Branch of Earthquake Tectonics and Risk
U. S. Geological Survey
Denver Federal Center, MS 966
Denver, CO. 80225
(303) 234-5091

Investigations

1. Continued operation of the 15-station Puerto Rico seismographic network to locate local and near-regional earthquakes.

2. Reduction of network data and preliminary analysis of earthquake locations for the time period between June 1 and November 15, 1977.

3. Initiated study of photogeology of Puerto Rico and the association of observed lineations with the spatial distribution of on-island or near-island earthquakes.

4. Completed development of the interactive data-entry system (IDES).

Results

1. Preliminary hypocenters were computed for 281 earthquakes which occurred in the time interval between June 1 and November 15, 1977. Arrival times have been read for the last two weeks of November and films, through April 14, scanned for event identification.

2. Six seismic source regions have been defined on and in the vicinity of Puerto Rico. The approximate locations of these zones are: northeast Puerto Rico (lat. 18.25° - 18.50°N, long. 65.5° - 66.25°W), southeast Puerto Rico (lat. 17.8° - 18.25°N, long. 65.85° - 66.5°W), southwest Puerto Rico (lat. 17.75° - 18.2°N, long. 66.75° - 67.25°W), northwest Puerto Rico (lat. 18.25° - 18.75°N, long. 66.75° - 67.1°W), northeast of Puerto Rico (lat. 18.5° - 19.15°N, long. 64.8° - 65.6°W), and northwest of Puerto Rico (lat. 18.5° - 19.25°N, long. 67.5° - 68.3°W).

3. Use of the interactive data-entry system (IDES) has increased the speed and efficiency of data handling and management. The analyst picks the P- and S- phase times from the develocorder film of analog tape playback, enters tha data directly into the computer by a remote terminal, and determines a preliminary hypocentral location in one operation. This preprocessing eliminates a large percentage of the timing and entry errors that usually have to be corrected at some later date.

Seismic Data Library of WWSN Seismograms

8-9930-01501

W. H. K. Lee
U.S. Geological Survey
345 Middlefield Road
Menlo Park, CA 94025
(415) 323-8111, ext. 2630

This is a non-research project, and its main objective is to keep the WWSN seismograms up to date and properly filed.

Network Installation, Permitting & Supplies

8-9970-01170

Herb Mills
U. S. Geological Survey
345 Middlefield Rd
Menlo Park, CA 94025
(415) 323-8111 ext. 2113

Goals

It is our intent to assist and provide a service to the scientific staff of this office by installing, operating and maintaining instruments used to conduct geophysical experiments. The ultimate goal of this project lies in the separate goals of the many projects that it serves.

Our objectives are to plan and organize geophysical experiments, acquire the necessary equipment, secure the proper permits, install the instruments, and maintain all portable seismic networks and arrays. As a service project we also install and maintain radon sampling cups, water level recorders, and a large network of creepmeters. We also maintain a staff of specialists to provide assistance to all projects involved in field programs.

Investigation

To provide service to and for the scientific staff of this office and its contractor for geophysical research.

Results

1) We now have a Memorandum of Understanding with San Bernardino National Forest, Angeles National Forest, and Los Padres National Forest. The terms of these agreements afford quick processing of our request for land use permits. Negotiation is continuing with California Bureau of Land Management for a similar agreement.

2) Three new creepmeters have been installed on the San Andreas fault, one northwest of Taft above the Carrizo Plain in Central California, and two near Palmdale in Southern California. The Taft creepmeter is already on digital telemetry; the Palmdale stations will be put on telemetry soon.

   The entire creepmeter network has been reviewed and the decision made to upgrade selected stations and abandon others. Upgrading the older stations will require installation of the newer type wire instrument. In addition, three new stations are to be installed in Southern California.

Telephone drops and equipment necessary to put the creepmeter network on digital telemetry have been ordered. Modifications to creepmeter electronics are being made to allow hookup to the telemetry system.

3) Monthly servicing of five water level recorders continued, including record changes, depth measurements, pH tests, and monitoring of temperature, salinity, and conductivity of the water. Also, in a cooperative effort with Geochemistry personnel, water samples are collected and filtered for their analysis and use. As requested, additional visits between regular servicing trips are being made to the well sites whenever possible for extra readings on conductivity.

   Four new water-level recorders have been set up in the lab for testing, prior to installation at new sites. Work is progressing on permitting the new sites and arranging to have the wells drilled.

4) A field program is underway and should be completed by May 15, 1978 in the New Madrid area. We installed and maintained 12 each 5 day tape recorders and 5 each smoke paper. One calibration shot was fired as a part of this program.

5) Six 5 day recorder and five (5) smoke paper recorders were deployed to record the earthquakes that followed the Willis, California shock in November 1977.

6) Centipede system was deployed south of Hollister to record signals as a result of the vibra seis program with U.C. Berkeley. More than 70 stations, both Horizontal and Vertical were used.

7) Many new seismic stations were installed throughout Central California.

C.A.

SEMI-ANNUAL REPORT SUMMARY

1 July 1977 - 31 December 1977

For the Establishment of a Southern California Geophysical Data and Analysis Center, U.S.G.S. contract No. 14-08-0001-16629.

The Southern California Geophysical Data Center currently has two data acquisition systems. One is the CEDAR (Caltech Earthquake Detection and Recording) system. It acquires data from a short period seismic array network. The second is CROSS (Caltech Remote Observatory Support System) which is designed to be a data logging and telephone telemetry system for servicing remotely sited long-period geophysical instrumentation.

CEDAR is fully operational and in full support of the Southern California Seismic Array network. (USGS Contract No. 14-08-0001-16719). CROSS is currently under development. It consists of a central computer, an Eclipse S/230, and remote Telemetry Interface Module (TIM) subsystems that communicate via standard voice grade direct dial telephone lines. A prototype of a TIM unit has been built. This TIM unit, a microprocessor based subsystem, consists of a number of card modules, each having a functional purpose, contained in a card cage with a front control panel. The cards that have been designed and constructed are:

1. CPU-memory; 6100 microprocessor (PDP8/E software compatible), 2048 words of Random-Access-Memory and 512 words of Programmable-Read-Only Memory.

2. Clock-status; low precision 1 Hz clock and control panel interface.

3. Data RAM; 4096 words of Random-Access-Memory for data storage.

4. Analog input; eight analog channels multiplexed to a 12 bit analog-digital converter.

5. Digital input; four multiplex channels of serialized digital input.

6. Digital control output; 16 multiplex channels of serialized digital output.

7. Modem controller; Modem; Telephone line coupler; — Three board set for telephone telemetry

Eighteen of these units are currently under construction for deployment at selected sites.

Robert F. Nickerson
Seismological Laboratory
California Institute of Technology
Pasadena, California 91125

Northeast Seismic Network

8-9950-01745

Paul W. Pomeroy
Branch of Earthquake Tectonics and Risk
U. S. Geological Survey
P.O. Box 224
Stone Ridge, New York 12484
(914) 687-9150

Investigations

The Northeast Seismic Network which consists of approximately 85 seismic stations in 12 states is designed primarily to provide uniform seismic recording capability throughout the area of interest. The locations of stations in the network as of June 1977 are shown in Figure 1. Sub-network operators include:

Weston Observatory of Boston College
Massachusetts Institute of Technology
Lamont-Doherty Geological Observatory of Columbia University
Pennsylvania State University
Delaware Geological Survey

An agreement with the Earth Physics Branch, Department of Energy, Mines and Resources in Ottawa, Ontario, Canada, is currently being negotiated to provide several additional stations in Eastern Canada.

It is the objective of this project to promote cooperation among the various sub-network operators, to recommend courses of action to them, to recommend support for them as needed and to disseminate their epicentral information to federal, state and local legislative, planning and regulatory agencies.

Objectives

The objectives of the Northeast Seismic Network include:

1. The location and identification of sources of ground vibrations including information on latitude, longitude, origin times, depths and magnitudes for all events of $m_b \geq 2$.

2. The identification of zones of seismic activity and their relationship to geologic processes.

3. The evaluation of regional geologic structure and tectonics using network results including fault plane solutions, travel time residuals, seismic moments, stress drops, attenuation determinations and crustal and upper mantle structure (from refraction data).

The ultimate goal of the network is to provide a realistic evaluation of the earthquake risk on a regional basis throughout the area and to disseminate this information to public and private planning and regulatory groups for appropriate action.

Results

The epicentral information collected by the sub-networks is synthesized and published in regional quarterly bulletins of the network. Cumulative epicentral information from the inception of the network through June 1977 is shown in Figure 2 which is taken from the latest quarterly bulletin.

In addition to the epicentral results, numerous scientific investigations have been carried out by investigators at the operating institutions. These investigations are published in *Science*, *Journal of Geophysical Research*, *EOS* and *Bulletin of the Seismological Society of America*.

Publications

A *Quarterly Bulletin of the Northeastern United States Seismic Network* is published by Weston Observatory of Boston College on behalf of NEUSSN. Seven (7) bulletins covering the period October 1975 to June 1977 have been published to date. The quarterly bulletins are distributed directly to over 400 addresses, including regulatory agencies, members of Congress from the affected areas and state legislators. As indicated above, research results of the individual sub-networks are published in scientific journals.

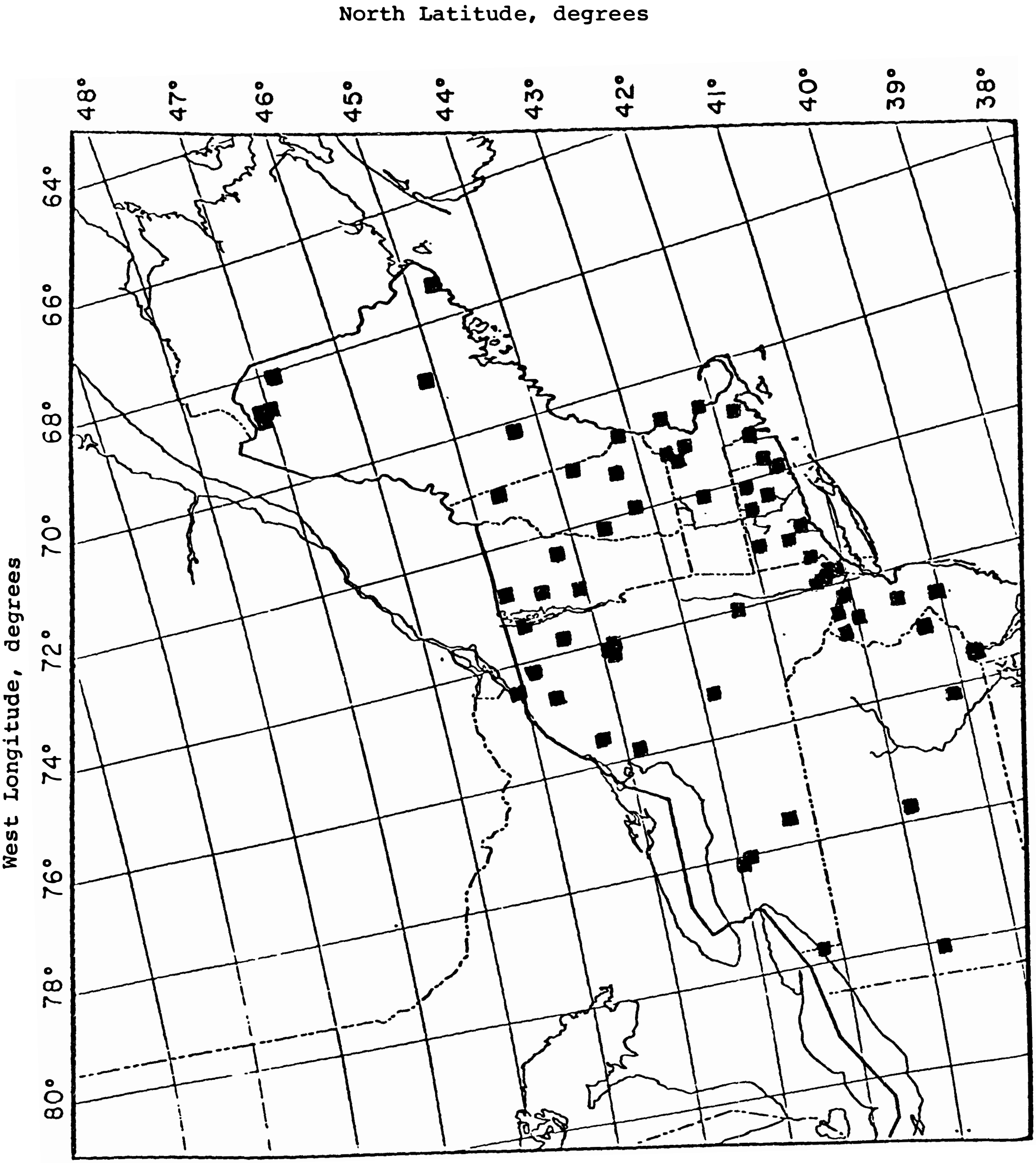

Figure 1. Seismic stations operating during the period April - June 1977

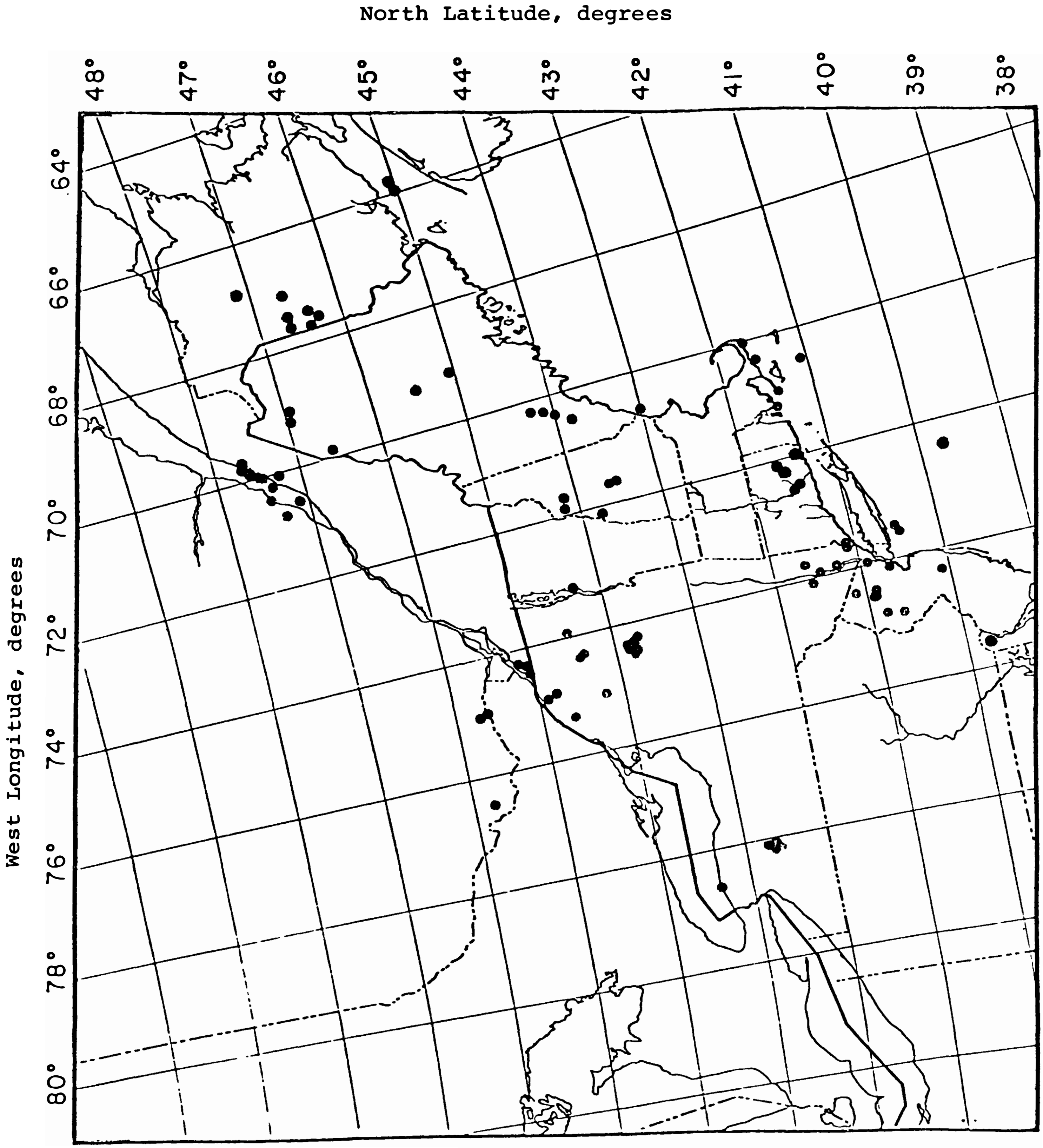

Figure 2. Earthquake epicenters during the period October 1975 - June 1977

C.A.

University of Utah

EARTHQUAKE RESEARCH AND NETWORK OPERATIONS IN THE INTERMOUNTAIN SEISMIC BELT--WASATCH FRONT

Summary of Semi-Annual Technical Report: Oct. 1, 1977-March 31, 1978

USGS Contract No. 14-08-0001-16725

Investigators: R. B. Smith, W. J. Arabasz, W. D. Richins, K. L. Cook
Department of Geology and Geophysics
University of Utah
Salt Lake City, Utah 84112

Seismicity and Blast Monitoring.--Notable earthquake activity during the six months of this report period included: aftershocks of an M4.5 earthquake that occurred on September 30, 1977, approximately 80 km east of the Wasatch Front along the south flank of the Uinta Mountains; and a series of small earthquakes ($M \leq 3.3$.) during February 28-March 13, 1978, in the northwestern part of the Salt Lake Valley--15 km from the center of Salt Lake City.

The latter sequence occurred within the source region of the M5.1 Magna earthquake of 1962 and included four felt shocks over a two-week period (see Figure 1). Considerable local attention was caused by the occurrence of these earthquakes beneath a populated and industrialized area. Whether or not the shocks represented foreshock activity could not immediately be assessed with confidence--but the incident emphasizes the "foreshock problem" that seismologists must be prepared to confront when unusual earthquake activity occurs close to a large metropolitan center.

Subsequent cessation of activity in the Magna area (for more than 8 weeks to the present) and the absence of any local velocity anomaly associated with the long-term monitoring of local quarry blasts lead us to minimize any expectation of follow-up larger activity. For blast ray paths penetrating the region of this earthquake activity, a slight velocity increase of 1.2% appeared to coincide with the earthquake sequence; however, two data points defining this increase are within two standard deviations of the mean of nearly 40 data points for a preceding one-year period.

Continued monitoring of Bingham quarry blasts for this report period involving four standard profiles across and along the Wasatch fault has shown no variations of apparent velocity beyond two standard deviations of a mean. However, as in the previous two years, there has been little earthquake activity of significant size within the area of profiling.

Seismic Risk.--Analyses of probabilistic seismic risk have been initiated for local areas of the Wasatch Front--patterned on methods of risk analysis by McGuire (1976) and Mayer-Rosa (1978). The aim is to understand the effects of primary assumptions upon calculated seismic risk and to use new earthquake and fault data to better characterize source areas. Revised catalogs of seismicity, new tectonic models of relevant areas, geologic evidence of late Quaternary fault recurrence, and rates of earthquake energy release estimated from moment-magnitude studies are expected to improve the risk analyses.

Epicenter Map of Utah Earthquakes 1962-1977.--Seismological research at the University of Utah has been hampered by the lack of a thorough analysis of instrumentally recorded earthquakes on a state-wide basis.

For the period 1962 to the present, reliable data have been available only for Wasatch Front epicenters and for locations and magnitudes of the 40 largest instrumentally recorded earthquakes throughout Utah from 1962-1975 that form a calibration set.

As we collected data from our detailed Wasatch Front array it became apparent that many of the earthquakes in north-central Utah were located at or near the edge of our USGS study area. The important influence of seismicity on the Wasatch Front from earthquakes surrounding the USGS study area prompted us to begin an assessment of the seismicity of an extended area. At the same time personnel from projects supported by the State of Utah, NSF and DOE initiated a systematic analysis of earthquakes from 1962 through 1977 in central and southern Utah. Earthquake locations from four principal sources of data were merged to develop a new catalog of Utah earthquakes--the first reliable state-wide compilation. These data include: 1) USGS-supported summaries of Wasatch Front seismicity; 2) earthquake locations outside the Wasatch Front USGS study area and north of 40° lat.; 3) new analyses of earthquakes from central and southern Utah south of 40°lat.; and 4) the set of Utah calibration earthquakes.

Paleo Focal Mechanisms.--Mapping of fault-plane striations along an excavated scarp of the Wasatch fault at the northern end of Salt Lake City yields paleo-movement (Quaternary) directions that can be compared with slip vectors from nearby current focal mechanisms. Along an undulating fault plane with an average strike of N40°W, dipping 70°SW, striations consistently record two independent slip directions with one superposed on the other--an older more westerly trending set (288°) and a younger southwesterly trending set (239°). Axes of undulations on the fault plane with wavelengths of several tens of meters define an intermediate slip direction. "Paleo focal mechanisms" implied by these data are similar to focal mechanisms to the west of the Wasatch fault, but dissimilar to those on the east. Distinct episodes of faulting apparently characterized development of the studied segment of the Wasatch fault with suggested rotations of 30°-40° in principal stress directions.

Seismicity and Geological Structure.--Faced with persistent problems in interpreting current Wasatch Front seismicity--because of its diffuseness, absence of strong correlation with active faults, and abundance to the east of the Wasatch fault--satellite imagery has been interpreted for new insights. Photogeological studies have focused interest on several structural problems, notably: (1) the influence of pre-Cenozoic thrust faulting on Basin and Range structure, particularly the development of extensional valleys both west and east of the Wasatch fault; 2) variations in preferred lineament orientation for different parts of our Wasatch Front study area; and (3) the seemingly anomalous NNW trend of a major sector of the Wasatch fault between Provo, Utah, and Malad City, Idaho. Prominent seismic gaps occur along the latter sector of the Wasatch fault, whose NNW trend is surprisingly weak as a lineament trend in the Basin and Range-Middle Rocky Mt. transition. Most of the seismically active faults in our study area trend NNE--the dominant lineament trend throughout the region.

Miscellaneous.--Other information summarized in the technical report includes results of multiple linear regressions relating coda magnitude to short-period Benioff seismographs operated in Utah since 1962, and a brief outline of isoseismal information for five felt earthquakes (M2.5-M4.2) that occurred during the report period.

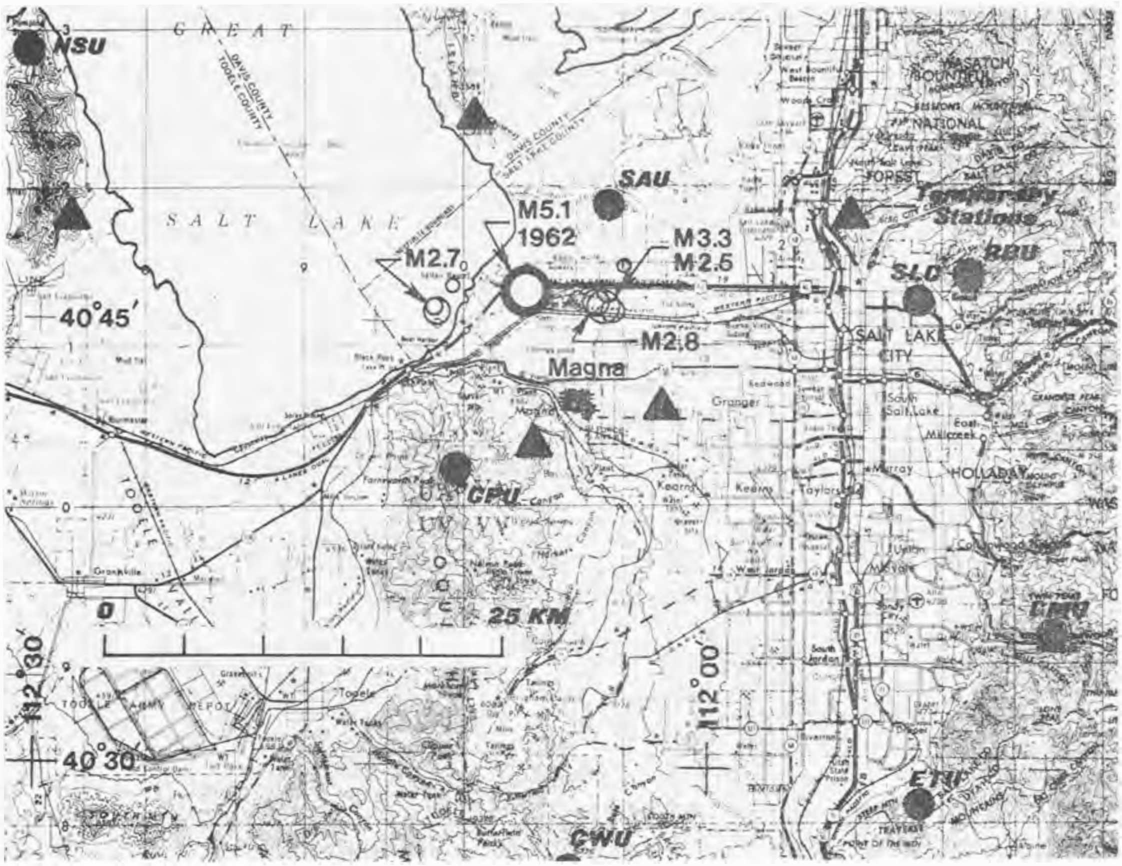

Figure 1. Map of Salt Lake City area showing epicenters in northwestern Salt Lake Valley of four felt shocks and related smaller events during February 28-March 13, 1978. Epicenters are within source region of M5.1 Magna earthquake of 1962.

Earthquake Hazard Studies in Southeast Missouri

14-08-0001-16794

W. Stauder and R. Herrmann
Department of Earth and Atmospheric Sciences
Saint Louis University
St. Louis, MO 63103

October 1, 1977 - March 31, 1978

Goals

Monitor seismicity in the New Madrid Seismic Zone using a sixteen station seismic array.

Perform research on eastern North America seismic sources by using array data and that from other stations.

Investigations

The present effort has been directed toward location of events in the New Madrid Seismic Zone, estimation of source parameters of the events there, estimation of source parameters of larger eastern North America earthquakes, and inference of source parameters of the 1811-1812 New Madrid earthquakes.

Results

1. Focal mechanisms have been associated with some of the linear seismicity trends near New Madrid. In particular, a clear picture of the nature of faulting on a 120 km long NE-SW trend in northeastern Arkansas has been found. The motion is oblique with a component of right lateral strike slip.

2. The total seismic moment of the 1811-1812 New Madrid earthquake sequence is on the order of 7.0 E 27 dyne-cm. Present seismicity studies indicate a fault area of about 2000 km^2. A fault displacement on the order of 10 meters would follow. Using the Nuttli (1973) estimate that M_s=8.0, the 1811-1812 sequence would fit into Kanamori and Anderson's (1975) "intra-plate" worldwide earthquake classification with a stress drop of 60-100 bars.

3. Studies of twenty-two earthquakes occurring in eastern North America, large enough to excite usable long period surface waves, indicates that most events have significant components of strike-slip motion and that the majority have depths between 5 and 15 km.

Publications

Herrmann, R.B. and J.A. Canas, 1978, Focal mechanism studies in the New Madrid seismic zone: Seismol. Soc. America Bull., (in press).

Herrmann, R.B., S.H. Cheng and O.W. Nuttli, 1978, Archeoseismology applied to the New Madrid earthquakes of 1811-1812, (in final preparation).

Herrmann, R.B., P. Murtha, J. Voss, and J. Zollweg, 1977, Focal mechanisms for eastern North America - a tectonic synthesis; EOS, Am. Geophys. Union. Trans., v. 58, p. 1194.

National Seismic Network Feasibility Study
8-9920-02143

James Taggart
Branch of Global Seismology
U.S. Geological Survey
Denver Federal Center, MS 967
Denver, CO 80225
(303) 234-5079

Goal

The purpose of this study is to make practical evaluations of the costs and usefulness of a national digital seismic network.

Investigations

a. The scope, objectives, and basic assumptions for the project were discussed at two meetings.

b. Jon Peterson, Albuquerque Seismological Laboratory, assumed responsibility for developing recommendation for instrumentation and data collection.

c. Marvin Carlson, John Derr, David Gordon, James Taggart, and Arthur Tarr, Office of Earthquake Studies, Golden, Colorado, assumed responsibility for developing recommendations concerning site selection, network evaluation, data transmission, real-time visual monitoring of signals, data cataloging, software development, and data distribution.

d. Published data on seismic background noise and regional attenuation were collected and modified for use with a network evaluation program.

e. Potential funding sources were identified.

f. Liaison between this project and the National Research Council, Panel on National, Regional, and Local Seismograph Networks, was established with E. R. Engdahl and R. Page representing the Geological Survey.

Results

a. Recommended seismic instrumentation at the network stations includes short period, intermediate period broad band, long period, and strong motion systems, sampled at 20, 10, 1, and 50 times per second, respectively.

b. Jon Peterson has developed cost estimates for several different options on the instrumentation package, and for annual operation and maintenance of the network as a function of the number and location of the stations.

c. It is recommended that the digital data from the network stations be assembled in the form of network-day tapes at a data management center for distribution to the scientific community. The network-day tapes should be processed for cataloging into a widely accessible data base.

d. A review of preliminary results was presented on April 5, 1978 in Albuquerque. The various options on instrumentation, site distribution, data transmission, and data management were considered. It was decided that the options should be restricted to two trial networks for consideration by the National Research Council, Panel on National, Regional, and Local Seismograph Networks.

Topical Seismicity Studies

8-9950-02092

Arthur C. Tarr
Branch of Earthquake Tectonics and Risk
U. S. Geological Survey
Denver Federal Center, MS 966
Denver, CO 80225
(303) 234-5078

Investigations

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

2. Compile earthquake catalogs for southeastern United States for entry into the Multics DBMS (MRDS) as 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

1. A preliminary relational data base has been designed for the U.S. earthquake catalog, consistent with the MRDS software currently implemented on the Multics computers and the architecture of the larger NEIS global seismological data base. The U.S. earthquake data base currently consists of three earthquake relations, and one *in situ* stress measurements relation. Relation ORIGIN contains hypocenter coordinates, magnitudes, error estimates, methods of determination, and appropriate references as attributes. Relation MAXIMUM INTENSITY contains maximum intensity information, methods of determination, quality indexes and references. Relation FOCAL MECHANISM contains focal mechanism parameters, the strikes and dips of nodal planes, plunges and trends of the P and T axes, error estimates, and quality evaluations. Relation STRESS contains *in situ* stress determination results, errors, estimates, and evaluations. A separate relation, called EVENT, contains keys of a preferred hypocenter and preferred maximum intensity in relations ORIGIN and MAXIMUM INTENSITY.

2. The Bollinger southeastern U.S. historical earthquake catalog, the South Carolina seismic network catalog, and historic maximum intensity catalog used by Algermissen and Perkins for the U.S. risk map have been entered as separate ORIGIN relations. FORTRAN user-application programs (selective searches, printing camera-ready copy of catalogs, edit routines, and the like) have been written and tested on the separate relations. They will be merged soon into one master ORIGIN relation which will eventually contain the "preferred" and alternate values of attributes.

3. A grant to the University of Michigan was funded to compile published *in situ* stress measurements in North America. Most literature search tasks have

been completed, and evaluation of the determinations is currently underway. Major problems have arisen where the published account gives no estimate of precision or accuracy of the determination; authors are currently being contacted for further information. Difficulties with reproducibility of results, inherent in some in situ stress methods, may make evaluation of many measurements impossible.

4. A global focal mechanism catalog, originally compiled for contribution to the Circum-Pacific Mapping Project, has been entered as relation FOCAL MECHANISM. Several thousand mechanisms, including composite solutions from the United States, are in the current catalog.

5. A FORTRAN computer program NETWORTH, obtained from Geotech Teledyne, has been converted to the Multics system. The program computes detection threshold and location capability for networks of seismic stations. The U.S. Network project has tested the program and it is currently considered operational.

Instrument Development and Quality Control

8-9970-01726

John Van Schaack
U.S. Geological Survey
345 Middlefield Road
Menlo Park, Ca. 94025
(415) 323-8111 ext. 2584

Goals

The major goals of this project are to assist other projects in the office in the design, development, evaluation, and specification of new instrumentation, and the monitoring and calibration of systems to insure the quality of the data collected.

Investigations

The period from Oct. 1, 1977 to Jan. 3, 1978 was spent testing, troubleshooting, and calibrating the 100 portable cassette seismic recording systems that were to be shipped to Saudi Arabia. Investigation was completed on the most effecient method of playing back the data that was collected on the tape cassettes. A prototype hand held programmer was tested for programming the record times into the portable cassette units and for monitoring the important electronic parameters of these units.

Various methods of transmitting data from field radon detecting systems were investigated.

Four Terra Tech digital seismic event recorders and one playback unit were tested and evaluated for C. Bufe of this office.

Results

One Hundred portable cassette seismic recording units were completed on Dec. 15, 1977 and shipped to Saudi Arabia.

The design for the cassette playback and dubbing system was completed and five systems were built and shipped to Saudi Arabia. The playback and dubbing system consists of one reproduce tape unit, four data tape dubbing recorders, a discriminator bank, a direct print paper recorder, a time code translator, and a program controller. This system seperates the seismic recordings according to programmed times and dubbs the events on the proper tape dubbing unit. This allows editing of the tape and produces a tape that contains a series of seismic recordings from a specific shotpoint in sequence according to distance from the shotpoint. Direct print playbacks can be made during this process to verify the data quality of the signal being dubbed.

Five hand held programmers were built which contain a master clock, memory, time comparator, and monitor functions. These units are used to program the memories of the portable cassette seismic recording systems, compare their clocks with the hand held programmer clock, display the difference and adjust the recording system clocks to within one hundred micro seconds of the hand held programmer clock. The hand held programmers also monitor selected electrical parameters of the portable recorders.

Two FSK telemetry transmitters and signal conditioners were designed and built which will transmit the data from two radon detection systems installed by Chi Yu King to Menlo Park.

Thirty two J 402 preamp/VCO units were calibrated and shipped to Cal Tech to be installed in the Southern California network.

IMPERIAL COLLEGE OF SCIENCE AND TECHNOLOGY
GEOLOGY DEPARTMENT, LONDON SW7 2BP, GREAT BRITAIN.

SOME SPECIFIC EXPERIMENTAL AND FIELD STUDIES PERTAINING DIRECTLY TO THE MECHANISMS OF SEISMIC AND ASEISMIC FAULTING

Summary of the first semi-annual technical report for FY1978 covering the period from 1/OCT/1977 to 31/MARCH/1978.

Principal Investigators: B.K.ATKINSON, E.H.RUTTER, R.H.SIBSON, S.H.WHITE.

Date: 15/APRIL/1978

Contract No.: 14-08-0001-G-466

Amount of Contract: $30,000.

This project consists of three interrelated sub-projects. Progress made to date with each of these is summarized in the following sections.

Experimental Study of Aseismic Fault Slip

This study is designed to assess the influence on the sliding of pre-faulted cylinders of quartz rocks of the presence of pore water at temperatures of ca. 300°C. In earlier work we have performed stress relaxation experiments on Tennessee Sandstone and noted a dramatic weakening effect at strain rates below ca. $10^{-6}s^{-1}$. At yet lower strain rates of ca. $10^{-8}s^{-1}$ the stress relaxation data show remarkable agreement with a theoretical model of fault slip controlled by the rate of removal of asperities by pressure solution, although it should be realised that this is not proof of the validity of the model. Transmission electron microscopy of deformed specimens has revealed that mass transfer processes have ocurred (growth and segregation of phyllo-silicates) but definite evidence of quartz overgrowth textures has not been obtained. We are thus not able to infer at this stage whether or not pressure solution of quartz grain asperities exerted a controlling influence over the low strain rate sliding behaviour.

In order to provide specimens more suitable for microstructural studies then those deformed in the stress relaxation mode (where<<1% strain is accumulated at the slowest strain rates investigated) we have been concerned in recent months with long term (several months) constant strain rate and creep experiments at strain rates of ca. $10^{-9}s^{-1}$.

Two constant strain rate experiments have been completed, each of 5 months duration at a temperature of 300°C under an effective confining pressure of 1.5 kb (pore pressure of 200 bars). The deformed specimens, one of which was pre-faulted and the other which was not, are currently being prepared for optical and electron microscopy. Both specimens displayed stress/strain curves which show no marked post-yield work hardening.

Two creep experiments (constant force maintained by servo controllers) with an expected duration of 6 months each are currently in progress. Both samples are wet and pre-faulted and are being deformed at 300°C and an effective confining pressure of 1.5kb. One specimen has a pore pressure of 0.2kb and the other one of 1.2kb. At this early stage the strain rate difference between the two tests at constant differential stress is within a factor of 10. Preliminary stress change experiments suggest that strain rate is roughly proportional to the applied stress as suggested by the earlier stress relaxation experiments.

We have conducted preliminary fast constant strain rate experiments on a number of quartz rich rocks in order to find a rock that is less impure than Tennessee Sandstone,but which is also suitable for testing in our deformation rigs.We have found that Oughtibridge Gannister,a pure quartz siltsone from the British Coal Measures,is likely to suit our purpose. This material will be used in a future series of experiments to investigate the sliding of pre-faulted quartz-rich rocks which have a very much lower phyllosilicate content then Tennessee Sandstone.

Fracture Mechanics Studies of Slow and Fast Cracking in Rocks and Minerals.

A range of experimental techniques are being used to establish for common rocks and minerals fracture mechanics parameters to describe the catastrophic mode I(opening) and the slow,stable mode I type of cracking. The parameters determined are the critical stress intensity factor for catastrophic cracking,K_{Ic}, and the sub-critical stress intensity factor/ crack velocity relationship for slow,stable cracking.(Experimentally it is sometimes more convenient to determine the strain energy release rate,G, rather than K.These two parameters are related to each other by expressions involving the elastic constants.)

Using apparatus and techniques developed in the previous FY(1977) we have expanded our studies to include quartz,Carrara Marble,Tennessee Sandstone, and Arkansas Novaculite.In future months we hope to study Oughtibridge Gannister and Mojave Quartzite,as well as Solnhofen Limestone.We should then have a fairly comprehensive idea of crack propagation behaviour in quartz-rich rocks and calcite-rich rocks.

Using the double torsion testing method,fracture toughness,K_{Ic}, values for Arkansas Novaculite and basal-cut single crystals of synthetic quartz cracked in the a-direction have been obtained,as well as revised values for Tennessee Sandstone and Carrara Marble. These are respectively 1.193 ± 0.185, 0.930 ± 0.050,0.454 ± 0.016,and 0.644 ± 0.021 $MN.m^{-3/2}$.

Hertzian indentation studies of slow,stable cracking on the r-plane of quartz in water environments at room temperature have been performed. A notable feature of these experiments is that even at quite low fractions of K_{Ic}(1/5 to 2/5) slow,stable cracking still continues in air or liquid water at geologically significant rates(10^{-8} - $10^{-10}s^{-1}$).Water assisted stress corrosion crack growth is thus likely to be a significant contributor to cracking in quartz during long term geological processes.

Using a new apparatus for 3- and 4-point bend tests,studies are in progress of the fractography of quartz.We are particularly concerned to investigate the possibility that the size of the fractüre mirrors bears a simple relationship to the fracture stress and hence may be a possible palaeostress indicator.

The double torsion testing technique has been used in the load relaxation mode to study slow stable cracking of Tennessee Sandstone,Carrara Marble and Arkansas Novaculite in liquid water environments.All of these materials show geologically significant slow,stable cracking under these conditions at even quite low fractions of K_{Ic}.

Factors Affecting the Genesis of Fault Rocks

As a necessary preliminary to transmission electron microscopy,fault rocks collected last summer from the Alpine Fault zone,New Zealand are being studied by optical microscopy.

The first sequence of rocks to be worked on comes from the Saddle Creek area where the Alpine Fault is bounded by oligoclase grade Haast Schists to the SW and granite to the NE.On approaching the fault zone both types of rock are progressively mylonized to form "green mylonites".Optical microscopy of "green mylonites" cannot discern between the two possible parent rock types.

The quartz in mylonites on both sides of the fault has well-developed sub-grains and they will be used to make stress/strain rate estimates. The size of recrystallised grains will also be used for this purpose wherever the phyllosilicate content is low.It has been found in studies of stress estimates for the rocks of the Moine Thrust that the presence of phyllosilicates inhibits the development of equilibrium grain sizes and renders the quartz grains useless as piezometers.

Optical microscopy and transmission electron microscopy of fault gouges from the Alpine fault zone have shown that the gouges have been derived from the mylonites and that they show a preferred alignement of micaceous material.The matrix of the gouge may consist of pellets of ground-up material. Microanalysis using a scanning transmission electron microscope will be needed for positive identification of minerals in the matrix.

These studies will continue in the coming months as more of the material collected from the Alpine Fault Zone last summer is studied.Preparation for this coming summer's field work in New Zealand is well under way.

Theoretical studies of the factors which determine whether or not friction melting occurs during seismic slip have continued with an investigation of seismic source parameters possibly related to the process.Source parameters and faulting modes for 19 moderate to large earthquakes for which the rise time has been determined have been collated.Calculations of the radiant flux have been made for these earthquakes,which reflects the rate of energy dissipation on the fault surface and,in turn,the seismic efficiency. The large variation in this parameter leads to the conclusion that there is a considerable variation in seismic efficiency,not only between different faulting modes but also for earthquake faults of the same type.

Seismic Studies of Fault Mechanics

8-9930-02103

W. L. Ellsworth
U.S. Geological Survey
345 Middlefield Road
Menlo Park, CA 94025
(415) 323-8111, ext. 2778

The primary objective of this project is the synthesis of kinematic models of fault mechanics from seismological observations and other geophysical measurements. Ultimately, these models will be systematically applied to data from central California and other regions to aid in the identification of temporal changes in the "state" of the fault system. Current work is focused on the construction of crustal velocity structures in regions of complex geology for use in the accurate determination of local earthquake hypocenters and focal mechanisms.

Planning is nearing completion for a detailed seismological study of the velocity structure and seismicity of a 15 km long portion of the creep-active central segment of the San Andreas fault. The objectives of the experiment are the determination of the three-dimensional velocity structure within and adjacent to a geologically and tectonically simple segment of the San Andreas system and the absolute location of earthquake hypocenters along that segment.

The study area encompasses the part of the San Andreas fault lying within Dry Lake Valley, Little Rabbit Valley and Rabbit Valley about 50 km SE of Hollister, California. This segment of the fault is characterized by a high creep rate and the occurrence of frequent small earthquakes. Earthquakes with $M > 4$ are unknown in the historic period. Because shear strain is not accumulating along this segment of the fault system, it is likely that the observed equilibrium between the driving forces and fault movement is maintained almost entirely by aseismic creep.

A detailed re-examination of the spatial distribution of the earthquakes occurring between 1970 and 1975 reveals that their hypocenters are restricted to a few prominent clusters on the fault plane which have recurrent activity throughout the entire time period. These hypocentral clusters occupy only about 20% of the area on the fault plane to a depth of 10 km. No reliably locatable events (M 1.5) fall within the remaining 80% of the fault surface. The apparent spatial stationarily of these localized hypocentral zones suggests that the mode of fault movement--either aseismic fault slippage or small earthquakes--is controlled by local variations in the physical properties of the fault zone.

Preliminary re-examination of the earthquakes also indicates that some of the persistent source regions lie very close to the surface, perhaps as shallow as 1 km. As such shallow zones would be accessible by a drilling program using existing technology, the precise location of shallow source regions takes a high priority in experiment design. We intend to determine the source regions of these very shallow earthquakes using the 96 sensor Centipede array deployed in a tight pattern spanning the active fault trace. Detailed seismic refraction studies are also planned to aid in the measurement of velocities at shallow depth. Development continues on programs to manipulate and analyze the high volume of data to be collected in the experiment.

Active Seismology in Fault Zones

8-9930-02102

David P. Hill
Seismology Branch
U.S. Geological Survey
345 Middlefield Road
Menlo Park, CA 94025
(415) 323-8111, ex. 2891

The objective of this project is to provide constraints on the composition and physical state (pore pressure, temperature, stress, etc.) of rocks in the crust and upper mantle in the vicinity of active fault zones using the latest field and analysis techniques of active seismology (refraction and reflection methods) together with results from physical properties measurements on relevant rock samples in the laboratory. An immediate and important consequence of this objective will be improved velocity models for fault zones and the adjacent crustal blocks that will in turn improve the resolution of hypocenter locations for earthquakes associated with the fault zones.

The initial effort under this project will involve participation in an intensive study of fault zone properties along a creeping section of the San Andreas fault in Dry Lake Valley (immediately south of Bear Valley and about 50 km south of Hollister). The intent of this study is to resolve the detailed structure in the upper few km of the fault zone and the immediately adjacent blocks as a prelude making in situ measurements of physical properties in holes drilled directly into a shallow seismogenic section of the fault. Dry Lake Valley is one of the few areas along the central section of the San Andrews fault with evidence for current earthquake activity at depths as shallow as 1 to 2 km, and this was a major actor influencing the choice of the area for the intensive study.

Arrangements to begin field work in June on the seismological part of this study are nearly complete. The active seismic experiment planned for this summer involves finding a pattern of six to eight shots along profiles roughly 20 km in length parallel with and perpendicular to the fault zone in the Dry Lake region. These shots will be recorded by a temporary 90-element array of densely-clustered seismometers (the Centipede system) set out in an area with a diameter of about 20 km centered on Dry Lake and by linear profiles of 50 to 100 of the new seismic-refraction cassette recorders developed under the leadership of J. Healy. We expect that the results of these seismic experiments in Dry Lake Valley in terms of detailed velocity structure and accurate hypocentral locations for shallow earthquakes will provide a critical basis for choosing the location and target depth for hole(s) drilled for in situ measurements in the shallow seismogenic part of the fault later in the year.

"A STUDY OF THE RELATIONSHIP AMONG PORE PRESSURE CHANGES, SEISMIC AND ASEISMIC SLIP AND CHANGES IN SEISMIC VELOCITY ON THE SAN ANDREAS FAULT"

Contract No. USDI 14-08-0001-15885

December 1, 1977

Robert L. Kovach and Amos Nur

Velocities of seismic compressional waves are anomalously low in and around a 600 meter deep well-bore located in Stone Canyon, San Benito County, California. These low velocities are attributed to the extensive fracturing of rocks along the San Andreas fault. Although laboratory studies on specimens of core from the well show that the mineral assemblage and microcrack behavior of the quartz diorite around the well exhibit the elastic properties typical of granitic rock, sonic logs show that nowhere in the well does the P-velocity exceed 70% of the expected velocity. A vertical seismic profile and surface refraction studies confirm the low P-velocities detected by the sonic log. Analysis of other geophysical data gathered by borehole instruments suggests that saturated macrocracks, while producing only a 6-10% porosity, are responsible for the 30-50% deficiency in the velocity of P-waves around this well.

These macrocracks fail to close in response to confining stress at the depths predicted by laboratory studies. This is attributed to dilatancy induced by the shear stress which drives the San Andreas fault. This low-velocity wedge seriously influences the ray paths taken by seismic waves. Lateral refraction of waves traveling nearly parallel to the fault zone precludes standard inversion of traveltime data obtained from sources or stations located near the fault.

Granitic rocks in the Gabilan Range exhibit near-surface P-velocities higher than those encountered in the wedge, but which still are lower than the velocities expected in granitic rocks. 3.80 km/sec is characteristic of saturated, unweathered near-surface quartz diorite _in situ_, while laboratory specimens exhibit P-velocities of nearly 6 km/sec under similar conditions of pressure and saturation.

First arrivals at Gabilan Range stations are fit with traveltimes predicted by a velocity-depth function of the same form used to fit laboratory pressure-velocity behavior. This successful fit explains the mechanism for the Pg refracting 'layer' in the Gabilan Range in terms of closing the macrocracks. The sensitivity of these rocks to pressure _in situ_ is higher than the sensitivity of laboratory specimens.

Velocity changes induced by variations in tectonic stress are confined to the upper few kilometers of the crust. Precise seismic refraction experiments in Stone Canyon detect a P-velocity anisotropy consistent with the regional tectonic stress. Changes in velocity associated with the buildup or relaxation of tectonic stress will be anisotropic, because relaxation of the compressive stress allows cracks to open in one direction while having little effect on cracks oriented in other directions. These considerations demand that extreme care be taken in experiments meant to monitor velocity changes. An airgun fired in a tank of water proved a suitable source of energy. The system tested exhibits the stability and repeatability of signal necessary for monitoring subtle changes in velocity as well as the portability required for optimum design of shotpoint-geophone geometry. These investigations provide the basis for using seismic velocities as a means of monitoring changes in stress _in situ_.

Mechanics of Geologic Structures Associated with Faulting

8-9960-02112

David D. Pollard
U. S. Geological Survey
345 Middlefield Road
Menlo Park, CA 94025
(415) 323-8111 ext. 2635

Goals

A variety of geologic structures including folds and fractures with characteristic dimensions ranging from millimeters to several tens of meters are commonly observed in outcrops near faults or within fault zones. In some cases these structures apparently formed during faulting, so their origin is intimately associated with processes of faulting. The research goals of this project are:

a) to locate and map in detail, geologic structures associated with several well exposed faults in relatively simple tectonic settings;

b) to derive and study idealized models of these structures using various methods of continuum mechanics;

c) to better understand the processes of faulting in light of these field data and theoretical analyses.

Investigations and Results

Pollard has searched for a suitable field area to study well exposed structures associated with small faults in granite. With help from Jim Moore and Malcolm Clark (USGS) several regions in the Sierra Nevada have been tentatively selected. Numerous faults with centimeters to meters of apparent offset crop out over much of the granitic terraine along the Sierran Crest. Moore has mapped and analyzed these on a regional scale. We will begin detailed field investigations this summer. Of particular interest will be the correlations, if any, between structures associated with these faults and those observed by others in laboratory specimens of granite subjected to loads which induce faulting.

Pollard has begun the derivation of a solution for the 2-d elastostatic problem for multiple fractures of arbitrary length and orientation in an infinite region. It is anticipated that this analysis will help to explain structures associated with closely spaced echelon faults in the Sierran granite. The solution will be constructed by the iterative superposition of analytical solutions using the Schwarz's Alternating Method (Sokolinkoff, 1965, Mathematical Theory of Elasticity, McGraw-Hill, 318-326). The basic analytical solutions have been derived. The design of the numerical (iterative) techniques will be undertaken during the second half of this fiscal year.

Arvid Johnson has studied the folding and faulting of single and multi-layers of incompressible, strain-hardening (and strain-softening), elastic-plastic materials, using strength properties of sedimentary rocks reported in the literature. The general question is whether sedimentary rocks will tend to fault or to fold at high levels in the Earth's crust, where transport processes that apparently are responsible for "viscous" folding are too slow to be important. Analyses have been for layers of dolomite, limestone, sandstone, and siltstone in media of shale. The results indicate that single-layer folds of such rock are unlikely to develop, whether contacts between layer and media are bonded or free to slip. Instead of folding, single layers tend to fault, as shown by considering faulting as a process of deformation banding described by Rudnicki and Rice (1975, J. Mech. Phys. Solids, 23:371-394). Multilayers will fold readily if contacts between layers are free to slip and if there is a sufficient number of structural members in the multilayer.

Therefore, folds due to layer-parallel compression in sequences of sedimentary rocks appear to generally reflect low contact strengths between structural units. Faults may accompany the folds, of course, occurring where compression is increased in cores of folds. Faulting, without folding, apparently reflects high contact strengths or very few structural members. There are two directions in which this research will be extended. One is to treat folding and faulting of dilatant, strain-hardening materials. Rudnicki and Rice have analyzed faulting of such materials. The second is to determine the relevant properties of some sedimentary rocks so that the theoretical analyses can be checked quantitatively. Such data are lacking in the literature.

Part of Johnson's time has been spent writing a first draft of an U.S.G.S. Professional Paper on theories of folding of elastic, viscous, power-law and strain-hardening materials, a paper to be co-authored by Raymond Fletcher. Johnson has completed drafts of three chapters. The purpose of the professional paper is to bring together a coherent presentation of the fundamentals of folding theory which have been developed during the last ten years, primarily for the use of structural geologists and geomechanicists.

Raymond Fletcher has studied quasi-static creep on a wavy fault surface which cuts an homogeneous deformable medium. The results of the analysis will be applied to observations on natural faults, including the evidence for extensive pressure solution accommodating slip past obstacles, measurements of fault surface roughness spectra, and observations of deformation in the vicinity of fault surfaces.

In the first model considered the medium is a linear viscous fluid. The fault is treated as the limiting case of a weak surface which cannot support a shearing stress. However, a macroscopic shearing stress parallel to the mean fault surface can be supported by a distribution of normal stress across the fault surface. Slip is accommodated by the flow of the medium and in addition, by diffusional transfer of the medium along the fault surface between loci of high normal stress and loci of low normal stress. The analysis is performed for a sinusoidal surface with wavelength $L = 2\pi/k$ and amplitude A. The results are accurate to second-order in the slope of the surface, kA. The slip velocity u is found to be related to the mean shear stress, $\bar{\sigma}_{xz}$, according to

$$\bar{\sigma}_{xz} = (1 + \eta\alpha k^3)^{-1} \eta k (kA)^2 \bar{u}$$

where η is the viscosity of the medium and α is a parameter controlling the rate of diffusional transport along the fault surface. If diffusional transport is the dominant slip mechanism, $\eta\alpha k^3 >> 1$, and the relation reduces to

$$\bar{\sigma}_{xz} \cong \alpha^{-1} A^2 \bar{u} .$$

This last result is independent of the properties of the medium, and was obtained by Raj and Ashby (1971, Metallurgical Trans., 2:1113-1127) for grain boundary sliding with the grains treated as elastic solids. The former result is equivalent to that obtained for sliding of a temperate glacier by Nye (1970, Proc. Royal Soc. London (A), 315:381-) and Kamb (1970, Reviews of Geophysics and Space Physics, 8:673-728). The present method of analysis is somewhat different from that used in these studies. To the accuracy of the present analysis, the sinusoidal fault surface form is preserved as slip continues.

Further analytical work will include: (1) the characterization of a wavy fault surface of arbitrary shape; (2) the extension of the analysis to the case of an elastic medium, and the case of a non-linear power-law fluid medium; (3) extension to faults which support a local shear stress.

Coherent Seismic Wave Analysis

8-9930-01892

Paul Reasenberg
U.S. Geological Survey
345 Middlefield Road
Menlo Park, CA 94025
(415) 323-8111, ext. 2049

Goals

1. We wish to develop a method for determining crustal seismic velocity variations (and thus for inferring crustal stress variations). The method applies seismic array techniques to existing USGS seismograph network data. Seismic waves arriving coherently across an array contain velocity-related information in the fine structure of relative P delays to stations in the array. To observe a crustal velocity change of 1 percent, timing precision of a few milliseconds is required. Cross correlation of coherent phases across an array provides a means to achieve this precision. We are developing programs for an Eclipse minicomputer which simulate an array processor's cross correlation and stacking ability.

2. We wish to use the above method to study the temporal and lateral variations in crustal seismic velocity in California. Temporal variations may be interpreted in terms of stress changes.

Investigations

1. Teleseisms recorded by the USGS central California network are being digitized and timed by cross correlation. Thirty-two teleseisms in 1976 were dubbed, and comprise the starting data set. All stations in the network are being timed. The relative residuals will be used in two ways. First, they will be inverted for 3-dimensional velocity structure, using the block inversion method of Aki and Ellsworth. Secondly, they will be used to begin monitoring average seismic velocity within smaller regions of the network. After correcting for hypocentral variations, a search will be made for co-seismic and pre-seismic regional velocity changes.

2. We are investigating the possibility of using vibroseis data to monitor changes in crustal velocity within a small (up to 25 km) region. We have installed a 64-element linear array in the Gabilan Range (east of Monterey Bay) and have recorded signals from McEvilly's current (Spring '78) reflection experiment in that area. Pulse reconstrctuion by matched filtering, for a vibroseis chirp, consists of cross correlation. A standard reflection technique uses a hardware correlator. We will use our software correlator for the same purpose. We will concentrate on the 8-second (Moho)

reflection. An iterative combination of stacking and correlation will be used to enhance the reflected wave and reduce ground roll. The aim of this investigation is to demonstrate that a small array can be effective in vibroseis reflection work when optimal signal processing is used.

Results

1. The version of the computer program for the teleseism investigation is operational.

2. Timing precision, using the correlation program, has been statistically estimated. Ensembles (N = 71) of synthetic waveforms were generated. Each waveform consists of a damped 1-second sinewave (resembling a teleseismic P wave) plus band-limited Gaussion noise. Both spectral content of the noise and S/N ratio were varied from ensemble to ensemble. All traces in each ensemble were timed by correlation over a 2-second interval. Since the ensembles are stationary, the rms correlated "delay" for the ensemble is an unbiased estimate of the timing precision, as a function of S/N and noise spectrum. For 30 Hz bandwidth noise, the expected errors in timing were found to be (95% confidence) 3, 7, and 17 milliseconds for S/N = 20, 10, and 5, respectively. The synthetic data sampling rate was 100 samples per second.

Publications

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Crustal Inhomogeneity in Seismically Active Areas

8-9930-01169

S. W. Stewart
U. S. Geological Survey
345 Middlefield Road
Menlo Park, CA 94025
(415) 323-8111 ext. 2525

Goals

The major goal is to study the nature of crustal inhomogeneity as revealed primarily by seismic waveform data. In these early stages the principal source of data will be seismograms recorded by the central California seismic telemetry network. Attention will be given to delineating vertical velocity variation in the lower half of the crust. Present objectives are to assist in getting digitized seismic waveform data routinely produced by the ECLIPSE Computer system, and to design and develop a seismic trace plot package for the MULTICS computer system.

Investigations

Digitized seismic waveform data are to come routinely from the interactive seismic analysis system being designed and implemented by Pete Stevenson's project (9970-02118), for analysis of the central California telemetry data. This system will generate archive tapes of digitized waveforms, and all pertinent station and hypocenter data, in a format convenient to read on the USGS Multics Computer system. I am participating in that portion of the project relevant to designing the format for the magnetic tapes, and verifying that the tapes can indeed be read into MULTICS. The interactive processing system seems close to completion but the archive digital tapes are not yet being produced.

I investigated which of the plot packages on the MULTICS computer systems would be best to develop plot software, for running interactive or batch, to display the digitized seismic waveforms. The commercially developed DISSPLA graphics package is the obvious choice. Unfortunately, this is not yet available on the Menlo Park MULTICS system, although it is available on the Denver and Reston systems. We hope for installation in Menlo Park by early summer.

Maintenance and minor changes in the online earthquake detection and location system, developed when this project was titled "Automatic Earthquake Processing", continued.

Results

A format was developed for the nine-track digital archive tapes generated by the DGC ECLIPSE Computer systems during analysis of the central California seismic network data. In order to make the archive tapes as compatible as possible with other computer systems, a nine-track ASCII-coded tape is generated by the ECLIPSE computer. Even the digitized waveform data are written as valid ASCII characters, though not all the valid characters are printable characters. The tapes are read into the MULTICS system as an ASCII representation. The alphanumeric text information (e.g., station coordinates, hypocenter results, etc.) can be printed directly. The digitized waveform data have a simple unpacking algorithm, and then are available for further analysis. Several notable features of the tape format include: (1) printable text as well as packed digitized waveform data can be written on the tape, while still retaining the ASCII mode for the entire tape; (2) because the archive tapes will be roughly 90% digitized data and 10% text, the packing algorithm using two bytes per data sample, rather than the more standard 4 or 5 bytes for ASCII "card image" format, results in a 2 to 1 ratio for increasing the amount of data on each archive tape; (3) although 10-bit digitizers presently are on the ECLIPSE system, 12-bit digitizers can be used without any change in the tape writing or reading and unpacking algorithms; (4) each physical record on the archive tape begins with an 80-character ASCII string that describes what kind of information is in that record, and gives approprate parameters. A tape verify program was written for the MULTICS computer to aid in checking out (i.e., de-bugging) archive tapes written on the ECLIPSE computer.

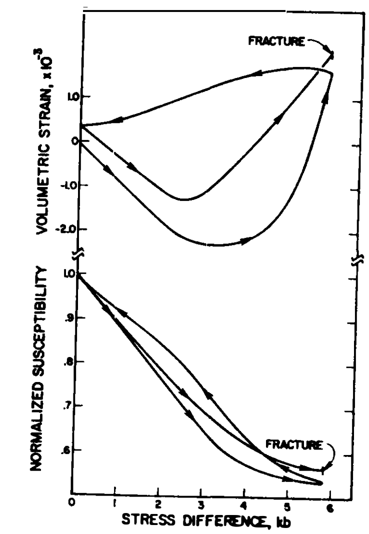
DILATANCY AND MAGNETIC PROPERTIES OF ROCKS UNDER NON-HYDROSTATIC STRESS

Charles B. Archambeau, H. A. Spetzler, Max Wyss, and R. J. Martin III
CIRES, University of Colorado, Boulder, Colorado 80309
May 10, 1978

Magnetic Susceptibility

A series of laboratory experiments have been initiated to examine the relation between stress, volumetric strain and magnetic susceptibility during cyclic loading and fracture. The changes in susceptibility are monitored using a bridge apparatus modified after the design of Christie and Symons (1969). All the tests are carried out in a beryllium copper pressure vessel at confining pressures up to 2 kb.

The results of a preliminary experiment at 500 bars confining pressure on the Ralston intrusive are shown below. Normalized axial susceptibility and volumetric strain are plotted as a function of differential stress. When the sample was loaded the susceptibility began to decrease linearly. At the onset of dilatancy (approximately 2300 bars) the susceptibility vs. stress curve became nonlinear and its slope started to decrease. At the peak stress of 5800 bars, the susceptibility had decreased by 46 per cent. There was a slight hysteresis on unloading and no permanent demagnetization at the completion of the cycle.



The rock was brought to failure on the second cycle. The shape of the susceptibility curve for the second cycle was similar to that of the first cycle except the change in susceptibility was somewhat less. Furthermore there was no precursory change in susceptibility just prior to failure.

While this is only a preliminary result and cannot be directly compared with the remanent magnetization results on Ralston at 500 bars confining pressure until we have finished calibrating the susceptibility apparatus, several significant points are apparent. First, the axial component of the remanent magnetization increased up to the onset of dilatancy whereas the axial susceptibility decreased over the same stress range. As the sample was increasingly loaded after dilatancy commenced, the axial components of magnetization decreased for both types of measurement. Second, the parmenent demagnetization was large in the remanent experiments, whereas there was virtually no permanent demagnetization in the susceptibility experiment.

DEFORMATION AND FRACTURE CHARACTERISTICS OF PYROPHYLLITE UNDER GENERALIZED TRIAXIAL LOADING

I. C. Getting, C. H. Sondergeld and H. A. Spetzler
CIRES, University of Colorado/NOAA, Boulder, CO 80309

In a recently designed compressive testing apparatus cubic-shaped samples of pyrophyllite were loaded to failure under generalized triaxial stress, i.e., $\sigma_1 \neq \sigma_2 \neq \sigma_3$. Fractures ran out on the intermediate stress face, normal to σ_2, which was viewed with laser illumination through a window in the vessel. Displacement contour maps of the σ_2 face were obtained by double exposure holographic interferometry at contiguous 50 bar increments in σ_1. The surface displacement history of fracture zones on the σ_2 face was followed by analyzing these holograms. At a stress rate of ~ 0.1 bars/s, the ultimate strength was typically $\sigma_1 = 2.4$ kb with $\sigma_2 = 1.0$ kb and $\sigma_3 = 0.5$ kb. Under these conditions a pair of fracture planes was formed intersecting at the center of one σ_1 face and running through the $\sigma_1 : \sigma_3$ edges of the opposite σ_1 face. Also, acoustic velocities in the three principal stress directions and stress-strain values in the maximum principal stress direction were continuously monitored. The stress rate dependence features will be presented and discussed in terms of current dilatancy models.

ANISOTROPIC Q AND VELOCITY IN DILATANT ROCK

D. J. Holcomb
CIRES, University of Colorado/NOAA, Boulder, Colorado 80309

Relative Q and velocity were measured simultaneously for the three possible polarizations of sound body waves (SH, SV, and P) in dilatant granite for two orthogonal directions. Measurements were made during loading and unloading for many consecutive cycles, with triaxial loading.

A crack density distribution, in terms of average crack size, number of cracks and spatial orientation, can be inferred from the velocity measurements since data is available for several polarizations. For the first time, the computed density of cracks whose normals were parallel to the axis of maximum compressive stress was close to zero, in accord with the usual assumptions about dilatancy. The resultant stress-dependent density distribution was used to check a model of dilatancy that was developed to explain the stress-strain relations of dilatant material. An interesting prediction of the model, confirmed by the data, was that velocities remain nearly constant for a large part of the unloading cycle. This may have implications for observing velocity anomalies before earthquakes. If the region surrounding an incipient earthquake has been only partially unloaded, then dilatancy may occur but with a much reduced velocity anomaly.

Changes in Q were interpreted as being due to changes in the amount of Rayleigh scattering. As cracks are opened they become effective scatterers. This scattering is polarization-dependent for an anisotropic distribution of crack orientations. Because of the strong frequency dependence, peak-to-peak amplitude measurements were not a valid measure of Q. The waveforms changed too greatly.

ROCK MECHANICS

8-9960-01179

J. Byerlee
U.S. Geological Survey
345 Middlefield Road
Menlo Park, CA 94025

Goals

The goals of this project are to study the mechanical behavior of rocks at high confining pressure, pore pressure, differential stress and temperature and to apply the result of the experiments to understanding earthquake source mechanisms and to the solution of problems related to earthquake prediction and control.

Some time was spent installing a PDP 11/03 microprocessor to monitor and adjust parameters such as differential stress etc. on four separate rock presses. The equipment is now fully operational and experiments are now underway.

The time-dependent deformation of Westerly granite containing a sawcut separated by crushed Westerly granite fault gouge was studied at 4 kbars of confining pressure. Differential stress was increased in steps and held constant at each stress level which fault creep was monitored. Decaying primary creep occurred immediately after each increase in the differential stress level. Primary creep was followed by constant rate secondary creep above 9,200 bars of differential stress and the displacement rate increased rapidly with increasing stress levels. At 10,834 bars of differential stress primary and secondary creep were followed by accelerating tertiary creep, which culminated in violent slip. Our results may be applicable to earthquake prediction along the central San Andreas fault. They suggest that sudden seismic slip in the area of constant rate fault creep should be preceded by a period of accelerating creep. We plan to conduct further experiments designed to study the effects of time, confining pressure, pore pressure, and temperature on experimental fault creep under constant differential stress.

A large granite sample containing a saw-cut filled with crushed granite, modelling a natural fault with gouge, was loaded triaxially at confining pressure of 4,000 bars. Changes in pore volume of the simulated gouge layer were measured during application of confining pressure and during axial loading to failure by sudden stick-slip. Pore volume strain in this configuraton, with a thin layer of gouge between rock surfaces, was significantly less with increasing confining pressure than similar experiments in which the entire sample was of crushed granite. Our sample continued to decrease in volume upon application of axial load up to the point at which sliding on the saw-cut started. At this point, the decrease in volume slowed down, and the volume increased just before failure. Dilatancy amounted to 1.8% of the total decrease caused by the axial load. It is interesting the amount of grain crushing, a phenomenon generally associated with decreases in volume. Also, failure occurred at a stress below that required to cause dilatancy in intact rock.

Severe damage to the loading apparatus prevented any measurements after sample failure and has delayed further experiments. After a suitable system is constructed, experiments will be conducted to measure both pore volume and permeability in gouge during both stick-slip failure and stable sliding. We also plan to measure these parameters during multiple stick-slip events in the same sample, in order to study the effects of the cyclic loading represented by repeated failures.

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Mechanics of Earthquake Faulting

9960-01182

James H. Dieterich
U.S. Geological Survey
345 Middlefield Road
Menlo Park, CA 94025
(415) 323-8111 ext. 2573

Experimental Observations of Preseismic Slip

An interval of stable sliding preceding unstable (seismic) slip on simulated faults has been widely recognized for a variety of experimental conditions. By analogy similar stable fault slip may precede earthquakes and may explain some observations of earthquake precursors. However, no direct experimental data have been available to establish the relationship between the dimensions of the sliding surface and the parameters that characterize the magnitude and duration of preseismic slip. Large scale biaxial friction experiments using a sample with dimensions of 150 cm x 150 cm x 40 cm show that stable slip is a consistent precursor to unstable slip and provide an indication of scaling relationships. Strain gages adjacent to the sliding surface give 10 channels of shear strain data (DC to 50 KHz) during preseismic and seismic slip episodes. As observed in similar small scale experiments (sample dimensions of 13 cm x 13 cm x 4 cm) inhomogeneity of initial shear stress along the fault relative to frictional strength controls preseismic slip. The amount and duration of preseismic slip increases with inhomogeneity. Comparison with the small scale experiments shows that the strain changes arising from preseismic slip are independent of sample dimensions (Fig. 1). As a result, preseismic fault displacements are proportional to fault dimensions. Preseismic displacements measured in the large-scale experiment which has a fault length of $\sim$200 cm were in the range 10^{-3} to 10^{-2} cm compared to 5-15 x 10^{-4} cm for similar experiments on a sample with a fault length of $\sim$20 cm.

Constitutive Law for Rock Friction

Direct shear experiments on ground surfaces of Raymond Granite at normal stresses of $\sim$60 bars demonstrate that competing time, displacement and velocity effects control rock friction. Results suggest that the strength of the population of points of contacts between sliding surfaces determines frictional strength and that the population of contacts changes continuously with displacement. Previous experiments demonstrate that the strength of the contacts increases with the age of the contacts. The present experiments have established that a characteristic displacement, d_c, proportional to surface roughness, is required to change the population of contacts. Hence, during slip the average age of the points of contact and therefore frictional strength decrease as slip velocity increases. Displacement weakening and consequently the potential for unstable slip occurs whenever displacement reduces the average age of the contacts. In addition to this velocity dependency which arises from displacement- and time-dependency, the experiments also show a competing but transient increase in friction whenever slip velocity increases. Creep of the sliding surface at stresses below that for steady-state slip is also observed. The following empirical relationships permit quantitative simulation of both static friction and sliding friction vs. displacement as functions of surface roughness and for different time and velocity histories.

$$\mu = [c_1 + c_2 \log (c_3 t + 1)] \left[f_1 + \frac{1}{f_2 \log\left(\frac{f_3}{v} + 10\right)} \right] \tag{1}$$

where μ is the coefficient of friction, t is age of contacts, v is velocity of slip and c_1, c_2, c_3, f_1, f_2, and f_3 are constants. For static friction t is simply the time of stationary contact and during slip t is given by

$$t = \left(\frac{d_c}{v}\right)\left(\frac{v}{d_c} t_o\right)^{e^{(x_o - x) d_c}} \tag{2}$$

where d_c is the critical displacement, proportional to roughness; x is displacment; and x_o, t_o are the initial time of contact and initial displacement respectively. Figure 2 gives an example of the experimental observations and a simulation using (1) and (2).

The time and velocity dependency of (1) apparently arise because of asperity creep at the points of contact. Preliminary experiments suggest that the asperity creep is caused by weakening of the asperities due to adsorbed water. Samples heated to 300° C in a dry Argon atmosphere for 24 hours do show greatly reduced time or velocity effects. Exposure of the "dry" samples to atmospheric humidity restores the time- and velocity-dependence.

Modeling of Preseismic Slip

The constitutive relations (1) and (2) have been used to model detailed observations of preseismic slip and the onset of unstable slip in the biaxial laboratory experiments. The simulations employ a plane strain finite element model to represent the interactions both within the sliding blocks and between the blocks and the loading apparatus. Both experiments and simulations show that preseismic slip is controlled by initial inhomogeneity of shear stress along the sliding surface relative to the frictional strength. As a consequence of the inhomogeneity, stable slip begins at a point on the surface and the area of slip slowly expands as the external loading increases (Fig. 3).

A previously proposed correlation between accelerating rates of stable slip and growth of the area of slip is supported by the simulations. In the simulations and in the experiments unstable slip occurs shortly after breakout of preseismic slip at the ends of the sample. In the model the breakout of stable slip causes a sudden acceleration of slip rates. Because of velocity dependency of the constitutive relationship for friction the rapid acceleration of slip causes a decrease in frictional strength. Instability occurs when the frictional strength decreases with displacement at a rate that exceeds the intrinsic unloading characteristics of the sample and test machine. A simple slider-spring model that does not consider preseismic slip appears to adequately approximate the transition from stable sliding to unstable slip as a function of normal stress, machine stiffness and surface roughness for small samples. However, for large samples and for natural faults the simulations suggest that the simple model may be in error because it does not account for preseismic slip.

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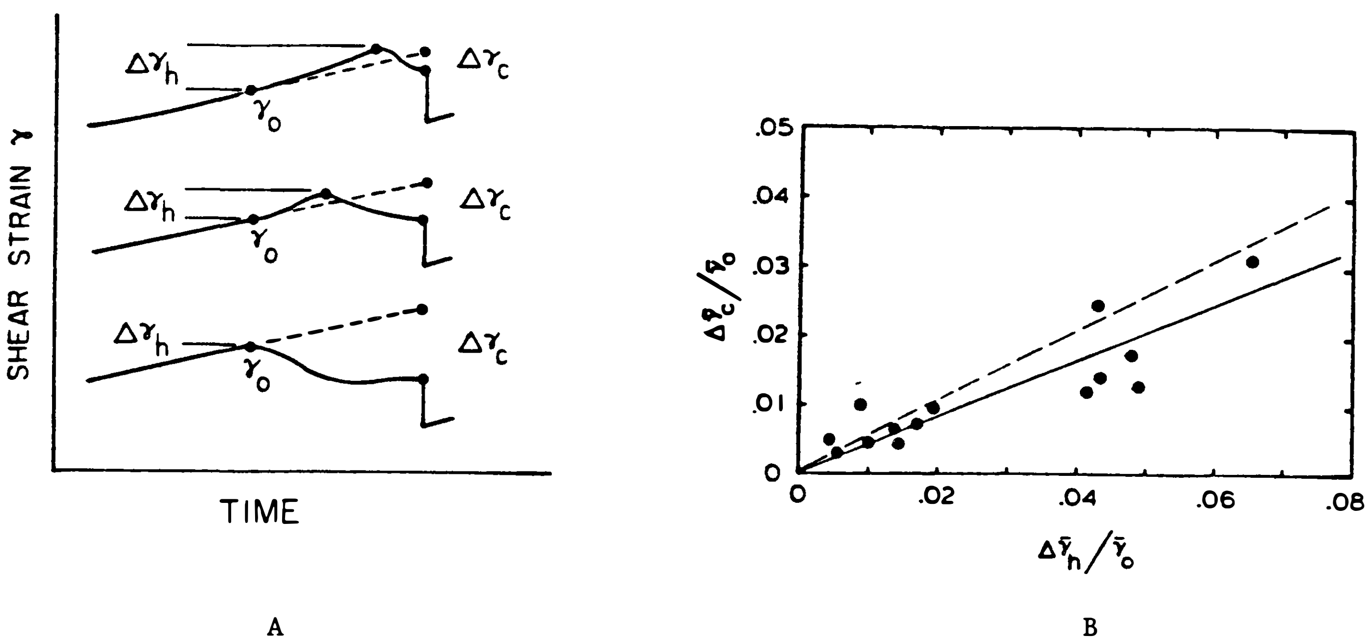

Figure 1. Average change in shear strain caused by preseismic slip, $\Delta\bar{\gamma}_c$ vs. average inhomogeneity of strain relative to the critical shear strain to induce slip, $\Delta\bar{\gamma}_h$. (A) illustrates the characteristics of the strain records and indicates how the quantities are defined. A flattening of the curves marks the beginning of slip at that location on the fault. The solid line in (B) is a least squares fit for the data shown (large scale experiment). The dashed line is the least squares fit from the previous small scale experiment.

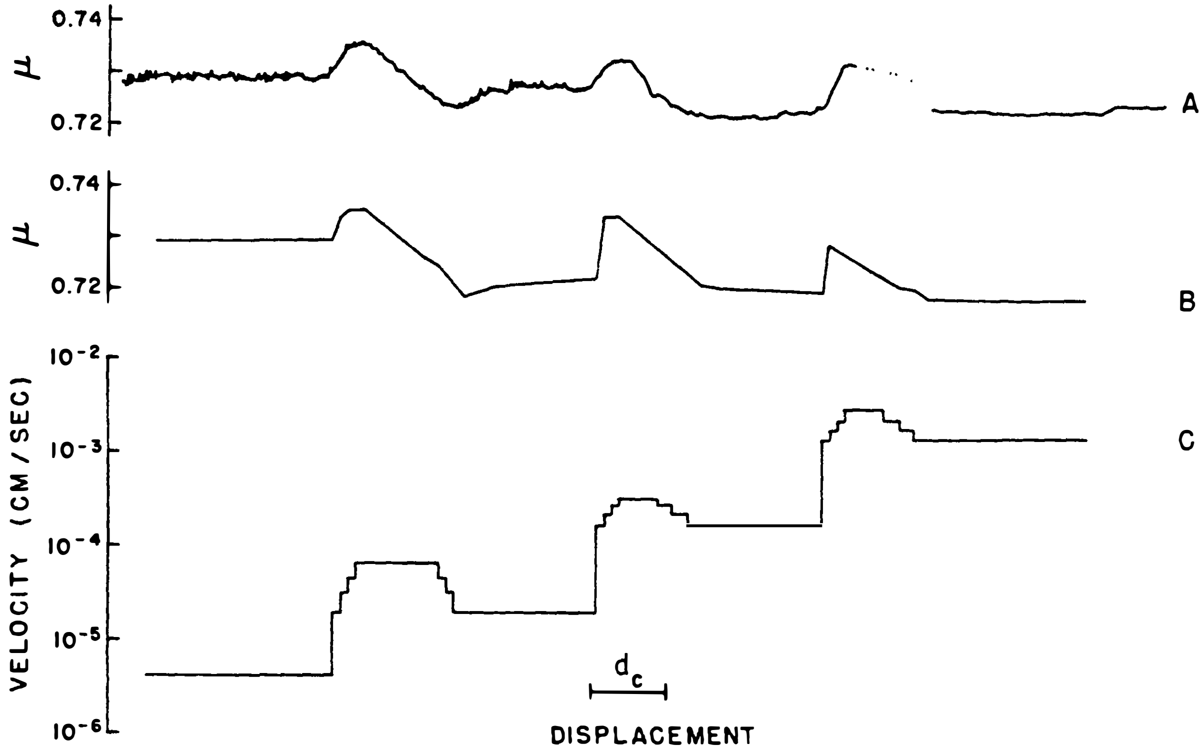

Figure 2. Top curve (A) gives experimental results for the variation of friction, μ vs. displacement for the velocity history shown at the bottom (curve C). Simulation of the experiment using equations (1) and (2) is given by (B).

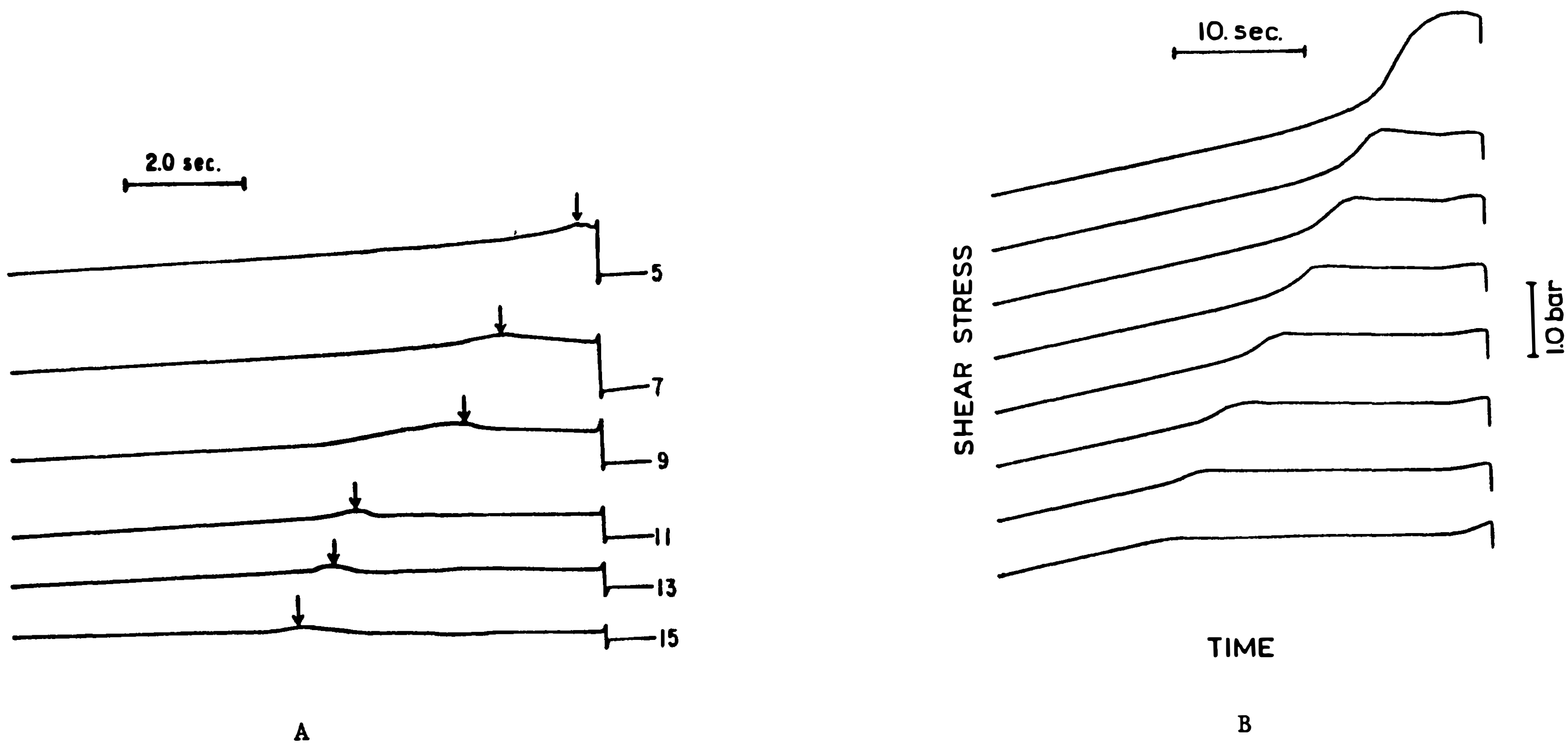

Figure 3. (A) Shear strain vs. time at 6 locations adjacent to the sliding surface. The curves are arranged by position on the fault and the arrows mark the beginning of preseismic slip at each location. (B) Simulation of preseismic slip using finite element model of the experiment and friction equations (1) and (2).

Experimental Rock Mechanics

8-9960-01180

Stephen H. Kirby
U.S. Geological Survey
345 Middlefield Road
Menlo Park, CA 94025

Goals

The widespread aseismic accommodation of relative plate movements and the expected effects of increasing temperature with depth in the lithosphere require that the physicals laws governing time dependent ductile strength be assessed for the principal rock forming minerals and rock types of the crust and upper mantle. Such rheological laws are essential for realistically modelling tectonic processes involving large-scale flow. The approach of this project is to establish the rheological behavior of rocks by laboratory experiments coupled with micromechanical modelling and comparison of deformation microstructures between naturally and experimentally-deformed rocks.

Investigations

1. Rheology of olivine: a critical review:

At the invitation of the convenors, a review of the rheology of olivine was prepared and presented as the lead-off paper in the special session on the Deformation of Olivine at the Spring Annual Meeting of the AGU.

2. Rheology of clinopyroxenite:

In collaboration with Andreas Kronenberg, presently at Brown University, continuing experiments have extended the temperature, pressure, and strain rate range of the previous suite of experiments.

3. Rheology of orthopyroxenite:

A series of experiments, which parallel those on clinopyroxenite, have been performed.

4. Creep of hydrolytically-weakened synthetic quartz single crystals:

The effects of crystal orientation are being explored.

Results

1. Rheology of Olivine: a critical review. Salient results of the review (Kirby, 1978) are as follows:

A. Comparison of the experimental data on the effects of temperature T and stress σ on strain rate $\dot{\varepsilon}$. The flow law material constants A, n, and E* have been compared for the experimental data on polycrystalline olivine (both anhydrous and in the presence of water) and on anhydrous single crystals (See Table I and II): The stress and strain rate relationships at T=1350°C are also plotted for direct comparison (Fig. 1). The hydrous olivine results clearly produce the highest strain rates at a given stress but no quantitative relationship between creep rates and water concentration has been established. While the nominally anhydrous polycrystalline olivine data of Carter and Ave' Lallemont (1970) and Kirby and Raleigh (1973) compare well with the single crystal creep results, the creep rates predicted by Post's (1977) results are three orders of magnitude lower when compared at the same stress. Post's samples were subject to a more thorough heat treatment to remove water than the earlier nominally anhydrous dunite samples. I conclude that Post's (1977) results are the anhydrous data to be compared to with the anhydrous single crystal results and that the grossly different creep rates predicted by the two classes of data are real and stem from the different nature of crystal constraints. This conclusion is supported by the following evidence.

1. Zeuch and Green (Personal communication, 1978) have reported high strengths similar to those of Post (1977) in a dry synthetic dunite.

2. Greater creep strength of polycrystals compared to single crystals have been reported in halite, calcite, and many metals.

3. The strikingly different transient creep regimes in the two sets of data (transients hardly exist in the single crystals) suggest that the grain boundary constraints in the polycrystals require the development of a different substructure during creep.

4. Direct comparison of the creep-induced substructures indicate that while the same slip systems are activated, the dislocations produced do not form subgrains as they do in the polycrystals. Thus the dislocation micromechanics may be quite different for single crystal and polycrystalline olivine.

The above results suggest that Post's (1977) creep data are more appropriate for modelling of the creep behavior of the mantle, than the single crystal data, assuming anhydrous conditions.

B. The pressure effect on creep rates.

The first-order effect of pressure on creep rates can be described by an activation volume V*, which appears in the Boltzmann factor with argument -(E*+PV*)/RT. Various empirical and theoretical estimates suggest V* is about 11 cm^3/mole or 37 cm^3/mole (see Table III). The latter estimate, based on the assumption that the diffusion of $[SiO_4]^{4}$ groups controls bulk crystal diffusion and creep rates, is unlikely, since it assumes that S_i-O bands are too strong to be broken. The slip systems which operate in olivine (Raleigh, 1968; Durham & Goetze, 1977) require that S_i-O bonds be broken, even at low shear stress.

The basic experimental problem in directly measuring V* is that the pressure effect is small compared to the sensitivity of creep rates to variations in stress σ and temperature T. Experimental uncertainties in T and σ can thus lend to a large scatter in creep rates. For example, a $\pm$ 27 °C variation in temperature leads to a $\pm$ 50% variation in creep rates at 1350 °C (Fig. 2). In order to reduce creep rates by more than 50% by the pressure effect, a pressure difference of greater than 10 kilobars must be used. This, coupled with the need to completely suppress microfracturing over the range of pressures utilized, requires the use of the solid medium piston-cylinder device, with attendant problems of measuring stress accurately. I conclude that it is unlikely that V* can be measured directly and accurately using current technology and apparatus.

2. Rheology of clinopyroxenite (Kirby and Kronenberg, 1978). We summarize the results as follows:

A. A confining pressure of about 10 kilobars is sufficient to suppress microfracturing and faulting at T = 600°C and a strain rate of 10^{-5}/s. Above this pressure, strength is insensitive to pressure effects and reflects the intrinsic plastic strength of the material (Fig. 3).

B. Two flow regimes exist in clinopyroxenite. At low temperatures and high strain rates, deformation occurs by mechanical twinning and [001] slip and the strength is very insensitive to variations in strain rate (Fig. 4) and temperature (Fig. 6). At high temperatures and low strain rates deformation is dominated by multiple slip and associated subgrain formation and recrystallization; the strength is very sensitive to variations in strain rate (Fig. 5) and temperature (Fig. 6). The temperature and strain rate fields these two regimes are established (Fig. 7) as are the flow law constants.

C. The flow behavior of the low temperature regime is closely approximated by a perfectly plastic rheology, with yield strength of about 15 $\pm$ 3 kilobars. If such a simple rheology is general for rock-forming silicates at low to intermediate temperatures, then the mechanical behavior of the upper half of the lithosphere is greatly simplified.

3. Rheology of orthopyroxenite:

Preliminary results indicate that the strength orthopyroxenite is quite similar to that of clinopyroxenite (summarized above) at low to intermediate temperatures.

4. Creep of hydrolytically-weakened sythetic quartz crystals.

Preliminary results indicate that crystals oriented with respect to compression which promotes slip parallel to $\langle a \rangle$ are considerably more creep resistant than those orientations that promote $\langle c \rangle$ slip and that the creep curves in the experiments in which $\langle a \rangle$ slip operated show less hardening than those in which $\langle c \rangle$ slip operated.

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TABLE I
SUMMARIZED FLOW LAW DATA FOR OLIVINE - NOMINALLY ANHYDROUS

FORM OF THE FLOW LAW: $\dot{\varepsilon} = A\sigma^{n}\exp[-(E^*+PV^*)/RT]$

DATA SOURCE	SAMPLE TYPE	A, $s^{-1}kb^{-n}$	n	σ range, kb	E*+PV*, kcal/mole	T range, °C	P, kb
C and A (1970)	Mt. Burnet Dunite	1.2×10^{10}	4.8 ± 0.4	1 to 9	119.8 ± 16.6	1100-1300	15
		(5.1×10^{9})*	(3.3)*	1 to 9	(111)*	1100-1300	15
Post (1977)	Mt. Burnet Dunite	7.95×10^{8}	3.56	1 to 8	126 ± 15	1100-1400	10-15
		4.30×10^{8}	3	1 to 3	126 ± 15	1100-1400	10-15
K and R (1973)	Mt. Burnet Dunite	1.1×10^{8}	3	1 to 7	100 ± 15	1100	15
	Single Crystals				E*, kcal/mole		
	Orientation						
K and G (1974)	Random	3.6×10^{11}	~3	0.1 to 1.5	126 ± 2	1400-1600	10^{-3}
K, G, and D (1976)	All Data	2.69×10^{11}	3 ± 1	0.1 to 1.5	125 ± 15	1500-1600	10^{-3}
D and G (1977)	"Odd"	1.04×10^{12}	3.5 ± 0.5	0.1 to 1.0	~125	1500-1600	10^{-3}
	$[110]_c$	3.44×10^{12}	3.6 ± 0.3	0.2 to 0.4	~125	1200-1600	10^{-3}
	$[101]_c$	1.22×10^{12}	3.7 ± 0.2	0.1 to 0.6	~125 ~80	1430-1560 1200-1400	10^{-3} 10^{-3}
	$[011]_c$	7.59×10^{10}	3.5 ± 0.3	0.3 to 0.8	~125 ~90	1400-1600 1200-1400	10^{-3} 10^{-3}
	On Axis#	-	-	0.8 to 1.8	-	1500-1600	10^{-3}

Sample strain less than 1%, flow law not determined

* Corrected by Carter(1976) for sample bulging

TABLE II
SUMMARIZED FLOW LAW DATA FOR POLYCRYSTALLINE OLIVINE WITH WATER (WET)

FORM OF FLOW LAW: $\dot{\varepsilon} = A\sigma^{n}\exp[-(E^*+PV^*)/RT]$

DATA SOURCE	SAMPLE TYPE	A, $s^{-1}kb^{-n}$	n	σ range, kb	E*+PV*	T range, °C	P, kb
C and A (1970)	Mt. Burnet Dunite	6.2×10^{6}	2.4 ± 0.2	1 to 7	79.9 ± 7.5	975-1350	10-15
		(1.3×10^{3})*	(2.1)*		(54)*		
Post (1977)	"	4.5×10^{7}	5.1 ± 0.3	1 to 8	93.8 ± 2.8	800-1150	5-15
		4.3×10^{8}	3	1 to 3	93.8 ± 2.8	800-1150	5-15

* Corrected by Carter(1976) for sample bulging

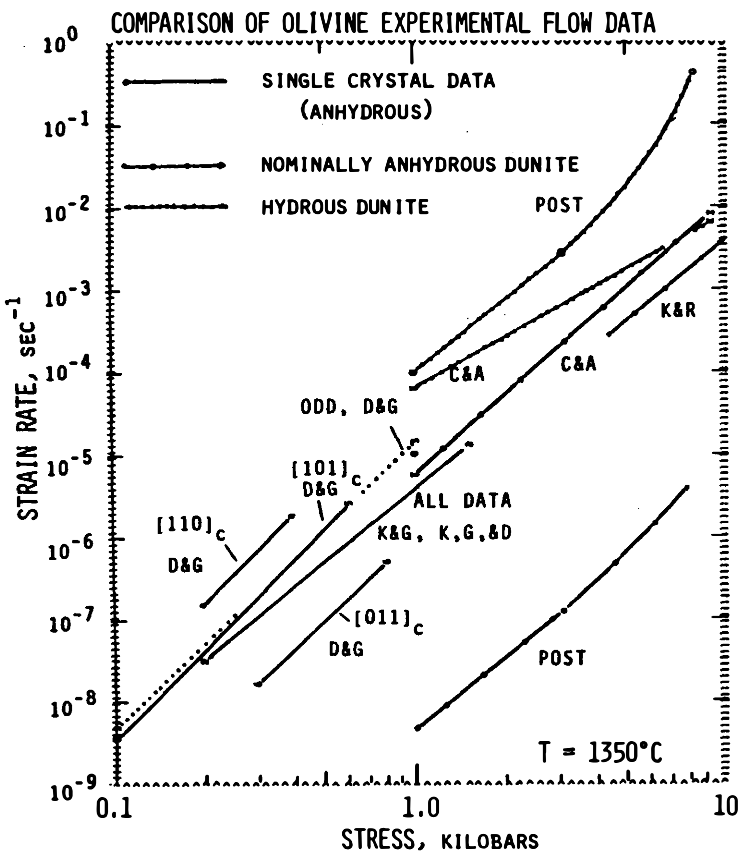
TABLE III

PUBLISHED ESTIMATES OF THE ACTIVATION VOLUME FOR CREEP IN OLIVINE

SOURCE	V^*, cm^3/MOLE	METHOD
GOETZE AND BRACE (1972)	15-20	dT_m/dP and estimates of E^* in mantle minerals#
KIRBY AND RALEIGH (1973)	11	dT_m/dP for forsterite and E^* for dunite#
	11	$V^* \cong V_a^{O--}$
STOCKER AND ASHBY (1973)	11	$V^* \cong V_a^{O--}$
	37	$V^* \cong V_a^{SiO_4^{4-}}$
SAMMIS *ET AL.* (1977)	8.0-11.5	Keyes relation between $G^* = E^*$ and elastic constants
	11.6±0.9	dT_m/dP for forsterite and E^* from single crystal creep data#

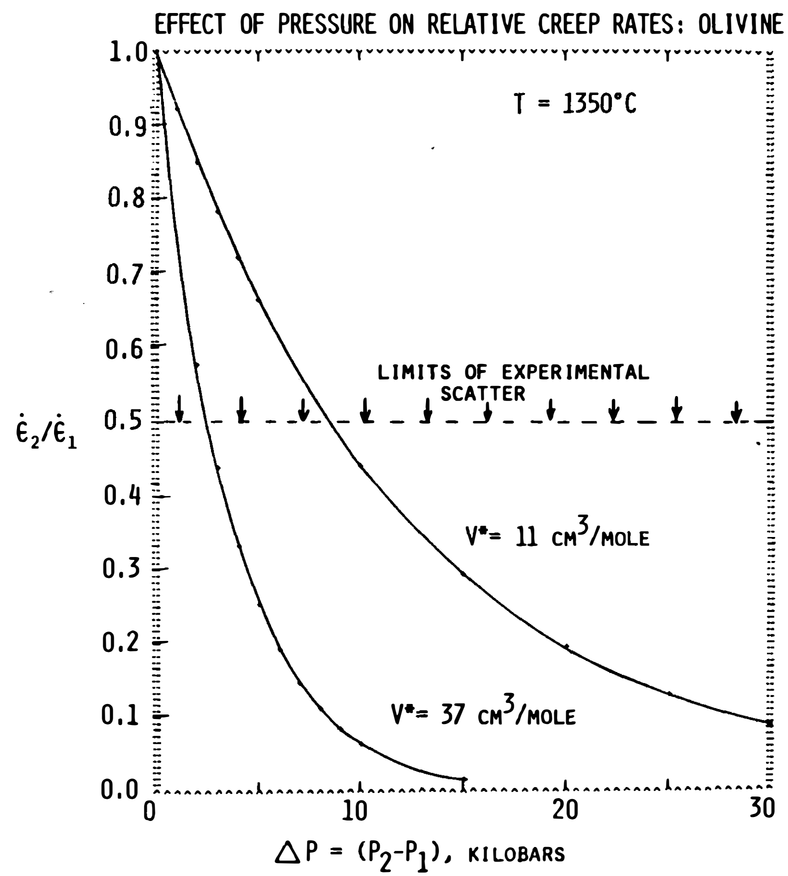
$\frac{gT_m}{T} = \frac{E^*+PV^*}{RT}$ Sherby and Simnad (1971)

$V^* \cong (E^*\, dT_m/dP)/(T_m - P\, dT_m/dP)$



COMPARISON OF OLIVINE EXPERIMENTAL FLOW DATA
SINGLE CRYSTAL DATA (ANHYDROUS)
NOMINALLY ANHYDROUS DUNITE
HYDROUS DUNITE
POST
C&A
C&A
K&R
ODD, D&G
[101]c D&G
[110]c D&G
ALL DATA K&G, K,G,&D
[011]c D&G
POST
T = 1350°C
STRAIN RATE, SEC^-1
STRESS, KILOBARS
0.1
1.0
10

Fig. 1



EFFECT OF PRESSURE ON RELATIVE CREEP RATES: OLIVINE
T = 1350°C
LIMITS OF EXPERIMENTAL SCATTER
V* = 11 CM3/MOLE
V* = 37 CM3/MOLE
ε̇2/ε̇1
ΔP = (P2-P1), KILOBARS

Fig. 2

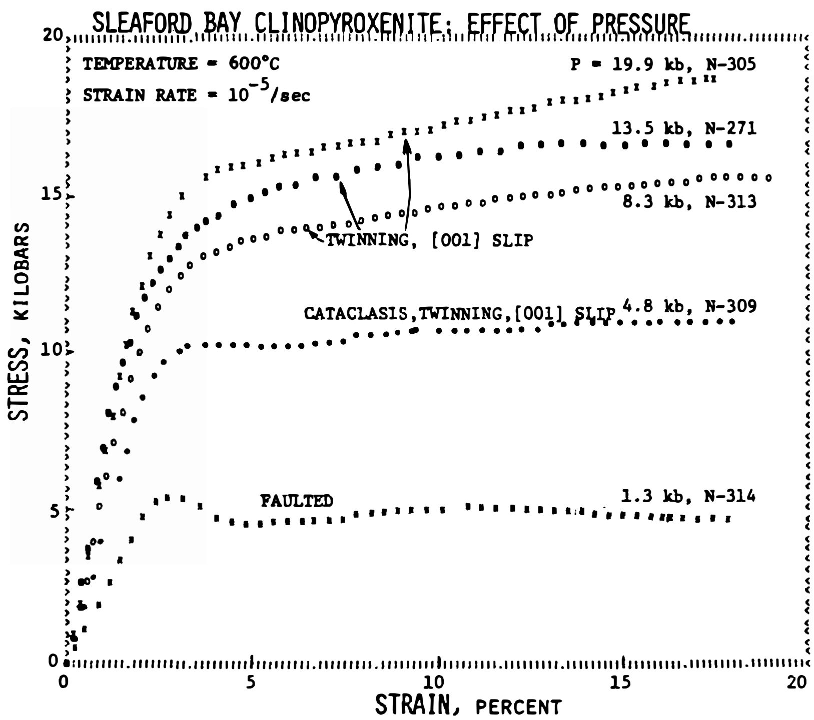

SLEAFORD BAY CLINOPYROXENITE: EFFECT OF PRESSURE
TEMPERATURE = 600°C
STRAIN RATE = 10^-5/sec
P = 19.9 kb, N-305
13.5 kb, N-271
8.3 kb, N-313
TWINNING, [001] SLIP
CATACLASIS,TWINNING,[001] SLIP
4.8 kb, N-309
FAULTED
1.3 kb, N-314
STRESS, KILOBARS
STRAIN, PERCENT
0
5
10
15
20

Fig. 3

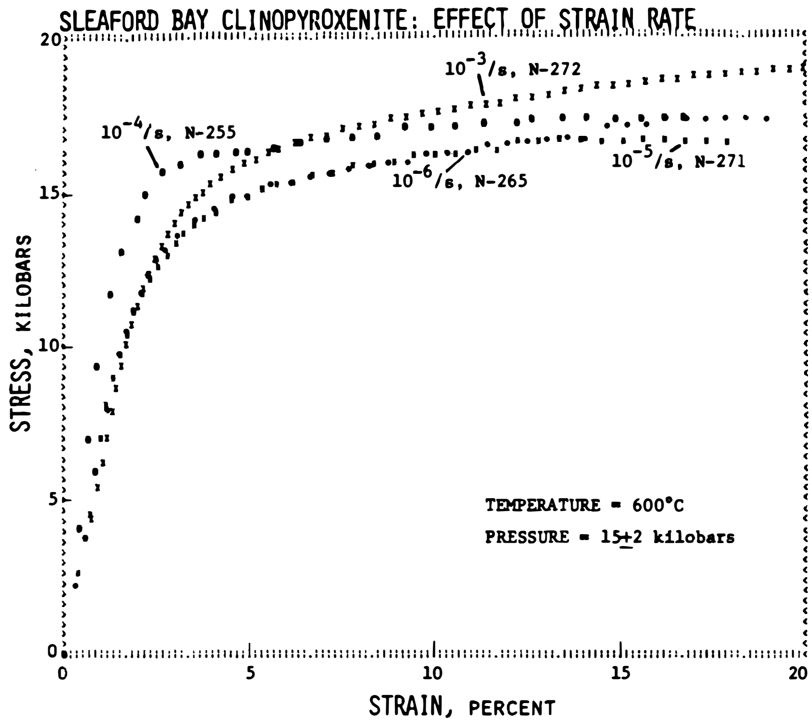

SLEAFORD BAY CLINOPYROXENITE: EFFECT OF STRAIN RATE
10^-3/s, N-272
10^-4/s, N-255
10^-5/s, N-271
10^-6/s, N-265
TEMPERATURE = 600°C
PRESSURE = 15±2 kilobars
STRESS, KILOBARS
STRAIN, PERCENT
0
5
10
15
20

Fig. 4

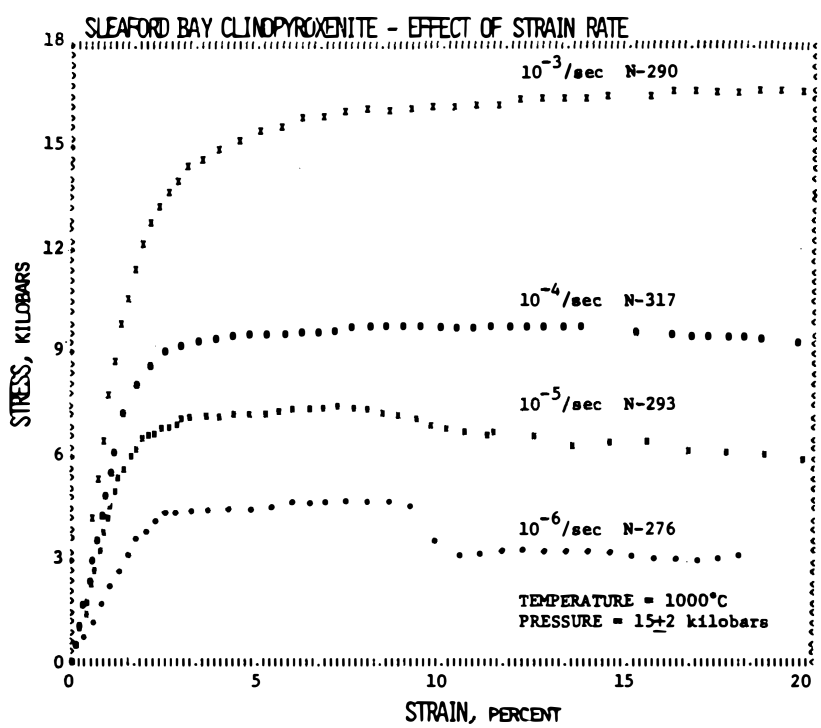

SLEAFORD BAY CLINOPYROXENITE - EFFECT OF STRAIN RATE
10^-3/sec N-290
10^-4/sec N-317
10^-5/sec N-293
10^-6/sec N-276
TEMPERATURE = 1000°C
PRESSURE = 15±2 kilobars
STRESS, KILOBARS
STRAIN, PERCENT
0
3
6
9
12
15
18
5
10
15
20

Fig. 5

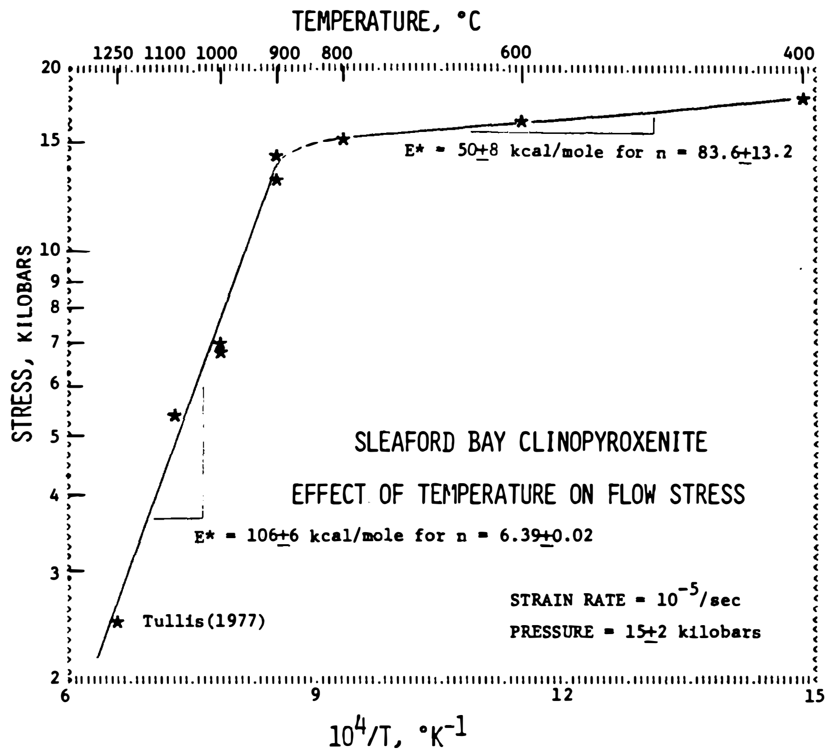

TEMPERATURE, °C
1250 1100 1000 900 800 600 400
STRESS, KILOBARS
$E^* = 50 \pm 8$ kcal/mole for $n = 83.6 \pm 13.2$
SLEAFORD BAY CLINOPYROXENITE
EFFECT OF TEMPERATURE ON FLOW STRESS
$E^* = 106 \pm 6$ kcal/mole for $n = 6.39 \pm 0.02$
STRAIN RATE = 10^{-5}/sec
PRESSURE = 15 ± 2 kilobars
Tullis(1977)
$10^4/T$, $°K^{-1}$

Fig. 6

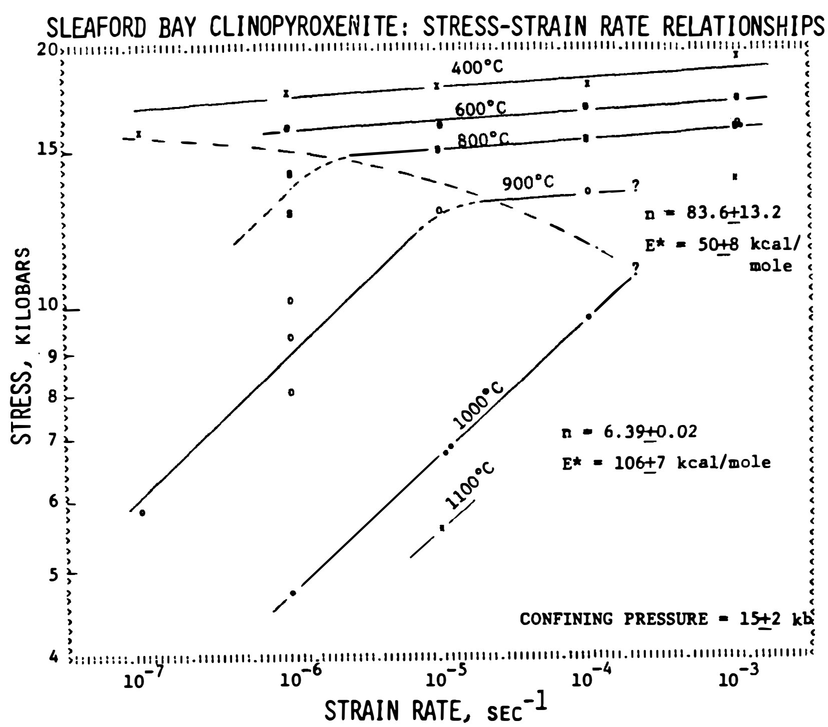

SLEAFORD BAY CLINOPYROXENITE: STRESS-STRAIN RATE RELATIONSHIPS
400°C
600°C
800°C
900°C
$n = 83.6 \pm 13.2$
$E^* = 50 \pm 8$ kcal/mole
1000°C
1100°C
$n = 6.39 \pm 0.02$
$E^* = 106 \pm 7$ kcal/mole
CONFINING PRESSURE = 15 ± 2 kb
STRESS, KILOBARS
STRAIN RATE, sec^{-1}

Fig. 7

LABORATORY AND FIELD INVESTIGATIONS OF FAULT GOUGE

Grant No. 14-08-0001-G-460

John M. Logan
Center for Tectonophysics
Texas A&M University
College Station, Texas 77843

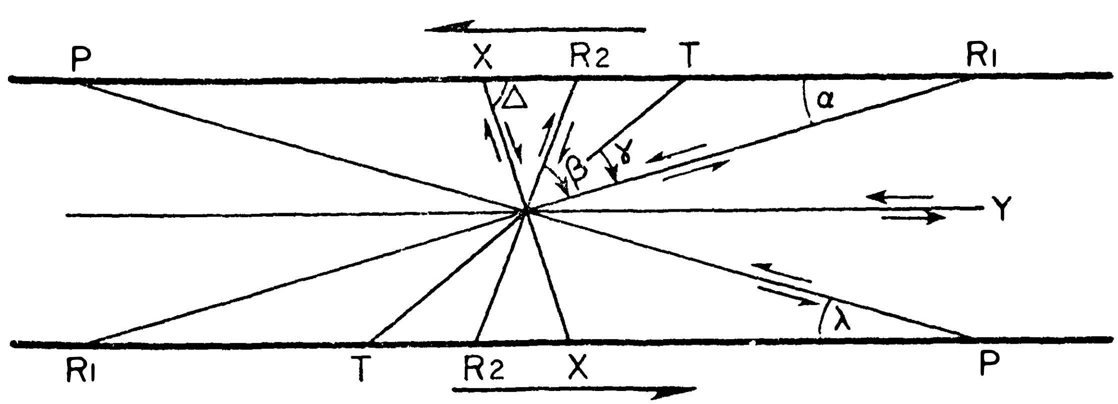
April 30, 1978

Premonitory Slip Associated with Stick-Slip Sliding in Tennessee Sandstone

Triaxial stick-slip experiments have been conducted on 35° precuts of Tennessee sandstone in order to measure and characterize premonitory slip. Premonitory slip always precedes stick-slip events, occurring within 10 percent or less of the peak shear stress. It is apparently an essential and necessary part of the stick-slip process. The amount of premonitory slip before an event increases with increasing confining pressure, decreasing displacement rate, increasing total shear displacement along the sliding surface, and when the precut is water saturated. In all of these cases, an increase in the asperity contact area on the sliding surface is expected and it is suggested that premonitory slip is dependent on the behavior of the asperity contacts. If premonitory slip occcurs on a large scale it may not only be an important precursive phenomenon for predicting earthquakes, but also may be an essential part of the earthquake process.

Fabrics of Laboratory Simulated Fault Gouges

Studies of the fabric of simulated quartz, orthoclase and anhydrite gouges deformed between two sliding blocks in triaxial compression at room temperature, confining pressures to 300 MPa, dry, and at a displacement rate of 10^{-3} cm/sec have suggested that the following fracture array exists.



The relative abundance of the fractures, in decreasing order, is generally: R_1, R_2, X, P, and T. Sets R_1, R_2, T and P have been reported by other workers for fine grained soft sediments under very low confining pressures, and for surface exposure of some natural faults. Comparison of the angular relations between the fracture elements measured in the laboratory specimens show remarkably good correlation with those reported from natural fault zones. Following the logic of Riedel (1929) and Tchalenko and Ambraseys (1970) an angle of internal friction was calculated for the simulated gouge zones. The values ranged from .62 - .77, with an average of .69.

The investigation also substantiates the previously found conclusion that most of the displacement is taken up by movement at the interface of the simulated gouge and the bounding blocks.

The recognition of a persistant fracture array in the laboratory suggests that a systematic investigation of natural fault zones should be undertaken to test the applicability of these laboratory observations. Such a study is in progress (see below).

The Effects of Temperature on Simulated Fault Gouge

Sliding friction experiments have been conducted for the rock-gouge-rock system of Tennessee sandstone with a 35° sawcut containing simulated calcite gouge. The specimens were deformed in triaxial compression at 200 MPa confining pressure, a nominal shortening rate of 10^{-4}/sec and temperatures ranging from 20° to 600°C. A transition from stick-slip to stable sliding occurs between 250° and 400°C and a dramatic reduction in strength between 400° and 600°C. An investigation of the deformed simulated gouge warrents the following additional observations:

1) The transition from stick-slip to stable sliding and the reduction in strength with increasing temperature correlates with changes in deformation mechanisms within the gouge. The gouge fabric evolves from cataclasis to gliding flow followed by recrystallization.

2) Cataclastic flow is associated with stick-slip and is manifest by the development of R1 and R2 Riedel shears, crushing and compaction of the gouge, and some rigid body rotation of the porphyroclasts.

3) Porphyroclasts become highly elongated at $\geq$ 400°C primarily as a result of translation gliding on $\underline{r}$ and accompanying external rotation. The grain elongation and c-axis orientation pattern that results are essentially identical with those observed in intact cylinders of Yule Marble deformed at 300° to 400°C (Turner et al., 1956).

4) Recrystallization starts in or at the boundaries of highly elongated porphyroclasts, the neoblasts are equi-dimensional, the $\underline{c}$-axes in the neoblasts are inclined at 30° to those in the host clasts, and $\underline{r}$-planes in the neoblasts are parallel to $\underline{c}$ (0001) in the host; all agree with previous studies of experimentally annealed and sytectonically recrystallized Yule Marble.

5) The temperatures for extensive recrystallization within the calcite gouge are about the same (500° to 700°C) as those reported previously for both annealing and syntectonic recrystallization.

6) The principal axes of stress and finite strain are not coaxial in these experiments as they were in previous triaxial experiments on intact specimens, thus it can be demonstrated that an attempt to infer the principal stresses from the observed recrystallized c-axis pattern based on previous experimental work would be wrong. The inferred σ_1 would be in error by some 60° and the corresponding inferred sense of shear across the gouge zone would be just backward.

Field Studies of Fault Zones

Studies of two shear zones and one gouge zone from the Motagua Fault Zone in Guatemala, have resulted in recognition of fractures previously described from laboratory investigations on simulated fault zones. R1, R2, P, X, and Y fractures were recognized. Contrary to the experimental data fracture Y is much better developed in the field than in laboratory specimens. This may be due to the larger displacements of the fault zone found in the field. Fracture type T has not been recognized, and R2 is far less developed in the field than in laboratory experiments. The angular relations between fractures and the boundary with the country rock are very similar to those reported for the experiments on simulated gouge. Significantly, no other dominant fracture types have been identified in the field that have not been recognized in the experiments. However, there are fractures in naturally deformed rocks which do not fit any of the recognized types. This may be due to random fracture patterns associated with the original emplacement of the serpentine along the fault zone, or due to rotated fractures of any of the above types. This field documentation of the laboratory experiments is felt critical to future laboratory work of this type and clearly increases the level of confidence in the present program.

Studies of Dilatancy in Porous Sandstones

To date most investigations of dilatancy have concentrated upon low-porosity crystalline rocks. Although some work has been published regarding dilatancy in higher porosity rock, the relationship between dilatancy and the mechanisms of deformation have not been well documented. Additionally, few studies have been made as the rock passes through the brittle-ductile transition. We have preformed a series of triaxial compression tests on Berea sandstone at effective confining pressure to 120 MPa, which spans the brittle-ductile transition. Tests were done at 25°C, and strain rates for 10^{-4} to 10^{-7}/sec. Volume changes where determined by monitoring changes in the pore fluid system, a technique that allowed changes beyond those permitted by the use of strain gages to be measured.

The following observations have been made.

1) The brittle-ductile transition is reflected in the volumetric strain by a shift from relative dilatancy to relative compaction (based upon the hydrostat) during the application of the differential load.

2) The amount of pre-failure dilatancy diminishes with increasing Pe in the brittle regime of the sandstone.

3) Unloading of the sample prior to the inception of macrofracture results in complete recovery of the incurred dilatancy.

4) Effectively no change in pore volume occurs during the development of the macrofracture.

5) Decreasing the strain rate results in increasing the relative dilatancy as a function of mean pressure within the brittle regime.

6) Thin section examination of the specimens, indicates that microfracturing, although present, is not enough to account for the observed dilatancy. It is suggested that much of the dilation is a result of grain boundary separation rather than microfracturing.

Summary of Semi-Annual Technical Report

Grant Number: USGS 14-08-0001-G372

Title: A study of the role of premonitory creep in the mechanism of stick-slip friction in rock

Principal Investigators: C. H. Scholz and T. L. Johnson

Contractor: Lamont-Doherty Geological Observatory of Columbia University

Date: April 5, 1978

Previous studies indicate that overall friction increases as sliding velocity decreases. Recent work shows that a component of friction directly related to sliding velocity is hidden in the overall inverse relation. Different behaviors in time allow detection of the components but separation of the effects allowing individual characterization of their velocity dependencies has not been accomplished yet. A small (about 10%) transient increase in stress generated when displacement rate is increased is sufficient to trigger a transition from stable sliding to stick-slip behavior.

Experimental Source Mechanics

8-9960-02113

Roger Stewart
U.S. Geological Survey
345 Middlefield Road
Menlo Park, CA 94025
(415) 323-8111 ext. 2041

Goals

A laboratory fault model has been constructed by James Dieterich. The model consists of a square slab of granite (ca. 2m x 2m x .5m), loaded on its edges. A sawn, polished surface passes through the sample. Application of stress to the edges of the sample results in slip over the polished surface. Static and dynamic strain changes caused by loading and slip will be recorded, allowing measurement of rupture velocity, radiation pattern, stress drop, strain spectra, and seismic efficiency. The data recorded will be used to determine details of fault propagation and to test theoretical predictions. Broad-band measurements of strain changes associated with faulting under well-controlled conditions will result in a better understanding of fault propagation, the sensitivity of fault parameters (e.g., radiation pattern, rupture velocity, seismic efficiency) to premonitory stress changes, and the transition from premonitory stable sliding to stick-slip. Theoretical models may be tested and, if successful, applied to field observations. Thus, data generated will be useful for understanding, faulting in general and certain premonitory phenomena in particular.

Results

1) A broad-band (0-2MHZ), high gain (2500), 14 channel recording system, and strain gage bridges, have been assembled and tested. The major difficulty encountered was the presence in the laboratory of persistent high frequency noise pulses of considerable amplitude and unknown source. Because of the wide band pass and high gain of the system amplifiers, the latter were set into oscillation by the noise pulses. Careful attention to the design of shielding and bridge power supplies proved successful in eliminating amplifier instability due to noise pulses.

2) Initial experiments have been run to demonstrate the capability of the recording system and to examine signals for different strain gage configurations. These tests have demonstrated that signal from slip events in the sample contains frequencies above the bandwidth of previously used recording equipment, and that adequate signal-to-noise ratios may be obtained. Experiments utilizing 4 sensors are under way.

Rock Physics

8-9960-01181

Roger Stewart
U. S. Geological Survey
345 Middlefield Road
Menlo Park, CA 94025
(415) 323-8111 ext. 2041

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.

2) Investigation of shear and compressional velocity in saturated basement rocks from Oroville, California area.

3) Investigation of geologic structure, lithology, and elasticity of young rocks near the San Andreas fault.

Results

1) Simultaneous measurement of compressional and shear wave velocity in rocks has been under study during the first half of FY 1978. The advantages of simultaneous measurements are obvious: time taken for sample preparation, jacketing, loading, and measurements are reduced by 50%, and physical conditions during measurements are identical for all waves. This last point is particularly important when environmental conditions are such that cracks influence physical properties of the samples. The behavior under high pressure and high temperature of ceramic shear wave transducers (which generate appreciable P wave energy) was studied for steel and rock samples by recording wave-forms of acoustic pulses on magnetic tape for various pressures, temperatures, and transducer configurations. Several conclusions may be drawn from the work to date.

a) Compressional wave velocity may be reliably determined from the relatively small P waves generated by the shear mode tranducers. However, compressional waveforms are not stable at pressures below 1 kb or so, and timing errors may result if this fact is ignored.

b) Examination of the records shows that the shear wave arrival, which may be obscured by the compressional wave coda on any given record, can be followed from record-to-record as pressure and temperature change, and that phase differences between the shear arrival and waves in the compressional coda change systematically with pressure and temperature. Thus, it appears that correlation techniques can be used to determine pressure and temperature derivatives of compressional and shear waves with good precision.

2) The technique outlined above has been applied to measure compressional and shear wave velocity to 7 kb and 200°C in a Franciscan rock. Compressional wave velocity agreed well with previous measurements obtained through the use of compressional mode transducers. A ratio of compressional to shear wave velocity of 1.68 was found at pressures above 2 kb, independent of temperature. The rock sample is quite typical of Franciscan low grade metagraywackes in its mineralogy, density, and compressional wave velocity. Further measurements are under way to determine if the sample's shear wave velocity is also typical.

3) A small pressure vessel of 2 kb capacity and its auxilliary pressure generating equipment has been constructed, specifically for measuring compressional and shear wave velocities in saturated rocks under variable pore pressure and confining pressure. The vessel is designed for rapid sample assembly and loading and will be used to examine the influence of pore fluids at relatively low confining pressures, where the influence of cracks is at a maximum. Experiments on Franciscan rocks are expected to start in May, with experiments on Oroville rocks following.

4) A collection of data from oil wells drilled in or near the San Andreas fault zone has begun, concentrating on obtaining velocity logs. To date (May 1978), a catalog of wells of interest has been established and geologic structure in the vicinity of the wells has been determined from available maps. The systematic examination of velocity will be undertaken when more logs are on hand. Preliminary examination, however, suggests a much more heterogeneous lithology in the San Andreas fault zone than is generally imagined, as sedimentary rocks whose velocity suggests a mesozoic age have been penetrated west of currently recognized traces of the San Andreas fault.

5) Seismic data for earthquakes and explosions recorded in 1974 in the Bear Valley region of Central California are being used to create record sections and examine the shear and compressional wave velocity structure in a complexly deformed region east of the fault zone. Records have been obtained for 6 earthquakes with focal depths ranging from approximately 3 to 9 km, over a profile 35 km long. It is hoped that shear wave velocity structure can be resolved sufficiently well to shed some light on fluid pressures near the fault.

Publications

Stewart, R., and L. Peselnick, 1978, Compressional and shear wave velocities in dry Westerly granite at high pressure and temperature, approved for publications.

Stewart, R., and L. Peselnick, 1978, Systematic behavior of compressional wave velocity in Franciscan rocks at high pressure and temperature, Jour. Geophys. Res., 83, p831.

AN EXPERIMENTAL STUDY OF THE RHEOLOGY OF CRUSTAL ROCKS

J. Tullis and R. A. Yund
Department of Geological Sciences
Brown University, Providence, RI 02912

April 25, 1978

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 fluid pressures; to determine both the macroscopic and microscopic brittle-ductile transitions for these rocks as a function of these variables; and to determine the flow laws for these rocks within the fully ductile regime so that it is possible to make extrapolations to natural conditions. Our approach is to deform samples of crustal rocks such as granites and dolerites in the laboratory at controlled conditions, and to do detailed petrographic and transmission electron microscope (TEM) analysis of the deformed specimens. We have completed a study of the deformation mechanisms and brittle-ductile transition as a function of temperature and pressure for dry Westerly granite (Tullis and Yund, 1977). During the first 6 months of this year we have studied the effect of water on the deformation of Westerly granite, we have continued a study of the deformation mechanisms and brittle-ductile transition for dry dolerite, and we have made an optical study of two suites of mylonites and ultramylonites. Our results are summarized below.

Hydrolytic weakening of Westerly granite

Samples were deformed at temperatures of 300 to 600°C, confining pressures of 15 and 10 kb, at a constant strain rate of 10^{-6}/sec. Samples were vacuum impregnated in distilled water and mechanically sealed in a platinum capsule. The amount of water added was .1 to .2 weight percent, which is about the same amount as contained in a wet crystal of synthetic quartz. All of the wet samples were preheated at 700°C at pressure for 24 hours prior to deformation.

All of the wet samples were weaker than their dry equivalents. However, many of them show one or more through-going faults, whereas dry samples deformed at 10 and 15 kb confining pressure never show faults. This indicates that the fluid pressure was significant, and the effective pressure was probably more like 5 to 10 kb rather than 10 to 15 kb. Strength reduction alone cannot be used as evidence for hydrolytic weakening, and we have relied on comparisons of wet and dry samples using optical and transmission electron microscope (TEM) observations.

Optically, samples deformed at 300°C wet appear no different than do samples deformed dry at the same temperature. However, in samples deformed wet at 400°C, 500°C, and 600°C the quartz shows much more evidence of deformation and recovery than does the quartz in equivalent dry samples.

The feldspar in samples deformed wet at 400^{o} and $500^{o}C$ does not appear any different than does the feldspar in equivalent dry samples, but in the sample deformed wet at $600^{o}C$ there is definitely more deformation and recovery than in the equivalent dry sample.

TEM observations confirm these observations and add more detail. They show that even at $300^{o}C$, the quartz in the wet sample shows a higher average and maximum dislocation density than does that in the dry sample. At 400^{o}, 500^{o}, and $600^{o}C$ the quartz in the wet samples also shows higher dislocation densities and more evidence of recovery features such as cells and subgrains than does that in equivalent dry samples. The feldspar shows no noticeable difference between wet and dry samples at 300^{o} and $400^{o}C$, but at $500^{o}C$ the feldspar in the wet sample shows higher and more uniform dislocation densities than does that in the dry sample. At $600^{o}C$ the effect is especially pronounced, and the feldspar in the wet sample shows recovery features such as cells, whereas the feldspar in the dry sample shows low and irregular dislocation densities.

Water is known to enhance crack propagation by stress corrosion, and to enhance dislocation glide and climb, so it is not immediately clear what the net effect of water on deformation in the transition region should be. Our observations indicate that dislocation glide and climb is enhanced more than microcracking, so that the net effect of the water (at this strain rate) is to reduce the temperature of that transition in both the quartz and the feldspar. This is the first time that hydrolytic weakening has been proven for feldspar, and the magnitude of the effect appears about the same as for quartz.

The role of pressure on hydrolytic weakening appears to be greater than realized previously. The results described above were for samples deformed at 15 kb confining pressure, the same pressure as the original experiments of Griggs and Blacic on quartz. Since then, M. Paterson (personal communication, 1977) has been unable to induce hydrolytic weakening in dry natural quartz crystals when given the same treatment as did Blacic, except at 3 kb instead of 15. For synthetic quartz crystals which already contain substantial water in their structure the pressure does not matter, and they can be plastically deformed at room pressure. However, the pressure does appear to be important in allowing penetration of water into crystals that are initially dry, in two ways. First the solubility of water in crystals increases with pressure, and second, the diffusion rate of oxygen in crystals increases with fluid pressure.

We have some direct evidence that pressure is important in hydrolytic weakening. Two quartzite experiments were done in talc, at $850^{o}C$ and 10^{-6}/sec, where some water is released by dehydration. One sample was deformed at 15 kb and one at 8.5 kb, and the one deformed at 15 kb was 4 times weaker even though it contained no faults.

We have done wet experiments on Westerly granite at 10 kb. These samples show a lower average and maximum dislocation density than do the 15 kb wet experiments deformed at equivalent temperatures. We have also done a few experiments in which the wet sample was preheated at 15 kb, but then deformed at 10 kb. These samples show the same general microstructures as samples preheated and deformed at 15 kb; that is, they show a higher average dislocation density than samples preheated and deformed at 10 kb. Thus as anticipated the pressure is important for driving water into the structure.

Thus it appears that the hydrolytic weakening effects found in minerals experimentally deformed at 15 kb may be less pronounced at lower pressures, and that some caution may be necessary in extrapolating the laboratory results to crustal deformation.

Deformation mechanisms and brittle-ductile transition for dry dolerite

Samples of Maryland diabase, containing roughly 30% plagioclase of composition An_{70} and roughly 65% of clinopyroxene, have been deformed at 5 to 15 kb confining pressure, temperatures of 600 to 1000°C, at a constant strain rate of 10^{-6}/sec. Results thus far indicate very similar patterns of behavior as seen in Westerly granite, except in the diabase the plagioclase is the weaker phase, equivalent to the quartz in the granite, and the pyroxene is the stronger phase, equivalent to the feldspar in the granite. Even at 1000°C, TEM observations show that the plagioclase has a high dislocation density with abundant cells, but the pyroxene contains very few dislocations.

Optical study of natural mylonites and ultramylonites

We have collected suites of samples from two natural faults, of Paleozoic age, which exhibit mylonites and ultramylonites. We have prepared samples of these for TEM examination. One of these ultramylonites exhibits apparently intrusive relations into its host rock, whereas the other appears more gradational, but both are too fine-grained to examine in detail optically. We plan TEM observations in order to determine whether either one exhibits evidence of true melting, whether either one exhibits any evidence of dislocation generation and motion, and how similar these samples appear to the gouge produced in experimentally deformed samples. These observations will be very important for understanding the transition in deformation mechanisms with depth on actual faults, and in ascertaining the importance of frictional heating.

Recent Publications

Tullis, J. and R.A. Yund (1977) Experimental deformation of dry Westerly granite: Jour. Geophys. Res., 82, 5705-5718.

Tullis, J. and R.A. Yund (1978) Hydrolytic weakening of experimentally deformed Westerly granite: Trans. Amer. Geophys. Union, 59, p. 376.

EFFECTS OF SHEAR DISPLACEMENT ON PERMEABILITY AND FLUID PRESSURES WITHIN A FAULT ZONE

Paul A. Witherspoon
University of California, Berkeley

The purpose of this project is to conduct laboratory experiments on large-scale rock samples in order to determine the fluid flow behavior of fractured rock under various boundary conditions of stress, displacement and fluid pressure.

Work in the laboratory continues to be suspended while the new equipment, which will greatly increase the control of testing and reliability of data, is being installed. The large-scale triaxial testing system is being updated and converted to servocontrol (closed-loop control) from the present, out-of-date and unreliable manual control.

When completed, the loading system will have a new hydraulic power supply, 20 GPM servovalve, servocontroller and arbitrary digital function generator to drive the four-million-pound (17.8 MN) actuator now on the load frame. The system will be capable of using load, strain, stroke and auxiliary as program and feedback. The existing, built-in load cell (1000 $\mu\varepsilon$ at full load) will be used as load sensor. A new displacement transducer with a 28-inch (71 cm) range and reolution of .01 inch (25 micron) will be used as stroke sensor.

The electronic instrumentation will allow load, stroke or strain parameters to be controlle diwth great precision over predetermined load paths. The human error is removed, greatly increasing the repeatability of boundary conditions.

In addition, the systems for measurement of flowrates and head loss are being rebuilt.. The former will then allow measurement of much lower flowrates and the latter will automatically normalize the pressure profile in order to gain a better understanding of the effects of small changes in stress, pressure and fracture opening.

The expected date for completion of construction is the end of July. By mid-Augst testing will resume.

Digital Signal Processing of Seismic Data

8-9930-02101

W. H. Bakun
U. S. Geological Survey
345 Middlefield Road
Menlo Park, CA 94025
(415) 323-8111 ext. 2777

The ultimate objective is a detailed description of the earthquake source and propagation-path operators using seismic data recorded on an array of stations surrounding the earthquake epicenter. The immediate goals are the development of methodologies for processing seismic data to obtain these descriptions and an analysis of some of the seismic data now available for central and northern California earthquakes, particularly foreshocks.

Conversion of existing computer programs to the USGS MULTICS system has taken up a considerable proportion of our resources. Some code has been converted and it is anticipated that the remaining routines to be converted will be available for use on the MULTICS by January, 1979.

An examination of the high-frequency body-wave radiation from two foreshocks of the January 15, 1973 Bear Valley earthquake resulted in the documentation of the unambigious signature of directed rupture propagation (i.e., ≡ directivity) of the earthquake source. Foreshocks of the January 1, 1973 earthquake tend to be characterized by more unilateral rupture expansion in contrast to more bilateral rupture expansion for the aftershocks.

An examination of normal Parkfield earthquakes and foreshocks and aftershocks of the 1966 Parkfield, California and foreshocks and aftershocks of the 1975 Oroville, California earthquake suggests that the identification of foreshocks by means of the frequency content of body-wave radiation is not trivial. Foreshock radiation is neither universally higher- nor lower-frequency than comparable aftershocks or normal earthquakes. Foreshocks and normal earthquakes tend to be either high- or low-frequency events in comparison to aftershocks. The body-wave spectra of foreshocks and comparable normal earthquakes are similar. If foreshocks can be discriminated on the basis of the frequency content of body-wave radiation, then a network of seismographs surrounding the epicentral region will be necessary to sort out the three-dimensional pattern of high- and low-frequency body-wave radiation.

Bakun and Lindh (1977) used the high-gain short-period seismographs of the USGS central California seismic network to compute "synthetic" Wood-Anderson (W-A) seismograms from which M_L as low as 0.1 were reliably determined for Oroville earthquakes. The procedure for producing the synthetic W-A records from the USGS systems was tested by operating a low-gain 3-component USGS system at the Branner vault of Stanford

University. These systems and the Wood-Anderson seismographs were located on the same pier in the vault. Waveforms of synthetic W-A records, computed using the Branner vault low-gain USGS systems match the actual W-A records. The agreement of the waveforms is a direct confirmation of the procedure outlined by Bakun and Lindh (1977).

Publications

Bakun, W. H., Stewart, R. M., and Bufe, C. G., 1977, Unilateral rupture propagation of foreshocks (abs.): EOS (Am. Geophys. Union Trans.), v. 58, no. 12, p. 1193.

Bakun, W. H. Houck, T., and Lee, W. H. K., 1978, A direct comparison of "synthetic" and actual Wood-Anderson seismograms: Seismol. Soc. America Bull. (in press)

Bakun, W. H., Stewart, R. M., and Bufe, C. G., 1978, Directivity in the high-frequency radiation of small earthquakes: Seismol. soc. America Bull. (in press)

Bakun, W. H., and McEvilly, T. V., 1978, Are foreshocks different? Evidence from Parkfield and Oroville (abs.): Earthquake Notes, v. 49, no. 1, p. 61.

University of Arizona
Lamont-Doherty Geological Observatory

DETERMINATION OF THE IN SITU STRAIN PATTERN IN THE VICINITY OF THE PALMDALE UPLIFT, CALIFORNIA

Terry Engelder
Lamont-Doherty Geological Observatory
of Columbia University
Palisades, New York 10964

Marc L. Sbar
University of Arizona
Department of Geosciences
Tucson, Arizona 85721

Grant No. 14-08-0001-G404

Grant No. 14-08-0001-G417

Final Techincal Report Summary

We made 29 in situ strain relaxation measurements distributed among eight sites spaced on a 35 km transect running from the foothills of the San Gabriel Mountains, across the San Andreas fault, into the western Mojave desert southeast of Palmdale. This was a pilot study to see if a strain relaxation technique can be used to detect the regional stress field and any modification of it in a tectonically complicated area. Strain was measured by overcoring strain gauge rosettes which had been bonded to the flattened bottom of a borehole. We found NNE trending maximum compressive stress (σ_1) at our sites most distant from the fault. This is parallel to the σ_1 inferred from fault plane solutions in southern California. Near the fault, stress orientations vary locally. There appears to be a clockwise rotation of σ_1 from NNE to approximately east-west on the north side of the fault. On the south side of the fault, σ_1 varies from N6Ø°W to NNE. The stress we observed appears to be dominantly tectonic. Some of our measurements, however, may have been modified by decoupling across fractures and bedding planes, and by topographic stress.

Spectral and Time Domain Analysis

8-9930-02105

Jon B. Fletcher
U.S. Geological Survey
345 Middlefield Road
Menlo Park, CA 94025
(415) 323-8111, ext. 2701

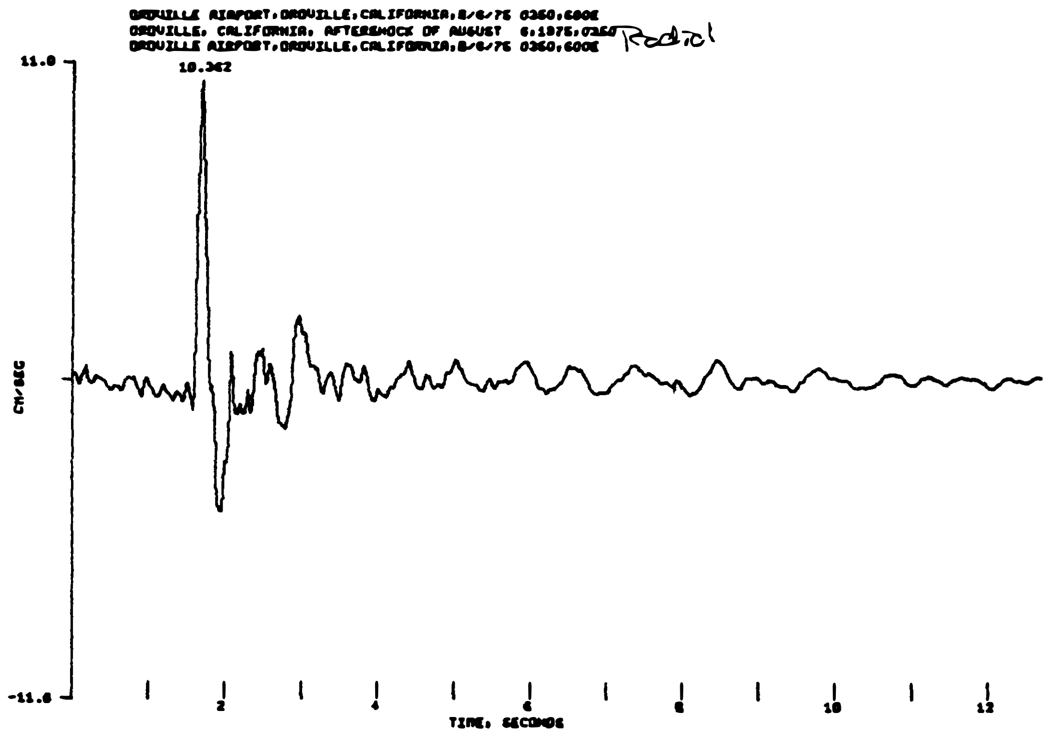
Initial analysis of the Oroville strong motion accelerograms has focused on a magnitude 4.7 aftershock that occurred on August 6, 1975, 0350 GMT. Using the formula from Brune (1970), but estimating the corner frequency from pulse durations and the spectral level at the long period limit by pulse area in displacement traces, values of 4.0×10^{26} dyne-cm and 426 bars were calculated for moment and stress crop. These values are averages of data from nine stations and the standard deviation was about 25% of the mean in each case. Thus the stress drop has the same precision as the moment.

Although the general appearance of the Oroville displacement results can be explained as a single S-phase preceded by a near-field phase and followed by a multiply-reflected SH-wave at stations which are over at least 100 meters of Great Valley sediment, several aspects of the velocity and displacement traces may shed some light on the starting mechanism, stopping mechanism and rupture velocity of this event which appears to be unusually energetic compared to even other Oroville aftershocks.

1. Peak velocities, which are here used to estimate radiated energy are generally in the 3 to 5 cm/sec range with OAP having the largest value at 10.4 cm/sec. Other stations 1, 4, 5, and EBH all of which are near a maxima for the S-radiation pattern have higher peak velocities than the other 4 stations. As radiated energy should be a strong indicator of directivity, the rupture may have propagated towards OAP, which is the station furthest to the NW of the array. Rise times have also been tabulated and do not appear to have any systematic change across the array with the exception of stations 2 and 3 which are underlain by 700 to 800 m of Great Valley sediment and have durations that are comparatively longer.

2. Several velocity records such as OAP shown below appear to have a stopping phase whose beginning is relatively well defined. Further identification of the stopping phase in other records may give a better idea of faulting duration and rupture velocity.

The major emphasis in the analysis of the Oroville records is now being placed on a synthesis of source parameters of all of the aftershocks in the accelerogram data set. Further processing refinements, however, appear to be necessary to eliminate the effects of non-causality in the filtering and to modify the baseline scheme to preserve the shape of the near-field signature.



Abstracts

Fletcher, J. P., Brady, A. G., and Hanks, T. C., 1978, Processing errors associated with accelerograms of the Oroville, California aftershocks: Earthquake Notes, v. 49.

Fletcher, J. P., and Hanks, T. C., 1977, Precise source parameters of a multiple event using ten strong motion records from the August 6, 1975 Oroville, California aftershock: EOS (Am. Geophys. Union Trans.)

Semi Annual Progress Report for
Contract No. 14-08-0001-16721, April, 1978

A COMPLETE SOLUTION OF A ONE DIMENSIONAL PROPAGATING FAULT WITH NONUNIFORM STRESS AND STRENGTH

by

Moshe Israel and Amos Nur
Rock Physics Project
Stanford University
Dept. of Geophysics
Stanford, Ca. 94305

We have investigated details of the dynamics of faults with strongly variable stress and frictional strength, which are in most likelihood responsible for nonuniform fault slip, multiple events, random ground acceleration, and the earthquake frequency-magnitude relation. In order to obtain a full dynamic solution to faulting with great heterogeneity, we used a one dimensional continuum model in which stress and strength varied along the fault.

The results show that the process of rupture in an heterogeneous system is closely linked with the stopping phase of the motion, or the healing process of faults. This process, which may involve strong nonlinear effects such as discontinuous motion, cannot be seen in static models, and requires a dynamic approach with a numerical scheme which remains stable at high frequencies. We have used the method of characteristics to obtain the results in this paper.

We found that heterogeneous rupture can be due to either intitally non-uniform stress or spatially non-uniform strength. However, non-uniform stress drop - the difference between tectonic stress and frictional stress - tends to become smooother with increasing slip. This means that after some initial heterogeneous sliding, fault slip becomes very uniform and repetitious - a condition which is clearly not observed in nature.

Spatially variable strength, however, can produce and maintain a heterogeneous stress drop. We found that when the strength was sufficiently variable from place to place, the final stress was statistically at least as variable as the initial stress. This means that the character of fault activity can remain heterogeneous with time, without tending to a smooth, uniform behavior which is not observed in situ. We conclude therefore that spatially variable fracture energy can be responsible, and may in fact be responsible for the heterogeneous nature of earthquake faulting. Non-uniform stress by itself cannot maintain with time the heterogeneous nature of faults.

The model is applied to the irregular slip distribution of the Borrego Mountain (Coyote Creek), California, earthquake of April 1968, showing the links between irregular rupture propagation, multiple events and fault slip and stress drop.

THE MECHANICS OF CRYSTAL FAULTING

Principal Investigators: A. M. Nur, Stanford University
D. M. Barnett, Stanford University

Contract No.: 14-08-0001-15260

Report Date: April 27, 1978

In situ velocity data and laboratory measurements reveal that the rigidity of the earth's crust, as a function of depth x, is reasonably modelled by:

$$\mu(x) = \mu_\infty (1-\theta \exp [-x/X_o]).$$

The best fits to the available data give $0.45 \leq \Theta \leq 0.95$ and $X_o = 2.5$ kilometers. Using the available solution for a screw dislocation in an inhomogeneous elastic medium D. M. Barnett, International J. of Solids and Structures, 8, 651, (1972), we have developed a model for a very long strike-slip fault in a crust with a downward varying shear modulus. Free surface displacements and fault stress changes have been computed and compared with the corresponding homogeneous half-space model.

The results indicate a striking difference between faults which break the free surface and buried faults, and these results may be summarized as follows:

(1) Surface-breaking faults produce free surface displacements which are insensitive to rigidity, but the associated fault stress changes are quite sensitive to rigidity (Θ).

(2) Buried faults produce stress drops which are insensitive to θ, but have associated free-surface displacements which are quite sensitive to θ.

As a consequence, use of a homogeneous (uniform) rigidity model instead of the variable rigidity model can lead to overestimates of the statically determined seismic moment by as much as 100% and overestimates of the average stress drop by as much as 50%.

Our analysis indicates that the buried fault model may shed some insight on the amount of anomalous surface strain to be expected as a result of non-uniform crystal rigidity. A buried slip episode on an active fault (such as a creep event), can cause large strain episodes in the case of a long two-dimensional strike slip fault. Some of the rather puzzling surface deformation data reported in the literature may have as their origin buried creep events which did not break the surface. This study also suggests that discrepancies between observed surface offsets and seismically deduced fault offsets may be quite common and large due to the gradient in near-surface rigidity.

FUNDAMENTALS OF DEFORMATION AND RUPTURE PROCESSES IN POROUS GEOLOGICAL MATERIALS

James R. Rice and Donald A. Simons
Division of Engineering
Brown University
Providence, Rhode Island 02912

Contract No. 14-08-0001-15866

Summary

Our studies of deformation and rupture processes in porous materials have been concentrated on the further investigation of stabilization of earthquake rupture processes due to pore fluids effects; on a crack propagation model incorporating in a precise way combined effects of fluid saturation in the surrounding medium and dilatancy in the near-tip failure zone; on constitutive modelling of inelastic rock deformation and on the investigation of the stress state near the tip of a steadily growing tensile crack in a porous medium.

Rice and Rudnicki (the latter now at California Institute of Technology) have analyzed two mechanisms by which pore fluid could partially stabilize the earthquake rupture process in natural rock masses. These mechanisms are based on dilatancy strengthening and on the increase of elastic stiffness for undrained as opposed to drained conditions, and are studied in relation to an inclusion model in which a seismic gap zone is represented by an ellipsoidal inclusion, driven by concentrated stress into the strain weakening range. Both mechanisms are shown to allow failure to occur in a less abrupt manner than without consideration of fluid coupling: instead of an instantaneous dynamic (seismic) instability, there is a period of initially quasi-static deformation that ultimately accelerates to a dynamic process. Quantitative estimates of these precursory processes were developed. Calculations for the duration of the precursory period and its dependence on the constitutive parameters show that the effects considered can be significant for values of constitutive parameters consistent with experimental and observational data. For a spherical inclusion of 1 km radius precursory times calculated are of the order of 15 to 240 days for representative values of constitutive parameters; the predicted times are shorter by a factor of 10 for a flattened ellipsoidal inclusion with an 18:1 aspect ratio. Full details are given in Technical Report 13 and in a paper presented by Rice and Rudnicki at the USGS Conference on Fault Mechanics in December 1977. Because of uncertainty of observational data it is difficult to compare directly the precursor times predicted with observations. Also, many simplifications were made (in particular, each of the two stabilizing mechanisms was considered separately). However, it is shown that pore fluid stabilization of faulting merits further attention and may play a significant role in setting the time scale of processes immediately preceding seismic rupture.

Simons has been pursuing the analysis of a crack propagation model which ultimately will incorporate in a direct and precise way the combined effects of fluid saturation in the surrounding medium and dilatancy in the near-tip failure zone. The frictional resistance to sliding has been assumed to decrease linearly with increasing sliding displacement in the failure zone, and to reach a constant, residual friction stress outside the zone. This approach is physically more realistic than the earlier model of Palmer and Rice, but mathematically more complex. In the first stage, which is now completed, fluid effects and dilation have been

ignored. Two complementary techniques, analytical and numerical, for solving the governing equations were developed. The next step is to incorporate the porous medium effects and the dilation. It will require solutions for steadily propagating "gliding" and "climbing" dislocations and fluid sources in a porous medium. The former two have been derived in closed form, and the latter was obtained earlier by Cleary. Numerical implementation of these features is now underway.

Ruina, a research assistant, in work with Rice and Simons, has solved the Biot field equations for saturated porous media to determine the stress near the tip of a steadily growing tensile crack. The results show how hydraulic fractures can be slowed by porous media effects. Since the solution is analytical, the role of the various physical parameters is clearly displayed. The results obtained may be used in hydraulic fracture models that take other features (such as fracturing fluid pressure) into account.

Kachanov, a research assistant, has been working on constitutive relations for inelastic deformation of rock, based on a microstructural model. He has considered deformational response of a medium with randomly oriented fissures and found incremental moduli for the earlier stage of inelastic deformation when only frictional sliding (without further fracturing) occurs. The moduli found cannot explain the deformational parameters typically observed at localization; it shows that fracturing has to be taken into account to obtain the mentioned parameters. Development of the corresponding model is underway.

SEMI-ANNUAL SUMMARY

G.A.

Branch of Global Seismology

Date: April 26, 1978

Project No. 9920-01206 Title Seismicity and Tectonics

Project Chief William Spence

Mailing Address and Phone No. U. S. Geological Survey, Branch of Global Seismology, Stop 967, Box 25046, Denver Federal Center, Denver, Colorado 80225 (303) 234-4041

Report Period October 1, 1977 to March 30, 1978

I. Investigations and Results:

Peru Study. A a study of the pre-seismicity and aftershocks of the destructive October 3, 1974 Peru shock (M_S = 7.8) shows several distinctive space-time groupings of hypocenters. The aftershocks were distributed spatially in a 'T'-shaped pattern. The main branch of the 'T' is 80-100 km off the coast and parallel to it for a length of about 220 km. The other branch is perpendicular to the first at its approximate midpoint and extends 150 km downdip to beneath the coastal town of Chilca. Pre-seismicity, from May 1971 to the last large foreshock on September 27, 1974, was concentrated in the same zone as the aftershock activity trending towards Chilca. The aftershocks of the interval October 7-24, 1974 occurred in four mutually exclusive groups, the activity oscillating from the offshore branch to the perpendicular-to-coast (Chilca) branch. During the two quiet times of the Chilca Branch, even extremely small earthquake activity was greatly diminished, as indicated by seismograms from a regional seismograph operated at Chilca. During the two active phases of the offshore branch, aftershocks regularly oscillated between the northern and southern ends, jumping a gap that is 100-150 km long. The final two aftershocks of the primary aftershock series were the two largest aftershocks: Nov. 9, 1974 (M_S = 7.1) and Nov. 14, 1974 (m_b) = 5.4). Since this time, aftershocks appear to be occurring on the outside periphery of the primary aftershock zone. These results, which may reflect a continuing tectonic instability of this region, are now being refined by relocating the entire seismicity for this region, 1964-present. The relationship of the 1974 earthquake to its seismic gap, as defined by Peruvian earthquakes occurring in 1940 (M_S = 8.0), 1942 (M_S = 8.1), 1966 (M_S = 7.5), and 1970 (M_S = 7.8) is also under study. An element of this study is the relocation of the aftershock sequences of each of these earthquakes.

1957 Aleutian Arc Earthquake. Arrival time data are now being collected for the Aleutian arc earthquake of March 9, 1957 (M_S = 8.3) and its aftershock series. These data will be used for the relative location of earthquakes in this zone. These results, coupled with focal mechanism studies, should provide a base for tectonic interpretations of this great subduction zone earthquake and its aftershock sequence.

Rio Grande Rift. A P-wave delay study, using teleseismic arrivals at the Albuquerque, New Mexico seismic network (a trans-Rio Grande Rift seismic array), is now in progress. These P-wave delay data, corrected for known velocities in the shallow rift, will be inverted to place bounds on probable velocity structure beneath the rift, in the lower crust and the upper mantle.

2. Reports:

Spence, W. and Pakiser, L. C., 1978: Toward earthquake prediction on the global scale, EOS, 59, 36-42.

Spence, W. and Langer, C. J., 1978: A notable space-time distribution for the 1974 Peru aftershocks (abstract): 73rd Seis. Soc. Am. Ann. Mtg., Sparks, NV, Earthquake Notes, 49, 53-54.

Langer, C. J. and Spence, W., 1978: A study of aftershocks of the October 3, 1974 Peru earthquake (abstract): 73rd Seis. Soc. Am. Ann. Mtg., Sparks, NV, Earthquake Notes, 49, 54.

3. Goals:

(1) To improve our understanding of the tectonic processes that produce large earthquakes, (2) to improve our understanding of the mechanics/dynamics of the faulting processes associated with large earthquakes, (3) to develop models that relate detailed aftershock studies to the deformation accompanying and following a main shock, (4) to test hypothesized empirical models of seismicity patterns precursory to large subduction-zone earthquakes, (5) to determine the specific tsunami-causing parameters of certain earthquakes.

SEMI-ANNUAL SUMMARY

G.B.

Branch of Global Seismology

Date: April 10, 1978

Project No. 9920-01261 Title USGS and Cooperative Observatories

Project Chief Howell M. Butler

Mailing Address and Phone No. U.S. Geological Survey, Albuquerque Seismological Laboratory, Building 10002, Kirtland AFB-East Albuquerque, New Mexico 87115 (505) 474-3785

Report Period October 1, 1977 to March 31, 1978

1. Investigations and Results:

Field activities consist of occasional visits to the seismic stations for the purpose of maintenance, calibration, or installing 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.

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.

2. Reports:

None

3. Goals:

Continue to provide logistical support for the observatories. Project activities include technical advice and assistance to the stations, engineering support, equipment replacement, calibration and repair, and the provision of operating supplies.

SEMI-ANNUAL SUMMARY

G.B.

Branch of Global Seismology

Date: April 10, 1978

Project No. 9920-01971 Title World-Wide Standardized Seismograph Digital Network (WWSSN/DR)

Project Chief Howell M. Butler

Mailing Address and Phone No. U.S. Geological Survey, Albuquerque Seismological Laboratory, Building 10002, Kirtland AFB-East Albuquerque, New Mexico 87115 (505) 474-3785

Report Period October 1, 1977 to March 31, 1978

1. Investigations and Results:

Development work on the WWSSN/DR program is continuing by the ASL staff. A decision was made to switch from 800 to 1600 CPI recording. We are currently awaiting delivery of a 1600 CPI tape recorder from Kennedy. (The recording system is operational using an 800 CPI unit.)

All the operating software for the recording system has been written and tested except for the event detector algorithm. The detector software has been written and tested in Fortran, but has not yet been incorporated into the system software.

The contract for the Digital Time Encoder has been awarded to Intelligent Systems, Inc., Dayton, Ohio. The contract for the Seismic Amplifier/Filter Assemblies has not yet been awarded, due to delays in the Contracts and Procurement Office. Although all other components were to be off-the-shelf purchases, four of them had to go out as RFP's. Current status of these four major items is as follows:

a) Helicorders and amplifiers - awarded to Teledyne-Geotech on 3/29/78
b) ADC systems - not yet awarded
c) Microcomputer systems - not yet awarded
d) Tape recorders - not yet awarded

All other components needed for assembling 15 systems plus depot spares have been ordered and/or received, except for standby power systems. The power systems will be ordered within 2 weeks.

2. Reports:

None

3. Goals:

A. Develop low-cost digital recorder that can be attached to WWSSN system.

B. Install approximately 15 digital recorders at WWSSN stations.

C. Operate digital network and process digital data for distribution to USGS and non-USGS research users.

SEMI-ANNUAL SUMMARY

G.B.

Branch of Global Seismology

Date: April 19, 1978

Project No. 9920-01899 Title U.S. Seismic Network

Project Chief Marvin A. Carlson

Mailing Address and Phone No. U.S. Geological Survey, Branch of Global Seismology, Stop 967, Box 25046, Denver Federal Center

Denver, CO 80225 (303) 234-3994

Report Period October 1, 1977 to March 31, 1978

1. Investigations and Results:

Data from the U.S. Seismic Network was recorded continuously in real time at the NEIS main office in Golden, Colorado. At the present time, 60 channels of SPZ data are being recorded at Golden on Develocorder film. Record analysts interpret the develocorder film and the seismic readings are entered into the NEIS seismic data base. The data is also used by NEIS standby personnel to monitor seismic activity in the U.S. and world-wide on a real time basis. This use has become more important as time goes on. 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. A PDP 11/03 has been obtained and will be used to automate some of the data collection process. It will be used as an event detector monitoring the U.S. Network in real time. Finally, the data is used in such NEIS publications as the "Earthquake Data Report," Preliminary Determination of Epicenters," etc.

2. Goals:

Upgrade the quantity and quality of the data received by the U.S. Seismic Network to make possible the more rapid and accurate location of U.S. earthquakes and significant earthquakes worldwide.

SEMI-ANNUAL SUMMARY

Branch of Global Seismology

G.B.

Date: April 10, 1978

Project No. 9920-01262 Title ASL, Systems Engineering

Project Chief Harold E. Clark, Jr.

Mailing Address and Phone No. U.S. Geological Survey, Albuquerque Seismological Laboratory, Building 10002, Kirtland AFB-East Albuquerque, New Mexico 87115 (505) 474-3785

Report Period October 1, 1977 to March 31, 1978

1. Investigations and Results:

The Albuquerque Seismological Laboratory Systems Engineering supports engineering activities at the Albuquerque Seismological Laboratory in conjunction with various world wide seismic and observatory activities. Under this program new microprocessor based seismic instrumentation systems and circuits are being designed, developed, and tested to improve seismic systems performance and lower the cost of new systems.

The prototype microprocessor based Digital Recording System has been under test and evaluation. This system was designed to digitally record up to three channels of long-period seismic data, event record up to three channels of intermediate seismic data, and event record up to three channels of short-period seismic data. This system will use a 16 channel, 16 bit analog to digital converter under control of dual 8-bit microprocessors to record the digital seismic data on a 9 track 1600 CPI digital recorder. One microprocessor will control the analog to digital converter operation, strobe a digital timing system for time data, control two types of event detection programs and store the three different types of seismic data in a common 16 kilobyte memory. The second microprocessor will control the transfer of formatted digital records from the common memory to the digital recorder. A special digital timing system is under contract development. This new digital timing system will replace the existing WWSSN analog time programmer and will provide parallel digital time for use by the Digital Recording System as well as the WWSSN time pulses.

2. Reports:

None

3. Goals:

Design and develop microprocessor based seismic systems.

Design and develop microprocessor based digital telemetry systems for NEIS.

Develop low power seismic field systems.

Provide technical assistance in world-wide installation of the Digital Recording Systems.

Provide technical assistance in the development of the U.S. Seismic Network Systems.

SEMI-ANNUAL SUMMARY

Branch of Global Seismology

G.B.

Date: April 10, 1978

Project No. 9920-01263 Title Tsunami Network Support

Project Chief Harold E. Clark, Jr.

Mailing Address and Phone No. U.S. Geological Survey, Albuquerque Seismological Laboratory, Building 10002, Kirtland AFB-East Albuquerque, New Mexico 87115 (505) 474-3785

Report Period October 1, 1977 to March 31, 1978

1. Investigations and Results:

Field activities consisted of field test, operation, and evaluation of microprocessor based Tsunami Seismic Alarm Systems and Tsunami Tide Systems. Laboratory activity consisted of design, assembly, test, operation, and evaluation of a microprocessor based Tsunami Systems. All Tsunami Seismic and Tide Systems are operational through the GOES Satellite Network on command from the National Environmental Satellite Service at Suitland, Maryland. A microprocessor based Tsunami Seismic Data System is operational at the Albuquerque Seismological Laboratory, Albuquerque, New Mexico. A microprocessor based Tsunami Tide System is operational at the NOAA/NWS facility in La Jolla, California. Five microprocessor based Tsunami Seismic Systems are being assembled. Three of these systems will be installed in a New Mexico-Colorado array. One system will be installed in Alaska. The fifth system will be installed in Hawaii.

The results of the Tsunami Tide System and Tsunami Seismic System development provided guidance and information useful in future implementation of a large scale Tsunami Alarm System using GOES SMS satellites in conjunction with command interrogatable Tsunami Tide and Tsunami Seismic Systems. Such a warning system could be controlled from a central location and could cover large areas of the earth, such as the majority of the Pacific Ocean area to include coast lines of North America, South America, Alaska, and Pacific Island areas. This system would provide the fastest lowest cost alert system available and could save numerous lives in the event of a large Tsunami. The operation of the microprocessor based Tsunami seismic data system over a satellite network provided additional information on the use of satellites for the transmission of seismic data from remote locations into centralized data recording facilities. The present satellite networks do not have adequate channel allocation and channel band-width to transmit numerous continuous seismic data. With present satellite network systems, only limited seismic data or event data can be transmitted.

A second result from the seismic event detector circuit provides conformation that seismic event parameters can be obtained from on-line computer analysis of seismic events.

2. Reports:

Clark, Harold E. Jr., and Heckendorn, Gary L., Tsunami Microprocessor Tide System, 1978: USGS Open-File Report 78-95.

3. Goals:

Design and develop microprocessor based Tsunami Tide Satellite data systems.

Design and develop microprocessor based Tsunami Seismic Satellite data systems.

Install and operate three microprocessor based Tsunami Seismic Systems in a New Mexico and Colorado array.

Install and evaluate operations of microprocessor based Tsunami Seismic System in Alaska.

Install and evaluate operations of microprocessor based Tsunami Seismic System in Hawaii.

SEMI-ANNUAL SUMMARY

G.B.

Branch of Global Seismology

Date: April 10, 1978

Project No. 9920-01260 Title Albuquerque Observatory

Project Chief Lawrence H. Jaksha

Mailing Address and Phone No. U.S. Geological Survey, Albuquerque Seismological Laboratory, Building 10002, Kirtland AFB-East Albuquerque, New Mexico 87115 (505) 474-3785

Report Period October 1, 1977 to March 31, 1978

1. Investigations and Results:

The primary efforts of the Albuquerque Observatory during the report period have been directed at implementing a statewide seismic network in New Mexico. Three stations of this network are now operational. These stations are:

ID	LOCATION	OPERATOR
NMH	Las Vegas, New Mexico	New Mexico Highlands Univ.
SVM	Silver City, New Mexico	Western New Mexico Univ.
TUC	Tucson, Arizona	Arizona Bureau of Mines & Geo.

An additional 5 stations are in the early planning and fabrication stage.

A 3-station long-period array is presently being installed in New Mexico. The station at Socorro (New Mexico Tech) is awaiting modifications to the underground vault. A site selection trip to the Grants/Corona areas is scheduled for early spring.

2. Reports:

None

3. Goals:

The Albuquerque Observatory produces seismic data for earthquake studies on a global scale. The present goal of the project is to increase the observatories capabilities to include New Mexico seismicity and long-period noise studies.

SEMI-ANNUAL SUMMARY G.B.

Branch of Global Seismology

Date: March 28, 1978

Project No. 9920-01193 Title Seismic Observatories

Project Chief Harry Whitcomb

Mailing Address and Phone No. U.S. Geological Survey, Branch of Global Seismology, Stop 967, Box 25046, Denver Federal Center, Denver, CO 80225
(303) 234-5083

Report Period October 1, 1977 to March 31, 1978

1. Investigations and Results:

Continued to maintain and operate seismological and geomagnetic instruments at the various observatories. Provided seismological data to the Global Seismology Branch for the preliminary determination of earthquake epicenters and the early earthquake reporting program. At Guam and Newport, Washington, 24-hour watches were maintained to provide input to the Tsunami Warning Service operated at Honolulu Observatory by NOAA. Provided geomagnetic data to the Branch of Electromagnetism and Geomagnetism. Responded to inquiries from the public, interested scientists, state and federal agencies regarding geophysical data and phenomena.

The standard seismograph at Tucson, Arizona is now operated under a cooperative agreement between the Arizona Bureau of Mines and the USGS. To implement this agreement the recorders for the system have been reinstalled at the Arizona Bureau of Mines offices on the campus of the University of Arizona. The seismic signal is telemetered by hard wire from the existing vault to the campus and to the National Earthquake Information Service in Golden, Colorado. The data produced will be made available for use in an expanding earth sciences program of the University of Arizona which will be coordinated by Mark Sbar.

2. Goals:

To record and provisionally interpret seismological and geomagnetic data. These data serve as input for government research, and for scientific programs conducted by state, local, and educational institutions. To support the Tsunami Warning Service by providing input on a 24-hour basis from Guam and Newport observatories.

SEMI-ANNUAL SUMMARY

G.C.

Branch of Global Seismology

Date: April 10, 1978

Project No. 9920-01194 **Title** National Earthquake Information Service

Project Chief John Derr

Mailing Address and Phone No. U.S. Geological Survey, Branch of Global Seismology, Stop 967, Box 25046, Denver Federal Center, Denver, CO 80225 (303) 234-3994

Report Period October 1, 1977 **to** March 31, 1978

1. Investigations and Results:

The NEIS has completely eliminated its work backlog, and all Preliminary Determination of Epicenter bulletins covering earthquakes in 1977 have been published. This work was accomplished by the NEIS staff using a contract computer. The work was completed ahead of schedule and on cost, thanks to a number of employees who worked evenings and weekends to take advantage of lower computer rates. During this time, the entry of 1978 earthquake data has proceeded on schedule and is maintained in a current status. We now anticipate a short delay before we can resume publication of formal PDE bulletins, because the new programs on the Honeywell Multics are not ready. In the meantime, we will continue to publish provisional hypocenters using data from our U.S. Network and other stations which report rapidly.

The new PDE system will publish most epicenters within two weeks of the earthquake. This will be possible because of the interactive nature of the software, and because of the rapid flow of data into the NEIS. New arrangements continue to be made to receive more data by telegram and direct computer link. In the latter area, we are embarking on a program to replace domestic telegrams wherever possible with direct computer entry, via the national computer network system Tymnet. A pilot program with Weston Observatory, Massachusetts, has shown that this method results in significant labor saving for all involved, and increases the speed and accuracy of data received. At the same time, computer costs remain essentially constant for this method of data entry.

Tymnet is also used extensively now to reduce the workload on the Denver Multics during prime time. A number of time-consuming utility programs are available on all three computers, and users are encouraged to use Reston and Menlo for hypocenter data file searches and rapid location of epicenters whenever the Denver load is heavy. These other computers also now function as alternate resources for our rapid hypocenter determination service.

The international directory of seismograph stations has been completely overhauled. Now a USGS circular entitled "Catalog of Global Seismograph Station Codes and Characteristics," it contains more stations, more information, better organization, and more extensive cross-indexing. Virtually all of it is written on the Multics, and should be ready for publication within a few months.

We continue to provide public information services on recent earthquakes, in response to increasing demands from the general public.

2. Reports:

"Preliminary Determination of Epicenters Monthly Listing," 10 issues, March 1977 through December 1977. Compilers: John S. Derr, David Gordon, W. Leroy Irby, Reino Kangas, John Minsch, Waverly J. Person, Bruce Presgrave.

3. Goals:

Provide rapid and comprehensive hypocenter location services to the government and the scientific community.

Provide rapid notification of significant or damaging earthquakes to relief agencies, press, the scientific community, and the general public.

Improve the content of our scientific publications.

SEMI-ANNUAL SUMMARY

G.C.

Branch of Global Seismology

Date: April 4, 1978

Project No. 9920-01204 Title Seismic Review and Data Services

Project Chief Robert P. McCarthy

Mailing Address and Phone No. U. S. Geological Survey, Branch of Global Seismology, MS 969, Box 25046, Denver Federal Center, Denver, CO 80225 (303) 234-5080

Report Period October 1, 1977 to March 31, 1978

1. Investigations and Results:

The quality control and technical review of over 112,000 seismograms (610 station-months) generated by the 110 station World-Wide Standardized Network (WWSSN) was carried out.

Station performance reports detailing instrumental occuracies, timing precision, noise patterns, record quality, records reviewed etc. were sent to all but nine (9) of the stations. Overall quality was high.

Two stations (Nilore, Pakistan (NIL), and Bulawayo, Rhodesia (BUL) experienced severe flooding and are out of operations temporarily.

Contact through the Air Attache in Paris, France by William Green of the OES has been reestablished with Lormes (LOR). The last time seismograms were received from LOR was over 3 years ago and these were sparse in numbers and substandard in quality.

Monthly computerized listings were routinely provided to USGS and NOAA/EDS scientists and officals covering station magnifications, seismograms received, and the date these were received.

All seismograms were usually processed and reviewed within the week received and then sent to the micro-filming facility in Boulder, Colorado. Constant liaison day-to-day is maintained with this Department of Commerce, NOAA facility.

Maintenance of film files and reader-viewers for users was carried out. Study is underway for appropriate reader-printer and filming facilities for microfiche format of the filmed seismograms. Archived records at the National Archives and Records Center in the Denver Federal Center were made available to interested researchers in the USGS and CIRES through this project. Electrostatic copies of current WWSSN seismograms covering events of special interest were also provided to researchers.

Otner areas of assistance was to administrators in the USGS and other agencies in station assessments, data availability, suitability, reliability, instrumental characteristics and responses, along with consultations on other aspects of seismological data.

2. Reports: NA

3. Goals:

Provide an ADP format for review data covering historical and current phases.

Improve station performance at those stations with lower capabilities through informal notes and guide lines. Keep lines open to those inactive stations where reactivation remains possible.

Reduce flow-time of the WWSSN seismograms in the system.

SEMI-ANNUAL SUMMARY

G.C.

Branch of Global Seismology

Date:

Project No. 9920-01222 Title United States Earthquakes

Project Chief Carl W. Stover

Mailing Address and Phone No. U.S. Geological Survey

Branch of Global Seismology, Stop 967, Box 25046, DFC

Denver, CO 80225 303-234-3994

Report Period October 1, 1977 to March 31, 1978

1. Investigation and Results:

Sixty-four earthquakes in 17 states were canvassed for felt and damage data by means of a questionnaire. The questionnaires plus additional data have been evaluated for intensity. United States earthquake data on location, magnitude, intensity, damage, and other appropriate parameters have been processed for 1977 and are being prepared for publications in quarterly circulars.

The maximum intensity assigned to an earthquake for this period was VIII for an event on November 27, 1977, located near Willits, Calif. at 39.45° N., 123.26° W., origin time 21 15 52.5 UTC, depth 5 km, magnitude 4.8 M_L (Berkeley). In Willits, 65 chimneys were damaged, some thrown down, others shifted or twisted at the roof line, windows were broken, and objects were thrown from shelves, especially in grocery stores. An open-file report on this earthquake is in preparation by R. B. Simon and others.

We are moving ahead with the compilation of historical earthquake data by state in preparation for the publication of state seismicity maps. We are currently focusing on the New England states and adjacent areas of Canada.

Intensity VI was assigned to six earthquakes during this period, four in California, and one each in Idaho, New Hampshire, Utah, and Washington. This intensity was primarily based on reports of cracked plaster or dry wall, cracked and broken windows, or cracked masonry.

2. Reports:

Simon, R. B., C. W. Stover, W. J. Person, and J. H. Minsch, 1978, Earthquakes in the United States, January-March 1976: GS Circular 766-A, 33 p.

Person, W. J., 1977, Earthquakes March-April 1977: Earthquake Info Bull., vol. 9, no. 5, p. 25-26.

Person, W. J., 1977, Earthquakes May-June 1977: Earthquake Info Bull., vol. 9, no. 6, p. 26-27.

Person, W. J., 1977, Earthquakes July-August 1977: Earthquake Info Bull., vol. 10, no. 1, p. 26-27.

Person, W. J., 1977, Seismological Notes, March-April 1976: Bull. Seismol. Soc. Am., vol. 67, no. 6, p. 1671-1673.

3. Goals:

Collect, evaluate, and publish U.S. earthquake locations, felt and damage information, and other earthquake related data for the 50 states. Publish seismicity maps of earthquake activity on a world-wide basis. Distribute earthquake data to the public, scientists, engineers, and others interested in such data.

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